GrowSmarter

Transforming cities for a smart, sustainable Europe

D5.4 FINAL REPORT ON RESULTS OF TECHNICAL AND SOCIAL VALIDATION

NOVEMBER 2019

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1) The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation
2) The home page of the website should contain the European flag which are available in electronic format at the Europa website (European flag: http://europa.eu/abc/symbols/emblem/index_en.htm) and the Horizon 2020 programme name.

GrowSmarter
Transforming cities for a smart, sustainable Europe

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1 INTRODUCTION

1.1 Background

This Report constitutes the Deliverable D5.4 and is the final compilation of technical results from the GrowSmarter project, and as such it is the output of WP5, responsible for technical and social validation of the Measures implemented in WP2, 3 and 4. The report is based on evaluations reported by the individual partners for each of the implemented Measures. It is important to note that the evaluations of the Measures have been done as part of WP2, 3 and 4, based on the methodology agreed on with WP5. The process has been the following:

- WP5 proposed the evaluation methodology described in the Evaluation Plan, D5.1. This was done in communication with the partners of the specific Measure to ensure that the proposed methodology is feasible. The plan determines which parameters should be measured, at what frequency, and what are the Key Performance Indicators to be evaluated. It does not specify in any detail how this should be done. The Evaluation Plan was agreed on by the General Assembly.
- WP 5 defined the distribution of responsibilities between WP5 and the other work packages. This was done in Deliverable D5.2, Guidelines for Monitoring and Evaluation.
- Each reporting partner then delivered a detailed Evaluation Strategy based on the Evaluation Plan and the Guidelines.
- WP5 provided a template for Periodic Evaluation Reports of results from each Measure. It was decided at the general assembly in Cork that reporting of results should be done twice a year (September and February) using the template provided by WP5. In fact, an update of the reports was also requested at the General Assembly in Barcelona, November 2018, to be delivered by December 15, 2019.
- WP5 used the Periodic Evaluation Reports delivered to write a Draft Report on Results of Technical and Social Evaluation, deliverable D5.3.
- Finally, the present report, D5.4, is based on the information reported up to November 14 2019.

The division of work between WP5 on the one hand and WP2, 3 and 4 on the other is based on what is written in the Grant Agreement. The following is from that source:

> *Each implemented Measure will be monitored for a minimum of 2 years. Gathered data ... will be used to evaluate innovation potential, theoretical vs practical energy savings, user acceptance and real investment costs, etc. The results will be [the] main input to WP 5 where the data will be analyzed on a global project level and [WP5 will] further validate the Measures from technical, economic and social perspectives….. The results from the monitoring and evaluation will be compiled into a deliverable from each Measure.*

It was later agreed with the EC that an evaluation period of 1 year should be sufficient. Due to delays, and high ambitions of the partners, a large part of the last year of the project has been used to collect data and to ensure high quality of the data.

The objectives of WP5 were defined in the Grant Agreement. The first objective is to:

- *Provide a transparent framework and methodology for comparable performance evaluation …to enable validation and comparison of deployed smart solutions at all project sites ….*

This objective was fulfilled by setting up the procedures described in the evaluation plan, Deliverable D5.1.

The second objective of WP5 is to:

- *Guide data collection and analysis to assess the implemented Measure's impact on reduction of greenhouse gas, other emissions, energy efficiency and share of renewable energy sources…*

This objective was fulfilled by the Deliverable D5.2 and by evaluating and accepting the Evaluation Strategies presented by the partners.

Other objectives of WP5 are more related to the present report. According to these WP5 is to:

- *Assess the vulnerability/robustness of the deployed smart city solutions, with specific focus on their cumulative effects on other resources, economics, and security of energy and transport service supply.*
- *Assess replicability of the implemented Measures, including key success factors, impact of local specifics on success, key stakeholders to be involved, standardization and interoperability issues.*
- *Provide input for assessment of potential for wider market uptake of the implemented Measures and pathways to upscaling*
- *Visualization and presentation of assessment results*
- *Develop and disseminate recommendations for European and national policy makers and practitioners*

Since the Grant Agreement was first formulated, there have been Amendments, and in one of these, it was decided that the report with Recommendations for Policy makers should be moved to WP1. However, the first four bullet points are still the responsibility of WP5. It has been the ambition and intention that the present report should cover these objectives.

Accomodating this type of project within the time frame of five years has been a challenge. In particular considering that the results should be confirmed through actual measurements. This requires a first measurement period to determine a baseline and then a second measurement period for determining the effect of the measures. As the effect of many of the measures depend on the season, both the baseline period and the evaluation period should cover one full year. This means that there has been less than three years to plan and implement the measures to be evaluated. In some cases there have been problems influencing the quality of the data for the evaluations. In other cases data is missing or is not in the form expected. This has influenced the possibility to validate the evaluations done by the partners and from WP5 we have to acknowledge that the results presented are in some cases to be seen as preliminary. However, we do not believe that this has influenced the general conclusions of the project.

1.2 Report structure

Chapter 2 presents the results of technical and social validation of the Measures related to *Work Package 2: Low Energy District*.

Chapter 3 contains the validation of the Measures related to *Work Package 3: Integrated infrastructures*.

Chapter 4 contains the validation of the results of the Measures related to *Work Package 4: Sustainable urban mobility*.

The structure of Chapters 2, 3 and 4 is conceived to give an overview of the results obtained in the project and their validation towards the expectations and prescriptions contained in the evaluation plan (D5.1).
In particular, each chapter contains an introduction to the specific Measures of the corresponding work package followed by a section where general considerations about the evaluation methodology are presented. The core sections of these three Chapters are dedicated to the Measures involved in each Work Package. Each Measure is identified by the number assigned in the evaluation plan (D5.1) and has a prefix „M“.
For each Measure, the introduction summarizes the expectation and recommendations prescribed in the evaluation plan (D5.1), with focus on the Measure intentions and the key performance indicators that are needed for the evaluation of the Measure. The summary of the results from each demonstration site involved is then presented and followed by the technical feasibility of the Measure and its potential for upscaling and replicability.

Chapter 5 contains considerations and recommendations on the overall results from the activities implemented in all the work packages. Finally, general conclusions from the current results are drawn with reference to each Work Package.

Note: The official names of three project partners have changed during the project. In this report the new official name has been used. In particular, changes have been applied according to the following table:

Table 1: Name changes of some Project partners

Previous name	New name
Fortum AB	Stockholm Exergi AB Fortum Markets AB
GNF (Gas Natural)	Naturgy
KTH-IE	KTH-SEED

1.3 Energy and emission factors

In order to estimate the CO2 emission related to the energy consumption or production evaluated in the Measures, the following tables present a summary the conversion factors considered in Stockholm, Cologne and Barcelona. The values in Table 5 are supplied only for comparison and are not used in the calculations.

Stockholm

Table 2 CO2 emission factors considered in Stockholm

	CO2 factor (g/kWh)
Nordisk mix, 2016 5 year average	62.9
Renewable mix	5.5
Wind	15.2
Solar PV	30.0
District heating	93.1

All emission factors represent the CO2 equivalent considering the LCA (Life Cycle Assessment approach), based on Miljöfaktaboken (2011) and Naturvårdsverket (2017)

Cologne

Table 3 CO2 emission factors considered in Cologne

	CO2 factor (g/kWh)
Electricity	(2015) 431 (2017) 306
Gas	206
Solar PV[1]	24
District heating	78

[1] https://data.europa.eu/euodp/sv/data/dataset/jrc-com-ef-comw-ef-2017

Barcelona

Primary energy factor (electricity): 2.403
Primary energy factor (gas): 1.195
Primary energy factor (electricity): 0.262

Table 4 CO_2 emission factors considered in Barcelona[2]

	CO2 factor (g/kWh)
Electricity	357
Gas	252
Oil (heating)	311
Solar PV[3]	48

Covenant of Mayors for Climate and Energy

Table 5 CoM Default Emission Factors for Germany, Spain, Sweden and all the Member States of the European Union. The values are referred to 2013 and consider the LCA approach.[4]

	Germany	Spain	Sweden	EU 28
CO2-eq due to electricity consumption (g/kWh)	658	343	38	444

[2] https://energia.gob.es/desarrollo/EficienciaEnergetica/RITE/Reconocidos/Reconocidos/Otros%20documentos/Factores_emision_CO2.pdf
[3] https://thinkstep.com/sustainability-data/lci-data/global-industrial-process-database
[4] https://data.europa.eu/euodp/sv/data/dataset/jrc-com-ef-comw-ef-2017

2 WORK PACKAGE 2: LOW ENERGY DISTRICT

2.1 Introduction

Buildings and the activites inside are responsible for about 31% of the global energy use in today's society. The European Union has an ambitious goal to significantly reduce the environmental impact from all sectors, including buildings. The present project aims at reducing the energy use in buildings by up to 60%, reduce the energy costs and the greenhouse gas emissions. By using novel and innovative technical solutions, the aims are to create a better indoor climate, indoor air quality, improve living quality and extend the buildings' life expectancy.

In Work Package 2 (WP2), the Measures implemented are mainly focusing on the built environment. Several different kinds of Measures are implemented, some in the same building, some in different buildings. The present sections aim at highlighting the final results, of WP2. During the project, there have been some delays in reporting the results of the Measures. In many cases this is a result of delays within the refurbishment projects. In general, all Measures are evaluated based on **measured data**. It is believed, and also documented in the literature, that there is a gap between the predicted performance of a building and the actual achieved performance. Hence, demonstrating the impact of a Measure needs to be done by measurements rather than by simulations in order to estimate the actual expected outcome when the Measures are scaled and implemented in many buildings in different cities. The savings obtained by the Measures are validated against a baseline. The baseline is normally the **measured** performance before the Measures have been implemented. In some instances this has not been possible or relevant to do, as the use of the building after the refurbishment is completely different to the use before the refurbishment. In those instances, the baseline may be a simulated baseline.
In addition to the purely technical measurements of performance, the social impact of the Measures are estimated and for some Measures, surveys have been conducted.

2.2 Evaluation methodology

In the current project, the main purpose is to demonstrate the effect, or smartness, of implementing the suggested Measures. Therefore, the evaluation procedure is designed for that main purpose. Demonstration in general is done by inspecting the outcome of a similar earlier carried out project. Hence, as the current project aims at demonstrating the outcome of different Measures, the documented outcome of these should be used for the evaluation. The documented outcome must be determined by measurements. The outcome of each Measure has been evaluated as reduced energy consumption or reduced emissions at maintained or improved service level. Hence, the outcome of each Measure has, whenever possible, been determined by measurements. Since savings is what is monitored, the energy performance and the service level before and after implementation of the Measures are required.

The monitoring are for the most cases done for an extended time period, as climatic conditions affects the performance and need to be captured. For a number of Measures, the climatic variations occurring throughout the year is not expected to change the outcome of the Measure, these Measures have been evaluated using a shorter time period.

In many cases, several individual Measures have been installed in a common building. As all systems in a building interact in one way or the other, it is impossible to monitor only the overall energy performance of the building, better resolution is required. Therefore the evaluation is in these cases done in a more elaborate and detailed manner, aiming at separating the effect of each Measure. Hence, since some of the Measures are saving on the "same" number, the aggregation of several Measures is of course not the same as the simple addition of the savings of the individual Measures. The used evaluation procedure is also aimed at highlighting these aggregation issues, in order to be able to make better predictions of the combination of any Measures for any building in any city.

Normalization for climate conditions

The results of GrowSmarter Project are mainly presented by comparing annual measurement campaigns carried out before and after the implementation of each Measure. When comparing the measurement campaigns for buildings over different years it is important to account for the different climatic conditions which occurred within the considered years. The method adopted in this project to normalize the results before and after the implementation of each Measure is the Degree Day method.

The Degree-Days (DD) represent "the degrees needed each day" for the heating or cooling of a building in a given location.

The Heating Degree Days (HDD) for any single day can be determined considering the (measured) daily mean outdoor temperature T_m, a threshold temperature T_{lim} and a defined indoor temperature T_i. T_{lim} can be interpreted as the temperature at which a building needs no heating.

The calculation of the HDD is performed considering only the days where T_m is lower than T_{lim}[5]. The following two formulations are possible:

- [5] ÖNORM B 8110-5

$$HDD = \sum_{1}^{n}(Ti - Tm)_n$$

$$HDD = \sum_{1}^{n}(Tlim - Tm)_n$$

Where n is the number of days of the period considered, typically one year. The value of T_{lim} varies depending on the location.

The HDD normalization is widely adopted to compare the energy consumption of a building over different years, in order to analyse the variation of the energy consumption over different climatic conditions compared to previous years. The normalized energy consumption of a building can be calculcated as

$$E_n = E \cdot \frac{HDD_{ref}}{HDD}$$

where E is the building energy consumption for heating in a specific year and location, E_n is the normalized energy consumption and HDD_{ref} is the average of the HDD for a given location over a long term of typically 30 years.

Similar definitions and considerations can be formulated regarding the Cooling Degree Days (CDD) and heating and cooling degree hours.

Upscaling of the results: General assumptions (for Stockholm)

KTH carried out a quantitative upscaling of the results focusing on the results obtained in Stockholm within the following Measures:

- M1.1.1: Low U-values of Windows
- M1.1.2: Reducing hot water losses
- M1.1.3: Recovering waste water heat from the drain
- M1.1.5: New efficient air heat pumps
- M1.1.8: Air tightness

For all these measure the climatic conditions of Stockholm was required. For that purpose, the official simulation climatic data files provided by SVEBY[6] has been used as a source for the hourly dry bulb outdoor temperature. Some of the estimations have been obtained using the hourly data on the entire building stock of Stockholm, while some others have been obtained using the degree hour concept, using the latest calculation procedure of SMHI[7] and the climatic data file from SVEBY. The degree hour considered for Stockholm is $89\,458\ K \cdot hr$.

As the entire building stock has been considered, the corresponding heated floor area of various kinds of buildings was required, including building age, ventilation principle and other features relevant to the different evaluated measures. For this purpose a software tool, developed in a previous research project[8], has been used to connect to the database of filed

- [6] www.sveby.org
- [7] http://www.smhi.se/polopoly_fs/1.3482!/Menu/general/extGroup/attachmentColHold/mainCol1/file/Faktablad%20SMHI%20Graddagar%20150601.pdf
- [8] https://www.e2b2.se/forskningsprojekt-i-e2b2/stad-och-planering/big-data-analys-foer-energieffektivisering-av-stockholm/

Energy Declaration Protocols. The database of these protocols is continuously maintained by Boverket[9] (the Swedish National Board of Housing, Building and Planning). The required data for the upscaling has been available only for Stockholm, and the results of this exercise are presented at the end of Chapter 2.

2.3 Measures of WP2

M1.0 - Energy efficient refurbishment of buildings

Introduction

The aim of this Measure is to evaluate the energy savings in residential and tertiary buildings for the whole building retrofit, including passive Measures, active Measures as well as the Building Energy Management System (BEMS) and the Home Energy Management System (HEMS).
Savings have been determined by comparing measured consumption before and after the implementation, making suitable adjustments for comparing both consumptions under the same conditions, such as building occupancy or weather conditions.

According to the evaluation plan (D5.1), the intention of the Measure was to enhance the energy performance of evaluated buildings (kWh/m^2).

The instructions for determining the baseline has been as follows:
1. Baseline determined based on performance before the Measure implementations.
2. Baseline for Heating, Cooling and Electric energy obtained through measurement of annual energy demand (kWh/m^2) corrected for ambient conditions (heating- cooling degree day correction).
3. Annual performances displayed as energy signature, highlighting any difference between the two cases.
4. Emission data established from official authorities and used throughout the evaluation period of baseline and evaluation of conducted Measures.
5. Bought energy mix (per energy carrier) established and used throughout the evaluation period of baseline and evaluation of conducted Measures.

The agreed key performance indicators to be determined are:
1. Heat energy required (kWh) per year and month normalized for climatic conditions.
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.
3. Electric energy required (kWh) per year and month.
4. CO_2 emissions due to heating energy demand (kt/year).
5. CO_2 emissions due to cooling energy demand (kt/year).
6. CO_2 emissions due to electric energy demand (kt/year).

- [9] https://www.boverket.se/energideklaration

Stockholm

Industry partners	Contact persons	Validation partner
Skanska Stockholmshem L&T FM AB Fastigetskontoret Miljöförvaltningen	Harry Matero Gunnar Wiberg Peter Andersson Royne Juhlin Anna Sundman	KTH-EGI

Table 6 Measures evaluated by Skanska (*House 2A, 3B and 5E have been indirectly evaluated, since they are identical to House 7G and 8H)

		Measures						
		1.0	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	1.1.9
RESIDENTIAL	House 6F	X					X	
	House 7G (2A*, 3B*)	X		X	X	X	X	X
	House 8H (5E*)	X	X	X			X	X

Table 7 Measures evaluated by L&T

		Measures			
		1.0	1.1.6	1.1.7	4.1
R	Valla Torg		X	X	
TERTIARY	Årstakrönet	X	X		X
	Kylhus	X			X
	Slaughterhouse	X	X		X

In Stockholm, Skanska is responsible of the renovation of a total of 6 houses. Four fourteen-story buildings and two 4-story buildings from 1961. These buildings all together include 302 apartments before renovation and 324 apartments after renovation.
The evaluation of the house's energy performance has been performed by measuring the energy before and after the deep renovation interventions.

House 6F

The installed technology includes now a combination of district heating, geothermal heat pumps, exhaust air heat pumps and heat recovery from waste water. The total conditioned area before and after the deep renovation changed from 4942m^2 to 5191 m^2.
New digital energy meters and indoor temperature meters have been also installed during the renovation.
The obtained results are reported in Table 8, Table 9 and Table 10. In particular, Table 8 shows the baseline values measured over 2017, while Table 9 reports the energy consumptions, purchase and production after the refurbishment.

Table 10 shows the results in terms of energy achieved savings. Worth noticing, the photovoltaic system started to produce electricity only from June 2018.

Table 8 Baseline evaluated for M1.0 House 6F (Stockholm)

Baseline	2017-01-01 2017-12-31	Units	KPI	Units
District heating (space heating and hot water)	643339	kWh	124	kWh/m²
Purchased electricity	38031	kWh	7	kWh/m²
Total purchased energy*	681370	kWh	132	kWh/m²
Hot water circulation losses	11861	kWh	2	%

* excluded: laundry room and commercial activities

Table 9 Energy use after refurbishment for M1.0 House 6F (Stockholm)

After refurbishment	2018-10-01 2019-09-30	Units	KPI	Units
District heating (space heating and hot water)	0	kWh	0	kWh/m²
Heat pump electricity consumption	128 740	kWh	24.8	kWh/m²
Purchased electricity	189 021	kWh	36.4	kWh/m²
Total purchased energy*	172 398	kWh	33.2	kWh/m²
Produced solar energy	8067	kWh	1.6	kWh/m²

* excluded: laundry room and commercial activities

Table 10 Energy use variation for M1.0 House 6F (Stockholm)

Results	Variation
District heating (space heating and domestic hot water)	-100%
Purchased electricity	+397%
Total purchased energy	-75%

Figure 1 shows the Energy Signature of House 6F. The x-axis represent the monthly average of the outdoor temperature. The “mean power” includes the total purchased energy divided by the number of hours in the month.

Table 11 shows the results in terms of KPIs required by the Evaluation Plan D5.1.

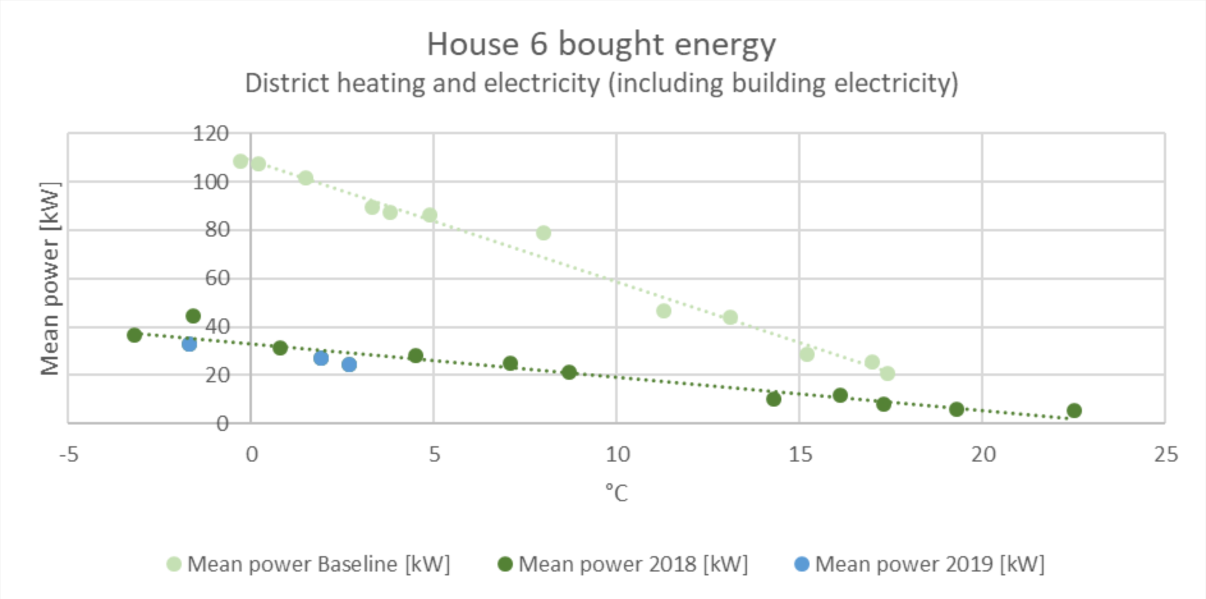


Figure 1 Energy signature for House 6F in Stockholm

Table 11 KPIs evaluated for M1.0 House 6F (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	643339	138757	-78 %
2. Cooling energy required (kWh) p7er year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	38031	33746	-11 %
3.1 Electric energy required (kWh) for heating	-	138757	-
4. CO2 emissions due to heating energy demand (t/year)	59.895	8.098	-86 %
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)	2.409	2,72	13 %
Total purchased energy	681370	172503	-76 %

House 7G

The installed technology includes now a combination of district heating, smart building control, exhaust air heat pumps and heat recovery from waste water.

New digital energy meters and indoor temperature meters have been also installed during the renovation. The total conditioned area before and after the deep renovation changed from 5401.5m² to 5651 m².

The obtained results are reported in Table 12, Table 13 and Table 14. In particular, Table 12 shows the baseline values measured over 2017, while Table 13 reports the summary of the measurements performed after the refurbishment. Table 14 shows the results in terms of achieved energy savings.

Table 12 Baseline evaluated for M1.0 House 7G (Stockholm)

Baseline	2017-01-01 2017-12-31	Units	KPI	Units
District heating (space heating and hot water)	680043	kWh	120	kWh/m²
Purchased electricity	38031	kWh	7	kWh/m²
Total purchased energy*	718074	kWh	127	kWh/m²

*excluding laundry room and outdoor lighting

Table 13 Energy use after refurbishment for M1.0 House 7G (Stockholm)

After refurbishment	2018-10-01 2019-09-30	Units	KPI	Units
District heating (space heating and hot water)	137198	kWh	24	kWh/m²
Purchased electricity	165446	kWh	28	kWh/m²
Total purchased energy*	282047	kWh	49,9	kWh/m²
Produced solar energy	7247	kWh	1.3	kWh/m²

*excluding laundry room and outdoor lighting

Table 14 Energy use variation for M1.0 House 7G (Stockholm)

Results	Variation
Space heating and domestic hot water	-80 %
Purchased electricity	+366 %
Total purchased energy	-61 %

Table 15 shows the results related to the estimated CO_2 saving obtained with the refurbishment of House 7G.

Table 15 CO2 emission for M1.0 House 7G (Stockholm)

CO_2 emissions	Value
CO_2 emission before the refurbishment	65.7 t
CO_2 emission after the refurbishment	22.9 t
CO_2 emission variation	-65.0 %

Figure 2 shows the Energy Signature of House 7G. The x-axis represent the monthly average of the outdoor temperature. The “mean power” includes the total purchased energy divided by the number of hours in the month.

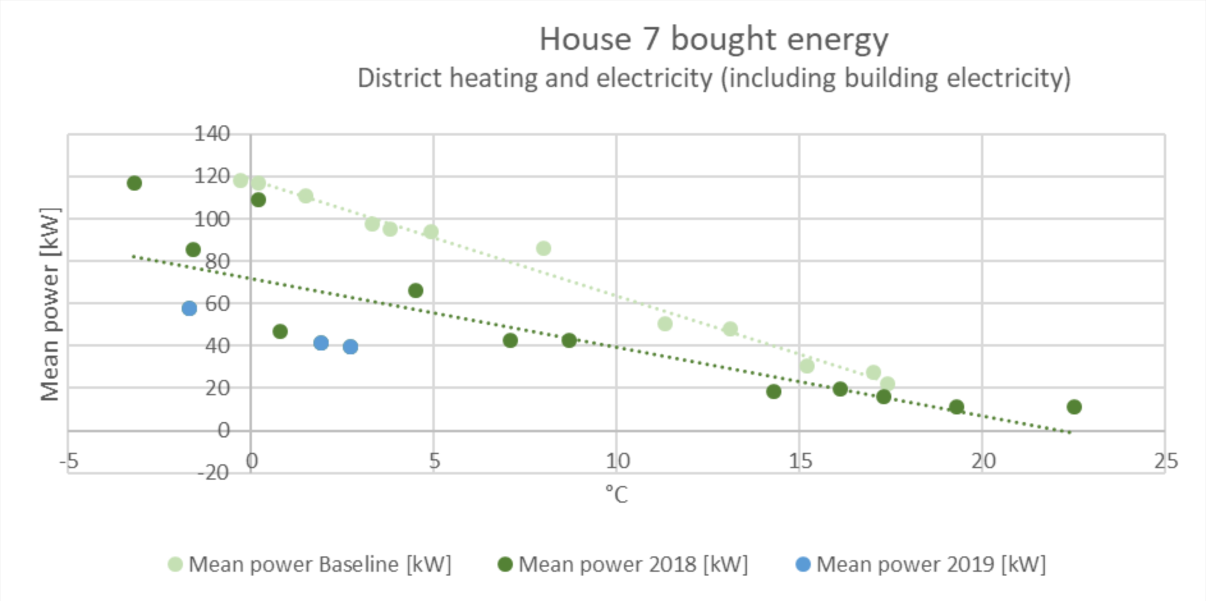


Figure 2 Energy signature for House 7G in Stockholm

Table 16 KPIs evaluated for M1.0 House 7G (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	680043	246029	-64 %
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	38031	36018	-5 %
3.1 Electric energy required (kWh) for heating		108831	
4. CO2 emissions due to heating energy demand (t/year)	63.312	18960	-70 %
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)	2.409	2,863	19 %
Total purchased energy	718074	282047	-61 %

House 8H

The installed technology includes now a combination of district heating, smart building control, exhaust air heat pumps and heat recovery from waste water.

New digital energy meters and indoor temperature meters have been also installed during the renovation. The total conditioned area before and after the deep renovation changed from 4571m^2 to 4626 m^2.

The results obtained within the Project are reported in Table 17, Table 18 and Table 19. In particular, Table 17 shows the baseline values measured over 2017, while Table 18 report the summary of the measurements performed after the refurbishment. Table 19 shows the results in terms of achieved energy savings. Worth noticing, the photovoltaic system started to produce electricity only from July 2018 and the exhaust heat pumps were not fully in operation until November 2018.

Table 17 Baseline evaluated for M1.0 House 8H (Stockholm)

Baseline	2017-01-01 2017-12-31	Units	KPI	Units
District heating (space heating and hot water)	544850	kWh	119	kWh/m²
Purchased electricity	26752	kWh	6	kWh/m²
Total purchased energy	571672	kWh	125	kWh/m²

Table 18 Energy use after refurbishment for M1.0 House 8H (Stockholm)

After refurbishment	2018-07-01 2019-06-30	Units	KPI	Units
District heating (space heating and hot water)	126157	kWh	27,3	kWh/m²
Purchased electricity	107907	kWh	23	kWh/m²
Produced solar energy	21161	kWh	4.6	kWh/m²
Total purchased energy*	234064	kWh	50,6	kWh/m²

* excluded: laundry room and outdoor lighting

Table 19 Energy use variation for M1.0 House 8H (Stockholm)

Results	Variation
District heating (space heating and domestic hot water)	-77%
Purchased electricity	+299%
Total purchased energy	-60%

Table 20 shows the results related to the calculated CO_2 savings obtained with the refurbishment of House 8H.

Table 20 CO2 emission for M1.0 House 8H (Stockholm)

CO_2 emissions	Value
CO_2 emission before the refurbishment	50.7 t
CO_2 emission after the refurbishment	18.5 t
CO_2 emission variation	-64 %

Figure 3 shows the Energy Signature of House 8H. The x-axis represent the monthly average of the outdoor temperature. The “mean power” includes the total purchased energy divided by the number of hours in the month.

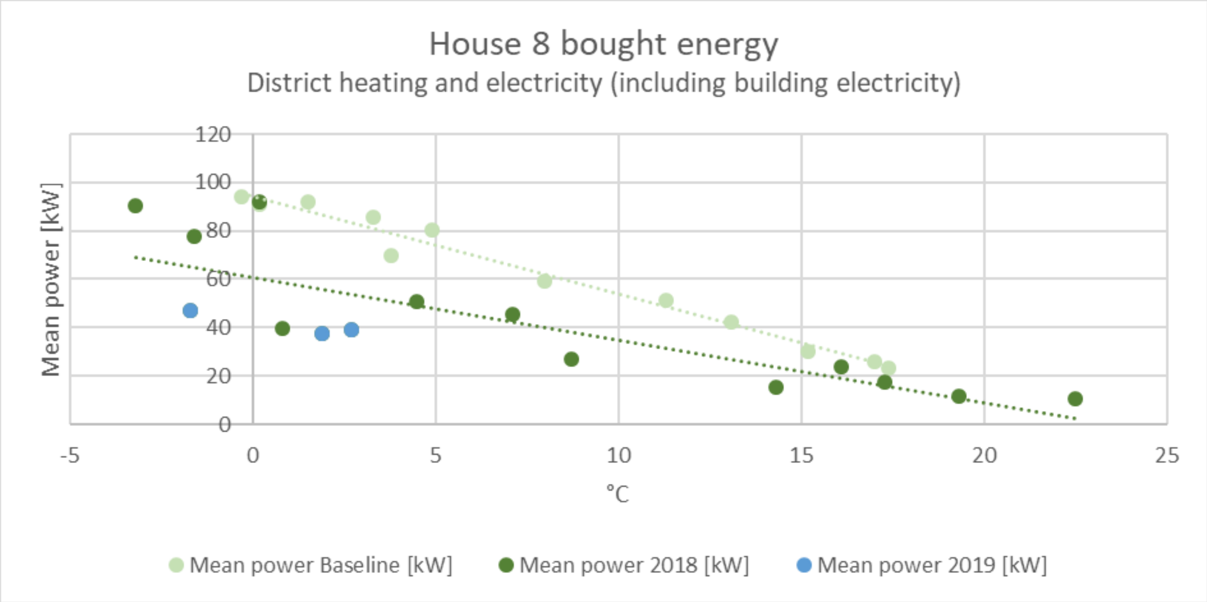


Figure 3 Energy signature for House 8H in Stockholm

Table 21 KPIs evaluated for M1.0 House 8H (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	544850	209324	-62 %
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	26752	23542	-12 %
3.1 Electric energy required (kWh) for heating	0	83167	-
4. CO2 emissions due to heating energy demand (t/year)	50.726	16,674	-67 %
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)	1.683	2,053	22 %
Total purchased energy	571602	232866	-60 %

Årstakrönet

L&T has implemented several interventions in Brf Årstakrönet, including:

- PV cells
- Battery storage
- Energy HUB
- Smart ventilation control
- Indoor climate control
- Energy Quality Control (EQC)
- Adaptive control system for heating-Indoor temperature control
- Air tightness test
- Thermographic control

Space heating is controlled by an adaptive control system. Indoor temperature meters have been installed in all apartments as well as a smart ventilation control for the garage, water saving equipment, electricity meters, District Heating meter and water measurement equipment. Also Photovoltaic panels have been installed in combination with a battery storage system.

With the installation of these technologies and tools, L&T aimed to guarantee energy savings from different energy consuming facilities in the building. The entire installation is supervised through L&Ts Energy Saving Center. The total conditioned area is 4950m^2.

The obtained results are reported in Table 22, Table 23 and Table 24. In particular, Table 22 shows the baseline values measured over 2017, while Table 23 report the summary of the measurements performed after the refurbishment. Table 24 shows the results in terms of achieved energy savings. Worth noticing, the impact of the water circulation losses increased due to the lower overall energy consumption. The content reported in the following tables is based on monthly values.

Table 22 Baseline evaluated for M1.0 Årstakrönet (Stockholm)

Baseline	2015-01-01 2015-12-31	Units	KPI	Units
District heating (space heating and hot water)	547 911	kWh	111	kWh/m^2
Purchased electricity	68 008	kWh	13.8	kWh/m^2
Total purchased energy	615 919	kWh	124.8	kWh/m^2
Hot water usage	5 346 000	liters	1080	kWh/m^2
Hot water circulation losses	27 000	kWh	4.9	%

Table 23 Energy use after refurbishment for M1.0 Årstakrönet (Stockholm)

After refurbishment	2018-01-01 2018-12-31	Units	KPI	Units
District heating (space heating and hot water)	487 502	kWh	98	kWh/m^2
Purchased electricity	45 095	kWh	9	kWh/m^2
Total purchased energy	532 597	kWh	108	kWh/m^2
Produced solar energy	11 442	kWh	2.3	kWh/m^2
Total consumed energy	542 581	kWh	110	kWh/m^2
Hot water usage	5 001 000	liters	1010	kWh/m^2
Hot water circulation losses	27000	kWh	5.5	%

Table 24 Energy use variation for M1.0 Årstakrönet (Stockholm)

Results	Variation
Space heating and domestic hot water	-11%
Purchased electricity	-33.7%
Total purchased energy	-14%
Electricity consumption	-19%
Hot water usage	-6.4%
Hot water circulation losses	+12.2%

Table 25 shows the results related to the estimated CO_2 saving obtained with the refurbishment of Årstakrönet.

Table 25 CO2 emission for M1.0 Årstakrönet (Stockholm)

CO_2 emissions	Value
CO_2 emission before the refurbishment	58.4 t

CO_2 emission after the refurbishment	45.8 t
CO_2 emission reduction	22%

Figure 4 shows the Energy Signature of Årstakrönet based on the final data collected.

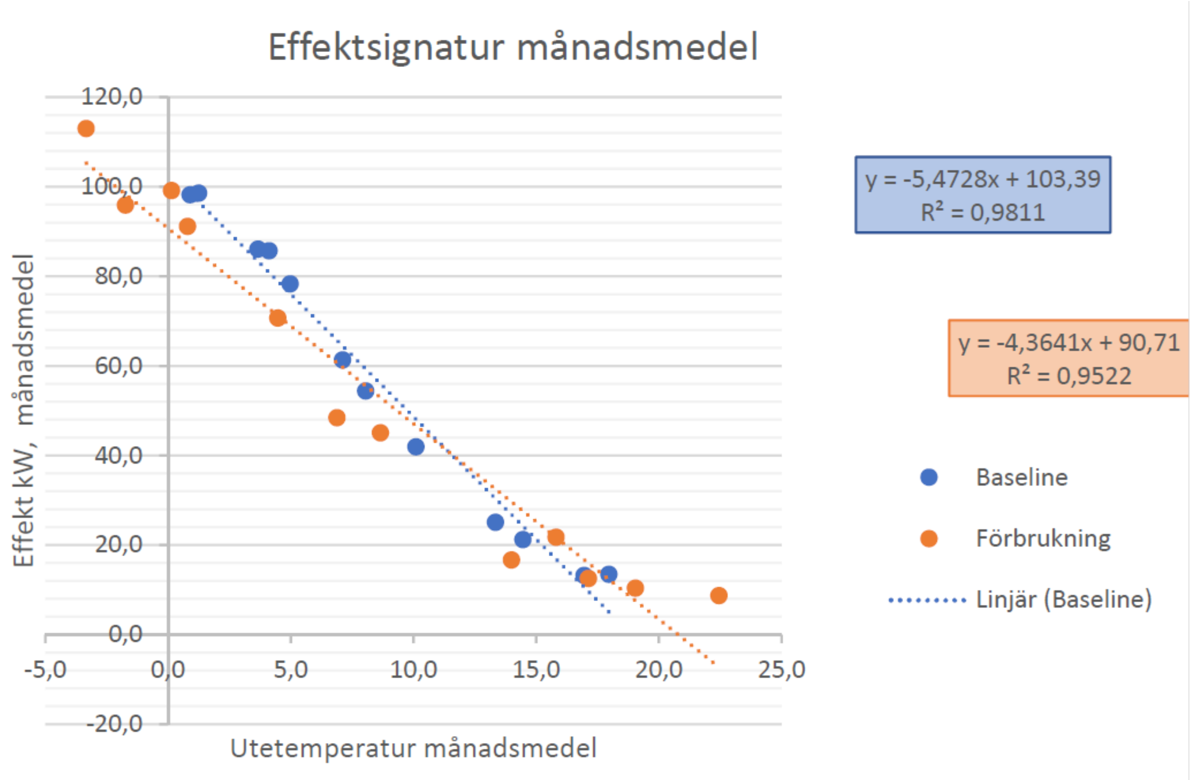


Figure 4 Energy signature for Årstakrönet in Stockholm

The indoor temperature is hourly monitored and Figure 5 shows an example of the available information.

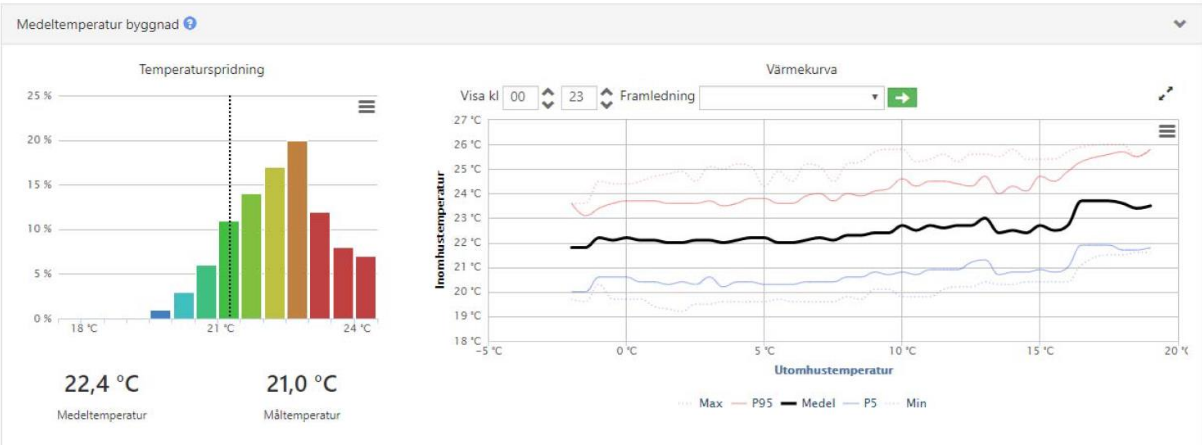


Figure 5 Example of indoor temperature monitoring in Årstakrönet, Stockholm. Reference period: October 2018.

Table 26 KPIs evaluated for M1.0 Årstakrönet (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	547 911	486 502	-11 %

2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	68 008	46001	-17 %
4. CO2 emissions due to heating energy demand (t/year)	54.1	43.0	-20.5 %
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)	4.3	2.8	-34.8 %
Total purchased energy			**-14%**

Slaughterhouse area

In Slaughterhouse the baseline has been calculated instead of measured, due to the fact that the house has not been heated for the past 50 years. A theoretical baseline has been calculated as if the building had been in use. The first year to be compared to baseline is 2018.

The installed technology in the Slaughterhouse includes now a combination of district heating, adaptive control, exhaust air heat pumps, PV cells and batteries.

New digital energy meters and indoor temperature meters have been also installed during the renovation. The total conditioned area is 906 m^2.

The obtained results are reported in Table 27, Table 28 and Table 29. In particular, Table 27 shows the baseline values measured over 2017, while Table 28 report the summary of the measurements performed after the refurbishment. Table 29 shows the results in terms of achieved energy savings.

Table 27 Baseline evaluated for M1.0 Slaughterhouse (Stockholm)

Baseline	**2017-01-01 2017-12-31**	**Units**	**KPI**	**Units**
District heating (space heating and hot water)	346 791	kWh	383	kWh/m^2
Purchased electricity	12 000	kWh	13	kWh/m^2
Total purchased energy	358 791	kWh	396	kWh/m^2

Table 28 Energy use after refurbishment for M1.0 Slaughterhouse (Stockholm)

After refurbishment	**2018-04-01 2019-03-31**	**Units**	**KPI**	**Units**
District heating (space heating and hot water)	150 010	kWh	165,6	kWh/m^2
Purchased electricity	41 085	kWh	45.3	kWh/m^2
Total purchased energy	191 095	kWh	210,9	kWh/m^2
Produced solar energy	9 630	kWh	10,6	kWh/m^2
Total consumed energy	200 725	kWh	221.6	kWh/m^2

Table 29 Energy use variation for M1.0 Slaughterhouse (Stockholm)

Results	**Variation**
Space heating and domestic hot water	-57%
Purchased electricity	+242%
Total purchased energy	-47%

Table 30 shows the results related to the estimated CO_2 saving obtained with the refurbishment of Slaughterhouse.

Table 30 CO2 emission for M1.0 Slaughterhouse (Stockholm)

CO_2 emissions	Value
CO_2 emission before the refurbishment	35,0 t
CO_2 emission after the refurbishment	15,8t
CO_2 emission reduction	55%

The indoor temperature is hourly monitored and Figure 6 shows an example of the available information.

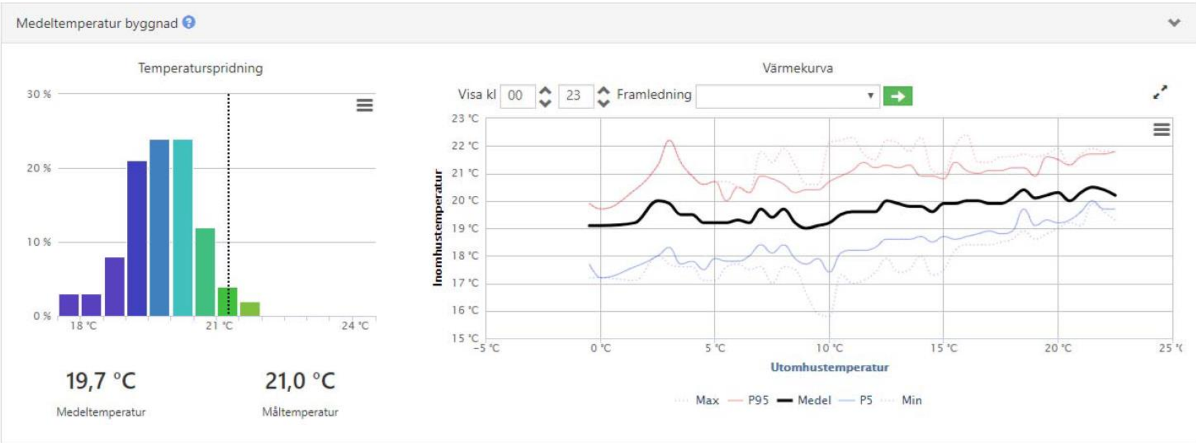


Figure 6 Example of indoor temperature monitoring in Slaughterhouse, Stockholm. Reference period: September 2018.

Table 31 KPIs evaluated for M1.0 Slaughterhouse (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	346 791	150 010	-57%
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	12 000	41 085	+242%
4. CO2 emissions due to heating energy demand (t/year)	34,3	13,2	-61 %
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)	0.8	2.6	+242 %
Total purchased energy			**-47%**

Kylhuset

The interventions carried out in Kylhuset includes:

- A new air handling unit with a rotary heat exchanger and new automation system
- New PV cells on roof
- EnergyHUB and battery storage
- New membrane and insulation on roof

- Waste heat recovery from data center (in a building nearby)

The installed technology includes waste heat recovery to district heating, a new air handling unit, roof insulation, PV panels and a battery storage system. The total conditioned area is 3405m^2.
The obtained results are reported in Table 32, Table 33 and Table 34. In particular, Table 32 shows the baseline values measured over 2016, while Table 33 reports the summary of the measurements performed after the refurbishment. Table 34 shows the results in terms of achieved energy savings. The content reported in the following tables is based on monthly values.

Table 32 Baseline evaluated for M1.0 Kylhuset (Stockholm)

Baseline	2016-01-01 2016-12-31	Units	KPI	Units
District heating (space heating and hot water)	356 140	kWh	105	kWh/m^2
Purchased electricity	150 160	kWh	44	kWh/m^2
Total purchased energy	506 300	kWh	149	kWh/m^2

Table 33 Energy use after refurbishment for M1.0 Kylhuset (Stockholm)

After refurbishment	2018-01-01 2018-12-31	Units	KPI	Units
District heating (space heating and hot water)	243 036	kWh	71	kWh/m^2
Purchased electricity	123 160	kWh	36	kWh/m^2
Total purchased energy	366 196	kWh	108	kWh/m^2
Produced solar energy	12 000	kWh	4	kWh/m^2
Energy recovered from data center	205 000	kWh	60	kWh/m^2
Total consumed energy	173 196	kWh	51	kWh/m^2

Table 34 Energy use variation for M1.0 Kylhuset (Stockholm)

Results	Variation
Space heating and domestic hot water	-32%
Purchased electricity	-18%
Total purchased energy	-28%

Table 35 shows the results related to the estimated CO_2 savings obtained with the refurbishment of Kylhuset.

Table 35 CO2 emission for M1.0 Kylhuset (Stockholm)

CO_2 emissions	Value
CO_2 emission before the refurbishment	42.6 t
CO_2 emission after the refurbishment	30.3 t
CO_2 emission reduction	29%

Figure 7 shows the Energy Signature of Kylhuset. It is worth noticing that the figure includes the aggregated data from 3 buildings and not only from Kylhuset "Building A". The CO2 emission coefficient adopted for the District Heating energy consumption is 93.1 g/kWh.

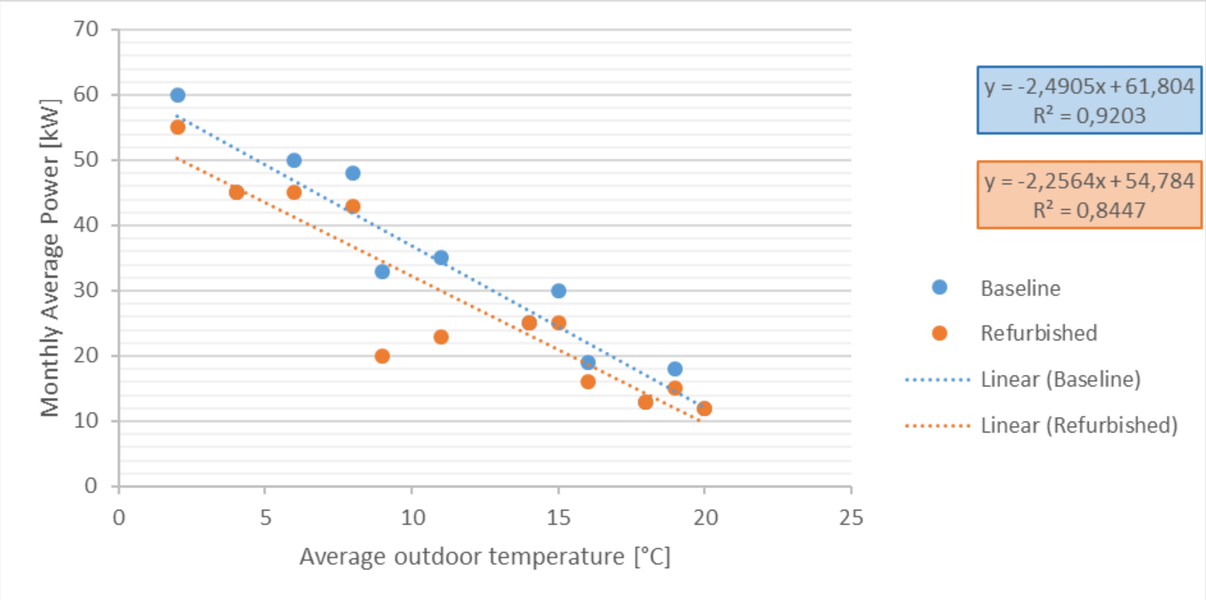


Figure 7 Energy signature for Kylhuset in Stockholm

Table 36 KPIs evaluated for M1.0 Kylhuset (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	356 140	243 036	-32 %
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	150 160	123 160	-18 %
4. CO2 emissions due to heating energy demand (t/year)	33.1	22.6	-31.7 %
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)	9.4	7.7	-18 %
Total purchased energy			**-28%**

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie Dewog	Andreas Wolba Christian Remacly André Esser	KTH-EGI

In Cologne the Measures related to building renovation and improvement have been implemented in the neighbourghood of Stegerwaldsiedlung, which includes 16 buildings, under the coordination of RheinEnergie.

Dewog has insulated the building envelopes, basement ceilings and roofs. Triple glazed windows have been installed in some of the buildings. The total renovated area is about 44000 m^2 (about 33500 m^2 of living area).

Table 37 Measures evaluated by RheinEnergie within WP2

			Measures						
		Type	1.0	1.1.1	1.1.5	1.1.8	1.1.9	4.1.1	4.1.2
RESIDENTIAL	Deutz-Mülheimerstr 152-168	2	X	X			X*	X	
	Deutz-Mülheimerstr 170-182	2	X	X			X*	X	
	Gaußstr 2-4	2	X	X			X*	X	
	Legienstr 2-10	1	X	X			X*	X	
	Sonnenscheinstr 1-3	3	X	X			X*	X	
	Legienstr 1-7	1	X	X			X*	X	
	Edith-Steinstr 2-6	1	X	X		X	X*	X	
	Edith-Steinstr 1-7	1	X	X	X	X	X*	X	
	Sonnenscheinstr 2-8	3	X	X			X*	X	
	Adam-Stegerwaldstr 16-26	1	X	X	X	X	X*	X	
	Adam-Stegerwaldstr 11-17	3	X	X		X	X*	X	
	Adam-Stegerwaldstr 19-25	3	X	X	X	X	X*	X	
	Edith-Steinstr 14-16	2	X	X			X*	X	
	Edith-Steinstr 18-22	2	X	X			X*	X	
	Ulitzkastr 1	4	X	X			X*	X	
	Edith-Steinstr 26-34	1	X	X			X*	X	

*Results not available

Monitoring systems started being operative at the beginning of 2018 for the first and second construction phases. Among the devices installed for the monitoring system there are temperature sensors, electricity and heat meters for heat pumps, heat meters for district heating in each building and space heating meters. In fact, all activities related to the monitoring are part of Measure M4.1 by RheinEnergie.

The energy consumptions have been corrected for ambient conditions (heating degree day correction). The total electricity consumption results from the consumptions of the tenants and the public electricity. For the Baseline they have been measured by meters and in the post-refurbishment period.

The calculation model "EnEv" has been used to provide uniform and comparable evaluation of energy consumption[10]. In particular, the EnEV values were taken as a solution to provide realistic preliminary figures.

With reference to Table 37, Figure 8 shows the map of the buildings involved in Cologne within WP2.

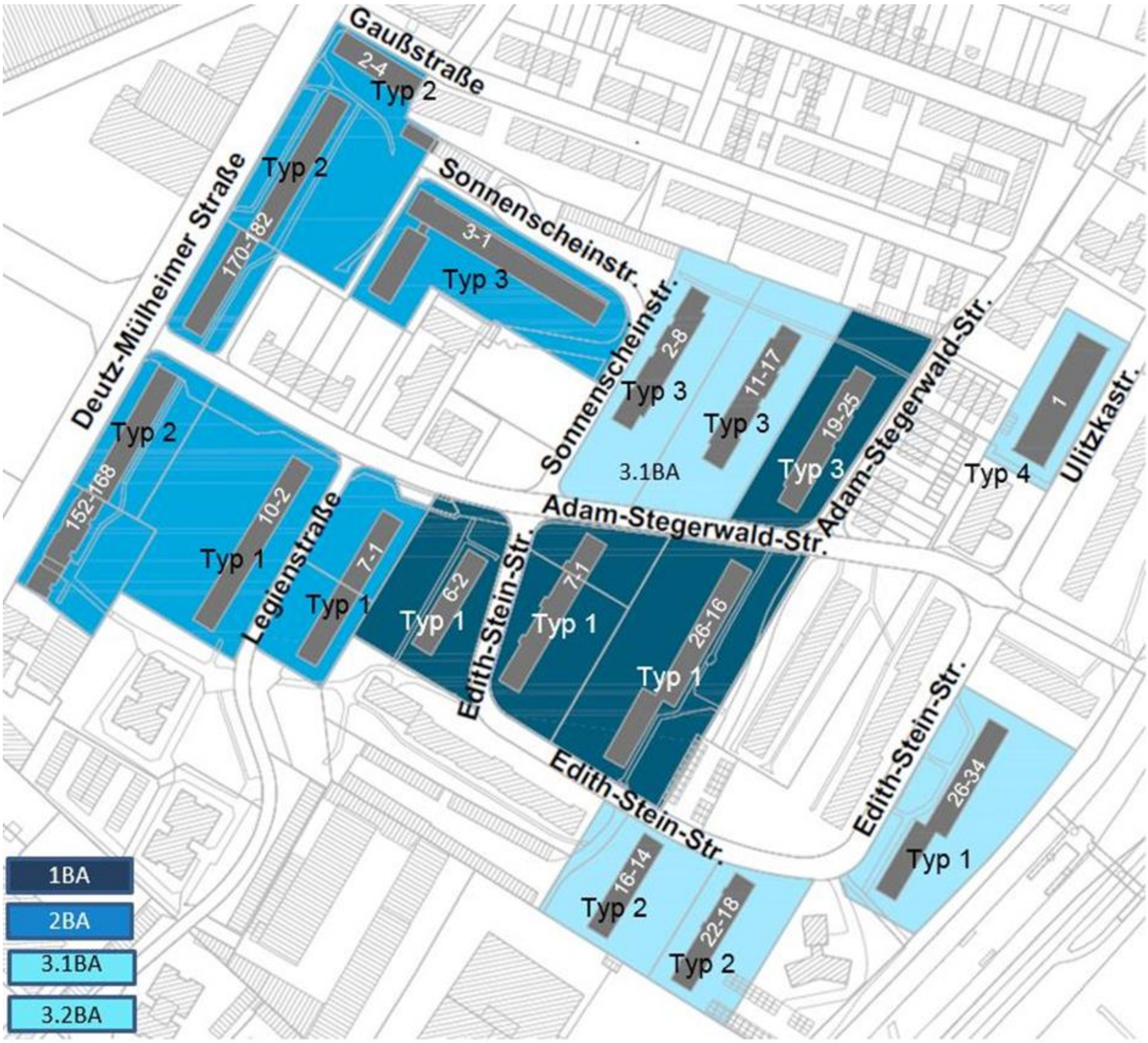


Figure 8 Map of the buildings involved in Cologne within WP2.

The 16 buildings have been assigned to different groups (see type in Table 37). The type assignment is independent of the construction stages and is based on the different renovation Measures.

<u>Type 1</u>

- [10] http://www.gbpn.org/databases-tools/bc-detail-pages/germany

The buildings have an ETICS (External Thermal Insulation Composite System) of 60mm thickness, new windows and new doors. The buildings have a roof extension and an insulation of the basement ceiling as well as a heat supply via district heating and air/water heat pumps.

Type 2

The buildings are similar to type 1 with a new ETICS of 160mm thickness.

Type 3

The buildings do not have a roof extension but only a new ETICS of 160mm thickness, as well as an insulation of the basement and top floor ceiling. The heat supply is also provided by district heating and air/water heat pumps.

Type 4

This type is a building which has been removed from type 2 and is equipped with a new condensing heating system including heat water in the existing building. Also new windows and doors have been installed in the existing building. The building also has a new ETICS of 160mm thicknes

In the following, the results of final energy consumptions are summarized for all the 16 buildings involved. The calculated values related to 2015 are considered as baseline.

The following paragraphs present the KPIs evaluated within M1.0 for the buildings of Stegerwaldsiedlung (Table 37) refurbished within the Project. It is worth noticing that the refurbished area is relatively large and a measurement campaign was carried out in 2018. By then not all the refurbishment works were completed and the results are not available. It is also important to mention that in Germany the adoption of smart-meters have been delayed due to legislative issues and the measurement of building energy consumption is officially available only once per year (tipically in December). For all these reasons, the hourly measurements prescribed by the Evaluation Plan D5.4 are unfortunately not available and the KPIs presented have been calculated considering an extra ordinary measurement campaing carried out in October 2019. The energy signature charts (based on monthly values) are also not available. The results are therefore evaluated considering the Mesured values for less than one year, between January and October 2019, extrapolated to 12 months following the German standard. Worth noticing, in the tables presented in the following paragraphs the electricity is the bought energy from the grid, which is less than the used energy due to the contribution of the PV production.

It worth also to notice that in only four of the buildings the heat pumps installed have been equipped with dedicated energy meters to track the electricity consumption. For this reason the purchased energy can only be estimated considering the measured heat from the heat pumps and an average Coefficient of Performance (COP). The average COP from the four monitored heat pump units is 2.5.

Despite the fact that the official CO_2 emission factors for 2015 (baseline) and 2019 (year of the evaluation) changed from 0.431 to 0.306 kg/kWh, respectively, the calculation of the CO_2 emission KPIs has been carried out considering an average value of 0.368 in order to better highlight the impact of the refurbishments. Nevertheless, the results of the CO_2 emissions presented in the following tables could not be validated. A summary of the results is available in Table 146.

Deutz-Mülheimerstr 152-168

In addition to the energetic renovation, the roof was extended and 14 new apartments were created.

Table 38 KPIs evaluated for M1.0 Deutz-Mülheimerstr 152-168 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1.0 Heat energy required (kWh) per year and month normalized for climatic conditions.	385601	325662	-16%
1.0 in kWh/m²	98	69	-30%
1.1 Heat Pump (kWh)	-	19928,5	-
1.2 Gas (kWh)	385600,5	-	-
1.3 District heating (kWh)	-	305733,5	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	105191	111970,5	6%
3.0 kWh/m²	26,7	23,7	-11%
4. CO2 emissions due to heating energy demand (t/year)*	79,4	31,2	-61%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	38,7	41,3	6%
Total bought energy (kWh)	**490791,5**	**437633**	**-11%**
Total bought energy (kWh/m²)	**125**	**93**	**-26%**

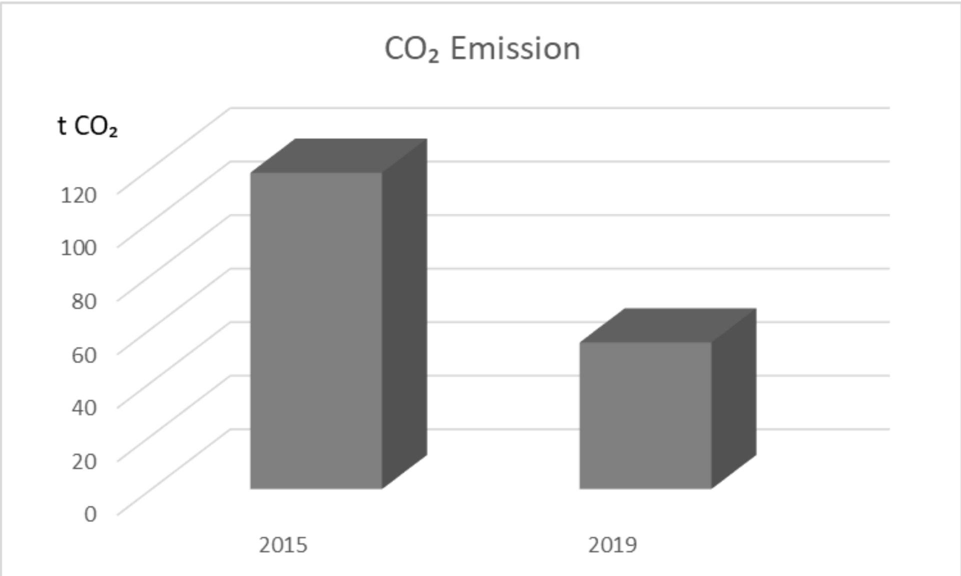


Figure 9 Total CO_2 emissions for Deutz-Mülheimerstr 152-168 in Cologne*

*Results not validated

Deutz-Mülheimerstr 170-182

In addition to the energetic renovation, the roof was extended and 13 new apartments were created.

Table 39 KPIs evaluated for M1.0 Deutz-Mülheimerstr 170-182 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1.0 Heat energy required (kWh) per year and month normalized for climatic conditions.	585461	321589	-45%
1.0 in kWh/m²	1450	66	-54%
1.1 Heat Pump (kWh)	-	73776,1	-
1.2 Gas (kWh)	585461	-	-
1.3 District heating (kWh)	-	247813,2	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	104004	34877,9	-66%
3.0 kWh/m²	25,8	7,2	-72%
4. CO2 emissions due to heating energy demand (t/year)*	120,6	46,5	-61%
5. CO2 emissions due to cooling energy demand (t/year)	-		-
6. CO2 emissions due to electric energy demand (t/year)*	38,3	12,8	-66%
Total bought energy (kWh)	**689465**	**356467**	**-48%**
Total bought energy (kWh/m²)	**171**	**74**	**-57%**

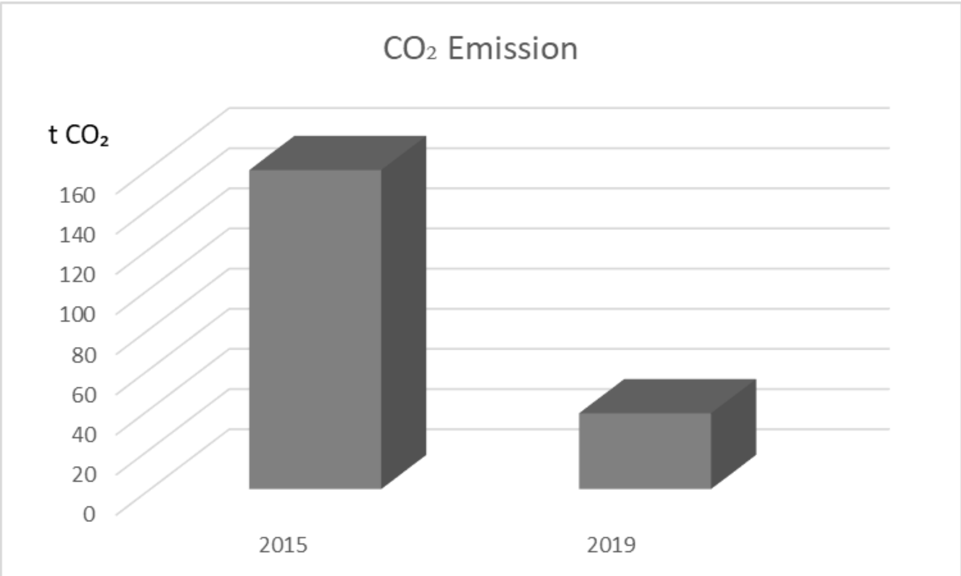


Figure 10 Total CO_2 emissions for Deutz-Mülheimerstr 170-182 in Cologne*

*Results not validated

Gaußstr 2-4

In addition to the energetic renovation, the roof was extended and 4 new apartments were created.

Table 40 KPIs evaluated for M1.0 Gaußstr 2-4 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1.0 Heat energy required (kWh) per year and month normalized for climatic conditions.	120782	78275	-35%
1.0 in kWh/m²	87	47	-46%
1.1 Heat Pump (kWh)	-	12347,6	-
1.2 Gas (kWh)	120782	-	-
1.3 District heating (kWh)	-	65927,3	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	36577	22306,4	-39%
3.0 kWh/m²	26,5	13,5	-49%
4. CO2 emissions due to heating energy demand (t/year)*	24,9	9,6	-61%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	13,4	8,2	-39%
Total bought energy (kWh)	**157359**	**100581**	**-36%**
Total bought energy (kWh/m²)	**114**	**61**	**-47%**

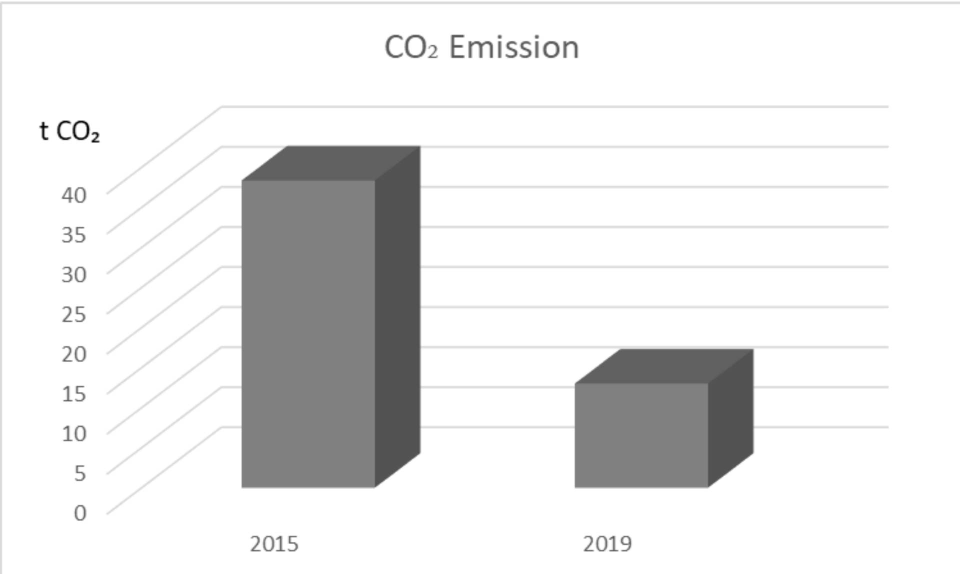


Figure 11 Total CO_2 emissions for Gaußstr 2-4 in Cologne*

*Results not validated

Legienstr 2-10

In addition to the energetic renovation, the roof was extended and 10 new apartments were created.

Table 41 KPIs evaluated for M1.0 Legienstr 2-10 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1.0 Heat energy required (kWh) per year and month normalized for climatic conditions.	236265	207812	-12%
1.0 in kWh/m²	86	63	-27%
1.1 Heat Pump (kWh)	-	14604,4	-
1.2 Gas (kWh)	236264,8	-	-
1.3 District heating (kWh)	-	193207,3	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	71436,00	55211,6	-23%
3.0 kWh/²	26,3	16,8	-36%
4. CO2 emissions due to heating energy demand (t/year)*	48,7	20,4	-58%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	26,3	20,3	-23%
Total bought energy (kWh)	**307701**	**263023**	**-15%**
Total bought energy (kWh/m²)	**112**	**80**	**-29%**

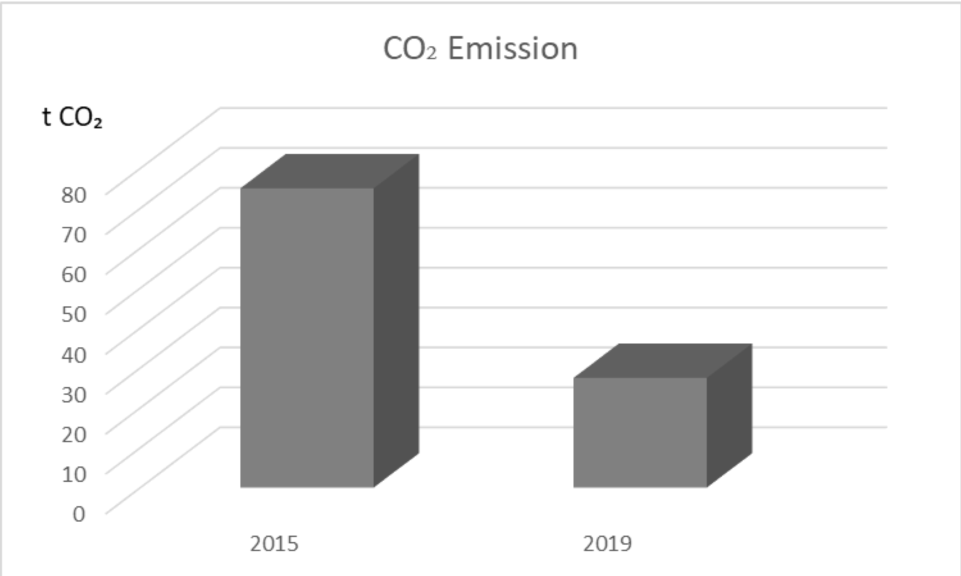


Figure 12 Total CO_2 emissions for Legienstr 2-10 in Cologne*

*Results not validated

Sonnenscheinstr 1-3

Measurements revealed an increase of the total energy consumption. The reason for this increase is currently unknown.

Table 42 KPIs evaluated for M1.0 Sonnenscheinstr 1-3 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1.0 Heat energy required (kWh) per year and month normalized for climatic conditions.	697394,1	734692	5%
1.0 in kWh/m²	111	117	5%
1.1 Heat Pump (kWh)	-	83556	-
1.2 Gas (kWh)	697394,1	-	-
1.3 District heating (kWh)	-	651136,3	
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	170096,0	30373	-82%
3.0 kWh/m²	27,14	4,8	-82%
4. CO2 emissions due to heating energy demand (t/year)*	143,6	81,6	-43%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	62,7	11,2	-82%
Total bought energy (kWh)	**867490,1**	**765065**	**12%**
Total bought energy (kWh/m²)	**138**	**122**	**12%**

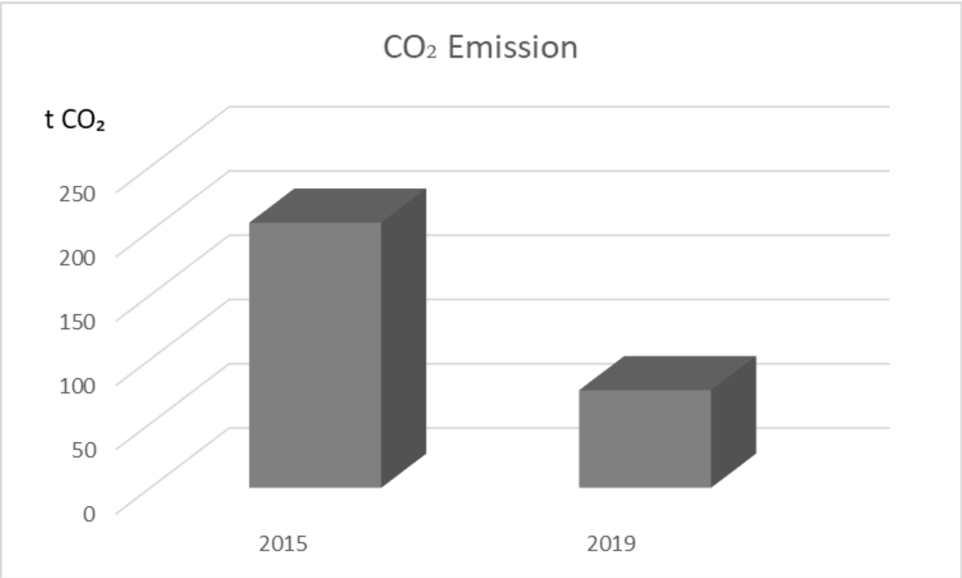


Figure 13 Total CO_2 emissions for Sonnenscheinstr 1-3 in Cologne*

*Results not validated

Legienstr 1-7

In addition to the energetic renovation, the roof was extended and 8 new apartments were created.

Table 43 KPIs evaluated for M1.0 Legienstr 1-7 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1.0 Heat energy required (kWh) per year and month normalized for climatic conditions.	414294,6	220404	-47%
1.0 in kWh/m²	169,9	75	-56%
1.1 Heat Pump (kWh)	-	3567,1	
1.2 Gas (kWh)	414294,6	-	-
1.3 District heating (kWh)	-	216837,1	
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-		
3. Electric energy required (kWh) per year and month.	59696	69861,9	17%
3.0 kWh/m²	24,5	23,9	-2%
4. CO2 emissions due to heating energy demand (t/year)*	85,3	18,2	-79%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	22	25,7	-17%
Total bought energy (kWh)	**473991**	**290266**	**-39%**
Total bought energy (kWh/m²)	**194**	**99**	**-49%**

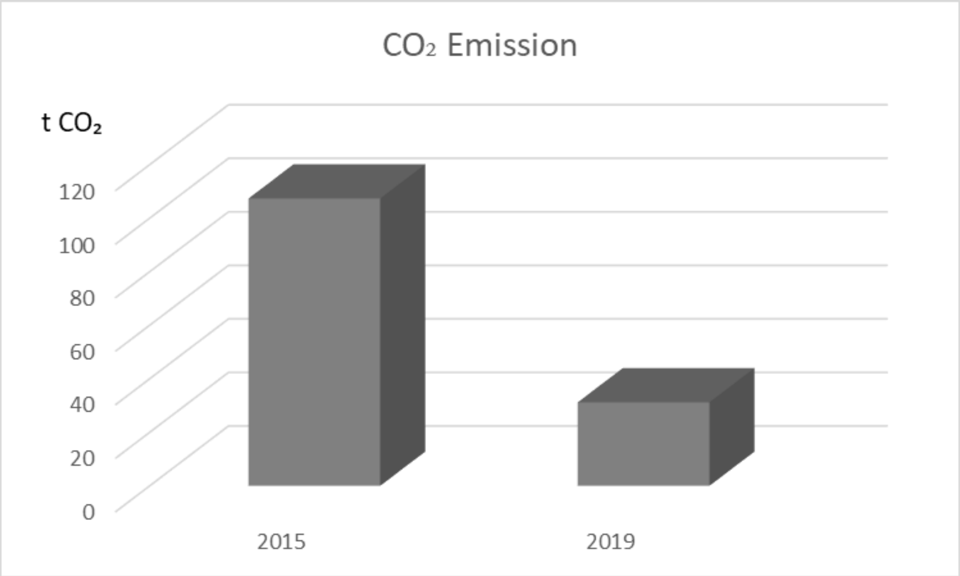


Figure 14 Total CO_2 emissions for Legienstr 1-7 in Cologne*

*Results not validated

Edith-Steinstr 2-6

In addition to the energetic renovation, the roof was extended and 6 new apartments were created.

Table 44 KPIs evaluated for M1.0 Edith-Steinstr 2-6 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	135620	113248	-16%
1.0 kWh/m²	84,1	59	-30%
1.1 Heat Pump (kWh)	-	10340,4	-
1.2 Gas (kWh)	135619,7	-	-
1.3 District heating (kWh)	-	102907,4	
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	32732,0	23372,6	-29%
3.0 kWh/m²	20,3	12,1	-40%
4. CO2 emissions due to heating energy demand (t/year)*	27,9	11,8	-58%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	12,1	8,6	-29%
Total bought energy (kWh)	**168352**	**136620**	**-19%**
Total bought energy (kWh/m²)	**104**	**71**	**-32%**

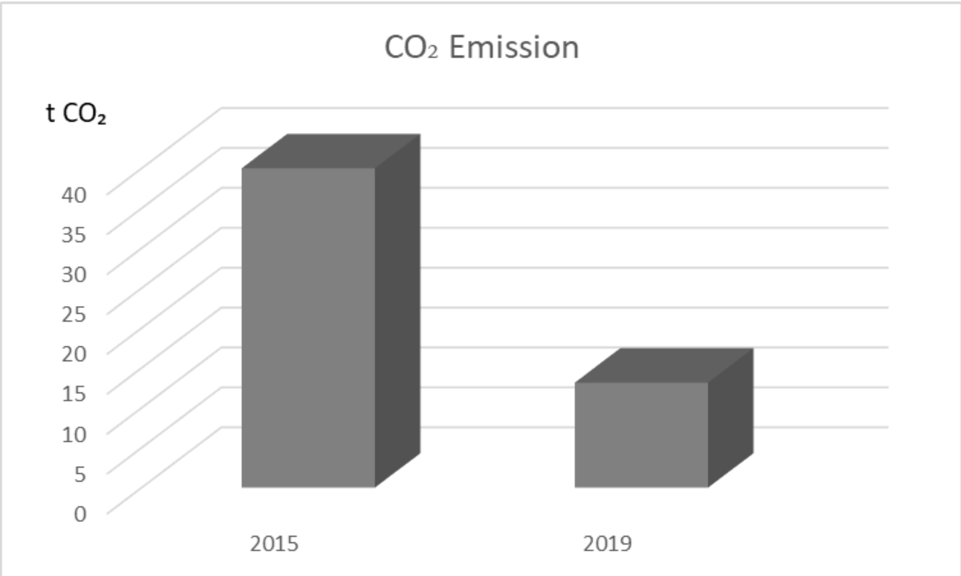


Figure 15 Total CO_2 emissions for Edith-Steinstr 2-6 in Cologne*

*Results not validated

Edith-Steinstr 1-7

In addition to the energetic renovation, the roof was extended and 8 new apartments were created.

Table 45 KPIs evaluated for M1.0 Edith-Steinstr 1-7 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	249650,4	197868	-21%
1.0 kWh/m²	102	67	-34%
1.1 Heat Pump (kWh)	-	13654,2	-
1.2 Gas (kWh)	249650,4		-
1.3 District heating (kWh)	-	184214	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	68321,0	42291,8	-38%
	27,8	14,3	-48%
4. CO2 emissions due to heating energy demand (t/year)*	51,4	19,4	-62%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	25,2	15,6	-38%
Total bought energy (kWh)	**317971**	**240160**	**-24%**
Total bought energy (kWh/m²)	**129**	**81**	**-37%**

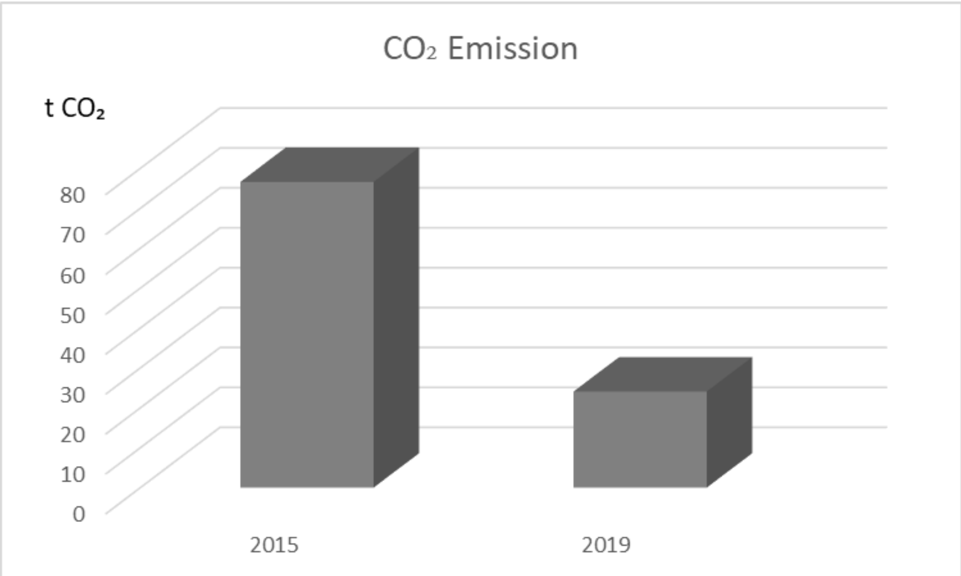


Figure 16 Total CO_2 emissions for Edith-Steinstr 1-7 in Cologne*

*Results not validated

Sonnenscheinstr 2-8

Table 46 KPIs evaluated for M1.0 Sonnenscheinstr 2-8 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	294218	121204	-59%
1.0 kWh/m²	126	52	-59%
1.1 Heat Pump (kWh)	-	24984,1	-
1.2 Gas (kWh)	249650,4		-
1.3 District heating (kWh)	-	96219,7	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	68763,0	18885,9	-73%
3.0 kWh/m²	29,4	8,1	-73%
4. CO2 emissions due to heating energy demand (t/year)*	60,6	16,7	-72%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	25,3	6,9	-73%
Total bought energy (kWh)	**362981**	**140090**	**-61%**
Total bought energy (kWh/m²)	**155**	**60**	**-61%**

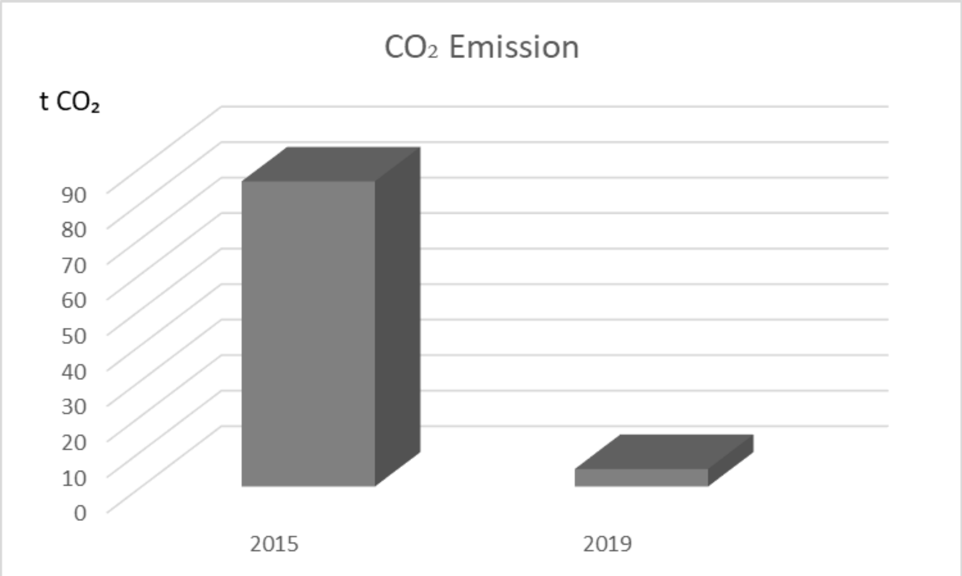


Figure 17 Total CO_2 emissions for Sonnenscheinstr 2-8 in Cologne*

*Results not validated

Adam-Stegerwaldstr 16-26

In addition to the energetic renovation, the roof was extended and 12 new apartments were created.

Table 47 KPIs evaluated for M1.0 Adam-Stegerwaldstr 16-26 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	363193	231147	-36%
1.0 kWh/m²	104	55	-47%
1.1 Heat Pump (kWh)	-	37300,7	-
1.2 Gas (kWh)	363193,0		-
1.3 District heating (kWh)	-	193846,3	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	87059,0	57338,3	-34%
3.0 kWh/m²	24,97	13,7	-45%
4. CO2 emissions due to heating energy demand (t/year)*	74,8	28,8	-61%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	32,1	21,1	-34%
Total bought energy (kWh)	**450252**	**288485**	**-36%**
Total bought energy (kWh/m²)	**129**	**69**	**-47%**

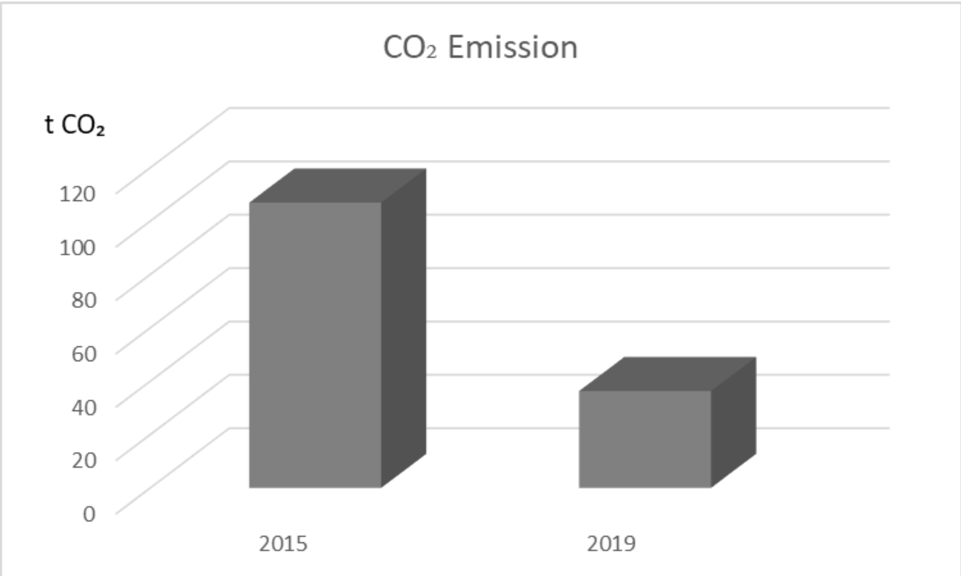


Figure 18 Total CO_2 emissions for Adam-Stegerwaldstr 16-26 in Cologne*

*Results not validated

Adam-Stegerwaldstr 11-17

Table 48 KPIs evaluated for M1.0 Adam-Stegerwaldstr 11-17 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	334280,4	163049	-51%
1.0 kWh/m²	143,1	70	-51%
1.1 Heat Pump (kWh)	-	7332	-
1.2 Gas (kWh)	334280,4	-	-
1.3 District heating (kWh)	-	155716,9	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	65821,0	45398,0	-31%
3.0 kWh/m²	28,2	19,4	-31%
4. CO2 emissions due to heating energy demand (t/year)*	68,8	14,8	-78%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	24,2	16,7	-31%
Total bought energy (kWh)	**400101,4**	**208447**	**-48%**
Total bought energy (kWh/m²)	**171**	**89**	**-48%**

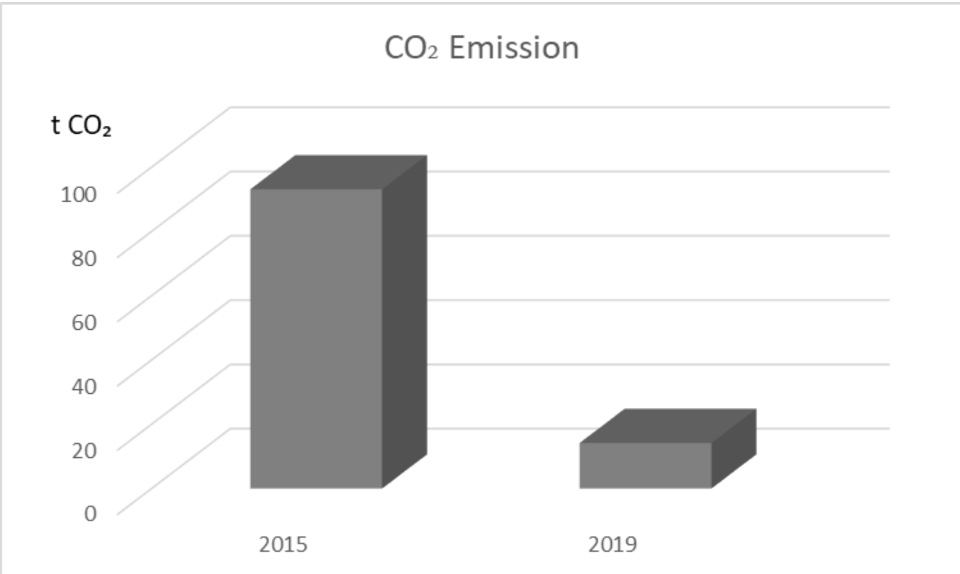


Figure 19 Total CO_2 emissions for Adam-Stegerwaldstr 11-17 in Cologne*

*Results not validated

Adam-Stegerwaldstr 19-25

Table 49 KPIs evaluated for M1.0 Adam-Stegerwaldstr 19-25 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	267695,4	137123	-49%
1.0 kWh/m²	115	59	-49%
1.1 Heat Pump (kWh)	-	23099	-
1.2 Gas (kWh)	267695,4		-
1.3 District heating (kWh)	-	114024,4	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	59902,0	21892	-63%
3.0 kWh/m²	25,6	9,4	-63%
4. CO2 emissions due to heating energy demand (t/year)*	55,1	17,4	-68%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	22,1	8,1	-63%
Total bought energy (kWh)	**327597**	**159015**	**-51%**
Total bought energy (kWh/m²)	**140**	**68**	**-51%**

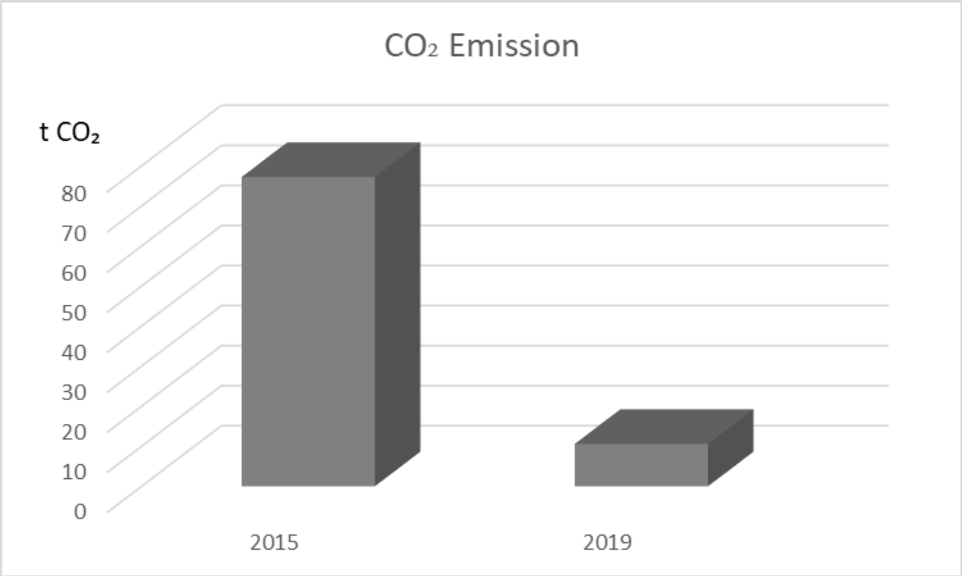


Figure 20 Total CO_2 emissions for Adam-Stegerwaldstr 19-25 in Cologne*

*Results not validated

Edith-Steinstr 14-16

In addition to the energetic renovation, the roof was extended and 12 new apartments were created. This building have been completed at the beginning of 2019.

Table 50 KPIs evaluated for M1.0 Edith-Steinstr 14-16 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	228368	149043	-35%
1.0 kWh/m²	141	77	-46%
1.1 Heat Pump (kWh)	-	1276	-
1.2 Gas (kWh)	228367,6	-	-
1.3 District heating (kWh)	-	147767,3	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	62427,0	53351	-15%
3.0 kWh/m²	38,5	27,4	-29%
4. CO2 emissions due to heating energy demand (t/year)*	47	12	-75%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	23	19,6	-38%
Total bought energy (kWh)	**290795**	**202394**	**-30%**
Total bought energy (kWh/m²)	**179**	**104**	**-42%**

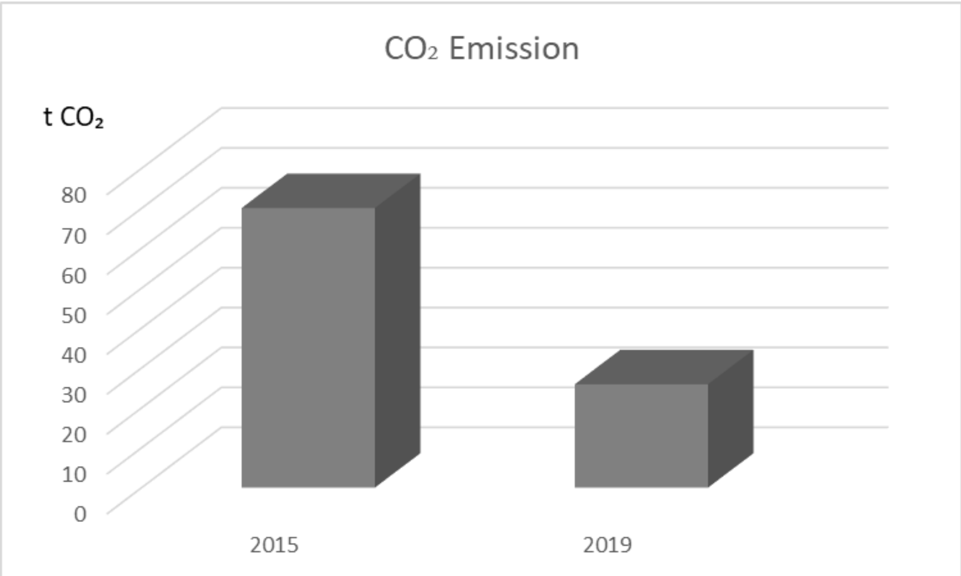


Figure 21 Total CO_2 emissions for Edith-Steinstr 14-16 in Cologne*

*Results not validated

Edith-Steinstr 18-22

In addition to the energetic renovation, the roof was extended and 6 new apartments were created. This building have been completed at the beginning of 2019.

Table 51 KPIs evaluated for M1.0 Edith-Steinstr 18-22 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	228964,5	178392	-22%
1.0 kWh/m²	119	77	-35%
1.1 Heat Pump (kWh)	-	10,9	-
1.2 Gas (kWh)	228964,5	-	-
1.3 District heating (kWh)	-	178381,23	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	56986,0	55635,1	-2%
3.0 kWh/m²	29,7	24,1	-19%
4. CO2 emissions due to heating energy demand (t/year)*	47,2	13,9	-70%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	24,6	17	-31%
Total bought energy (kWh)	**285950**	**234027**	**-32%**
Total bought energy (kWh/m²)	**149**	**102**	**-18%**

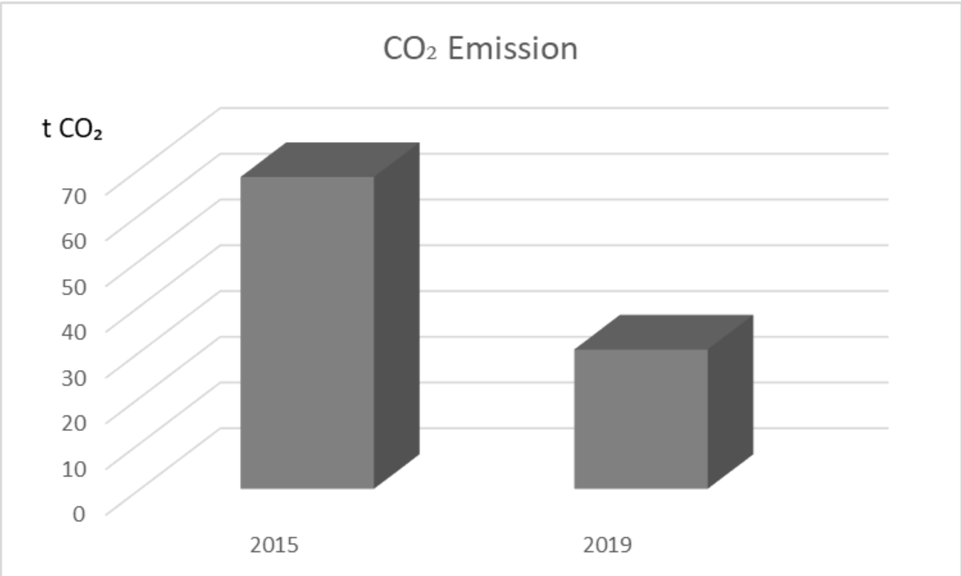


Figure 22 Total CO_2 emissions for Edith-Steinstr 18-22 in Cologne*

*Results not validated

Ulitzkastr 1

A new gas condensing boiler was installed in Ulitzkastr. 1 shortly before the beginning of the project. Measurements revealed an increase of the total energy sonsumption. The reasons of this increase is currently unknown.

Table 52 KPIs evaluated for M1.0 Ulitzkastr 1 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	161296	185436	15%
1.0 kWh/m²	77	88	15%
1.1 Heat Pump (kWh)	-	-	-
1.2 Gas (kWh)	161295,5	185436,4	15%
1.3 District heating (kWh)	-	-	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	70803	73573	4%
3.0 kWh/m²	33,7	35,0	4%
4. CO2 emissions due to heating energy demand (t/year)*	33,2	38,2	15%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	26,1	27,1	4%
Total bought energy (kWh)	**232099**	**259009**	**12%**
Total bought energy (kWh/m²)	**110**	**123**	**12%**

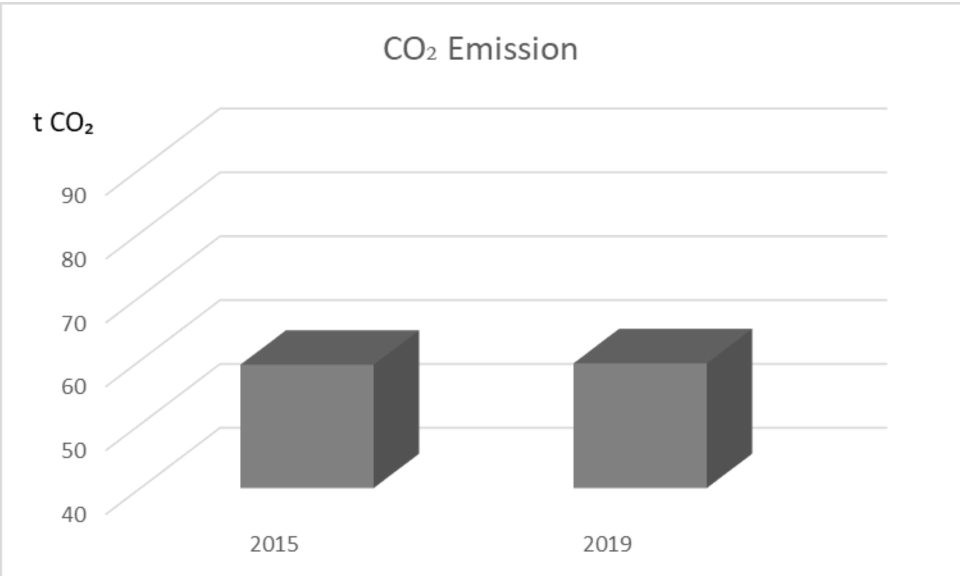


Figure 23 Total CO_2 emissions for Ulitzkastr 1 in Cologne*

*Results not validated

Edith-Steinstr 26-34

In addition to the energetic renovation, the roof was extended and 10 new apartments were created. This building has been completed at the beginning of 2019.

Table 53 KPIs evaluated for M1.0 Edith-Steinstr 26-34 (Cologne)

KPI (values are estimated)	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	315929,3	354756	12%
1.0 kWh/m²	103	97	-6%
1.1 Heat Pump (kWh)	-	2809,7	-
1.2 Gas (kWh)	315929,3		-
1.3 District heating (kWh)	-	351946,3	-
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	77475	60707,3	-22%
3.0 kWh/m²	25,4	16,6	-35%
4. CO2 emissions due to heating energy demand (t/year)*	65	28,5	-56%
5. CO2 emissions due to cooling energy demand (t/year)	-	-	-
6. CO2 emissions due to electric energy demand (t/year)*	28,5	22,4	-22%
Total bought energy (kWh)	**393404**	**415463**	**6%**
Total bought energy (kWh/m²)	**129**	**113**	**-12%**

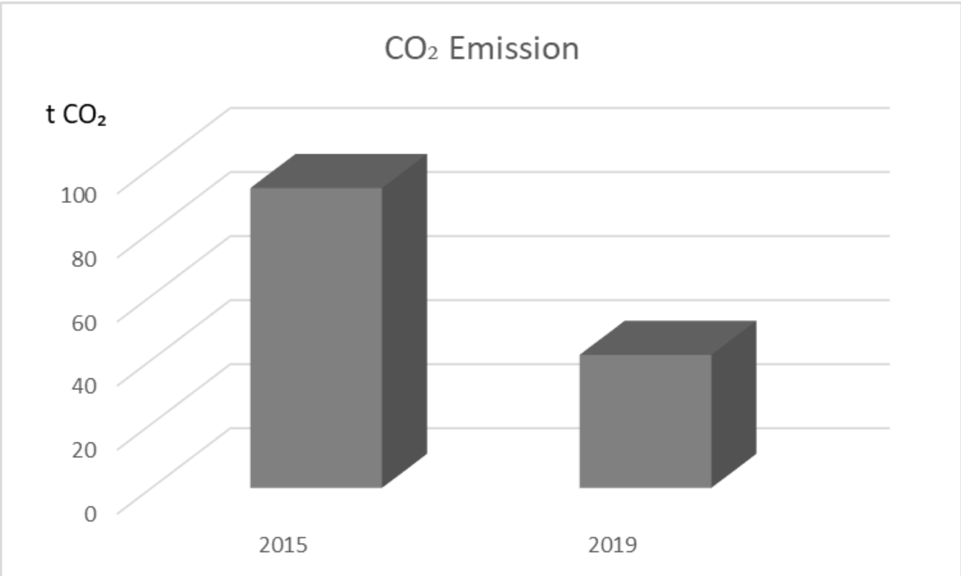


Figure 24 Total CO_2 emissions for Edith-Steinstr 26-34 in Cologne*

*Results not validated

Barcelona

Industry partner	Contact person	Validation partner
Naturgy IREC Barcelona Municipality	Helena Gibert (Naturgy) Alaia Sola (IREC)	KTH-EGI

Under the coordination of IREC, Naturgy and Barcelona Municipality, 10 buildings have been involved in refurbishment interventions.

Table 54 Measures evaluated by Naturgy in Work Package 2

		Measures						
		1.0	1.1.10.1	1.1.10.2	1.1.11	3.1.3	4.2	6.2
RESIDENTIAL	Canyelles	X	X	X		X		X
	Ter 31	X	X	X		X		
	Lope de Vega	X	X	X		X		
	Melon District	X		X				X
	Sibelius 3						X	X
	Meridiana 141						X	X
TERTIARY	Hotel H10 Madison	X	X	X				X
	CEM Claror	X		X	X			
	Escola Sert	X		X				
	Monestir de Valldonzelles						X	X
	Barceloneta						X	

Table 55 Measures evaluated by IREC in Work Package 2

		Measures					
		1.0	1.1.9	1.1.10.1	1.1.10.2	6.3	3.1
RES.	Passeig Santa Coloma	X		X			
	Virtual Energy Advisor						X
TERTIARY	Ca l'Alier	X				X	
	Library Les Corts	X	X	X	X		

Ca l'Alier (IREC)

The building Ca l'Alier has been transformed from an abandoned textile factory acquired by the Municipality to an R&D center for Smart Cities and the Internet of Things. The building renovation finished in April 2018, but first occupancy and use started only in August 2018. The building is fully functional only starting from September 2018. Due to the singularity of Ca l'Alier building, Barcelona City Council has promoted the evaluation of the performance of this building by subcontracting different studies. In November 2018, Ca l'Alier building obtained the LEED (Leadership in Energy and Environmental Design) certificate in its PLATINUM category.

Since the building was previously abandoned, no baseline could be measured but, instead, a simulation was performed considering standard construction criteria (minimum requirements of Spanish Building Technical Code 2018) and making hypotheses about the use of the building. The total conditioned area after the refurbishment is 2100 m^2.

The District Heating and Cooling and electricity consumptions are currently monitored on an hourly basis but the available data is not including yet a complete year. The monthly energy consumption of District Heating and District Cooling per unit of surface are plotted for the period September 2018 - July 2019. The BEMS monitoring started in August 2018 and includes the hourly data of electricity, indoor temperature, indoor relative humidity, and district heating and cooling. Outdoor temperature of Barcelona airport weather station is used for the normalization of building energy consumption data and the Energy Signature Method.

The Energy Signature of Ca l'Alier with the available actual data is shown in Figure 13 and Figure 14. Table 57 shows the results obtained in the Project.

Indicator	**Baseline (simulation)**	**Post-retrofitting**
Heating degree day	796	647
Cooling degree day	389	425
Surface (m2)	2173	2100

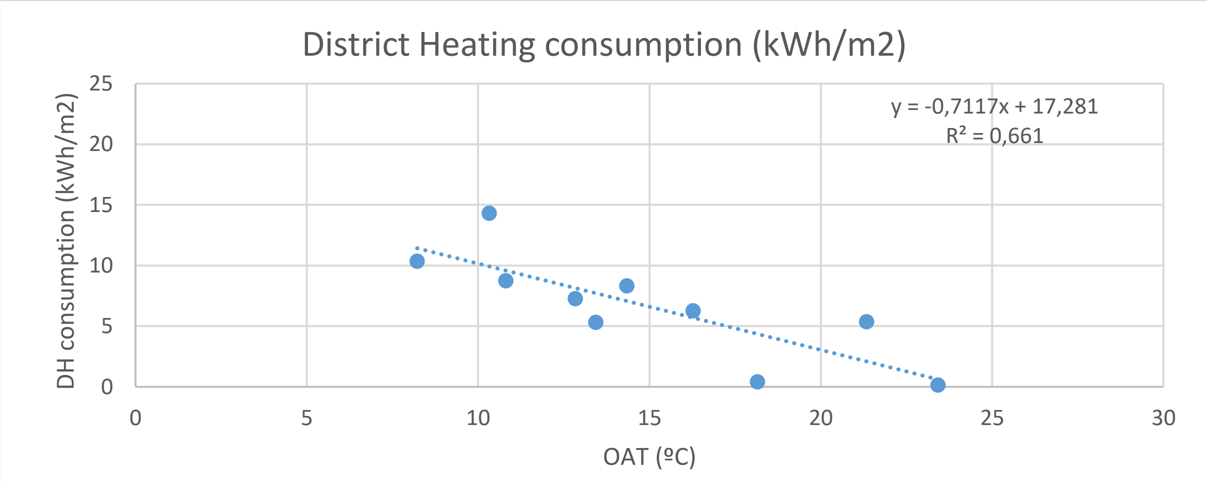


Figure 25 Energy signature of Ca l'Alier: district heating consumption

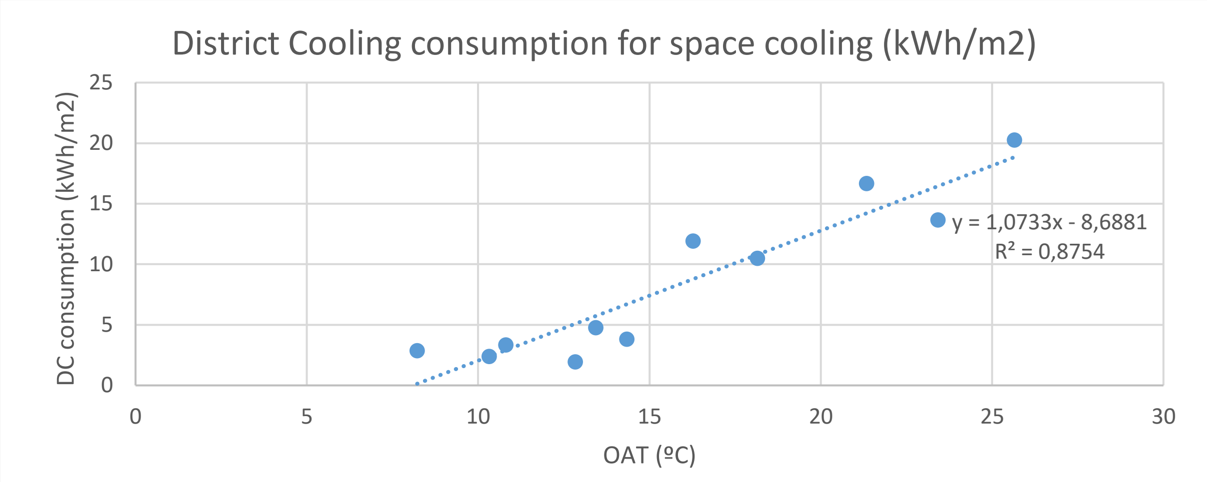


Figure 26 Energy signature of Ca l'Alier: district cooling consumption

Table 56 Final Energy Consumption M1.0 Ca l'Alier, Barcelona

Indicator (normalized for climate conditions)	Baseline (simulation)	After retrofit	Units	Variation
Annual final energy consumption for SPACE HEATING	91062	124481	kWh/year	+36.7%
Annual final energy consumption for SPACE HEATING per unit of surface	41.90	59.28	kWh/m2	+41.5 %
Annual final energy consumption for SPACE COOLING per unit of surface	31530	n/a	kWh/year	n/a
Annual final energy consumption for SPACE COOLING per unit of surface	14.51	n/a	kWh/m2	n/a

Table 57 KPIs evaluated for M1.0 Ca l'Alier (Barcelona)

KPI (normalized for climate conditions)	Baseline	Post-retrofitting	Units	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	41.9	59.3	kWh/m2	+41.5 %
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	14.5	n/a	kWh/m2	n/a
3. Electric energy required (kWh) per year and month.	176 917	144 398	kWh/year	-18 %
4. CO2 emissions due to heating energy demand	10.5	1.6	kg CO2/m2	-84 %
5. CO2 emissions due to cooling energy demand	4.80	n/a	kg CO2/m2	n/a %
6. CO2 emissions due to electric energy demand	59	48	ton CO2/year	-19 %

The building is still under commissioning and currently shows a high energy demand compared to the forecasted energy demand for a nearly-zero energy building. Data collected through the monitoring system is inconsistent. An observed innacurate energy management explains why it does not fulfill the objectives set for building energy consumption. This may be justified as follows:

- No activation of advanced Building energy management systems: the predicted adaptive control of the HVAC and lighting systems has not been put into practice to date, but common control strategies have been applied (on/off schedule).
- Different schedules for HVAC compared to baseline: A strange behavior of indoor temperature was observed in some rooms during the analysis of data. Thanks to the high-frequency monitoring performed, it was observed that an inaccurate control was being applied. Empty rooms were being heated out of the occupation hours of the building. Also, the current occupation of the building has been changed from a regular office-hours schedule to 24x7, due to the permanent presence of security personnel. In contrast, the simulations performed to build the baseline building assumed common office hours for the operation of HVAC system (8am-8pm) which lead to lower energy consumption for heating and cooling.

Wrong installation of fan coils: As an output of data analysis, it was also detected that there is an excess of ventilation power installed in one section of the building, which claims for flow adjustment of fan coils. In addition, it was also detected a wrong installation of Fan Coils in some rooms, making part of the supply flow go into the false ceiling and therefore become wasted. This detected deficiency is in process of being corrected by the building general manager.
Nevertheless, it is worth mentioning that even if the district heating final energy consumed for space heating of the building is higher than the final energy consumed in the baseline simulations (in the form of natural gas), calculations show a reduction of 83% of CO2 emissions due to space heating on annual basis. This is due to a much less pollutant energy source selected in the building retrofitting (district heating that recovers waste heat) in front of the traditional natural gas heating system in the baseline.

Library Les Corts (IREC)

Library Les Corts is an example of integral refurbishment of a municipality-owned industrial building in Barcelona. Three adjacent buildings have been retrofitted to become a new public library. The previous existing buildings were a former industrial building lately used as a warehouse and 2 former offices buildings (unused for some years).

In November 2018, the building obtained the BREEAM certification with a “Very Good” score, being the first public building owned by the Municipality to obtain this certification. This proves that this public building retrofitting action has been done by specifically following sustainability criteria.

Since the building was previously partly used as a warehouse and partly unused, no baseline could be measured but, instead, a simulation was performed considering standard construction criteria and the current use of the building as a Library. For these reasons, Table 58 and Table 59 show simulation results for the baseline. The gas and electricity consumptions are currently monitored on an hourly basis. Worth mentioning, there is no domestic hot water use in this building. The total conditioned area after the refurbishment is 4005 m^2.

Table 58 Final Energy Consumption M1.0 Library Les Corts, Barcelona

Indicator (normalized for climate conditions)	Baseline (simulation)	After retrofit	Units	Variation
Annual gas energy consumption for SPACE HEATING	204354	115747	kWh/year	-43.4%

Annual gas energy consumption for SPACE HEATING per unit of surface	54.92	28.90	kWh/m2	-47.9 %
Electricity consumption for SPACE COOLING	72538	68910	kWh/year	-5.0%
Annual electricity consumption for SPACE COOLING per unit of surface	19.49	17.21	kWh/m2	-11.7%
Annual gas energy consumption for SPACE HEATING	204354	115747	kWh/year	-43.4%
Annual gas energy consumption for SPACE HEATING per unit of surface	54.92	28.90	kWh/m2	-47.9 %

Table 59 shows the obtained results related to the estimated CO2 saving obtained with the refurbishment of Library Les Corts

Table 59 CO_2 emissions M1.0 Library Les Corts, Barcelona

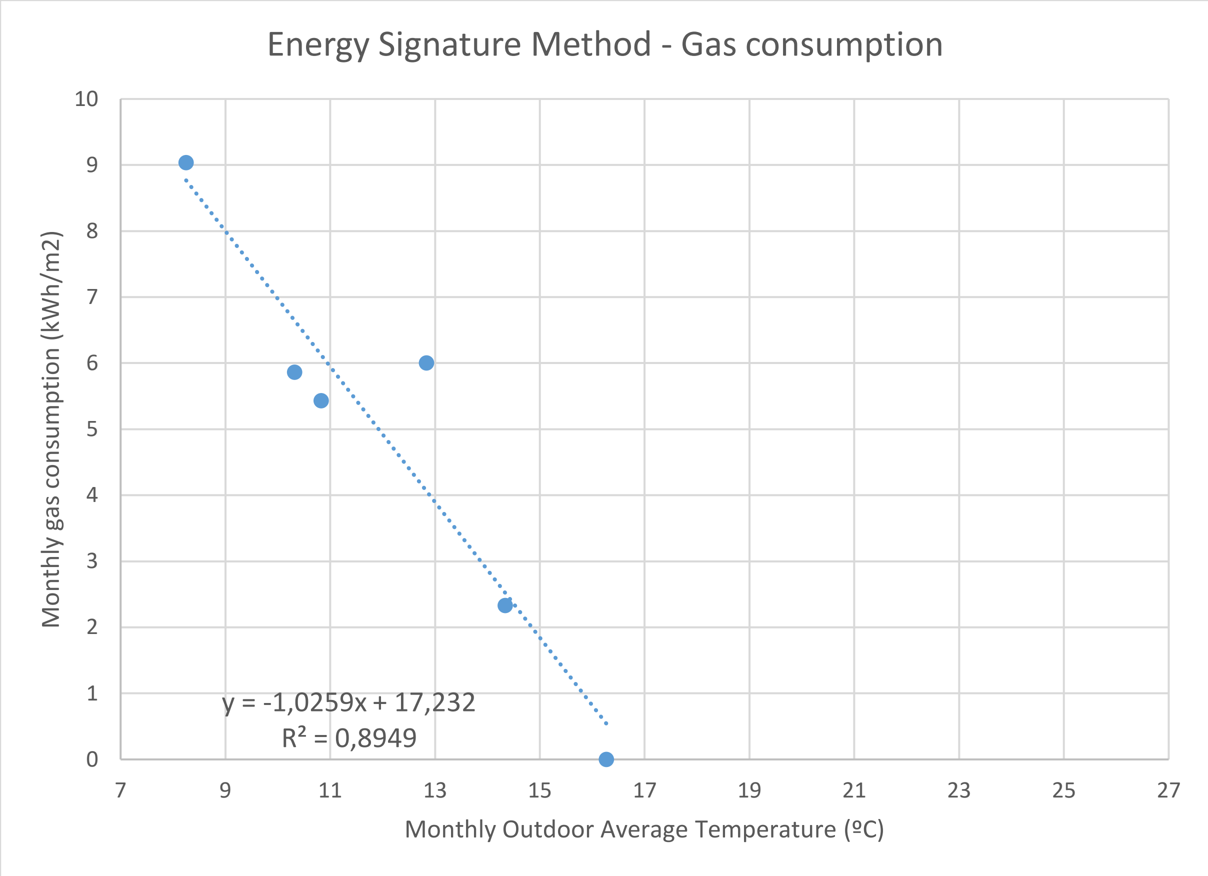
Indicator (normalized for climate conditions)	Baseline (simulation)	After retrofit	Units	Variation
CO2 emissions due to heating energy demand	51.5	29.2	ton/year	-43.4 %
Annual CO2 emissions due to heating per unit of surface	13.84	7.28	kg CO2/m2	-47.9%
CO2 emissions due to cooling energy demand	24.0	22.8	ton/year	-5.0%
Annual CO2 emissions due to cooling per unit of surface	6.45	5.70	kg CO2/m2	-11.7%

The Energy Signature method of Library Les Corts with the available monitored data is shown in Figure 27.

Table 60 shows the KPIs of Library Les Corts required by the Evaluation Plan and based on the obtained set of data.

Table 60 KPIs evaluated for M1.0 Library Les Corts (Barcelona)

KPI (normalized for climate conditions)	Baseline	Post-retrofitting	Units	Variation
1. Heat energy required (kWh) per year and month	54.9	28.9	kWh/m2	-47.9 %
2. Cooling energy required (kWh) per year and month.	19.5	17.2	kWh/m2	-11.7 %
3. Electric energy required (kWh) per year and month.	n/a	251123	kWh/year	n/a
4. CO2 emissions due to heating energy demand	13.84	7.28	kg CO2/m2	-47.9%
5. CO2 emissions due to cooling energy demand	6.45	5.70	kg CO2/m2	-11.7%
6. CO2 emissions due to electric energy demand	n/a	83.1	ton CO2/year	n/a
Total primary energy				-28.4 %



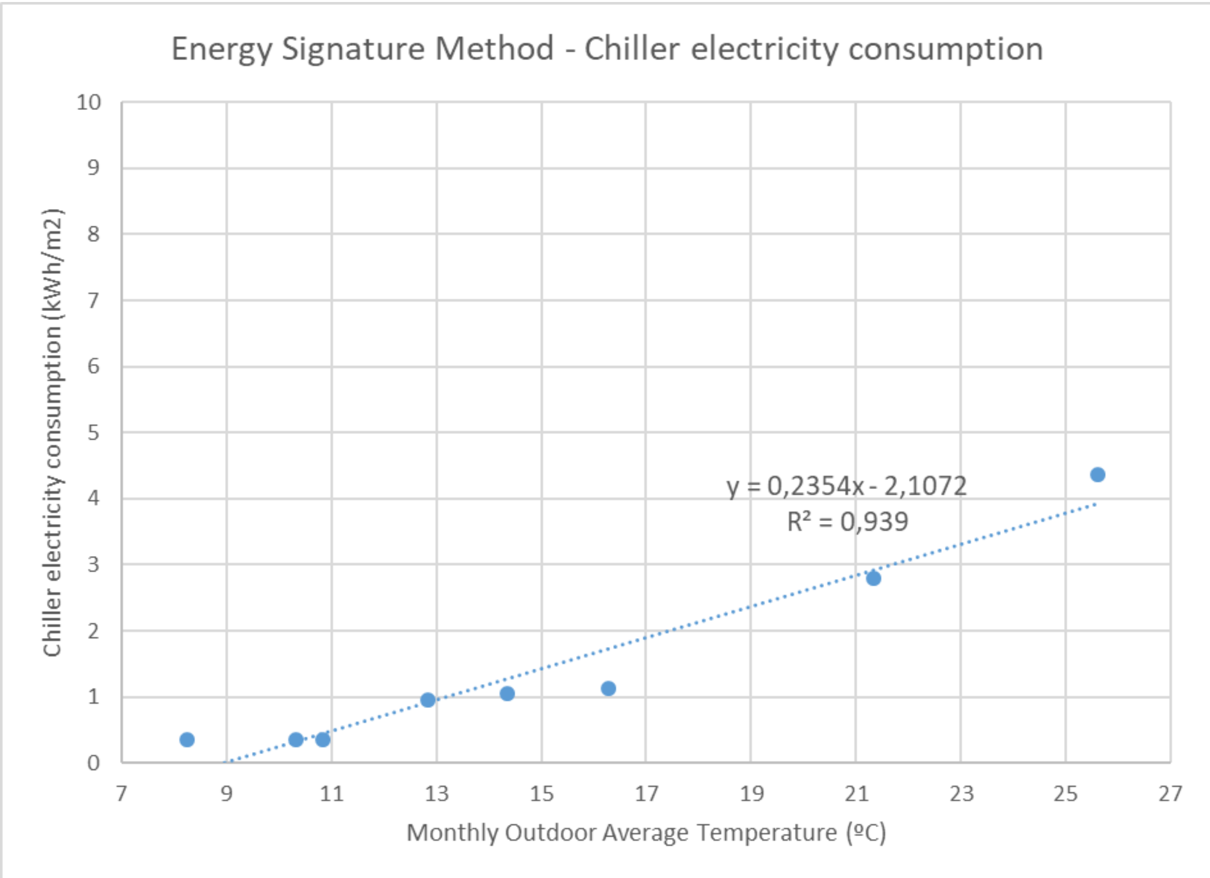


Figure 27 Energy signature of Library Les Corts: electricity consumption

The retrofitted building is able to reduce by 48% the gas consumption for space heating on an annual basis compared to the simulated baseline building. The reduction of the cooling consumption is lower, i.e. 11% reduction (after normalization for climatic conditions). In the cooling period, the lack of building envelope insulation in baseline simulations helps to evacuate the heat generated by the internal gains through the enclosures. Therefore, the impact of energy efficiency measures shows to be lower for space cooling rather than space heating. In total primary energy terms, the building is able to reduce its energy consumption by 28.4% on an annual basis.

Passeig Santa Coloma - Big Blue (IREC)

The building retrofitting works started in February 2017 and finished in December 2017. The baseline period is 2016. The data considered as post-retrofitting starts from 2018.

The total conditioned area is 14165 m^2. Among a total of 207 dwellings, 21 dwellings participated in the monitoring campaigns and surveys done before and after the retrofitting. The monitoring of gas consumption includes space heating and the auxiliary heating of domestic hot water. The domestic hot water is mainly produced by the solar thermal system installed in the building. A total of 4 dwellings are monitored 24/7 since April 2017 but they were not monitored for the baseline measurements. Therefore, the monitored data of this 4 dwellings must be compared against invoice data for baseline period.

The baseline for an average dwelling in this building is built by calculating the average consumption from the gas invoices related to year 2016 considering 9 of the 21 dwellings involved in this study. The resulting baseline is pictured in Figure 28 and shows the Energy Signature of the average dwelling of Passeig Santa Coloma building. The differences in dwelling surface are not significant, thus energy consumption is not normalized by unit of surface. The baseline figures will be compared to the resulting average dwelling consumption related to year 2018 (post-retrofitting status).

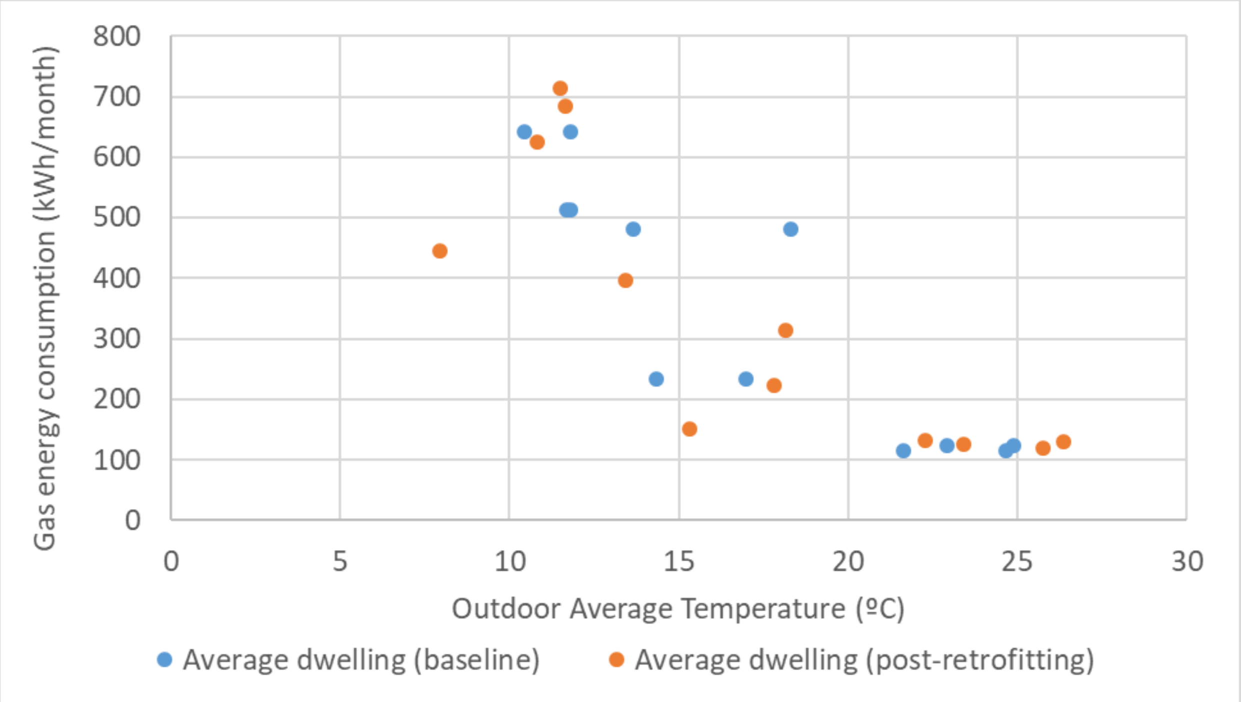


Figure 28 Energy signature of Passeig Santa Coloma

Table 61 shows the primary energy and emission factors from the Ministry of Energy of Spain.

Table 61 Emission and primary energy factors M1.0 Passeig Santa Coloma, Barcelona

	Primary energy factor (kWh primary energy/kWh final energy)	Emission factor (kg CO2/kWh final energy)
Gas	1.195	0.252
Electricity	2.368	0.331

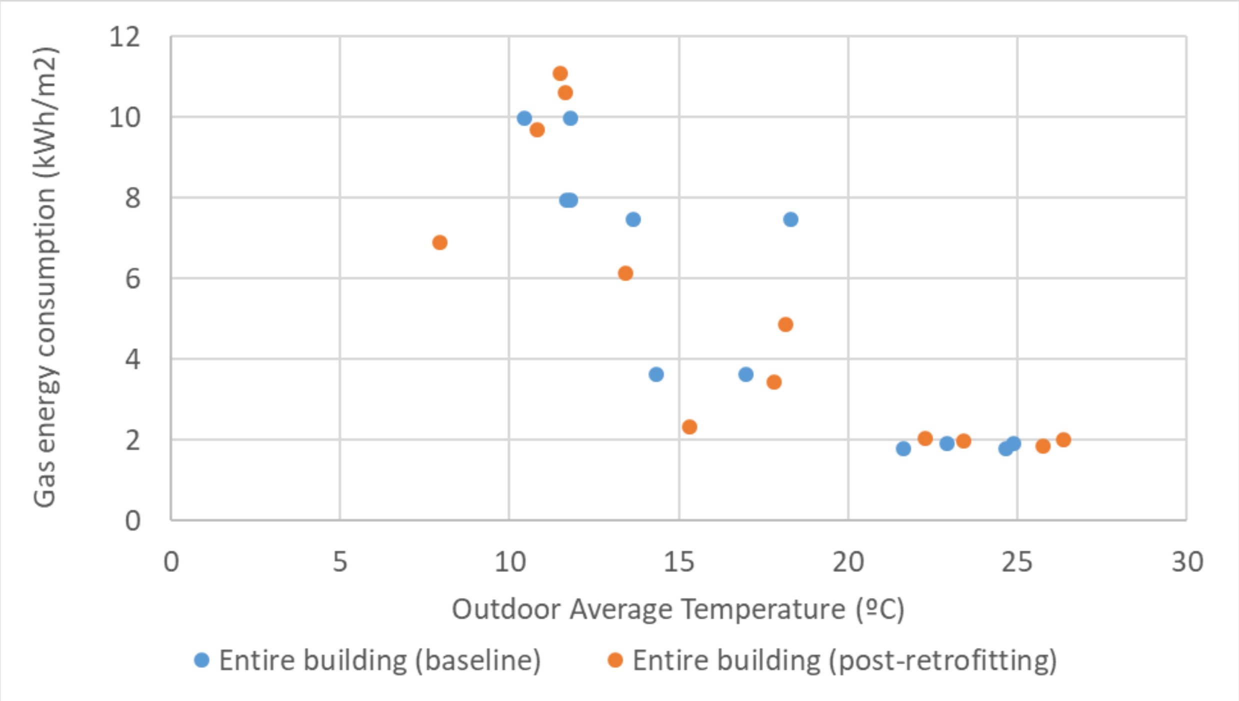


Figure 29 Energy signature chart for Passeig Santa Coloma, Barcelona

Table 62 and Table 63 present the KPIs evaluated for Passeig Santa Coloma considering the average dwelling and the entire building.

Table 62 KPIs evaluated for M1.0 Passeig Santa Coloma (Barcelona): Average dwelling

KPI (normalized for climate conditions)	Baseline	Post-retrofitting	Units	Variation
1. Heat energy required (kWh) per year and month	2965	2077	kWh/year per dwelling	- 29.9%
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-		-
3. Electric energy required (kWh) per year and month.	2266.7	2090.5	kWh/year per dwelling	-7.8%
4. CO2 emissions due to heating energy demand	747	523	kg CO2/year per dwelling	-29.9%
5. CO2 emissions due to cooling energy demand	-	-		-
6. CO2 emissions due to electric energy demand	750	692	kg CO2/year per dwelling	-7.8%

Total primary energy	-9.9%

Table 63 KPIs evaluated for M1.0 Passeig Santa Coloma (Barcelona): entire building

KPI (normalized for climate conditions)	Baseline	Post-retrofitting	Units	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	613755	429939	kWh/year	- 29.9%
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-		-
3. Electric energy required (kWh) per year and month.	469205	432743	kWh/year	-7.8 %
4. CO_2 emissions due to heating energy demand	56	39	ton/year	-29.9 %
5. CO_2 emissions due to cooling energy demand	-	-		-
6. CO_2 emissions due to electric energy demand	155.3	143.2	ton CO_2/year	-7.8 %
Total primary energy				-9.9 %

The feedback during the survey campaign performed among over 20 volunteer dwellers after the retrofitting works revealed an improvement on their thermal comfort in winter. A common feedback was related to the lower gas-fired heating system operation, despite the post-retrofitting winter was colder than the pre-retrofitting one.

The improvement of external façade insulation and replacement of blinds by more isolating blinds has proven to lead to an average of approximately 30% of dwelling annual gas energy savings for space heating. A slightly lower energy reduction may be expected in terms of the overall building gas energy demand, because tenants that participated voluntarily in the present study (and provided their energy consumption data) already showed a minimum interest in energy efficiency that may have also impacted their energy consumption patterns.

Worth noticing, the proposed energy savings at the beginning of the project were higher because a much higher initial space heating consumption of the dwellings was assumed. We have learnt with this project that it may be incorrect to assume common national energy consumption ratios for the residential sector when it applies to vulnerable areas of the city and/or social housing. Due to the real initial low gas energy demand of the participant dwellings, the real energy savings after the energy renovation have proven to be lower than expected. Nevertheless, the proposed suggested specification of dwelling gas energy consumption after the building retrofitting has been achieved (average heating energy consumption of 36.6 kWh/m2 year).

Canyelles (Naturgy)

The refurbishment carried out in Canyelles was focused on one hand in the reduction of the energy demand and the improvement of the thermal conditions through the implementation of passive measures. Furthermore, active measures were implemented with the aim to increase the efficiency of the installation.

Passive measures:
-Improvement of the façade (opaque walls and windows) and the roof insulation.

-Installation of high efficient windows and frames with low U-values in the dwellings interested. The windows have been changed in almost all the dwellings, the participation in this measures reached the 79% of dwellings (45/57)
-Installation of shutters and shading elements in the dwellings interested. (45/57)

Active measures:
-Substitution of old boilers by high efficient boilers in the dwellings interested. In this measure participated 19/57 dwellings.
-Installation of water efficient taps in the dwellings that need them.

Moreover, HEMS (Home Energy Management System) and Smartmeter gas have been installed in the dwelling interested to use and prove the technology. The total number of dwellings that installed HEMs in Canyelles are 22 dwellings of 57 and the total number of dwellings that accepted to install the Smartmeter gas installation are 12/57 dwellings. The data obtained through HEMs and the Smartmerter is being and will be used to analyze the impact of the retrofitting actions, whenever possible. It is worth mentioning that data is collected with hourly resolution.

The Baseline in Canyelles (as in Ter 31 and Lope de Vega in the following sections) has been based on the following parameters. To evaluate these parameters invoices have been used.

- Heating consumption (kWh/m^2) calculated through Gas invoices that aggregate Space heating, DHW and Cooking consumption. The desaggregation of the gas consumption for each use is done through simulation models.

- Electricity consumption (kWh/m^2) calculated through Electricity invoices that aggregate cooling, ventilation, lighting and others.

- Cooling consumption (kWh/m^2). The cooling consumption of the baseline is obtained through simulation models calibrated by electricity invoices and considering existing equipment stock from surveys (See annex I) and monitoring data. This parameter is taken in consideration only for the dwellings that have some cooling equipment installed and also, it is relevant to highlight that the majority of the cooling equipment are systems that act partially on the dwellings and not for all the rooms.

The calculation of these parameters has been done through simulation models. For the sake of accuracy and reliability, a dataset based on at least with one year of data (invoices or monitorization) was required for the correction of the data with the ambient conditions.

Figure 30, Figure 31 and Figure 32 show, respectively, the heating, cooling and electrical energy signatures for Canyelles.

The baseline heating energy demand is affected by the climate conditions of the after-refurbishment period, extending the average heat consumption linearly with the average outdoor temperature. The Figures also show a different average heat consumption between the climate corrected baseline and after-refurbishment cases, for low average outdoor temperatures, indicating that savings on the heating demand have been achieved

The electrical energy signature of Canyellas, Figure 32, shows almost no difference between the electrical consumption of the different cases. There are only differences with the lowest and highest outdoor average temperatures. The differences in the highest outdoor temperatures are explained due to the changes in the cooling energy demand. The differences in the lowest outdoor temperatures are explained due to fact that some dwelling uses electrical heaters or heat pumps to satisfy part of their heat energy demand.

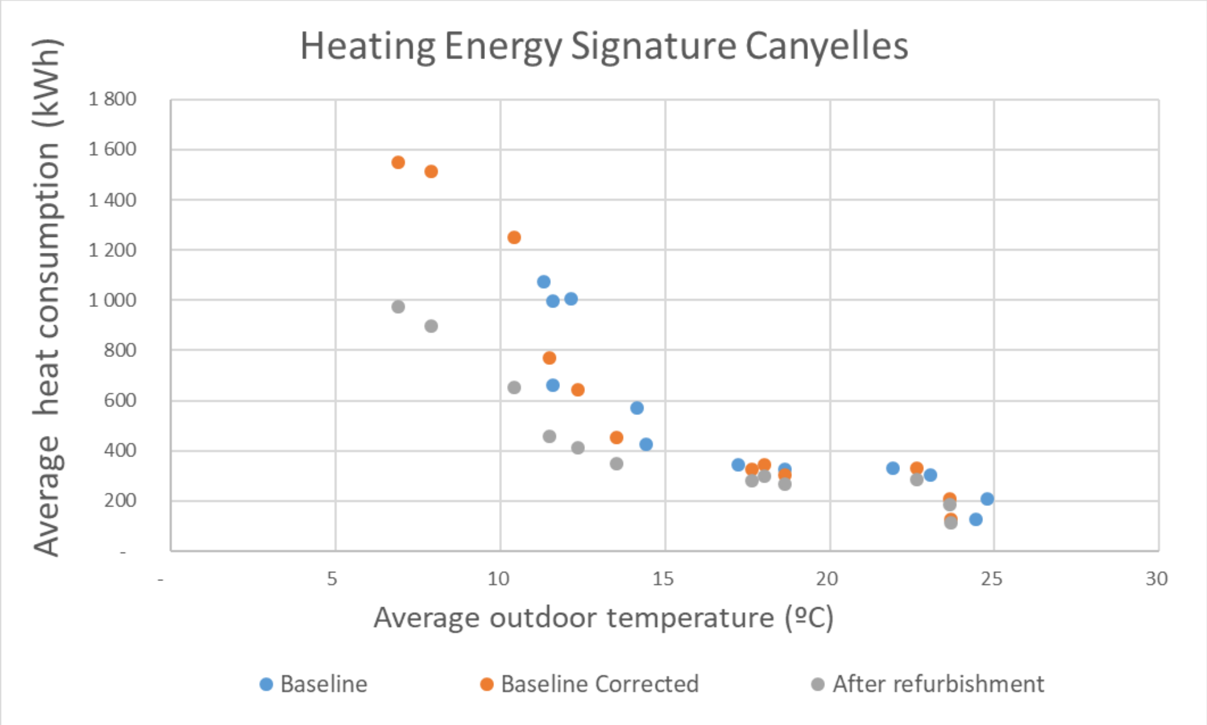


Figure 30 Heating Energy Signature for Canyelles (Barcelona)

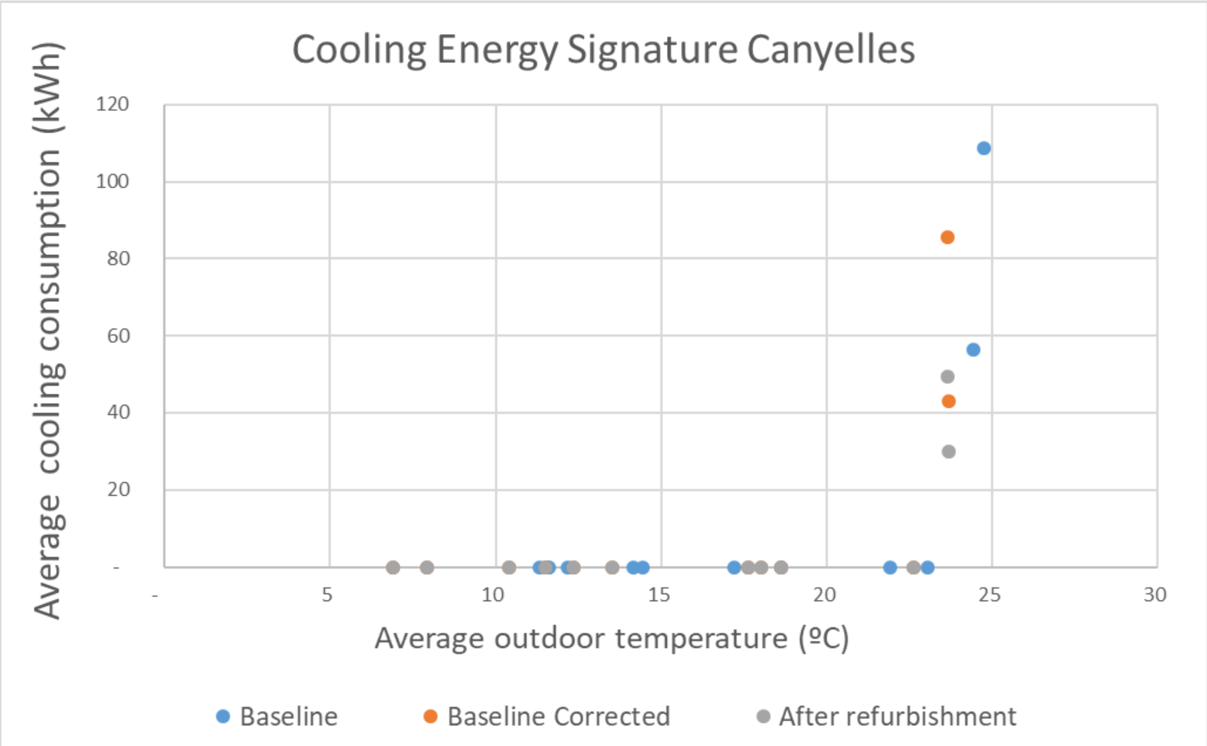


Figure 31 Cooling Energy Signature for Canyelles (Barcelona)

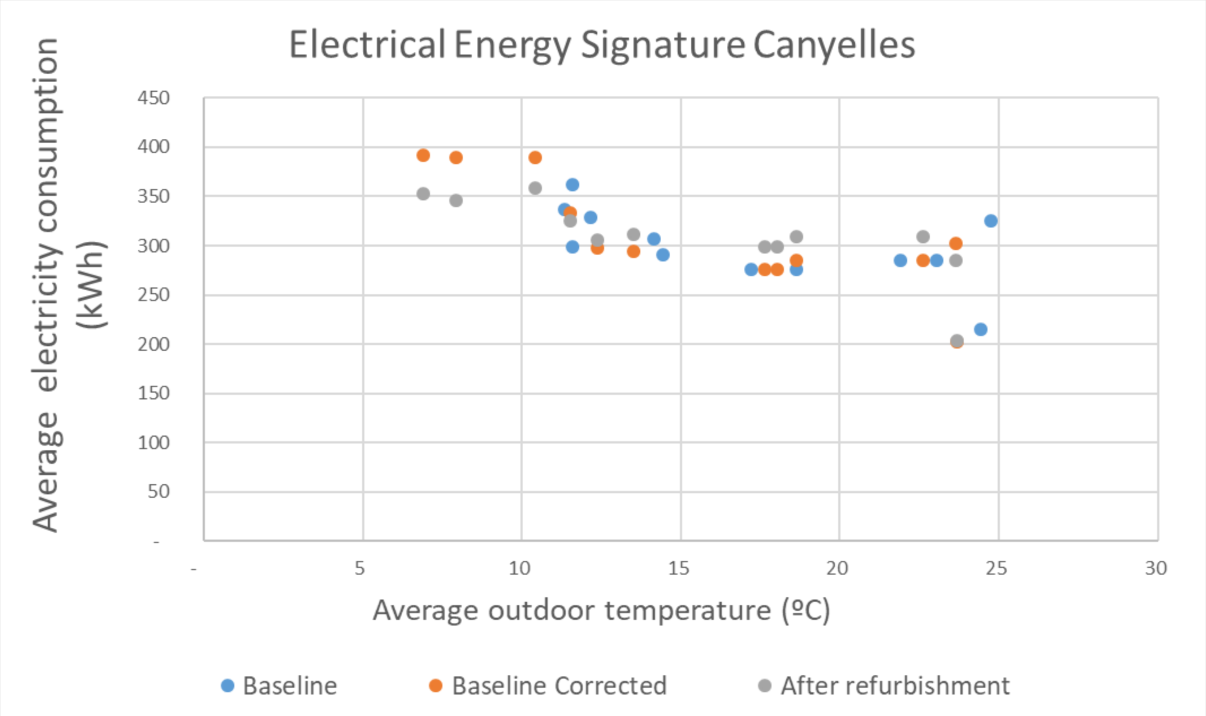


Figure 32 Electrical Energy Signature for Canyelles (Barcelona)

Table 64 shows the KPIs for Canyelles that have been evaluated according to the Evaluation Plan.

Table 64 KPIs evaluated for M1.0 Canyelles (Barcelona)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	263023	173743	-34 %
1.1 Gas (kWh)	253195	67264	-33 %
1.1 Electricity (kWh)	9828	43828	-61 %
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	3995	2453	-39 %
3. Electric energy required (kWh) per year and month.	113000	112573	-0.4 %
4. CO2 emissions due to heating energy demand (kt/year)	67264	43828	-35 %
5. CO2 emissions due to cooling energy demand (kt/year)	1322	812	-39 %
6. CO2 emissions due to electric energy demand (kt/year)	37476	37106	-1 %
Total primary energy			-20 %

Lope de Vega (Naturgy)

The Baseline in Lope de Vega has been calculated as in Canyelles. The same simulation models mentioned above for Canyelles has been used to disaggregate the energy consumption.

Figure 33, Figure 34 and Figure 35 show, respectively, the heating, cooling and electrical energy signatures for Lope de Vega.

Table 65 shows the KPIs for Lope de Vega that have been evaluated according to the Evaluation Plan.

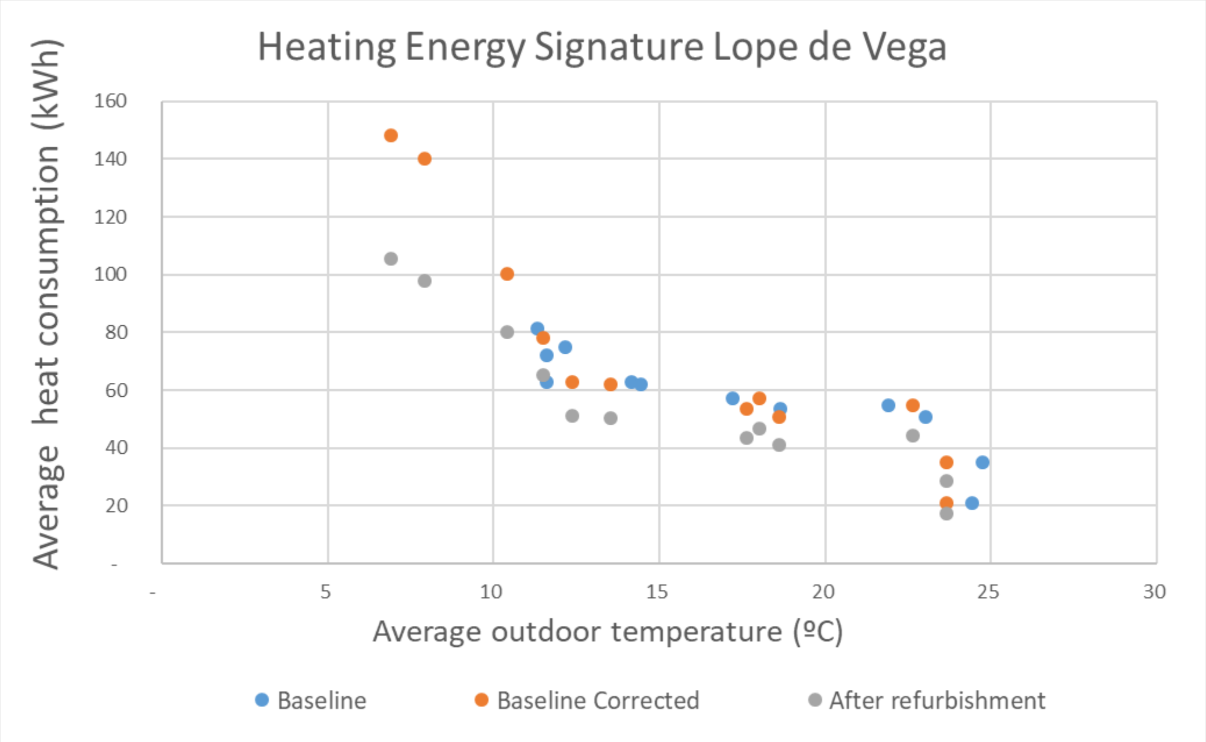


Figure 33 Heating Energy Signature for Lope de Vega (Barcelona)

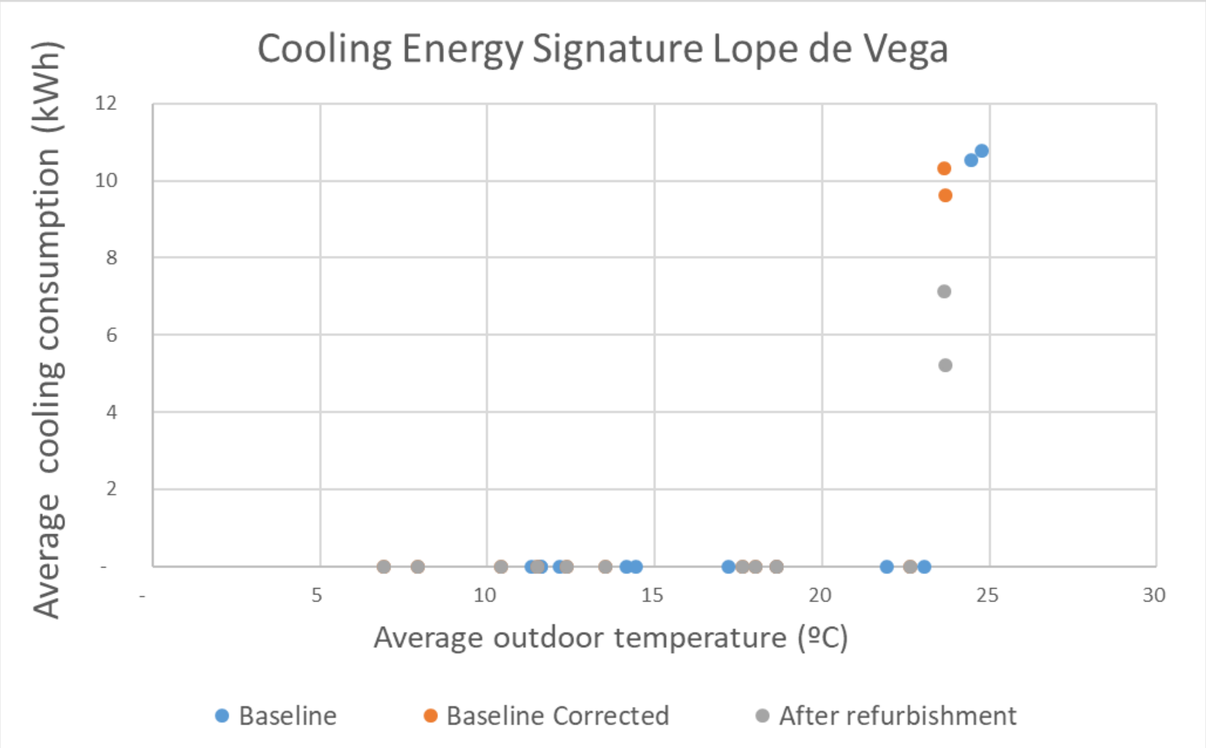


Figure 34 Cooling Energy Signature for Lope de Vega (Barcelona)

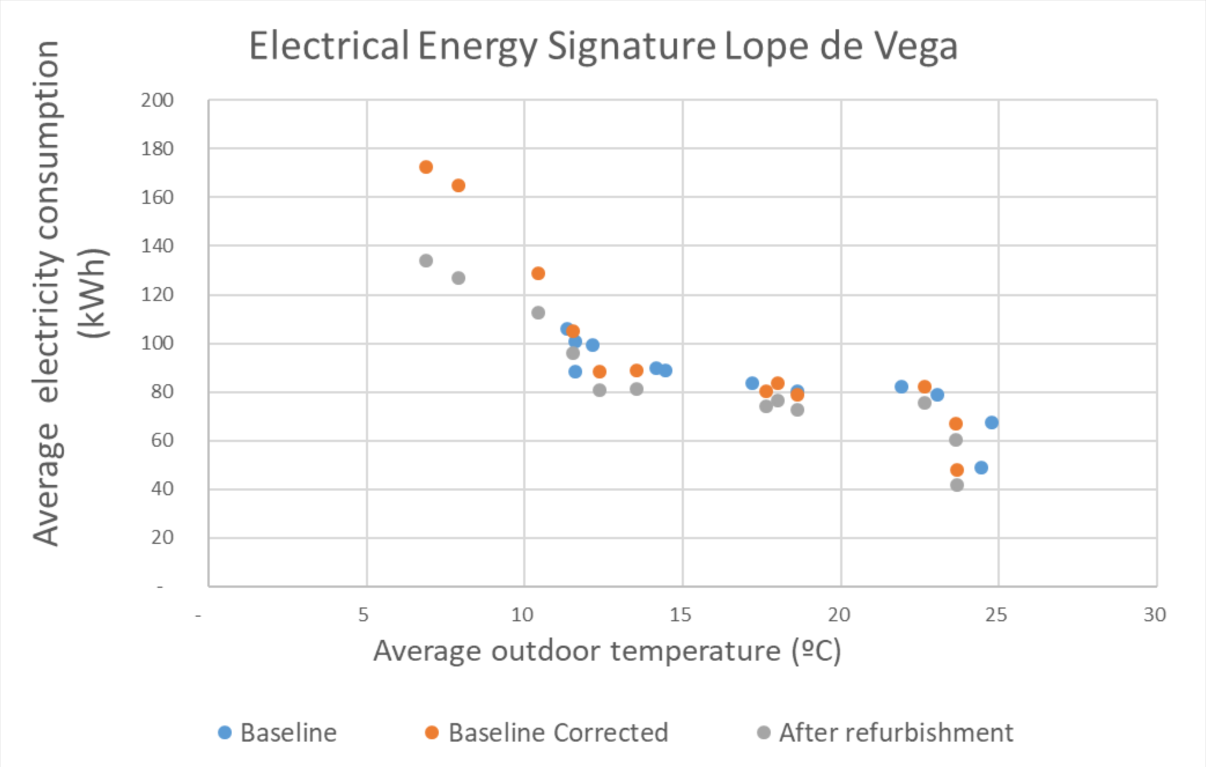


Figure 35 Electrical Energy Signature for Lope de Vega (Barcelona)

Table 65 KPIs evaluated for M1.0 Lope de Vega (Barcelona)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	26247	20404	-22 %
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	619	383	-38 %
3. Electric energy required (kWh) per year and month.	36107	31325	-13 %
4. CO_2 emissions due to heating energy demand (kt/year)	6926	5385	-22 %
5. CO_2 emissions due to cooling energy demand (kt/year)	167	103	-38 %
6. CO_2 emissions due to electric energy demand (kt/year)	9749	8458	-13 %
Total energy use			-17 %

Ter 31 (Naturgy)

The Baseline in Ter 31 has been calculated as in Canyelles. The same simulation models mentioned for Canyelles and Lope de Vega has been used to disaggregate the energy consumption.

Figure 36 and Figure 37 show, respectively, the heating and electrical energy signatures for Ter 31.

Table 66 shows the KPIs for Ter 31 that have been evaluated according to the Evaluation Plan.

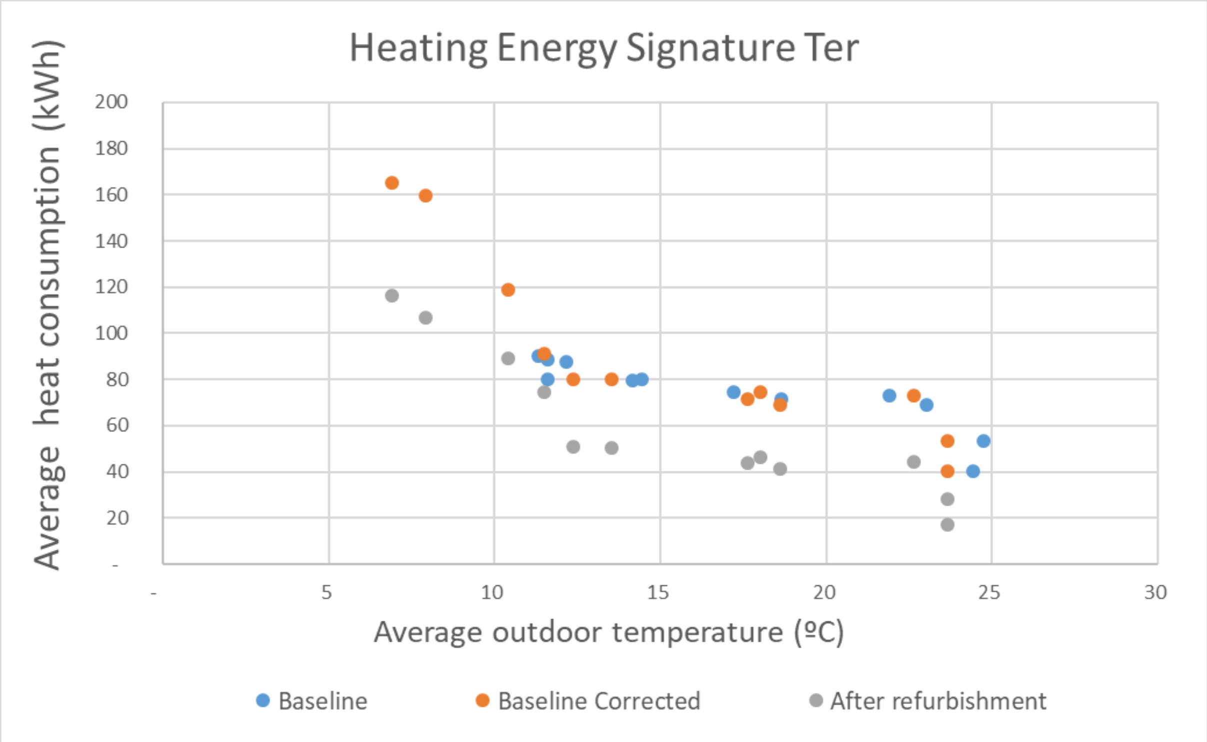


Figure 36 Heating Energy Signature for Ter 31 (Barcelona)

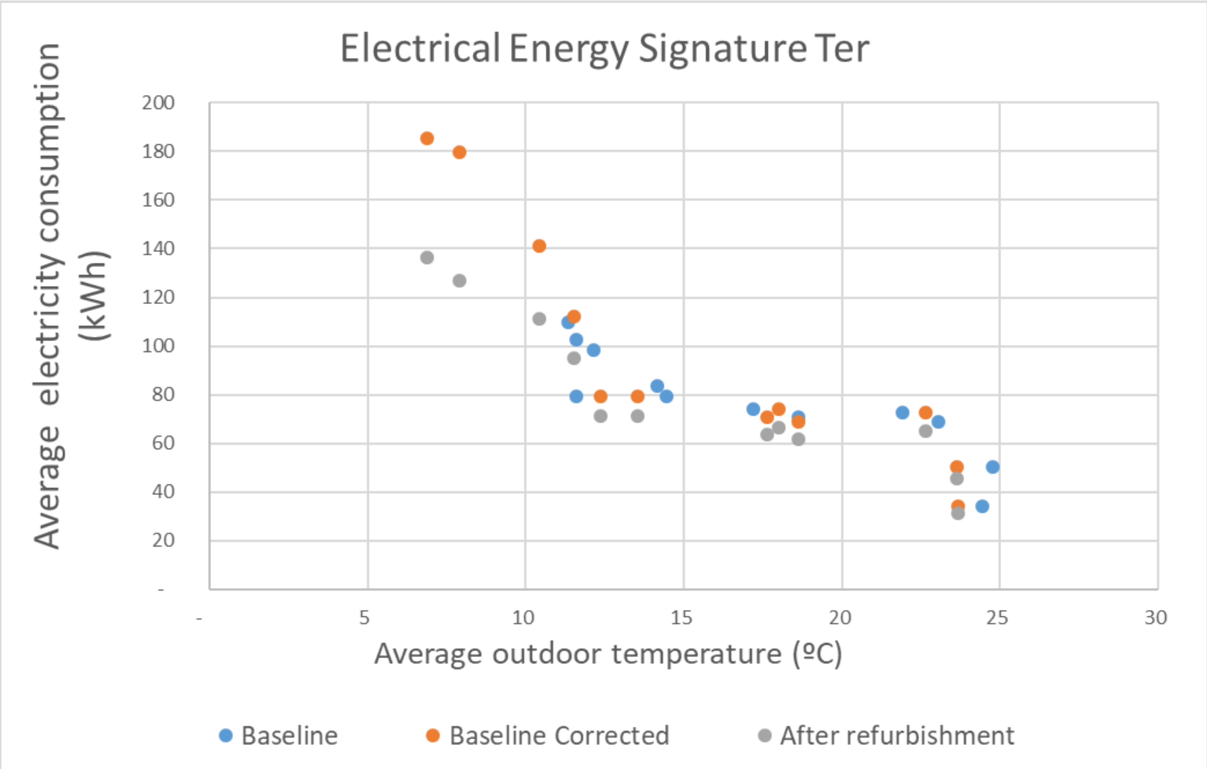


Figure 37 Electrical Energy Signature for Ter 31 (Barcelona)

Table 66 KPIs evaluated for M1.0 Ter 31 (Barcelona)

KPI	Baseline	Post-retrofitting	Variation
1. Heat energy required (kWh) per year and month normalized for climatic conditions.	27644	21515	-22 %

2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	-	-	-
3. Electric energy required (kWh) per year and month.	34831	28714	-18 %
4. CO2 emissions due to heating energy demand (kt/year)	10066	7838	-22 %
5. CO2 emissions due to cooling energy demand (kt/year)	-	-	-
6. CO2 emissions due to electric energy demand (kt/year)	13550	9961	-26 %
Total energy use			-20 %

Melon District (Naturgy)

The refurbishment scope in Melon District was totally different compared to the other residential buildings. In that case, only one active Measure (no passive Measures) was carried out in the building. The active Measure consisted in the substitution of the electric heaters used for the heating demand by a connection to the nearest district heating network, the generation of Domestic Hot Water by the District Heating and the substitution of approximately 35% of the heat pumps used for refrigeration of some aisle places. The connection allows Melon District to reduce its primary energy consumption through the substitution of the use of electricity by waste heat from the DH to supply the heating building, the domestic hot water and some of the refrigeration demand.

In order to evaluate the baseline, the following monitored data will be used:

- Monthly electricity consumption coming from the building's energy management system or from utility invoices (kWh).
- Monthly heating consumption supplied from the DH from the building's energy management system or from DH invoices (kWh).

Apart from these variables, the independent variable selected for the development of the mathematical models are: weather conditions and monthly occupancy.

The models to be defined are the global energy consumption models: electricity model and heat model. The baseline models for electricity and heat demand of Melon District are available Figure 38 and Figure 39 show an example extrapolated from the calibration and validation process of the global energy consumption models.

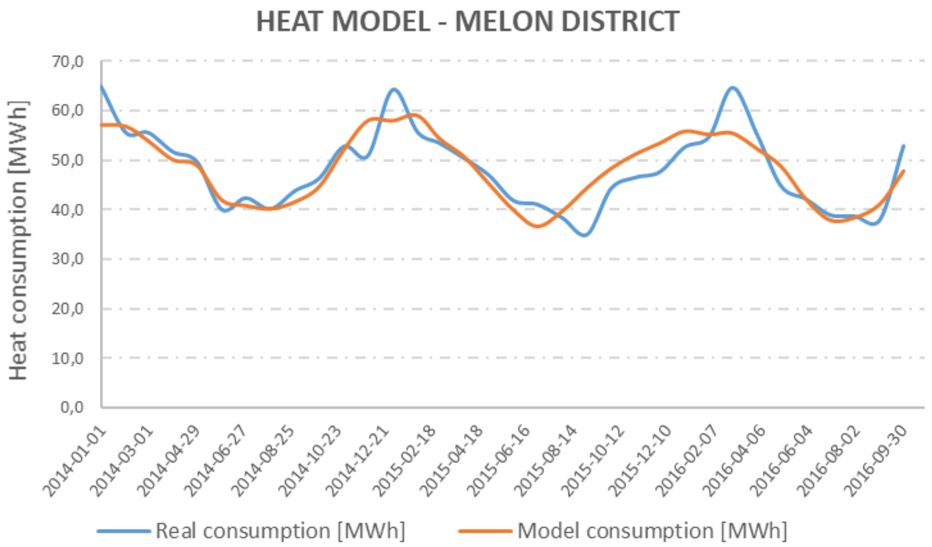


Figure 38

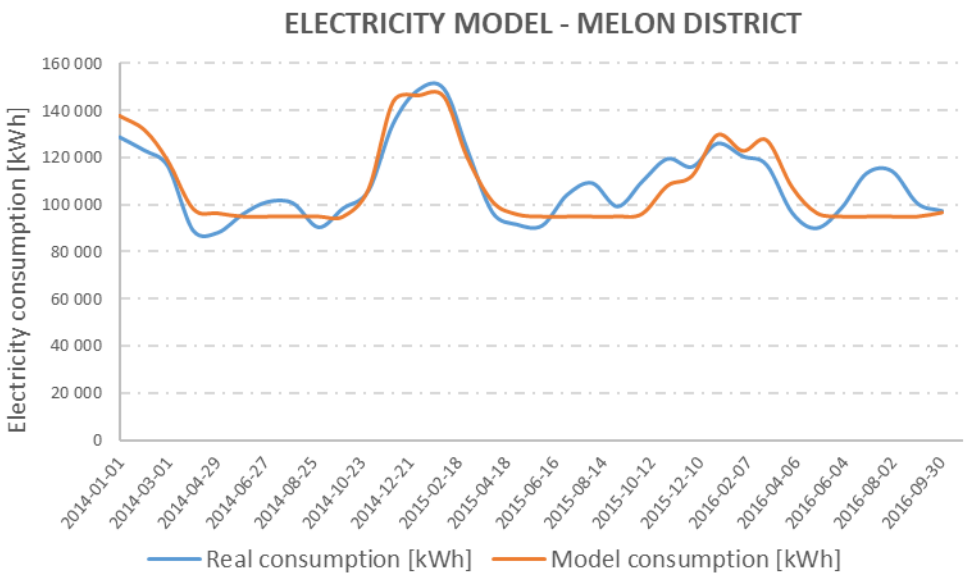


Figure 39

Since in Melon District the refurbishment had only affected to the heating system installation the evaluation will only analyse the impact in the winter period. The winter period will be defined trough the Heating Degree Days (HDD).

Considering year 2017, the winter period has been defined accounting for the months that have HDD positive values. In particular, the year 2017, the winter season includes the periods January – Abril and November- December.

Figure 40 qualitatively illustrates the savings that have been obtained from the substitution of the electrical heaters.

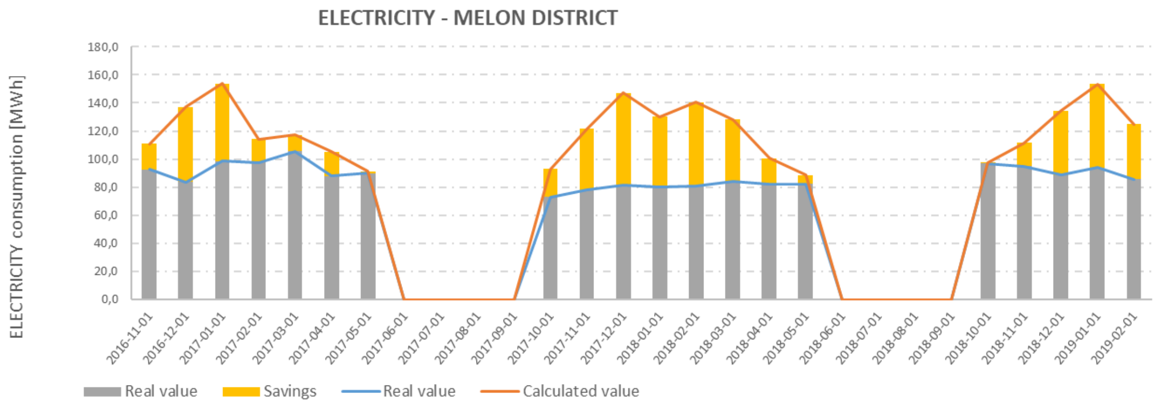


Figure 40 Savings for electrical heaters sustitution – Melon District (Barcelona)

As shown in Table 67, after the refurbishment an increase of district heating consumption of about 300MW has been calculated. On the other hand, a decrease of about 200MW in the electricity consumption has been calculated. As a result, a total primary energy saving of about 490MW has been calculated.

Table 67 Overview of primary energy savings in Melon District, Barcelona

	Savings final energy (MWh/yr)	Conversion ratio (MWhP/MWhf)	Savings primary energy (MWh/yr)
Heat (DH)	-849	0.262	-222
Electricity	371	2.403	891
Total savings primary energy			**668**

Regarding the CO_2 emissions, the increase of emissions due to the increase of heat consumption is 19.1 t/year while the reduction of emissions due to the reduction of electricity consumption is 119 kt/year (Table 68).

Table 68 Overview of CO_2 savings in Melon District, Barcelona

	Savings final energy (MWh/yr)	Conversion ratio (CO_2/MWhf)	Savings primary energy (tCO_2/yr)
Heat (DH)	-849	0.018	-15
Electricity	371	0.372	138
Total savings tCO_2			**123**

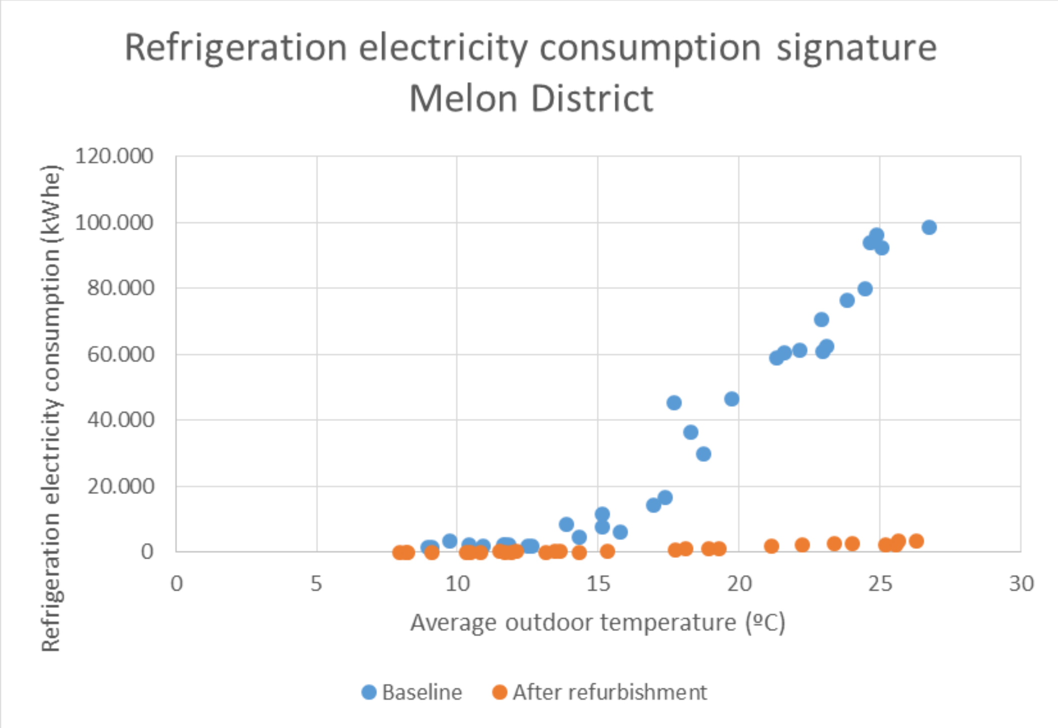


Figure 41 Energy signature for Melon District (Barcelona)

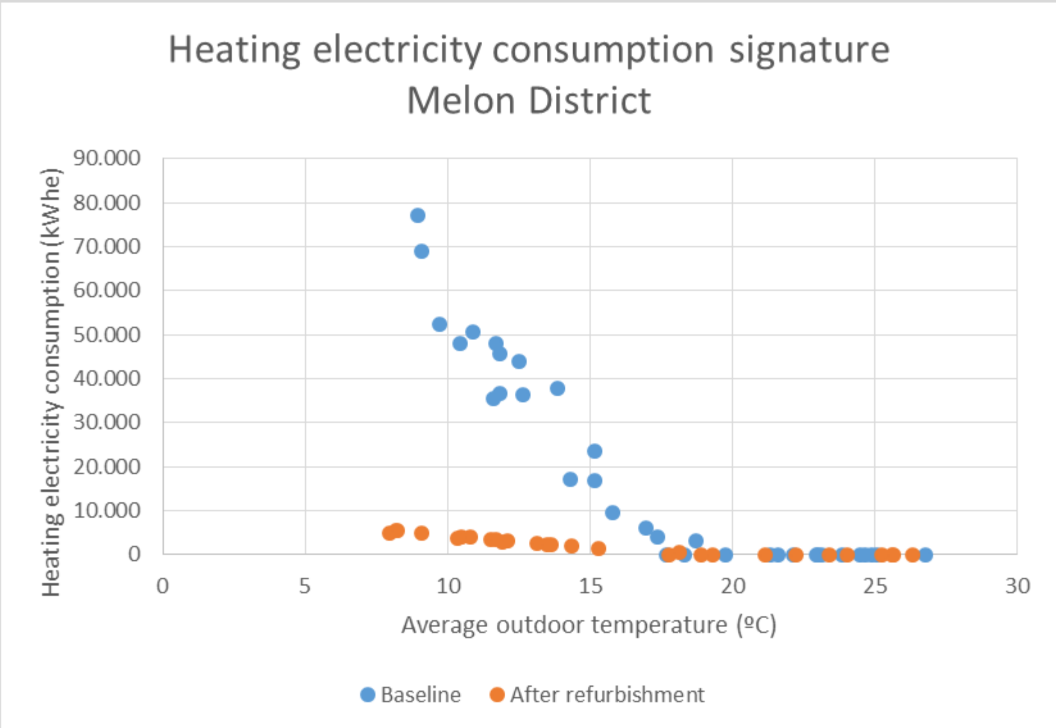


Figure 42 Energy signature for Melon District (Barcelona)

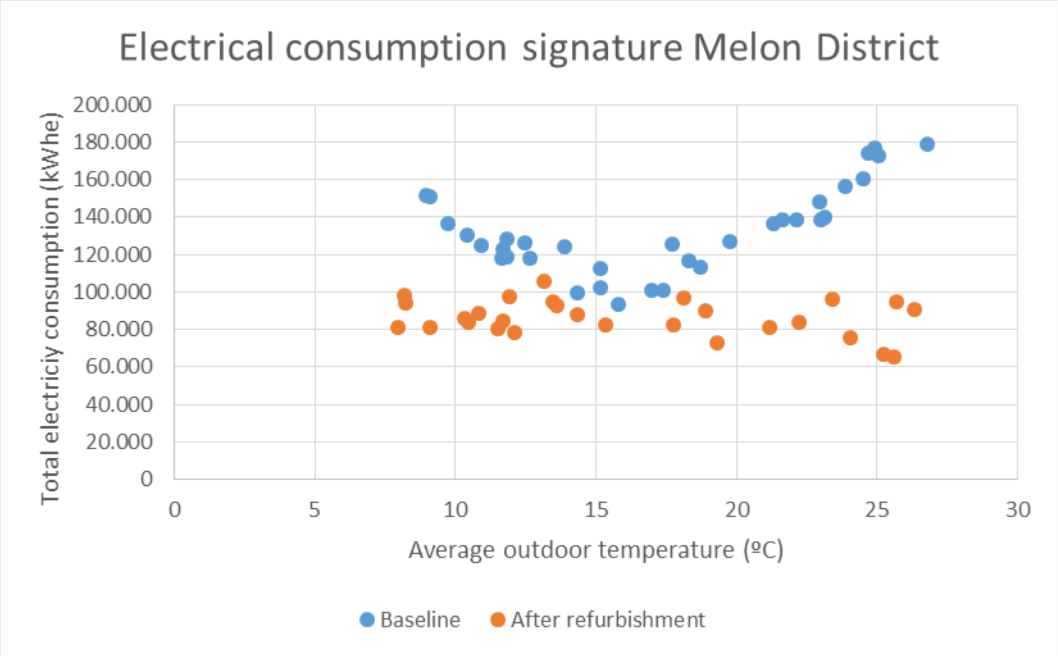


Figure 43 Energy signature for Melon District (Barcelona)

Table 69 shows the KPIs evaluated within the refurbishment work carried out in Melon District.

Table 69 KPIs evaluated for M1.0 Melon District (Barcelona)*

KPI*	Baseline	Post-retrofitting	Variation
1. Heat energy (kWh) per year	n/a	n/a	n/a %
1.1 Heat energy supply by District Heating (kWh) per year.	-	968200	- %
1.2 Gas natural consumption to cover DHW (kWh) per year	718305	-	- %
2. Distributed cooling energy required (kWh) per year.	401364	260887	-35,0%
3. Electric energy required (kWh) per year.	1074437	701077	-34,7%
3.1 Electric energy required by the heat pumps (kWh)	133788	87962	-35,00 %
Total energy use (kWh/year)	2194106	1930164	-12%
4. CO2 emissions due to heating energy demand by District Heating (kt/year)	-	0,017	- %
5. CO2 emissions due to distributed cooling energy demand (kt/year)	0,050	0,032	-35,0%
6. CO2 emissions due to electric energy demand (kt/year)	0,400	0,261	-34,7%
7. Primary energy consumption due to heating demand (MWhp/year)	986	108	-89,1%
8. Primary energy consumption due to DHW demand (MWhp/year)	769	115	-85,0%
9. CO2 emissions due to heating demand (kt/year)	0,153	0,0074	-95,2%
10. CO2 emissions due to DHW by DH (kt/year)	0,135	0,0079	-94,1%

11. CO_2 emissions due to electric consumption excluding refrigeration and heating (kt/year)		0,351	0,351	-
12. CO_2 emissions due to electric consumption by independent refrigeration systems (kt/year)		0,050	0,032	-35,0%
13. Primary energy consumption due to electric consumption excluded refrigeration and heating (MWhp/year)		2270	2270	-
14. Primary energy consumption due to electric consumption by independent refrigeration systems (MWhp/year)		321	209	-35,0%
Total primary energy consumption	MWhp/year	4346	2702	-37,8%
	ktCO_2/year	0,689	0,399	-42,1%

*Not completely validated

Hotel H10 Madison (Naturgy)

The Hotel H10 Madison has been built from two adjacent buildings previously dedicated to residential use. Due to this fact, the baseline could not be measured and cannot be calculated by using the utility invoices, since before the refurbishment the hotel did not exist.

A computer simulation that will be calibrated using some actual performance data is being used for determining the baseline. The software to be used for the building energy simulation is DesignBuilder, which is a standard for energy building simulation.

A computer simulation that will be calibrated using some actual performance data is being used for determining the baseline. The software to be used for the building energy simulation is DesignBuilder, which is a standard for energy building simulation.

Once the baseline was estimated through the building simulation, a mathematical model has been obtained to adjust results with the weather conditions and the occupancy. Two models have been obtained, one for the general electricity consumption and one for the HVAC.

General Electricity consumption (kWhe) =-29450, 09+3008, 52 days+ 478, 67·HDD_{15} +· 297, 87·CDD_{21}

HVAC Electricity consumption (kWhe) = 22.077,21 + 399, 25 HDD_{15} +· 236, 52· CDD_{21}

As for all other buildings, Naturgy collects the hourly data that will be used in combination with the simulation models. Figure 44 shows an example of the data collected.

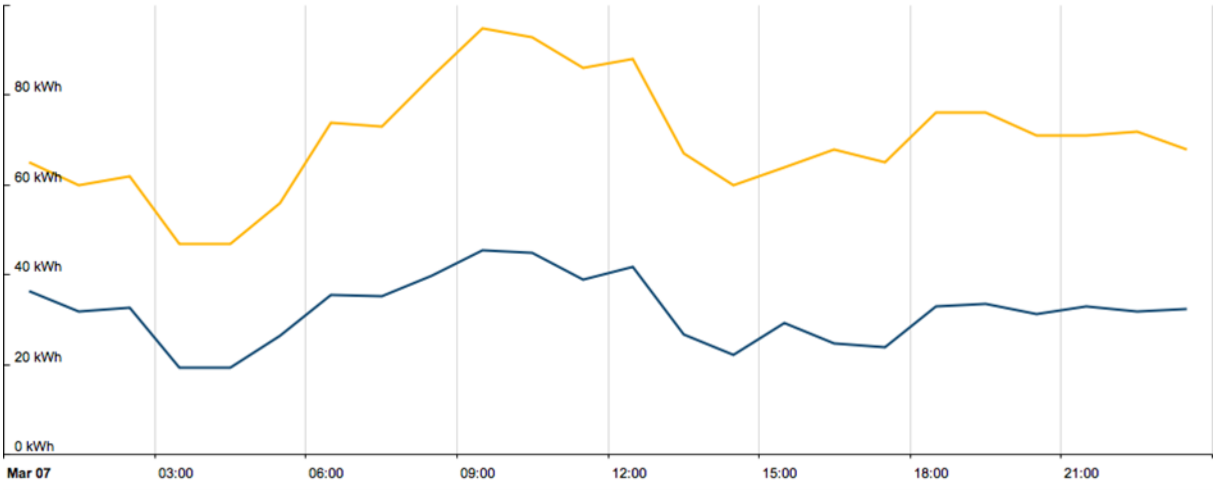


Figure 44 Example of data monitored in H10 Madison. Hourly values of building electricity consumption (yellow) and the new variable refrigerant volume system (blue).

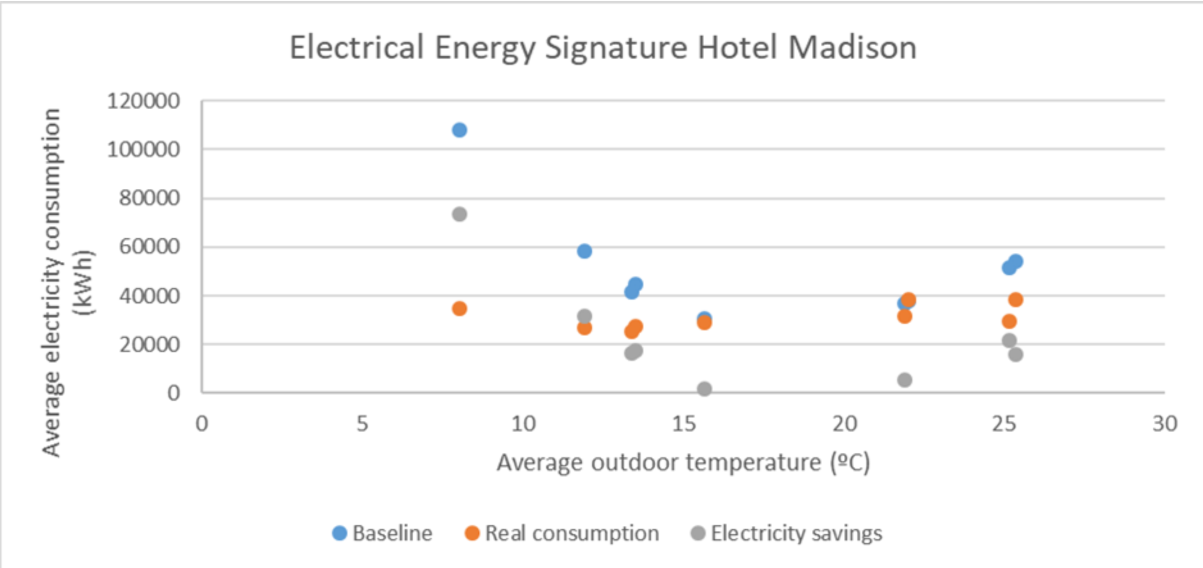


Figure 45 Energy signature for Hotel Madison (Barcelona)

Table 70 KPIs evaluated for M1.0 Hotel H10 Madison (Barcelona)

KPI	Baseline	Post-retrofitting	Variation
1. Final energy required (kWh) for heating per year and month normalized for climatic conditions.	211 202	88 891	-58 %
2. Final energy required (kWh) for cooling (kWh) per year and month normalized for climatic conditions.	180 394	138 409	-23 %
3. Total electric energy required (kWh) per year and month.	879 579	628 718	-29%
4. CO2 emissions due to heating energy demand (t/year)	75	31	-58%
5. CO2 emissions due to cooling energy demand (t/year)	64	49	-23%
6. CO2 emissions due to electric energy demand (t/year)	314	224	-29%

Total primary energy	-29 %

CEM Claror Sport Center (Naturgy)

A dedicated baseline model for the electricity consumption has been developed. The electricity model is based in 6 different variables and savings of 12% have been achieved during 2019. Regarding gas consumption, significant savings have been achieved (~51%). The obtained results are summarized in Table 71 for year 2019.

Table 71 Monthly results obtained in CEM Claror for 2019

[MWh]	Electricity Consumption	Gas Consumption		Electricity Savings	Gas savings
	[MWh]	[MWh PCS]	[MWh PCS]	[MWh]	[MWh PCS]
January	108,6	115,4	114,5	3,2	105,3
February	102,8	89,3	88,6	7,0	54,7
March	108,2	87,2	86,5	10,4	35,5
April	104,7	63,7	63,2	6,7	54,1
May	104,8	61,5	61,0	7,2	39,1
June	100,1	44,0	43,7	19,7	43,5
July	106,6	39,5	39,1	12,9	48,0
August	66,0	18,7	18,6	44,4	68,6
September	89,2	0,0	0,0	10,9	0,0
October	0,0	0,0	0,0	0,0	0,0
November	0,0	0,0	0,0	0,0	0,0
December	0,0	0,0	0,0	0,0	0,0
Yearly Total	**890,9**	**519,4**	**515,1**	**122,7**	**449,0**

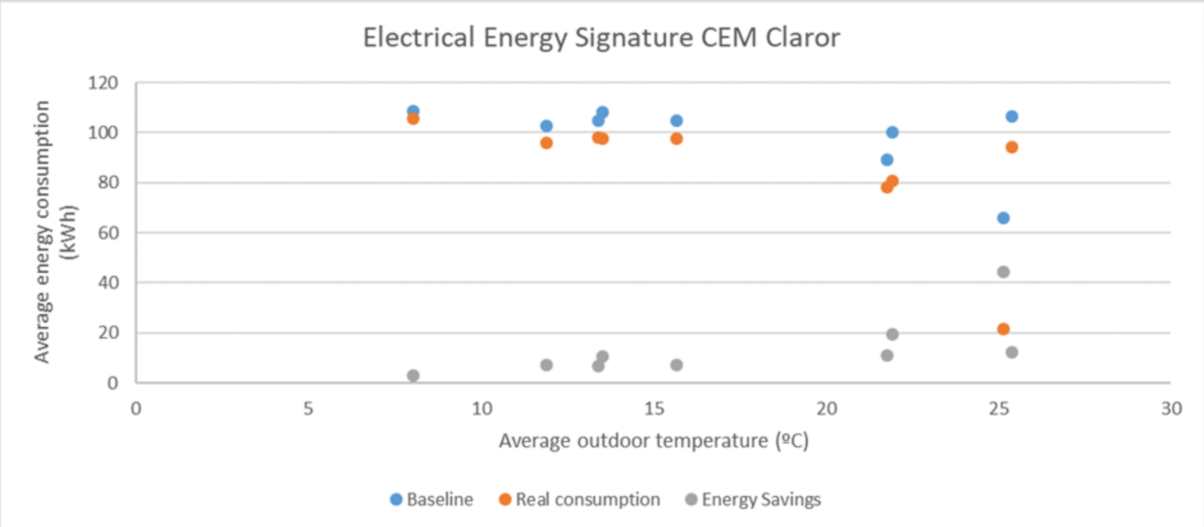


Figure 46 Energy signature for CEM Claror (Barcelona)

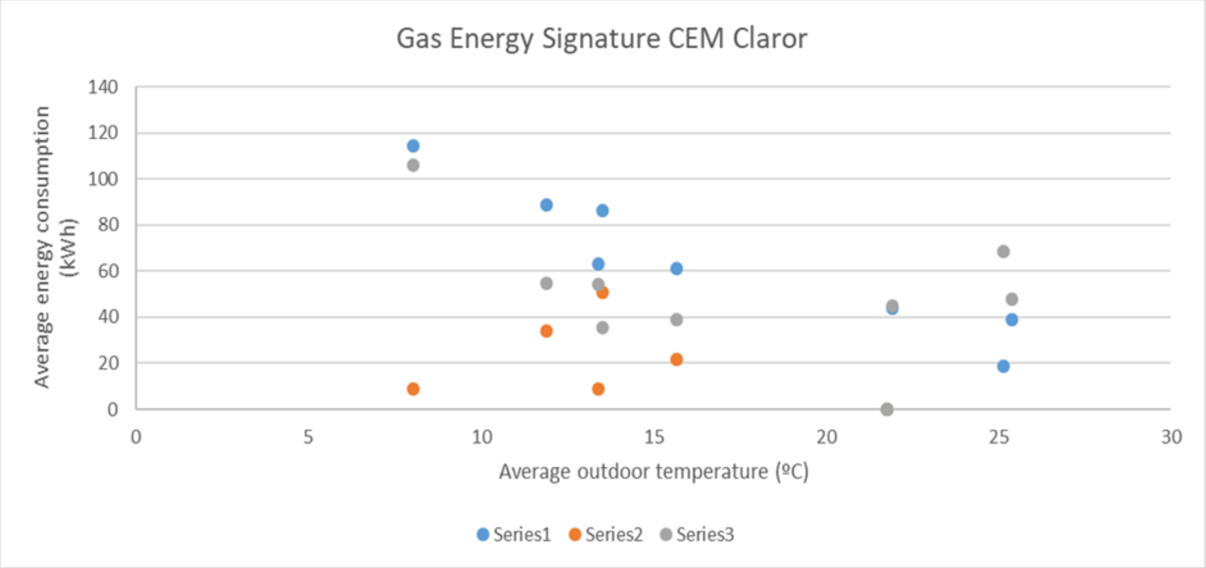


Figure 47 Energy signature for CEM Claror (Barcelona)

Table 72 KPIs evaluated for M1.0 CEM Claror (Barcelona)

KPI*	Baseline	Post-retrofitting	Variation
1. Heat energy required (MWh) per year and month normalized for climatic conditions.	591.71	591.71	0%
2. Cooling energy required (kWh) per year and month normalized for climatic conditions.	115.90	115.90	0%
3.Gas required (MWh) per year and month	1053	515.15	-51%
4. Electric energy required (MWh) per year and month.	1012.6	890.9	--12%
5. CO2 emissions due to heating energy demand (t/year)	N/A	N/A	N/A
6. CO2 emissions due to cooling energy demand (t/year)	N/A	N/A	N/A
7.CO2 emissions due to gas energy demand (kt/year)	239	118	-50%
6. CO2 emissions due to electric energy demand (t/year)	361	318	-12 %
Total primary energy			-18 %

*Not completely validated

Escola Sert (Naturgy)

The project consists of a global renovation that includes the renovation of the building façade, as well as the renovation of the air-conditioning distribution system to adapt it to the new distribution of spaces within the building and the implementation of a 19.5 kWp façade-integrated PV plant for self-consumption.

Although the only Measure implemented within the GrowSmarter project is the PV plant, the evaluation of this Measure considers the impact of the complete renovation.

The results reveal an increase of the electricity consumption during summer. This is caused by the façade refurbishment (it is common that a higher insulation implies an increase of the cooling needs) and by the replacement of individual chillers installed in some of the floors. The cooling demand covered by these individual chillers will be now covered by the centralized chiller, which is an old inefficient chiller with a lower SEER. Moreover, the occupancy of the building has increased after the refurbishment and this has an important impact in, both, electricity and cooling demands. As the façade refurbishment is out of the GrowSmarter scope and the Measure to be analyzed within the project is the PV production (see M1.1.10.2), the assessment of the non-routine adjustments in the electricity model due to this chiller replacement will not be performed.

Regarding the gas consumption, significant savings have been achieved due to the façade refurbishment. As aforementioned, after refurbishment has been a 30% higher occupation so we have normalized electricity and gas consumption to this higher usage. Regarding the PV installed, the production represents about 5% of the total electricity consumption of the building.

For Escola Sert the KPI table is available only in M1.1.10.2.

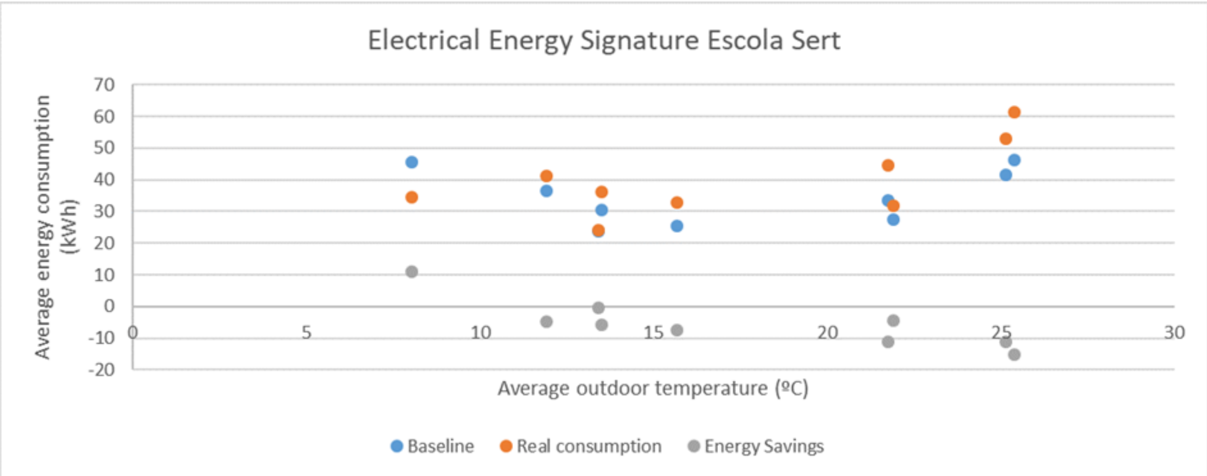


Figure 48 Energy signature for Hotel Escola Sert (Barcelona)

M1.1.1 - Low U-values of windows

Introduction

New windows with a U-value of 0.7 W/m^{2}K developed for easier mounting have been used when refurbishing existing buildings in Stockholm and Cologne. The new concept includes not only more energy efficient windows but also a more time efficient mounting procedure.

The evaluation has been performed according to the Evaluation Plan D5.1.
1. Air leakage testing with blower door
2. Window thermal status determination (such as transmission and solar gain coefficients)
3. Indoor environmental investigation
4. Installation effects (surroundings of the frame of window) by e.g. thermal imaging

The intention of the Measure was to:
1. Simplify mounting of windows when refurbishing building.
2. Reduce space heating demand.
3. Increase comfort and quality of living.

Stockholm

Industry partner	Contact person	Validation partner
Skanska Stockholmshem	Harry Matero	KTH-EGI

In order to minimize energy losses and create a good comfort conditions, old windows with a U value of about 2.0 have been replaced by windows with a U value of 0.7. This is one of many Measures in the energy renovation of the houses at Valla Torg. The implementation has been successful. However, it is worth noticing that a frost formation problem has been identified with the outside of the new windows at low outdoor temperatures.

The old windows have been removed and the new windows that have been installed have been adapted to the existing dimensions. When the new windows are installed, they have adapted them to the new facade, in order to minimize the change in the architecture of the building.

Thermal investigations (measurements and thermal Imaging) have been carried out before and after the energy renovation in some of the apartments. Figure 49 shows an example of the hourly measurement of the indoor temperature in one dwelling.

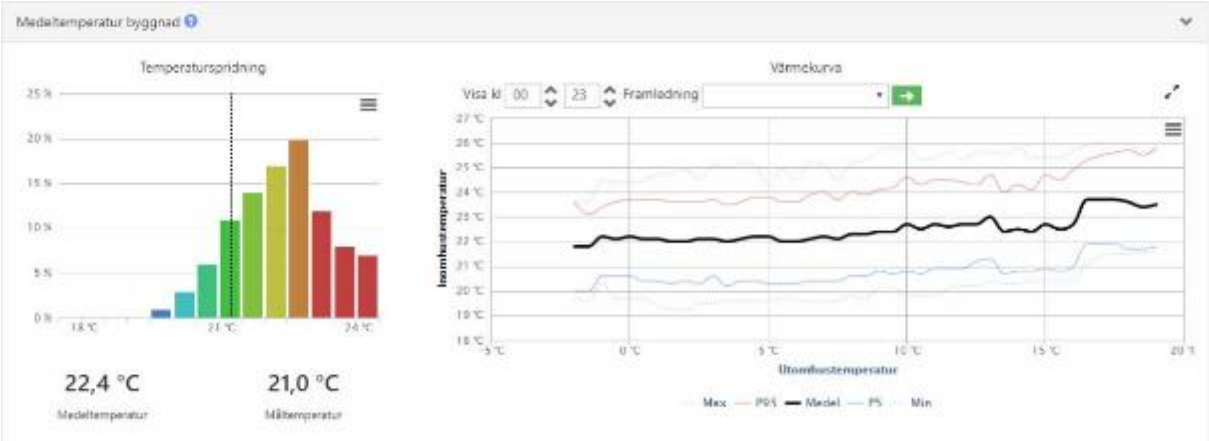


Figure 49 Example of hourly indoor temperature measurements in Valla Torg, Stockholm.

A complete report on the Air leakage tests performed in Valla Torg is available and Figure 50 and Figure 51 show an example of the preliminary results.

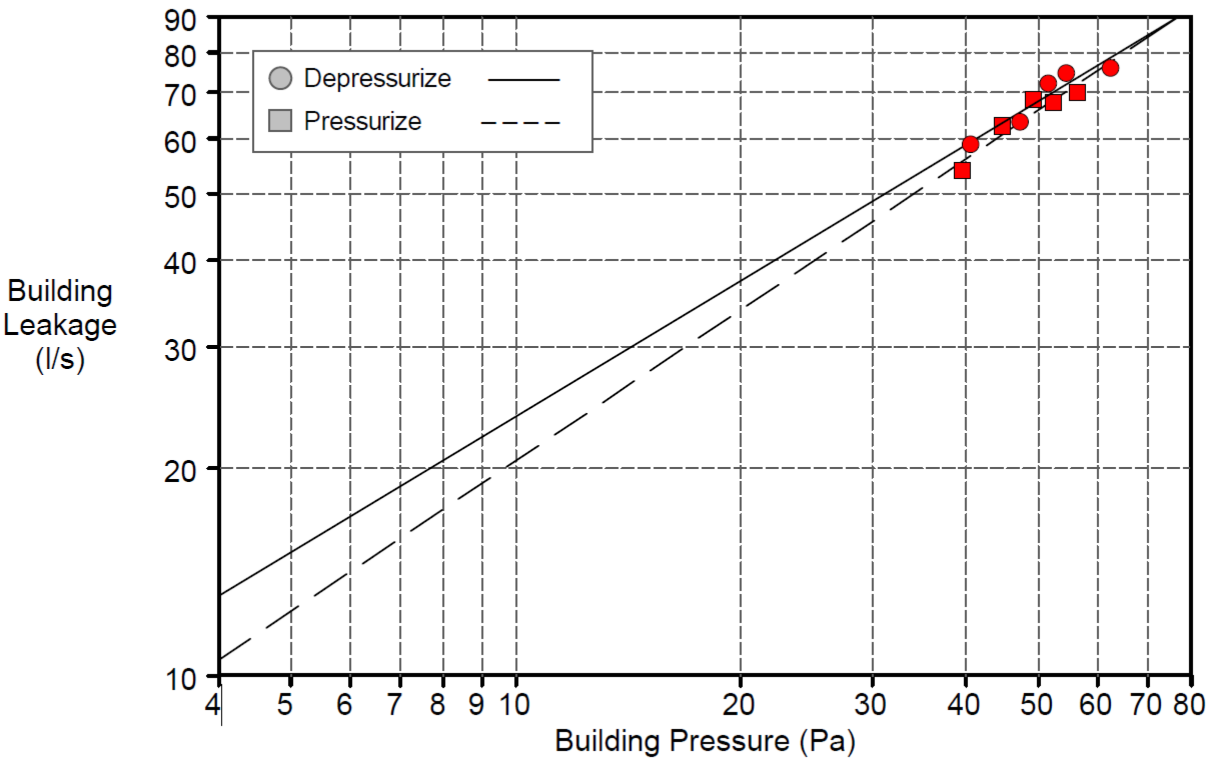


Figure 50 Example of Air-leakage test (baseline) in Valla torg, Stockholm

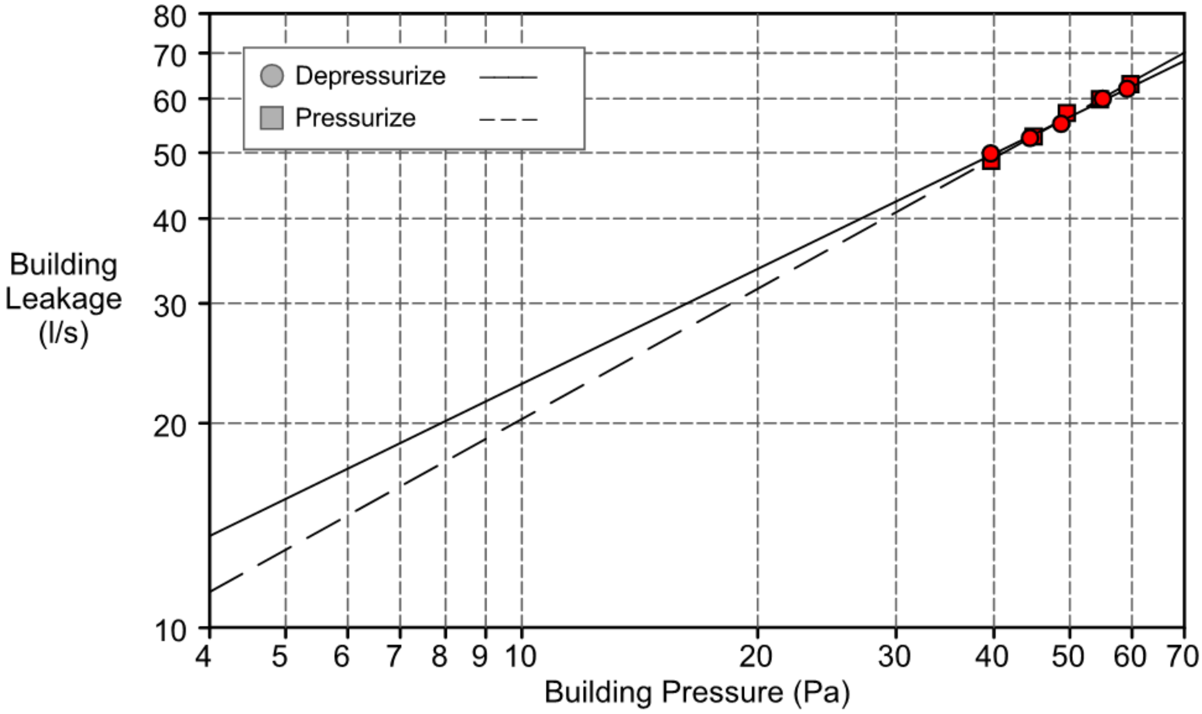


Figure 51 Example of Air leakage test (after refurbishment) in Valla torg, Stockholm

Table 73 shows the KPIs evaluated for M1.1.1 in Valla Torg, Stockholm.

Table 73 KPIs evaluated for M1.1.1 Valla Torg (Stockholm)

KPI	Baseline	Post-retrofitting	Variation
1. Air leakage in air flow l/s at 50 Pa	67	57	-14.9 %
1. Air leakage in air changes per hour at 50 Pa (ACH50)	1.32	1.2	-9.1 %
2. U Value of windows (incl. frame) in W/m2.K	1.8-2.0 (avg. 1.9)	0.7-1.0 (avg. 0.8)	-58 %
3. Solar gain coefficient (%)	-	33%	- %
4. PPD of overall thermal environment evaluated at reference point of window)	N/A	N/A	- %
5. PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference)	N/A	N/A	- %
6. Sensible air temperature of the reference apartments according to relevant standards (e.g. ISO 7726, 7730).	N/A	N/A	- %

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie	Andreas Wolba Christian Remacly	KTH-EGI
Dewog	André Esser	

As a result of the building refurbishments of M1.0, the U-values and the heat losses of external walls have been reduced. The following figures show example of analysis carried out with thermographic cameras.

Figure 52 Example of thermographic measurements, Adam Stegerwald Straße 21

Point 1 refers to the insulation of the external wall. The house has a new thermal insulation of 160mm WLG035. The thermogram shows particularly low contrasts if the heat exchange through this surface (outer wall) is particularly small. The existing lack of structure of the temperature is a characteristic for a good insulation. Point 2 states that warm room air escapes through open windows.

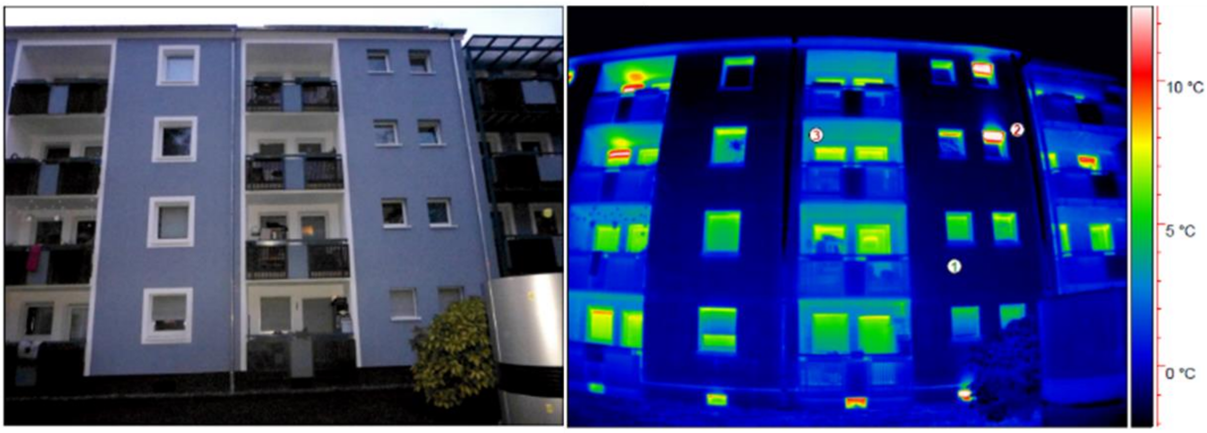


Figure 53 Example of thermographic measurements, Adam Stegerwald Straße 21

As described above, the thermogram shows good insulation (shown in point 1) in this image for the whole building. Point 2 shows an open window. Point 3 shows an increased temperature due to heat accumulation under the roof/ balcony overhang.

Figure 54 Example of thermographic measurements

As show in Figure 54, the thermogram shows good insulation (shown in point 1) in this image for the almost whole building. Point 2 shows the rain pipe. Point 3 shows a tilted window.

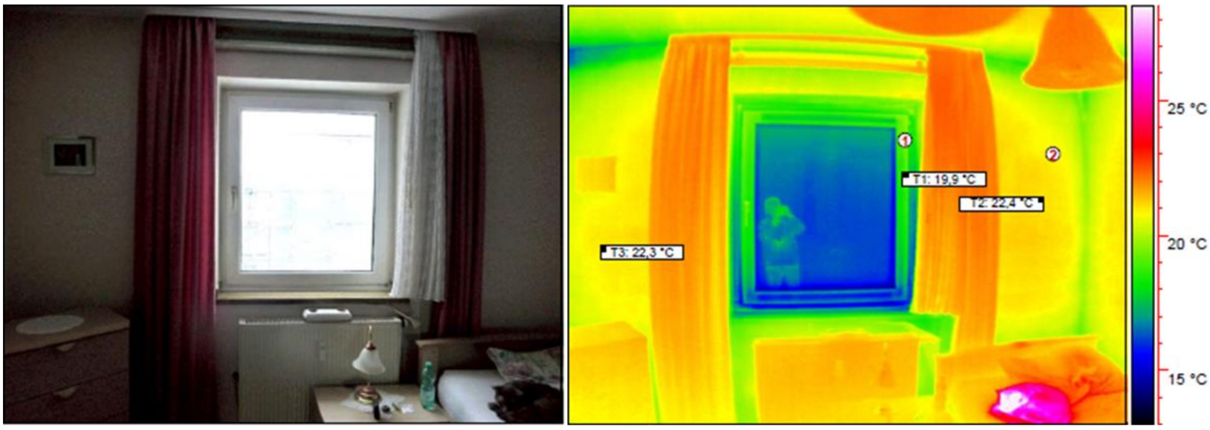


Figure 55 Example of thermographic measurements, Adam Stegerwald Straße. 21

Figure 56 Example of thermographic measurements

The measured temperature values are assigned to the so-called “false colours”. The result is a colored or grayscale thermal image (thermogram) that shows the temperature distribution on the surface of the measured object. As a rule, low temperatures are represented by dark colors and bright temperatures by light colors.

The thermographic measurement shows that the new windows also have sufficient surface temperature of the frames and the tightness according to the Blowerdoor protocol is sufficiently good. Since the glazing can only be determined thermographically inaccurately, the verification of the Suppliers with Ug=0.6/W/m2K is sufficient. (Example Edith-Stein Straße 5).

Thermal bridges are areas of the building envelope that have a much lower thermal resistance than the adjacent wall and ceiling parts. They therefore also have lower room-side surface temperatures and cause greater local heat dissipation. Moist room air can condense on these cooler surfaces and thus lead to condensation damage.

Table 74 KPIs evaluated for M1.1.1 Adam Stegerwald Straße 21 (Cologne)

KPI	Baseline	Post-retrofitting	Variation
1. Air leakage in air changes per hour at 50 Pa (ACH50)	-	Edith-Stein-Str.5 1 Adam-Stegerwald-Str. 22 1,5 Edith-Stein-Str.18 1 Adam-Stegerwals-Str. 21 2,9	-
2. U Value of windows (incl. frame) in W/m2.K	2.7-2.9	0.9-0.95	-66 %
3. Solar gain coefficient (%)	-	0.52	-
4. PPD of overall thermal environment evaluated at reference point of window)	N/A	N/A	N/A
5. PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference)	N/A	N/A	N/A
6. Sensible air temperature of the reference apartments according to relevant standards (e.g. ISO 7726, 7730).	N/A	N/A	N/A

Conclusions

Changing windows is a relatively expensive investment, but since the windows are a significant part of the buildings' envelop, a low U-value is necessary in an energy renovation. Switching to windows with low U-value is also positive based on the experienced indoor climate.

However, 0.7 may well be a low U value as it may become frost on the outside of the glass. This is perceived by the tenants as negative as it limits the view from the apartment.

Potential for full scale implementation

Technical, economic and social feasibility

The feasibility of this Measure is good for all cities. The energy performance of a window depends on three main characteristics, solar gain transmittance, daylight transmittance, and thermal transmittance.

Thermal transmittance determines the rate at which thermal energy is transported over the window per a given temperature difference. Less transmittance yields lower energy transport. For a cold climate this is beneficial as less energy is required to compensate for the losses of thermal energy over the window. In warm climate, in which active cooling is used to maintain the internal temperature below the outside ambient temperature, low transmittance is also beneficial as it decreases again the energy transportation rate over the window. The rate of energy transported may be estimated given the properties of the window is known as

$$\dot{Q} = U \cdot A \cdot (t_i - t_o)$$

If, instead the energy over a certain time interval, (a week, a month, or a year) may be estimated using concept of degree hours, as

$$Q = U \cdot A \cdot DH$$

For which the degree hours are an integrated temperature difference between indoor and outdoor. The impact of the thermal transmittance is mainly due to the window characteristics as well as the thermal properties of the framing. In addition, the workmanship of the installers will also affect the overall performance, as thermal bridges as well as unintended leakages around the perimeters of the windows decrease the overall thermal performance of the newly installed window.

The benefit of low solar gain transmittance, on the contrary to thermal transmittance, is not always positive. For cold climate, when there exists a heating need in the building, any free energy (such as solar energy) is beneficial. Hence, for those instances, the solar gain transmittance should be high, mitigating the use of artificial heating. However, when cooling needs are present, any additional gain from the sun is undesirable. Hence, for a building with air conditioning and cooling during the summer time and a heating need during winter, solar transmittance should be low during summer time, and high during winter.

In practice, one must select a window which minimized the annual energy consumption rather than sub-optimizing the window for a certain climatic season. A better option is to use a window with as high solar gain transmittance as possible and using shading devices, if possible, during the summer.

For a building with no heating need and only cooling, low solar gain transmittance should be chosen, preferably combined with solar shadings.

The solar gain of a window may be estimated as

$$\dot{Q} = SHGC \cdot A \cdot F_c \cdot q''_{solar}$$

F_c is the impact of the shading device, which is much simpler to alter, compared to the SHGC (solar gain transmission) of the window.

The optical properties (daylight properties) does not directly impact the energy flow over the window, however it affects the level of artificial lighting required inside the building.

As may be understood by the above discussion, the impact of the change of window from one city to another depends on the climatic conditions, and whether active cooling is utilized. If active cooling is not implemented in a building located in a warm climate, the properties discussed should still be maintained, however excessive heat may be required to be dissipated using natural ventilation strategies (e.g. operable windows).

The economic feasibility will be determined by the energy savings of the Measure compared to the cost of installation. As the climatic conditions and costs are difference for different cities, each city needs to be evaluated individually, based on the measured and predicted saving.

The social impact of the Measure may include:

- Tenants may need to move out of the apartments during the renovation. Most of the time though, if changing windows is the sole Measure, tenants most probably is not required to move out, however the apartment will be somewhat exposed to outdoor conditions for a short while.

- Better insulation of the windows implies that the indoor climate most probably will improve, since the cold draft sensation and directive operative temperature difference will be improved (i.e. decreased).

- If the newly installed windows also mean that the leakages at the perimeter of the windows is decreased, again the draft sensation will be reduced and living comfort improved.

Upscaling and replicability of the Measure: general considerations

This Measure is applicable to all cities. The outcome may be different depending on climatic conditions, but there are no technical limitations. There are no limitations on this Measure for upscaling, apart for the fact that some buildings within the cities will be protected from changes.

Upscaling of the Measure in Stockholm

The windows of an older building will be of lower thermal quality compared to newer types. The main thermal property affecting energy consumption in a building will be the effective overall heat transfer coefficient,

$$U\ \left(\frac{W}{m^2 \cdot K}\right).$$

As windows have very low thermal storage capabilities the thermal performance may to a good approximation be assumed to be in steady state, especially for typical one hour calculation steps.

In order to estimate the upscaling effect of retrofitting new windows to the entire building stock, an estimation of the currently used buildings are required. Data from a Swedish guideline for conducting Energy Declarations have been used[11]. It was assumed that buildings from 1980 and forward will have good enough windows, hence not up for renovation at this point. The motivation will be that there will not be any economic incentive to only retrofit windows, as this will always be done with other major renovations of buildings.

As the database used do not contain neither the wall area nor the window area, an estimation had to be done. It was assumed that the "old" rule-of-thumb for daylighting design have been used for sizing minimum window area. This rule state that the window area should be 10% of the floor area[12].

- [11] Energibesiktning av byggnader - Flerbostadshus och lokaler (Karin Adelberth, Åsa Wahlström, 2009, ISBN 978-91-7162-755-1
- [12] PBL kunskapsbanken. – en handbok om plan- och bygglagen. Boverket (https://www.boverket.se/sv/PBL-kunskapsbanken/regler-om-byggande/boverkets-byggregler/ljus-i-byggnader/dagsljus/)

The new windows used have been evaluated within the GrowSmarter project and in Stockholm it was found that the new windows have an overall heat transfer coefficient of $0.8 \frac{W}{m^2 \cdot K}$.

The degree hour method is used for this evaluation, as

$$\dot{Q} = U \cdot A \cdot GH$$

Based on the typical expected topology of the building window stock, the energy use associated with the old windows would be $\sim 900\ GWh$ of thermal heat. If these windows were to be replaced with new, as found in Valla Torg (Stockholm), the saving of thermal heating energy will be $\sim 640\ GWh$.

This would indicate a saving of the thermal loss through windows only corresponding to $\sim 70\%$. If, instead, the saving of heating energy is related to the total heating[13] in the entire building stock of Stockholm, this would correspond to $\sim 14\%$.

- [13] The total energy heating requirement relates to all space heating, ventilation heating, and domestic hot water heating for all buildings in Stockholm. Data taken for total energy heating energy are from the Building Energy Declaration database, as previously described.

M1.1.2 - Reducing hot water losses

Introduction

Poor insulation of the pipes in the hot water circulation (HWC) have been overlooked for a long time and recent studies have shown that the heat losses can be in the range of 6-20kWh/m^2 (heated area) annually. According to the expectations expressed in the evaluation plan (D5.1), in this Measure the losses should be cut by 50 %. A new type of pipe in pipe hot water circulation pipe system will be used in the buildings in Årsta, Stockholm.

According to the evaluation plan (D5.1), the baseline includes the measurements of heat losses (in kWh/h) in the hot water circulation as average over one year. Flow rate of circulated water was measured together with temperature of the hot water supply and return. The data was over one year for two reference buildings.

The key performance indicators evaluated are:
1. DHW heating demand (kWh/h) during one year.
2. Temperatures (˚C) of the delivered DHW.
3. Temperatures (˚C) of the incoming water mains.

Stockholm

Industry partner	Contact person	Validation partner
Skanska	Harry Matero	KTH-EGI

The "Viega Smartloop Inliner System" has been installed with the aim to reduce energy losses from the hot water circulation system. Energy meters have been installed to measure energy losses in hot water circulation systems before and after refurbishment of the houses.

The "Viega Smartloop Inliner System" is a simple and passive energy saving measure. There are no technical barriers to perform a similar measure in a future deep energy renovation project.

House 7G

The results for House 7G show that the annual hot water circulation loss has been reduced from 6.3kWh/m^2 to 2.4kWh/m^2.

Table 75 KPIs evaluated for M1.1.2 House 7G (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Hot water circulation losses (kWh), annual measurement	34029	13562	-62 %
2. Annual hot water circulation loss (kWh/m2) (heated area of building).	6.3	2.4	-62 %

House 8H

The results for House 8H show that the annual hot water circulation loss has been reduced by over 25%.

Table 76 KPIs evaluated for M1.1.2 House 8H (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Hot water circulation losses (kWh), annual measurement	28797	21280	-27 %
2. Annual hot water circulation loss (kWh/m2) (heated area of building).	6.3	4.6	-27 %

Results

The obtained results show that an overall reduction of annual hot water circulation loss of more than 25% can be achieved. It is worth noticing that this Measure can be fully implemented only through a complete replacement of the piping loop.
The result is low because the size of the hot water circulation system has been increased with pipes from basements to the third floor.

Potential for full scale implementation

Technical, economic and social feasibility

The losses of the circulated hot water depend on the level of insulation, the size and length of the hot water circuit and the temperature difference between the hot water circulated and the surrounding air. The hot water temperature is maintained at a certain level in order to mitigate the growth of legionella bacteria, as well as providing sufficiently high temperature to the users. None of these parameters are expected to change during the course of a year. The actual momentary losses of the Hot Water Circulation (HWC) are estimated by

$$\dot{Q}_{HWC} = U \cdot A \cdot (t_{hw} - t_{air})$$

However, if none of the parameters change over time, the energy loss for a given time period will simply be

$$Q_{HWC} = U \cdot A \cdot (t_{hw} - t_{air}) \cdot \Delta\tau$$

where $\Delta\tau$ is the time period of interest.

The savings for this Measure is simply the cost of hot water production that the HWC-losses corresponds to. As most of the heat loss will be absorbed by the building, this part will decrease the need for heating during the heating season, but for buildings in need of cooling part of the year, the loss will constitute an additional heat load.
This Measure has very little social impact. The energy savings will lead to reduced bills of heating in the building. The installation of better insulation may affect the tenants differently, depending on which type of HWC that will be installed (one could add insulation in the existing one, or use a coaxial setup). For the latter one, the users may be out of hot water for the duration of the installation as the pipes need to be exchanged.

Upscaling and replicability of the Measure

This Measure may easily be applied to a building in any city.

This Measure may be upscaled to most buildings, probably to protected buildings as well, unless it is protected on the highest level (no alterations allowed).

Upscaling of the Measure in Stockholm

All multifamily houses are required to have a circulation of the hot water in order to be able to meet the requirement of availability of hot water for all tenants according to the building regulations in Sweden. As the temperature of that circulation system is maintained at elevated temperature, thermal losses occur. By increasing the insulation thickness or using more elaborative solutions, as done in the GrowSmarter project, these losses may be decreased. Evaluations carried out by the responsible partner indicate that the thermal losses decrease from $6.3\,\frac{kWh}{m^2}$ to $2.4\,\frac{kWh}{m^2}$ (savings of $62\,\%$). If this is to be implemented in all existing multifamily houses within Stockholm city, the savings will be $145\,GWh$ corresponding to a total saving of $3.1\,\%$ (considering all heating use in all multifamily buildings in Stockholm city).

M1.1.3 - Recovering waste water heat from the drain

Introduction

Recovering heat from the sewage system to preheat tap hot water is a new area for heat recovery with great potential. About 25 % of the energy for heating water can be saved.

As expressed in the evaluation plan (D5.1), waste heat recovery was installed in the drain system in Årsta, Stockholm, and the expectation was to achieve a recovery of 25% of the energy for heating domestic hot water (DHW).

The baseline was determined by measuring the heat used for DHW during one year, measuring heating energy required hourly (kWh/ h). The data was corrected for differences in occupancy in the buildings before and after implementation.

The key performance indicators evaluated are:
1. DHW heating demand (kWh/h) during one year.
2. Temperatures (˚C) of the delivered DHW.
3. Temperatures (˚C) of the incoming water mains.

Stockholm

Industry partner	Contact person	Validation partner
Skanska Stockholmshem	Harry Matero	KTH-EGI

Hot water use is a major part of a property's energy consumption and all the hot water used in a building is flushed into the drain. With a waste water heat exchanger in the drainage system, part of the energy that is flushed in the drain can be recovered.

The waste water heat exchanger is a passive component. The function is that cold water is preheated by the thermal energy in the drain before it warms up to hot water.

Energy meters have been installed to measure energy recovery of the waste water heat exchanger after the implementation of the product.

The collection of measurement data is in progress. The estimated saving based on obtained results is about 3.5 kWh/m^2 per year.

Table 77 KPIs evaluated for M1.1.3 House 7G (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
Energy saving from waste heat recovery. kWh/m^2	0	3.6	-
1. DHW heating demand kWh/m^2 during one year.	22.3	19,4	13 %
2. Temperatures (˚C) of the delivered DHW.	55-57	55-57	-
3. Temperatures (˚C) of the incoming water mains.	4-21		

Potential for full scale implementation

Technical, economic and social feasibility

The waste water heat exchanger is a simple and passive energy saving measure. There are no technical barriers to perform a similar measure in a future deep energy renovation project.

Upscaling and replicability of the Measure

The Measure is applicable for any city, given the cooling of the drain water is permitted. In some cities, the return temperature of the drain water is limited, e.g. it may not be lower than the temperature of the incoming CWM-temperature.

This Measure may easily be up-scaled for any building that is not highly protected. The drain water system needs to be accessible for installation as well as future service. Limitations of return temperatures may come into play, depending on the installed systems. According to the analysis above, it was assumed that the heat recovery was a passive heat exchanger. Then there will be no risk of colder return temperatures than supplied in the CWM. However, if a heat pump solution is utilized, care may be needed and the control system adjusted for local conditions and regulations.

Upscaling of the Measure in Stockholm

One underutilized available waste heat source is the tempered water leaving the building through the drain pipe. As essentially all the DHW water energy is present, along with some fraction of the space heating, this should be able to contribute to increased energy efficiency. There are practical solutions and system configurations that still could be refined in order to fully recover this energy loss. Measurements within the GrowSmarter project indicate that the saving will be from $22.3\frac{kWh}{m^2}$ to $19.4\frac{kWh}{m^2}$, a saving of $13\ \%$, corresponding to a saving of $178\ GWh$ if employed to all multifamily buildings in Stockholm city. Seen from the total heating energy in that building sector, it corresponds to $3.8\ \%$.

Conclusions

This is overall a good energy-saving measure. However, it is important to find a system that is maintenance free, otherwise the cost of maintenance may be higher than the energy saving.
Experience from previous projects is that there are different solutions that work differently well. The solution in Valla Torg within GrowSmarter resulted to be a successful solution.

M1.1.4 - Energy classified DHW fixtures

Introduction

By using energy classified hot water fixtures it is possible to save ca. 5 kWh/m^2 annually. As expressed in the evaluation plan (D5.1), the intention of the Measure was to reduce the need of DHW while maintaining or increasing comfort and service as provided with older fixtures. This Measure was implemented in Årsta, Stockholm.

In particular, the baseline was determined by measuring the used DHW (m^3) over the period of one year.

The key performance indicators evaluated are:
1. Energy use for DHW (kWh/h).
2. Annual DHW use (m^3).
3. Energy use for DHW per person in building (kWh/person).
4. Energy use for DHW per square meter (kWh/m^2).

Stockholm

Industry partner	Contact person	Validation partner
Skanska Stockholmshem	Harry Matero	KTH-EGI

Hot water use is a major part of a property's energy consumption and all the hot water used in a building is flushed into the drain. To install water efficient tap water fixtures is an easy way to minimize the cold and hot water without compromising on the comfort.

Energy meters have been installed for measuring hot water consumption before and after refurbishment of the houses.

Results

Two buildings in particular have been considered in Stockholm for this Measure. In one case the measured DHW energy consumption was 22.2 kWh/m2 per year and in the second case the measured DHW energy consumption was 19.4 kWh/m2 per year.

It is worth to notice that the baseline measurements are relatively low since some years ago, water saving measures were taken in the form of installation of water-saving tap aerators. In case of normal building with no modified-fixtures the DHW energy consumption can be easily be over 30 kWh/m2.

Table 78 KPIs evaluated for M1.1.4 House 7G (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Energy use for DHW (kWh), annual consumption.	120453	109629	-9 %
2. Annual DHW use (m^3).	2147	2154	0.3 %
3. Energy use for DHW per person in building (kWh/person).	N/A (GDPR)	N/A (GDPR)	-
4. Energy use for DHW per square meter (kWh/m^2).	22.3	19.4	-13 %

Potential for full scale implementation

Technical, economic and social feasibility

The energy associated with the heating of the hot water (DHW) is

$$Q_{DHW} = \int \dot{m}_{CWM} \cdot c_p \cdot (t_{DHW} - t_{CWM}) \cdot d\tau$$

The temperature of the DHW is expected not change significantly, while the temperature of the City Water Main (CWM) changes with season. If the sampling interval of these are short enough, the temperatures may be assumed to be invariant for that time period. The installation of energy classified DHW fixtures will decrease the amount of water used. Hence, measurement of the water consumption before and after the installation enables to estimate the energy savings with this Measure.

Hence, again, the economic savings will be determined by the cost of heating energy for the DHW.
The social impact will be reduced energy bills, but also the risk of annoying tenants if the fill time of water for cooking or cleaning is significantly increase (which it is due to the function of these devices). Care is required to install them only at appropriate sinks.

Upscaling and replicability of the Measure

This Measure is readily applicable for any city and building. Any building anywhere may use this Measure. There is a limitation on which fixtures where this Measure is accepted by the tenants, i.e. it is primarily suitable for hand washing sinks in toilets. It is less suitable for other sinks (kitchen and laundry rooms) where the amount of water is of importance. Users will be greatly annoyed if it takes too long time to fill a bucket of water or a saucepan.

M1.1.5 - New efficient air heat pumps

Introduction

Heat recovery connected to the ventilation systems is unusual in old buildings. When exhaust air heat pumps are used, the temperature of the air is typically reduced to about 0-5˚C. Initially, a new type of heat pump was planned to be used in Årsta, Stockholm, which cools the exhaust air to between - 10 and -15 ˚C. However, it was later decided to install a more ordinary exhaust air heat pump decreasing the temperature to around 1-2 ˚C.

As stated in the evaluation plan (D5.1), the intention of the Measure is to recover heat from the exhaust ventilation system to space heating and DHW, as no supply ventilation system will be used, and enable annual savings up to 50 kWh/m^2.

The key performance indicators evaluated are:
1. Heat recovery ratio (%).
2. Effectiveness of the heat recovery system (i.e. overall COP of the system)

In Cologne, the installed heat pumps are using ambient air as a heat source. Heat is delivered to the hydronic heating system.

Stockholm

Industry partner	Contact person	Validation partner
Skanska Stockholmshem	Harry Matero	KTH-EGI

New type of high performance extract air unit with integrated heat pump. The compressor is speed controlled via a frequency inverter, constantly adjusting depending on the amount of energy that is available to recover. When tenants cook or take a shower, the heat pump also recovers the extra energy that arises as a result of a higher moisture content and increased air flow. This is unique to this type of heat pumps. This type of heat pump can lower the temperature down to +1ºC in the extract air.

The enery performance of the exhaust air heat pumps is currently monitored. Before the installation of the exhaust air hea pumps all exhaust air was contributing to ventilation losses since there was no recovery of energy.

House 6F, House 7G, House 8H

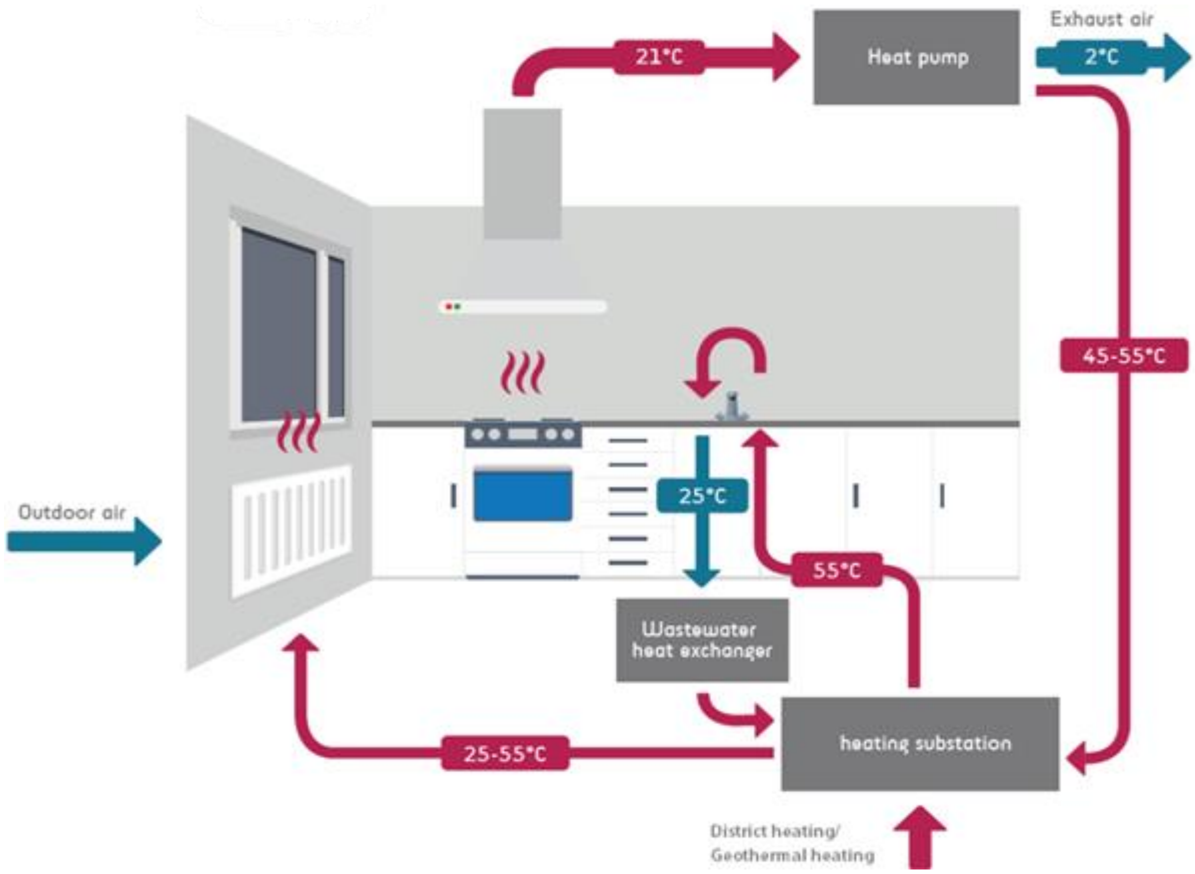


Figure 57 Energy flow scheme in House 6F, House 7G, House 8H

Figure 57 shows the energy flow scheme in House 6F, House 7G and House 8H.

Table 79 KPIs evaluated for M1.1.5 House 6F (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Heat recovery ratio (%).	-	~86 %	-
2. Effectiveness of the heat recovery system (i.e. overall COP of the system)	-	3.66 (avg)	-

Table 80 KPIs evaluated for M1.1.5 House 7G (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Heat recovery ratio (%).	-	~86 %	-
2. Effectiveness of the heat recovery system (i.e. overall COP of the system)	-	3.26 (avg)	-

Table 81 KPIs evaluated for M1.1.5 House 8H (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Heat recovery ratio (%).	-	~79 %	-

2. Effectiveness of the heat recovery system (i.e. overall COP of the system)	-	3.23 (avg)	-

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie	Andreas Wolba Christian Remacly	KTH-EGI

The Vitocal 300-A type AWO-AC 301.B reversible air/water heat pump with electric drive for room heating and domestic hot water heating was installed inside the estate. All 41 heat pumps were installed in front of the houses for space reasons. The selected model is specially designed for outdoor installation.

A complete monitoring system for the heat pump units has been installed and data collection is ongoing. Thermal energy, electric energy, temperatures and noise are among the monitored variables.

In order to reproduce the performance of the heat pump, an example calculation has been carried out for the Adam Stegerwaldstr 19-25 building.

The calculation for the building was carried out for the month of October. The heat pump energy meter measured 6166.6 kWh in total. The remaining heat is provided by district heating. This amounts to 6352.7 kWh. This means that the heat pumps account for 49% of heat generation.

The COP value indicates the ratio between the heat output and the required drive energy (electricity). The average COP of the heat pumps is 2.44.

The district heating is a greater support than initially expected. The heat pumps reach their limits especially when warm water should be heated to 60 °C in order to offer reliable protection against Legionella infections. The temperatures are between 38 and 62 °C, the rest of the heat is generated by the district heating system with temperatures of up to 96 °C

A complete audit for investigating the noise disturbance has been performed. The noise effect in connection with the operation of the heat pumps in the Stegerwald settlement is not disturbing for the residents.

Table 82, Table 83 and Table 84 present the KPIs evaluated in Cologne within M1.1.5. The measurement campaign has been performed after the refurbishment of the Stegerwaldsiedlung area.

Figure 58, Figure 59 and Figure 60 propose the monthly evolution over 2018 of the energy use from the heat pump (HP) and the district heating (DH), together with the monthly average of the outdoor temperature (T avg).

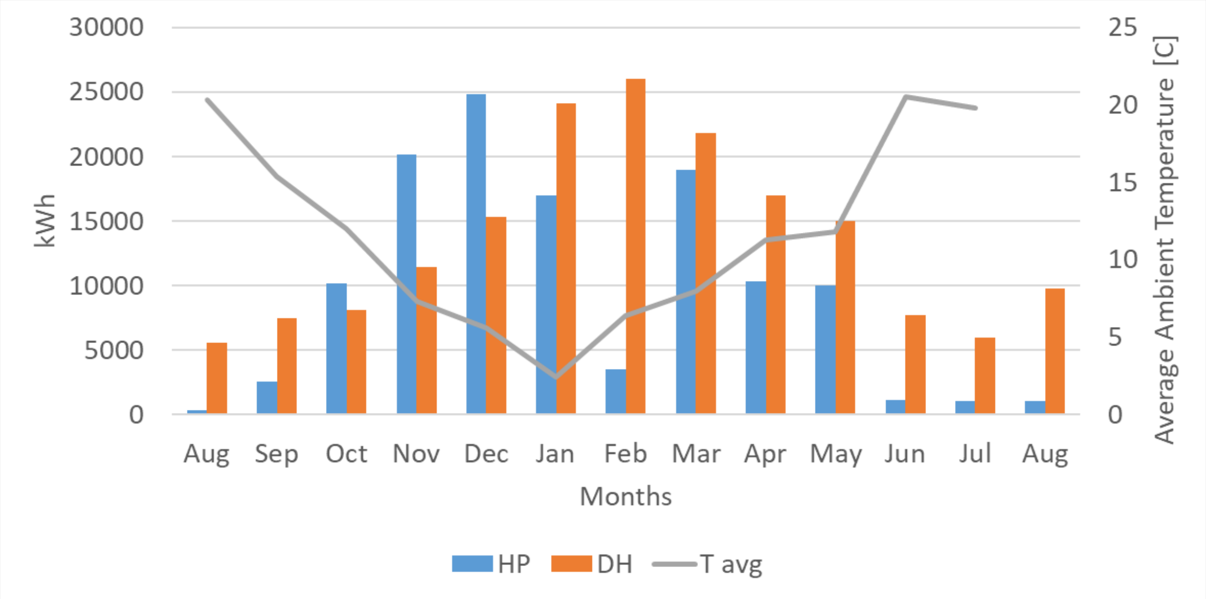


Figure 58 M1.1.5 Adam Stegerwaldstr. 16-26 (Cologne)

Table 82 KPIs evaluated for M1.1.5 Adam Stegerwaldstr. 16-26 (Cologne) – Type 1

KPI	value
1. average seasonal performance factor	2,41
2. amount of heat (kWh)	120855,8
3. amount of electricity (kWh)	47813,1
4. average flow temperature (°C)	49,4
5. average return temperature (°C)	46,1

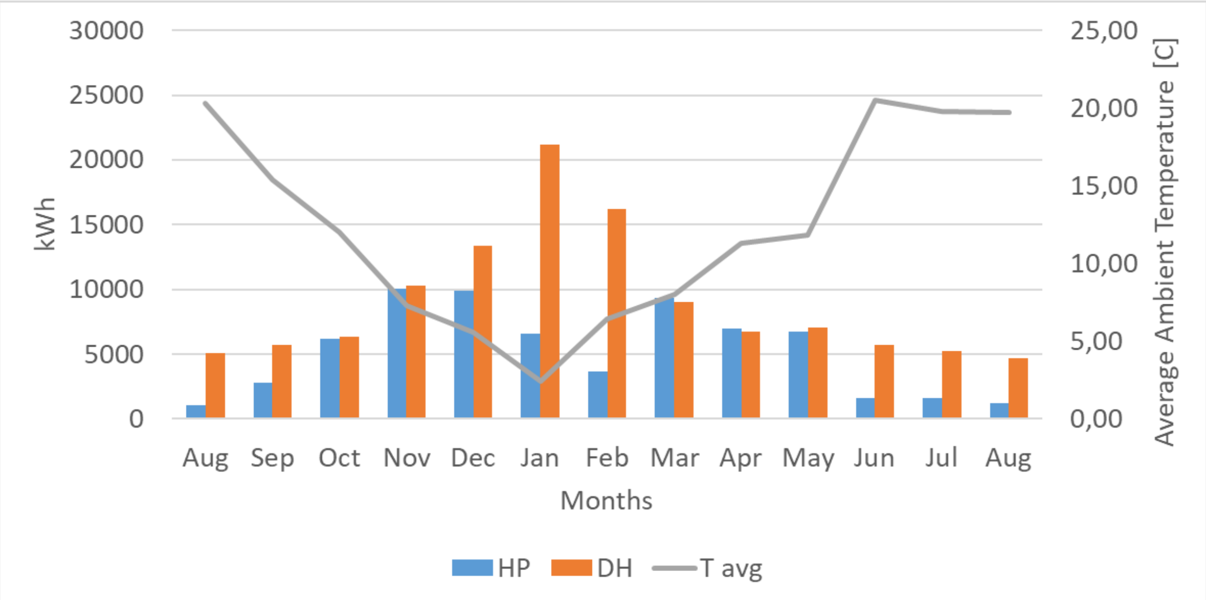


Figure 59 M1.1.5 Adam Stegerwaldstr. 19-25 (Cologne)

Table 83 KPIs evaluated for M1.1.5 Adam Stegerwaldstr. 19-25 (Cologne) – Type 3

KPI	value
1. average seasonal performance factor	2,82
2. amount of heat (kWh)	67469,4
3. amount of electricity (kWh)	24910,9

4. average flow temperature (°C)	49,5
5. average return temperature (°C)	47,1

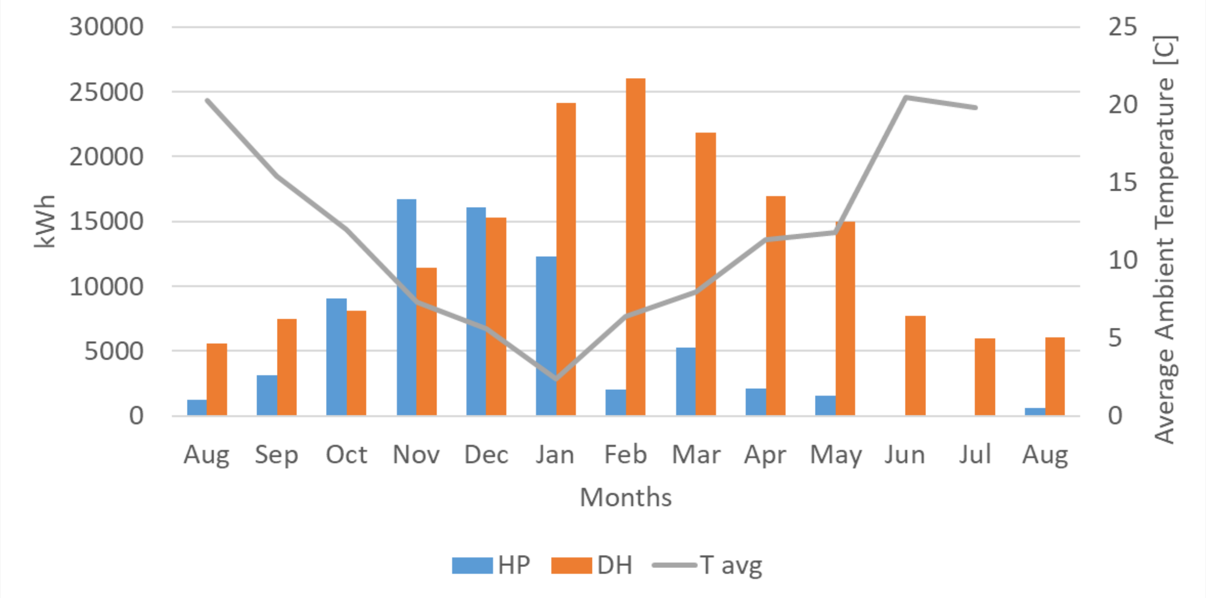


Figure 60 M1.1.5 Edith-Steinstr. 1-7 (Cologne)

Table 84 KPIs evaluated for M1.1.5 Edith-Steinstr. 1-7 (Cologne) – Type 1

KPI	value
1. average seasonal performance factor	2,05
2. amount of heat (kWh)	70122
3. amount of electricity (kWh)	28285
4. average flow temperature (°C)	50,7
5. average return temperature (°C)	46,9

Potential for full scale implementation

Technical, economic and social feasibility

The ventilation is used to dilute room air and transport away pollutants generated within the occupied space. Hence, the function of the ventilation system relies on the amount of provided air flow rate. It cannot be reduced below a certain level regulated by national legislation. Buildings may be ventilated in many different ways:

- Natural ventilation
- Mechanical ventilation
    - Exhaust system
    - Supply and exhaust systems.

In order to reduce the energy loss associated with the conditioning (i.e. heating) of the ventilation air, a heat recovery system may be fitted to the exhaust system. If the building is equipped with a supply system, it is convenient to simply fit a heat exchanger to transfer back the thermal energy from the exhaust air back into the supply air. If no supply system is installed, but only an exhaust system, a way to recover energy is to fit a heat pump to the exhaust system. The heat recovered from the heat pump may be used for various purposes in the building, i.e. DHW-production or space heating.

A heat pump uses significant amount of mechanical energy (in the compressor) to recover the heat. A heat exchanger, for the Supply and Exhaust system, on the other hand only uses fan power associated with the pressure loss of the heat exchanger as additional mechanical energy. The mechanical energy required of a heat pump may be estimated in several ways, the easiest is perhaps to Measure the provided mechanical work in relation to the recovered energy.

As a heat pumps is a thermodynamic cycle, the supplied energy to the cycle adds up to the amount of energy leaving the system, i.e. the first law of thermodynamics for a system. Hence, the energy balance of the heat pump is

$$\dot{Q}_1 = \sum \dot{E}_{el} - \dot{Q}_{rec}$$

where $\dot{Q}_1$ is the thermal power dissipated from the hot side of the heat pump, $\dot{E}_{el}$ is the electrical power provided to the heat pumps, and $\dot{Q}_{rec}$ is the recovered energy in the ventilation system.

The ventilation losses, without the heat pump, will be

$$\dot{Q}_{loss} = \rho \cdot \dot{V} \cdot c_p \cdot (t_{RA} - t_{OA})$$

where t_{RA} is the temperature in the return air from the rooms, t_{OA} is the outside air temperature. After the installation of the heat pump, the ventilation losses will be

$$\dot{Q}_{loss} - \dot{Q}_{rec} = \rho \cdot \dot{V} \cdot c_p \cdot (t_{EA} - t_{OA})$$

where t_{EA} is the temperature of the exhaust air from the building, after the heat pump. Hence, the recovered heat will be

$$\dot{Q}_{rec} = \rho \cdot \dot{V} \cdot c_p \cdot (t_{RA} - t_{EA})$$

Hence, the effectiveness of the recovery will be

$$\epsilon_{HP_{rec}} = \frac{\dot{Q}_{rec}}{\sum \dot{E}_{el}}$$

which will be the instantaneous coefficient of performance of the recovery, COP. Often the annual effectiveness is of more interest. As the effectiveness of the recovery system does not seem to depend on the outdoor air temperature (return and exhaust air temperatures), measurement of a shorter time period than a year will provide an adequate estimation of the annual effectiveness as well, assuming the compressor is not fitted with speed control.

The economic feasibility will depend on the energy saving compared to the driving cost, hence the ratio between electricity and thermal heat is important for this Measure. The investment cost of the heat pump should also be taken into account.

A separate consideration is the feasibility of reducing the temperature of the exhaust air to temperatures well below the ambient. This will result in a very low evaporation temperature, and thereby in a lower COP than if a higher outlet temperature was accepted. This solution gives a higher capacity but a lower COP than a more conventional exhaust air heat pump. In general, an alternative could be to use both exhaust air and ambient air as heat source, in order to keep the evaporation temperature at a higher level.
The social impact of using heat pumps could be decreased energy bills. The system will for most parts be installed outside the apartments, which does mean little impact on the tenants. During installation, there might be shorter periods with no or little ventilation, with the risk of poor indoor air quality unless actions is taken for mitigating this. Disturbing noise from heat pumps is another possible social impact. In Stockholm, the heat pumps are installed on the roofs and should not possibly be a disturbance. In Cologne, the heat pumps are located in separate shelters in between the buildings.

Upscaling and replicability of the Measure: general considerations

This Measure is applicable to all cities. For warm climates with limited space heating need, the heat pump ventilation recovery system may be used for DHW production. Also, this Measure is easily upscalable, as long as the building is or may be fitted with an exhaust ventilation system.

Upscaling of the Measure in Stockholm

This measure concerns the installation of a heat pump to recover losses in the ventilation air expelled from the building. This measure will typically work for buildings having mechanical exhaust ventilation systems, with or without mechanical supply systems. These buildings have been identified in the energy declaration database of Stockholm, not including the ones already having heat recovery.

The installed heat pump in Stockholm will decrease the exhaust ventilation air down to $1\,°C$, at a $COP_1 = 3.66$, as reported by the responsible partner. In this case the degree hour method may not be used, as the utilization of heat from the heat pump needs to be to accounted for[14]. As for the degree hour method, it has been assumed that no space or ventilation heating is required if the outdoor temperature is above $17\,°C$, only DHW heating.

To determine the effect of a general introduction of exhaust air heat pumps, the following calculations are done.

The obtained cooling of the exhaust air is first determined as:

$$\dot{Q}_2 = \rho \cdot A_{temp} \cdot q_v \cdot c_p \cdot (t_{RA} - t_{EA})$$

Where t_{RA} is the room return air temperature ($\approx 22°C$) and t_{EA} is the exhaust air temperature after the heat pump ($\approx 1°C$). The specific ventilation flow rate requirements in Sweden is $q_v = 0.35 \frac{l}{s \cdot m^2}$, and a measurement campaign has shown that for multifamily buildings the actual ventilation is slightly higher $\left(\approx 0.38 \frac{l}{s \cdot m^2}\right)$[15]. A_{temp} is the total heated floor area for which this measure is possible to implement. This, instead, corresponds to a possible heat recovery of $8.8 \frac{W}{m^2}$. The corresponding heat pump electrical requirement is estimated as

$$\dot{E}_t = \frac{\dot{Q}_2}{COP_1 - 1}$$

corresponding to $3.3 \frac{W}{m^2}$. The supplied heat from the heat pump will be estimated as

$$\dot{Q}_1 = \frac{\dot{Q}_2}{COP_1 - 1} \cdot COP_1$$

and corresponds to $12.1 \frac{W}{m^2}$. The ratio between the theoretically recovered heat from the heat pump and the annual ventilation losses will be

$$\frac{\int_{1yr} \dot{Q}_2 d\tau}{\int_{1yr} \dot{Q}_{vent} d\tau}$$

where the ventilation losses are estimated as

$$\dot{Q}_{vent} = \rho \cdot A_{temp} \cdot q_v \cdot c_p \cdot (t_{RA} - t_{OA})$$

The ratio of these are $140\,\%$, indicating that the heat pump, theoretically, can recover more heat from the exhaust air than what is required for heating the corresponding supply ventilation air. The reason for this is of course that the exhaust air temperature is lower than the outdoor air temperature for many hours of the year. If, Instead, the energy recovered,

- [14] What this means is that the heat pump may be too large compared to the required heat in the building for any given hour of the year.
- [15] ELIB rapport nr 37, TN30.

upgraded, and supplied to the building[16] is compared to the actual ventilation losses, the ratio will be 175 %.

However, these are merely theoretical numbers, as they do not account for the actual need of heat in the buildings. For this purpose, two scenarios are considered;

1. The heat pump only delivers heat to DHW, and only within the demand of DHW.
2. The heat pump delivers heat to space heating, ventilation heating, and DHW, if demand of any exists.

For the first scenario, it has been assumed that there exist a thermal storage to compensate for the continuous heat available on the return ventilation air and the intermittency of the need of DWH. It has been assumed that the standard apartment in Sweden is $68\,m^2$ and occupied by 1.86 persons.

It has been established that the annual hot water consumption in apartments in Sweden may be estimated as

$$V_{DHW} = \frac{12\,m^3}{apartment} + \frac{18\,m^3}{person}$$

This corresponds, using the “standard apartment” above, to an expected annual DHW consumption per heated floor area of

$$V_{DHW} = 0.67\frac{m^3}{m^2}$$

It was assumed that the temperature of the supplied DHW is $55\,°C$ and the average incoming city water is $8\,°C$. Doing so, the expected annual energy use for heating DHW in the city of Stockholm would be expected to correspond to $580\,GWh$. The available annual heat from the heat pumps corresponds to $1.70\,TWh$. Hence, only 34 % of the available heat may be utilized, making this a poor option.

A much better option, the second scenario, would be to utilize the recovered heat into the overall heating system of the building, providing heat to space heating, ventilation heating, and DHW, whenever possible. In order to be able to estimate the utilization, the heat requirement for each hour is required. Accounting only for buildings for which this measure is possible to implement, the total heating requirements for these buildings are obtained from the energy declaration database. Buildings with only exhaust ventilation system installed, the annual heating specific energy need corresponds to $131.8\frac{kWh}{m^2}$ and to $130.9\frac{kWh}{m^2}$ for buildings with supply and exhaust systems. Buildings with heat recovery already installed has been excluded from the analysis. The corresponding annual heating need for these buildings is then estimated to be $2.1\,TWh$. Subtracting the expected ventilation loss and energy use for DHW, the remaining heat will be lost through the envelope of the building ($Q_{TR} = 915\,GWh$). Hence, using the degree concept, and estimating of the loss coefficient for transmission loss may be estimated $\left(UA_{env} = 10\frac{MW}{K}\right)$. Once this is estimated, the hourly load of all buildings relevant for this measure may be estimated, most conveniently displayed with an energy signature. Comparing the available heat from the heat pump, and only using as much as is needed for any given hour, will provide an estimate of the total usefulness of the exhaust ventilation air heat pumps. Both of these load profiles are displayed in the same energy signature in Figure 61.

- [16] Only considering hours when space heating or ventilation heating are required, i.e. $t_{OA} < 17\,°C$.

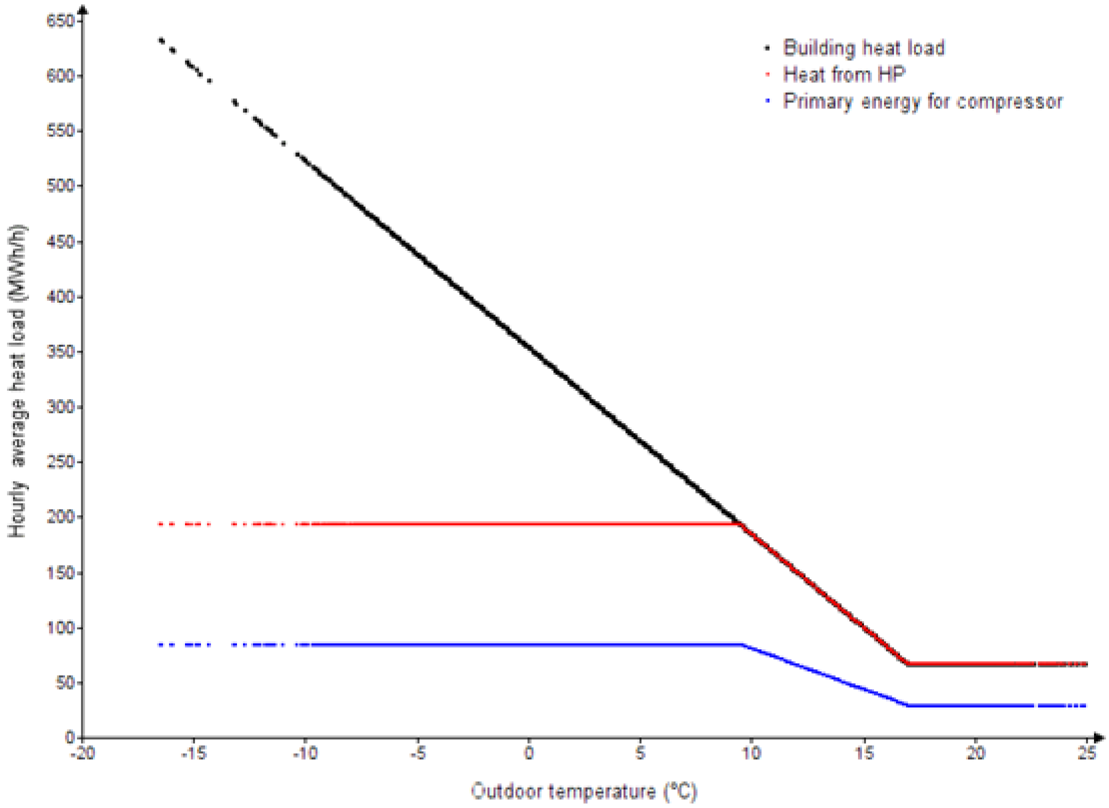


Figure 61 Energy signature for F and FT systems in Stockholm, not having heat recovery installed

The decrease of externally provided thermal heat will correspond to $1.43\ TWh$, which may be compared to the total annual heating need $(2.12\ TWh)$, being almost $67\ \%$ saving. The recovery from the heat pumps comes with an increase of electrical consumption, reaching almost $390\ GWh$. Since the Primary Energy Index for electricity in Sweden is 1.6, the primary energy increase due electricity will be $625\ GWh$. As the corresponding primary factor for district heating is 1, the reduction of Primary Energy associated with this measure will be $800\ GWh$. Hence, if that is compared to the total initial heating needs of these buildings $(2.12\ TWh)$, the reduction of primary energy corresponds to $38\ \%$.

M1.1.6 - New adaptive control and techniques for heating systems

Introduction

Indoor temperature sensors have been used to feedback information to the heating/cooling and ventilation control system. It is a system that adapts to the individual building's dynamics and responds to weather conditions. Hence, it provides heating/ cooling more efficiently compared to traditional systems which only use outdoor ambient temperature as the sole parameter.

As stated in the evaluation plan (D5.1), the intention of the Measure is to demonstrate the implementation of better control of the supplied heating and cooling to the building potentially decreasing overheating and undercooling the buildings.

In particular, the baseline has been determined by:
1. Establishing energy consumption for heating and cooling (kWh/m²) during one year, normalized to a typical climatic year, without the adaptive control algorithm engaged.
2. Determining climatic conditions, i.e. dry-bulb air temperature (˚C), humidity (-), wind speed (m/s), wind directions (˚), direct beam (normal) solar radiation (W/m²), global radiation on horizontal surface (W/m²), diffuse radiation on horizontal surface (W/m²), total cloud cover (Octas).

The key performance indicators evaluated are:
1. Saving of heat energy required (kWh/year) normalized by energy required without the Measure implemented.
2. Saving of cooling energy required (kWh/year) normalized by energy required without the Measure implemented.

Stockholm

Industry partner	Contact person	Validation partner
L&T FM AB	Peter Anderson	KTH-EGI

House 8H

An Adaptive control system was installed to complement the existing control system. The adaptive system takes into consideration the indoor temperature together with the outdoor temperature. This enabling the system to use the buildings inertia including solar radiation and other activity in the house giving a higher indoor temperature. Hence, it provides heating/ cooling more efficiently compared to traditional systems which only use outdoor ambient temperature as sole parameter.

The winter 2018 was the first winter where complete results were obtained.

The energy data is followed on hourly values measured with monthly values. The base line is set for 2015. The year 2017 and 2018 was other optimization task executed such as lowering temperature in stairways etc. This is leaving the Adaptive control system ready for alternately running 14 days on 14 days off during spring 2019.

The diagram in Figure 62 below shows an example of the monitored system:
- Design (set point) supply temperature

- Supply temperature required by the adaptive system,
- Average indoor temp based in selected reference indoor temperature sensors
- Outdoor temperature.
- Difference between the set-point and adjusted supply temperature (grey field)

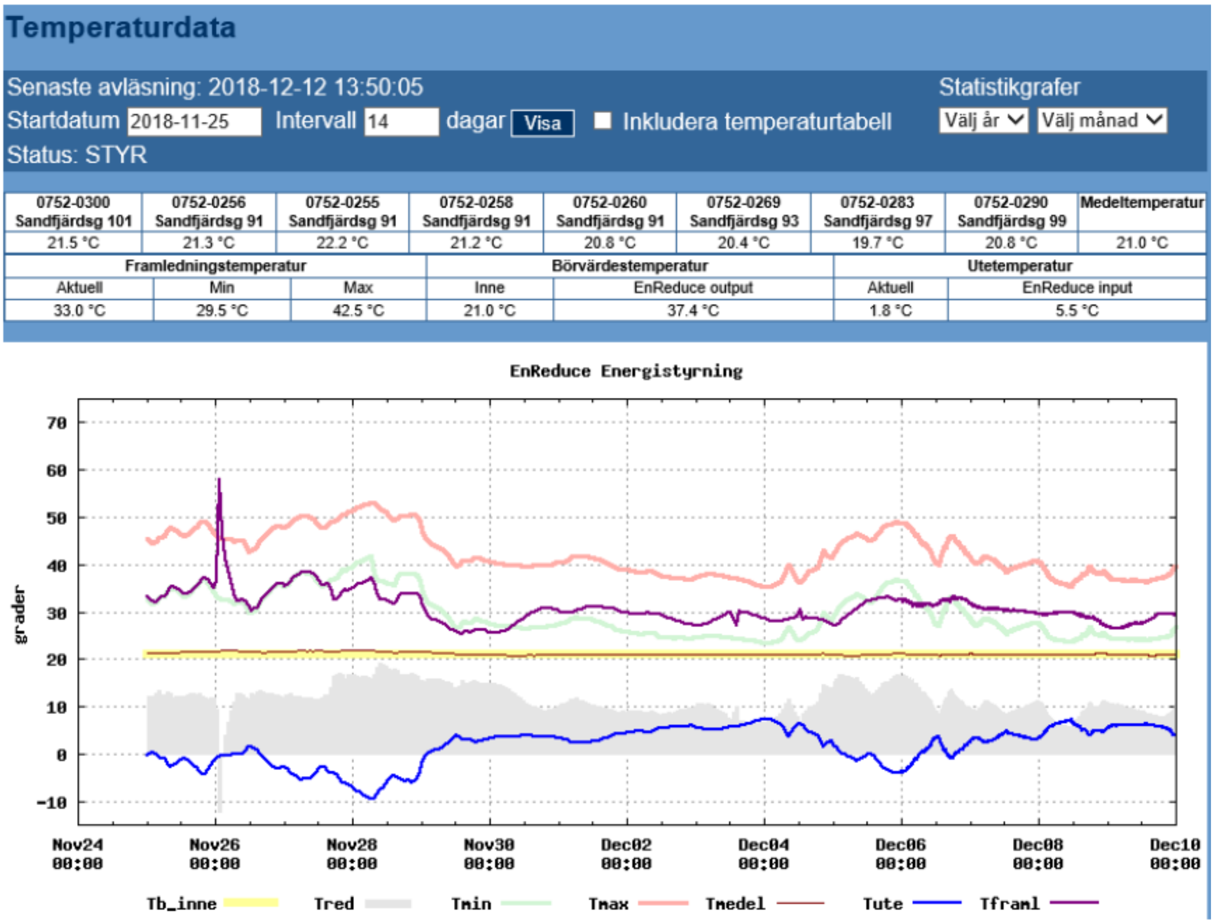


Figure 62 House 8H, example of the monitored system (M1.0 Stockholm)

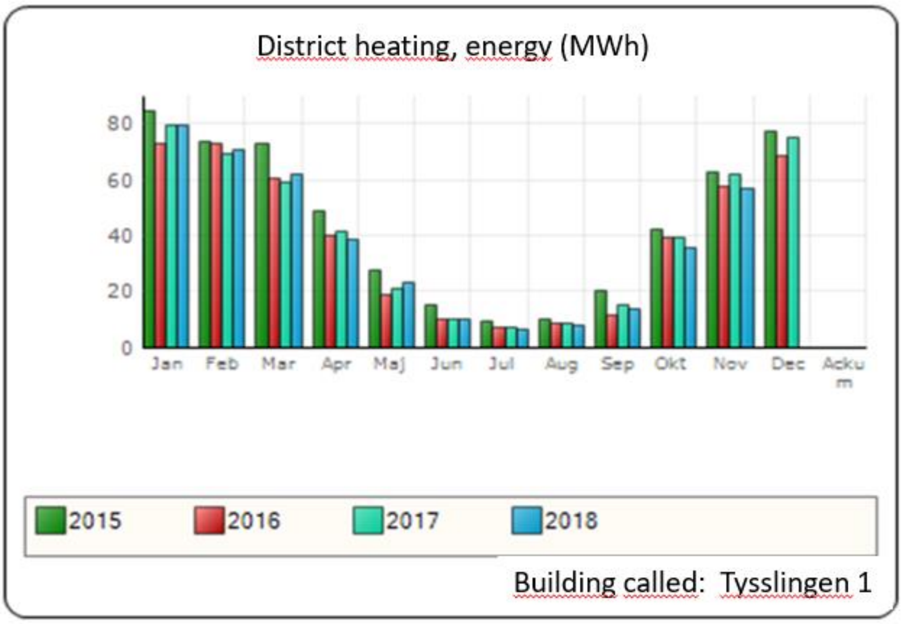


Figure 63

Figure 63 shows an extract from a selected period. Acording to the test were the system during a period was shut sown, we saw that the energy saving potential for this Adaptive Control System was 6-8% of the total savings of district Heating.

The results after winter season 2018 shows about -10% energy savings related to the adaptive heat control Measure.

Table 85 KPIs evaluated for M1.1.6 House 8H (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Heating energy required (kWh/year) normalized by energy required without the measure implemented.	See M1.0	See M1.0	See M1.0
2. Cooling energy required (kWh/year) normalized by energy required without the measure implemented	-	-	-

Slaughterhouse

Due to problems in the data monitoring and communications the measurements are continuously monitored only from late 2018.

The monitored variables are the same as in House 8H. Also in this case, the estimated energy saving is overall around 10%.

Table 86 KPIs evaluated for M1.1.6 Slaughterhouse (Stockholm)

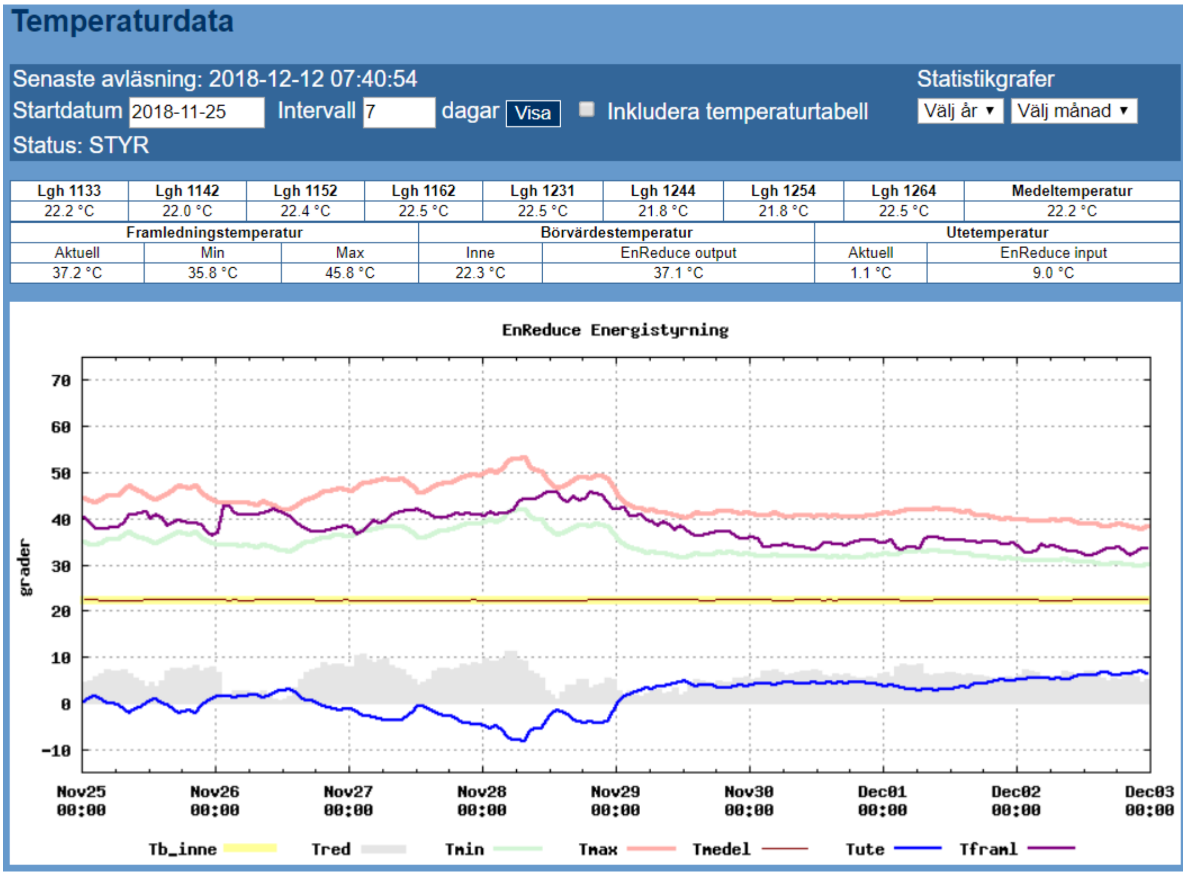
KPI	Baseline	Post- retrofitting	Variation
1. Heating energy required (kWh/year) normalized by energy required without the measure implemented.	See M1.0	See M1.0	See M1.0
2. Cooling energy required (kWh/year) normalized by energy required without the measure implemented	-	-	-

Årstakrönet

Similarly to House 8H, Figure 64 shows an example of the hourly data available for Årstakrönet. The results after winter 2018 confirms the level of energy savings related to adaptive control of about 10%.

Table 87 KPIs evaluated for M1.1.6 Årstakrönet (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Heating energy required (kWh/year) normalized by energy required without the measure implemented.	547 911	487 502	-11 %
2. Cooling energy required (kWh/year) normalized by energy required without the measure implemented	-	-	-



Lgh 1133	Lgh 1142	Lgh 1152	Lgh 1162	Lgh 1231	Lgh 1244	Lgh 1254	Lgh 1264	Medeltemperatur
22.2 °C	22.0 °C	22.4 °C	22.5 °C	22.5 °C	21.8 °C	21.8 °C	22.5 °C	22.2 °C

Framledningstemperatur			Börvärdestemperatur		Utetemperatur	
Aktuell	Min	Max	Inne	EnReduce output	Aktuell	EnReduce input
37.2 °C	35.8 °C	45.8 °C	22.3 °C	37.1 °C	1.1 °C	9.0 °C

Figure 64

Further analysis was carried out by alternately running during spring 2019. The result indicates a potential saving between 6-8% of energy used for heating.

Potential for full scale implementation

Technical, economic and social feasibility

The technical feasibility of this Measure is high. Better temperature control of indoor climate is becoming realizable through the ongoing digitalization of society, allowing e.g. information about weather forecasts to be utilized as part of the control at low costs. Also, the cost of sensors, and the infrastructure to transfer the sensor signals is constantly decreasing. It can therefore be expected that the indoor climate in the future can be better adapted to the specific needs, both reducing the cost of climatization (by avoiding overheating/undercooling) and the quality of the indoor climate. The level of detail that are controlled may vary and be adopted to the actual installed system. However, better performance is expected to involve more aspects of the buildings energy systems that can be controlled. In the simplest form the entire building systems is adaptably controlled by for instance outdoor air temperature and solar radiation. On the other hand, each room may be adaptably controlled using many indoor and outdoor sensors together with a learning algorithm to capture and be proactive on anticipated conditions rather than reacting on actual conditions.

The evaluation of this Measure is done in a sequential manner, trying to capture the various season in order to identify the differences between seasons. In this way both the base line and the performance of the installed Measure are captured at the same time, at the similar ambient conditions.

The economic feasibility will be two-fold, decreased energy consumptions and increased comfort. Increased comfort will tend to make the building more attractive for the tenants.

Upscaling and replicability of the Measure

The Measure may be installed in any city; the benefits will be similar regardless of the cold or warm climate. The Measure may be implemented in any building which allow automatic control of the building's central heating system. Depending on the existing infrastructure, the cost may be substantial for buildings not having sufficiently adapted energy system in place.

M1.1.7 - Energy quality assurance

Introduction

Using an energy supervisor for all parts influencing energy performance during the whole building construction phase is a new way of optimizing the building performance, usually referred to as Integral Design.

According to the evaluation plan (D5.1), the intention of the Measure was to show:
1. By involvement of all key actors early in the design phase, evaluating all possible alternatives, the most energy efficient design can be identified.
2. The energy quality manager is responsible to ensure that changes from design are assessed from an energy efficiency point of view.
3. Experience indicate that the cost of a building does not have to be higher by implementing energy efficient technology and solutions, if the whole processes are initially well thought through.

Stockholm

Industry partner	Contact person	Validation partner
L&T FM AB	Peter Anderson	KTH-EGI

Valla Torg

The main purpose of M1.1.7 is to coordinate a project from an energy point of view, from start to finish of a building construction. This with a focus at coordinating the work involving Energy that will avoid gaps in this process. Gaps that earlier lead to raised energy use and higher cost. By involving a person with responsibility as/for Energy Quality Assurance the question is put on the agenda at every meeting.

During the first years with tenants it should be ensured that the calculated values of e.g. energy use are in agreement with the actual values.

Based on earlier experiences, errors during planning and construction have been shown to lead to 10-20 % extra energy consumption. The result of this role in GrowSmarter is positive and accepted by all involved parties.

By nominating an exclusive Energy Coordinator to follow the project from planning phase through construction/refurbishment phase until finished installation, gaps related to different phases and staff transitions are avoided. Information is normally not transferred between the phases.

Figure 65 shows the conceptual scheme followed in GrowSmarter.

The role serves as an advisory role to the Project Manager but is not responsible for decision making. The Energy Coordinator ensures that the right techniques are chosen and put forward in the projection phase. The Energy Coordinator also ensures that the techniques are used optimally once the building process is concluded.

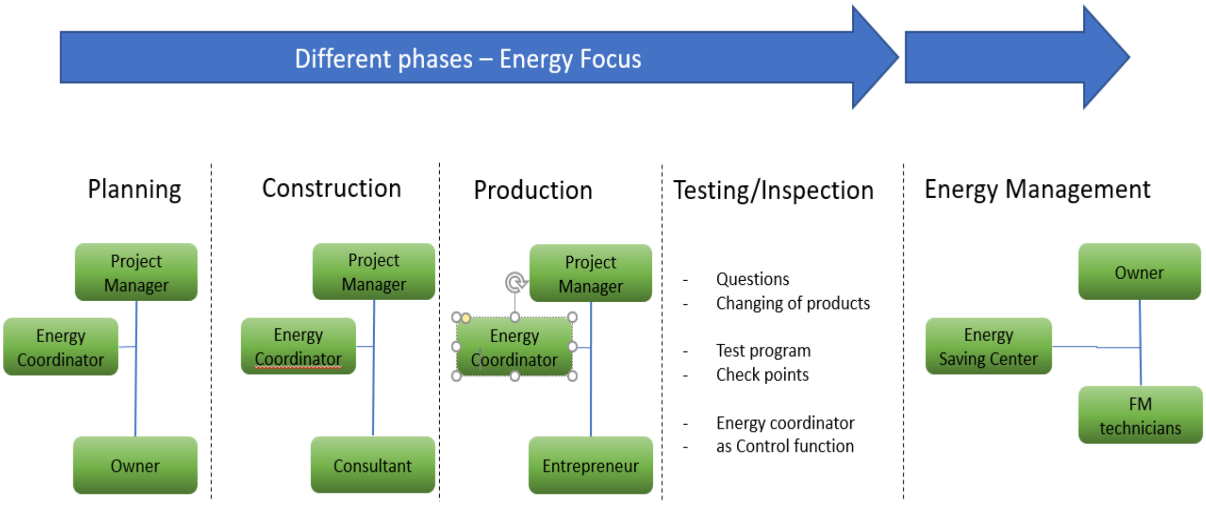


Figure 65

L&T had the role of Energy coordinator, following the building process from its initial planning to through implementation phase, focusing on energy savings. The Energy Coordinator ensures that installed products are individually tested to ensure that they are operating efficiently.

By implementing this process alongside the Energy Saving Center, it is possible to ensure that the calculated energy use matches actual use in the end of the project and most of all also during the coming years.

Potential for full scale implementation

Technical, economic and social feasibility

In general, implementation of this Measure should include a detailed economic analysis during the lifetime of the building. It should therefore be expected to be economically as well as technically feasible. Integral design tends to facilitate better building process. Since the sole purpose is to early in a project phase identify pitfalls and best options, savings is to be made at a later stage in the building process but also during the using phase of the building. Hence, the technical feasibility of this Measure is good, as the only thing that is changed is essentially the work process. As this Measure involves the construction process it is difficult to see any social implications apart from the better indoor climate and lower costs which could be the expected result with higher quality of the design process. Overall, the social feasibility can be considered good, as the process leads to better constructed buildings, with less issues and may lead to e.g. better indoor comfort and quality, less problems with correctional works.

Upscaling and replicability of the Measure

This Measure could directly be applied to any new development project in all parts of Europe. Any positive result from the GrowSmarter project should be possible to apply in other projects. However, the possible gains will depend largely on the competence of experts involved. The accuracy of the predictions can therefore not be expected to be high.

M1.1.8 - Air tightness

Introduction

Testing air tightness is not a Measure in itself, but a method to ensure the quality of the refurbishment. Part of the buildings have been tested in order to secure the quality of Measures implemented to the climate shield. This is not common practice to apply on large scale or in a renovation context but can be of great importance in a climate with a fairly long heating season.

According to the evaluation plan (D5.1), the intension of this action was the reduction of energy use for heating and cooling by reducing infiltration over the climate envelope with an increase IEQ (Indoor Environmental Quality) by decrease risk of draught.

In particular, the baseline was determined by measuring the infiltration flow rate ($m^3/s{\cdot}m^2$ envelope area) at 50 Pa pressure difference.

The key performance indicators evaluated are:
1. Infiltration flow rate ($m^3/s{\cdot}m^2$ envelope area) at 50 Pa.
2. Infiltration losses (cooling and heating) (kWh/m^2 floor area).
3. Reduction of energy use compared to baseline (kWh/m^2 floor area).

Stockholm

Industry partner	Contact person	Validation partner
L&T FM AB	Peter Anderson	KTH-EGI

As already described in M1.1.1, a campaign has been carried out to test the air leakage in the buildings involved in GrowSmarter.

Figure 66 shows an example of air leakage results obtained in one dwelling of Valla Torg.

Table 88 KPIs evaluated for M1.1.8 House 6F (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
Infiltration flow rate ($m^3/s{\cdot}m^2$ envelope area) at 50 Pa.	See M1.1.1	See M1.1.1	See M1.1.1
Infiltration losses (cooling and heating) (kWh/m^2 floor area).	See “Potential for full scale implementation”		
Reduction of energy use compared to baseline (kWh/m^2 floor area).	See “Potential for full scale implementation”		

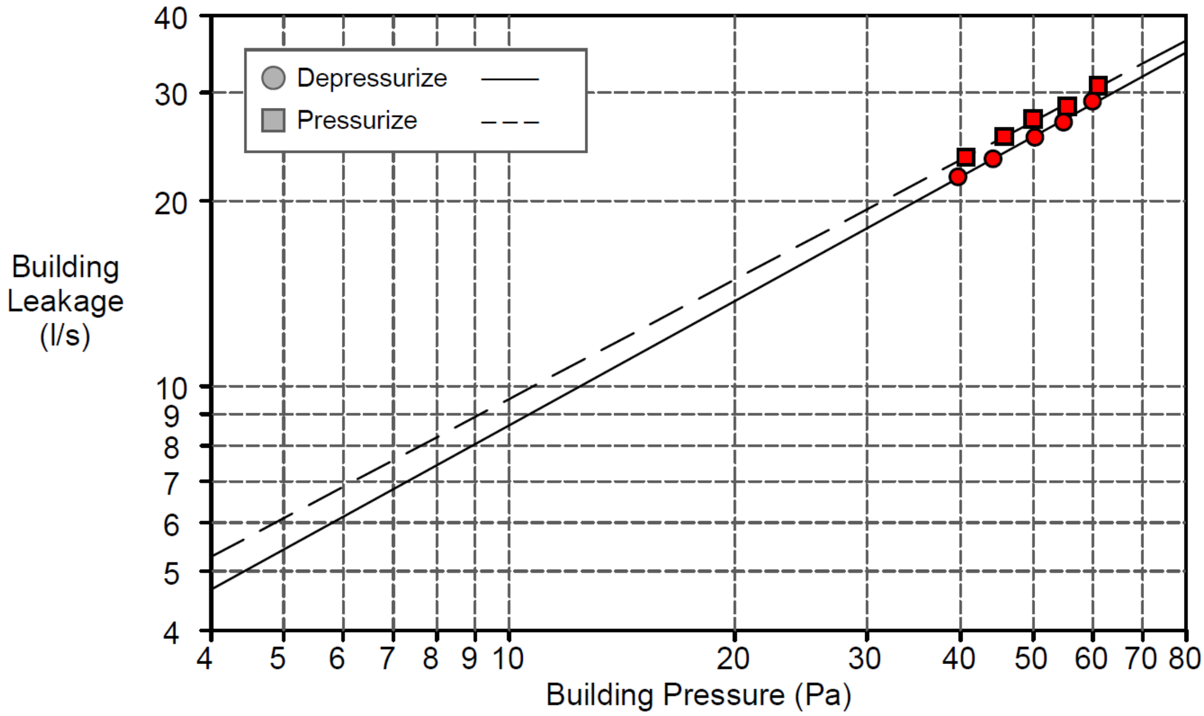


Figure 66 Example of Air-leakage test in Valla Torg, dwelling 168, House 6F.

Cologne

Industry partner	Contact person	Validation partner
Dewog	André Esser (Dewog)	KTH-EGI

The measurements for air tightness have been carried out in 4 buildings. When measuring the air tightness according to DIN EN 13829 (method B), the requirements for air tightness according to the Energy Saving Ordinance 2014 have been fulfilled.

All intentionally existing external openings of the building or part of the building to be examined are closed (windows, doors, chimney draught).

To comply with the method B procedure (building envelope), all adjustable openings are closed and all other intentionally present openings must be sealed. Heat generators with room air connections are switched off. Ash is removed from open fireplaces. Mechanical ventilation and air conditioning systems are switched off.

Some details of the Measure implementation have been already mentioned in M1.1.1. Table 90 shows an example of the results obtained from the test in one of the dwellings.

According to the Energy Saving Ordinance (2014), the air exchange rate at 50 Pa in buildings without ventilation systems should not exceed the value n50 of 3 [1/h]. With an average value of 1 [1/h], in Edith-Stein-Str.5, the reference threshold is not overcome.

In Adam-Stegerwaldstr. 22 the measured value is 1.5. Adam-Stegerwaldstr. 21 a value of 2.9. In Edith-Stein-Str.2 a value of 1.3.

Table 89 KPIs evaluated for M1.1.8 in Cologne

KPI	Baseline	Post- retrofitting	Variation
Infiltration flow rate (m³/s·m² envelope area) at 50 Pa.	See M1.1.1	See M1.1.1	See M1.1.1
Infiltration losses (cooling and heating) (kWh/m² floor area).	See "Potential for full scale implementation"		
Reduction of energy use compared to baseline (kWh/m² floor area).	See "Potential for full scale implementation"		

Table 90 Example of air tightness measurement, Edith-Stein-Str.5

Adam-Stegerwald-Str. 21 Typ III

negative pressure				
	Δp_{01+}	Δp_{01-}	Δp_{02+}	Δp_{02-}
		(-)4,6 Pa		(-)4,8

reducing orifice	building pressure [Pa]	blower pressure [Pa]	building pressure [Pa]	volumetric flow [m^3/h]
	Δpm		Δp	Vr
Δp_{01}	(-)4,6			
C	(-)50	275	(-)45	350
C	(-)40	209	(-)35	303
C	(-)35	171	(-)30	274
C	(-)27	124	(-)22	232
C	(-)19	77	(-)14	181
C	(-)14	46	(-)9	139
D	(-)10	66	(-)5	101
Δp_{02}	(-)4,8			

overpressure				
	Δp_{01+}	Δp_{01-}	Δp_{02+}	Δp_{02-}
		(-)4,8 Pa		(-)4,7 Pa

Results				
	V_{50}	insecurity	n_{50}	
	[m^3/h]	[%]	**[1/h]**	
negative pressure	172	(+/-) 7%	**2,7**	
overpressure	195	(+/-) 7%	**3**	
average	184	(+/-) 7%	**2,9**	

Potential for full scale implementation

Technical, economic and social feasibility

Testing air tightness does not by itself enable any savings, unless a correction clause comes into effect. Measurement of air tightness is a way to ensure the quality of the refurbishment of a building. If construction companies involved are aware of the requirement for air tightness, it can be expected that the quality of the refurbishment will increase.

It is well known that air tightness has been considered much more important in northern Europe, where the heating seasons are long, than in the south. Air tightness does affect both energy performance as well as perceived indoor climate. With increasing demands on indoor climate also in the south the energy losses through infiltration will increase both during the heating and the cooling seasons. The technical and economic aspects of this Measure will be depended on if correction Measures are forced into play, as well as the ventilation system configuration. Social impact is related to the perceived indoor climate and air quality.

Applicability of the Measure to different cities

This Measure may be implemented for any city. Tests of air tightness can easily be implemented at any scale and in any part of Europe.

Upscaling of the Measure in Stockholm

Airtightness Measure M1.1.18 is a complementary Mesure of M1.1.1. Care needs to be taken so that the desired ventilation is not obstructed with this measure. Hence, for consideration for upscaling, we considered only buildings within Stockholm city having mechanical ventilation, as natural ventilation relies upon air flow over the envelope. In addition, exhaust only ventilation also rely upon air movement over the envelope, however normally dedicated openings are provided.

The climatic data used are according to SVEBYs data for energy simulations in buildings (degree hours: $89\,458\ K \cdot hr$). The specific energy use and floor area for each ventilation type was retrieved from the energy declaration database. Again, building with natural ventilation was excluded from the analysis. In order to being able to estimate the saving of decreased leakages in buildings, the existing air tightness for typical buildings are required. These have been retrieved from an earlier Swedish investigation[17]. The airtightness of Swedish buildings are sorted in 4 original built year ranges, before 1941, between 1941 and 1960, between 1961 and 1975, and between 1976 and 1988. The corresponding floor area of these age ranges was retrieved from the energy declaration database. Then a floor area weighted area of the air tightness was determined as:

$$ACH_{50Pa} = \frac{4.96}{hr}.$$

The floor area averaged air tightness was then applied, using the floor distribution of the different ventilation systems installed, to estimate the leakage air flow rate according to EN ISO 13789:2007, as:

$$\dot{V}_{x_{old}} = \frac{V \cdot ACH_{50Pa} \cdot e}{1 + \frac{f}{e} \cdot \left(\frac{\dot{V}_1 - \dot{V}_2}{V \cdot ACH_{50Pa}} \right)}$$

In Valla Torg, Stockholm, the GrowSmarter project has found that the airtightness was decreased with $\xi = 62\,\%$. Hence, the new expected air leakage flow rate may be expected to be:

$$\dot{V}_{x_{new}} = \frac{V \cdot \xi \cdot ACH_{50Pa} \cdot e}{1 + \frac{f}{e} \cdot \left(\frac{\dot{V}_1 - \dot{V}_2}{V \cdot \xi \cdot ACH_{50Pa}} \right)}$$

$\dot{V}_1$ and $\dot{V}_2$ are supply air flow rate (if supply fan is fitted) and exhaust air flow rate. For a balanced system, it was assumed that these two are identical, meaning that infiltration and exfiltration flow rates also will be equal. Employing the degree hour concept indicate that the energy loss due to air leakages will decrease with $74\,\%$, and relating the saving to the total heating energy (of all multifamily houses) in Stockholm city will yield a $2.1\,\%$ saving.

- [1717] Kronvall J., Boman C.A. (1993): Energy impact of ventilation and air infiltration 14th AIVC conference, Copenhagen, Denmark 21, as referred to in: Classification of buildings with regard to airtightness, Yanke Zou, Chalmers, Master of Science Thesis, 2010:131.

M1.1.9 - Efficient lighting

Introduction

By implementing modern light sources, primarily LED, and control of lighting, a significant amount of electric energy can be saved. As a part of this Measure, the lighting in elevators in the buildings in Cologne will be controlled efficiently. These lights would, if they are on at all times, consume as much electricity as the elevator motor. The elevator motor will also be controlled efficiently. LED lighting will be used in staircases and other common spaces and energy efficient appliances will be installed in common laundry rooms.

As stated in the evaluation plan (D5.1), this Measure aims at reducing the electricity demand by implementing smart new systems for the property electrical system

In particular, the baseline is expected to be determined by:
1. Measuring property electricity consumption (kWh/m^2) for a year.
2. Measuring lighting intensity, illuminance (lux) before and after change of light sources in order to ensure that the savings is not due to reductions in illumination.

The key performance indicators to be evaluated are:
1. Lighting intensity (lux)
2. Annual electric energy use (kWh/m^2).
3. Reduction of electrical consumption related to baseline.

Stockholm

Industry partner	Contact person	Validation partner
Skanska	Harry Matero	KTH-EGI

House 7G, House 8H

In the scope of M1.1.9, all luminaires in the public areas have been replaced with low-energy lighting. The luminaires also have presence detection and improved control.

The evaluation has been carried out by measuring the energy consumption for the building before and after the renovation.

Worth noticing, when replacing the luminaires, it is always beneficial to switch to an energy-saving product. The price difference compared to standard installations is negligible. In particular, the maintenance costs in the long term are reduced.

Overall, the estimated energy saving from M1.1.9 is over 70%. The measurement results are presented in Table 92 and Table 94

Table 91 KPIs evaluated for M1.1.9 House 7G (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Lighting intensity (lx)	See Table 92		
2. Annual electric energy use (kWh/m2).	See M1.0	See M1.0	See M1.0
3. Electricity consumption	15963 kWh	3059 kWh	-81 %

Table 92 Light intensity and installed power for M1.1.9 House 7G (Stockholm)

Installation	Operation time variation	Energy use baseline	Energy use Post-retrofitting	Energy use variation %
Basement	-85%	3682 kWh	552 kWh	-85%
Stairwell	-85%	3156 kWh	473 kWh	-85%
Entrance	-65%	1052 kWh	368 kWh	-65%
Stairwell	-80%	5435 kWh	1087 kWh	-80%
Laundry	-80%	1052 kWh	210 kWh	-80%
Storage rooms	-85%	1403 kWh	210 kWh	-85%
Emergency lighting	0 %	158 kWh	158 kWh	0%

Installation	Lux baseline	Lux post
Entrance hall to the elevator	70 lx	180 lx
Entrance hall outside the elevator door	120 lx	200 lx
Room for mailboxes	210 lx	800 lx
Passage to stairwell next to luminaire	140 lx	250 lx
Passage to stairwell between luminaires	90 lx	150 lx
Stairwell next to luminaire	100 lx	200 lx
Stairwell between floors	20 lx	35 lx
Stairwell floor level next to luminaire	110 lx	300 lx
Stairwell floor between luminaires	65 lx	130 lx
Space for old garbage collection room	40 lx	900 lx

Table 93 KPIs evaluated for M1.1.9 House 8H (Stockholm)

KPI	Baseline	Post- retrofitting	Variation
1. Lighting intensity (lx)	See Table 94		
2. Annual electric energy use (kWh/m2).	See M1.0	See M1.0	See M1.0
3. Electricity consumption related to baseline.	16936 kWh	4102 kWh	-76 %

Table 94 Light intensity and installed power for M1.1.9 House 8H (Stockholm)

Installation	Operation time variation	Energy use baseline	Energy use Post-retrofitting	Energy use variation %
Emergency lighting	0 %	105 kWh	105 kWh	0%
Stairwell	-65%	4383 kWh	1534 kWh	-65%
Entrance	-65%	2104 kWh	736 kWh	-65%
Garage	-80%	2805 kWh	561 kWh	-80%
Laundry	-80%	701 kWh	140 kWh	-80%
Storage rooms	-85%	6837 kWh	1026 kWh	-85%

Installation	Lux baseline	Lux post
Entrance hall under luminaire	90 lx	300 lx
Entrance hall between luminaires	50 lx	250 lx
Stairs between floors	15 lx	30 lx
Stairwell floor	100 lx	300 lx
Apartment storage next to luminaire	120 lx	800 lx

Apartment storage between luminaires	50 lx	500 lx
Sub-central near the luminaire	100 lx	500 lx
Sub-central between luminaires	30 lx	200 lx

Cologne

Industry partner	Contact person	Validation partner
Dewog	André Esser	KTH-EGI

The stairway lighting in all renovated buildings have been replaced with efficient LED lighting. The annual electricity consumption by the lighting is recorded by the RheinEnergie meters. The electricity for the lighting falls under public electricity.

Table 95 shows a summary of the installed power of the lighting system before and after the refurbishment. Due to the low quality of the measurements the results in term of electricity consumption could not be validated and are not published. No measurement of light intensity has been provided.

Table 95 Installed power of the lighting system, before and after the refurbishment (M1.1.9 Cologne)

			Staircase		Cellar	
Building	installed lamps	area (m²):	Before	After	Before	After
Adam-Stegerwald-Str. 11-17	4	9	360W	70 W	360W	290W
Adam-Stegerwald-Str. 19-25	4	9	360W	70 W	360W	290W
Adam-Stegerwald-Str. 16-26	6	9	360W	77 W	360W	290W
Edith-Stein-Str. 1-7	4	9	360W	77 W	360W	290W
Edith-Stein-Str. 2-6	3	9	360W	77 W	360W	290W
Edith-Stein-Str. 14-16	2	9	360W	77 W	360W	290W
Edith-Stein-Str. 18-22	3	9	360W	77 W	360W	290W
Edith-Stein-Str. 26-34	5	9	360W	77 W	360W	290W
Legienstr. 1-7	4	9	360W	77 W	360W	290W
Legienstr. 2-10	5	9	360W	77 W	360W	290W
Deutz-Mülheimer-Str. 152-168	7	8,6	360W	77 W	360W	290W
Deutz-Mülheimer-Str. 170-182	7	8,6	360W	77 W	360W	290W
Gaußstr. 2-4	2	9	360W	77 W	360W	290W
Sonnenscheinstr. 1-8	6	144,9	11960W	896W	2580W	2436W

Barcelona

Industry partner	Contact person	Validation partner
IREC Barcelona Municipality	Alaia Sola (IREC)	KTH-EGI

Library les Corts

LED lighting has been used in all the building lights, and natural lighting has been thoroughly exploited.

Spot lighting measurements were done in November 2017 for Illuminance (Table 96). Measurements of the average maintained illuminance (lux) provided on both horizontal

ground plane and working plane were done once the building retrofitting action was completed. These spot measurements have shown to be compliant with National regulation (Table 97).
There is no existing monitoring of the disaggregated electricity consumption of the lighting system in the Library. Lighting electricity consumption of the retrofitted building has been calculated on an annual basis using the simulation software CALENER (software for building certification in Spain). As for the baseline, measurements are not available either because the building was not in use before retrofitting. Baseline results from simulations of a reference building also show the global annual electricity consumption for lighting.

Table 96 Spot lighting measurements performed in November 2017 (M1.1.9 Library Les Corts).

	Ground plane (lux)	Working plane (lux)	Result	Type of zone
Ground floor				
Entrance hall	1096,1214,1112, 859,946	-	Correct	Entrance hall
Main room	374,399,369,308, 322	339,378,313,373,397	Correct	Library: shelves zone
Attic	378,422,297,352	472,364,311,356	Correct	Library: shelves zone
First floor				
Main room	1294,1025,1466, 1220,1382,1360	1663,1226,1139,1377,15 08,1277	Correct	Library: Lecture rooms
Staircase	123,148	-	Correct	Staircases
Second floor				
Hall	1349	1296	Correct	Library: Lecture rooms
Room 1	1376,1287	1420,1619	Correct	Library: Lecture rooms
Room 2	1358,1279,1129, 1157	1445,1492,1020,1168	Correct	Library: Lecture rooms
Room 3	1088,1281,1328	1420,1439,1317	Correct	Library: Lecture rooms
Machine room	194	280	Correct	Machine room

Table 97 Recommended minimum values according to Spanish national regulation (CTE HE 3 Energy efficiency of lighting installations, based on UNE-EN 12464-1:2003).

Type of zone	Minimum average maintained illuminance on horizontal plane (lux)
Library: Lecture rooms	500
Staircases	150
Library: shelves zone	200
Entrance hall	200
Machine room	200

Table 98 Comparison of electricity demand and primary energy demand for lighting obtained with CALENER simulation software.

	Baseline	Post-retrofitting	Savings (simulations)
Annual electricity consumption for lighting (final energy)	116.7 kWh/m2·year	34.3 kWh/m2·year	70.6%
Total primary energy consumption for lighting	434,083 kWh/year	127,709 kWh/year	70.6%
CO2 emissions due to lighting (kg CO2/year)	73,679.0 kg CO2/year	21,582.7 kg CO2/year	70.6%

The Annual electricity consumption for lighting (final energy) obtained from the most updated simulations (with building final lighting configuration) concludes that:

Reduction of electrical consumption for lighting, compared to a baseline building complying with Spanish Building Technical Standard, is 70.6%.

Table 99 KPIs evaluated for M1.1.9 Library Les Corts (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1. Lighting intensity (lx)	n/a	See Table 96	n/a %
2. Annual electric energy use (kWh/m2).	116.7	34.3	-70.6 %
3. Reduction of electrical consumption related to baseline.	70.6 %		

Conclusions

The results from Library les Corts (Barcelona) are based on simulation of building energy demands and not from actual measurements. As a baseline cannot be established, the savings in this case have to be estimated through simulations, which have been done, indicating a saving of about 71% of the electric energy required if incandescent lighting had been used.

For the installation in Stockholm, the measured energy savings indicate an overall saving from M1.1.9 to be over 70%.

In Cologne the installed power decreased (Table 95) but no actual results in terms of measured energy are currently available. For this reason no conclusion can be drawn.

Technical, economic and social feasibility

The Measure of efficient lighting is a Measure which, relative to its own energy use, have potential for large savings. According to simulations 90% may be saved. It is important when evaluating these Measures that the service level is maintained. The lumens measurements serve that purpose. It has reported that energy efficient lighting will have longer lifetime compared to incandescence lighting. For a property owner with a large number of lighting fixtures to handle, the change for these may be paid off by the fact that changing light bulb occurs less frequent. In addition, lighting with less thermal energy dissipation will lead to less cooling requirement during the hot season. During the heating season, less free gains are obtained, however the heating by electricity from light bulbs will most probably be interchanged to more (cost) efficient heating means, such as district heating or heat pumps.

The social feasibility is also good; however, some occupants may feel discomfort by the spectral properties of the light emitted.

Applicability of the Measure to different cities

This Measure is applicable to any city and possible to upscale to any building. The more general light the more useful this Measure will be.

M1.1.10.1 - Efficient and smart climate shell and equipments refurbishment for buildings: passive Measures

Introduction

This particular Measure is referring specifically to activities carried out in Barcelona. As passive Measures, insulation improvement on facades and roof has been implemented, as well as, low-U values windows (window frame and glazing) and adding shading elements.

As stated in the evaluation plan (D5.1), the Measure intention was to demonstrate a reduction of heating and cooling demand through passive interventions while increasing comfort and quality of living.

This Measure is very wide in scope and the baseline has been determined by:
1. Measurement of aggregated gas consumption for the whole building over at least one year.
2. Measurement of aggregated electricity use for the whole building over at least one year.
3. For hotel and sport center, measurement of aggregated cooling use for the whole building, obtained from invoices provided by the utility or from separate sub metering.
4. Determination of the effect on energy use of implementation of Energy Management Systems (HEMS or BEMS).
5. Determination of independent variables that affect energy consumption, e.g., external and indoor temperatures, humidity and irradiation.
6. In residential buildings the baseline established by combination of above points was integrated with detailed building simulation when, for example, a change of the building type occurred within the refurbishment. The simulation results has been compared to utility data and adjusted for user behavior from surveys. In case a deviation between the simulated and utility data for each of the energy carrier was greater than 15%, then the following additional steps were required:
    a. Air leakage testing with blower door to determine air tightness before refurbishment.
    b. Window thermal status determination (such as transmission and solar gain coefficients).
    c. Facade thermal status determination to establish U value of existing façade.
7. In case of Hotel H10 Madison the baseline was established by a combination of the above points (1 – 5), together with detailed building model (with relevant user behavior). In case the deviation between the modelled data and utility data for each of the energy carrier was greater than 15%, the following addition steps were required:
    a. Air leakage testing with blower door to determine air tightness before refurbishment.
    b. Window thermal status determination (such as transmission and solar gain coefficients).
    c. Facade thermal status determination to establish U value of existing façade.
8. In Passeig Santa Coloma (Big Blue), the thermal status of walls has been determined using thermal imaging.
9. Determination of relevant indoor environmental parameters, such as temperature.

The key performance indicators evaluated are:
1. U Value of windows (incl. frame) in W/m^2K
2. U Value of facades in W/m^2K.
3. Relevant overall thermal environment evaluated at reference point.
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).

5. Sensible air temperature of the reference buildings.
6. Energy demand and consumption by heating, cooling (if applicable), DHW other electricity uses (kWh/m^2) normalized for a typical climatic year, quantified by simulation or other equivalent procedure.
7. Energy savings, in final and primary energy terms.
8. CO_2 emissions reduction.

Barcelona

Industry partner	Contact person	Validation partner
Naturgy IREC Barcelona Municipality	Helena Gibert (Naturgy) Alaia Sola (IREC)	KTH-EGI

Library Les Corts

The passive Measures in Library Les Corts included:

- Different passive sun protection systems were arranged, according to the orientation and needs of the building.
- Large openings in the north façade.
- High thermal performance glazing.
- Treatment of the existing facades: internal folding of 10 cm of thickness, creating an air chamber with rock wool insulation.

The main impact on the building energy use due to passive Measures is due to the insulation improvement on façades, ground floor and glazing. The total building electricity consumption and gas consumption was obtained from both the monitoring equipment and the invoices.

The refurbishment activities and some details of the baseline used for M1.1.10.1 have already been mentioned in M1.0.

Table 100 KPIs evaluated for M1.1.10.1 Library Les Corts (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1. U Value of windows (incl. frame) in W/m2K	N/A	N/A	N/A
2. U Value of facades in W/m2K.	N/A	N/A	N/A
3. Relevant overall thermal environment evaluated at reference point.		See M1.0	
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).	N/A	N/A	N/A
5. Sensible air temperature of the reference buildings.		See M1.0	
6.1 Energy demand and consumption by heating (Gas) (kWh/m^2)		See M1.0	
6.3 Cooling		See M1.0	
6.4 DHW		*No DHW*	
7. Energy savings (final energy)		See M1.0	
8. Energy savings (primary energy)-			-28.4 %
9. CO2 emissions reduction.		See M1.0	

Indoor temperature, relative humidity and CO2 concentration have been monitored on an hourly basis. Data are available from mid-November 2018 onwards.
The following charts present the monthly mean values of indoor conditions in four different spaces of the Library (F1, F2, F0, and F0 Ateneu, located in first, second and ground floors, respectively) compared to the outdoor humidity and outdoor temperature measured on site.

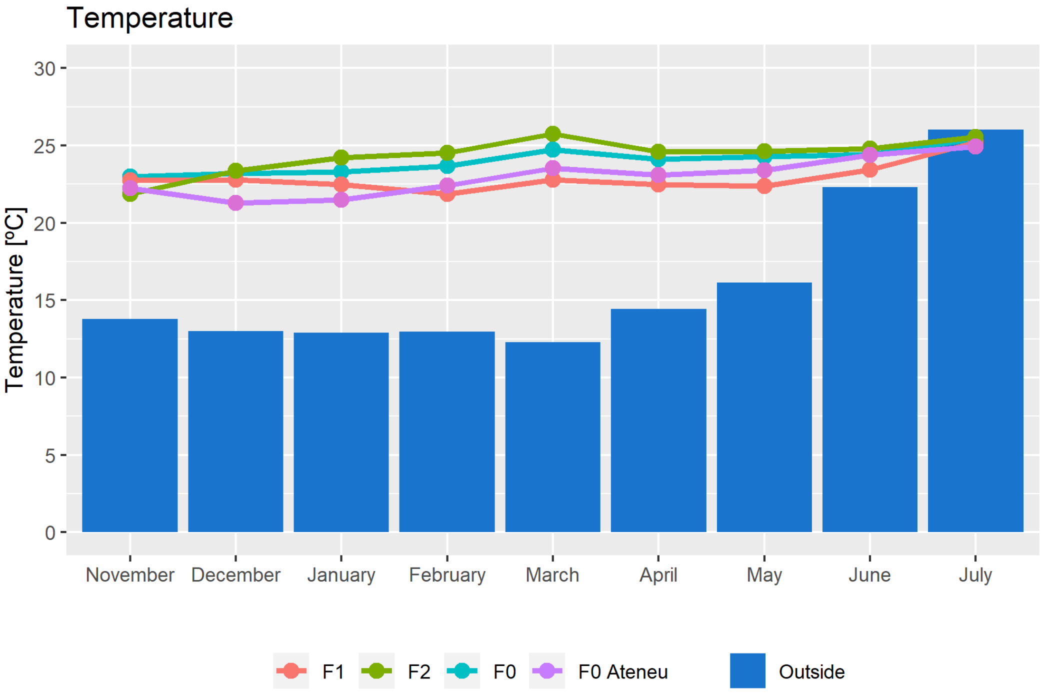


Figure 67 Temperature evaluated at reference point , Library Les Corts M1.1.10.1 Barcelona

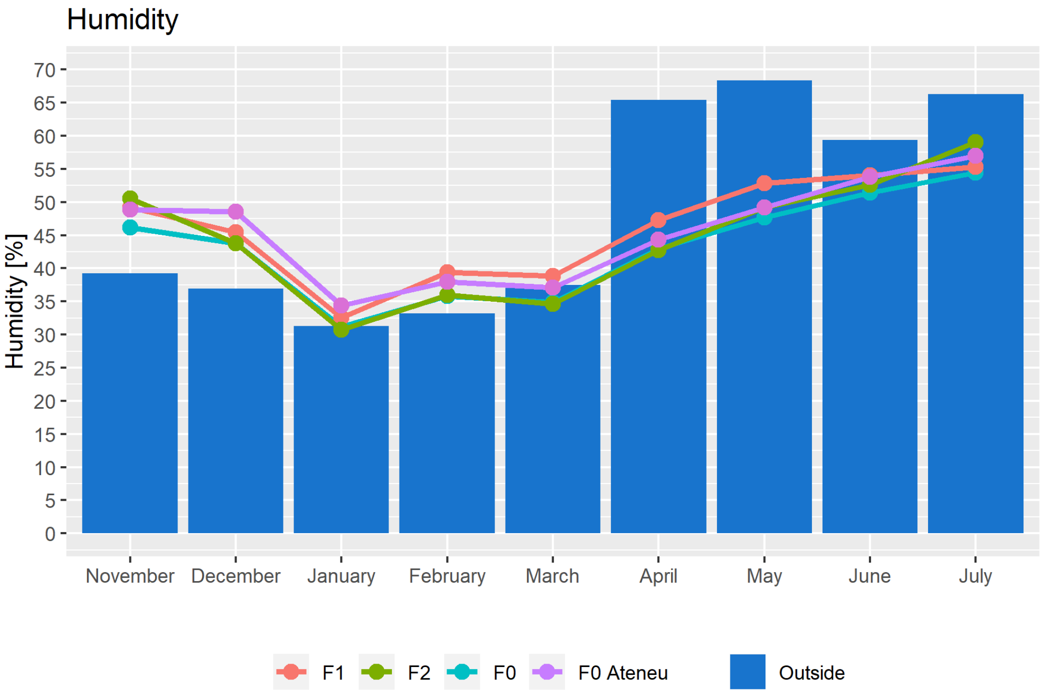


Figure 68 Humidity evaluated at reference point , Library Les Corts M1.1.10.1 Barcelona

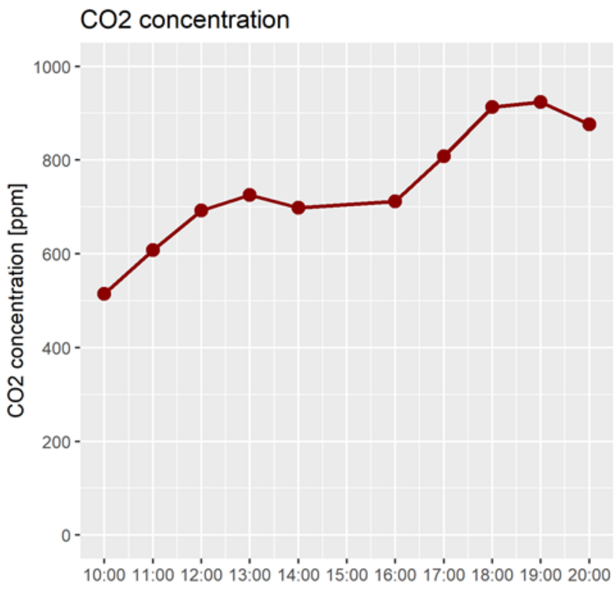


Figure 69 CO_2 concentration, Library Les Corts M1.1.10.1 Barcelona

As it can be observed, the mean indoor humidity is highly dependent on the mean outdoor humidity. Indoor relative humidity always falls between 30% and 70% of humidity, which is the range imposed by Spanish law to denote safety and comfort in offices/sedentary working spaces. It must be noted that the outdoor humidity in Barcelona city in January 2019 was very low (around 30% on average), which had an impact on indoor humidity.

It can be observed that, in front of lower outdoor temperature, the current control of HVAC tends to lead to higher indoor temperatures. According to Spanish law, the temperature of the premises where sedentary work takes place must be carried out between 17°C and 27°C indoor temperature. This is accomplished in the library.

In terms of air quality, the CO2 concentration has also been monitored in the Library. The following chart presents the typical evolution observed for the hourly indoor CO_2 concentration in the Library during its opening hours.

Even at the end of the day (the library closes at 8pm), the trend shows air quality values that fall within the comfort range (below 1000 ppm), thus ventilation systems are properly working and user comfort is guaranteed.

Passeig Santa Coloma (Big Blue)

The passive Measures in Passeig Santa Coloma included:

- Replacement of all blinds in the building for better insulated blinds.
- Installation of External Thermal Insulation Composite System (ETICS), i.e. addition of EPS and rockwool to the existing facades. In particular, the North, East and West facades and the South facades not protected by terraces were isolated with ETICS and ventilated façade methods, forming a mosaic in which: The EPS thicknesses are of 6, 8 and 10 cm in the coatings with mortar applied to the insulation. The rockwool thicknesses are of 6, 8, and 10 cm in the fragments covered with ventilated facade. The set of the satellites in the building were covered with EPS of 8 cm plastered on the insulation in the surfaces located from the first floor and above, and with 8 cm of rockwool and HPL ventilated facade on the surfaces of the ground floow dwellings.

In February 2017 and February 2018, extensive monitoring and survey campaigns were carried out to assess the indoor thermal comfort in Passeig Santa Coloma. Indoor air temperature, relative humidity and CO2 concentration were continuously monitored over a period of one week with a measurement resolution of 3 minutes, as well as surveys were done to the tenants. The survey was designed by IREC to provide information for the calculations of a series of parameters that determine the thermal comfort (PMV, PPD and indexes of local thermal discomfort) of the total population sample.

21 dwellings participated in the campaign for baseline period and 18 dwellings participated in the campaign done after refurbishment. In this study, the minimum number of dwellings that are required to estimate the indoor thermal comfort of the total population of the building was set to be equivalent to the minimum number of dwellings required for the estimation of the mean daily indoor temperature and the mean daily indoor relative humidity of the total population (with a pre-defined level of accuracy). A statistical approach was adopted to determine the minimum amount of dwellings to consider in order to have representative results in the monitoring campaigns. The result of this study showed that the minimum amount of dwellings to be monitored according was 14. The number of volunteer dwellings for the thermal comfort investigation in this building surpasses this figure.

The meters were placed in rooms facing three different façades (north, south and east) as representative rooms.

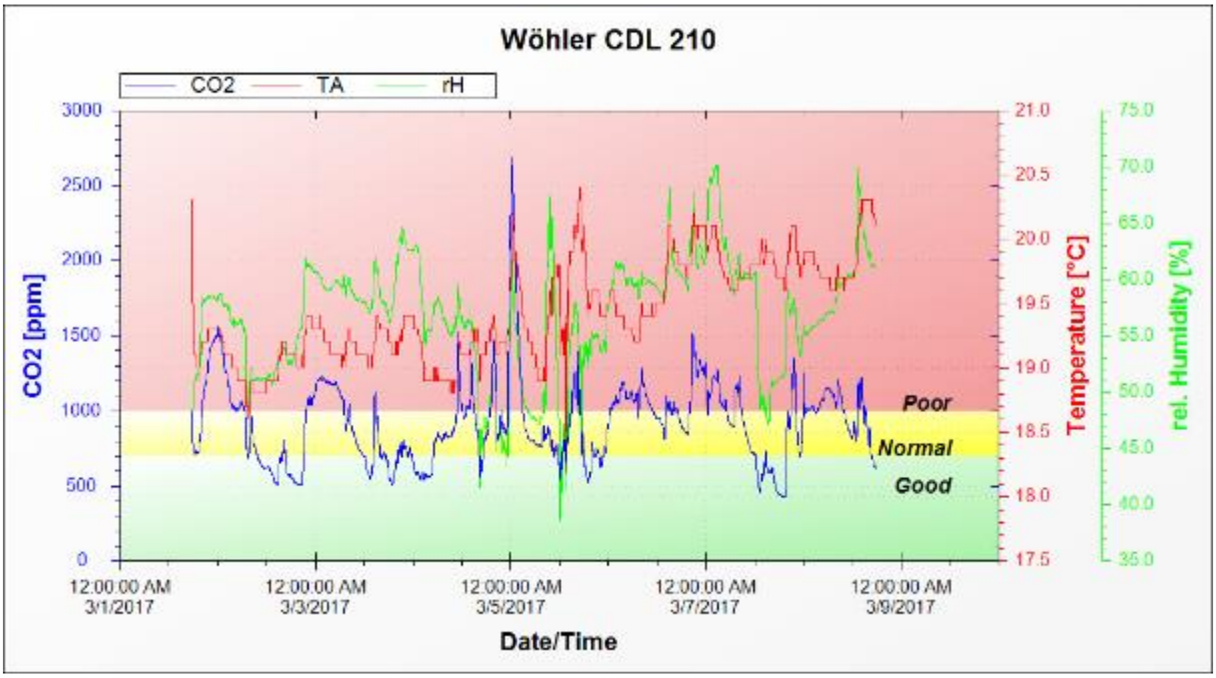


Figure 70 Example of the 3 variables monitored in a (south-facing) living room in one of the apartments: CO2 (blue), indoor air temperature (red), relative humidity (green)

Results on discomfort due to cold environment from PMV calculations:

The Predicted Mean Vote (PMV) index is an instantaneous index that reflects the expected average value of the votes cast by a group of people in case they would be exposed to the same environment. The resulting indicator is classified among 5 comfort categories. The PMV for each dwelling was obtained based on the methodology indicated in ISO 7730, which requires both answers from the surveys (physical activity undertaken + clothing) and measured variables in the dwellings (air temperature and humidity). Mean radiant temperature and air velocity was not possible to monitor due to the complexity of the available measurement equipment and to reduce the disturbance of the neighbours. Consequently, the hypothesis for PMV calculation are the following:

- Approximation of mean radiant temperature to air temperature monitored in the room.
- Estimation of the value of air velocity (set to 0.1 m/s). This parameter is set to a constant value throughout all calculations (pre- and post-refurbishment) in order to avoid disturbance in the results from PMV calculation.

The comparison of the calculated PMV between baseline and post-retrofitting period was finally done among 17 dwellings.

The PMV values have been classified in four categories, as shown in Table 101.

Table 101

PMV category	Category definition
A	Comfort category recommended for spaces occupied by weak/sensitive people
B	Minimum comfort category recommended for new or retrofitted buildings
C	Minimum comfort category recommended for existing buildings
D hot	Discomfort due to hot environment; to be accepted for limited periods of time
D cold	Discomfort due to cold environment; to be accepted for limited periods of time

The diagrams in Figure 71 show the results of the comfort analysis based on PMV and PPD classification.

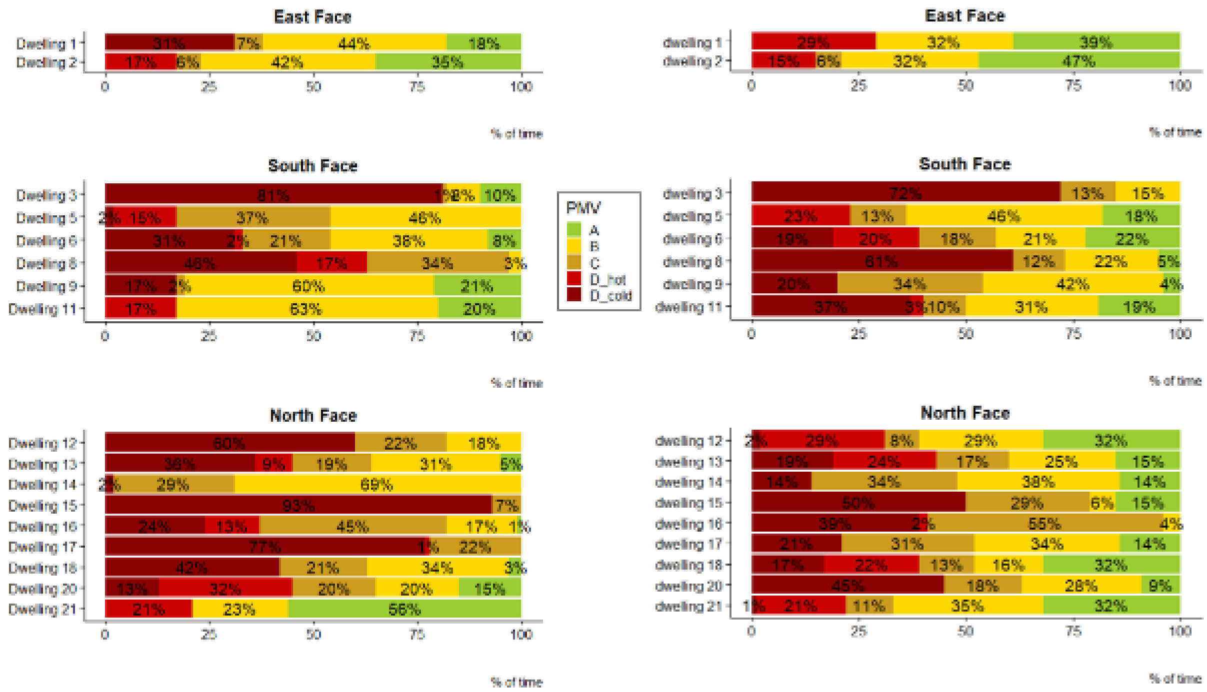


Figure 71 Classification of % of time that each dwelling is under each thermal comfort category based on the calculated PMV and PPD

Results on discomfort due to cold environment based on surveys:

On the qualitative side, the thermal comfort in winter has also been determined based on the answers provided to the question on surveys, shown in Table 102

Table 102

Thermal sensation:	*Cold*	*Cool*	*Slightly cool*	*Neutral*	*Slightly warm*	*Warm*	*Hot*

The results of the share of tenants that selected each option in the survey are shown in Figure 72.

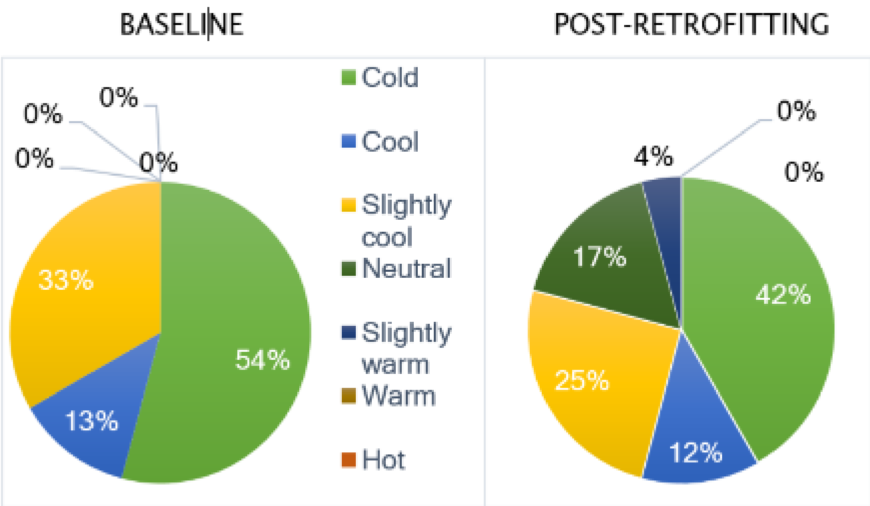


Figure 72 Share of answers obtained on the survey campaign for thermal sensation

- The answers on winter indoor thermal sensation of surveyed tenants are more favourable after the retrofitting works, i.e. a smaller share of tenants claim a "Cold" thermal sensation while a higher share claim "Neutral" thermal sensation.

- In general terms, the surveyed tenants explained that they had noticed an improvement on their indoor thermal comfort during the first winter after energy retrofitting works.

Results on local discomfort based on surveys:

- The PMV expresses the heating and cooling discomfort of the body as a whole. However, thermal discomfort may be caused by unwanted heating or cooling of a particular part of the body. This is known as local thermal discomfort. In these cases, the percentage of dissatisfied (PD) is calculated independently for each surveyed local discomfort situation.

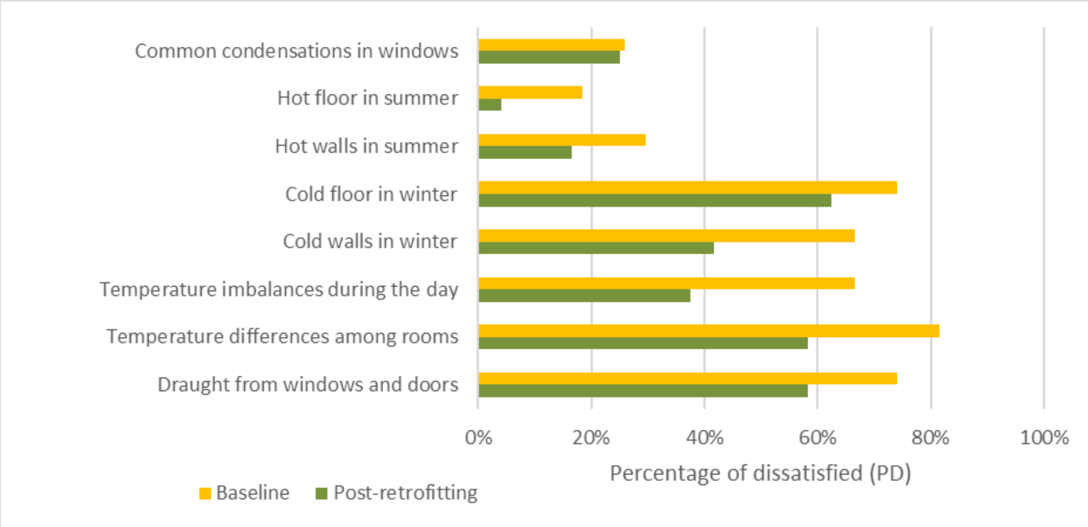


Figure 73 Results of Post-retrofitting survey campaign on local discomfort in Passeig Santa Coloma

- When occurring, local thermal discomfort is mainly due to: temperature differences among rooms (north-south orientation), cold floor and walls in winter, draught from windows and doors, and temperature imbalances during the day.

- The percentage of dissatisfied for all the situations above has considerably decreased during the first winter after building retrofitting.

    - The main local discomfort claimed are the temperature differences among rooms (due to north-south orientation of many dwellings). This has decreased according to the surveyed tenants thanks to the higher external wall insulation, which has improved the thermal comfort in the rooms facing the north façade. Due to the same reasoning, the percentage of dissatisfied due to cold floor and walls as well as temperature imbalances during the day have decreased.

    - Even though windows have not been replaced, the dissatisfaction due to draught has decreased. Therefore, the tenants' perception of this reason for local discomfort has improved with building retrofitting.

Qualitative study of thermal status of façades:

A qualitative study of the thermal status of building external walls through thermal imaging has been done pre- and post-refurbishment. A thermal imaging camera "FLIR 7460" was used for the study. The emissivity of the surfaces was adjusted in the camera to 0.95. Thermal imaging was only done from the outside of the facades. Outdoor temperatures ranged between 4 and 5ºC during the study.

The main conclusions regarding the impact of the retrofitting works on the facade thermal status are the following:

NORTH FAÇADE: after the facade retrofitting works, the energy leaks detected initially in forged fronts and wall enclosures are no longer detected (the surface distribution of the measured temperature is more uniform). The joints between the installed thermal insulation panels can be seen in some thermal images.

Figure 74 Thermal image of north facade before (left) and after (right) facade thermal upgrade works

WEST FAÇADE: the energy leaks initially observed in forging fronts as well as the thermal bridges in between the jambs and lintels joint point and the joinery are no longer observed after the retrofitting works in the sections of the facade that face the apartments. In the rest of the facade surface (which faces the staircases and is therefore not inhabited), no improvements are detected.

Figure 75 Thermal image of west facade before (left) and after (right) facade thermal upgrade works

SOUTH FAÇADE: given the small proportion of the solid part over the window hole, the protection of the eaves over the façade and the particular occupation of the terraces by the neighbors, there has been no intervention with external insulation in these areas of the south facade. The results from thermal imaging are therefore very similar before and after retrofitting works.

Figure 76 Thermal image of south facade before (left) and after (right) facade thermal upgrade works

For the climatic normalization of KPIs, the following figures have been used as a result of the calculation of Heating Degree Days (base temperature = 15ºC) in Barcelona for the corresponding years (baseline = year 2016; and post-retrofitting = year 2018).

- 527 Heating Degree Days in 2016
- 650 Heating Degree Days in 2018

Table 103 KPIs evaluated for M1.1.10.1 Passeig Santa Coloma (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1. U Value of windows (incl. frame) in W/m2K	-	-	-
2. U Value of facades in W/m2K.	-	-	-
3. Relevant overall thermal environment evaluated at reference point.	Figure 71		
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).	Figure 71		
5. Sensible air temperature of the reference buildings.	N/A	N/A	N/A
6. Energy demand and consumption by heating (kWh/m2/HDD) normalized for a typical climatic year	0.080	0.056	-29.8 %
7. Energy savings (final energy)	See point 6		
8. Annual primary energy for heating (kWh/m2/HDD) normalized for a typical climatic year	0.067	0.096	29.8 %
9. Annual CO2 emissions due to heating energy demand (kg CO2/m2/HDD) normalized for a typical climatic yearreduction.	0.020	0.014	-29.8 %

Canyelles

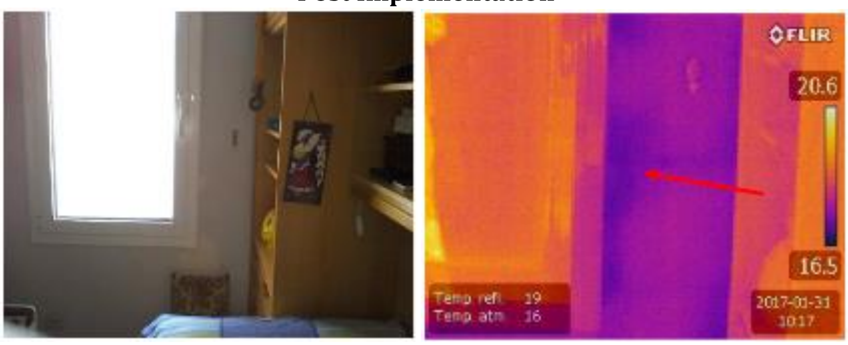
The passive Measures in Canyelles included:

- Improvement of façades (opaque walls and windows) and roof insulation
- Installation of new windows with low-U values, including the window frame and glazing
- Installation of shading elements

Figure 77 shows examples of the thermal images campaing carried out in Canyelles.

Dwelling **Post Implementation**

3 1



8 4

Figure 77 Thermal images after the implementation of M1.1.10.1 in Canyelles

Table 104 shows the results obtained by an extensive campaign of air leakage tests performed before and after the refurbishments. As shown in the Table, the improvements in the air leakage reductions are between 10% and 60%

Table 104 Campaign of air leakage tests performed before and after the refurbishments, M1.1.10.1 Canyelles

Dwelling	Variable	Units	BEFORE	AFTER	Variation
1 2	V_{50}	m^3/h	1.109,20	447,00	-59,7%
	n_{50}	h^{-1}	5,84	2,36	-59,7%
	q_{50}	$m^3/h.m^2$	4,6387	1,8694	-59,7%
	EQLA50	cm^2	554,34	223,39	-59,7%
3 1	V_{50}	m^3/h	927,50	488,50	-47,3%
	n_{50}	h^{-1}	4,89	2,57	-47,3%
	q_{50}	$m^3/h.m^2$	3,8789	2,0429	-47,3%
	EQLA50	cm^2	463,53	244,13	-47,3%
3 2	V_{50}	m^3/h	789,50	514,00	-34,9%
	n_{50}	h^{-1}	4,16	2,71	-34,9%
	q_{50}	$m^3/h.m^2$	3,3017	2,1496	-34,9%
	EQLA50	cm^2	394,56	256,88	-34,9%
8 4	V_{50}	m^3/h	908,02	594,50	-34,5%
	n_{50}	h^{-1}	4,78	3,13	-34,5%
	q_{50}	$m^3/h.m^2$	3,7974	2,4862	-34,5%
	EQLA50	cm^2	453,79	297,11	-34,5%
14 2	V_{50}	m^3/h	1.510,00	1.300,00	-13,9%
	n_{50}	h^{-1}	6,93	5,97	-13,9%
	q_{50}	$m^3/h.m^2$	5,9129	5,0906	-13,9%
	EQLA50	cm^2	754,64	649,69	-13,9%

Where:

- n: exponent of air flow
- V50: Relation of the filtered air at 50 Pa.
- V25: Relation of the filtered air at 25 Pa.
- V4: Relation of the filtered air at 4 Pa.
- n50: Relation of the change of air at 50 Pa
- n4: Relation of the change of air at 4 Pa
- q50: Air permeability at 50 Pa
- q25: Air permeability at 25 Pa
- q4: Air permeability at 4 Pa
- EQLA50: equivalent surface of the leak at 50 Pa

- n25: Relation of the change of air at 25 Pa

As an example of results, Figure 78 shows the results of the successful survey campaings run before and after the implementation for thermal sensation in summer and winter. A 7-level thermal sensation scale (Table 105) has been proposed before and after the implementation with the aim to evaluate the impact of the refurbishment on the comfort, considering both summer and winter.

Table 105 Thermal sensation scale adopted for the evaluation of M1.1.10.1 in Canyelles

Thermal sensation:	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

A total of 35 tenants completed the survey. Overall, the ratings after the refurbishment present good results for both summer and winter, in comparison to the results before the refurbishment. As can be observed, the neutral sensation in summer has increased more than 20 points and in winter, it has increased 30 points. Moreover, no one in Canyelles has a "Hot" sensation in summer, which it is a remarkable result in a Mediterranean climate.

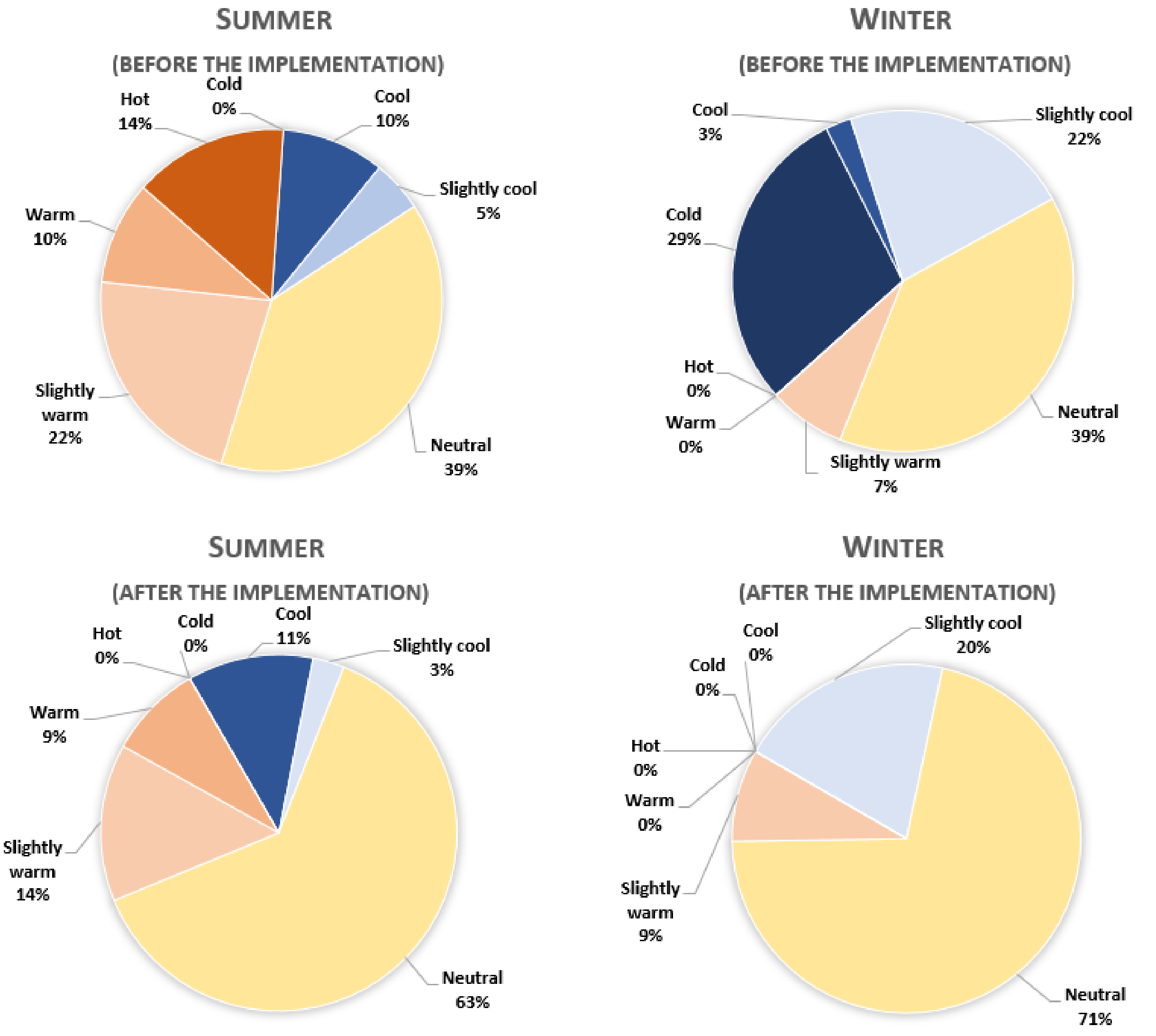


Figure 78 Results of the survey campaings before and after the implementation for thermal sensation in summer and winter

Table 106 KPIs evaluated for M1.1.10.1 Canyelles (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1. U Value of windows (incl. frame) in W/m2K	5.36	1.76	-67 %
2. U Value of facades in W/m2K.	2.18	0.47	-78 %
3. Relevant overall thermal environment evaluated at reference point.	Figure 78		
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).	Figure 78		
5. Sensible air temperature of the reference buildings.	N/A	N/A	N/A
6.1 Energy demand and consumption by heating (gas) (kWh)	114035	50002	-56 %
6.2 Heating (electricity)	9828	3847	-61 %
6.3 DHW	139009	119285	-14 %
6.4 Cooling	3995	2453	-39 %
6.5 Electricity	103172	112573	+9 %
7. Energy savings (final energy) (kWh)	370039	288160	-22 %
8. Energy savings (primary energy) (kWh)	602885/168435	484516/74421	-20%/-56 %
9. CO_2 emissions reduction (kg CO_2/m2)	21.9/7.12	17.6/3.14	-20%/-56%

Ter 31

The passive Measures in Canyelles included:

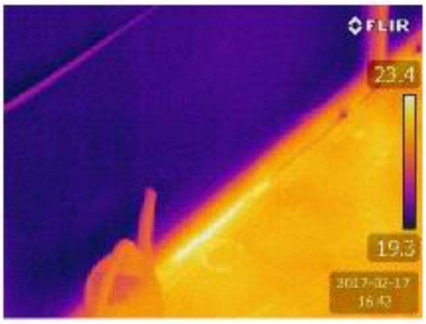
- Improvement of façades (opaque walls and windows) and roof insulation
- Installation of new windows with low-U values, including the window frame and glazing

Figure 79 shows the results, through thermal imaging, obtained before and after the refurbishment.

Dwelling	Pre Implementation	Post Implementation

E 1a

Pre Implementation:



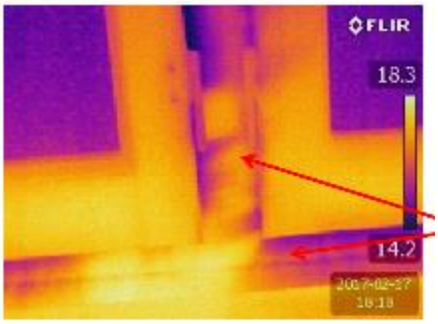
Infiltration in all the perimeter of the window

Post Implementation:

No infiltration detected

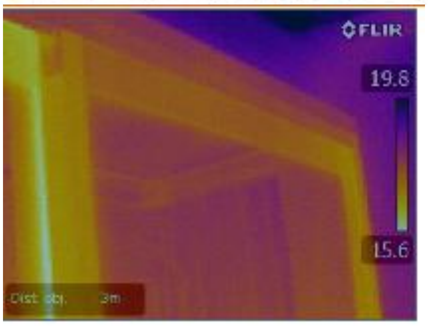
E 2a

Pre Implementation:



Problems with the enclosures

Post Implementation:



No infiltrations detected

Figure 79 Thermal images before and after the implementation of each dwelling

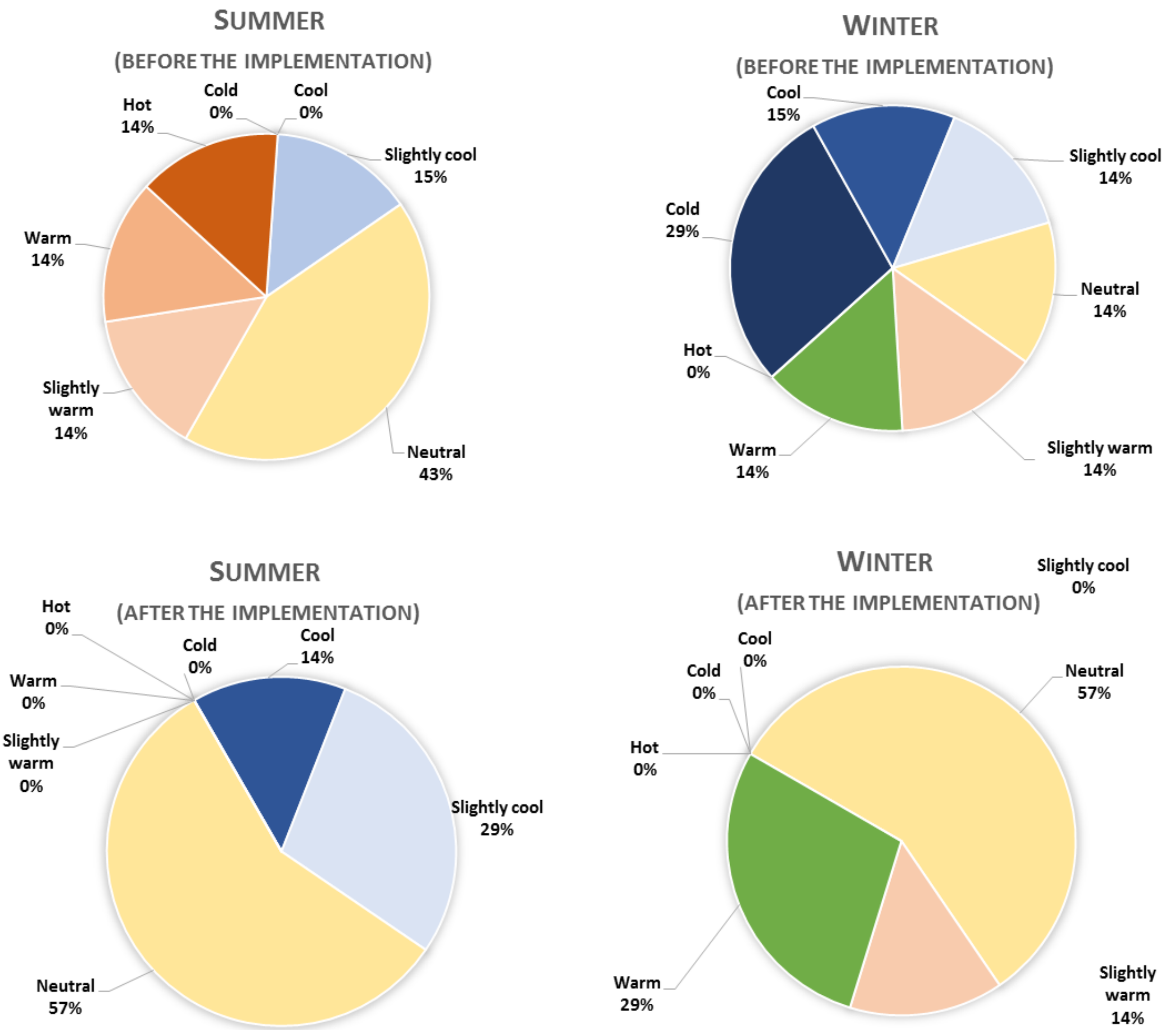


Figure 80 Results of the survey campaings before and and after the implementation for thermal sensation in summer and winter

From the campaign of air leakage tests, Table 107 shows an excerpt of the obtained results.

Table 107 Comparison between the results of the Blower Door Test before and after the implementation in Ter 31(EQLA is the Equivalent Leakage Area)*

Dwelling	Variable	Units	BEFORE	AFTER	Variation
E 1	V_{50}	m^3/h	896,40	622,90	-30,5%
	n_{50}	h^{-1}	6,07	4,22	-30,5%
	q_{50}	$m^3/h.m^2$	4,4910	3,1210	-30,5%
	EQLA50	cm^2	447,99	311,30	-30,5%
E 2	V_{50}	m^3/h	585,99	330,65	-43,6%
	n_{50}	h^{-1}	6,05	2,24	-63,0%
	q_{50}	$m^3/h.m^2$	4,4780	1,6560	-63,0%
	EQLA50	cm^2	446,66	165,25	-63,0%

*Results not validated

Table 108 KPIs evaluated for M1.1.10.1 Ter 31 (Barcelona)

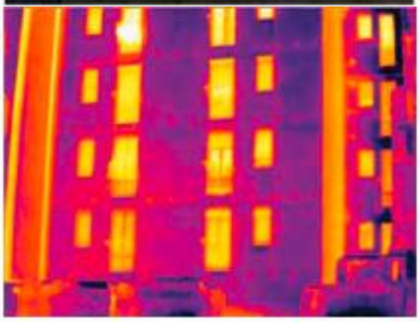
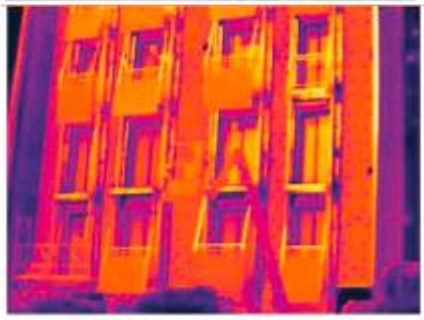
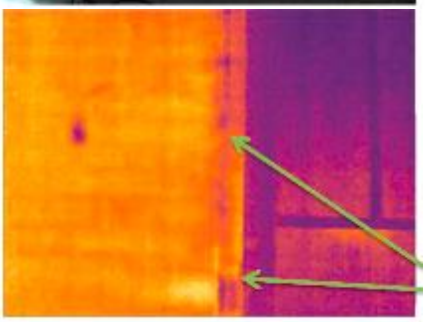
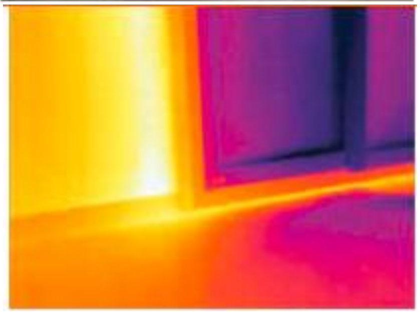
KPI	Baseline	Post- retrofitting	Variation
1. U Value of windows (incl. frame) in W/m2K	5.17	2	-61 %
2. U Value of facades in W/m2K.	1.8	0.54	-70 %
3. Relevant overall thermal environment evaluated at reference point.	Figure 80		
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).	Figure 80		
5. Sensible air temperature of the reference buildings.	N/A	N/A	N/A
6.1 Energy demand and consumption by heating (gas) (kWh)	-	-	-%
6.2 Heating (electricity)	8313	4922	-41%
6.3 DHW	19331	16592	-14%
6.4 Cooling	-	-	-
6.5 Electricity	34831	28714	-18%
7. Energy savings (final energy) (kWh)	62475	50229	-20%
8. Energy savings (primary energy) (kWh)	147940/19685	118941/11655	-20%/ -41%
9. CO2 emissions reduction (kg CO2/m2)	61.7/7	49.8/4	-19%/-41 %

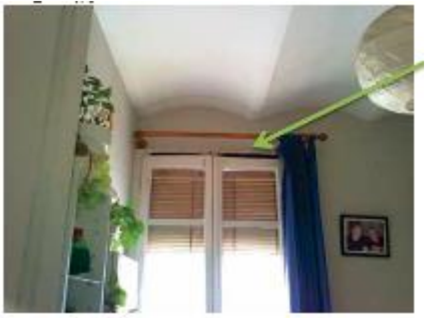
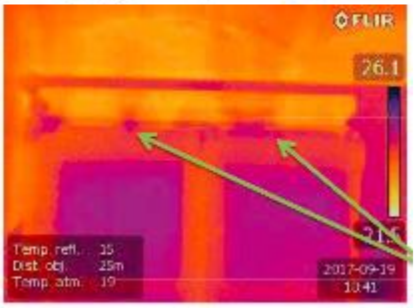
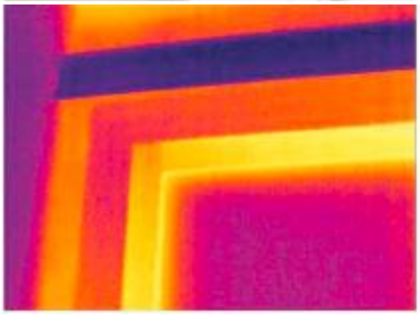
Lope de Vega

The passive Measures in Lope de Vega included:

- Improvement of façades (opaque walls and windows) and roof insulation
- Installation of new windows with low-U values, including the window frame and glazing

In Lope de Vega the results from the thermal imaging campaign and the air leakage tests is summarized in Figure 81 and Table 109.

Dwelling	Pre Implementation	Post Implementation
Façade	 	 
1 1	  Infiltration in the enclosures	  Infiltration problems solved

1 4	  Problems with the sealing	  Problems with the sealing solved
2 4	  Problems with the enclosures	  Problems solved
3 4		

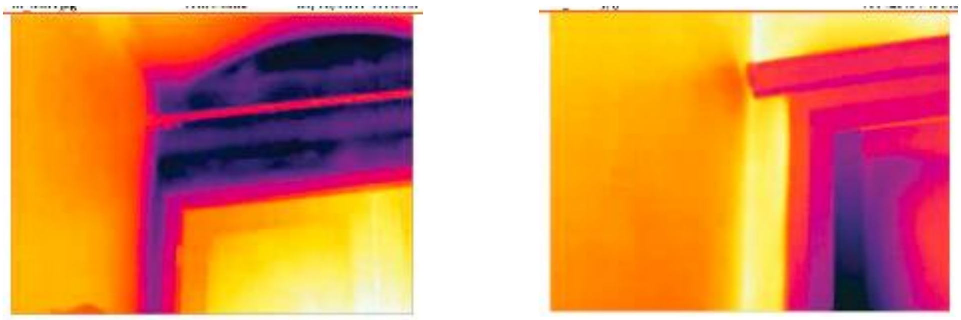


Figure 81 Lope de Vega: thermal images before and after the implementation

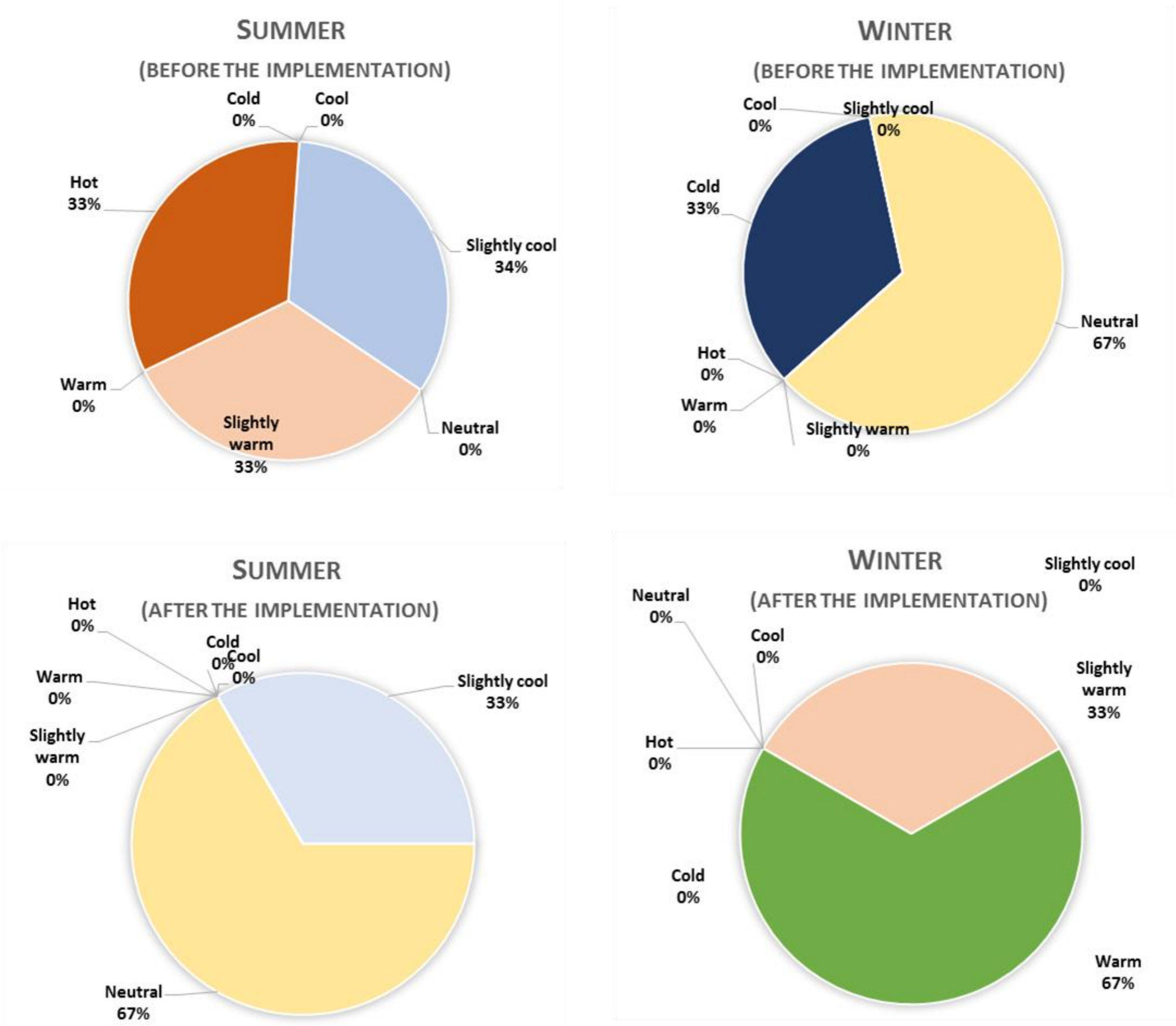


Figure 82 Lope de Vega: results of the survey campaings before and and after the implementation for thermal sensation in summer and winter

Table 109 Results of the Blower Door Test before and after the implementation in Lope de Vega (EQLA is the Equivalent Leakage Area)

Dwelling	Variable	Units	BEFORE	AFTER	Variation
1 1	V_{50}	m^3/h	895,40	539,65	-39,7%
	n_{50}	h^{-1}	7,72	4,65	-39,7%
	q_{50}	$m^3/h.m^2$	5,45	3,28	-39,7%

	EQLA50	cm^2	447,49	269,70	-39,7%
1 4	**V_{50}**	m^3/h	795,60	263,11	-66,9%
	n_{50}	h^{-1}	6,39	2,12	-66,9%
	q_{50}	$m^3/h.m^2$	4,6090	1,5240	-66,9%
	EQLA50	cm^2	397,61	131,49	-66,9%
2 4	**V_{50}**	m^3/h	642,20	324,55	-49,5%
	n_{50}	h^{-1}	5,16	2,61	-49,4%
	q_{50}	$m^3/h.m^2$	3,72	1,88	-49,5%
	EQLA50	cm^2	320,95	162,20	-49,5%
3 4	**V_{50}**	m^3/h	57,77	29,78	-48,5%
	n_{50}	h^{-1}	2,89	1,49	-48,4%
	q_{50}	$m^3/h.m^2$	1,30	0,67	-48,5%
	EQLA50	cm^2	28,87	14,88	-48,5%

Table 110 KPIs evaluated for M1.1.10.1 Lope de Vega (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1. U Value of windows (incl. frame) in W/m2K	5.17	2	-61 %
2. U Value of facades in W/m2K.	1.8	0.54	-70 %
3. Relevant overall thermal environment evaluated at reference point.	N/A	N/A	N/A
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).	N/A	N/A	N/A
5. Sensible air temperature of the reference buildings.	N/A	N/A	N/A
6.1 Energy demand and consumption by heating (gas) (kWh)	-	-	-
6.2 Heating (electricity)	5817	3784	-35%
6.3 DHW	20430	16620	-19%
6.4 Cooling	619	383	-38%
6.5 Electricity	36107	31325	-13%
7. Energy savings (final energy) (kWh)	62972	52112	-17%
8. Energy savings (primary energy) (kWh)	149120/15240	123401/9867	-17%/-35%
9. CO2 emissions reduction (kg CO2/m2)	46.3/4.7	38.3/3	-17%/-35%

H10 Madison

The passive Measures in H10 Madison included:

- High efficient windows: double-glazing with air chamber and wood or aluminum carpentry (depending on the location of the window)
- Roof insulation

A blower door test was carried out in the Hotel. The common procedure to select the windows where the infilitrations were going to be measured was to select those windows that are more representative (the one that faces the street, the courtyard or the one located in a corner), and use these results to extrapolate conclusions to the entire building. In addition, the test has been carried out in two different floors: the floor 4th (in the middle of the building) and the floor 7th (which has above the terrace).

Table 111 H10 Madison: blower Door Test results*

Room	Correlation	n	V_{50} [m³/h]	V_{25} [m³/h]	V_4 [m³/h]	n_{50} [h⁻¹]	n_{25} [h⁻¹]	n_4 [h⁻¹]	q_{50} [m³/h.m²]	q_{25} [m³/h.m²]	q_4 [m³/h.m²]	EQLA50 [cm²]
705	99.98%	0.621	1,010.9	657.31	210.63	**13.19**	8.58	2.75	**10.634**	6.915	2.216	**505.21**
707	99.75%	0.60	717.84	474.91	159.32	**8.59**	5.68	1.91	**6.126**	4.053	1.360	**358.75**
704	99.99%	0.60	1,478.2	975.92	325.60	**13.85**	9.14	3.05	**9.324**	6.156	2.054	**738.75**
713	99.96%	0.62	869.78	567.91	184.00	**12.69**	8.29	2.68	**8.322**	5.434	1.761	**434.68**
715	99.98%	0.62	1,408.6	919.08	297.23	**13.75**	8.97	2.90	**10.429**	6.805	2.201	**703.96**
405	100.00%	0.58	1,337.6	894.81	309.11	**17.45**	11.68	4.03	**14.071**	9.413	3.252	**668.48**
407	99.90%	0.59	882.59	585.12	197.37	**10.56**	7.00	2.36	**7.532**	4.993	1.684	**441.08**
404	99.96%	0.59	1,035	687.12	232.63	**9.69**	6.44	2.18	**6.528**	4.334	1.467	**517.25**
413	99.97%	0.51	1,214.3	851.53	333.20	**17.72**	12.42	4.86	**11.619**	8.148	3.188	**606.86**
415	99.97%	0.62	1,355.2	882.40	283.80	**13.23**	8.61	2.77	**10.034**	6.533	2.101	**677.28**

*Results not validated

After the new sealing of the windows with aluminium carpentry, the results of the blower tests in rooms 704 and 715 are:

Table 112 Blower door test post-refurbishment, room 704*

Room 704	Units	BEFORE	AFTER	Variation
V_{50}	m³/h	1,478.2	1114.0	-24.6%
n_{50}	h⁻¹	13.8	10.4	-24.6%
q_{50}	m³/h.m²	9.3	7.0	-24.6%
w_{50}	m³/h.m²]	47.1	35.5	-24.6%
AI50	cm²	450.6	339.5	-24.6%
EQLA50	cm²	738.6	556.5	-24.6%
AN50	cm²	2.84	2.14	-24.6%

Table 113 Blower door test post-refurbishment, room 715*

Room 715	Units	BEFORE	AFTER	Variation
V_{50}	m³/h	1408.6	1186.4	-15.6%
n_{50}	h⁻¹	13.7	11.6	-15.6%
q_{50}	m³/h.m²	10.4	8.8	-15.6%
w_{50}	m³/h.m²]	46.7	39.3	-15.6%
AL50	cm²	429.3	361.6	-15.6%
EQLA50	cm²	703.8	592.8	-15.6%
AN50	cm²	3.18	2.68	-15.6%

*Results not validated

In the Hotel H10 Madison the thermal imaging analysis allowed to identify a poor execution of the window installations. Figure 83 shows an example of the thermal imagin executed after the refurbishment. The installation of the window had not been executed properly and thermal losses have been clearly identified during the tests. Figure 84 shows the same window after the installation has been fixed.

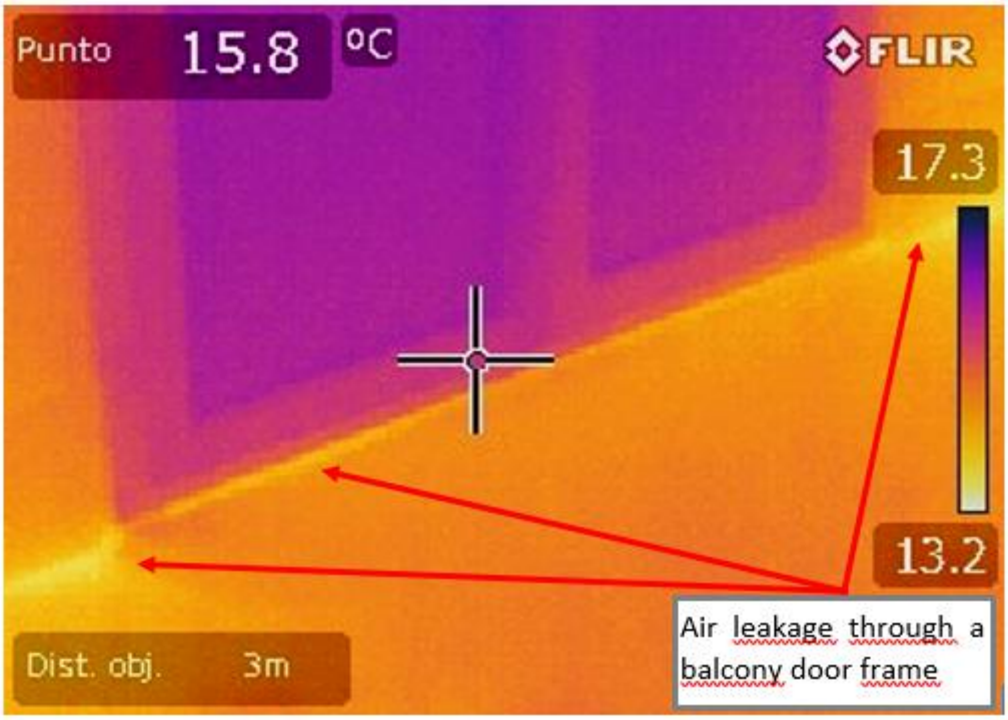


Figure 83 H10 Madison: thermal imaging after the refurbishment (poor installation)

Figure 84 H10 Madison: thermal imaging after the refurbishment (installation fixed)

Table 114 KPIs evaluated for M1.1.10.1 Hotel Madison (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1. U Value of windows (incl. frame) in W/m2K	5.9	3.24	45% %
2. U Value of facades in W/m2K.	N/A	N/A	N/A
3. Relevant overall thermal environment evaluated at reference point.	N/A	N/A	N/A
4. If required (based on user survey), PD of local thermal comfort (draught, radiant asymmetry, vertical air temperature difference).	N/A	N/A	N/A
5. Sensible air temperature of the reference buildings.	N/A	N/A	N/A
6. Energy demand and consumption by heating, cooling (if applicable), DHW other electricity uses (kWh/m2) normalized for a typical climatic year, quantified by simulation or other equivalent procedure.	95.5	55.4	42% %
7. Energy use (final energy)	391,596	227,300	42 %
8. Energy use (primary energy)	948,837	550,748	42 %
9. CO2 emissions reduction.	156,247	90,693	42 %

Potential for full scale implementation

Technical, economic and social feasibility

Improvements of the climatic shell of buildings are more or less technically feasible depending on the age and architecture of the building. In general, such improvements are technically possible but may be more or less economically feasible.
As adding insulation and/or changing windows of a building may influence the appearance, such improvements may or may not be acceptable from a social point of view.

Applicability of the Measure to different cities

In most cities, changes to the façade facing the street requires special permits and include the acceptance of the city architect or similar authorities. The conclusions from the specific buildings included in the GrowSmarter project may therefore not be directly on a large scale. This fact will be further investigated in the final report, through an investigation of the regulations for the three lighthouse cities.
Another fact concerning the replicability is that a change in the climate shell which is profitable in one city may not be so in another, as the possible savings due to the refurbishment may be different from one geographic location to another.

M1.1.10.2 - Efficient and smart climate shell and equipments refurbishment for buildings: active Measures

Introduction

In Barcelona, the renovation of the facilities has included led lighting, photovoltaic power plant, reducing the heating, DHW and cooling consumptions. In addition, high-efficient lighting and pumps were installed to reduce electricity consumption. New heating radiator loops were installed in apartments. In tertiary buildings, free-cooling and heat recovery was implemented.

According to the evaluation plan (D5.1), the intentions of the Measure were to:
1. Reduce space heating energy consumption.
2. Reduce space cooling energy consumption.
3. Increase share of RES in electricity supply
4. Reduce DHW energy consumption.
5. Reduce electric energy demand for lighting and other consumptions (if applicable).

This Measure is very wide in scope and the baseline was determined by:
1. Heating, cooling and DHW system evaluated on a global building level. Gas, electricity and water consumptions gathered and used as a basis to determine energy demands.
2. Equipment performances. A measurement campaign for a representative period, covering annual climatic conditions, to obtain information from some of the equipment to be replaced:
    a. Boilers
    b. HVAC system
    c. Other equipment that is going to be refurbished.
3. Independent variables that affect energy consumption, e.g., external and indoor temperatures.
4. Free cooling baseline determined by measuring, if possible, the cooling demand of HVAC system before the implementation of the Measures.
5. If available, driving energy for HVAC system for cooling for the duration of one year, normalized to typical climatic year.
6. If available, heat recovery in HVAC system determined by measuring the heating demand of HVAC system before the implementation of the Measures.
7. The change to LED lighting determined as the electrical energy demand to lighting system, see M1.1.9 for details.
8. Illuminance level (lux), see M1.1.9 for details.

The key performance indicators evaluated are:
1. Heating, cooling, DHW and electricity demands (kWh/yr). HVAC heat recovery system efficiency, heat recovery ratio (%).
2. Equipment performances.
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr). On-site electricity production (kWh/yr).
4. Energy savings in final and primary energy terms.
5. Share of RES in heating cooling and electricity supply.
6. CO_2 emissions savings.

Barcelona

Industry partner	Contact person	Validation partner
Naturgy IREC Barcelona Municipality	Helena Gibert (Naturgy) Alaia Sola (IREC)	KTH-EGI

Library Les Corts

The scope of the works related to active energy retrofitting evaluated in Growsmarter includes:

a) The air conditioning systems are of radiant floor, suitable to the large existing volumes. In addition, it has variable airflow conditioning systems dependent on the occupancy of the building.

b) The energy generation equipment for HVAC are highly efficient.

c) The lighting is based on LED Technology. The Library building has an automatic lighting regulation system consisting of photosensors connected to the lamps, allowing them to be regulated according to the external lighting. In addition, all areas designated to administrative use have individual control elements to manipulate the light ignition (evaluated under M1.1.9).

d) The installation of photovoltaic solar panels (28.8 kWp) for own consumption has been incorporated into the project. The PV installation was only commissioned in January 2019.

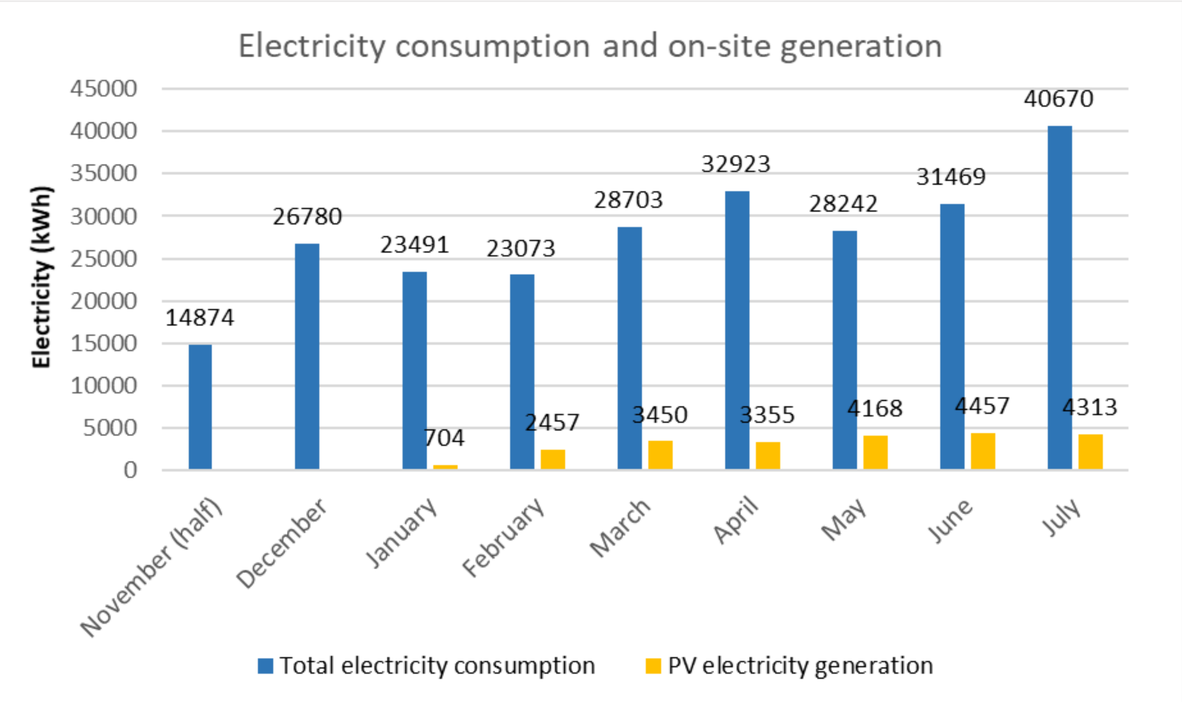


Figure 85 Total electricity consumption of the building and PV electricity generation (monitored data) in Library Les Corts

Table 115 shows the KPIs evaluated within M1.1.10.2 for Library Les Corts.
Worth noticing, regarding the on-site electricity consumption, the baseline is based on the building roof area, 18.9 kWp of PV should have been installed to comply with municipal regulation (equivalent to 21 735 kWh/year of PV generation according to simulations). The actual installation of PV is 28.8 kWp. PV generation only started on January 2019 due to legal issues that led to delays in commissioning. Therefore, no data for 1-year operation are

available. The reported annual PV energy generation (40889 kWh/year) is based on results from simulations performed with the same software used for baseline.
The share of RES is calculated based on the share of electricity consumption that is supplied by the PVs, since there is no other renewable source supplying the demand of this building.

Table 115 KPIs evaluated for M1.1.10.2 Library Les Corts (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1.1 Heating demand (kWh/yr)	See M1.0		
1.2 Cooling demand (kWh/yr)	See M1.0		
1.3 DHW demand (kWh/yr)	-	-	-
1.4 HVAC recovery system efficiency	-	-	-
1.5 Heat recovery ratio	-	-	-
2. Equipment performances.	-	-	-
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	See M1.1.9		
4. On-site electricity production (kWh/yr).	21 735	40 889	+88 %
5. Energy savings (final energy)	See M1.0		
6. Energy savings (primary energy)	See M1.1.10.1		
7. Share of RES in electricity supply.	5.9%	11.1%	+5.2 %
8. CO2 emissions savings due to local production (ton CO2/year)	7.2	13.5	+88 %

Canyelles

The active Measures in Canyelles included:

- Substitution of old boilers by high efficient boilers in the dwellings interested. In this measure participated 19/57 dwellings.
- Installation of water efficient taps in the dwellings that need them.

The analysis of the boiler performance has been done on one side with the average of the performance of all the boilers substituted and on the other only for the boilers whose data before and after the implementation was available.

Table 116 present the KPIs evaluated within M1.1.10.2 in Canyellas.

Table 116 KPIs evaluated for M1.1.10.2 Canyelles (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1.1 Heating demand (kWh/yr)	120 188	55 338	-54 %
1.2 Cooling demand (kWh/yr)	15 812	9217	-42 %
1.3 DHW demand (kWh/yr)	128 723	117 496	-9 %
1.4 HVAC recovery system efficiency	-	-	%
1.5 Heat recovery ratio	-	-	%
2. Equipment performances.	92.6 %	98.5 %	+5.9 %
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	3013	3233	+7 %
4. On-site electricity production (kWh/yr).	-	-	%
5. Energy savings (final energy)	370 039/248 912	288 160/172 835	-20/-31 %
6. Energy savings (primary energy)	602 885/297 449	484 516/206 538	-20%/-31%
7. Share of RES in heating cooling and electricity supply.	-	-	- %
8. CO2 emissions savings			-20%/-31 %

Ter 31

The active Measures in Ter 31 included:

- Installation of water efficient taps

Table 117 present the KPIs evaluated within M1.1.10.2.

Table 117 KPIs evaluated for M1.1.10.2 Ter 31 (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1.1 Heating demand (kWh/yr)	8146	4824	-41 %
1.2 Cooling demand (kWh/yr)	-	-	- %
1.3 DHW demand (kWh/yr)	15465	13274	-14 %
1.4 HVAC recovery system efficiency	-	-	%
1.5 Heat recovery ratio	-	-	%
2. Equipment performances.	-	-	%
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	150	150	0 %
4. On-site electricity production (kWh/yr).	-	-	%
5. Energy savings (final energy)	62475/23611	50229/18098	-20%/-23%
6. Energy savings (primary energy)	147940/55911	118941/42856	-20%/ -23%
7. Share of RES in heating cooling and electricity supply.	-	-	%
8. CO2 emissions savings			-20%/-31 %

Lope de Vega

The active Measures in Lope de Vega included:

- Installation of water efficient taps

Table 118 present the KPIs evaluated within M1.1.10.2 in Lope de Vega.

Table 118 KPIs evaluated for M1.1.10.2 Lope de Vega (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1.1 Heating demand (kWh/yr)	9947	6645	-33 %
1.2 Cooling demand (kWh/yr)	3960	1957	-51 %
1.3 DHW demand (kWh/yr)	16639	13623	-18 %
1.4 HVAC recovery system efficiency	-	-	%
1.5 Heat recovery ratio	-	-	%
2. Equipment performances.	-	-	%
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	316	340	+8%
4. On-site electricity production (kWh/yr).	-	-	%
5. Energy savings (final energy)	62972/26586	52112/20268	-17%/-24%
6. Energy savings (primary energy)	149117/62956	123400/47994	-17%/-24%
7. Share of RES in heating cooling and electricity supply.	-	-	%
8. CO2 emissions savings.	-	-	-17%/-24%

Melon District

The active Measures in Melon District included:

- Connection to a District heating for the heating demand.

For Melon District the evaluation oft he KPIs for M1.1.10.2 is not directly available. Please refer to M1.0.

Hotel H10 Madison

The active Measures in Melon District included:

- A new VRV (Variable Refrigerant Volume) system for heating and cooling
- Efficient LED lighting in common areas to reduce electricity consumption for this use

Table 119 present the KPIs evaluated within M1.1.10.2 in H10 Madison.

Table 119 KPIs evaluated for M1.1.10.2 Hotel Madison (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1.1 Heating demand (kWh/yr)	211202	88891	-58 %
1.2 Cooling demand (kWh/yr)	180394	138409	-23 %
1.3 DHW demand (kWh/yr)	N/A	N/A	N/A
1.4 HVAC recovery system efficiency	N/A	N/A	N/A

1.5 Heat recovery ratio	N/A	N/A	N/A
2. Equipment performances.	2.5	3.5	40%
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	32,850	22,995	70 %
4. On-site electricity production (kWh/yr).	N/A	N/A	N/A
5. Energy savings (final energy)	879579	628718	-29%
6. Energy savings (primary energy)	1510808	2113627	-29%
7. Share of RES in heating cooling and electricity supply.	-	71%	71%
8. CO2 emissions savings.	314,01	224,45	-29%

CEM Claror Sport Center

The active Measures in Melon District included:

- The replacement of the existing lighting for the equivalent LED lamps.
- The old chiller replacement with a new high efficient electric heat pump that produces simultaneously heat and cold.
- The spa basin connection to the new low temperature heating ring.
- The heating needs that are not covered by the Heat Pump are currently satisfied by a new set of high –efficient condensing boilers that replace the existing ones.
- The Building Energy Management System (BEMS). This monitoring system will allow to better assess the building's energy consumption with the aim of applying operational improvements

Table 120 present the KPIs evaluated within M1.1.10.2 in CEM Claror Sport Center.

Table 120 Key Performance Parameter – CEM Claror - Lighting

Key Performance Parameter	Result	Units
Annual lighting electricity consumption on the building level	41459.8	kWh/year
Reduction of electrical consumption related to baseline for lighting	24.82	kWh/m^2
CO_2 emissions reduction due to change of lighting	0.0265	kt/year
Primary energy savings due to changes in lighting	178535	kWhP/year

The results obtained by the installation of the new condensing boiler during first semester 2018 are shown in Table 121. Savings are calculated considering only heating demand satisfied by the new boiler, i.e. excluding heating demand satisfied by the heat pump, which is considered in the assessment of the savings achieved by the heat pump.

Table 121 Key Performance Parameter – CEM Claror – Boiler*

Month	Boilers natural gas consumption	Thermal demand satisfied	Boiler seasonal efficiency	Savings	PE Savings	CO_2 emissions reduction
	[MWh]	[MWh$_t$]	%	[MWh]	[MWh$_t$]	[t]
January	110.19	111.35	100.6	32.7	39.1	8.3

February	128.49	122.52	94.8	28.8	34.4	7.3
March	111.48	107.6	95.9	26.6	31.8	6.7
April	57.44	51.83	88.6	9.1	10.9	2.3
May	46.53	41.02	85.8	6.1	7.3	1.5
June	35.64	30.75	84.6	3.8	4.6	1.0
TOTAL	**489.68**	**465.07**	**94.01**	**107.2**	**128.2**	**27.0**

*Results not validated

In regard to the electric heat pump with heat/cold recovery, the results obtained during the first semester are shown in Table 122.

Table 122 Key Performance Parameter – CEM Claror – EHP*

Month	Electricity Consumption, EHP	Global Efficiency	Share of RES in heating supply	Savings in Electricity and Natural Gas		Primary Energy Savings	CO_2 emisssion savings
	[kWh_e]	[%]	[kWh_t]	[kWh_t]	[kWh_t]	[MWh_t]	[t]
January							
February							
March							
April	11,163.1	3.82	31,506.9	- 2,112.6	31,771.5	34.12	7.44
Mai	13,019.8	3.82	36,690.2	-383.4	31,694.5	36.95	7.85
June	14,236.6	3.53	36,003.4	2,521.0	21,899.9	32.23	6.42
TOTAL	**44,773**	**3.62**	**117,3570**	**24.9**	**85,365.9**	**102.07**	**21.52**

*Results not validated

The following conclusions can be formulated at this stage:

- Lighting: existing lighting equipment was replaced with equivalent LED lamps. Taking into account the data collected during measurement campaign, mainly the power avoided, the yearly electricity savings obtained with the implemetation of this measure are expected to be 41.5 MWh, which is equivalent to 178,5 MWh primary energy savings and 26.5 tonnes CO2 emissions reduction. The results obtained are satisfactory and aligned to the estimation performed during the energy audit.

- Natural gas boilers: old inefficient existing boilers, with a seasonal performance of 77.9% (LCV), have been replaced by condensing boilers. During the first six months the seasonal performance of these new boilers has been 94% (LCV), thus obtaining an increase of 16% in the performance, which is equivalent to 107.2 MWh natural gas savings (in LCV), 128.2 MWh primary energy savings and 27 CO2 emissions avoidance. The results obtained are satisfactory and aligned to the estimation performed during the energy audit, as the seasonal performance expected was 92.8% (LCV). It is worth mentioning that global natural gas savings in the sports centre have been higher, since savings are calculated considering only thermal energy provided by the new condensing boiler and a percentange of the thermal demand is satisfied by the new electric heat pump with heat/cold recovery.

- Heat pump with heat/cold recovery: the previous chiller, only used for covering the cooling needs, was replaced with a new Swegon AZURA PRO S4 HE 22.4 electric heat pump that produces heating (up to 275 kW) and cooling (up to 224 kW). When this production is simultaneous, heat and cold are recovered. It works in heat mode or cold mode depending on the main demand. For example: during the summer it is in cold mode and during winter or during the night, it is in heat mode. During the first six months the seasonal global efficiency has been 3.62, which is equivalent to 102.1 MWh primary energy savings and 21.5 CO2 emissions avoidance. The results obtained are satisfactory and aligned to the estimation performed during the energy audit, as the global efficiency expected was 3.52.

Table 123 KPIs evaluated for M1.1.10.2 CEM Claror (Barcelona)

KPI	Baseline	Post- retrofit ting	Variation
1.1 Heating demand (MWh/yr) (pool not included, see 1.1.11)	591.71	591.71	0
1.2 Cooling demand (MWh/yr)	115.9	115.9	0
1.3 DHW demand (kWh/yr)	N/A	N/A	N/A
1.4 HVAC recovery system efficiency	N/A	N/A	N/A
1.5 Heat recovery ratio	0	36%	36% %
2. Equipment performances (boilers and heat pump respectively)	0.779 (HHV) /1.9 (Heat pump)	0.914 (HHV)/3.27 (Heat pump)	14 %/
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	74286	41459	-44 %
4. On-site electricity production (kWh/yr).	N/A	N/A	N/A
5. Energy savings (final energy- gas) (MWh/year)	1053	515.15	-42.8%
Energy savings (final energy- electricity) (MWh/year)	1012	890.9	-12%
6. Energy savings (primary energy)	3,710.4	3,406.8	-8.2 %
7. Share of RES in heating cooling and electricity supply.	0	69%	69%
8. CO2 emissions savings (t/year)	600	436	-27.3 %

Escola Sert

The active Measures in Melon District included:

- Installation of a 19.5 kWp façade-integrated PV plant for self-consumption.

Table 124 KPIs evaluated for M1.1.10.2 Escola Sert (Barcelona)

KPI	Baseline	Post- retrofitting	Variation
1.1 Heating demand (kWh/yr)	Normalized for a 30% higher occupation: 84,611	52 710	- 38
1.2 Cooling demand (kWh/yr)	102 802	119 925	-16.6
1.3 DHW demand (kWh/yr)	N/A	N/A	N/A
1.4 HVAC recovery system efficiency	N/A	N/A	N/A

1.5 Heat recovery ratio	N/A	N/A	N/A
2. Equipment performances.	Gas boiler:0.75 (HHV) Chiller: 2.2	Gas boiler:0.75 (HHV) Chiller: 2	N/A
3. Average electric energy demand of lighting system and other electricity uses (kWh/yr).	N/A	N/A	N/A
4. On-site electricity production (kWh/yr).	0	13060	- %
5. Energy savings (final energy) (kWh/year)	252 911	239 851-	-5%
6. Energy savings (primary energy)	607 745	576 361	-5%
7. Share of RES in electricity supply.	0	5.45%	5.45 %
8. CO2 emissions savings.(t CO2)	90.29	85.63-	-5%

Potential for full scale implementation

Technical, economic and social feasibility

See Measure M1.1.10.1 for general comments about this type of Measures.

Applicability of the Measure to different cities

See Measure M1.1.10.1 for general comments about this type of Measures.

M1.1.11 - Efficient and smart climate shell and equipments refurbishment for buildings: pool Measure

Introduction

According to the evaluation plan (D5.1), this Measure has been implemented to reduce swimming pool area energy demand.

The key performance indicators initially expected to be evaluated are:
1. Decrease of heating demand due to heat pump for dehumidification compared to baseline total heating demand (%).
2. Decrease of heating demand due to pool insulation compared to baseline total heating demand (%).
4. Heat recovery ratio of shower waste water heat recovery system (%) and heat recovery system annual total COP.
6. Decrease of energy demand of swimming pool due to all Measures compared to baseline case (%).

As explained in the following, the KPIs have been estimated using building models.

Barcelona

Industry partner	Contact person	Validation partner
Naturgy	Helena Gibert (Naturgy)	KTH-EGI

Roof insulation and new dehumidifier with heat recovery have been installed in the CEM Claror building. The Measures that have been carried out in this building are:

- As passive Measure, the roof over the main pool hall has been refurbished by adding a layer of insulation within the dropped roof to reduce losses through this surface.
- The heating demand of the pool hall has been further reduced by replacing the current dehumidifier with a new machine that consumes less electricity and includes a thermal recovery module.

The baseline in CEM Claror consisted in data from utility meters and other available data (i.e. occupancy, etc.). Due to a lack of consistent data to build a reliable mathematic model of the baseline, a hybrid model using both real and simulated data was used to build it.

The baseline model has enable to identify the correlation between energy consumption and the key independent variables that affect this consumption. Energy savings has been then consistently calculated taking into account the adjustments (routine and non-routine) needed.

Concerning weather conditions, one of those variables impacting energy consumption, it has been important to take exactly the same source before and after the implementation to avoid inaccuracies. Moreover, as no meteorological sation was available in the building, the source used has been representative of the location.

The chosen weather source for the adjustments is AEMET, which is the Spain's Meteorological Agency operating under the Ministry of Agriculture, Food and Environment. It provides reliable data and all the variables needed. The weather station is located in the surroundings of Barcelona, concretely in the Fabra's Observatory (Latitude: 41˚ 25' 6'' N - Longitude: 2˚ 7' 27'' E – Altitude: 408 m). The weather data that this source provides is:

- Average temperature
- Rainfall
- Minimum temperature
- Hour of minimum temperature
- Maximum temperature
- Hour of maximum temperature
- Direction of the wind
- Wind speed
- Gust
- Gust hour

The parameters measured are:

- Pool space thermal demand measured at dehumidifier heating coil with a thermal meter in kWh
- Electricity consumption by the dehumidifier measured with an electricity meter in kWh

The data is collected from the BEMs installed in the different buildings and accumulated in the Naturgy's platform. Figure 86 shows an example of the data collected for the electricity consumption of the dehumidifier:

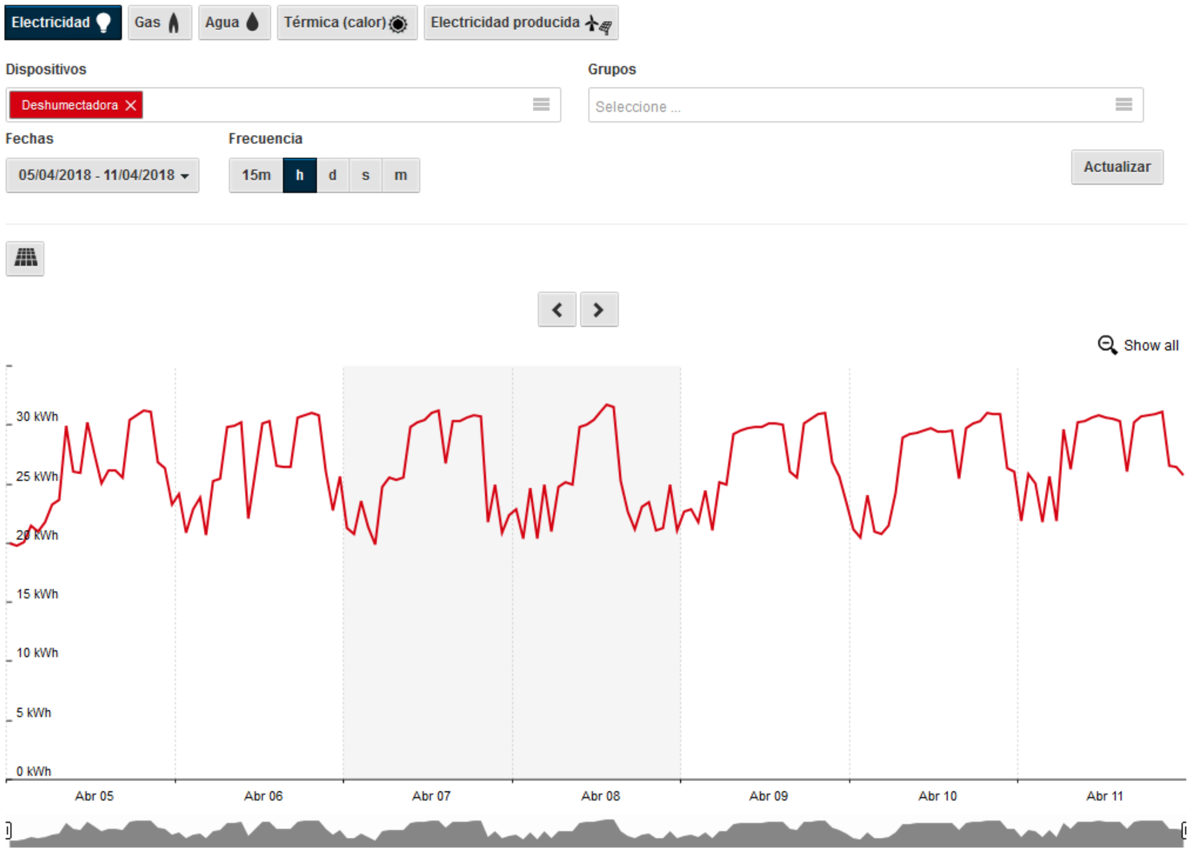


Figure 86: Hourly electricity consumption of the dehumidifier monitored and collected by BEMS – CEM Claror

Table 125 KPIs evaluated for M1.1.11 CEM Claror (Barcelona)

KPI	
Decrease of final energy consumed due to new dehumidifier and pool insulation	31%
3. Decrease of heating demand due to night covers of the pool compared to baseline total heating demand (%).	N/A
4. Heat recovery ratio of shower waste water heat recovery system (%)	N/A
5. Heat recovery system annual total COP.	3.27
6. Decrease of heating demand of ventilation due to heat pumps in ventilation system compared to baseline ventilation heating demand (%).	N/A
7. Decrease of energy demand of swimming pool due to all measures compared to baseline case (%)	31%

Potential for full scale implementation

Technical, economic and social feasibility

Indoor swimming pools are abundant all over Europe and constitute a complex thermodynamic system, with demands for heating at different temperature levels as well as cooling, particularly for dehumidification. For this reason, there are many possibilities of heat recovery, particularly using heat pumps. They also consume a lot of energy, and therefore the potential for energy savings is high. High indoor humidity in cold climates will cause condensation onto the inside walls and windows. In addition, humans tend to favor relative humidity around 50%, with a large range. On the other hand, high relative humidity, with a dew point close to the water temperature of the pool, will decrease the diffusion of water from the pool into the air. That diffusion will require new water to be added and to be heated up. As the water evaporate from the water surface, the energy associated with the vaporization process is taken from the water pool, which then requires external heating in order to maintain pool temperature at the desired level.

If the pool water temperature is higher than the surroundings, thermal energy will conduct through the wall of the pool. This rate of heat transfer will be decreased with added insulation. In order to maintain a good water quality of the pool water, the visitors are usually instructed to shower in advance of bathing in the pool. After the bathing, usually all visitors also shower to clean themselves from any cleaning agents present in the pool water. Significant amount of shower water is used in these facilities.

The type of Measures implemented in CEM Claror are not limiting the user experience and the customers would not notice them. Thus there is hardly any risk for complaints. The energy savings obtained for other installations may incorporate the local climate and user pattern.

Applicability of the Measure to different cities

The type of Measures could be implemented anywhere in Europe. However, there may be differences in available forms of energy supply (primarily electricity, gas and district heating), and differences in the relative prices of these forms. This may influence the replicability at different geographic locations.

M2.1 – integrated multi-modal transport for construction materials/logistics center in slakthusområdet

Stockholm

Industry partner	Contact person	Validation partner
Carrier, CSLogistics	Rasmus Linge	KTH-EGI

Definitions

Road minutes (RM): mesure of how much time a vehicle spends in traffic to cover a certain road link

Logistic center (LC): Site that enables the construction site to deliver bulk or small deliveries and to deliver them consolidated just in time

Delivery Container: A Container with digital locks for 24h deliveries

Consolidated deliveries: deliveries of goods from different suppliers going in a single carrier to one or more recipients at the construction site

Degree of Consolidated deliveries: The effect in percent of the proportion between incoming and outgoing goods (parcels) at the LC. (total incoming goods to LC – outgoing goods from LC)/total incoming goods to LC = X%

Description

The project "Trikåfabriken" consists in a construction site where Arcona AB refurbished and built 2 additional floors for the Real-estate company Faberge.

About 30% (2981 parcels) of the total amount of all the material for this refurbishment went first to a Logistic center where it got consolidated with other materials and delivered just in time to the construction site when it was needed. Also, bulk deliveries got delivered and that could be divided into consignment for daily works.

The comparison was made between the actual output of kilometers, energy and CO2 in a "last mile" perspective and a scenario (base-line) where all material in the same proportion of consignments but with one vehicle for each one.

The result differs most strikingly in traffic reducing numbers and CO2 reduced emissions. The total amount of kilometers used for transports is quite equivalent between the two modes.

The impact on traffic is improved considerably mostly in terms of flow, since the traffic volume is considerably reduced in the 2km area around the site. An up scaled scenario where we have to reduce emissions and energy by 60% is also demonstrated in the results.

Each delivery to the Logistic center has been booked and all parcels that have been called off and coordinated from the specific logistic (through a software called Myloc). All data on every consignment that has been planned with certain light/heavy trucks have been recorded and aggregated into Traffic minutes, kilometers energy and emissions in accordance with road section described below

All registration of the road sections that deliveries have traveled is limited to a last mile perspective according to illustration road section LC (inside black circle) Road sections measured in the Base-line is illustrated in road section base-line (inside black circle). With the data from the logistic software and the road-links described we get the result in RM, kilometers energy and emissions.

The intentions of the Measure have been fulfilled except for evaluation of train deliveries as first intended since Carrier moved from the initial terminal with offloading capacity for freight trains. In contrast a digital delivery container was added to handle small load deliveries which are normally complicated and demanding to distribute via a Logistic Centre.

Baseline

The baseline has been evaluated considering a scenario where all material in the same proportion of consignments, and called off from the logistic center, had to be carried with multiple vehicles, which is the case on a conventional construction site. Then it follows that each consignment can count as one delivery on a conventional site.

Methodology

Each delivery to the Logistic center has been booked and all parcels that have been called off and coordinated from the specific logistic (trough a software called Myloc). All data on every consignment that has been planned with certain light/heavy trucks have been recorded and aggregated into Traffic minutes, kilometers energy and emissions in accordance with road section described below.

All registration of the road sections that deliveries have traveled is limited to a last mile perspective according to illustration road section LC (inside black circle) Road sections measured in the Base-line is illustrated in road section base-line (inside black circle). With the data from the logistic software and the road-links described we get the result in RM, kilometers energy and emissions. The evaluation is not taking into account the return from the constructions site in regard of reasons explained below.

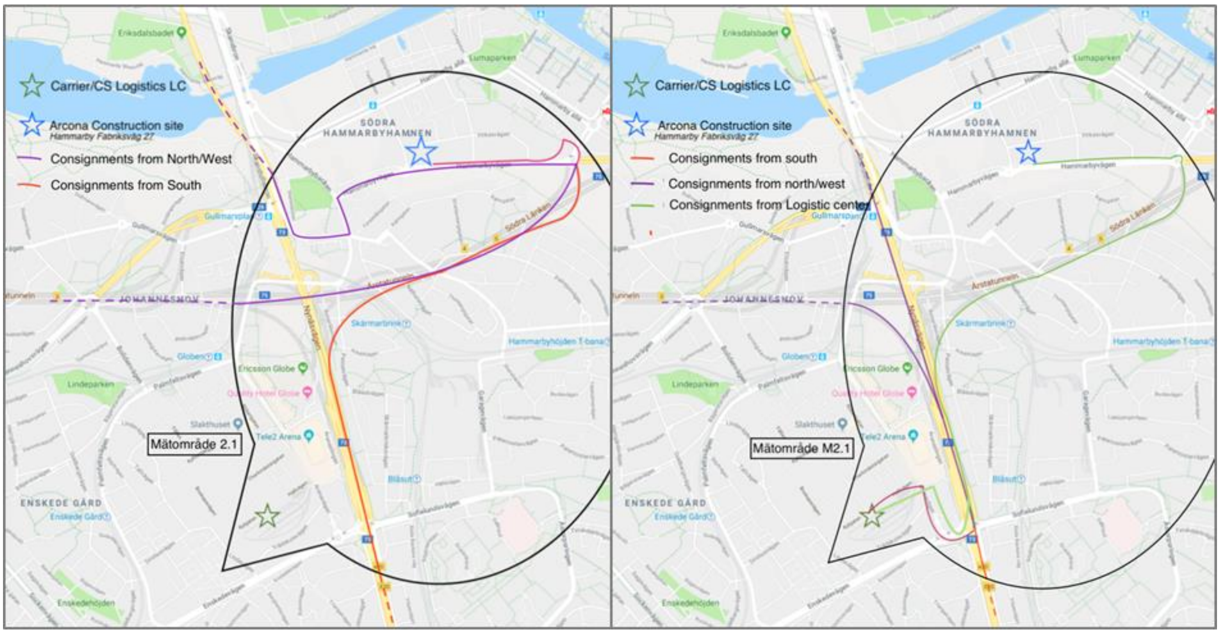


Figure 87 Road sections: Baseline (left), with logistic center (right)

Results

The intentions of the Measure been fulfilled except for evaluation of train deliveries as first intended since Carrier moved from the initial terminal with offloading capacity for freight trains. In contrast a digital delivery container was added to handle small load deliveries which are normally complicated and demanding to distribute via a Logistic Centre.

Table 126 Results for M2.1 (Stockholm)

Emissions and energy usage (Tank to Wheel)						
Scenario	**Total Fuel consumption L**	**Total emission Kg Co2 0630-1830**	**Total emissions KG Co2 1830-0630**	**Total KG Co2**	**Total Energy use MJ**	
Baseline	419,5	1090,7	0	**1090,7**	1625,7	
With logistic center	397	386,4	212,7	**595,4**	1574,4	

The most important step to reduce emissions in the measure is to use 100 % renewable fuels for all 259 deliveries from the LC to the construction site. This gave us a total of 50,8 kg CO2 whereas if this would have been EN590 (Swedish average described in table 1) this would have given us 455,3 kg CO2. A small but interesting amount of reduction was achieved by transferring 169 deliveries (by using delivery container) to nighttime with a fuel consumption reduction of 8,2% compared to daytime.

Table 127 Impact on traffic for M2.1 (Stockholm)

Impact on traffic (last mile Illustration 1,2)						
Scenario	**TM 0630-1830**	**TM 0630-1830**				
Baseline	4260					
With logistic center	1953	845				

The impact on traffic is considerable compared to the baseline scenario, deliveries had to spend 4260 RD in daytime (0630-1830) to deliver the goods that the implemented measure had to use 1953 RD in daytime and were 845 RD could be transferred to night time deliveries (1830-0630).

Degree of Consolidated deliveries

As is discussed in different studies, and 3PL agents in the branch often holds that a high degree of Consolidated deliveries is a value in itself and often find no need to explain why it has large positive effect on traffic and emissions. In our evaluations we find this less self-evident. In the implemented measure the degree of Consolidated deliveries was relatively low only 24,3% (259 deliveries to LC – 196 deliveries to site)/259 = 24,3% (see Table 2). The reason for this is that we need to receive as few deliveries to LC as possible and deliver goods in full loaded trucks to site, without crowding the site with goods and fail to deliver just in time which is of highest importance for the production at the construction site. This is discussed further below.

What would it take to reduce emissions by 60%?

Below is an up scaled scenario, in almost exact proportions as the implemented measure above, that illustrates one way to follow in order to reduce emissions to as much as 60% (Traffic flows is not demonstrated in this example). The most important part is 1) Bulk deliveries to Logistic center to keep numbers of deliveries to LC down and at the same time provide the site with just in time deliveries that the production requires at different phases of production. I.e. all different entrepreneurs at the construction site need to order their preferable quantity of parcels in every consignment (just in time deliveries), so the site doesn't get overloaded at the same time we have to fill up the trucks to keep number of deliveries down. This is possible with the LC where we can receive bulk deliveries and then consolidated many different small consignments in the same delivery. 2) Change to renewable fuels. The primary step that is different compared to the implemented measure is that in this scenario the deliveries to the delivery container at night time is contracted on 100% renewable fuels only. One minor difference is that with 100% of goods going to LC (or via delivery container) it would be possible to attain higher degree of consolidation and to skip light truck deliveries that has been necessary in the case of only 30% of goods going via the LC.

Table 128 Scenario: 60% emission reduction for M2.1 (Stockholm)

Output conventional logistic 100% of deliveries (baseline)							
Vehicle		**Deliveries to site**	**TM 0630-1830**	**TM 1830-0630**	**KM 0630-1830**	**KM 1830-0630**	
Heavy truck/crane truck EN590		1804	10 824	0	3969	0	
Light truck EN590		563	3378	0	1239	0	
Heavy truck/crane truck EN15940							
Light truck EN15940							
Total		2367	14 202	0	5207	0	
Output 100%with LC and consolidated deliveries and delivery container (consignment to delivery container 100% EN15940)							
Vehicle	**Deliveries to LC**	**Deliveries to site**	**TM 0630-1830**	**TM 1830-0630**	**KM 0630-1830**	**KM 1830-0630**	
Heavy truck/crane truck EN590	863				1381		
Light truck EN590							
Heavy truck/crane truck EN15940		656	3936		2165		
Light truck EN15940		563*		2815*		1126*	
Total							

*563 deliveries to delivery container during 1830-0630 contracted on 100% EN15940 or equal.

Table 129 Results on 60% emission reduction for M2.1 (Stockholm)

Emissions and energy usage (Tank to Wheel)						
Scenario	**Total Fuel consumption L**	**Total emission Kg Co2 0630-1830**	**Total emissions Co2 1830-0630**	**Total KG Co2**	**Total Energy use MJ**	
Baseline	1399	3637	0	**3637**		
With logistic center	1235	1223	60	**1283**		

Economic feasibility

The implemented measure is not economically sustainable for a single agent when it's isolated to just one site. Our number shows that we need at least 4 projects of the same magnitude to reach over break even, this will be elaborated further in the economic evaluation.

Possibility to replicate the Measure

The measure is possible to replicate, and the evaluation method is possible to develop further by making it even more refined. There is some aspect to consider, first of all, construction sites and buildings are by few exceptions unique in design, execution and conditions internally and externally. What is important to take into consideration in this particular case is that this project is an annex and restoration/modernization site. If this measure was going to be implemented on a new construction with prefabricated deliveries for foundation and frame etc. the result would probably be different because of the heavier load on these initial deliveries that has to be considered. In this project storage of goods on the construction site was very limited (which often is the case in urban projects) this means that the direct deliveries in a baseline scenario would have been large in number and small in terms of filling degree in the trucks offloading at the site. This is obvious if we look at the high number of consignments needed in baseline and the actual amount of deliveries to the logistic center. This tell us that the project has taken the opportunity to do bulk deliveries that can be delivered just in time to site.

Conclusions

The evaluation shows that even though the total amount of kilometers travelled is quite similar between the two scenarios there is improved traffic flows and reduction of Co2 emissions in using a LC. The reduction of emissions is in large amount connected to the fact that the trucks travelling from the logistic center were all using 100% EN15940 which in theory could be possible to solve in different modes also (for example, in theory, contracting suppliers on the term that they only could run their consignments on 100% EN15940). With a LC even better result could be attained by transfer traffic to more favorable time of the day (1830 – 0630) this can be worked out by complementing the delivery container and the logistic center delivering the great majority of goods at evenings/nighttime with special teams carrying the goods to its predetermined position on site. One implementable scenario based on the data in this particular measure above is shown in Table 128.

To have the opportunity to have just in time deliveries to the construction sites can be of very great value but it's a much larger field to study than this measure can handle, what we can say in this report that has support of precedent studies is that each reception of a delivery (i.e.

receiving and unload one vehicle) is associated with a certain cost, which is described in *Logistikmätning enligt SCOR-modellen vid Peab och kvarteret Bergstrollet i Motala.* The study shows that on an average each reception cost approx. 2888kr. The result presented shows that we have reduced the number of deliveries to the site by 345 (541 deliveries in base line to 196 in the measure) This is due to bulk deliveries and consolidated deliveries from LC to site and deliveries to the delivery container (that is placed outside the discharging zones). In this study we have not taken into account the return of the vehicle delivering to site and LC the reason for is the complexity of getting this information from all different kinds of supplier and haulage firms. A requisite to attain the vital combination of bulk deliveries and consolidated deliveries just in time for each entrepreneur at site is a logistic planning software sophisticated enough to handle digital representation of parcels and units starting from supplier and manufactures all the way to the predetermined position on site. To implement this sort of planning is the main obstacle for logistics in the construction branch.
Important to mention is the unforeseen synergy effect with other Grow Smarter Measures in this case from M9.1 where the supplier of the technique for the delivery room also developed this solution for the delivery container that has been implemented with good results in this Measure. The delivery container made it possible to transfer 169 deliveries in this project to nighttime. The concept of delivery container that has been proven as a valuable concept in this measure is now an important tool for CSL as Veidekke Sverige's affiliate Logistic company and will be offered to all construction sites in Sweden.

M3.1 – Smart, energy saving tenants

Introduction

The aim of the Measure is to utilize home energy management systems to achieve energy savings and increased home comfort in households.

Stockholm

Industry partner	Contact person	Validation partner
Fortum Markets	Larz Pohl	KTH-SEED

Fortum Markets has developed a home energy management system concept called the Active House (AH), which allows tenants to monitor and control their energy consumption through in-home displays.

Active House solution is a Smart Home solution by which the energy (electricity and hot water) consumption is controlled. Dimmers, plugs and sensors are coupled to a hub (called Tingco Box) and the data from those devices are shown on a tablet. Fortum has installed its Active House solution in 54 apartments in south of Stockholm, in an area called Årsta. The installation has been finalized in September 2017.

Active House reduce energy (electricity and hot water and heat) consumption in each apartment through increasing awareness.

This measure has been implemented by installing monitoring equipment and a tablet that shows how much electricity the tenants are using; how much it costs – right now or on a yearly basis. The implementation of this measure involved several activities: get consent by tenants, preparation of the cabinets to be installed in each apartment, integration of the sensors and dimmers to the cabinets, installation and adjustments of the tablets in the apartments, and teaching the tenants to use Active House. During implementation, all the installation works were supervised by Fortum as a single stakeholder and Fortum's common subcontractors were selected (equipment providers, platform developers, and installers).

Figure 88 Scheme of Active House solution (M3.1 Stockholm)

Table 130 Summary of the activities carried out within M3.1 in Stockholm

Activity	Stakeholders and their contribution
Ordering and preparation of central cabinet for the main Tingcobox in the basement	Fortum orders the cabinets from Alcadon AB (the cabinet manufacturer)
Make adjustments on cabinet for the Tingcobox and internet modem in each apartments	Fortum orders the cabinets from Garo AB (the cabinet manufacturer)
Ordering of electricity meters and delivery to Garo AB	Fortum orders them and deliver to Garo AB
Design and manufacturing of the Tingcoboxes	Fortum develop this internally
Delivery and installation of Tingcobox and wiring between meters and Tingcoboxes	Fortum deliveries Tingcoboxes to Bravida and they did the installation
Delivery and installation of dimmers	Fortum deliveries the dimmers to Caverion and they did the installation
Integration of the sensors and dimmers to the Tingco box	Fortum together with external consultants
installation and adjustment of the tablet	Fortum carried out this task

Due to the implementation of GDPR Fortum upgraded the solution to a new compliant version with a technical platform based on Amazon servers.

Figure 89 Example of monitoring platform installation (M3.1 Stockholm)

Figure 90 New dashboard with real-time visualization of energy usage and temperature (M3.1 Stockholm)

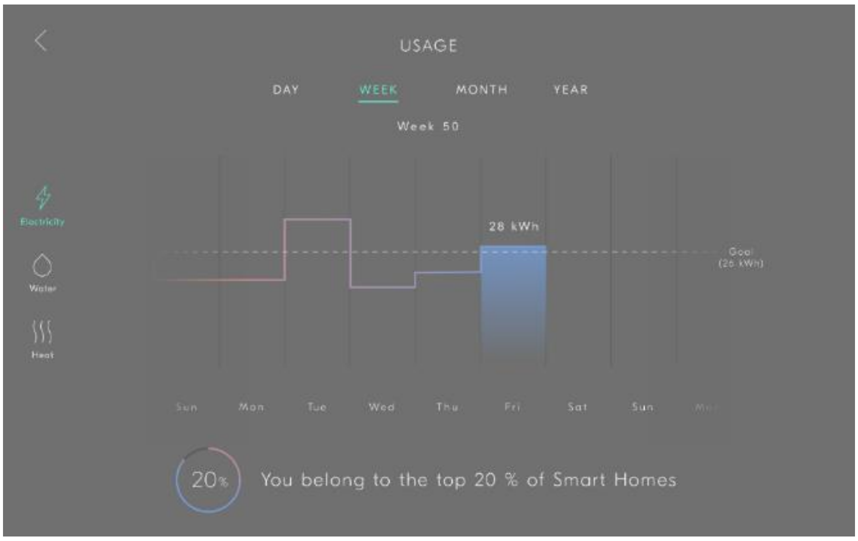


Figure 91 Monitoring of electricity, hot water, heating and temperature (M3.1 Stockholm)

Evaluation procedure (M3.1 Stockholm)

Household-individual electricity consumption data on an hourly level has been collected from all the Active House apartments. However, Stockholmshem could only deliver reference values on a building level and on a monthly basis. Hence, the analysis was limited why not all KPI's could be calculated, see Table 2 below.

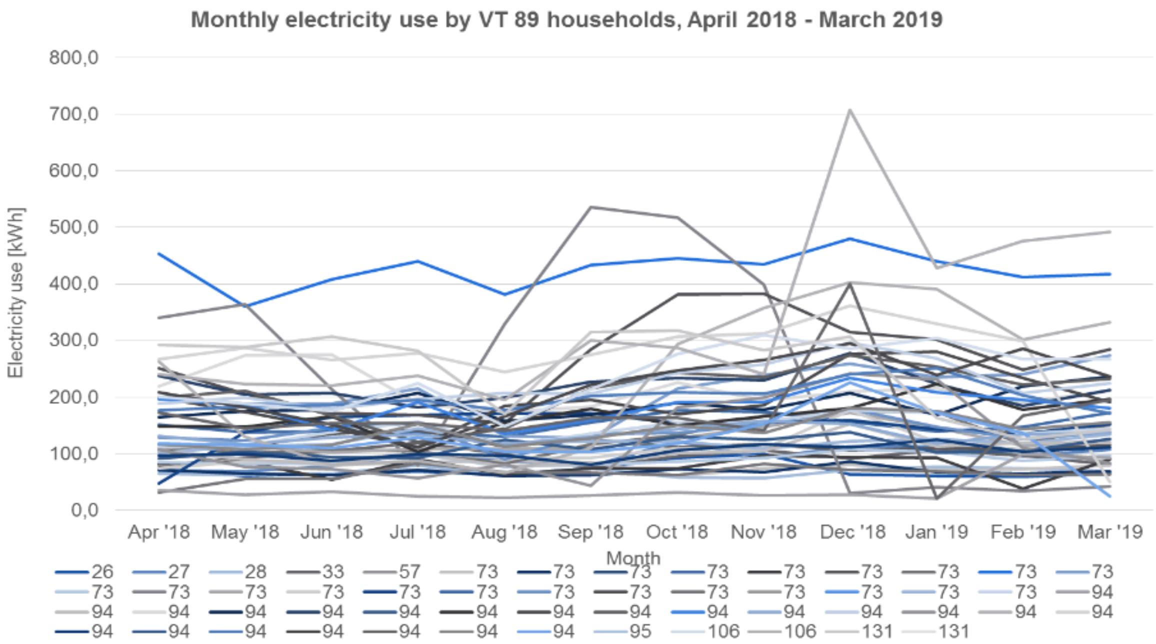


Figure 92 Example of monthly electricity use. April 2018 VT 89 households

Significant differences can be seen in the usage of electricity over the year, with some apartments of very high electricity consumption and some very low. However, it is shown that the consumption level not necessarily is connected to the size of the apartment, as the largest and lowest usage are in the same smaller size of m2.

Table 131 KPIs evaluated for M3.1 (Stockholm)

KPI	Baseline	Post implementation (yearly average household consumption)	Variation
1. Electricity consumption (kWh and liters per household)	***	1 932 kWh	***
2. Hot tap water consumption (kWh and liters per household)	***	36 556 liters	***
3. Load shift level (%)	***		
4. Climate impact potential of changes in energy consumption	***		
5. Perceived change in household behavior and average system availability	***		
***Not applicable due to limitations in data availability			

Technical feasibility (M3.1 Stockholm)

Installation of SmartLiving is technical feasible in most apartments and houses, most convenient is to do it together with other bigger renovations or in new builds.

Social feasibility (M3.1 Stockholm)

Within this Measure we have a high representation of elderly people that weren't keen on the whole renovation and the increase of the rent. The users have started to understand and accept the impact of the proposed solutions.

Fortum did several visits on site to educate and help them to understand the scope. Fortum employees, students from KTH and Fortum helpdesk helped the user engagement process.

Possibility to replicate the Measure (M3.1 Stockholm)

The measure is easy to replicate as it uses standard components and installation methods.

Conclusions (M3.1 Stockholm)

A larger number of apartments was necessary to correctly interpret the results. To be able to utilize the full potential of these systems a larger scale and a longer period implementation is needed.

The user engagement and selection process is definitely fundamental for this kind of Measure.

Barcelona (Virtual Energy Advisor)

Industry partner	Contact persons	Validation partner
IREC	Alaia Sola, Cristina Corchero, Manel Sanmartí	KTH-SEED

In March 2015, the City Council of Barcelona launched the campaign "Carrega't d'energia", based on an energy visualization platform (Virtual Energy Advisor), to decrease the electricity consumption in the residential sector. It was the first example in the City of Barcelona of energy policies focused on citizen behaviour.

The campaign has been carried out by means of a web platform and mobile App, with the following goals:

- To provide information on the renewable energy potential available on the user's rooftops.
- To provide information on the user's electricity consumption and give tips on how to reduce it (Virtual Energy Advisor tool).

The Virtual Energy Advisor features include:

- Visualization of electricity consumption and consumption profiles.
- Tips and advices on how to reduce the electricity consumption.
- Opportunity of becoming part of a virtual community to exchange experiences.
- Comparison of the current consumption with consumption of previous years.
- Comparison of the user consumption with typical consumption from other users with similar characteristics, in order to promote energy efficient behaviour.

The evaluation of this Measure is based on real measured data of the average electricity consumption and emissions of dwellings in Barcelona, and its relationship with dwelling surface and number of occupants.

The visualization platform was installed on different dates at each household. The two significant batches of users signing up occurred in March 2015 and in November 2015 (Figure 93).

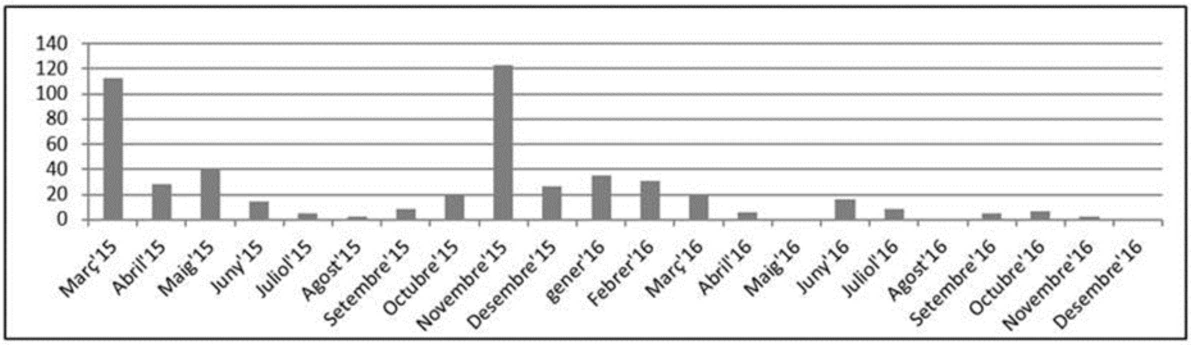


Figure 93 Number of new users signing up to the Virtual Energy Advisor platform each month

Within the Barcelona Municipality campaign, data have been gathered and analyzed based on electricity invoices from 378 dwellings.

Baseline has been defined as the consumption data between February 2014 and January 2015 because the first platforms started being operative in March 2015. The post-measure data have been defined as the consumption data between September 2015 and August 2016, although some dwellings joined the platform along this period.

The annual CO2 emissions of the Spanish electrical mix are higher for the defined baseline period compared to the defined post-measure period (Table 132).

Table 132 Average annual emissions of the Spanish electrical mix (Virtual Energy Advisor, Barcelona)

	Baseline	Post-Measure	Reduction
Average annual emissions of the Spanish electrical mix (g CO2/kWh)	248.88	227.60	8.6%

Results

Figure 94 shows the comparison between 2014, 2015 and 2016 of the monthly average electricity consumption considering the average dwelling consumption of each year. Figure 95 shows the same comparison in terms of electricity consumption per square meter and Figure 96 shows the results in terms of energy consumption per tenant.

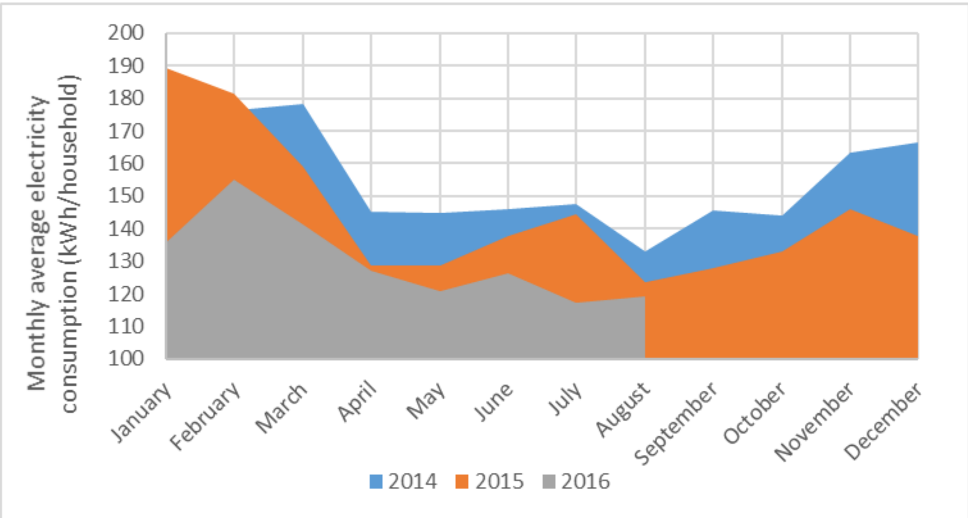


Figure 94 Comparison between 2014, 2015 and 2016 of the monthly average electricity consumption (average dwelling)

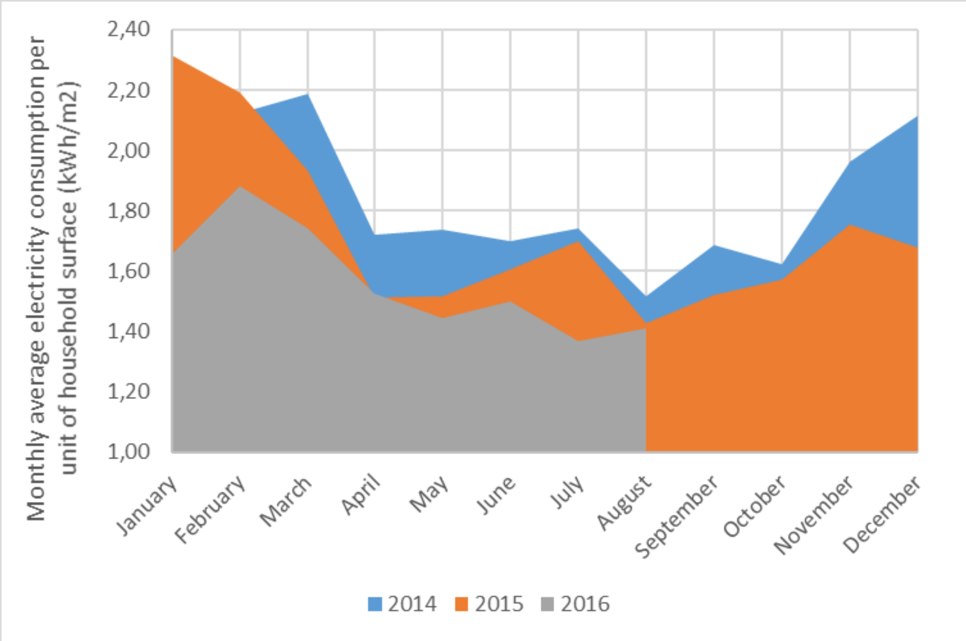


Figure 95 Comparison between 2014, 2015 and 2016 of the monthly average electricity consumption per square meter

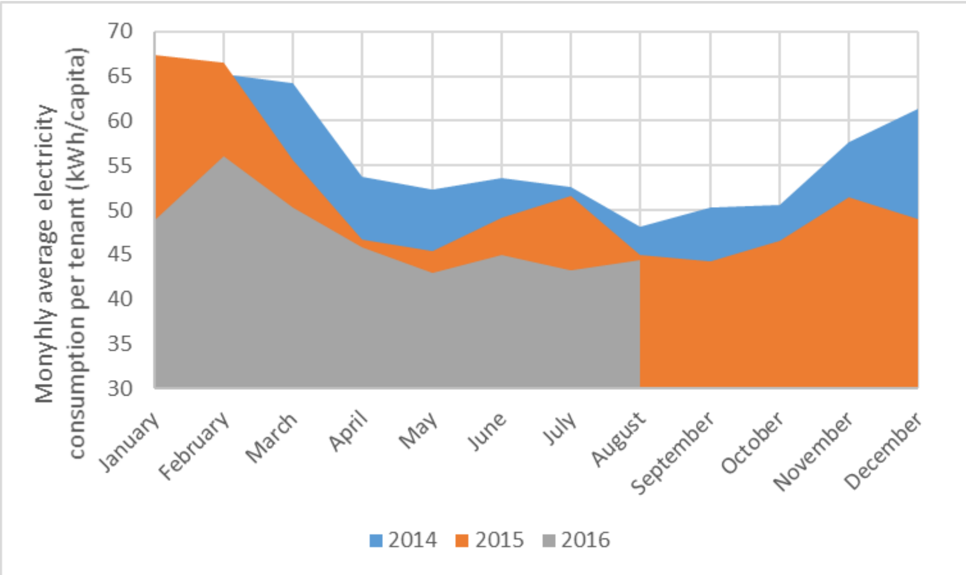


Figure 96 Comparison between 2014, 2015 and 2016 of the monthly average electricity consumption per tenant

The overall comparison between the baseline and the post-measure evaluation are shown in Figure 97. Figure 98 shows also the Energy Signature chart considering the average dwelling consumption and the outdoor average temperature in Barcelona.

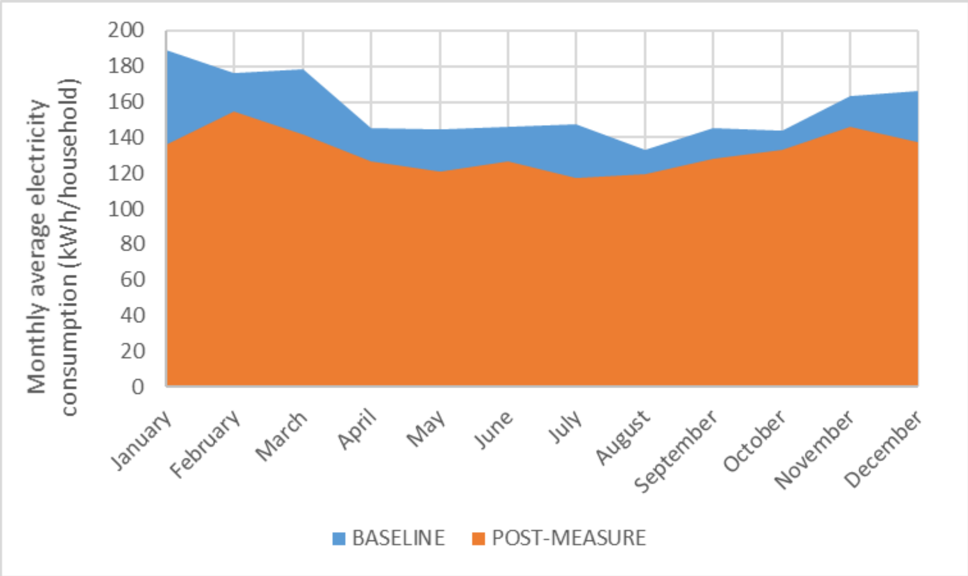


Figure 97 Comparison between baseline and post-measure results of the monthly average electricity consumption per household

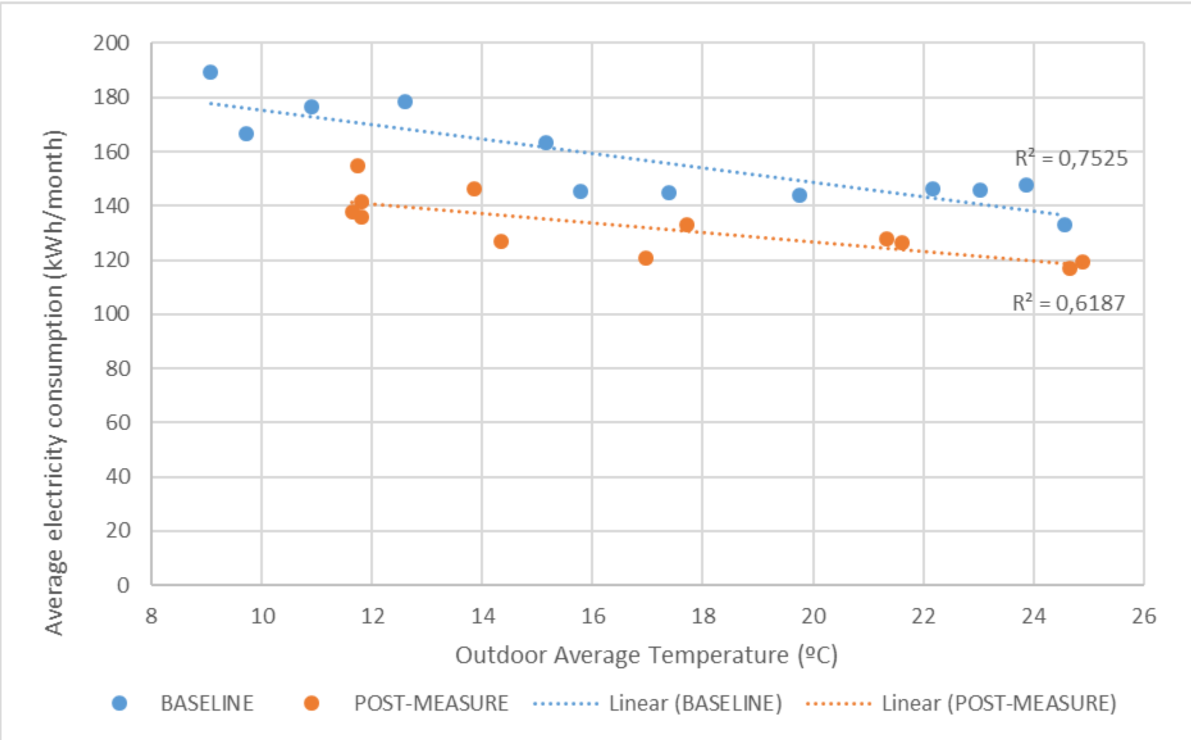


Figure 98 Comparison between baseline and post-measure results of the monthly average electricity consumption per household

Finally,

Table 133 shows the KPIs evaluated for the Virtual energy Advisor platform, according to the criteria established in the Evaluation Plan.

Table 133 KPIs evaluated for M3.1 (Virtual Energy Advisor, Barcelona)

Monthly average electricity consumption	Baseline	Post	Variation
Per household (kWh/household)	1880	1587	-15.6%
Per household size (kWh/sqm.)	22.4	19.0	-15,0%
Per tenant (kWh/capita)	677.2	568.1	-16.1%
Energy savings per household (kWh/household, %/household)	292,8 (15.6%)		
Peak load reduction per household (kWh/household,%/household)	-		
Emissions from electricity consumption	**Baseline**	**Post**	**Variation**
Per household (kg CO2/household)	459,9	361,1	-21,5%
Per household size (kg CO2/sqm.)	5,4	4,3	-20,6%
Per tenant (kg CO2/capita)	164,7	129,0	-21,7%
CO2 reductions due to energy savings per household (kg CO2/household, %/household)	98.8 (21.5)		
CO2 reductions due to peak load reduction per household (CO2/household,%/household)	-		

Technical feasibility

Connectivity issues have led to additional costs not initially foreseen. Another important barrier encountered during implementation of this measure is the data confidentiality constraints to evaluate the individual dwellings electricity consumption data.

Economic feasibility

This measure is not intended to be self-financing, as the aim of the Municipality is to both focus energy policies on citizen awareness and collect electricity consumption profiles to foster suitable energy policies for the city.

Social feasibility

Barcelona Municipality launched an on-line platform in 2015 as a pilot with the aim of decreasing the electricity consumption in the residential sector of the city. It was an innovative measure within the Municipality, as it was the first time that energy policies were focused on citizen actions.
With this tool, the Municipality is also able to gather information on the electricity consumption patterns of citizens based on the city district and other variables, which may help in fostering suitable energy policies for the city.
In order to attract new users and make the campaign to succeed, dissemination actions are of big importance and were a significant part of the work done by the Barcelona Energy Agency.

Once every month, the user received a Newsletter to the specified email address together with a report that indicated the expected cost of the coming user's electricity bill. It also told the user whether an energy saving had been achieved or not, and advices to save more energy.
The Communication Department of the Municipality disseminates the tool through the media.

The Environmental Education Department of Barcelona City Council carried out many workshops around all the districts of Barcelona. They are local workshops on energy savings, efficiency and energy self-sufficiency, and they always explained the tool and encouraged people to participate in the program.
It must be highlighted that a connection between the communication campaigns and the number of registered users has been observed. The months of March and November in 2015

were months with a higher number of registered users coinciding with released media communications. Since 2016, the registration of users showed to be quite constant and it mainly coincides with local workshops.

Replication potential

In order to avoid extra costs due to both sub-meter device purchase and connectivity issues, a proposal presented by the Municipality for future implementations is to obtain the consumption data directly from the digital smart meters operated by the DSO with an agreement. However, this solution is only feasible with new national regulations.

In Spain, digital meters are compulsory from 1st January 2019 on for all consumers below 15 kW of contracted power. Nowadays, the information regarding the hourly measurements by the digital meters is confidential and accessible only for the consumer, who is theoretically allowed to give access to it to third parties. However, in reality there is no regulation that establishes the technical and quality conditions in which the transfer of data to a third party can be carried out in a systematic, simple and scalable way. One has to currently use an FTP to access the data, as it is done by the consumer’s retailer, but the process is still too manual and the assignment of permits is not well established. Therefore, in practice, it becomes difficult to scale this solution by using data records from official smart meters in Barcelona.

It must be acknowledged that data confidentiality issues arose when the measured energy consumption data of the participant dwellings was to be evaluated. In order to avoid data privacy issues, it is recommended to include this discussion/agreement from the very beginning of the project design.

Conclusions

The electricity annual consumption of the average household has shown to be 15% lower during the period when a significant share of dwellings were using the energy consumption visualization platform compared to the baseline period (when no dwelling had signed up yet to the platform).

Although the overall decrease in electricity consumption may not be only attributed to the behavioral change of tenants, the use of this tool has proven a quantifiable impact in dwelling electricity consumption patterns. In terms of CO_2 emissions, the sample utilized in the present study has shown an average reduction of emissions of 21.5% (annual basis) originated from the reduction of the electrical consumption of the dwellings.

The tool has helped tenants that already showed an interest in energy efficiency to gain and share knowledge that was often applied to reduce the electricity consumption at home. However, it should be acknowledged that a more extensive use of the present visualization tool among other types of users (less motivated and proactive users) would not most probably lead to such a noticeable drop in dwelling electrical consumption as in the present case.

Barcelona (M3.1.3)

Industry partner	Contact person	Validation partner
Naturgy	Helena Gibert (Naturgy)	KTH-SEED

A Home Energy Management system (HEMS) has been designed and developed in the framework of GrowSmarter project. The main goal of the HEMS designed is to provide to the customer detailed information about its energy consumption and indoor conditions, like the temperature. Furthermore, the HEMS allow to the customer to control the boilers and some household appliance through a mobile APP. The fact to provide under the same platform the data monitored and control gives to the customer the opportunity to be more self-sufficient in its energetic consumption.

HEMS is being installed in the dwellings interested of the following buildings: Canyelles, Ter 31, Lope de Vega 111, and Sibelius 3. Moreover, HEMS will be installed in Meridiana 141 and a campaign of volunteers in GNF has been carried out with the objective to test the HEMs in different locations and environments.

Regarding evaluation, the GNF highlights that the same dwellings that have HEMS installed are the same dwellings that have participated in other Measures of GrowSmarter. This means that a comparison between the consumption pre-implementation and post implementation of the dwellings to evaluate the impact of HEMS does not have much sense because different Measures influence the reduction of the energy consumption. For that reason, the evaluation of this Measure will be based more on surveys, which allow to evaluate the customer experience about the devices, functionalities and usability of HEMS.

Some KPIs have changed compared to the initial plan in order to carry out a precise evaluation with the data available. The new set of KPIs is based more in data from surveys to evaluate the customer experience than in the data monitored. The reason for that change is because it is not possible to evaluate directly the savings achieve with HEMs only measuring the consumption before and after the implementation. The evaluation will be based more on the usability of HEMs, what information supply to the customer and on the user experience

Canyelles

Figure 99 shows the customer opinion about the HEMs device.

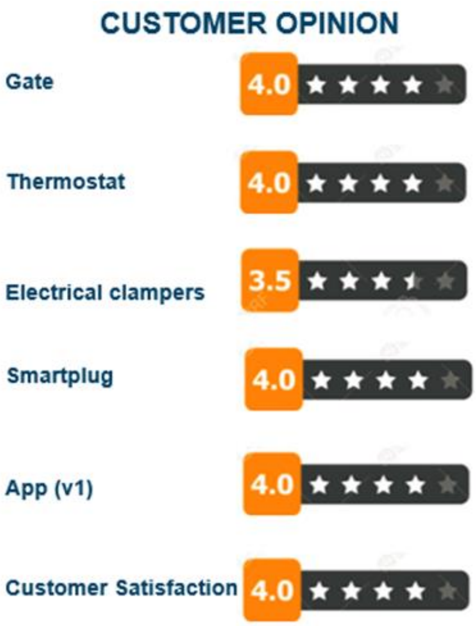


Figure 99 Customer opinion about the devices, app, and usability of HEMs in Canyelles

Table 134 KPIs evaluated for M3.1 Canyelles (Barcelona)

Energy consumption	Baseline	Post	Variation
Per household (kWh/household)	6788	5350	-21%
Per household size (kWh/sqm.)	81	64	-21%
Per tenant (kWh/capita)	2759	2174	-21%
Energy savings per household (kWh/household, %/household)	1430 (21%)		
Peak load reduction per household (kWh/household,%/household)	N/A	N/A	N/A
Emissions from energy consumption			
Per household (CO2/household)	1870	1507	-19%
Per household size (CO2/sqm.)	22.6	17.94	-19%
Per tenant (CO2/capita)	760	612	-19%
CO2 reductions due to energy savings per household (CO2/household, %/household)	363 (19%)		
CO2 reductions due to peak load reduction per household (CO2/household,%/household)	N/A		

Table 135 KPIs evaluated for M3.1 Lope de Vega (Barcelona)

Energy consumption	Baseline	Post	Variation
Per household (kWh/household)	5001	4232	-16%
Per household size (kWh/sqm.)	111	94	-16%
Per tenant (kWh/capita)	3125	2645	-16%
Energy savings per household (kWh/household, %/household)	769 (16%)		
Peak load reduction per household (kWh/household,%/household)	-	-	-
Emissions from energy consumption	**Baseline**	**Post**	**Variation**
Per household (CO2/household)	1630	1376	-16%
Per household size (CO2/sqm.)	36.23	30.57	-16%
Per tenant (CO2/capita)	1019	860	-16%
CO2 reductions due to energy savings per household (CO2/household, %/household)	255 (16%)		
CO2 reductions due to peak load reduction per household (CO2/household,%/household)	-		

Table 136 KPIs evaluated for M3.1 Ter 31 (Barcelona)

Energy consumption	Baseline	Post	Variation
Per household (kWh/household)	5805	4786	-18%
Per household size (kWh/sqm.)	129	106	-18%
Per tenant (kWh/capita)	1935	1595	18%
Energy savings per household (kWh/household, %/household)	1020	18%	
Peak load reduction per household (kWh/household,%/household)	-	-	-
Emissions from energy consumption	**Baseline**	**Post**	**Variation**
Per household (CO2/household)	1922	1584	-18%
Per household size (CO2/sqm.)	42.7	35.2	-18%
Per tenant (CO2/capita)	641	528	-18%
CO2 reductions due to energy savings per household (CO2/household, %/household)	338 (18%)		
CO2 reductions due to peak load reduction per household (CO2/household,%/household)	-		

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie AGT	Andreas Wolba Christian Remacly Martin Strohbach	KTH-SEED

Smart Home offers the opportunity for all participating tenants to control the different devices in their household via smartphone, tablet or PC. It also offers the possibility to create scenarios, rules or schedules that are automatically switched. So, the tenants can save energy without turning on the electrical appliances and heating itself every time. In combination with smart plugs you can keep track of the current energy consumption of the connected devices.

Tenants in Germany receive only once a year their invoice from the energy provider listing their yearly energy consumption. These sparse information provides almost no insights into the energy usage behaviour which would allow sound decisions on energy savings. Due to the regulations in Germany no Smart Meters are certified to be installed in private households. These Smart Meters would have provided energy data every 15 minutes. However, installation Smart Home systems in the tenants' homes has been selected as an alternative to the Smart Meters. In parallel to the technical implementation of the measure several events have taken place to promote the measure. The first event took place on 24.11.2015, where, among other things, the Smart Home measure was presented. Further events followed on 24.06.17, where the tenants could already express their interest in the system. At the following events 24.03.18 and 17.05.18, AGT and RheinEnergie as well as the Technical University of Cologne were on site with an information board where the system was installed. AGT, the Technical University of Cologne and RheinEnergie each had an information stand where the tenants were advised and could register directly for the system. All events took place within the settlement. In addition to the events, invitations were always sent to all tenants with contact details, which could be used to register for a system even without attending the event. The events were despite all efforts always very badly visited and there were only 3 participants. In addition to the advancement of the measure a door acquisition was accomplished, in which altogether 600 households (of approx. 700) were visited. This happened in the period from 24.09.-01.10.18 and 16.11.-26.11.18. The households are in the already completed 1 and 2 construction stages. The residents were found in about 50% of the households. In addition to the Smart Home System including Smart Plugs, our field staff also offered the RheinEnergie tenant electricity tariff. The GrowSmarter project was explained to most households again as soon as this was linguistically possible. In addition, the tenants found received a flyer with information about the Smart Home System (including Smart Plugs) and contact details. Overall, it was very difficult for the field staff to contact the tenants. Reasons for this included language barriers and general mistrust caused by the construction measures. A total of 5 tenants have registered where we installed the system.

A modular 3rd party smart home system had been chosen as the basis of the solution for Measure 3.1. The smart home system from homee was used as gateway/hub. The homee smart home system allows to add new radio protocols (such as ZigBee, Z-Wave, or EnOcean) to the base station allowing the connection of smart devices (e.g. smart plugs, heating control, or thermostat) from different vendors. This ensures the openness of the solution of this measure.

The goal is an effective and logical equipment of the apartment. For this reason, each window is equipped with a window contact, so that the Smart Home System can detect in any room whether a window is open or closed. Based on this, each heating system is equipped with a smart radiator thermostat in order to regulate the power of the radiator when the window is open. 5 smart thermostats, 5 window and door contacts and 3 smart plugs were installed in each of the participants' apartments.

As there is no technical possibility for the RheinEnergie to measure the energy consumption on a household level. Currently only the results from the questionnaires serve as a basis for the evaluation of this measure.

AGT deployed a fully cloud-based data collection and analysis infrastructure that provides insights about energy consumptions to tenants based on the measurements received from the smart plugs. A web-based energy insight dashboard was offered to tenants for visualizing and comparing their historic and real-time energy consumption. This means that tenants were able to identify high energy consumers and analyze their energy consumption in detail and reduce their overall energy consumptions and cost. Figure 100 shows a sample welcome screen of the energy dashboard that also provides usage statistics of devices, detection of connected appliance types and detailed analysis of the consumption data.

The adoption of the Smart Home systems is currently rather low. The Technical University of Cologne is available to answer questions about the applications or the creation of automations.

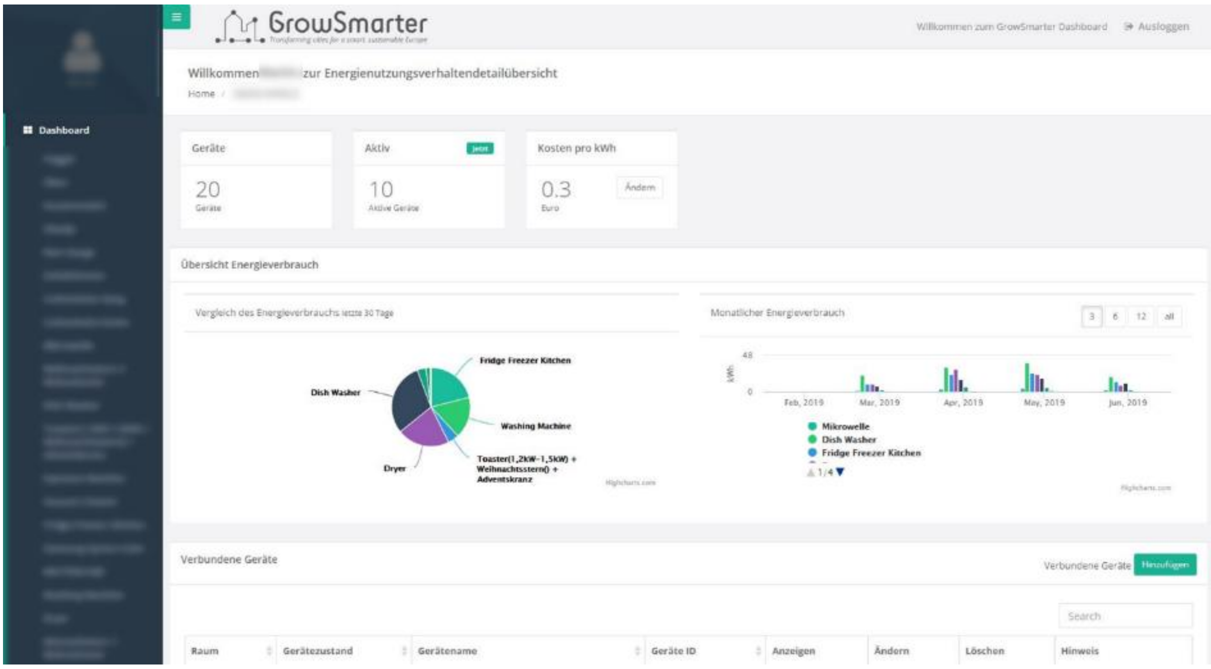


Figure 100: Welcome screen of the GrowSmarter energy insights dashboard offered to the tenants in Cologne.

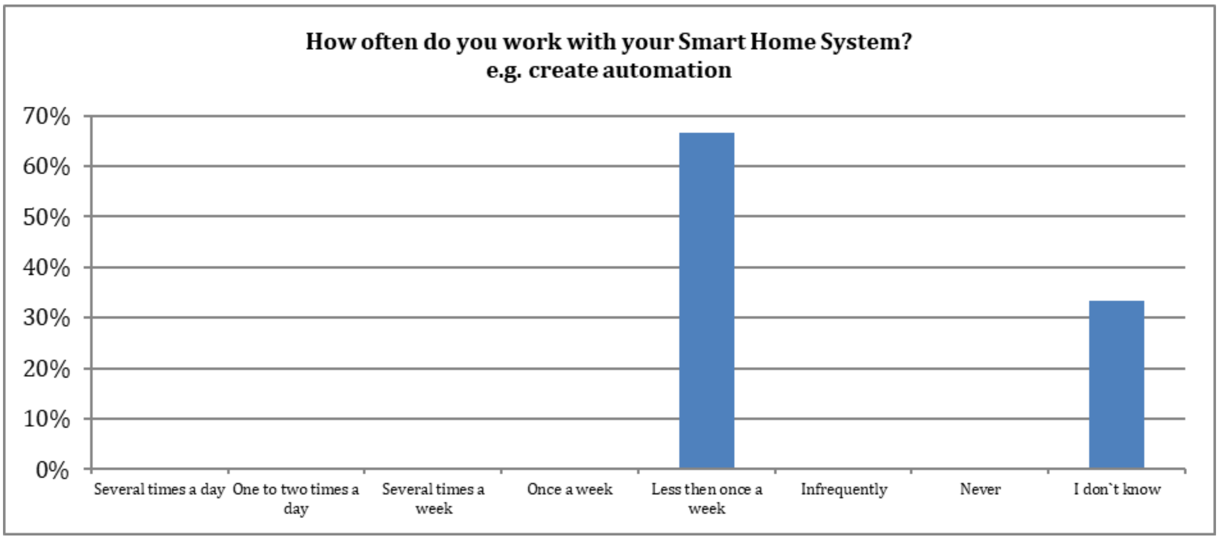


Figure 101 Example of automated questionnaire results

On the positive side, however, participants can better assess their energy consumption by using the Smart Home System. This applies to both electricity consumption and heating.

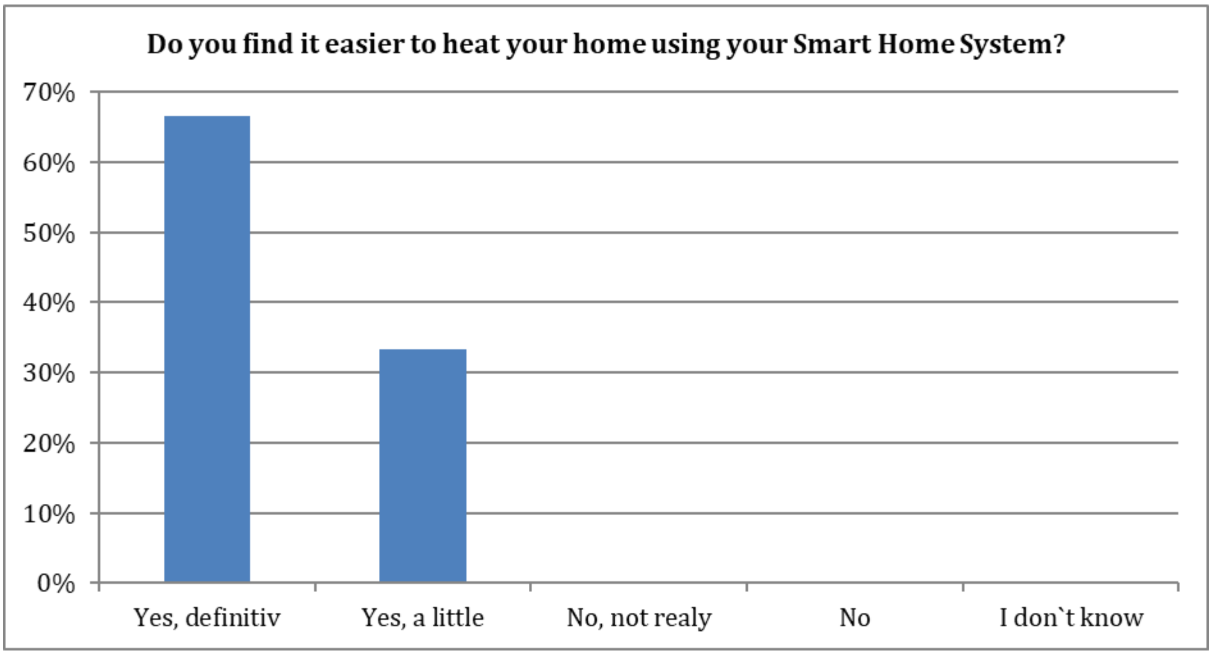


Figure 102 Example of automated questionnaire results

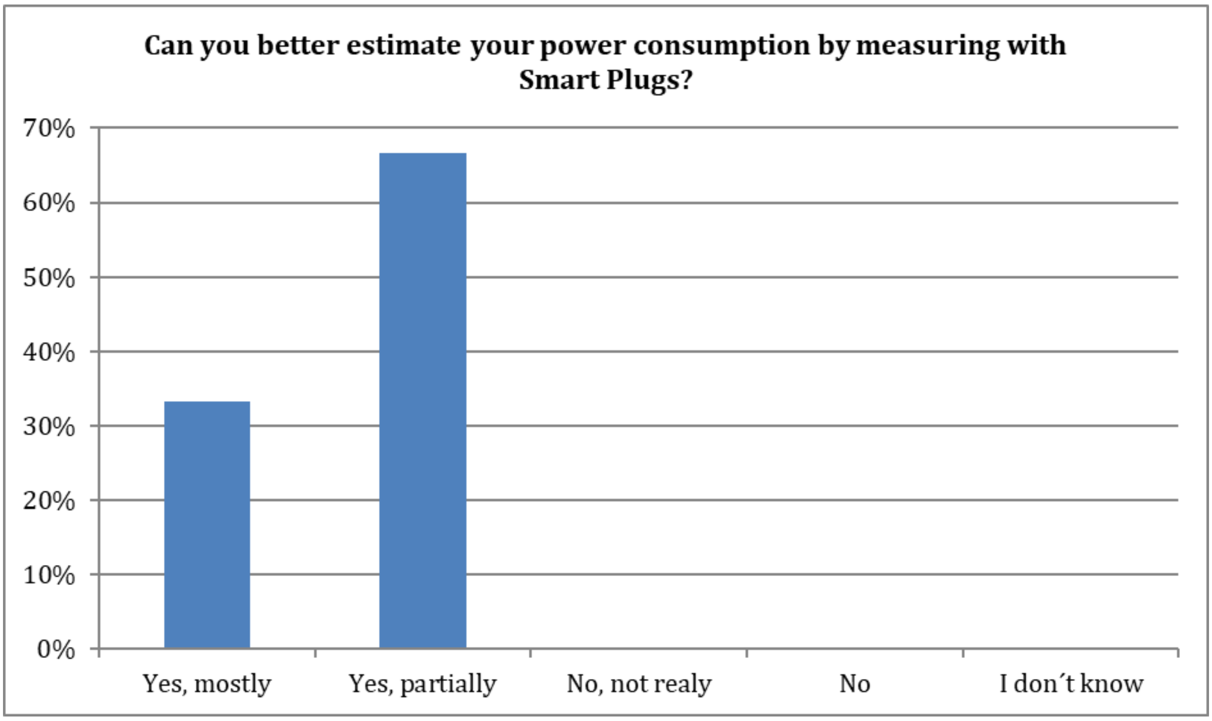


Figure 103 Example of automated questionnaire results

Overall the involved users are largely satisfied with the Smart Home System. However, due to the small number of participants, it is difficult to draw a more general conclusion.

Energy Savings Potential

The energy saving potential of using a Smart Home system is hard to measure. On one hand using smart plugs means that we can only obtain a small sample of the overall energy consumption of a home. On the other hand, the data from only five Cologne tenants are currently available in the system. In order to validate the effectiveness of the measure we therefore used the energy consumption from the smart plugs and checked whether the aggregated energy consumption shows a downward trend after introducing the dashboard. In order to obtain more data for the evaluation we have provided the GrowSmarter energy dashboard to Smart Home power users (up to 140 connected devices) in Germany that used the same gateway as the Cologne tenants (the homee gateway[18]). In total 16 Smart home systems from the Homee power users testbed fulfilled our criteria of (1) having full coverage of energy consumption data for at least two full months after the GrowSmarter dashboard had first been used and (2) excluding high energy consumers. We only used data from those smart plugs for which we had full coverage in these two months. For the homee power users this means that we could use data from 146 sensors in total, i.e. an average of 9 smart plugs per home. From the cologne tenants only two homes fulfilled and a total of 6 smart plugs fulfilled the criteria above, i.e. an average of 3 smart plugs per home. For more than half of the users we could observe a downward trend in their overall energy consumption within these two months.

[18] https://hom.ee/

Table 137 shows the quantitative results.

Table 137: Energy saving potential after introducing the GrowSmarter Energy Insights dashboard.

Target Users	Homes with positive impact	Average energy saving per home	Total energy savings
Cologne Tenants	50% (1 home)	15% (2.4kWh)	15% (2.4kWh)
Homee power users	50% (8 homes)	29.5% (21.5kWh)	28% (172.6kWh)

The distribution of absolute energy savings per home is displayed in Figure 104.

Potential for full scale implementation

The Measure is applicable to any city and household that allows household-individual metering of energy consumption (i.e., electricity, heating, gas, tap water, etc.). As the dashboard is implemented as a cloud-based solution, it can easily be scaled up to virtually any size of users and energy metering devices and easily be replicated in different cities or residential areas.

AGT has already started to replicate and upscale the Cologne GrowSmarter Energy Insight Dashboard making it available to any home owner that owns a homee Smart Home gateway. The users are primarily German citizens as this is the current target market for the homee Smart Home gateway. The users can be described as power users partially having 200-300 connected Smart home devices with a strong focus on monitoring energy production and consumption. Figure 10 shows the ratio of devices with energy metering capabilities versus other devices for this testbed.

In total we have 75 registered users in the GrowSmarter dashboard and data from over 2,200 devices. Note that the actual number of devices people are using may be higher as some people use the access control mechanisms of the gateway controlling what devices are visible to the GrowSmarter energy insights dashboard.

In general, there is huge interest in using the dashboard for understanding the energy consumption in a home. We are in contact with the end users and the gateway vendor extending the feature set and developing additional features and services which helps us to better understand the impact of the GrowSmarter dashboard on the end users and other stakeholders such as gateway manufacturers, cities and energy utilities.

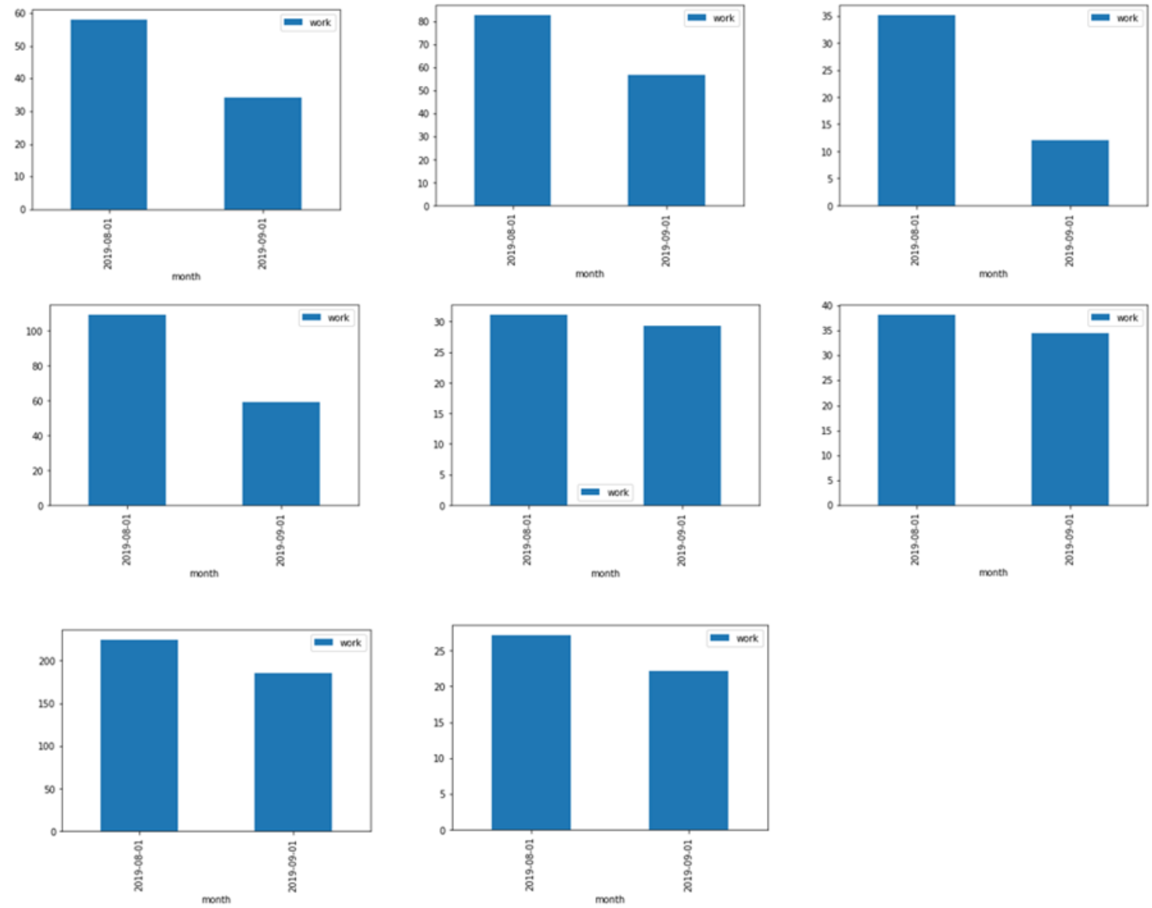


Figure 104: Energy consumption after introducting the GrowSmarter Energy Insights dashboard.. The y-Axis shows the aggregated energy consumption in kWh. On the x-axis the first two complete months after introducing the dashboard are shown. Only energy consumption of homee power users with positive impact, i.e. reduced energy consumption in the second month are being displayed-

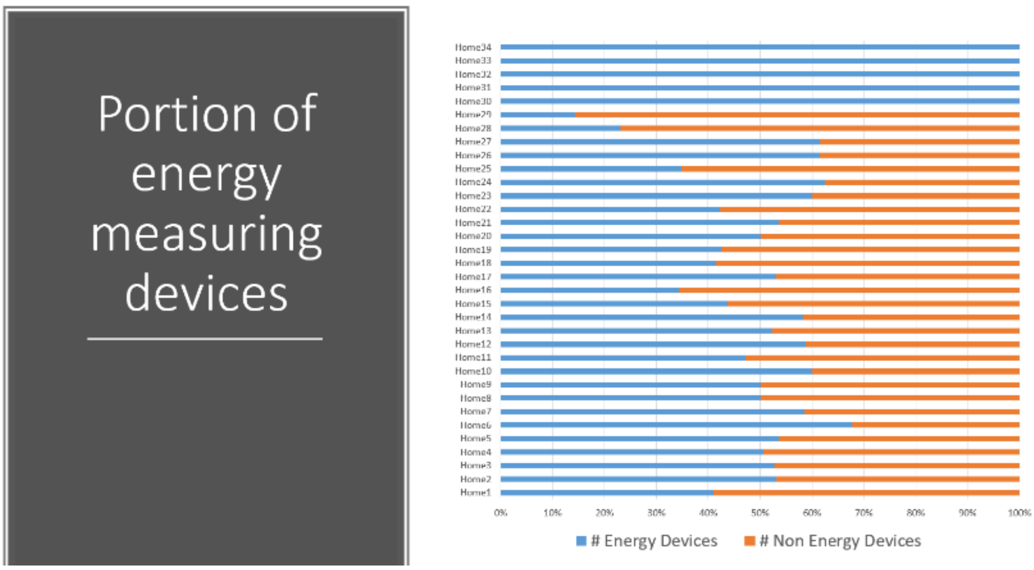


Figure 105: Ratio between devices with energy metering capability and other devices for the homes that are currently transmitting data to the extended GrowSmarter testbed.

M4.0 – Local renewable energy production and integration with buildings and grid

This section presents the results of M4.1.1, M4.1.2 and M4.2.1.

M4.1.1 – Local electricity production

Introduction

Installation of photovoltaic systems, mainly on rooftops and facades, storages (electricity) in combination with district heating and heat pumps.

According to the evaluation plan (D5.1), the intentions of this Measure are:
1. Decrease the need of externally supplied energy by local production units.
2. Increase the renewable share of energy consumption.

In particular, the baseline has been determined by evaluating the demand of externally supplied energy and the renewable share of the supplied energy.

The key performance indicators evaluated are:
1. Measured energy supplied by local production unit (kWh/year).
2. Measured energy supplied by local production unit (kWh/h).
3. Share of external renewable energy supplied of total local demand (%).
4. Reduction of CO_2 emissions due to local production (%).

Stockholm

Industry partner	Contact person	Validation partner
L&T Fastighetskontoret Miljöförvaltningen	Peter Andersson Royne Juhlin Anna Sundman	KTH-EGI

Slaughterhouse

The installation of Photovoltaic on rooftops was made in April 2018 in combination with EnergyHub and a small battery storage. Among several benefits the EnergyHUB works as a converter from DC to AC and AC to DC.

Table 138 KPIs evaluated for M4.1.1 Slaughterhouse (Stockholm)

1. Measured energy supplied by local production unit (kWh/year).	9630
2. Measured energy supplied by local production unit (kWh/h).	1,1
3. Share of external renewable energy supplied of total local demand (%).	5 %
4. Reduction of CO2 emissions due to local production (%).	4 %

Kylhuset

The installation of Photovoltaic was made during summer 2018. EnergyHUB and battery storage were added in December 2018.

Table 139 KPIs evaluated for M4.1.1 Kylhuset (Stockholm)

1. Measured energy supplied by local production unit (kWh/year).	12 000
2. Measured energy supplied by local production unit (kWh/h).	-
3. Share of external renewable energy supplied of total local demand (%).	9 %
4. Reduction of CO2 emissions due to local production (%).	4.6 %

Årstakrönet

The installation of EnergyHUB and battery storage were made in November 2016. This has provided valuable information of the energy and power used at Brf Årstakrönet. The analyses also gave us the information when installing PV cells that they should be directed, not in the optimal direction, but where they could deliver optimal result when the use of electricity in house reached its peak, around h16:00.

Table 140 KPIs evaluated for M4.1.1 Årstakrönet (Stockholm)

1. Measured energy supplied by local production unit (kWh/year).	11442
2. Measured energy supplied by local production unit (kWh/h).	-
3. Share of external renewable energy supplied of total local demand (%).	17 %
4. Reduction of CO2 emissions due to local production (%).	717 kg

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie	Christian Remacly Andreas Wolba	KTH-EGI

RheinEnergie has integrated the Siedlungsmanagement software with the installations in the Stegerwaldsiedlung neighbourhood to maximize the self-sufficiency of the settlement (16 buildings). Within the project the Siedlungsmanagement Software is oriented so that the optimization takes place under an ecological point of view. The software receives data from the performance of 41 heat pumps (492 kW_{th}), 6126m² of Photovoltaics (1084 kWp), district heating connection (1742 kW), and 16 batteries (210 kW, 655kWh), as well as estimated building energy demand. The software is prepared to run optimization algorithms and send set points to the energy generation units. The software merges the information of the two Measures M4.1.1 and M4.1.2.

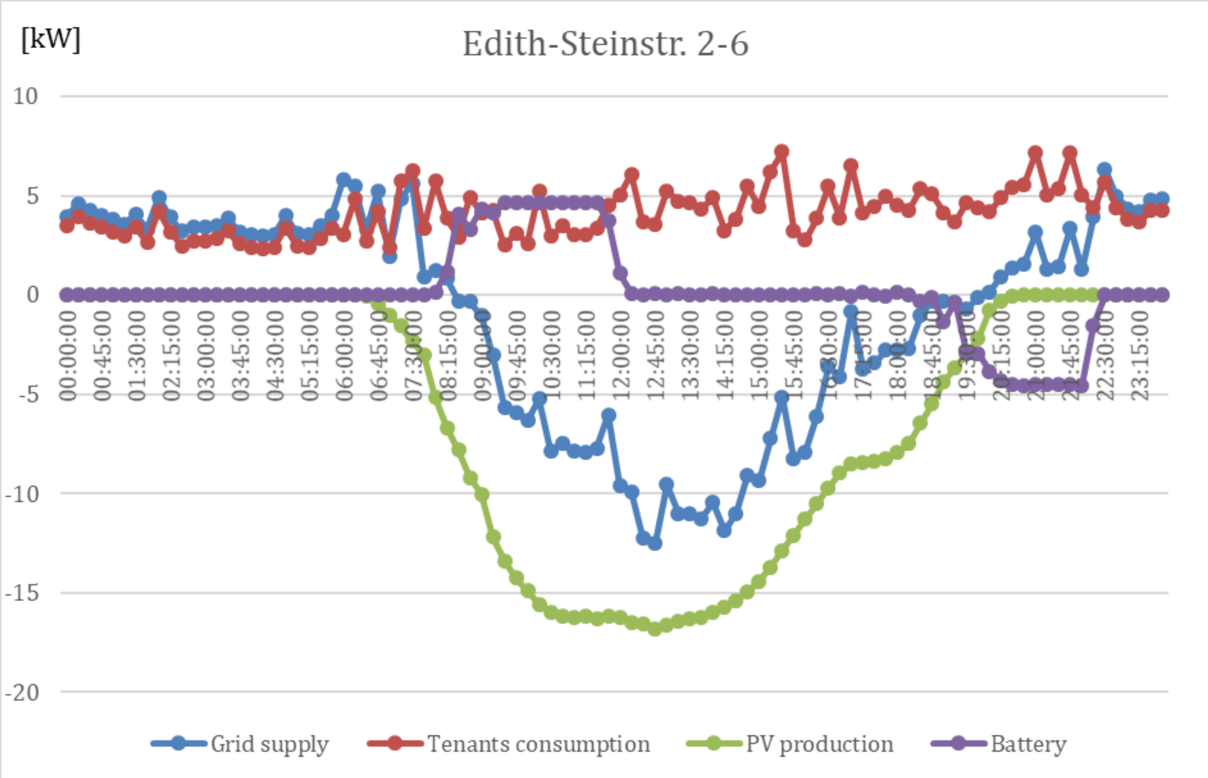


Figure 106 Example of measurement data. Battery with storage capacity of 20kWh.

The graph shows an example period of 24h where the battery system (purple) of 20kWh capacity and 5kW charging performance can reduce the external power consumption (Figure 106, Table 141). The blue line reflects the total performance power which is drawn from the building from the grid and which is fed into the grid. For example, feeding into the grid occurs around noon when we have a strong PV production (green). The PV system in the Edith Steinstr. 2-6 has a capacity of 32.5 kWp. During PV production, the storage starts to charge with its maximum charging performance. As soon as the PV production stops around 7 p.m., the battery starts to discharge. The consumption of the tenants is shown in red.

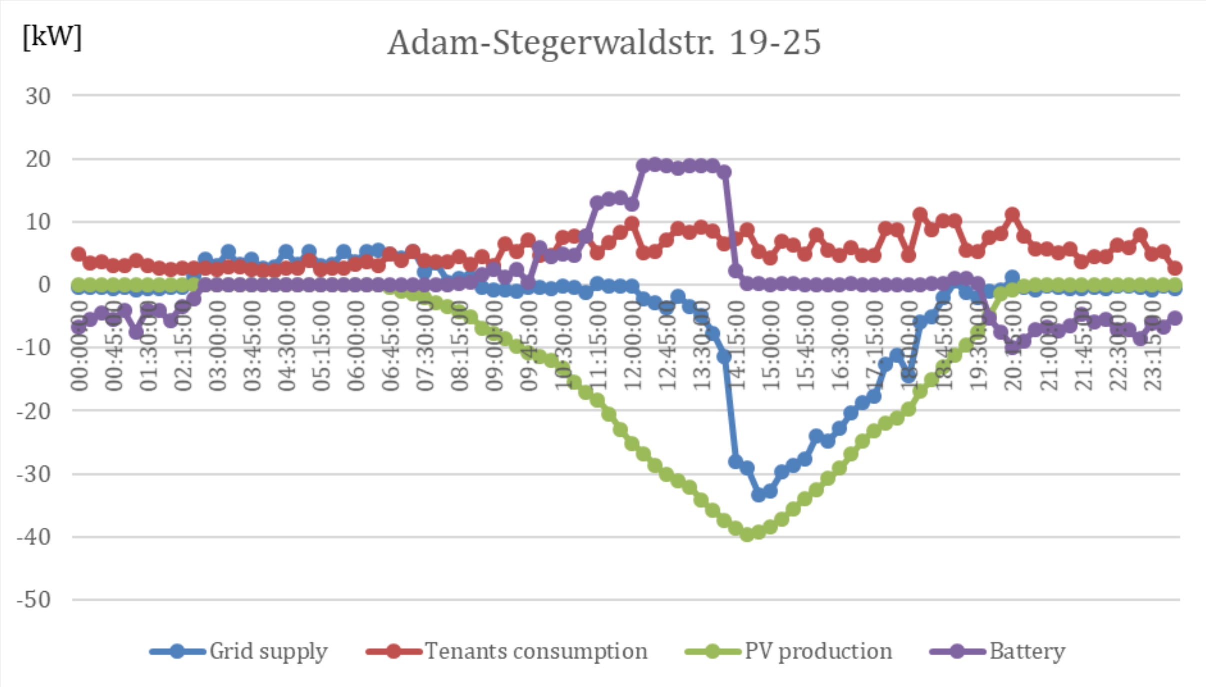


Figure 107 Example of measurement data. Battery with storage capacity of 60kWh.

The battery in Adam-Stegerwaldstr. has a storage capacity of 60 kWh (Figure 107, Table 142) and a charging performance of 20 kW. Also, here you can see that during the morning, especially around noon when the PV production is strongest, the battery stores with the maximum charging performance. In addition, we have such a strong PV production that we feed it into the grid. The PV system in the Adam-Stegerwaldstr. has a power of 80 kWp. At 19:30 the battery starts to discharge and thus prevents external power supply almost during the whole night (from 20:00 to 3:00 if we consider the presented 24h example as repeatable).

Table 141 KPIs evaluated for M4.1.1 Edith Steinstr. 2-6 (Cologne)

1. Measured energy supplied by local production unit (kWh/year).	76 179
1.1 PV production [kWh/year]	27 917
1.2 Energy supplied to the heat pumps for heat production [kWh/year]	48 262
2. Measured energy supplied by local production unit (kWh/h).	-
3. Share of external renewable energy supplied of total local demand (%).	48%
4. Reduction of CO2 emissions due to local production (%).	-
4.1 Due to PV production [kg CO2]	8 542,67

Table 142 KPIs evaluated for M4.1.1 Adam-Stegerwaldstr. 19-25 (Cologne)

1. Measured energy supplied by local production unit (kWh/year).	125 327
1.1 PV production [kWh/year]	57 858
1.2 Energy supplied to the heat pumps for heat production [kWh/year]	67 469
2. Measured energy supplied by local production unit (kWh/h).	-
3. Share of external renewable energy supplied of total local demand (%).	66%
4. Reduction of CO2 emissions due to local production (%).	-
4.1 Due to PV production [kg CO2]	17 704,6

Potential for full scale implementation

Technical, economic and social feasibility

Local electricity production by PV on rooftops is becoming common all over Europe, even in Sweden, where the electricity price is low during the summer. Most investigations done outside of GrowSmarter concerning the economic feasibility of such installations indicate that they will most likely pay off, at least with the government support available in many countries.

The usefulness of local electricity production depends on mainly two parameters, the instantaneous production and the instantaneous electrical need. As long as the production is less than the electrical need, all of the produced electricity may be used direct. If the production is greater than the need, either the excess production is sold; or stored; or given away. Either way, in order to evaluate the feasibility of this Measure, the above stated conditions must be known. Once known, it is fairly straight forward to estimate the outcome of an installation on a specific building. The economic feasibility will then also be determined. The technical limitation could be if implemented on a large scale in a city, and excess production occurs in many of the installations, there might be grid stability issues. Another limitation is of course also if a building is protected in any way, which will not allow installation of these devices.

A social aspect of PV installations on buildings is that they may be considered to have a negative influence on the appearance of the building. Therefore, permits are typically required and installations may be forbidden by the city architect or similar authority.

Applicability of the Measure to different cities

This Measure may be implemented in any city. Limitations may apply given the excess productions, as well as other regional and grid specific regulations.

In Stockholm, the city has taken the initiative to develop a Solar Map, indicating for each rooftop the feasibility of installing PV-panels. However, a technically favorable position may still be refused to install such panels for aesthetic reasons. The power to decide on the balance between the urge to increase production of renewable energy and the aesthetic concerns is in the hands of politicians. The evaluation of the possibilities for upscaling and replication is therefore difficult.

M4.1.2 – Demand/Storage

Introduction

Due to legislation issues this Measure could not be implemented as initially planned.

This Measure initially consisted of several actions:

- Dynamic pricing for individual households and industry, reducing electricity usage during scarcity periods
- Decision to store/not store the cars be managed by the manager
- VPP (settlement managing system) managed Batteries,
- Charging of Electric Vehicles – a price model will allow for temporarily reduction of the electricity to charging stations. A driver in no hurry can utilize this cheaper price model

- Heat pumps for heat storage in heating system and hot tap water system for each building.

According to the evaluation plan (D5.1), better load balancing through dynamic pricing and increased storage capacity will lead to better utilization of energy. The baseline was expected to be determined by establishing for the electric grid and the district heating system the 100 highest average peak loads during one year (in kWh/h).

The key performance indicators initially planned to be evaluated were:
1. Magnitude of peak loads (kWh/h).
2. Number of peak loads (-).
3. Reduced CO_2 emissions due to reduced energy demand (kt/year).

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie	Christian Remacly Andreas Wolba	KTH-EGI

In Germany, legislation has not yet passed the issue regarding certified smart meters. Their rollout was supposed to occur in 2015/2016 and is now delayed until the beginning of 2018, due to the needed IT adjustments. So far, the currently available Smart Meters do not fulfill the required German safety conditions. To get the consent from the tenants to install the uncertified smart meters, the Cologne Site has organised several events and information campains as well as regular open hours at the Stegerwalds café for the tenants to be able to ask questions in person.

Unfotunately the tenants did not agree so the Smart Meters cannot be installed. As the tenants in the Stegerwaldsiedlung did not agree to install uncertified smart meters (and certified smart meters are currently not available). The other solution already described in the DoA of theGrant Agreement with smart plugs will therefore be used in measure 5.3 Smart Meter information and actuators.

However, the smart plugs in measure 5.3 will not be connected to the virtual power plant since they will only measure the electric consumption of selected devices and not the complete household. Therefore, the text concerning smart meters needs to be removed from measure 4.1.

The VPP is still implemented in the project even if the Smart Meters will be replaced by Smart Plugs without connection to the VPP. The charging of vehicle will be part of the VPP and the possibility of electric vehicles as controlled energy back supply will technically be possible but, unfortunately, German legislation does not allow this due to the difficulty of identifying the origin of the electricity production in the car battery, so at this point the cars will not supply neither the building nor grid with electricity. The Law is named the EEG (The Renewable Energy Sources Act (German: Erneuerbare-Energien-Gesetz) which is a series of German laws that originally provided a feed-in tariff (FIT) scheme to encourage the generation of renewable electricity).

M4.2.1 – Self-sufficient block: photovoltaic on-site production

Introduction

Control of energy systems in residential and tertiary buildings by means of Home Energy Management System (HEMS) and Building Energy Management System (BEMS) will allow better control and minimize consumption of fossil fuels and electricity. The local renewable energy production is mainly dependent on weather conditions. BEMS have the capacity of planning an optimal supply/demand of energy and ensuring a system balance in real time.
The inputs for BEMS are: weather forecast affecting Renewable Energy Sources (RES) production, energy prices forecast and demand forecast in order to correctly balance the system in real time.
This information will be included in a control software integrating the block's electrical energy demand, RES, and available energy storage systems that will balance permanently production and storage capacity versus consumption needs.

According to the evaluation plan (D5.1), the intention of the Measure is to enable opportunities to increase renewable energy fraction in the local area.

In particular, the baseline is expected to be determined by the determination of the amount of electricity used on-site.

The key performance indicators to be evaluated are:
1. Increased fraction of renewable energy in local energy system (%).
2. Reduced CO_2 emissions due to reduced energy demand (kt/year).

Barcelona

Industry partner	Contact person	Validation partner
IREC Naturgy	Helena Gibert, Naturgy Alaia Sola, IREC	KTH-EGI

In this Measure, 3 photovoltaic installations with electric storage have been installed in the city of Barcelona. Two of these installations are implemented in tertiary buildings and one in a residential building. These 3 installations are:

Residential building:
- Sibelius

Tertiary buildings:
- Monestir de Valldonzella
- BTC Barceloneta

The methodology used for the evaluation is:
- The electricity consumed from the grid before implementation will be compared to the electricity consumed after implementation.
- Equal building occupation is assumed.

It is worth to notice that in this Measure, the emission factors adopted are not the ones recommended by the Ministry of Energy of Spain. The emissions have been calculated based on the Spanish pool share at every hour of operation of the installation. This is of particular interest as the Energy Management System is optimizing the use of the battery and decides

when to charge and discharge it in a smart way (based on the hourly forecast for the share of energy sources for the Spanish electricity pool, weather, and building load).
The reference of the emission factors used to calculate the hourly emission factor of the Spanish pool is the GaBi Professional Database from ThinkStep, using Spain Electricity generation datasets from different sources[19] , based on data from IEA, OCDE (Dataset valid from 2014 until 2020).

The following parameters have been monitored on a minute basis:

1. Supplied renewable energy from local production (kWh).
2. Supplied electricity from the grid (kWh).
3. Building electricity load (kWh).
4. Battery charge/discharge power (kW).
5. Climatic conditions: global radiation on horizontal surface (W/m²),

The following KPIs are calculated and shown on a monthly basis:

1. Solar energy production on a monthly basis (kWh).
2. Building electricity load on a monthly basis (kWh).
3. Electricity purchased from the grid on a monthly basis (kWh).
4. Self-sufficient fraction of the electricity consumption of the building (%).
5. Reduced CO2 emissions due to renewable energy contribution (kg CO2/month)

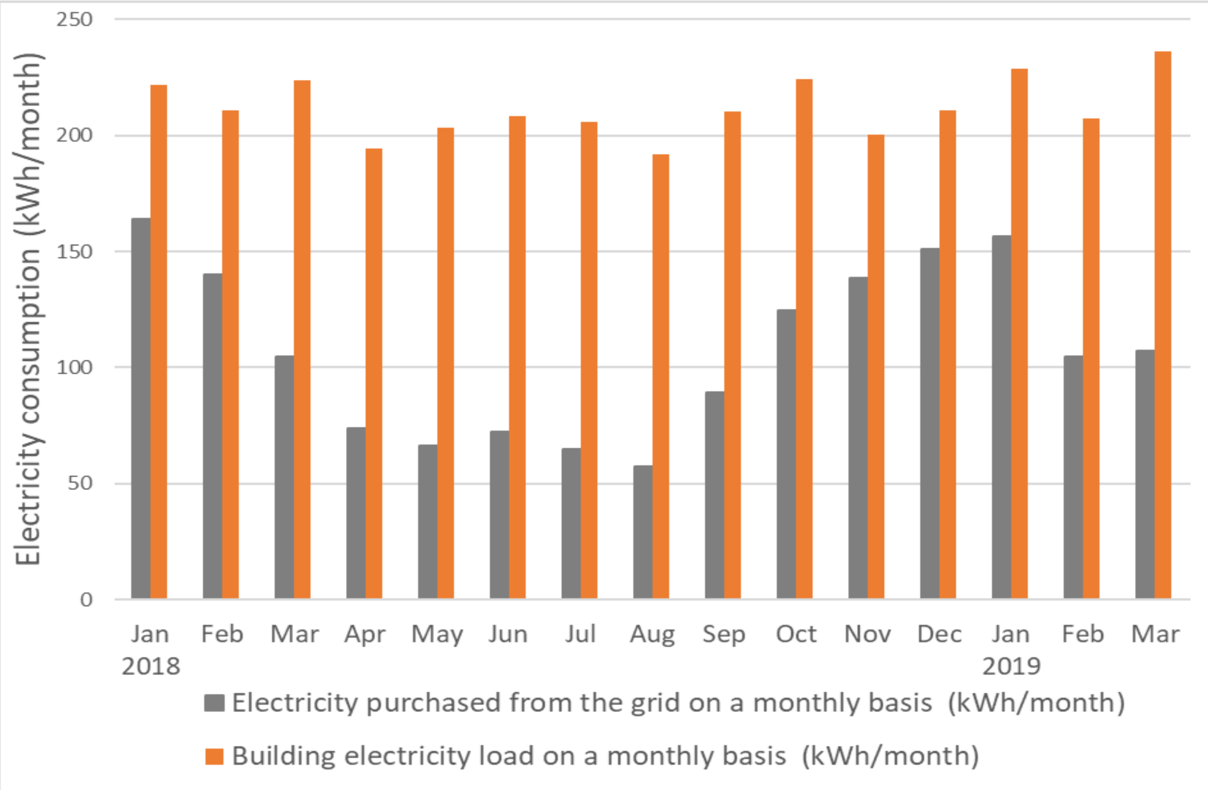


Figure 108 Monthly electricity consumption of the building & Electricity purchased from the grid in Sibelius installation.

- [19] https://thinkstep.com/sustainability-data/lci-data/global-industrial-process-database

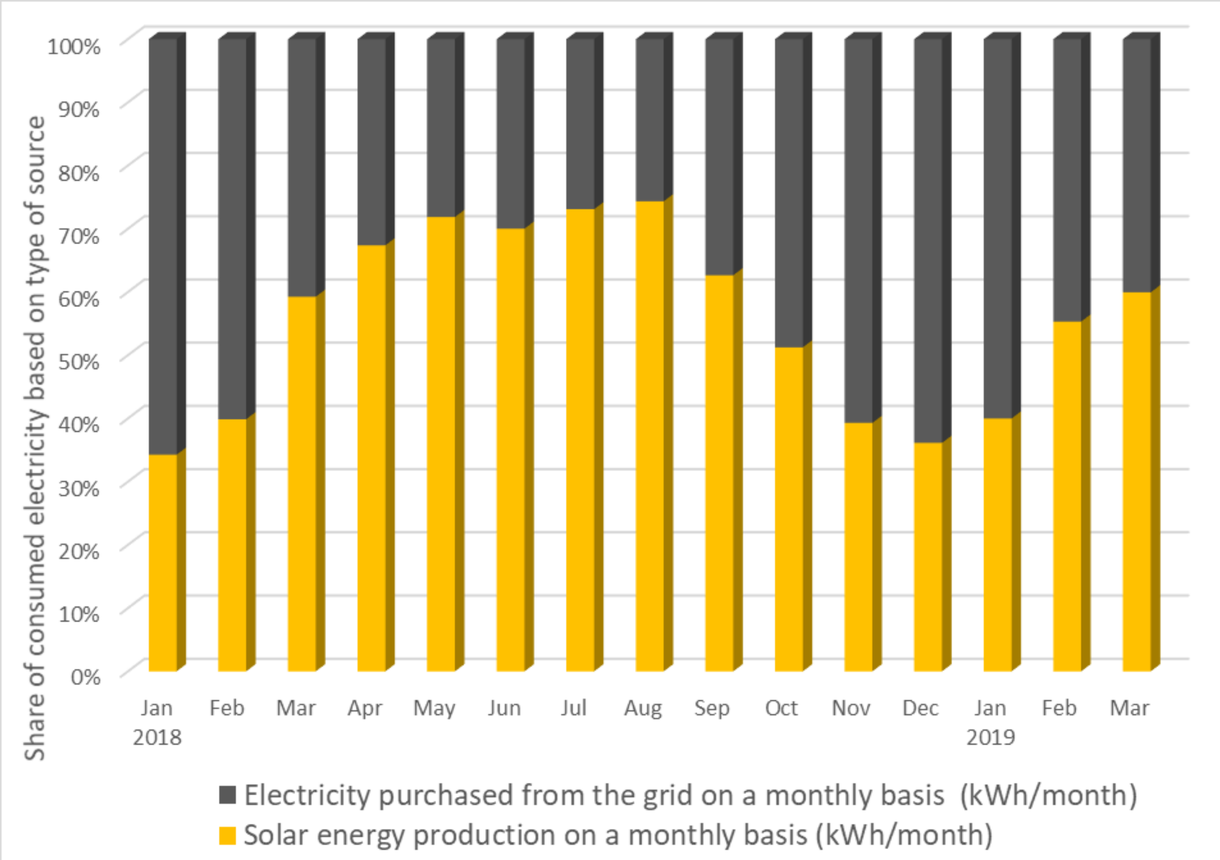


Figure 109 Share of electricity sources to supply building load for the analysed period in Sibelius installation.

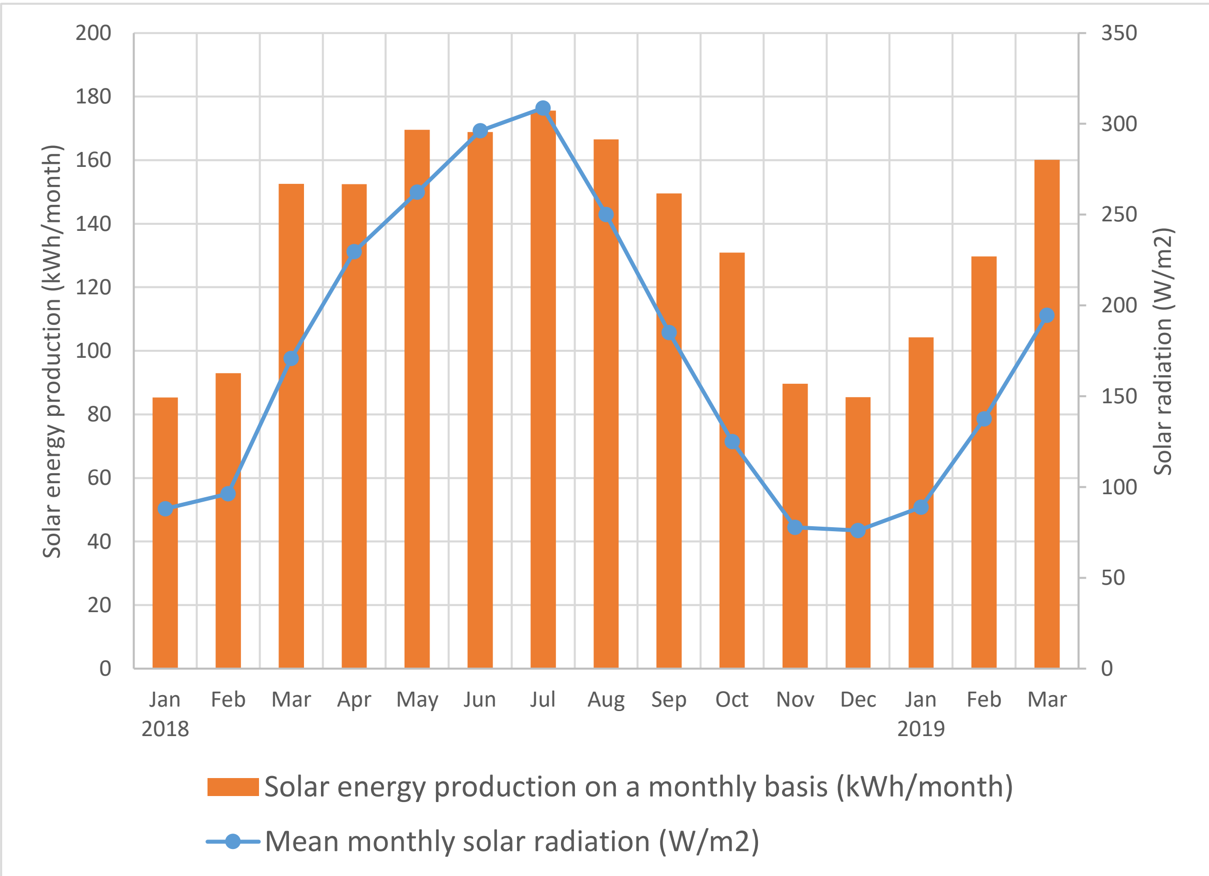


Figure 110 Solar monthly energy generation in Sibelius installation.

Table 143 KPIs evaluated for M4.2.1 Sibelius 3 (Barcelona)

1. Increased fraction of renewable energy in local energy system (%).	65% on annual basis
2. Reduced CO2 emissions due to reduced energy demand (kt/year).	0.287 ton CO2/year

The electrical load served by the PV and storage system in Sibelius building is relatively constant since it consists of the consumption of the elevator and the lighting system in the staircase of the multi-dwelling building. During 4 months, the PV and storage system is able to cover around 70% of the electrical load on a monthly basis. On an annual basis, the system has covered 65% of the total energy consumption of the common areas of the building (data for 2018). Considering that the installation is a 2,6kWp photovoltaic plant and the dimensions of the load, the system is providing the maximum possible self-sufficiency to the building.

In this measure, the battery is also used to store electricity purchased from the grid when the electrical pool price is the lowest of the day, under the control of the smart Energy Management System developed in the project. This doesn't affect the increased fraction of renewable energy in the system but it does contribute to the reduced CO2 emissions of the building. There is a trend that proves that in many cases, the lowest price periods of the electrical pool correspond to the use of low emitting technologies to generate electricity for the national grid. This has been considered in the calculations of the CO2 emission savings of the building.

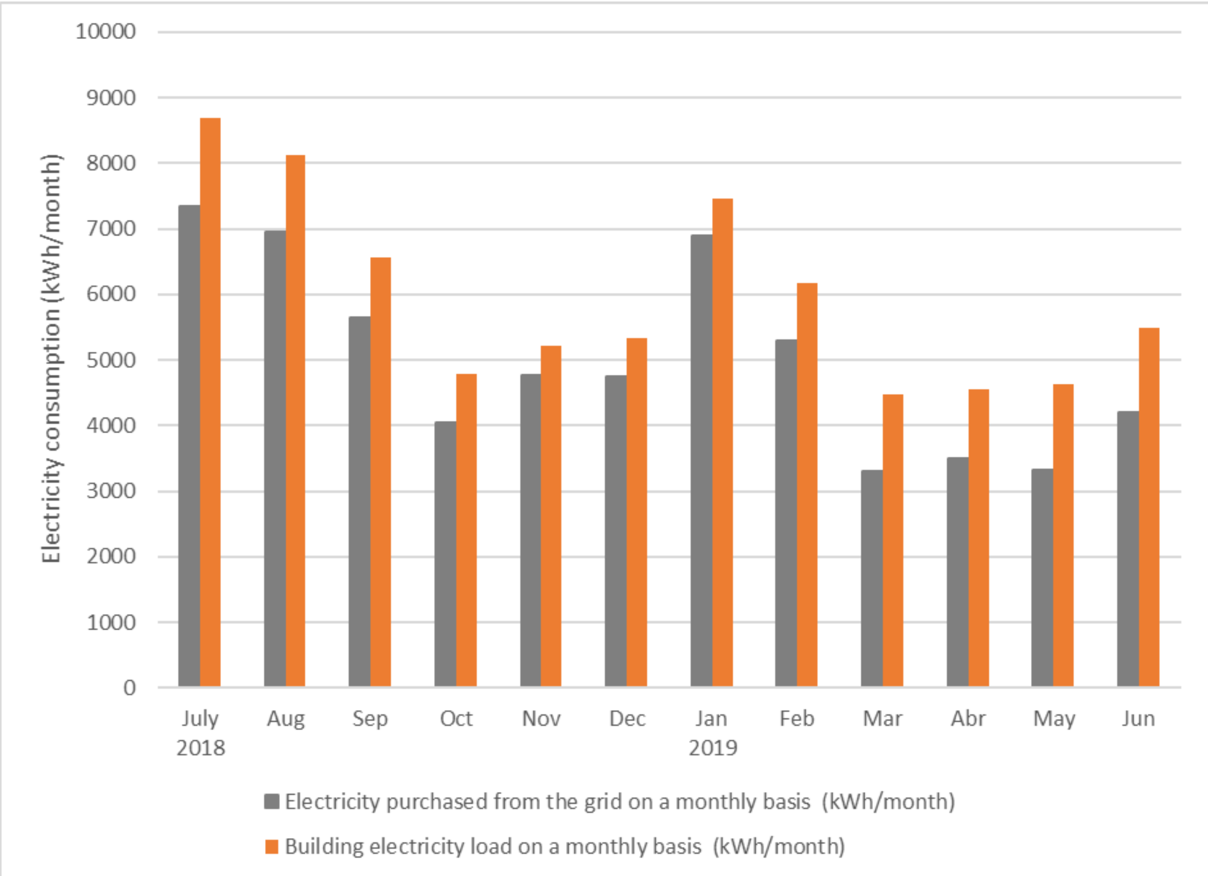


Figure 111 Monthly electricity consumption of the building & Electricity purchased from the grid in Valldonzella installation.

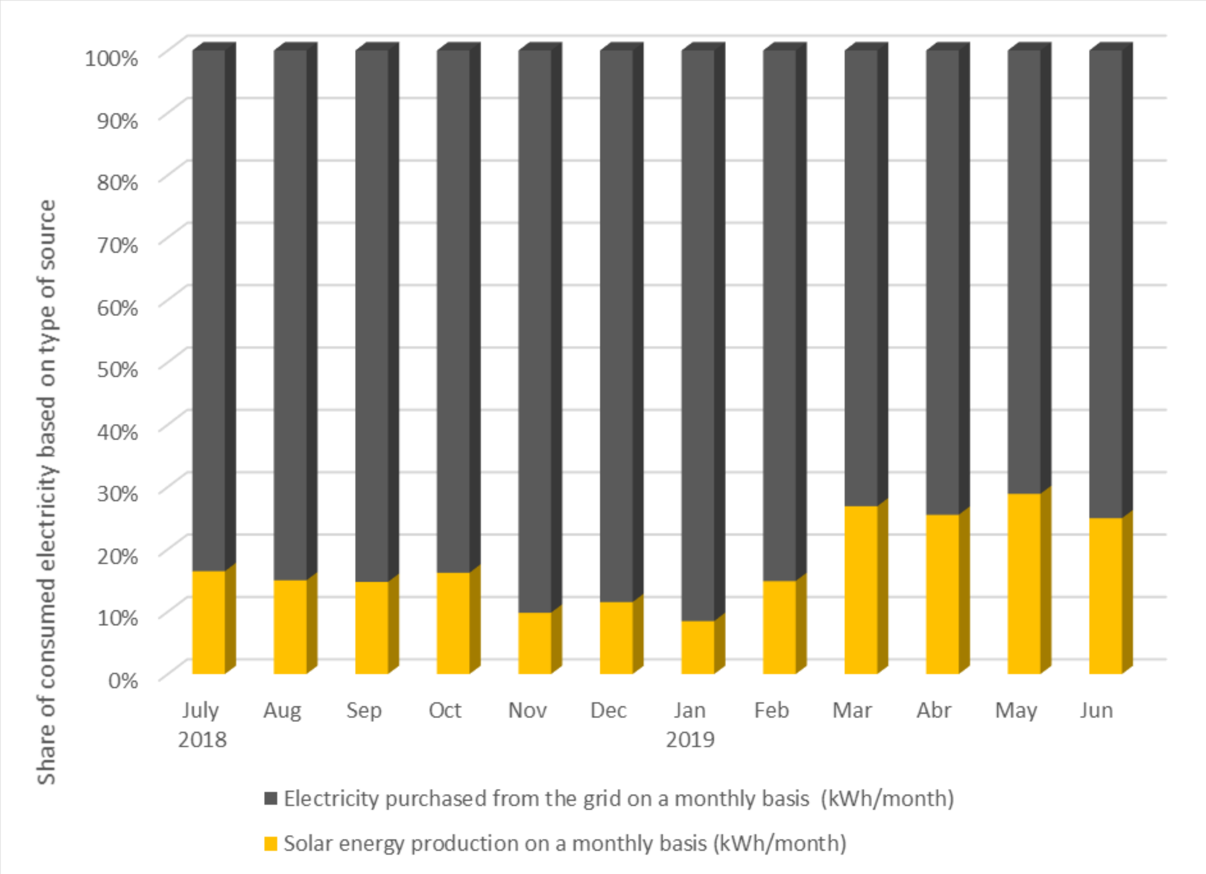


Figure 112 Share of electricity sources to supply building load for the analysed period in Valldonzella installation.

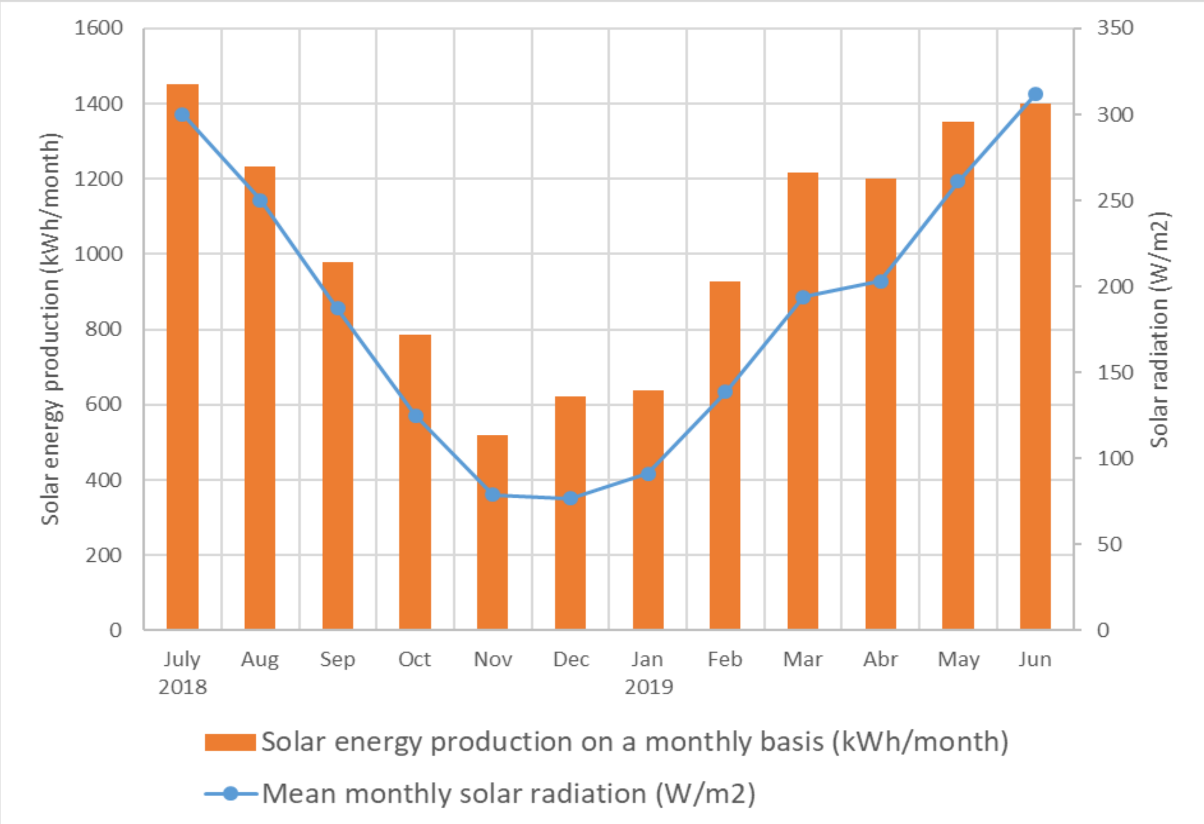


Figure 113 Solar monthly energy generation in Valldonzella installation.

Table 144 KPIs evaluated for M4.2.1 Monestir de Valldonzelles (Barcelona)

1. Increased fraction of renewable energy in local energy system (%). i.e. share of solar energy in building electrical consumption on annual basis	20%
2. Reduced CO2 emissions due to reduced energy demand (kt/year).	2.448 ton CO2/year

The electrical load served by the PV and storage system in Valldonzella building is climate-dependent since the building load includes HVAC. On an annual basis, the system has covered 20% of the total energy consumption of the building. Considering that the installation is a 11kWp photovoltaic plant and the larger dimensions of the load, the system is providing the maximum possible self-sufficiency to the building.

In this measure, the battery is also used to store electricity purchased from the grid when the electrical pool price is the lowest of the day, under the control of the smart Energy Management System developed in the project. This doesn't affect the increased fraction of renewable energy in the system but it does contribute to the reduced CO2 emissions of the building and to broaden the use cases for the battery.

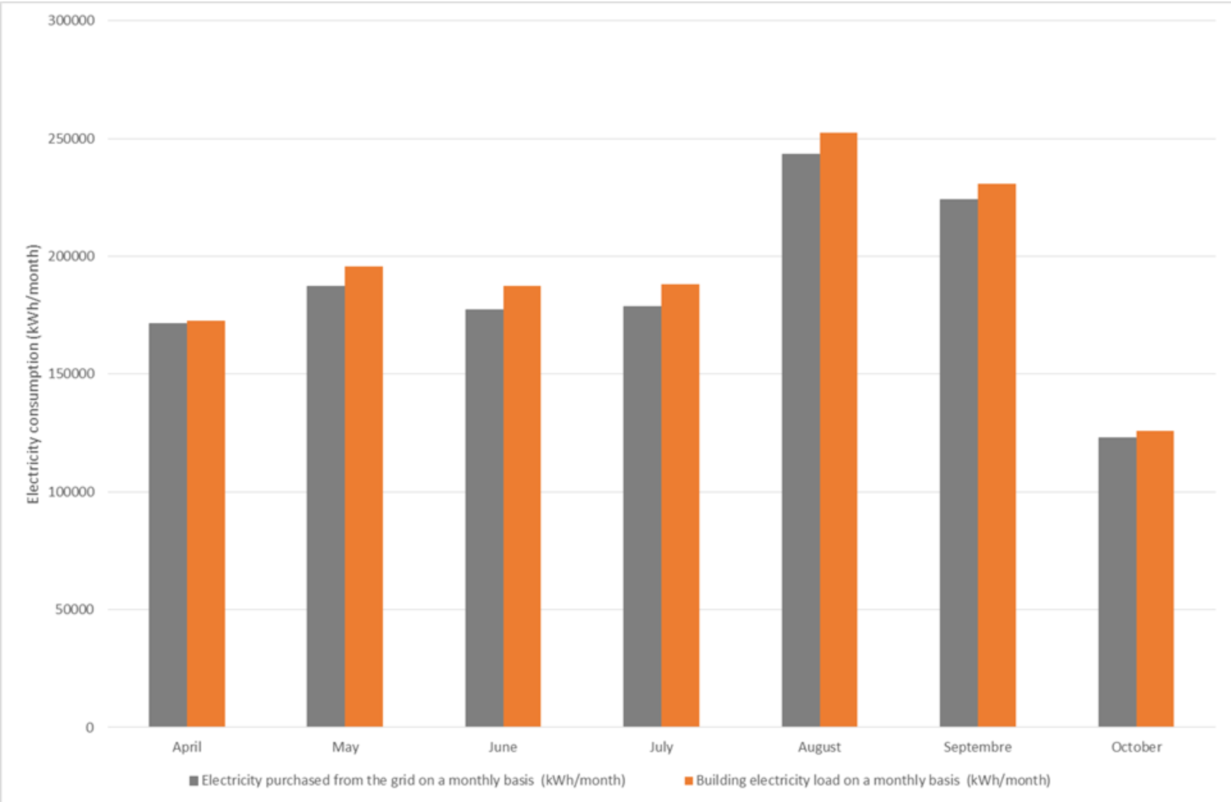


Figure 114 Monthly electricity consumption of the building & Electricity purchased from the grid in Barceloneta installation.

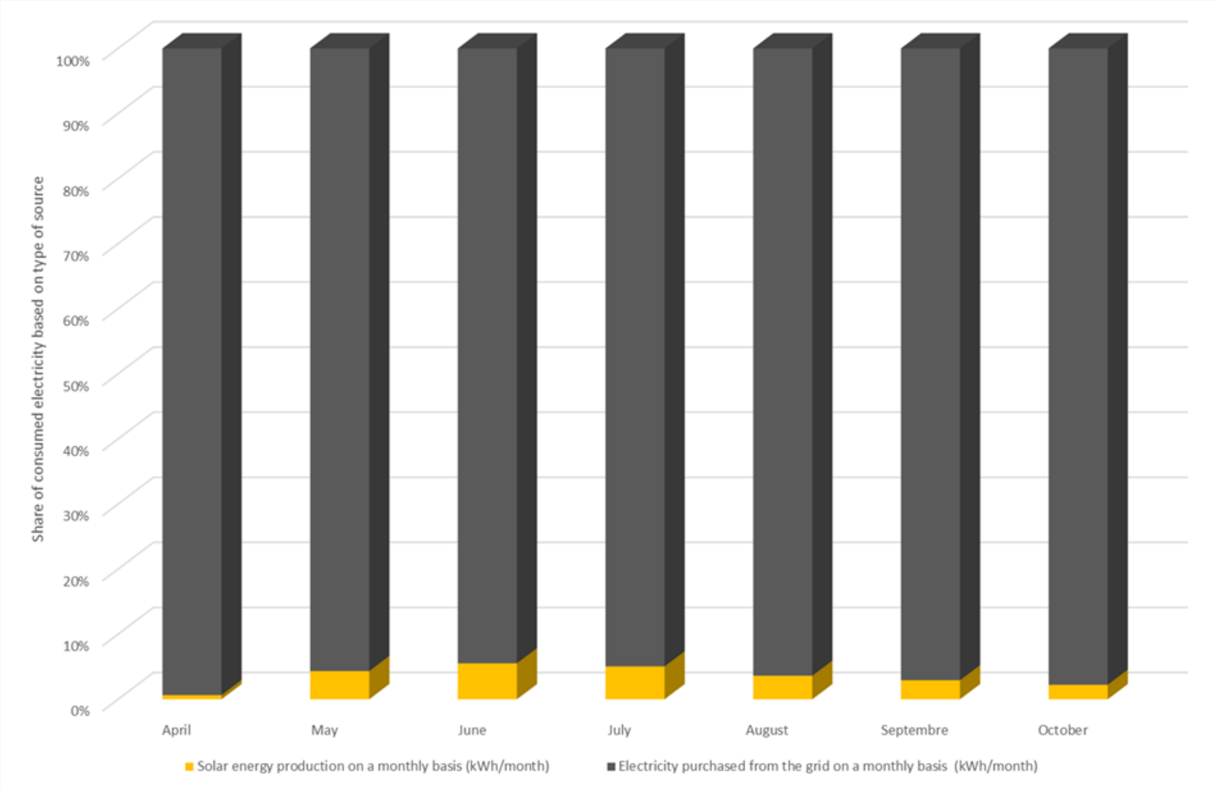


Figure 115 Share of electricity sources to supply building load for the analysed period in Barceloneta installation.

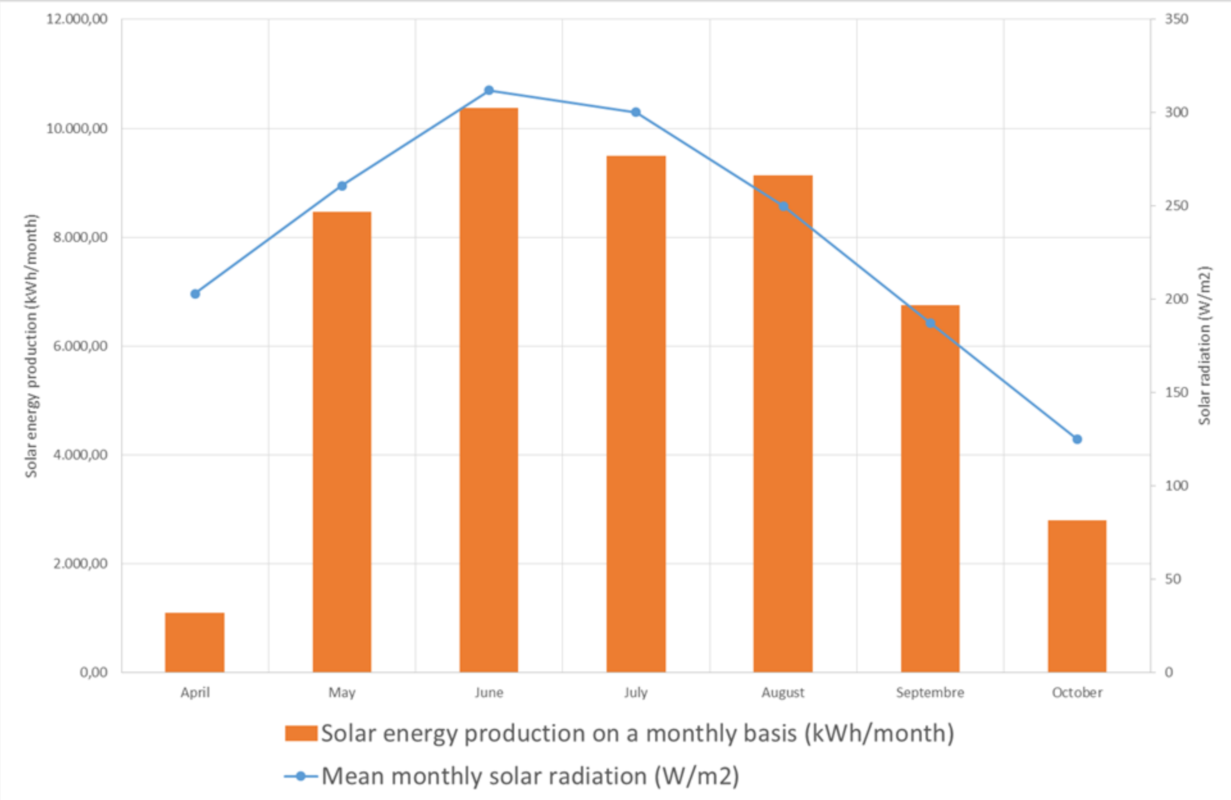


Figure 116 Solar monthly energy generation in Barceloneta installation.

Table 145 KPIs evaluated for M4.2.1 Barceloneta (Barcelona)

1. Increased fraction of renewable energy in local energy system (%).	4%
2. Reduced CO2 emissions due to reduced energy demand (kt/year).	1%

Potential for full scale implementation

Technical, economic and social feasibility

Smart building control systems enabling the systems to respond in advance to coming changes of ambient conditions and occupant use have the potential to respond exactly according to the coming need. This will maximize the use of the installed capacity and decrease the need for external provided services such as heating, cooling, and electricity. The technical limitations will be building in which the systems are not readily controlled; it may require additional installation on the existing energy systems. The outcome of this systems is reduced energy bills and increased share of RES. The social implications might be reduced number of hours outside the comfort zone, with increased satisfaction of the occupants.

Applicability of the Measure to different cities

This Measure may be implemented in any city. This Measure may be implemented in any building for which the energy systems are controllable by the installed control system. It may require additional installations if that is not the case.

2.4 Conclusions for Work Package 2

Most of the Measures included in WP2 can be considered saving significant amount of energy. The results show, in general, good results in terms of estimated energy saving and CO2 emission reduction. The ambitious challenges set in the GrowSmarter project of achieving 60% of energy saving and 60% of CO2 emission is in some cases fulfilled. In some instances the target has not been met. One reason for not meeting the set target may be underestimating the often-occurring gap between simulations and the outcome of real installation. Reasons for this to happen may be installation effects, i.e. quality of construction personnel, or difficulties to account for interactions with other parts of the building and its systems. In addition, the specific conditions at each location will determine the ability to implement the Measure, such as local regulation, climatic conditions, and cost of energy and cost relation between different energy carriers, which may not be fully understood at the initial phase of the renovation process.

The evaluation conducted by the partners on their individual measures show, as seen from the building perspective, good promise to reach the goal of 60% overall reduction of energy use in the existing built environment. The individual measure cannot, of course, by itself save 60 %, but it is the combined impact that in the end is of primary interest. As such, it is also a simpler task to monitor the performance of a whole building, for which all intertwined measures are aggregated. It may also be seen from the evaluations that significant refurbishment is required to meet such an ambitious target.

Regarding the individual measures, many of these are difficult to evaluate and only a few are easier. However, in order to estimate feasibility to full scale implementation and for other cities to make judgement on measures fitting for their specific conditions, such as climate and energy mix, these individual evaluations are crucial. An example may be the difference of primary energy factors used in different countries; in Sweden the primary factor for gas heating is, according to the Swedish National Board of Housing, Building and Planning, 1.0 and for electricity is 1.6. For Barcelona, significantly different numbers apply (1.195 and 2.368, respectively). Hence, in order to evaluate the impact and outcome of different locations, the impact of the individual measures must be presented at the highest resolution. It would be convenient if there would be a common reference concerning environmental impact from the various energy sources used throughout Europe. The energy carriers used in buildings will still have different total environmental impact, as the conversion and transmission are different for different regional areas. For example, the impact of solar collectors and solar panels will have different environmental impact in Sweden, for which mainly hydro and nuclear power are used for electricity production, compared to regions in Europe having an entirely different energy mix. In addition, during the summer when electricity production would be greatest, in Sweden there is usually very clean electrical production (not even near peak load of the electrical grid) replaced by the PV-cells, compared to southern Europe when significant amounts of AC-units operate at peak load and the electrical grid operates closer to peak loads, replacing peak production electricity.

It may also be interesting to note that some measures both save energy and has a social impact, as seen from the comfort surveys on indoor climate. New windows and adding insulation decrease the required energy for heating (and cooling) and at the same time increase comfort levels. Occupants are more pleased with the indoor environment. After all, that is the primary purpose of any building, maintain high Indoor Environmental Quality (IEQ), and the lowest possible environmental impact. Reducing summer peak load by minimizing cooling needs is extremely important for regions with a climatic condition requiring large cooling loads.

Seen from that perspective, the Work Package 2 should be considered successful as it has demonstrated the level of effort needed for the future existing building stock in Europe but also what improvement in IEQ that will accompany these future improvements through retrofitting.

Solution 1. Energy efficient refurbishment of residential buildings

Smart Solution 1 focuses mainly on improvements of the building thermal performance. Efficient solutions decreasing the need for capacity will be even more valuable in the production/conversion stage, as conversion losses are also saved. Saving 1 kWh of electricity will save 1 to 3 kWh of fuel used for the production. As seen from an environmental perspective, even greater savings are achieved, as transportation and transmission losses are also avoided.

Increasing the thermal resistance of walls and windows would imply that the thermal losses (during cold climate) and thermal gains (during hot climate) will decrease. This will reduce the heating need (cold climate) and cooling need (hot climate). The impact of the measure will not only be depending on the insulation level compared to before renovation, as craftmanship will impact the performance of the renovation. If the fitting of the window or air tightness of the wind cover in the wall surface is poor, insulation level will deteriorate. The craftmanship is extremely important in order to obtain the significant savings desirable in the future of Europe's built environment. Improving the thermal performance of walls and windows may (should) lead to decreased infiltration/exfiltration. It is then extremely important to make sure that the measure do not hinder ventilation (as may be the case if the building ventilation relies on free air movement over the envelope without special arrangement to accommodate the ventilation air movement). Hence, all renovation should always pay close attention to the overall functioning of the building and not only on separate parts.

An example of variation of the result could be the reduction of losses of the hot water circulation loop. Using similar buildings, similar building construction and similar retrofitting technology, one building is stated to achieve (through measurement) 62% reduction, while another building only achieve 27% reduction.

An interesting alternative to achieve the large savings which initial theoretical estimations suggests is to use an appointed Energy Quality Assurance (EQA) officer. Even though it is difficult to assess the importance of the EQA-officer, the task is to be ever present during construction and retrofitting, making sure installations are conducted according to suppliers' instructions. It is sometimes difficult for construction workers to fully appreciate and understand the importance of all the different suppliers' installations instructions, and the EQA-officer could be there to correct improper installations before it is too late and too expensive to rectify any mistake done. In real renovation projects, the impact of the individual measures done will not be possible to monitor, only the aggregated whole building performance. Hence, once the work is done by the different subtractors, there is no way to determine what part of the installed energy efficient measure that is not performing as expected. Hence, the EQA-officer will pay an extremely important role maintaining the quality of the installed measures.

Solution 3. Smart energy saving tenants

The main concept of this measure is really smart. It is known that there is a difference between single family owned apartments' and rental apartments' preferred temperature level (in Sweden). This may, to some part, be due to the fact that the single-family house owners pay their heating bill, while (in Sweden) the tenant pay indirectly through the rent. Hence, the actual cost is usually unknown, and the incentive to improve is lost. Visualization of energy use and the associated costs may trigger the occupants to perform better by knowing the magnitude of saving possible. Indeed, the results seems to indicate an improved energy performance by using these systems, even though the savings obtained are significantly larger than previous experience. However, earlier experience has also shown an initial boost which eventually levels off to lower levels of continuous savings.

Solution 4. Local renewable energy production and integration with buildings and grid

Local production using renewable sources have been implemented in all three cities. There seems to be some difficulties of monitoring some of these measures. For PV-installation in Barcelona, one could however see a significant share of self-produced electricity being used in the building. In Stockholm, measurements in one building seem to indicate that 16% of the total building electrical demand can be provided by local PV-installations. Examples from Cologne and Barcelona show considerably higher values.

Energy savings and CO2 reduction

The following table present the summary of the results obtained in the project considering the buildings that have been completely refurbished (i.e. where the insulation of the building envelope has been modified).

Table 146 Summary of the results obtained within Work Package 2

	no of buildings considered	Retrofitted Area (m^2)	Total energy savings (GWh)	Total energy savings (%)	CO2 emission reduction (ton)	CO2 emission reduction (kg/m2)	CO2 emission reduction (%)
Stockholm	6	31400	**2.5**	**63.9%**	**250.8**	**8**	**69.8%**
Cologne*	16	33500	**1.7**	**37.4%**	**740.7**	**22**	**57.0%**
Barcelona	5	30443	**1.5**	**30.3%**	**396.3**	**13**	**27.8%**
Residential	2	19345	0.3	22.1%	53.4	3	16.1%
Tertiary	3	11098	1.2	31.4%	342.8	31	27.7
Overall results	27	95340	**5.8**	**40.1%**	**1387.7**	**14.6**	**46.4%**

* values are estimated, see M1.0 for details.

Social Impact

The social impact of these Measures may in most instances be positive, but the main negative aspects are of course that any refurbishment could increase the rent of the apartment. In addition, the tenants may also be forced to move out during the renovation. In many of the Measures, the positive social impact will be decreased energy bills and improved indoor quality and climate.

Specifically, the social impact from improved thermal resistance (new efficient window) has been seen to improve the thermal comfort. If proper installation is done, this may lead to decreased draft sensation as well. Together with the fact that the energy bill will be reduced as a direct measure, improved thermal comfort may also lead to an increase in indoor winter temperatures and lower indoor summer temperatures.

Stockholm

As shown in Table 147, the refurbishment in Stockholm involved a residential area of about 40 500 m^2 and over 7000 citizens (estimation).

Table 147 Impact of M1.0 in Stockholm

Impact parameter	**Value**
Renovated m^2	40 657
Citizens engaged/benefited by the Measure	7300
M1.0 Stockholm – Valla Torg	**Value**
Renovated m^2	31 396
Citizens engaged/benefited by the Measure	600

M1.0 Stockholm – Slaughterhouse	Value
Renovated m²	906
Citizens engaged/benefited by the Measure (estimated users per year)	6 500
M1.0 Stockholm – Kylhuset	**Value**
Renovated m²	3 405
Citizens engaged/benefited by the Measure	50
M1.0 Stockholm – Årstakronet	**Value**
Renovated m²	4 950
Citizens engaged/benefited by the Measure	150

Cologne

As shown in Table 148, the refurbishment in Cologne involved a residential area of about 33 500 m² (living area) and about 1100 citizens (estimation).

Table 148 Impact of M1.0 in Cologne

Impact parameter	Value
Renovated m²	33 500
Citizens engaged/benefited by the Measure	1100

Barcelona

As shown in Table 149, the building refurbishment in Barcelona involved a residential area of more than 50 000 m² and more than 380 000 citizens (estimation, including a public library)., if we include the estimated annual users of the Library Les Corts.

Table 149 Impact of M1.0 in Barcelona

Impact parameter	Value
Renovated m²	50 378
Citizens engaged/benefited by the Measure	380 000
M1.0 Barcelona – Ca l'Alier	**Value**
Renovated m²	2100
Users and visitors benefited by the Measure	5200
M1.0 Barcelona – Library Les Corts	**Value**
Renovated m²	4005
Visitors benefited by the Measure	annual average: 380 000 monthly maximum: 66 900
M1.0 Barcelona – Library Les Corts	**Value**
Renovated m²	14 165
Citizens engaged/benefited by the Measure	620
M1.0 Barcelona – Canyelles	**Value**
Renovated m²	5180
Citizens engaged/benefited by the Measure	n/a
M1.0 Barcelona – Ter 31	**Value**
Renovated m²	393
Citizens engaged/benefited by the Measure	n/a
M1.0 Barcelona – Lope de Vega	**Value**
Renovated m²	450

Citizens engaged/benefited by the Measure	n/a
M1.0 Barcelona – Melon district	**Value**
Renovated m²	13000
Citizens engaged/benefited by the Measure	n/a
M1.0 Barcelona – Hotel H10 Madison	**Value**
Renovated m²	4100
Citizens engaged/benefited by the Measure	n/a
M1.0 Barcelona – CEM Claror	**Value**
Renovated m²	2993
Citizens engaged/benefited by the Measure	n/a
M1.0 Barcelona – Escola Sert	**Value**
Renovated m²	3427
Citizens engaged/benefited by the Measure	n/a

Upscaling of the results

Five different measures have been used and up-scaled to the entire multifamily building sector of Stockholm city.

- M1.1.1: Low U-values of Windows
- M1.1.2: Reducing hot water losses
- M1.1.3: Recovering waste water heat from the drain
- M1.1.5: New efficient air heat pumps
- M1.1.8: Air tightness

The Energy declaration database has been used to facilitate the up-scaling. It may be observed that these five measures are independent of each other, i.e. they do not decrease the same energy loss. Therefore, the total impact of these five measures are additive. Hence, as they all are related to the same total heating energy used in the entire multifamily sector, the percentages may also be added. Hence, it may be seen that the total estimated saving of the primary energy with these five measures (in Stockholm city) corresponds to ~ 61 %.

3 WORK PACKAGE 3: INTEGRATED INFRASTRUCTURES

3.1 Introduction

Work Package 3 (WP3) focuses on implementation of the concrete measures in each Lighthouse city (Stockholm, Cologne and Barcelona) within Integrated Infrastructure.

Within the GrowSmarter Project, the Measures included in the WP3 cover the Smart Solution 5 *Smart lightning, lampposts and traffic posts as hubs for communication*, Smart Solution 6 *New business models for district heating and cooling*, Smart Solution 7 *Smart waste collection, turning waste into energy* and Smart Solution 8 *Big open data platform for saving energy and improving the quality of life*.

As written in the Grant Agreement, the objectives of WP3 are to:

- Identify and procure industrial partner at local site.
- Implement and demonstrate energy savings measures in integrated infrastructures districts.
- Gather data from implemented measures for evaluation.
- Analyze legislative and structural barriers.
- Analyze replicability of integrated infrastructures measures.

In general, in addition to the overall GrowSmarter goal of reducing the energy consumption by 60%, the experience from the implementation of the Measures in WP3 is expected to provide insights about technical (e.g. which provider to use, interfaces, prototypes, WiFi capabilities, upcoming developments) and legal (e.g. data protection laws, traffic and parking restrictions, business tax exemptions, installation certifications) aspects within Integrated Infrastructure. The activities carried out in WP3 will outline the opportunities of integrated infrastructures to develop new services for citizens and to understand short and long term financial and technical implications to secure sustainability goals.

The conclusions of WP3 in the present evaluation report are expected to focus on validation towards the prescriptions of the evaluation plan (D5.1), the technical feasibility of the Measures and their potential for up-scaling and replicability.

3.2 Evaluation methodology

In WP3, Measures M8.1-M8.5 are “enabling Measures”, which means that they do not directly offer data, but rather offers access to data provided by other Measures.

More in general, the evaluation methodology for the Measures of WP3 has been defined individually in the evaluation plan (D5.1), due to the specific scope and features of the Measures.

3.3 Measures of WP3

M5.0 – Smart lighting, lampposts and traffic posts as hubs for communication

This section presents the results of M5.1, M5.2 and M5.3.

M5.1.1 – Smart LED street lighting

Introduction

Sensor controlled LED lighting for pedestrian and bicycle paths to enable the lights to provide base lighting to satisfy the feeling of safety at all times and increase the level of lighting when someone approaches.

According to the evaluation plan (D5.1), the intention of the Measure was to reduce the demand of energy for lighting of pedestrian and bicycle paths by 40-50%. The baseline was defined by measuring the electric energy demand during 6 selected months before Measure implementation.

Stockholm

Industry partner	Contact person	Validation partner
Trafikkontoret	Björn Lindelöf	KTH-EGI

The initial measurement of the baseline consumption according to bullet 1 above was not executed due to delays in the installation. The baseline is a theoretical value based on the burning hours and the maximum effected that was measured. Measurements were conducted over 24 month during 2017 and 2018.
The theoretical baseline shows that the LED-fixtures without sensors would have consumed 10 838 kWh over 24 months. After installing sensors, the consumtion was reduced to 7 407 kWh, a reduction of 31.6%.

Potential for full scale implementation

Technical, economic and social feasibility

Street lighting is generic to all cities. Hence the technical feasibility is very good since all cities have similar amount of hours requiring street lighting, since Stockholm having around 4520 hours of sun above the horizon, 4480 hours for Cologne and 4460 for Barcelona[20]. The technology thence would save similar amount in any city in Europe, per lamp post, yielding a saving up to 32%. The economic feasibility will be determined by the additional cost of the energy saving light compared to the old ones, together with the cost ratio between these two technologies. The social implications will be decreased energy bills or increased lighting in areas not earlier having artificial light. The may, at the same cost as before, increase the sense of security amongst the pedestrians and will have a very positive added value of the social impact of this technology.

[20] Sunrise, sunset, daylight in a graph [WWW Document], 2005. URL https://ptaff.ca/soleil/?lang=en_CA (accessed 10.29.18).

Upscaling and replicability of the Measure

This Measure is applicable to any city and may be upscaled to for all lamp posts of not constantly visited areas where the light dimming would allow energy saving, as long as the electrical connections can handle or be converted for any difference between the technologies.

Conclusions

This Measure may save up to 32% of electrical consumptions in areas similar to where the Measure was implemented. The saving may be used for additional lighting in order to increase the sensation of security during dark hours in areas not earlier having night light. Either way, it is a favorable Measure which will increase the attractiveness of any city.

M5.1.2 – Self-controlled LED street lighting

Introduction

The Measure consists of the installation of self-controlled LED street lighting with pre-set lighting schemes based on the idea that traffic intensity is reduced in the middle of the night to demonstrate the potential to saving energy compared to regular LED light.

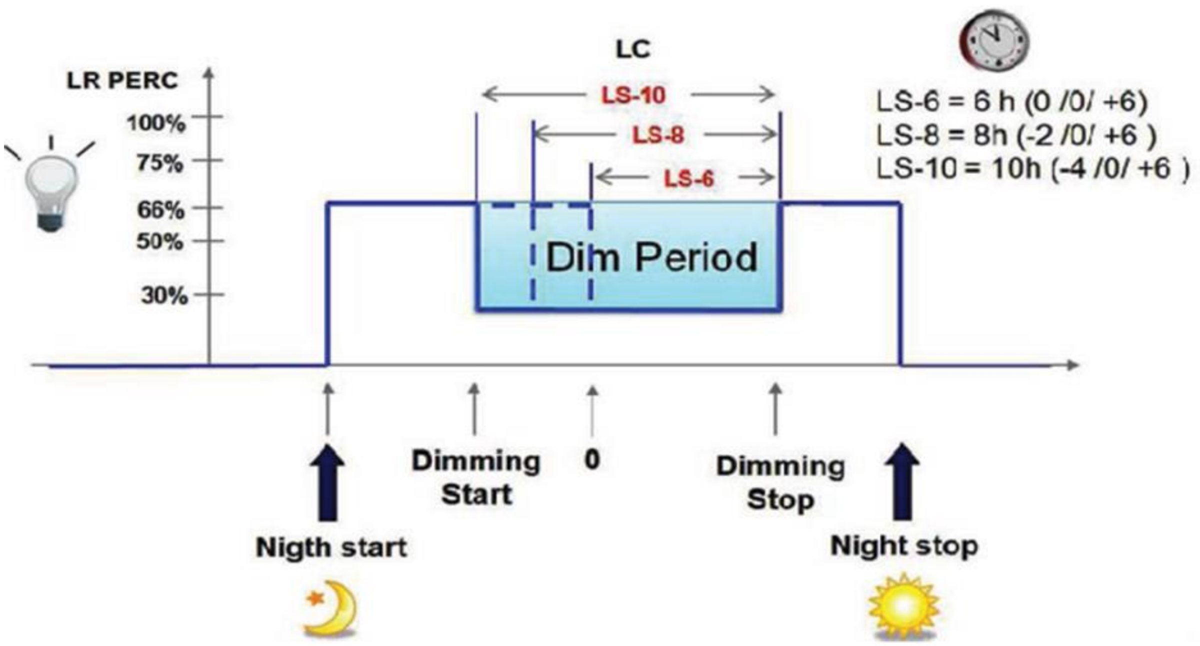


Figure 117 Schematic of the light dimming period modulation

According to the evaluation plan (D5.1), the intention of the Measure was to reduce the demand of energy for LED street lighting by 20%.

Stockholm

Industry partner	Contact person	Validation partner
Trafikkontoret	Björn Lindelöf	KTH-EGI

The initial measurement of the baseline consumption was not executed due to delays in the installation. The baseline is a theoretical value based on the burning hours and the maximum effected that was measured. Measurements were conducted over 24 month during 2017 and 2018.

The theoretical baseline shows that the LED-fixtures without pre-set lighting schemes would have consumed 24 894 kWh over 24 months. With the pre-set lighting schemes, the consumtion was reduced to 19 707 kWh, a reduction of 20.9%.

Potential for full scale implementation

Technical, economic and social feasibility

Street lighting is generic to all cities. Hence the technical feasibility is very good since all cities have similar amount of hours requiring street lighting, since Stockholm having around 4 520 hours of sun above the horizon, 4 480 hours for Cologne and 4 460 for Barcelona[21]. The technology thence would save similar amount in any city in Europe, yielding a saving up to 21%. The economic feasibility will be determined by the additional cost of the energy saving light compared to the old ones, together with the cost ratio between these two technologies. The social implications will be decreased energy bills or increased lighting in areas not earlier having artificial light. This may, at the same cost as before, increase the sense of security amongst the pedestrians and will have a very positive added value of the social impact of this technology.

Upscaling and replicability of the Measure

This Measure may be upscaled to all lamp posts, as long as the electrical connections can handle or be converted for any difference between the technologies.

Conclusions

The results obtained show an energy saving of about 21% due to the implementation of this Measure which has a good potential for being easily replicated in many European cities.

M5.1.3 – Remote controlled LED street lighting

Introduction

The Measure consists of the installation of remotely controlled LED Street lighting which can be controlled from a distance to provide sufficient lighting depending on the time of the day and the level of traffic that comes with it, similar to M5.1.3 with the difference that lighting schemes can be changed remotely in real-time. The aim is to use an advanced control system with standardized open protocol according to TALQ Consortium.

According to the evaluation plan (D5.1), the intention of the Measure is to save 30-50% of energy compared to regular LED lighting installations and evaluate the city benefits of the Measure, considering that savings of 7-12 GWh can be achieved yearly in the entire city using local grid energy supply.

The baseline should be defined by measuring the electric energy demand (in kWh/h) of regular LED lighting installation during 6 selected months before the Measure is implemented. For a quantitative evaluation of the results, the energy demand (kWh/h) should be logged using an

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[21] Sunrise, sunset, daylight in a graph [WWW Document], 2005. URL https://ptaff.ca/soleil/?lang=en_CA (accessed 10.29.18).

energy measuring equipment on an hourly basis during the same 6 months of a consecutive year.

It should be determined, in particular:

1. Average energy demand over 6 months before implementation of Measure (kWh/h).
2. Average energy demand over the same 6 months of a consecutive year after implementation of Measure (kWh/h).
3. City benefit if the Measure is implemented for all street lights, savings should be presented (GWh/year).
4. Reduced CO_2 emissions due to reduced energy demand (kt/year).

Stockholm

Industry partner	Contact person	Validation partner
Trafikkontoret	Björn Lindelöf	KTH-EGI

The initial measurement of the baseline consumption was not executed due to delays in the installation. The baseline is a theoretical value based on the burning hours and the maximum effected that was measured. Measurements were conducted over 24 month during 2017 and 2018.
The theoretical baseline shows that the LED-fixtures without lighting schemes would have consumed 10 770 kWh over 24 months. With the pre-set lighting schemes, the consumtion was reduced to 8 062 kWh, a reduction of 25.1%.

Potential for full scale implementation

Technical, economic and social feasibility

Street lighting is generic to all cities. Hence the technical feasibility is very good since all cities have similar amount of hours requiring street lighting, since Stockholm having around 4520 hours of sun above the horizon, 4480 hours for Cologne and 4460 for Barcelona[22]. The technology thence would save similar amount in any city in Europe, yielding a saving up to 25%, significantly less than the expected savings. The economic feasibility will be determined by the additional cost of the energy saving light compared to the old ones, together with the cost ratio between these two technologies. The social implications will be decreased energy bills or increased lighting in areas not earlier having artificial light. The may, at the same cost as before, increase the sense of security amongst the pedestrians and will have a very positive added value of the social impact of this technology.

Upscaling and replicability of the Measure

This Measure may be upscaled to for all lamp posts, as long as the electrical connections and infrastructure can handle or be converted for any difference between the technologies. This Measure may be upscaled to for all lamp posts, as long as the electrical connections and infrastructure can handle or be converted for any difference between the technologies.

Conclusions

This Measure may save up to 25% of electrical consumptions. The saving may be used for additional lighting in order to increase the sensation of security during dark hours in areas

[22] Sunrise, sunset, daylight in a graph [WWW Document], 2005. URL https://ptaff.ca/soleil/?lang=en_CA (accessed 10.29.18).

not earlier having night light. Either way, it is a favorable Measure which will increase the attractiveness of any city. Less saving than expected was obtained. It is at this stage not clear why that is the case. One should also keep in mind that Measure M5.1.2. and M5.1.3 are both savings done related to normal LED installation. Hence, both will not be installed, or if done, the aggregated savings will be less than indicated here.

M5.2 – Combined electrical charging and street lighting poles + WiFi-to-grid connection

Introduction

The growing demand of broadband mobile communications requires a dense network of small urban sites deployed around the city, in order support all the wireless connectivity needs. With the aim to rationalize the deployment of dense networks based on small cells and micro-sites the Measure aims at transforming the urban furniture, like street lighting poles, into smart infrastructures.

The Measure consists in combining multiple functionalities within shared infrastructure such as street lighting poles, traffic lights, and traffic signs with the aim to make walkable urban areas ubiquitously connected, and enable a shared sensing infrastructure in the open street spaces. By relying on the extensive fiber infrastructure prevalent around the city, new WiFi connections will be made available for people and things such as a variety of urban sensors supplying information that can be analyzed and used for control. Traffic signs will be made available for Telecommunication companies for installing 4G to increase local connectivity.

According to the evaluation plan (D5.1), the baseline was determined by:
1. Street level bandwidth from WiFi or cellular connection before implementation
2. Number of urban walkable space services and sensors before implementation

The intentions of the Measure were:
1. To make walkable urban areas ubiquitously connected
2. To provide high-speed internet to people and things in the walkable street environment
3. To enable higher degrees of urban sensing
4. To generate insights from the walkable urban areas
5. To increase 4G connectivity by enabling telecommunication companies to install 4G masts on traffic signs.

Stockholm

Industry partner	Contact person	Validation partner
City of Stockholm Trafikkontoret	Mika Hakosalo	KTH-EGI, KTH-SEED

M5.2 is an enabling measure and therefore still the amount of end-users is still limited. Currently the end-users are only within in the Traffic Administration of the city. The data collected into the IOT-platform is very rich and can be used by both users inside the city organisation as well as stakeholders (different service providers) in the Slakthus/Globen area. The data collected has also been used to develop a mobile application for visitors, but it has not yet been tested in public. Therefore there are no end-users in the form of citizens yet.

The implementation of IOT equipment in the city environment started in October 2017. All of the sensors measuring traffic were installed by the end of February 2018. The wifi-based sensor installations are still under installation, some 60% have been installed to this date. Information from these sensors will in turn give indications of the need of other IOT equipment in the city environment.

Originally the idea was to use street light or traffic poles as a structure for the sensors, but it turned out that the street light poles could not bear the weight of the traffic measuring sensors. It also turned out that it was not possible to use the same electricity as for street lights, so separate poles and electricity needed to be used. Also other existing infrastructure were used. Four traffic measuring sensors were installed on a pedestrian bridge running over the street. Another four sensors were installed in a portal that was existing partly, it had to be extended to make measurements possible on the other side of the street. Regarding the wifi-nodes they were installed in buildings owned by the city and could use the existing connectivity (broadband) there. No additional cabling for electricity was needed as the wifi-nodes were connected with power over Ethernet (PoE).

The existing infrastructures can be extended with other types of sensors. Currently the city is looking for using these for multi-sensors as well as for smaller air pollution sensors.

The deviation to the original evaluation plan is that the street level bandwith from wifi or cellular connection has not yet been in focus in the implementation as it is important to first understand flow of people and then based on the flow analysis analyse more in detail the bandwidth on the streets/passages with high flow.

The baseline for the number of urban walkable space services and sensors before implementation was defined as zero. There were no sensors or services in that area providing data into an IOT-platform were it could be stored, used and analyzed by different functions in the city.

All measurement points are defined and numbered and sensors are individually monitored. If a sensor does not provide data or the data is inaccurate it can be easily detected by the IOT-platform. Also inconsistencies between different sensors can be seen, for instance it was found that a person passing the first wifi-sensor was not detected by the next ones. The wifi-sensors raw-data also needed to be cleaned as any type of device (for instance a printer) tries to connect to it. All those have to be cleaned away before it is possible to make flow analysis of pedestrians and bicyclists.

The following Figures show examples of the visual and quantitative information that can be retrieved through the developed data platform.

Figure 118 shows a screenshot of the sensor location displayed with Google Maps. Figure 119, Figure 120 and Figure 121 show examples of the live data that can be obtained through the developed data platform. Figure 122 shows an example of the visualization of people passages and Figure 123 shows an example of chord diagram that help to investigate the vehicle patterns.

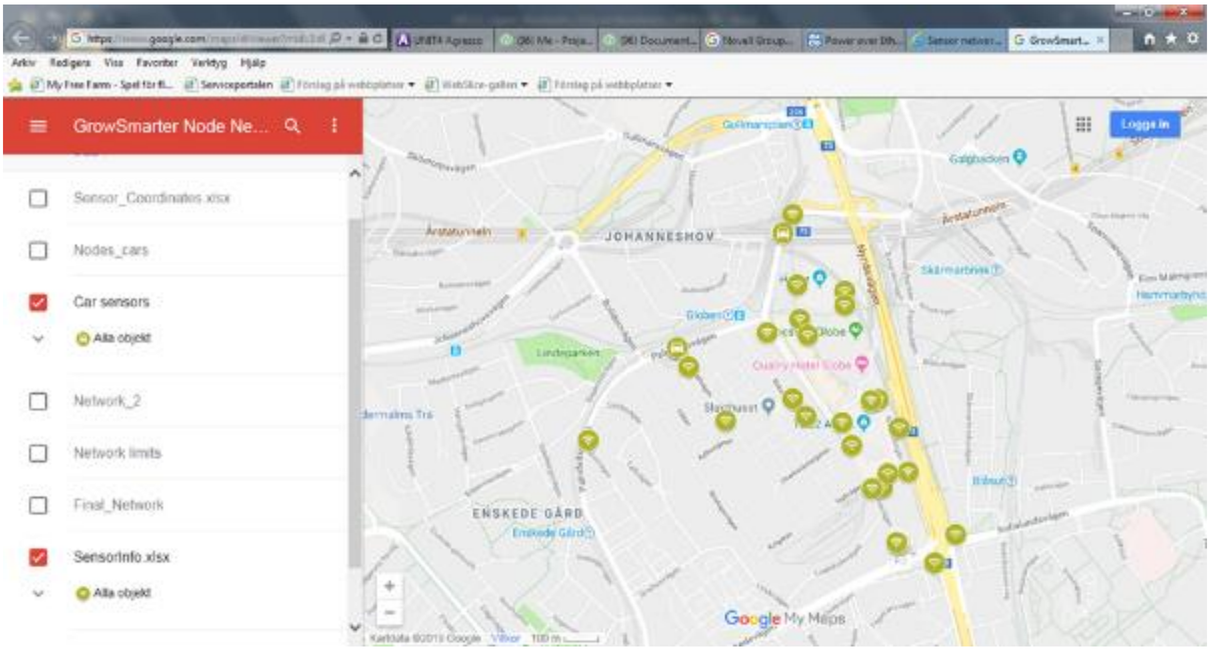

Figure 118 Sensor map (M5.2)

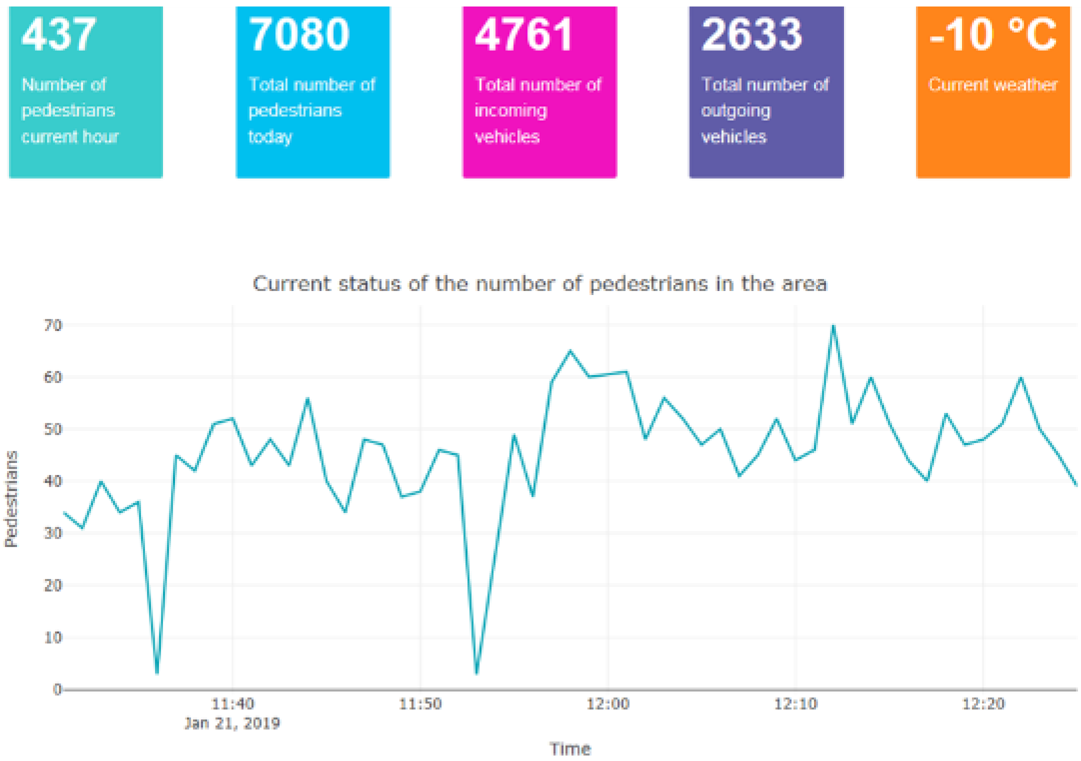

Figure 119 Live data example (M5.2)

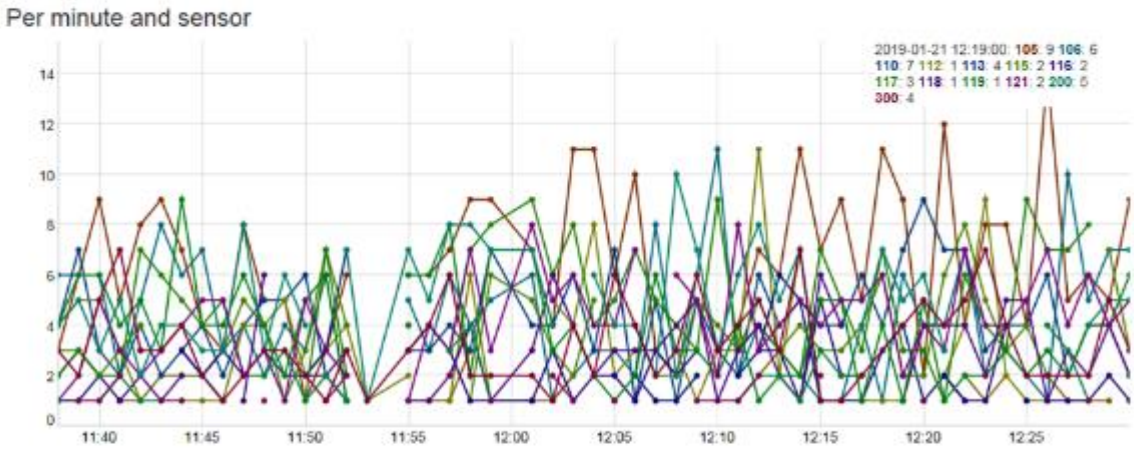

Figure 120 Example of live data per minute (M5.2)

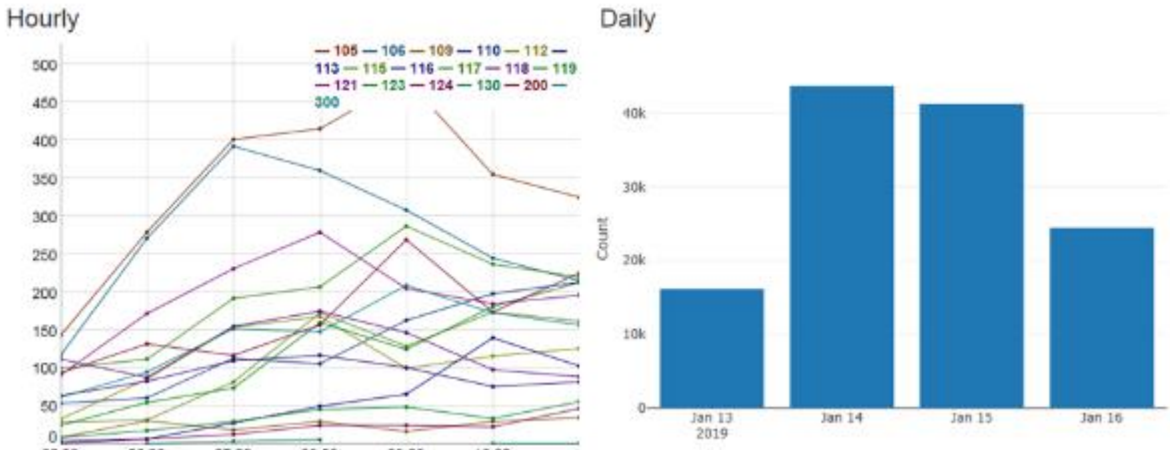

Figure 121 Example of live hourly and daily data

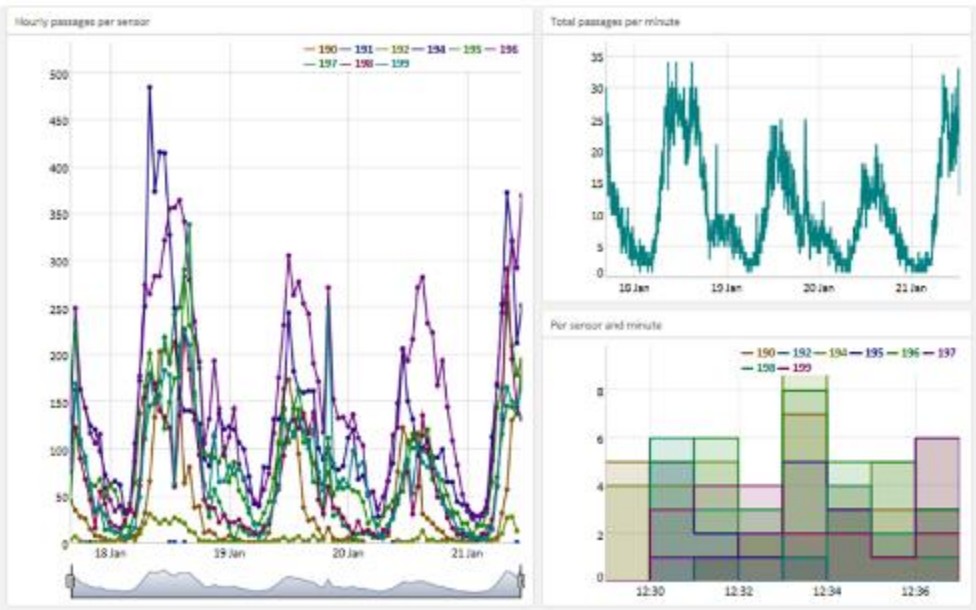

Figure 122 Example of data visualisations on passages (M5.2)

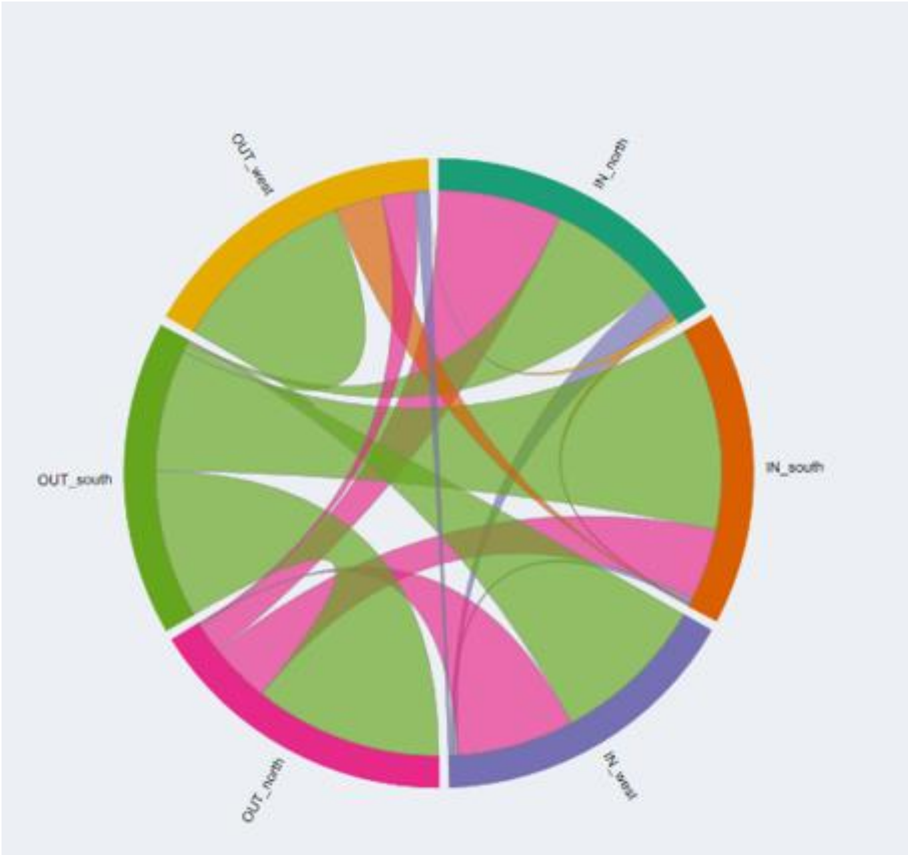

Figure 123 Example of chord diagram: vehicle entry and exit points in one area (M5.2)

Technical feasibility and implementation issues

It is important to understand that there are different levels of implementation and each has its own technical feasibility.

The first level was to implement sensors in existing infrastructures such as street light and traffic posts. Only partly this was technically feasible as neither the structure or availability of electricity 24/7 is existing in street light poles. Other traffic poles do not normally carry electricity and they are not always positioned optimally and/or their high might be too low. If the option was to put up separate portals and/or poles for sensors, then it is important that to have both connectivity and electricity available. It is also important to note that the structure built for the sensors can later be used for a various set of other sensors as it is very easy to mount and connect them.

The second level is the connectivity and data flow. The original idea was to use the existing optical fiber network existing in the city and use a wifi-network to collect data. Several different networks in a city have been considered (see Figure 124).

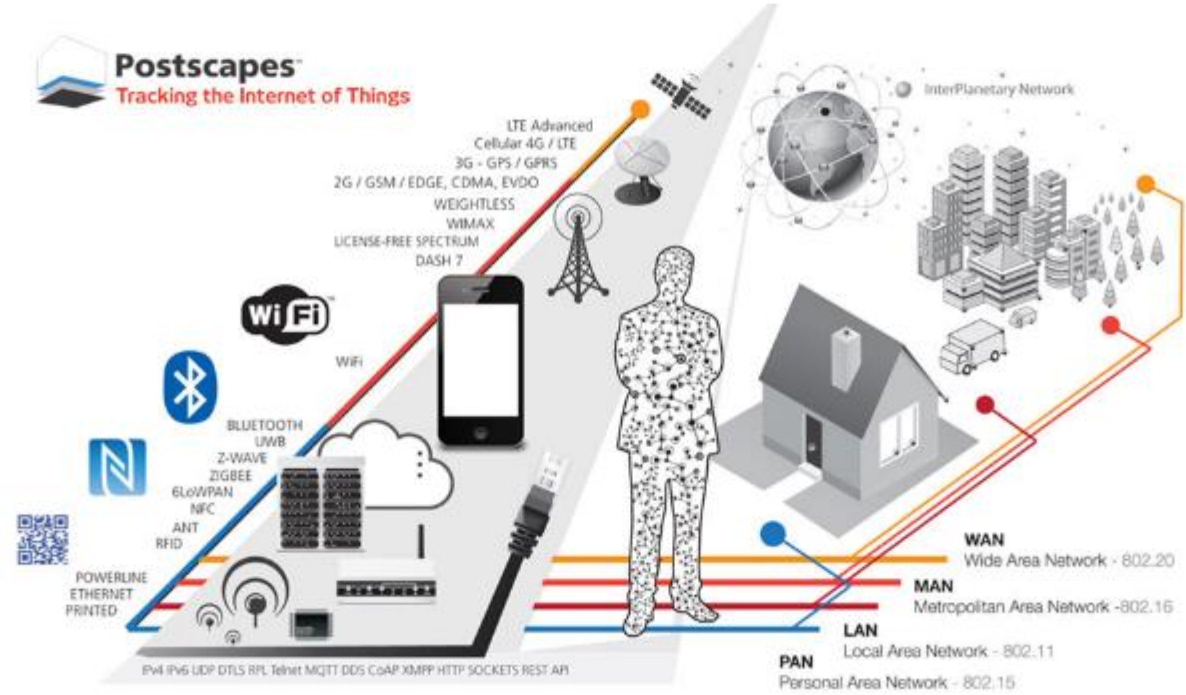

Figure 124 IOT connectivity: conceptual scheme

Ethernet has been used for the wifi-nodes and 3G has been used for traffic measurements. The technical feasibility in Stockholm is high for installing all these types of technologies.

The next level are the sensors themselves. Two different types of sensors have been implemented. The traffic measurement sensors has provided accurate and stable data after implementation. Only one sensor had problems with data delivery and it turned out that the electricity input was done in an inaccurate way by the electrical company, when this was corrected the sensor provided excellent data again. Considering the wifi-nodes which were supposed to detect bypassing people in a very accurate way in reality did not do so. First the sensors were sensitive and could stop providing data. At one point of the 23 installed sensors only half were actually providing data. The second problem was that the sensors were supposed to be contacted by the by-passing mobile device every 20 seconds. In reality it could be between 20 seconds and 3 minutes. This made the data quality poor for instance to define the average speed of the bypassing person. Without the average speed it was not possible to separate between a pedestrian or a bicyclist or a person inside a vehicle. For these sensors the technical feasibility was low. New sensor models are existing and that these have a much higher level of quality and accuracy.

The fourth level of technical feasibility is the quality of data itself and how much work is needed to be done to the raw-data before it can be used for analytics. With the traffic measurement sensors the raw-data was based on anonymised registration plate data and the information from the transport authority related to a registered vehicle. As the accuracy of the sensor to read registration plates was high also the raw-data quality was high. There was no need to further process the data in the IOT-platform, it could be directly used for analytics. Considering the wifi-nodes the raw-data contain a lot of information that was not needed for analytics. I great amount of work and effort was made to wash out all unnecessary data so that only data of bypassing persons was left. This had to be done in the IOT-platform environment. So in this sense the technical feasibility of the wifi-nodes was low.

The fifth level of technical feasibility is the integration of data into the platform. The platform provider (IBM) met with the sensor providers and defined the protocols to be used for data integration. Here the technical feasibility was high.

Economic feasibility

Is the implementation of this Measure economically sustainable?
This measure is an enabling technology. The initial costs are high and it takes time to gather data so that it can be properly analysed. This measure is not economically sustainable if it is for instance only used by traffic analytics in a city. But if the sensors and collected data can be used for a various of purposes and by different end-users it will become economically sustainable. Also the longer the installed sensors can provide data, the better analytics can be performed for instance to define what type of event in the Globen area causes the most traffic pollutions. Also predictions gets more accurate the more data is available.
What is the extra cost between the intervention included in this Measure compared to a standard intervention?
A standard intervention would be that an Analytics company provides the sensors, measurement and analysis with a report to the city. Traditionally the measurement time is 2-3 weeks. The city does not own the data, they just receive a report in hand with the results. A intervention like this costs 250 000 kr. If you would make two measurements per year the cost would be around 500 000 kr. During the procurement process the price for the same amount of sensors during 14 months costed around 580 000 kr. This prize did not include any analysis nor reports. The cost would have been some 50 000 kr extra. So the extra cost for the city is around 180 000 kr including sensors and two report.

How this extra cost compares to the benefits?
The main difference with a standard intervention is that in this case the city owns the data and can perform other analysis with that and that it is ongoing real-time measurements, giving a possibility to use data to predict and to steer city infrastructures. So you get a lot of extra value for the extra 180 000 kr.

Social feasibility

What is the social acceptance and impact of this Measure?
This Measure involves personal information. Data is collected from bypassing vehicles and people. A very important part of the measure was to find solutions that are tested in Sweden and have got an approval from the Data Inspection. These chosen measures had that. Both anonymize the data already in the sensor, so no personal data is stored or handled. To further ensure social acceptance signboards have been installed in all entry points to the area and the public have been informed through a website about the technology used and how personal anonymized data were treated. During this first 12 months the feedbacks and questions from the public were just a few. After answering them they have been satisfied to know that their personal integrity is not jeopardized. The solution has also been presented in different events, study visits, meetings and in media and also in these the social acceptance have been very positive.

How was the people engagement handled within this Measure?
Some of the people engagement work has been done outside the project as part of the strategy process of a smart connected city. Here a large amount of citizens were asked about their view about smart cities, that the city set up sensors, analyse data etc. The citizens were positive towards this. In interviews they for instance said that they have no problem if the city collects data, as a lot of large multinational companies already do that. In these sessions it was especially put forward that a subject of special interest for the citizens were id the city could with sensors and data analytics make it easier to travel in Stockholm. And this is exactly what the aim has been with the data collection in Slakthus/Globen area.
Several ideation and design thinking workshops has been organized with different stakeholders to find out what kind of needs there are and what kind of challenges could be solved with the data collected. The mobile application created by IBM as part of Measure 8.1 is an example of this approach.

Possibility to replicate the Measure
There is a good possibility to replicate this measure both in other areas of Stockholm as well as in other European cities. Even if quality problems occured with the wifi-sensors, there are alternatives available on the market which can provide the accuracy that the Measure originally

aimed for. The vehicle sensors if combined with air pollution sensors could be used in cities and areas where the air pollution from traffic exceeds the levels set by the EU. It is possible to combine the measurement point also with instant communication through digital screens that personalize the information based on the vehicle type passing. With this type of measurements it is possible to understand what type of vehicles should be restricted, at what times of the year or day. Wifi-sensors add a lot of information to the vehicle sensors, making it possible to understand all traffic modes including pedestrians and bicyclists. An alternative to wifi-nodes is to get a consent from visitors to follow their mobilephones. This can be done with a mobile application, for instance the SL application. This way no infrastructure for measurements would be needed to build, the data could be directly analysed in the platform. This has for instance been tested in the Roskilde Rock Festival with positive results.

Conclusions

This measure is in many ways the core point of many smart cities. The conclusion is that it has been a good idea to focus on a limited area in Stockholm as well as on a defined city challenge. The selection of Slakthusarea has two reasons, 1) It has a lot of events and the industrial area next to it will have 10 000 new apartments as well as thousands of new workplaces, so in miniature a fast growing city, 2) The people flow in the event area varies very much, during office hours it can be quite empty and during events very crowded. Also the amount of vehicles varies very much, from almost no vehicles to a total traffic chaos, which takes hours to solve.
An important part of the implementation has been to understand who the end-users are and what are their needs. A very common approach is to set up sensors in an area, collect data into an open big data platform and then hope that external developer will make innovative applications with the data. Unfortunately this have very rarely been the case. The adopted approach was instead to start with a defined group of end-users and ask what they would like to know about the city. This approach firstly revealed a little knowledge about pedestrians and secondly a not clear picture of what vehicles are in a city area and what kind of pollution they create.

Another important part has been the co-operation within the city. There is not one unit or organisation in the city who is responsible of this Measure. It is a Measure where many different functions in the city must be involved. Since the aim is a common shared sensor network and platform, no single unit in the city can own the whole process. This horizontal, cross-organisations approach has been slow. It speeded up significantly when the strategy for a smart connected city was approved and a political mandate was existing.

The measure 5.2 is an enabling measure and therefore still the amount of end-users is relatively limited. Currently the end-users are only found in the Traffic Administration of the city. The data collected into the IOT-platform is very rich and can be used by both users inside the city organisation as well as stakeholders (different service providers) in the Slakthus/Globen area. To attract more end-users a series of workshops will be held to different end-usersgroups during 2019. The data collected has also been used to develop a mobile application for visitors, but it has not yet been tested in production with public end users.

Cologne

Industry partner	**Contact person**	**Validation partner**
RheinEnergie	Christian Remacly Andreas Wolba	KTH-EGI, KTH-SEED

RheinEnergie installed three electric charging stations on existing street lighting poles. An existing WiFi grid connection hotspot is already in place at these locations.

By combining electrical charging to street lighting poles, the aim is to make walkable urban areas ubiquitously connected, and to enable a shared sensing infrastructure in the open street spaces. Wi-Fi and environmental sensors had already been installed at the lighting poles in this area prior to the GrowSmarter project. In the planned project area Mülheim (Stegerwaldsiedlung) the infrastructure is not well suited for this measure. Since several stations are installed, further expansion of charging infrastructure is not economically feasible.

For these reasons, the measure is currently carried out in another area, called “Klimastraße”. This area is part of the initiative SmartCity Cologne where RheinEnergie tests innovative technologies. An existing WiFi grid connection hotspot is already in place at these locations.

The following Figures show details of the installed light poles. The chargin stations (Figure 127) are open to the public and have a maximum charging capacity of 11kW. A parking lot for charging is located at the lantern and is reserved exclusively for electric vehicles which are being charged.

Figure 125 Localisation of the area used for M5.2 in Cologne

Figure 126 Details of the light pole installation in Cologne

Figure 127 Charging stations installed in Cologne

Over 14.000 kWh were loaded at the 3 stations altogether in 2018. If you estimate a consumption of 0,2 kWh/km and an emission of 0,15 kgCO2/km we have a reduction of 10 tCO2 in 2018.

Possibility to replicate the Measure

An essential precondition for the implementation was the advantage that the lanterns belong to RheinEnergie and this facilitated the entire installation process. In other cities this condition may not be verified and the installation process can be more costly and less feasibile.

Conclusions

In general, the system of charging infrastructure can also be developed and implemented in any other cities. A good charging infrastructure is the prerequisite for a better integration of E-mobility.

Finding suitable locations is often not easy. There are many parameters to consider, such as ownership or the network situation on site. In this case, the space in the lantern cavities should clearly be enough to allow the cable installation. In addition, the lantern structure must be strong enough to withstand the additional load from the charging station. The point with the ownership must be clarified individually in each case.

Barcelona

Industry partner	Contact person	Validation partner
Cellnex	Carmen Vicente	KTH-EGI

In the city of Barcelona, Measure 5.2 is a smart solution that provides enhanced wireless access networks, in order to support the growing demand of mobile connectivity in the city for broadband mobile connections and IoT services.

The solution is based on transforming urban furniture like street lighting poles into new small urban telecom sites, which are called Smart Towers (Figure 128). The new multifunctional

SmartTowers should be connected to backbone networks, in order to grant the provision of advanced communication access services.

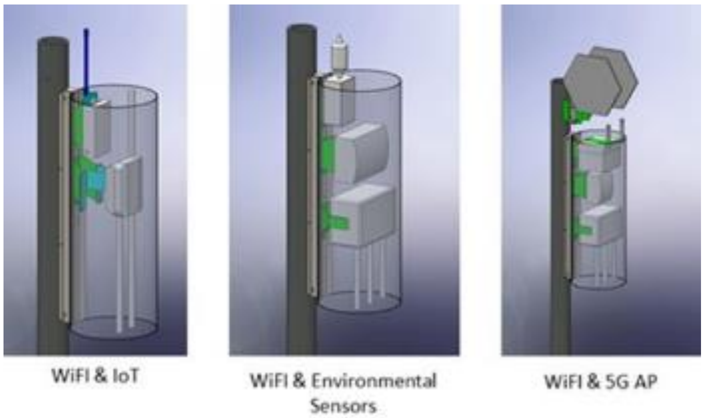

Figure 128 SmartTower design (M5.2 Barcelona)

The growing demand of broadband mobile communications requires of a dense network of small urban sites deployed around the city, in order support all the wireless connectivity needs. With the aim to rationalize the deployment of dense networks based on small cells and micro- sites in the city of Barcelona, the measure 5.2 transforms the urban furniture, like street lighting poles, into Smart Towers.

The Smart Towers are connected to high capacity backbone networks and provide space to collocate the communications devices that will provide the enhanced mobile connectivity services.

Implementation of this measure started in Feb 2016 and ended in Dec 2017. The initial agreement was for five Smart Towers, which were deployed during the second half of 2017 for the Municipality of Barcelona. In Dec 2017, the scope was then expanded with four additional Smart Towers.

Figure 129 Localisation of Smart Towers in Barcelona

The main implementation activities regarded:

- Meetings with stakeholders & collection of requirements (aesthetic, functional, operation and maintenance issues)

- Pilot areas analysis (energy supply, connectivity to FO network, urban furniture availability, link budget analysis, WiFI coverage, IoT coverage, people affluence, etc)
- Agreement with the landlord about the location and the Smart Tower design
- Assessment of the Smart Tower design:
    - Physical and mechanical evaluation: devices layout into the Smart Tower, fixings, energy supply, connectivity aspects, etc.
    - Operative and functional evaluation: interference tests, data service configurations.
- Development of the technical project and fulfilment of all the administrative procedures to obtain licenses to execute the works
- Gathering of material and equipment
- Implementation of Smart Towers:
    - Execution of civil works to supply energy and FO links to the SmartTower
    - Installation of sensors and communication devices
    - Logical set-up & commissioning.

Figure 130 shows pictures related to the installation phase.

M5.2 is a technological enabling measure. Therefore, most of the evaluated parameters are related to measure WiFI connectivity services, as planned in the evaluation strategy.

Data for evaluation is collected and processed from the monthly statistics that are provided by the Smart Towers Management System.

Figure 130 M5.2 Smart Towers - Implementation tasks (Barcelona City case)

The evaluation of the Measure included:

- Number of potential users: represents the rate of mobile users inside the coverage area of the Smart Tower.
- Number of WiFI connectivity services: Each Smart Tower can provide more than one connectivity services. Each “connectivity service” represents a wireless access network.
- Number of connected users: represents the rate of mobile users that have established traffic data sessions with the wireless access networks provided by the Smart Tower.
- Data throughput: represents traffic data rate of the sessions, in both channels: downlink and uplink.

This measure demonstrates that is feasible to transform the urban furniture into SmartTowers to provide wireless connectivity services.

The measure also demonstrates that to monitor connectivities could be useful to check urban policies related to reduced traffic congestion and create more spaces for pedestrians.

Results demonstrates that there isn't a direct correlation between the number of potential users and the connected ones for a given Smart Tower. Whereas potential users could be both pedestrian and drivers. Connected users use to be pedestrians. Then, the location of the Smart Tower influences the measured values. Thus, Smart Towers located near big streets with a lot of traffic, such as LLACDIAG, detects more potential users that Smart Towers that are located in smaller streets (Figure 131).

Besides, Smart Towers located near pedestrian streets, such as PEIVRPOB, detects more connected users because most of these users are pedestrians.

Then, Smart Towers could be used to monitor crowded areas.

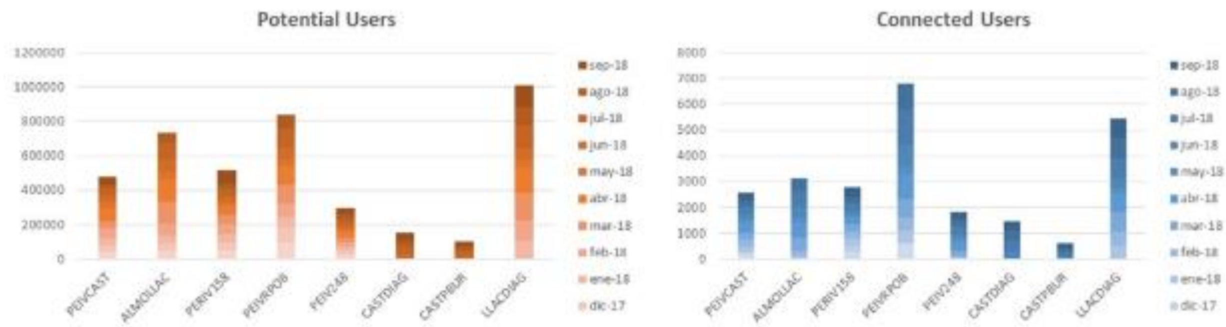

Figure 131 Potential users and connected users per SmartTower

Figure 132 Downlink and Uplink data per SmartTower (M5.2 Barcelona)

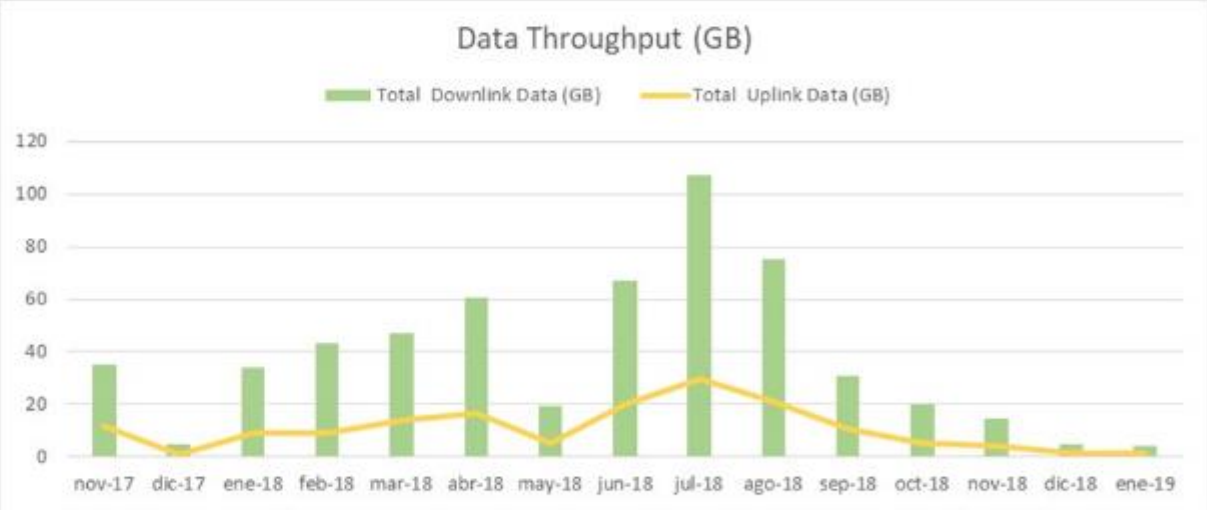

Figure 133 Data Throughput evolution (M5.2 Barcelona)

As shown in Figure 132 and Figure 133, the SmartTowers processed more data traffic during the summer season, as expected.

Technical feasibility, implementation issues

The measure has demonstrated that there are different options to make feasible the transformation of the urban furniture with the aim to provide enhanced wireless connectivity services in the cities.

Economic feasibility

Cities have to face up the growing demand of mobile connectivity due the large increment of personal smart devices, IoT services or massive broadband mobile connections at anytime and anywhere. Quick access to any information has been converted in a must, not only for citizens. City managers need also access to real time, updated and accurate information about what is happening in the city, in order to take the most convenient decisions. Therefore, a wide network of sensors and actuators should be deployed around the city to monitor and control the city status. In addition, small micro-sites have to be deployed in the city to support hyper-connected spaces and massive mobile connectivity.
These measure shows how to transform the urban furniture in Smart Towers, to resolve the connectivity trends in the city.

Social feasibility

The solution transforms traditional furniture to provide more services related to IoT, wireless connectivity, and real time digital information.

Improving quality of life

Smart Towers offer new services that enhance daily life of citizens. For example, hyper-connected spaces resolve the wireless connectivity demand; while environmental sensors hosted into Smart Towers provides real time information about the status of the city, helping city managers to take the most suitable decisions.

Reducing environmental impact

Smart Towers rationalizes the use of the public space and organizes the deployment of access points for wireless communications and IoT devices in the city.

Promoting sustainable economic development

Smart Towers solution opens a new paradigm of business model in the city, related to neutral host operators and the use of shared infrastructures. The deployment of dense access networks becomes feasible for mobile operators if they can contract "Connectivity as a Service". On the other hand, the marketplace of IoT services allows collaboration and co-creation of new services for the city and its citizens.

Possibility to replicate the Measure

Smart Tower solution can be easily replicated in other European cities. The add-on option chosen by Barcelona Municipality can be fitted in any other lamppost around the world. The solution can be easily adapted to include the required IoT devices and access points.

Conclusions

In the city of Barcelona, measure 5.2 is an enabling ICT measure that aims to provide connectivity services for other GrowSmarter actions, using lighting poles as base for sensors and communication devices.

Therefore, the evaluation is focused on technical parameters, to measure throughput data and connections through the Smart Towers. In this way, the evaluation has provided more quantifiable parameters than defined in the initial Evaluation Plan.

Potential for full scale implementation

Technical, economic and social feasibility

The technical feasibility seems to be good, as all three cities have implemented the Measure. The economic feasibility will be determined by the increase of cost of the light fixtures used for this purpose compared to the cost of two separate systems used for lighting and city WIFI-network. The social impact will be increased possibility to be connected, having smarter services provided at a higher rate, which potentially could save energy and environment as in e.g. decreased transportations. The social implications could be that the users e.g. will easier find closest service rather than the familiar ones, decreasing need for transportation, decreasing city pollution levels, increased productivity and increased quality of life.

Upscaling and replicability of the Measure

This Measure may be applicable for any city and the possibility for upscaling is good

M5.3 – Smart Meter information analysis and actuators

Introduction

The smart meter information will be used to better assign priorities on the energy asset management. Smart Meter information of these public assets will be available through the GrowSmarter platform.

According to the evaluation plan (D5.1), the intention of the Measure was to enable smart solutions through better possibility to connect devices.

In particular, the key performance indicators to be evaluated were:
1. Average energy demand of traditional services (kWh/h) per week.
2. Average energy demand of New Smart Services (kWh/h) per week.
3. Average data traffic relayed over smart street and traffic posts (Mb) per week.
4. Reduced CO_2 emissions due to reduced energy demand (kt/year).
5. Reduced CO_2 emissions due to increase use of EV (kt/year).

Cologne

Industry partner	Contact person	Validation partner
AGT RheinEnergie	Martin Strohbach Christian Remacly Andreas Wolba	KTH-EGI, KTH-SEED

In Cologne the evaluation of M5.3 has been carried out under M3.1.

M6.0 – New business models for district heating

This section presents the results of M6.1, M6.2 and M6.3.

M6.1 – Open district heating with feed in of waste heat

Introduction

Within this Measure, waste heat from data centers and supermarkets is transferred to the district heating system in Stockholm. The recovered heat fed into the system has the potential to replace other less economic and less environmentally friendly heat production. It is financially viable to utilize this waste heat and create a win-win situation for utilities, their customers, the environment and data center/supermarket owners. Currently, mid-level heat can be fed into forward district heating line after being further heated by efficient heat pumps using renewable electricity.

M6.1.1 – Waste heat from data centers

Introduction

Heat recovery equipment has been installed in order to recover heat from the cooling process of a datacenter to the district heating/cooling system. The recovered heat is transferred to the district heating network and used to heat up apartments and offices. The recovered heat from a 1 MW data center could in this way heat approx. 800 standard apartments (including tap water).

A typical datacenter of 1 MW generates annually approx. 12 GWh (based on 8760 hours of operation/year) of waste heat which is usually released into the atmosphere through cooling towers. For these reasons, according to the evaluation plan (D5.1), roughly 50% of the generated heat is economically feasible to be recovered.

In particular, the key performance indicators to be determined are:
1. Heat recovery ratio (%).
2. Effectiveness of the heat recovery system (i.e. overall COP of the system).
3. Total Carnot efficiency of the heat pump recovery system.
4. Reduced CO_2 emissions due to reduced net energy demand (kt/year).
5. Carbon footprint of cooling with heat recovery

The parameters to be monitored are (measurements on an hourly resolution basis for a reference year):
a. Data center electric energy demand (kWh/h).
b. Electric energy demand for cooling with heat recovery, incl compressor and pump work (kWh/h).
c. Data center cooling energy demand (kWh/h).
d. Recovered heat from heat recovery system (kWh/h).
e. Estimation of saving potential if heat recovery systems were installed in all data centers in Stockholm where it would be economically feasible.

Stockholm

Industry partner	Contact person	Validation partner
Stockholm Exergi	Martin Brolin	KTH-EGI

The heat pumps need to be suitable to transform mid-level energy streams from waste heat at a temperature around 25 ˚C to a temperature of 68 ˚C. There is potential for waste heat recovery of around 0.5 TWh annually in Stockholm from existing data centers. However, there are no regulations in place forcing data centers to recover their waste heat, despite an increasing interest and attention at European level. With the business model Open District Heating (ODH) the data centers gain incentives to recover its excess heat through an added revenue for sold heat.

With Open District Heating, Stockholm Exergi aims to recover waste heat into existing district heating networks in Stockholm to meet local energy demands and to reduce the need of peak production, which makes the total production more sustainable. This is done by developing an innovative business model for a yet unexplored potential as an integrated energy solution. This new business model involves plug and play heat pumps and contracts where the district heating provider buys waste heat from local energy sources such as e.g. data centers and supermarkets.

More in detail, in this Measure the heat is recovered from a data center into the nearby district heating network. Data centers together with its cooling system generate lots of excess heat which is often costly to get rid of or just dumped into the air. The heat reuse of the data center chosen for the GrowSmarter project is expected to increase gradually to a level of approximately 1MW heat, a heat recovery that is sufficient to heat more than 1,000 apartments while reducing annual CO_2 emissions in Stockholm. From the technical perspective, the main innovative solution applied to the data center is the heat pump model used, which is the first of its kind in Sweden. The heat pump is able to produce hot water at a temperature of 85C instead of around 68C. This is an advantage since a higher delivery temperature allows for more running hours in the district heating system, also during cold days when district heating customer SLA requires temperatures above 68C. The implementation of this measure has involved the procurement of suppliers for pipes and heat pumps (trusted subcontractors of Stockholm Exergi), the construction of pipes and 2 heat pumps in serial installations and the optimization of heat pump parameters, and finally the start of heat delivery and invoicing (Stockholm Exergi purchase the heat from the data center).

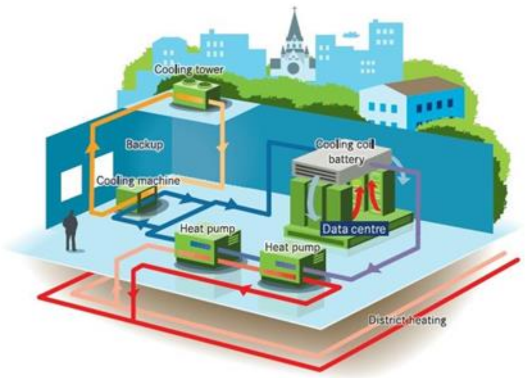

Figure 134 Open district heating concept (example for data centers)

The conclusions regarding the sustainability of this measure shows a good example of a sustainable solution which contributes to decreasing the use of fossil fuels and carbon emissions.

The data center supplier Glesys has provided Stockholm Exergi with consumption data from baseline cooling machine, IT-load and installed heat pumps. Assumptions of energy losses have been made regarding the IT-load and other power consumers such as lighting, electrical radiators etc. regarding total power consumption.

Stockholm Exergi has used two different alternatives for carbon emissions for different electricity mixes. The first alternative is the Nordic electricity mix regarding year 2017 which has a carbon emission of 50 gCO2/kWh. (https://energiradgivningen.se/klimat/miljopaverkan-fran-el)

The data center supplier Glesys has an electricity contract with only renewable energy sources, so as the second alternative the electricity mix assumes to have 0 gCO2/kWh for alternative 2.

Data regarding delivered heat was measured by Stockholm Exergi. The amount of delivered district heating from recovered data center heat by Glesys during 2017 was 1033 MWh, which is only for the second half of the year. The energy delivered during 2018 was 3173 MWh, which is three times as high. The evaluation was carried out during November 2018, presented figures for December 2018 is a forecast.

Regarding reduction of carbon emissions due to avoided centralized district heating production offset by the recovered heat the value 65.7 gCO2/kWh has been used. The number has been taken from Stockholm Exergi's Sustainable Report from year 2017 (https://arsredovisning.stockholmexergi.se/2017/)

The results are show in the following Tables which include the baseline data, the quantified parameters and the evaluated KPIs, in agreement to the Evaluation Plan.

Table 150 Baseline values for M6.1.1

1. Determination of data center annual total energy demand broken down to electricity, and cooling (MWh).	IT-load: 2588 Cooling: 588
2. Alternative 1 with Nordic electricity mix. Determination of carbon footprint of conventional cooling of the data center (kg/y).	29 000
3. Alternative 2 with Renewable electricity mix. Determination of carbon footprint of conventional cooling of the data center (kg/y).	0

Table 151 Quantified parameters for M6.1.1

a. Data center electric energy demand (kWh/h).	542
b. Electric energy demand for cooling with heat recovery, incl compressor and pump work (kWh/h).	184
c. Data center cooling energy demand (kWh/h).	295
d. Recovered heat from heat recovery system (kWh/h), Q4-2018	540
e. Estimation of saving potential if heat recovery systems were installed in all data centers in Stockholm where it would be economically feasible.	50 MW 200 GWh

	(50000 stand. apartments)

Table 152 KPIs for M6.1.1

1. Heat recovery ratio (%).	73%
2. Effectiveness of the heat recovery system (i.e. overall COP heat of the system). Reference Q4-2018 with 1 of 2 heat pumps in operation with respect to the cooling need	2,9
3. Total Carnot efficiency of the heat pump recovery system.	0,5
4. Alternative 1 with Nordic electricity mix. Determination of carbon footprint of conventional cooling of the data center (tCO2/y).	-174
5. Alternative 2 with Renewable electricity mix. Determination of carbon footprint of conventional cooling of the data center (tCO2/y).	- 208

Additional results

In Table 153 the used CO2 emissions for both Stockholm Exergi's district heating and the two different electrical mixes are presented. These numbers are then used in the calculations of CO2 emissions.

Table 153 Carbon emissions used in evaluation calculations (M6.1.1)

District Heating	Stockholm Exergi	65,7	g/CO2 kWh
Electricty	Nordic electricity mix 2017	50	g/CO2 kWh
Electricty	Renewable electricity mix	0	g/CO2 kWh

In Table 154 the reduced CO2 emissions are calculated from the recovered heat that the data center has produced. For 2017 the reduced CO2-emissions were 68 tCO2 and for 2018 it was 208 tCO2.

Table 154 Recovered heat and reduced CO2 emissions (M6.1.1)

Description	**Unit**	**2017**	**2018**	**2019 (Jan-July)**
Recovered heat	kWh	1 032 920	3 172 820	1 595 160
Reduced district heating CO2 emission	tCO2	68	208	105

In Table 155 the added CO2 emissions have been calculated for the different alternatives, which will have minor impact on the outcome of CO2 emissions.

Table 155 Added CO2 emissions for the different alternatives (M6.1.1)

Description	**Unit**	**2017**	**2018**	**2019 (Jan-July)**
Added power consumption heat recovery	kWh	224 355	689 150	346 476
Alt.1 Added CO2 emissons (Nordic electricity mix)	tCO2	11	34	17
Alt.2 Added CO2 emissons (Renewable electricity mix)	tCO2	0	0	0

In Table 156 the net CO2 emissions are presented. Where both alternatives are reducing the CO2 emissions substantially.

Table 156 Net CO2 emissions for the different alternatives (M6.1.1)

Description	Unit	2017	2018	2019 (Jan-July)
Alt.1 Net CO2 emissons (Nordic electricity mix)	tCO2	-57	-174	-87
Alt.2 Net CO2 emissons (Renewable energy sources)	tCO2	-68	-208	-105

The data center is now having a load of 0,54 MW heat and will annually generate approx. 4,7 GWh (based on 8760 hours of operation/year) of heat to the district heating network which is usually released into the atmosphere through cooling towers. For this measure an economically feasible running time is estimated to over 75% instead of the initial aim of 50%. This is mainly due to a general cost increase in Stockholm Exergi's production due to higher fuel prices, which increases the competitiveness of heat recovery in the district heating system a hence the number of economically feasible running hours. The available heat load to recover is dependent on the data centre IT-load and cooling demand. The targeted 1 MW for this measure is estimated to be reached within a 2-year period.

Economic feasibility

For this measure it has been economical feasible for both the district heating company Stockholm Exergi and the supplier Glesys. For Stockholm Exergi the recovered heat has been cost efficient compared to other production units with a long yearly operation time as explained above under "technical feasibility". For a large-scale implementation of heat recovery into the district heating network Stockholm Exergi gains other values such as avoided peak production capacity investments and reduced operation and maintenance costs thanks to third party ownership of the production asset. For the data center, Glesys, heat recovery generates a revenue stream from the waste heat that otherwise would drive cost to get rid of. Since Glesys had expansion plans for the data center with an investment need in more cooling capacity. Instead of another conventional cooling machine this heat pump solution with heat recovery was chosen. Comparing these two options this measure shows economical gains for the supplier compared to conventional data center cooling. Pay-back for the supplier will be within 5 years' time but the economical values will sustain over the total technical lifetime of approximately 15-25 years.

Potential for full scale implementation

Technical, economic and social feasibility

Technical feasibility, implementation issues

Heat recovery from data centers as a production unit in the total production mix for a large-scale district heating network is technical feasible. The heat production is stable and economical feasible a longer time over the year than expected. The main implementation issue is the increased responsibility put on the supplier who needs to handle production and maintenance of the heat pumps.Upscaling and replicability of the Measure

This Measure is applicable to any city where there is a heating system nearby into which the waste heat can be fed. The DSO needs to allow, and pay, for third party feed in into the network. The upscaling possibility of this Measure is good for networks where third-party feed in is allowed.

Social feasibility

The social acceptance of this measure is high both among the public and the City of Stockholm. The solution is also very appreciated by the supplier Glesys. When feeding back energy to the district heating system instead of just ventilating it into the ambient, Stockholm Exergi can offset the use of fuels, including those with fossil content. In that way the scheme contributes to a more sustainable city at the same time as it is a good fit in the CSR agendas of both Glesys and Stockholm Exergi.

Upscaling and replicability of the Measure

To replicate this technical solution at large-scale a district heating system is required that can transfer the recovered heat to where it is needed. The business model is easy to establish and replicate, but the economic value of the recovered heat will differ between geographies depending on the alternative cost for heating. Small clustered district heating network can also benefit from using heat recovery as a heat source.

Conclusions

This measure is a good example of a sustainable and economically feasible solution which contributes to decreasing the use of fossil fuels and the carbon emissions. To implement the solution at large-scale a district heating system is required to which a number of energy sources, such as data centres, are connected. Recovering heat to the district heating system requires investment at the beginning but can be beneficial from both an economical and a sustainable perspective over the technical lifetime of the installation.

M6.1.2 – Waste heat from fridges and freezers in supermarkets

Introduction

The measure consists of installation of heat recovery equipment in order to recover heat from the cooling equipment of a supermarket to the district heating system. The recovered heat is transferred to the district heating network and used to heat up apartments and offices. The recovered heat during one year from a 200 kW supermarket could in this way heat up approx. 160 standard apartments (including tap water).

A supermarket with 200 kW cooling capacity generates annually approx. 2,5 GWh (based on 8760 hours of operation/year) of waste heat which is usually released into the atmosphere through cooling towers.

In particular, the key performance indicators to be determined are:
1. Heat recovery ratio (%).
2. Effectiveness of the heat recovery system (i.e. overall COP of the system).
3. Possible annual savings in Stockholm (kWh/year).
4. Reduced CO_2 emissions due to reduced net energy demand (kt/year).
5. Carbon footprint of cooling with heat recovery
6. Estimate of possible annual energy savings in Stockholm if recovery was installed in all supermarkets where economically feasible.

The parameters to be monitored are (measurements on an hourly resolution basis for a reference year):
a. Supermarket energy demand for cooling with heat recovery, including pumps and fans (kWh/h).

b. Supermarket electric energy demand (kWh/h).
c. Supermarket cooling energy demand (kWh/h).
d. Recovered heat from heat recovery system (kWh/h).

Stockholm

Industry partner	Contact person	Validation partner
Stockholm Exergi	Martin Brolin	KTH-EGI

The studied supermarket had a heat recovery potential up to 30 kW which would approx. generate 219 MWh annually. As long as the measure was in operation, during January to August 2017, the running time was over 99%, way higher than the initial aim of 50%.

The conclusions regarding the sustainability of this measure shows that implementing heat recovery will contribute to decreasing the use of fossil fuels and carbon emissions independent of the electricity mix used when calculating the footprint.

The economic feasibility could not be adequately evaluated in this measure due to lack of data caused by the limited time of operation. The pay-back period for the supplier is estimated to be within 10 years' time but the generation of economical value would continue over the equipment's total technical lifetime of approximately 15-25 years.

With Open District Heating, Stockholm Exergi recover waste heat into existing district heating networks in Stockholm. The reuse of the waste heat offsets other means of production with a higher carbon footprint, and hence makes the total production of heating in Stockholm more sustainable.

More in detail, in this measure the heat is recovered from a supermarket into the nearby district heating network. Supermarkets with many freezers and coolers generate lots of excess heat which is often costly to get rid of. The heat reuse of the supermarket chosen for the GrowSmarter project has the potential of recovering 0.5 GWh of heat annually a heat recovery that is sufficient to heat more than 40 standard apartments (assuming an average energy use of 12MWh/apartment per year) while reducing annual CO_2 emissions in Stockholm. The solution in this supermarket does not involve recovering energy for the district cooling network. The implementation of this measure has involved the procurement of suppliers for pipes and 2 serial connected transcritical CO_2 cooling unit, the construction of pipes and system installation, and finally the start of heat delivery and invoicing (Stockholm Exergi purchase the heat from the supermarket).

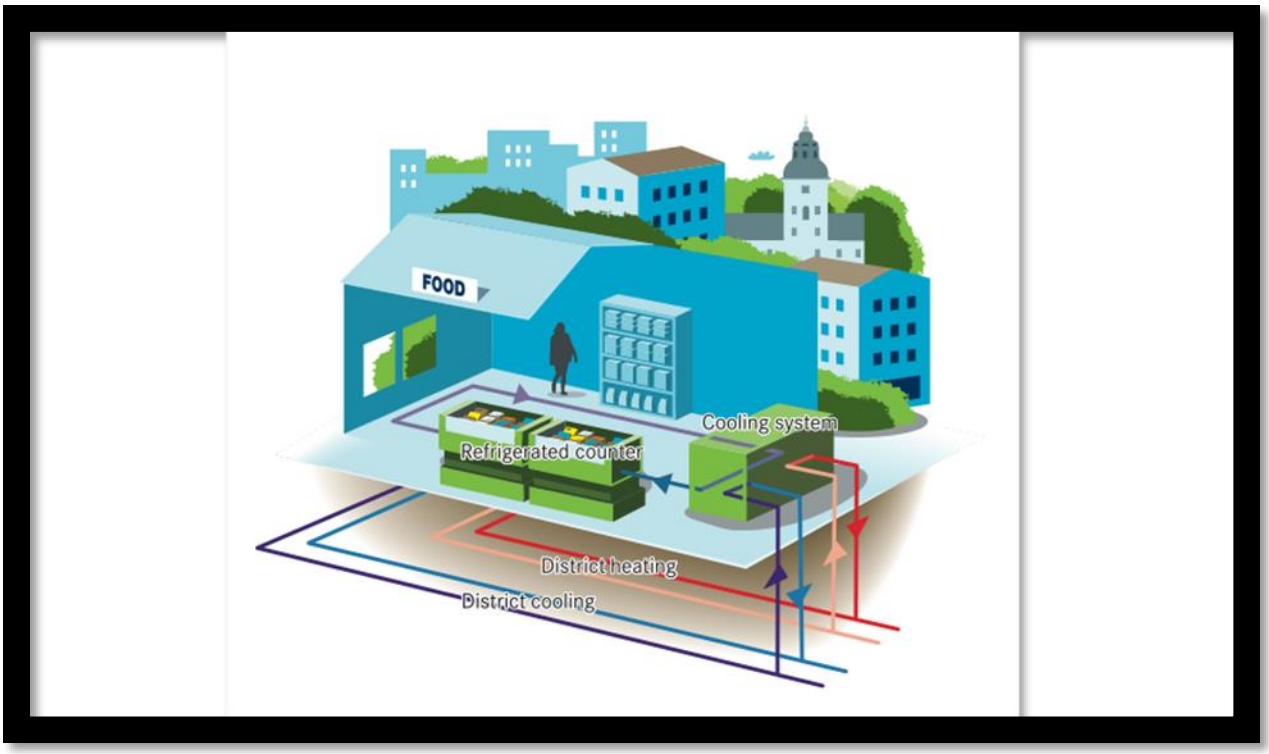

Figure 135 Open district heating concept in M6.1.2: an example for supermarkets

This measure has been difficult to evaluate due to the fact that the supplier decided to end the project by the end of Q3 2017. Therefore, Stockholm Exergi only have heat recovery data available between January and August 2017.

The supermarket supplier Hemköp has provided Stockholm Exergi with electricity consumption data until March 2017. Stockholm Exergi has used electricity consumption data from 2016 as a reference.

Stockholm Exergi has used two different electricity mixes when estimating the carbon emissions from the measure. The first mix is the Nordic electricity mix regarding year 2017 which has a carbon content of 50 gCO2/kWh. (https://energiradgivningen.se/klimat/miljopaverkan-fran-el)

The supermarket supplier Hemköp has an electricity contract with only renewable energy sources, so as the second electricity mix is assumed to contain 0 gCO2/kWh.

The delivered heat was measured by Stockholm Exergi. The amount of delivered heat from Hemköp during January to August 2017 is 152 MWh.

Regarding reduction of carbon emissions due to avoided centralized district heating production off set by the recovered heat the value 65.7 gCO2/kWh has been used. The number has been taken from Stockholm Exergi's Sustainable Report from year 2017, (https://arsredovisning.stockholmexergi.se/2017/).

The results available at this stage are show in the following Tables which include the baseline data, the quantified parameters and the evaluated KPIs, in agreement to the Evaluation Plan.

Table 157 Baseline values for M6.1.2

1. Determination of all supermarkets annual total energy demand for cooling in Stockholm (GWh).	856 supermarkets

	342 GWh
2. Determination of total annual cooling demand (kWh) of reference supermarkets.	400 000
3. Determination of annual cooling demand for the supermarkets with implemented measure (kWh).	193 000
4. Determine required driving energy (compressors, pumps, fans, etc.) to provide the annual cooling demand (kWh).	38 500
5. Alternative 1 with Nordic electricity mix. Determination of carbon footprint of conventional cooling of the supermarket (kg/y).	1 924
6. Alternative 2 with Renewable electricity mix. Determination of carbon footprint of conventional cooling of the supermarket (kg/y).	0

In the greater Stockholm area there are approximately 856 supermarkets and together with Stockholm Exergi's assumption of an average cooling demand 400 MWh annually per supermarket the annual total energy demand for cooling in Stockholm is 342 GWh.

Table 158 Quantified parameters for M6.1.2

a. Supermarket energy demand for cooling with heat recovery, including pumps and fans (kWh/h).	12-36
b. Supermarket electric energy demand (kWh/h).	0-12
c. Supermarket cooling energy demand (kWh/h).	11-36
d. Recovered heat from heat recovery system (kWh/h).	8-32

Cooling demand and added electricity demand for heat recovery are fluctuating heavily during the year. During the summer time the cooling demand is at the highest level and no added electricity for heat recovery is needed, and during the winter time the cooling demand is going down to the minimum level and added electricity for heat recovery is at the highest level.

Table 159 KPIs calculated for M6.1.2

1. Heat recovery ratio (%). (Recovered energy of total / Heat recovery availability during operation time)	50% / 99 %
2. Effectiveness of the heat recovery system (i.e. overall COPheat of the system).	1,97 (winter) - no added electricity needed (summer)
3. Possible annual heat recovery from measure (MWh/year).	219
4. Alternative 1 with Nordic electricity mix. Reduced CO2 emissions due to reduced net energy demand (tCO2/year).	12,5
5. Alternative 2 with Renewable electricity mix. Reduced CO2 emissions due to reduced net energy demand (tCO2/year).	14,3
6. Estimate of possible annual energy savings in Stockholm if recovery was installed in supermarkets where economically feasible	16 GWh

In greater Stockholm area there are approximately 856 supermarkets. Of these Stockholm Exergi assumes that 75 supermarkets are within Stockholm Exergi's district heating network and economical feasible to install a heat recovery system which leads to a possible annual energy saving of 16 GWh.

<u>Additional results</u>

In Table 160 the used CO2 emissions for both Stockholm Exergi's district heating and the two different electrical mixes are presented. These numbers are then used in the calculations of CO2 emissions.

Table 160 Carbon emissions used in evaluation calculations (M6.1.2)

District Heating	Stockholm Exergi	65,7	g/CO2 kWh
Electricty	Nordic electricity mix 2017	50	g/CO2 kWh
Electricty	Renewable electricity mix	0	g/CO2 kWh

In Table 161 the reduced CO2 emissions are calculated from the recovered heat that the supermarket has produced. For 2017 (January until August) the reduced CO2-emissions were 10 tCO2.

Table 161 Recovered heat and reduced CO2 emissions (M6.1.2)

Description	Unit	2017
Recovered heat	kWh	152 000
Reduced district heating CO2 emission	tCO2	10

In Table 162 the added CO2 emissions have been calculated for the different alternatives, which will have minor impact on the outcome of CO2 emissions. For 2017 (until August) the added power consumption 27MWh.

Table 162 Added CO2 emissions for the different alternatives (M6.1.2)

Description	Unit	2017
Added power consumption heat recovery	kWh	37 000
Alt.1 Added CO2 emissons (Nordic electricity mix)	tCO2	1,9
Alt.2 Added CO2 emissons (Renewable electricity mix)	tCO2	0

In Table 163 the net CO2 emissions are presented. Where both alternatives are reducing the CO2 emissions.

Table 163 Net CO2 emissions for the different alternatives (M6.1.2)

Description	Unit	2017
Alt.1 Net CO2 emissons (Nordic electricity mix)	tCO2	-8,1
Alt.2 Net CO2 emissons (Renewable energy sources)	tCO2	-10

The supermarkets targeted cooling capacity was 200kW which would annually generate approx. 1,8 GWh (based on 8760 hours of operation/year) of heat to the district heating network which is usually released into the atmosphere through cooling towers. This measure was having a heat recovery capacity up to 30 kW which would approx. generate 260 MWh annually.

As long as this measure was in operation during January to August 2017 a running time is estimated to over 99%.

Potential for full scale implementation

Technical feasibility, implementation issues

Heat recovery from supermarkets as a production unit in the total production mix for a large-scale district heating network is technical feasible. The heat production is stable and economical feasible during a larger part of the year than expected. The main implementation issue is the increased responsibility put on the supplier who needs to handle production and maintenance of the heat recovery system. When in operation the running rate is almost 100%, however the implementation cost for smaller supermarket may not be economical feasible.

Economic feasibility

In this measure payback has not been reached for neither the district heating company Stockholm Exergi nor the supplier Hemköp, due to the short operation time. For Stockholm Exergi the recovered heat has been cost efficient compared to other production units with a long yearly operation time as explained in above technical feasibility. For a large-scale implementation of heat recovery into the district heating network Stockholm Exergi gains other values such as reduced operation costs and avoided investments related to third party ownership.

For the supermarket, Hemköp, heat recovery never generated enough revenue stream from the waste heat to ensure the economic feasibility due to the limited operation time. Instead the supplier Hemköp chose to end the pilot project without enough data to validate the economic feasibility over a longer period. Pay-back for the supplier would be within 10 years' time but the economical values will sustain over the total technical lifetime of approximately 15-25 years.

Social feasibility

From a general perspective the social acceptance of this measure is high both among the public and the City of Stockholm. When feeding back energy to the district heating system instead of just ventilating it into the ambient, Stockholm Exergi can offset the use of fuels, including those with fossil content. In that way the scheme contributes to a more sustainable city at the same time as it is a good fit in the CSR agendas of Stockholm Exergi and the supplier.

Upscaling and replicability of the Measure

To replicate this technical solution at large-scale a district heating system is required that can transfer the recovered heat to where it is needed. The business model is easy to establish and replicate, but the economic value of the recovered heat will differ between geographies depending on the alternative cost for heating. Small clustered district heating network can also benefit from using heat recovery as a heat source.

Conclusions

The conclusions of this measure are that the evaluation is not adequate due to the lack of data and insufficient measuring time. The lessons learned from this project have been that anchoring throughout the whole organisation is very important and also inform and establish trust with subcontractors that are facing the supplier of recovered heat. What happened in this project was that the owner structure was completely changed during the implementation at the supplier and that the new organization was positive to the heat recovery system but didn't see the benefits over a longer period.

What Stockholm Exergi have seen in these two measures 6.1.1 and 6.1.2 and other similar projects is that the amount of available excess heat need to be larger than what was the case at Hemköp in order for the measure to be economically feasible for the supplier.

Today, the focus from Stockholm Exergi is no longer on small scale supermarkets, but other potential suppliers of recovered energy such as data centres.
In Stockholm, the recovered heat from supermarket during 2017 (not full year operation): 152.2 MWh.

M6.2 – District heating rings

Introduction

Given the adverse legislation on heating and electricity rings in Spain at the time of the measure implementation, this task has evolved to a virtual analysis of a block self-sufficiency potential. Given the demand diversity of the buildings included in this measure, complementarity of the curves are analysed and the self-sufficiency of the overall block is estimated based on distributed generation (photovoltaics and storage) and district heating. Buildings included in the measure are the following: Melon District, Canyelles, H10 Hotel, Sibelius and Valldonzelles

Barcelona

Industry partner	Contact person	Validation partner
Naturgy	Helena Gibert	KTH-EGI

The analysis has been carried out considering a block at the 22@ neighbourhood in Barcelona depicted at Figure 136. The buildings considered include the Hotel, the sport center, the educational centre and residential buildings. Annual monitored electrical and thermal curves of those buildings have been considered in the self-sufficiency analaysis of thermal and electrical demand (see Figure 137 and Figure 138).

Figure 136 Block Analysed at the 22@ neighbourhood in Barcelona

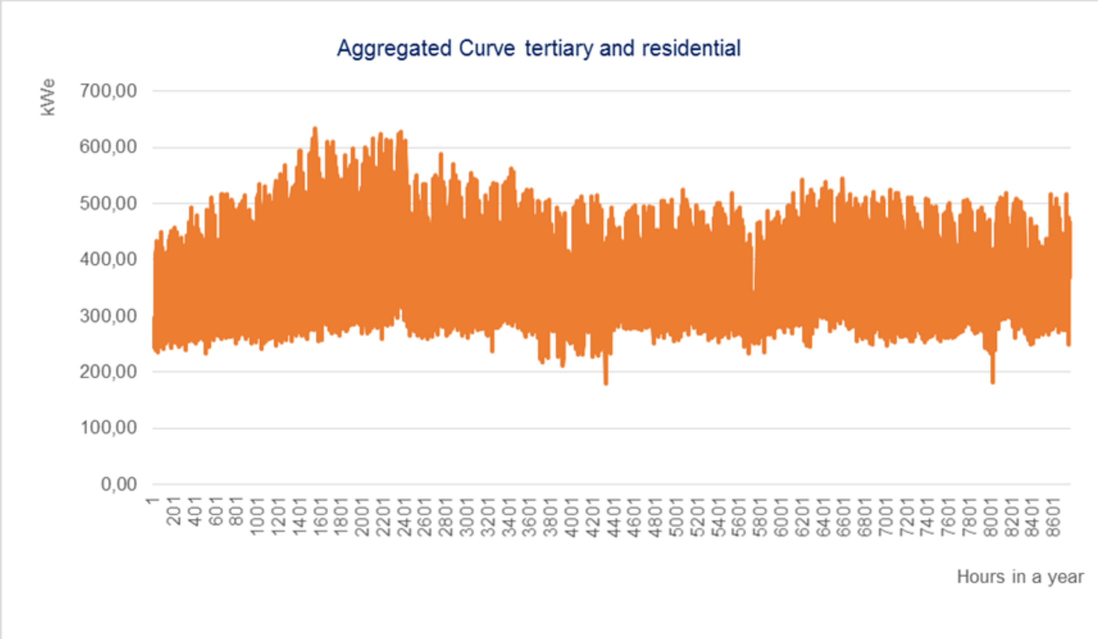

Figure 137 Hourly aggregated electricity curve for the buildings in the block

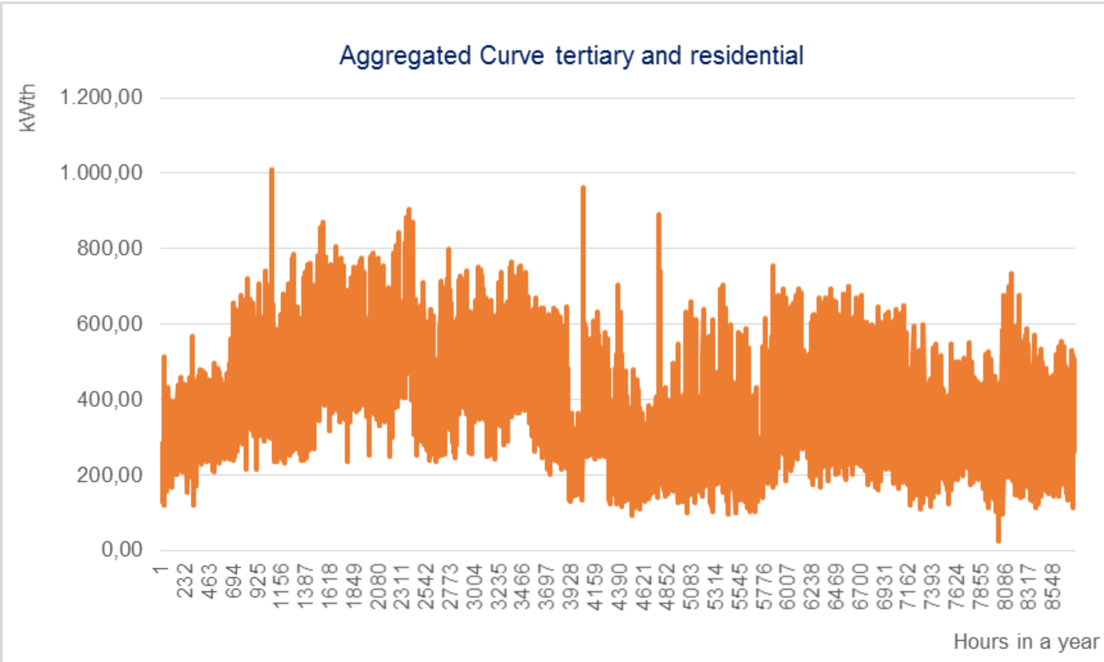

Figure 138 Hourly aggregated thermal curve for the buildings in the block

An analysis of the photovoltaic (PV) capacity of the rooftop has been analysed based on useful area on each of the buildings and considering that the new Spanish Royal Decree allows collective self-consumption. The area calculation is depicted in

Table 164.

Table 164 Photovoltaic estimation of the building rooftops

Photovoltaics		
A1	1.300,00	m^2
A2	1.139,00	m^2
A3	2.500,00	m^2
A4	1.162,00	m^2
TOTAL Area (sqm)	6.101,00	m^2
Tota useful area (sqm)	3.660,60	m^2
Total Installed power	546,36	kWp
RATIOS		
Photovoltaic useful area	60%	% of total area
Photovoltaic area	6,7	m^2/kWp

The total installed capacity (kWp) estimated reaches 546kWp and the annual hourly curve has been simulated based on Barcelona radiation monitored on the 4.2 installations. The annual hourly curve is depicted in Figure 139.

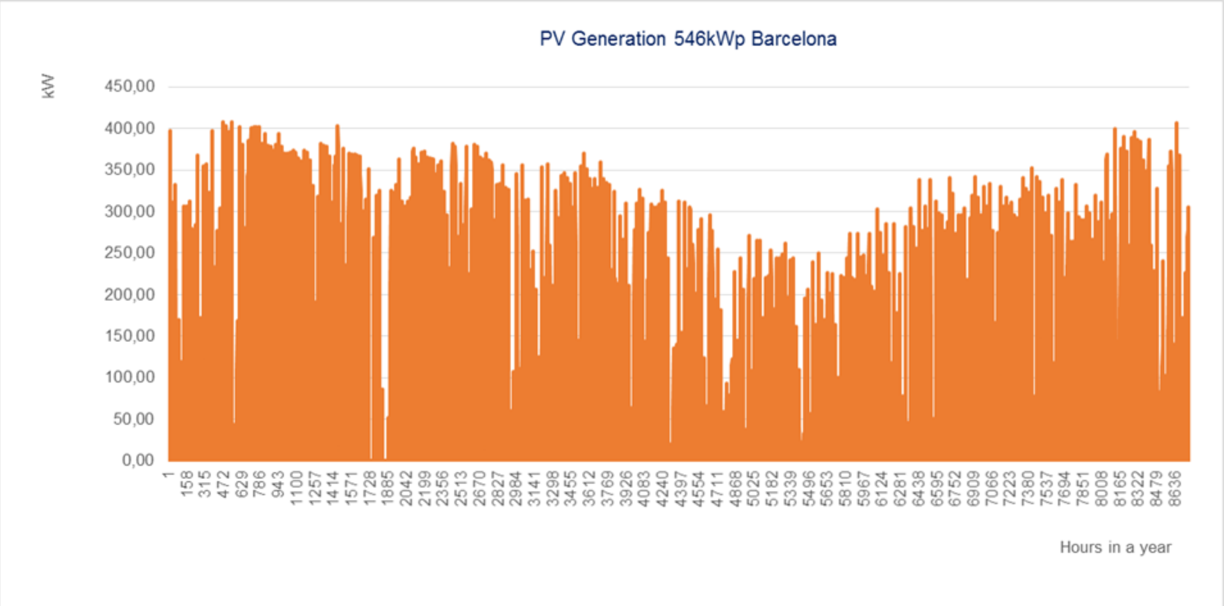

Figure 139 Hourly PV generation curve

The electricity self consumption ratio has been calculated and the results of savings in final energy and emissions are depicted in Table 165.

Table 165 Electricity savings due to PV self-consumption

BENEFITS			
Electricity			
Savings for self consumption (kWh)	501.023,43	kWh	
Savings for self consumption (t CO_2)	178,87	t CO_2/year	

Concerning thermal demand self-sufficiency it has been considered the connection of all buildings to the existing district heating. The analysis has considered that new sub-stations are built for the new buildings as well as the internal distribution network inside buildings. Losses on the distribution network itself as well as losses on the heat distribution inside the building has been considered. It is considered that boilers are replaced by a district heating that is running on municipal waste and 30% on high efficiency boilers.

Table 166 Gas savings due to district heating (DH) connection

Gas			
Scenario with DH			
Total heating demand	4.534.622,44	kWht	
% of demand satisfied by gas boilers	30,00%		
Losses on distribution network	20,00%		
Losses on dwelling distribution	10,00%		
η_0 =	95%		
Consumption of Natural gas	1.584,06	MWh	
Scenario without DH			
η_0 =	86%		
Consumption of Natural gas	5.832,76	MWh	
Savings (MWh)	4.248,71	MWh	
Savings Primary Energy	5.077,20	MWh	
Savings Emissions (tCO2)	1.070,67	t CO2	

Total savings of emissions in tons of CO_2 are 1250 tCO2.

M6.3 – Smart local thermal districts

Introduction

Smart local thermal district (offices, residential and social spaces) aimed at demonstrating the integration in existing district heating and cooling network including PV generation. The Measure intended to demonstrate the technical and social viability of this type of solution at higher scale.

The definition of the baseline was determined with the local area annual total energy demand (kWh), broken up into heating, cooling, electricity, and normalized to a typical climatic year.

For buildings where the intended purpose (e.g. apartments, after implementing Measure) of the building is significantly different from the original purpose of the building (e.g. storage facilities), the baseline was determined by building energy simulation according to standard ISO 13790 or equivalent procedure.

The key performance indicators evaluated are:
1. Fraction of locally generated heating energy compared to baseline case (%).
2. Fraction of locally generated cooling energy compared to baseline case (%).
3. Fraction of locally generated electric energy compared to baseline case (%).
4. Reduced CO_2 emissions due to reduced energy demand (kt/year).
5. Savings in final and primary energy.

Barcelona

Industry partner	Contact person	Validation partner
IREC	Alaia Sola Manel Sanmartí	KTH-EGI

The Measure aims at demonstrating the impact in building energy consumption from the grid of the combination of onsite electricity generation (with PV panels) and connection to local existing district heating and cooling networks.

The results are expected to demonstrate the technical, social and economic viability of this type of solution with the connection of the low-energy offices building Ca l'Alier to:

- The existing local DHC network, which uses steam from the incineration of the city urban waste and condenses its equipment by using the nearby sea water in its main energy generation plant (close to Ca l'Alier building).
- A 68.4kWp PV plant on the building rooftop which aims at considerably reducing the electricity import by the building from the grid.

Table 167 KPIs evaluated for M6.3 (Barcelona)

KPI	Baseline	Post-retrofitting	Variation
1. Fraction of locally generated heating energy	0%	100%	100%
2. Fraction of locally generated cooling energy	0%	100%	100%
3. Fraction of locally generated electric energy	4.4%	19.8%	+350%

	If PV installation is limited to comply with municipal regulation only	With the final dimensions of PV installation in the retrofitted building	
4. Reduced CO2 emissions due to reduced energy demand (kt/year).	see M1.0	see M1.0	see M1.0
5. Savings in final and primary energy.	see M1.0	see M1.0	see M1.0

The fraction of locally generated heating and cooling for baseline is 0% because baseline simulations have considered traditional energy sources (i.e. natural gas and electricity, respectively), which are not locally produced. In contrast, the retrofitted Ca l'Alier building is fed by heating and cooling from the local DHC network of the district where it is located. This thermal network uses local resources. The existence of large waste heat sources in the urban environment represent an opportunity for the deployment of DHC infrastructure.

The connection of the building to the local DHC network has helped to upgrade the building energy rating and allowed using available local energy resources to supply a large part of the building energy demand.

The installation of a large PV plant on the rooftop was completed in 2018. However, PV generation did not start by the date of this report republication due to administrative issues that led to delays in commissioning. The approval of a new Royal Decree in Spain in 2019 (under which the administrative, technical and economic conditions for energy self-consumption are regulated) affected the commissioning of the present installation. First, the latest Royal Decree defines different types of self-consumption (previously there was only individual self-consumption connected to an internal network) and therefore the procedure for registration of the installation has changed. Secondly, the new provision simplifies the mechanism of payment for any surplus energy injected back into the grid. Previously prosumers were only compensated if they were legally authorized energy producers, with all the paperwork and tax declarations that involved. According to this, the building operators wanted to run the installation based on the new law (more economically favourable, less taxes) and they are working on adapting the registration of the installation to take over the regime of paid surplus (so the potential excess electricity can be remunerated). Therefore, no data for 1-year operation of the PV plant are available. The reported annual PV energy generation is based on results from simulations performed with the same software used for baseline calculations (no PV installation existed in baseline period). According to the Spanish Building Technical Code, Ca l'Alier does not meet the requirements for a compulsory installation of PV generation units. However, according to Barcelona Municipal regulation for retrofitted tertiary buildings, Ca l'Alier must have PV generation units. Based on the building roof area, a minimum of 16.5 kWp of PV have to be installed (equivalent to 19 320 kWh/year of PV generation according to simulations). In the retrofitted building, the actual PV generation is 86 074 kWh/year according to simulations reported in the installation legalization memory.

The share of Renewable Energy Sources (RES) is calculated based on the annual share of electricity consumption of the real retrofitted building that would be supplied by the PVs, since there is no other renewable source supplying the electrical demand of this building. As can be observed, the PV installation is able to supply approximately 20% of the total building electrical consumption. The system doesn't account for battery storage since all the electrical generation is designed to be instantly consumed by the building.

Potential for full scale implementation

Technical, economic and social feasibility

Measures like M6.3, as well as M6.1 and M6.2, are key to maximize the utilization of available resources and use all synergy effects available. The main obstacle for these and similar solutions to find a broader use is the lack of business models and how to deal with security of delivery of service. Once these obstacles have been solved, the city block could pretty much be considered like an industrial process, where exergy content and flow of energy is carefully considered and used to maximum efficiency. Eventually, the implementation of this Measure will enable greater use of RES and therefore improve global and local air quality, with increased quality of life as a result.

Upscaling and replicability of the Measure

The Measure is easier to implement in new developments, in existing building blocks the potential is entirely depending on the existing possibilities. However, there are nothing that hinder the Measure to be implemented, in fact it should always be carefully considered.

M7.0 – Smart waste collecting, turning waste to electricity, heat and biogas for vehicles

Overall, the waste sorting is more than satisfactory, with a reduction of rest waste by 66%, but the coming introduction of an incentive system could possibly increase the sorting ratio even further. Environmental impact of the implementation is very promising with a traffic reduction of 90% within the residential area, even though the number of fractions is increased from three to four.

This section presents the results of M7.1, M7.2 and M7.3.

Stockholm

Industry partner	Contact person	Validation partner
ENVAC	Hans Anebreid	KTH-SEED

M7.1 – Optical Sorting of Waste

The Measure aims to optically sort collected waste bags from 300+ households within an AWCS (Automated Waste Collection System) terminal into separate waste streams for further processing. The waste bags are entering the AWCS terminal through an underground pipe system transported by force of vacuum. The mixed waste stream consisting of differently colored bags will be optically identified, separated and moved and stored into a dedicated container for that specific waste stream. The solution has reduced heavy traffic in the area by 90%, CO_2 emissions by 71%, and the rest waste has been reduced by 66%.

The intention of the Measure is to:

1) simplify recycling and thereby increasing the recycling rates of residents
2) increase comfort and quality of living (Clean, convenient, accessible and efficient waste collection service).

The Measure has involved the collection of optically sorted waste bags from 300+ households within an AWCS terminal into separate waste streams for further processing (average 242 households during the 12 month evaluation period from September 1st 2018 to August 31st 2019). The waste bags are entering the AWCS terminal through an underground pipe system transported by force of vacuum. The mixed waste stream consisting of differently colored bags (four colors, one each for the four fractions) is optically identified, separated and moved and stored into a dedicated container for that specific waste stream. Due to limited space in the area, the actual sorting of the bags is designed to take place in a separate sorting facility. In particular, the sorting takes place in the city of Eskilstuna, nearby Stockholm.

The evaluation baseline has been based on data collected in the AWCS system, covering the 12 month period of September 1st 2018 to August 31th 2019. The following data was collected:

- Number of waste bags deposited
- Color of each bag deposited
- Weight of each bag deposited
- User RFID for each deposit
- Time stamp for each deposit

The color registration of the four fractions in the system is technically correct. However, some bags are classified with unknown color at the inlet point. The actual share of unknown bags deposited into the AWCS is around 10%, and those 10% unknown bags are almost only consisting of normal shopping bags that the residents have used as a substitute for white bags, i.e. containing rest waste. This 10% is calculated from a sample test performed by Envir in early September 2019, and the data is further strengthen by ocular inspections inside the container on six occasions dated 2017-12-06, 2017-12-15, 2017-12-29, 2018-01-26, 2018-02-07, and 2019-02-15.

However, an average of 50% of deposited bags are classified as unknown at the waste inlet point. This is caused by users who choose not to register the bag with the optical reader, and may also occur for bags that have a color other than one of the four that the system is designed for. E.g. a blue bag will induce a registration as “Unknown”, same will happen if the user does not register the bag – they will be able to deposit the bag but the color will register as “Unknown”. There is a notable difference over time, where inlets that have been in operation for over a year and a half have an average of 32%, while more recent inlets have an average of 74%. This shows that residents learn over time how to use the inlets.

Hence, the real share of unknown bags in the AWCS is close to zero, and the sorting of the waste is guaranteed at the optical sorting facility. But, the analysis of the data is presently difficult to automize, and to use as a base for feedback to the user. Figure 140 illustrates the actual content of the container on four different dates.

Figure 140 Content of the waste container. Illustrating a very low share of unknown coloured bags

To increase the accuracy a new information material for the waste inlets was developed during the project. It contains a new set of stickers with instructions that is easier to understand, as well as a highlighting of the optical reader so it is easier to identify it. The ambition of this is that more of the users will understand the functionality better and that they will use the optical reader to a larger extent. There have also been a few information meetings in the area where the residents have been invited to learn about the waste management system and how they can take best advantage of the possibilities with it, e.g. regarding waste sorting.

There are no major disturbances regarding weighing of the deposited bags. The weighing data from the inlet points have been compared with weighing data of the container itself (from the sorting facility in Eskilstuna). The data does not cover a full 12 months, but rather the 307 day/11 months period from September 1st 2018 to July 4th 2019. The deviation is 9% between the two data sets, which is derived to temporary disturbances of the weighing system in some of the inlet points. All temporary disturbances have been technically adjusted and does not induce any long term issues. Uncertainties in this particular two sets of data lies mainly within the accuracy of the weighing system in the inlet as well as at the sorting facility. Table 168 illustrates the comparison of the data.

Table 168 Deviation of weighing data between inlet points in Valla Torg and container weighing system at the sorting plant in Eskilstuna. Data gathered for the period from September 1st 2018 to July 4th 2019

Accumulated Container Weight	43960	kg
Accumulated Weight registrered at inlet	39913	kg
Difference, total	-4047	kg
Difference, per day	-13	kg
Difference, %	-9	%

Results

To describe collected waste and the recycling ration, the following parameters are measured:
1. kg of waste per fraction
2. Waste generation kg/capita
3. Weight of fraction and time of generation by household
4. Recycling Rate

Since the above mentioned measures overlap each other to some extent, they have partly been bundled in the presentation as follows.

Figure 141 shows kg of waste collected per fraction divided per household and day during the 12 month evaluation period from September 1st 2018 to August 31st 2019. This covers parameter 1 and 2 above, and partly parameter 3.

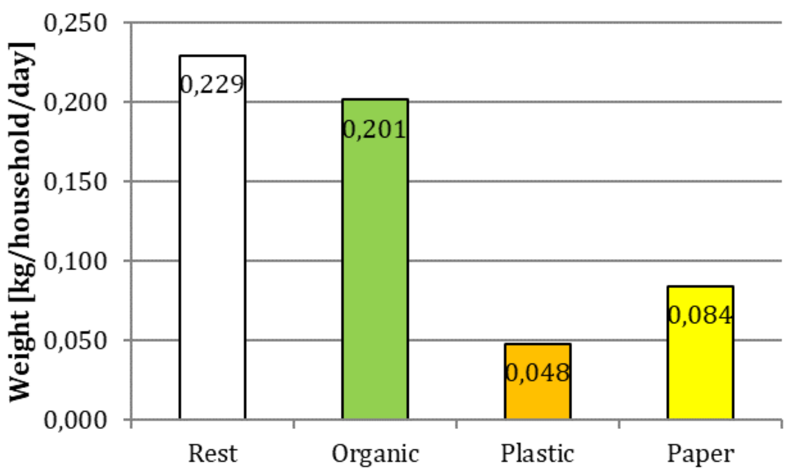

Figure 141 Collected waste over 12 months, from September 1st 2018 to August 31st 2019

Since data is missing for sorting rate (between fractions) prior to the AWCS installation (and food waste was not separated before the AWCS installation), the data in Figure 141 is for illustration of the current status. To enhance the understanding of these levels, there is a comparison with another city using the same colored bags later in this chapter, as well as a comparison with average waste data from the city of Stockholm

Figure 142 shows the distribution for when during the day waste is deposited into the AWCS for the typical period November 22nd to December 13th 2018. This covers parameter 3 above. This measure has no baseline and is intended for illustration and general knowledge.

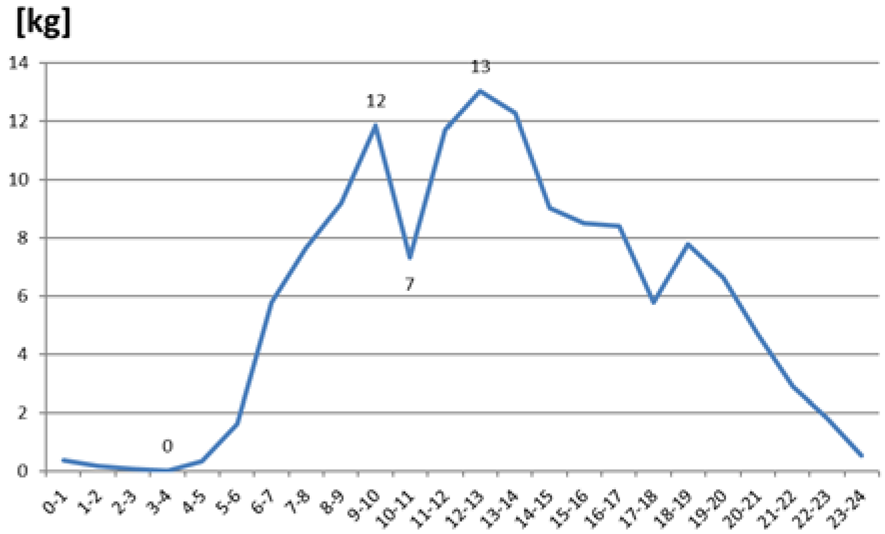

Figure 142 Weight deposited distributed over the day. Average per hour for the evaluation period, with some extreme values marked

Figure 143 shows the sorting rate as percentage of total weight for each fraction collected by the AWCS.

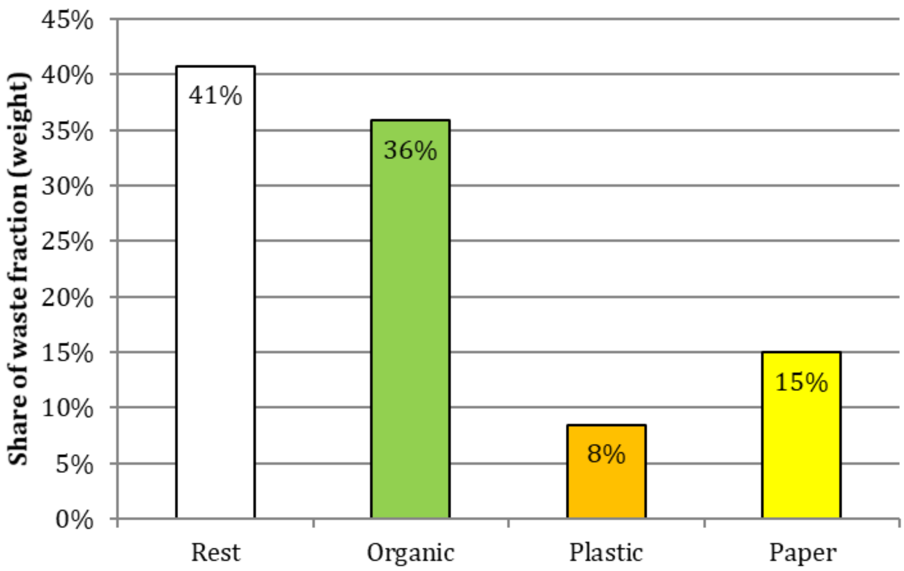

Figure 143 Ratio of waste fractions (weight).

As stated above, there is no data available for the sorting rate (between fractions) prior to the installation of the AWCS, so the sorting rate is compared to reference values from the Optibag sorting facility in the city of Eskilstuna (see Table 169). Notably the residents in Årsta sort their waste better than residents of Eskilstuna. There is less rest fraction and more of organic fraction and paper packaging, even though plastic packaging is on the same level. This is a good sign, since there were no sorting of organic waste prior to the installation of the AWCS in Årsta.

Table 169 Distribution of colors/fractions. Comparison between Eskilstuna (optical sorting facility) and Årsta (Growsmarter installation)

Fraction	Årsta (from 180901 to 190831)	Eskilstuna reference values (source : Envac Optibag AB)
Rest fraction	41%	52%
Organic fraction	36%	34%
Plastic packaging	8%	8%
Paper packaging	15%	7%

To deepen the understanding of recycling behavior in the Valla Torg area post the AWCS installation, data has been compared to the average values of the city of Stockholm. Data is publically available at www.ftiab.se and www.stockholmvattenochavfall.se. The assumption for Valla Torg was of 2 inhabitants per apartment. This assumption brings a certain level of uncertainty.

Table 170 Comparison between the AWCS installation in Valla Torg and the city of Stockholm

Fraction	Årsta/Valla Torg. [kg/person/year]	Stockholm average [kg/person/year]. Years 2015 and 2018.
Rest fraction	41,8	248,3
Organic fraction	36,8	17,3
Plastic packaging	8,7	5,5
Paper packaging	15,4	10,0

To cover point 4 above (Recycling Rate) even further, a sample analysis of the content of the rest fraction pre and post installation has been performed by an independent third party company (Envir) on behalf of the city of Stockholm Waste Management Authority (SVOA). The results of the analysis are striking. The total weight of rest fraction is substantially decreased and the main sources for this is that food waste (organic fraction) and packaging has been sorted out. Total rest waste is reduced by 66%, or from 4,9 to 1,7 kg/household/week, by introducing a sorting system nearby the apartments in form of an AWCS. Figure 144 and Figure 145 illustrate the reduction of total rest fraction for the sample weeks, including the fractions of the actual content of the rest fraction. These figures are very good and shows that the AWCS has been a success in terms of reducing rest waste and increasing waste sorting.

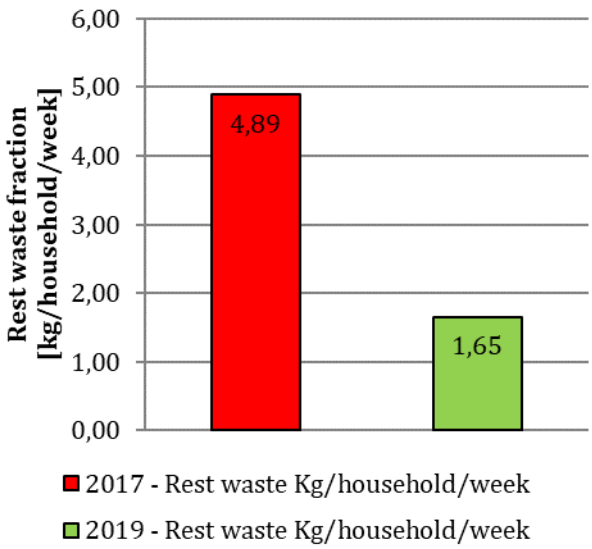

Figure 144 Reduction of rest waste fraction by 66%. Difference from pre to post AWCS installation. Data from sample analysis made by Envir on behalf of SVOA

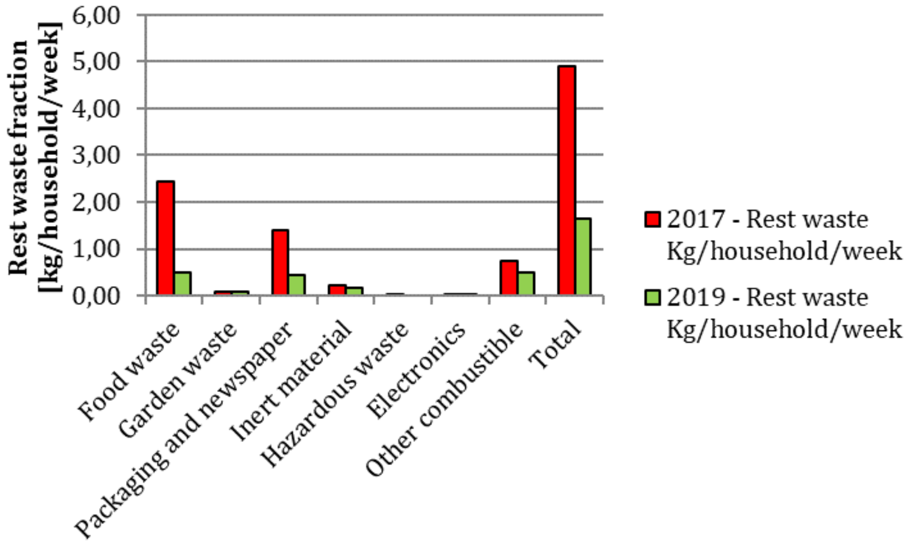

Figure 145 Content of the rest fraction (white bags only). Reduction of rest waste, divided into its actual contents. Difference from pre to post AWCS installation. Data from sample analysis made by Envir on behalf of SVOA

To illustrate the quality of the sorted waste, the content of the organic fraction (the green bags) has been classified by Envir, and the results are described in Table 171 below. The actual incorrect content of the food/organic fraction is around 7%, which is in analogue with other areas in the city of Stockholm according to SVOA representative

Table 171 Content of the food waste fraction (green bags only). Illustrating a good/normal sorting behavior

Content in the green bags	Share
Actual food waste	84,1%
Green bags themselves	9,2%
Incorrect sorted waste	6,7%
Total	100,0%

M7.2 – Automated Waste Collection System (AWCS)

To describe energy usage in the AWCS, the following parameters are measured:
1. Net electricity use (kWh) for vacuum system
2. kWh Energy/Capita
3. kWh Energy/kg collected waste

These parameters are covered by Table 172 which shows the energy usage for three different states of the AWCS during the 12 month evaluation period from September 1st 2018 to August 31st 2019.
- Idle energy: energy usage when the system is not transporting waste from inlets to container. This is mainly from the air compressor, even though some usage derives to the control system.
- Automatic energy: energy usage when the system is collecting waste in automatic mode (normal operation).
- Manual energy: energy usage when the system is collecting waste in manual mode. This is done eg. for maintenance purposes, to handle some types of disturbances, to prepare for connections of new inlets, among other reasons.

Table 172 Energy usage during 20 days (Nov 22nd to Dec 11th) the 12 month evaluation period from September 1st 2018 to August 31st 2019, net value, per user, and per kg collected waste

	Total	Per user per day	Per kg waste collected
Manual energy [kWh]	351,55	0,0040	0,0064
Idle energy [kWh]	6893,6	0,0780	n.a.
Automatic energy [kWh]	951	0,0108	0,0174
Total	8196,1	0,093	0,0238

Table 172 shows the energy usage per type, aggregated, divided per user, and divided per kg of collected waste. The actual collection of waste uses (0,0064 + 0,0174) = 0,0238 kWh per kg collected waste. When idle energy is added the usage is 0,15 kWh per kg collected waste.

During the 12 month evaluation period, the waste inlets have registered a collection of 49728 kg of waste. However, as explained above, this is 9% lower than the actual amount of collected waste according to the weighing system at the sorting facility in Eskilstuna. Thus, for the energy calculation in Table 172, the deviation of 9% has been adjusted to make a total amount of waste of 54 646 kg.

Notably the idle energy is on a high level. This is related to the technology used for the inlet operation where pneumatic pressure is used to open and close the hatch, and to rotate the drum for waste deposit. Since users approach the inlet on a more or less random pattern, pneumatic pressure must always be available to avoid unnecessary waiting time for the user. Acceptable waiting time is in the range of a few seconds, but to build up pneumatic pressure on demand will take substantially longer than that. To reduce the idle energy it is necessary to use another technology for the described operation, and this development is currently ongoing (September 2019).

The energy consumption in kWh can be transferred to equivalent CO_2 emissions. The Swedish electricity mix on average generates 13 gram CO_2 per kWh[23]. The converted result is shown in

- [23] https://energiradgivningen.se/klimat/miljopaverkan-fran-el

Table 173, based on the 12 month evaluation period from September 1st 2018 to August 31st 2019. An average of 2 users per apartment have been assumed, making a total of 484 users.

Table 173 CO2 emissions corresponding to the energy use shown in Table 172.

Full year	Total CO_2 [kg]	CO_2 Per user per day [kg]
Manual energy	4,6	0,00003
Idle energy	89,6	0,00051
Automatic energy	12,4	0,00007
Total	106,5	0,00060

M7.3 – Statistical analysis of sorted waste (turning waste to electricity, heat and biogas for vehicles)

A normal consequence of the installation of an AWCS from Envac is a substantial reduction of waste truck traffic in the area. This is also the result for the Growsmarter installation in Årsta/Valla Torg. The figures are presented in Table 174 and are visualised in Figure 147-Figure 150. The traffic in the area is reduced by 90% within the residential area.

Table 174 Driving distances in the area. No collection of organic waste pre AWCS. All four fractions are collected in the same container.

	Manual handling (pre AWCS)	AWCS
Rest fraction [km/year]	26	5,2**
Paper packaging [km/year]	13	**
Plastic packaging [km/year]	13	**
Organic waste* [km/year]	0	**
Total [km/year]	52	5,2

Converting driving distances from km to CO2 emissions requires a few assumptions and estimations, since it is difficult, or even impossible, to trace reliable data.

Hence, the calculation below has the following assumptions and estimations:

- Data is used from the Swerea report "Indikatorer för bedömning av miljöpåverkan" dated 2014-10-03, since this is the only report we could find that contains CO2 emission values for both rear loaded waste trucks (pre installation) and container waste trucks (post installation).
    - Rear loaded waste truck with 9 ton capacity: 0,402 kg CO2-eq/tonkm
    - Container waste truck with 15 ton capacity: 0,122 kg CO2-eq/tonkm
- Filling ratio for rear loaded waste truck estimated to 50% average.
- Waste weight pre installation assumed to be equivalent to post installation for the four fractions. Food waste assumed to be included in rest fraction pre installation.
- Weight of waste is based on weighing data from the sorting facility in Eskilstuna, and is 1,1 tonnes for an average week.
- Weight of AWCS container (empty) is 4 ton
- Weight of rear loaded truck assumed to be
    - Empty: 14,5 ton
    - Full: 23,5 ton
    - Average: 19 ton
- Weight of container truck assumed to be
    - Empty: 12,0 ton

- Full: 17,1
- Average: 14,6 ton

The obtained results are presented in Table 175 and Figure 146. Overall, the CO2 emission from traffic in the area has been reduced by 98%. Figure 147, Figure 148, Figure 149 and Figure 150 show the graphic illustration of the driving distance before and after the AWCS installation.

Table 175 CO2 emission from waste truck traffic in the residential area

	CO_2 from manual handling [kg/year]	CO_2 from AWCS [kg/year]
Total	52*19*0,402=397,2	5,2*14,6*0,122=9,3

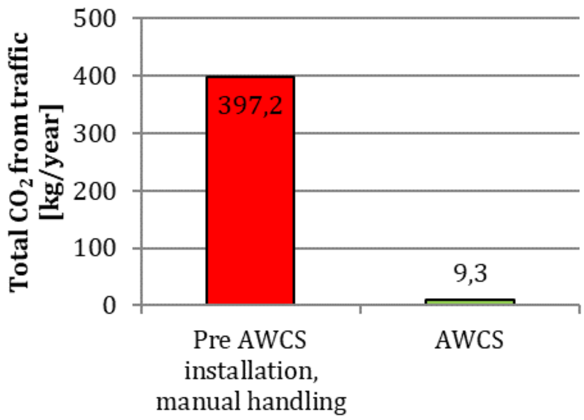

Figure 146 CO_2 reduction from waste collection traffic pre and post the AWCS installation in Valla Torg

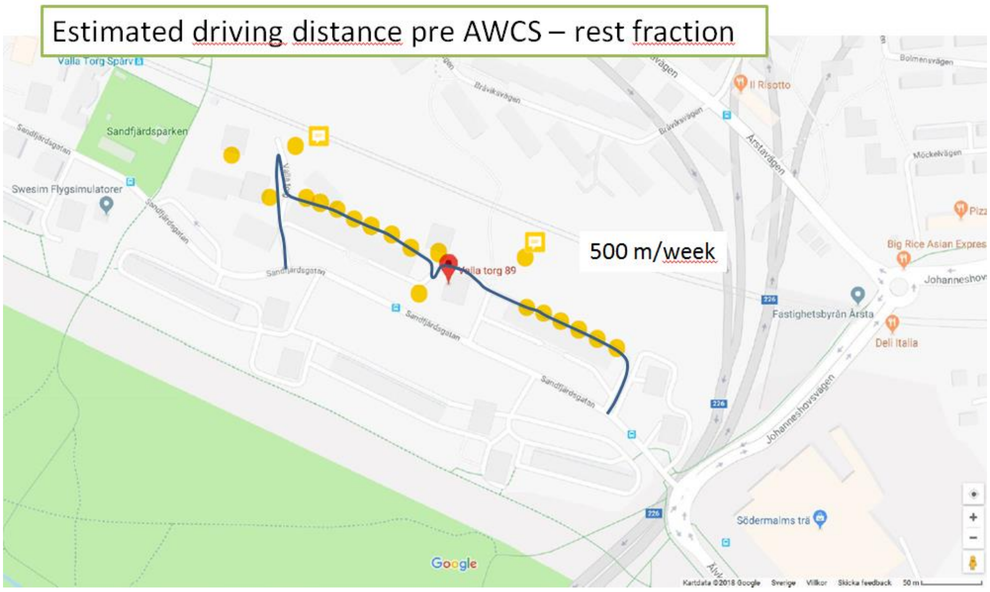

Figure 147 Driving distance for rest fraction prior to the AWCS installation

Figure 148 Driving distance for plastic packaging prior to the AWCS installation

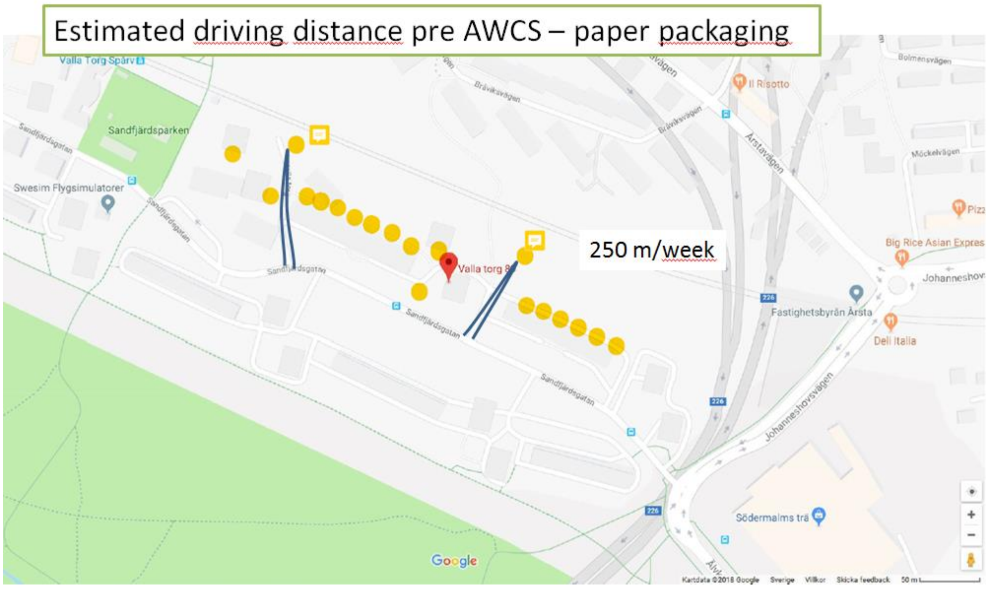

Figure 149 Driving distance for paper packaging prior to the AWCS installation

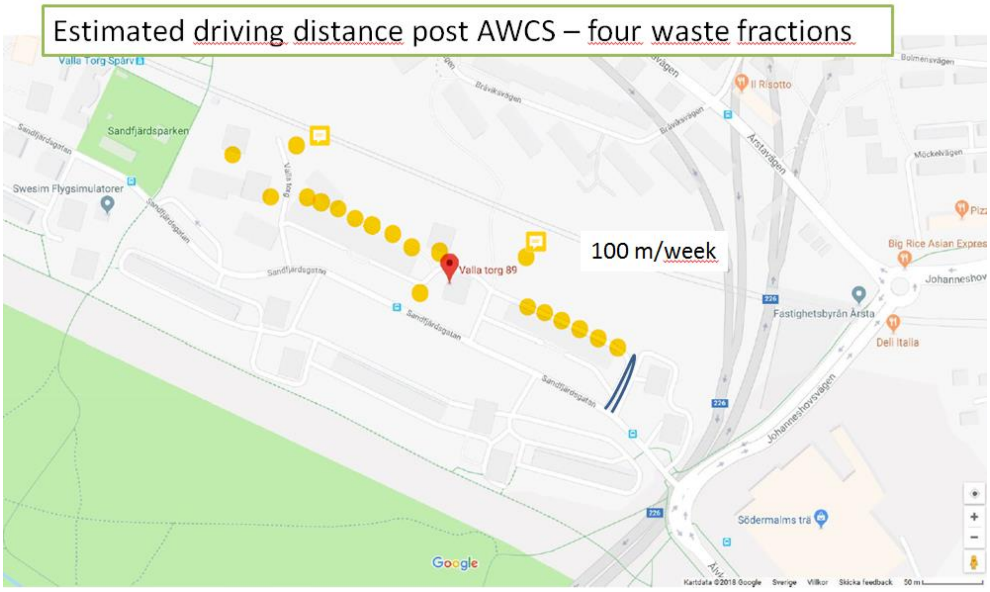

Figure 150 Driving distance for all four fractions after the AWCS installation

Table 176 shows the KPIs evaluated for M7.1, M7.2 and M7.3, according to the Evaluation Plan D5.1.

Table 176 KPIs evaluated for M7.1, M7.2 and M7.3 (Stockholm)

1.% Recycling rates	Rest fraction: 41% (weight) Organic fraction: 36% Plastic packaging: 8% Paper packaging: 15%
2.Waste generation kg/household	Rest fraction: 0,229 (substantially reduced post the AWCS installation) Organic fraction: 0,201 (new fraction post AWCS installation) Plastic packaging: 0,048 Paper packaging: 0,084
3.GHG/Capita	0,24 kg CO2/capita/year. A reduction by 71% thanks to the AWCS installation.
4.Relative awareness (survey based)	See "Social feasibility" section.

Potential for full scale implementation

Technical, economic and social feasibility

The system is, at this time, technically feasible and ready to be delivered. However, there are a few improvements that need to be introduced to increase the end user experience and to reduce energy usage. Eg. waiting time for the user at the inlet is considered too long, and the idle energy consumption can be reduced substantially.

Social feasibility

Stockholmshem has performed a survey on awareness of the waste management system. Of 70 respondents the average answer was 5,5 on a scale from 1 (not at all) to 10 (a lot more) to the question "How much more aware are you about waste sorting and recycling now compared to before the renovation?". Answers are distributed on all 10 levels from 1 to 10 except for 3 which had no answers.

Upscaling and replicability of the Measure

Potential of Standardization is medium to high depending on the local/regional availability of a recycling industry. The measure intends to deploy a collecting system to send waste to a specific location where it is treated and recycled. It means that the scalability of the measure depends on the city having a recycling plant to send the separated garbage bags. Scale Advantage is high for areas with an existing sorting facility and recycling industry. If not, costs and benefits escalate proportionally to the area covered by the service, reducing the scalability.

The service will be delivered through a public procurement long-term contract with the company to provide Engineering, Construction, Equipment installation, Management of the system, Waste management and Biogas production with processed food waste. It means that the implementation requires collaboration between the City Council -the client that has to offer waste collection management to the residents of the city-, residents -who should separate waste in different colored bags- and the specific company, in charge of carrying out the works providing a service to the City Council. In addition, the potential collaboration with equipment manufacturers, engineering companies, architects, construction companies and energy companies should be taken into account. Therefore, a Public-Private partnership (PPP) arises as the best option to implement the solution.

CO2 summary comparison

As shown in Table 177 and Figure 151, within the GrowSmarter Smart Solution 7 the total CO2 emission have been reduced by 71%. In order to grasp the full picture on a national or European level it is necessary to extrapolate to include transports to and from, among others, recycling plants, sorting facilities. This is however not included in the Growsmarter project. Excluded in the summary is also the CO2 emissions caused by heated waste rooms and the maintenance of these pre installation of the AWCS.

Table 177 CO2 summary comparison, Smart Solution 7.

	CO_2 Baseline [kg/year]	**CO_2 Post installation [kg/year]**
Traffic	397,2	9,3
Collection by AWCS	-	106,5
Total	397,2	115,8
Total, per capita	0,82	0,24
CO_2 reduction [kg]		281,4
CO_2 reduction [%]	71%	

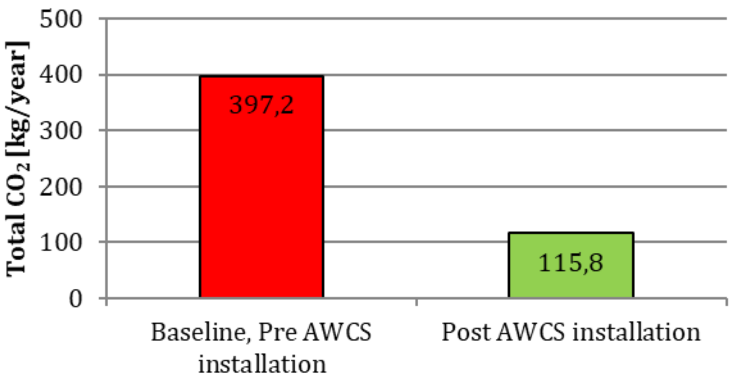

Figure 151 CO2 reduction thanks to the AWCS installation, Smart Solution 7

M8.0 – Big data protocol for saving energy and improving the quality of life

This section presents the results of M8.1, M8.2, M8.3, M8.4 and M8.5.

M8.1 – Big consolidated open data platform

Introduction

By consolidating, aggregating and using existing and new sensor data from infrastructure, traffic and users will generate a new base for innovation to support a new generation of management, control and policies. The Measure aims also at enabling the monitoring of the status and the impact of various Measures in real time at a low cost. This also enables to simulate short and long-term trips and transports in more detail in a dynamic way to improve the quality of decisions. The environment impacts will be monitored more efficiently and new generations of policies will be enabled. New innovative services based on the open and available data will also be enabled. Finally, this platform also will form a base for dialogue with citizens and the business community by a more transparent management.

In order to improve the energy efficiency of the public infrastructure, the information from City OS or other Service Provider Systems will be integrated. The platform will monitor the overall performance of lighting, traffic, bus shelters, environmental, and small EVSE from the energy point of view, assign priorities and command based on decision making algorithms via a "multi-functionality towers".

The intentions of the Measure are:
1. Integrating asset data and monitoring performance
2. Enabling real-time measurement and verification of Grow Smarter Measures
3. Making generated Grow Smarter data accessible for management, evaluation, and policies
4. Enabling smart city services
5. Enabling dialogue with citizens and business community
6. Enable insights of the urban spaces derived from those sensors.

Stockholm (M8.1)

Industry partner	Contact person	Validation partner
IBM	Stanley Ekberg, IBM	KTH-SEED

The Measure 8.1 aims at measuring flow of vehicles and people in a certain geographical area of Stockholm, Sweden. The area has a large variety in flows due to several large multipurpose arenas that are located within the area. The aim is to better understand these flows and using the increased knowledge to support planning, decision-, and policy-making within the city and to inform people staying in the area. A better understanding of the sources of emissions could help policy makers make better informed meassures, which might lead to reduced emissions from vehicles moving in the area and thereby help meeting the GrowSmarter target to reduce emissions from transport by 60%. By connecting additional data sources, the solution can also scale up to monitor energy use and greenhouse gas emissions in support of other GrowSmarter sustainability targets.

Being an enabling Measure, the technical evaluation will mainly consist of two parts: Data collected from the implemented solution itself (such as data volumes), and qualitative data collected from key stakeholders through interviews.

The enabled service, within GrowSmarter, is described in M5.2 (Stockholm).

Measurement within the selected area consists of sensors measuring the flow of vehicles and flow of pedestrians and bicyclists using Wi-Fi sensors. The target is to measure the flow of people and vehicles in the selected area to identify flow patterns.
As the area consists of large arenas, flow of people is changing based on what activities that take place in the arenas. Large flows of people are common especially before and at the end of an event. These peaks of flows can cause issues in accessing the public transports within the area.

Vehicle identification is used to retrieve emission data that can be used to calculate environmental impact. The project is conducted in a limited area and the 10 vehicle sensors and the 30 Wi-Fi sensors in use give a good understanding of the movements in the area. Statistical calculations are used to estimate the flow in areas where no sensors are available and to determine the probable path between sensors when several different paths might be possible to take.

The sensors measure data 24 hours per day 7 days of the week and will do so until the project ends in December 2019. Together with KTH and traffic operations specialists at the City of Stockholm, calculations of the current level of emissions will be calculated. This can then be used when implementing different programs and actions to limit the traffic in the area and by that reduce emissions.

The area has several local public transport possibilities including three subway stations and several bus stops. Analyzed data from people flows can be used to improve the experience by providing information about crowds and what option would be the best to take for an individual given the current situation based on real time data and predictive analytics.
With regards to the technical platform, the Measure has been implemented using the IBM Cloud platform, creating the necessary services and developing application programming interfaces (APIs) and visualizations as needed to provide the service to the end users.

Data sources:

1. Vehicle passage data (Facility Labs)
2. Wi-Fi Ping data (Need Insights)
3. Weather Data (The Weather Company)
4. Event information (Stockholm Live)
5. Local traffic planning function and live data (SL)
6. Libelium environmental sensors
7. Multi-sensor (Bosch and Axis)

Integration with the sensor providers have been implemented by means of integration components. For Wi-Fi sensor data (from Need Insights), an MQTT gateway has been set up using the Watson IoT service. A component on the provider's system regularly connects to the gateway and sends newly arrived data as MQTT messages.

For vehicle data, a component provided by the vendor (Facility Labs) runs on the IBM Cloud infrastructure, connects to the vendor's proprietary database and stores newly arrived passage records into a data lake in the IBM Cloud platform. These are picked up by an integration program and passed on for further processing.

Integration with weather data from The Weather Company (an IBM Company) is performed by means of a weather service that is already available in the IBM Cloud platform. Information on planned events in the area are captured by an integration program that scans the web site of Stockholm Live and feeds this information into the platform.

Libelium will be used to measure carbon dioxide and particles in the area of Growsmarter. While the multi-sensor will verify the pedestrian congestion, counting bicycles and vehicles.

Finally, real time data on local traffic is retrieved to support users navigating in the area (using the MetroLive app described in later chapters). This data is not stored in the platform but is used by the platform to serve individual users.

The overall architecture of the implementation is shown in Figure 152. The solution contains a data lake where all data is stored, as well as integration components, analytics & enrichment flows, APIs and prepared data marts where a subset of the data is stored for online access from users or services.

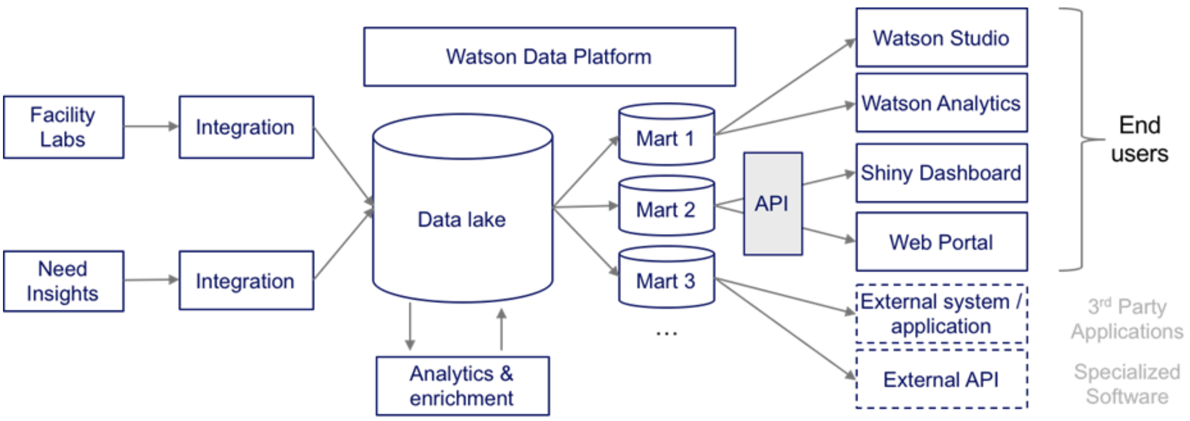

Figure 152 Architecture Overview (M8.1)

A more detailed view illustrating key data flows in the solution is given by Figure 153. It illustrates how data flows from the sensor vendors' systems via two separate entry points. The data is then immediately stored in the data lake for later processing but also fed online via the IBM Event Streams system for online processing, e.g. real time counting of unique visitors, or passages through the system.

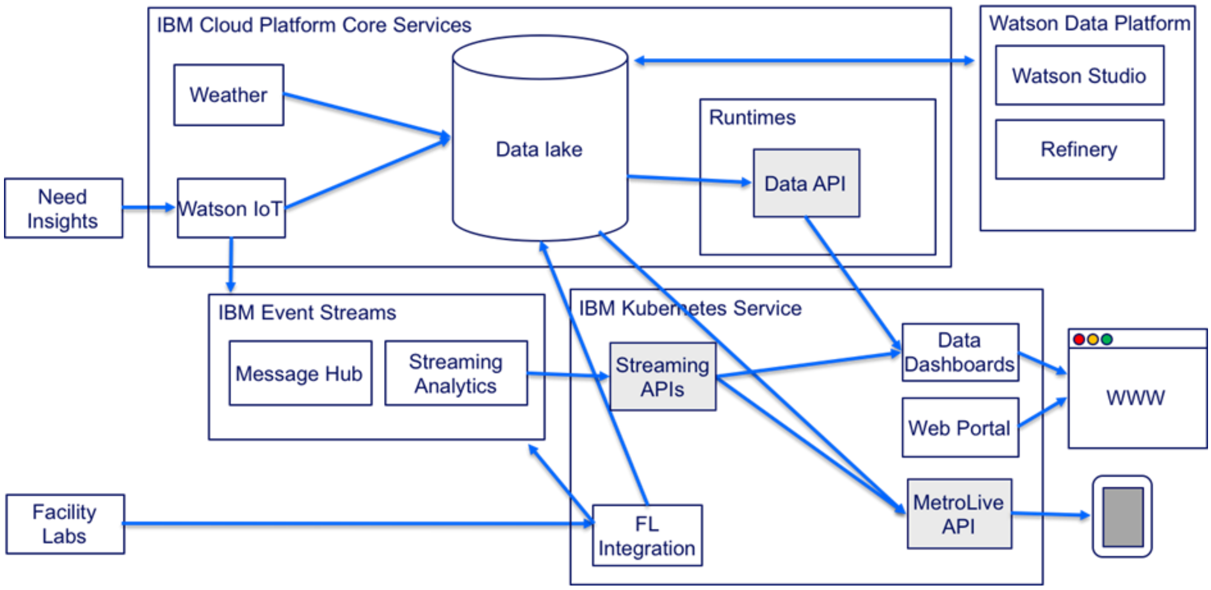

Figure 153 Technical view: Data flows (M8.1)

Table 178 shows the available KPIs calculated for this Measure and the indicators that will be available for this final report D5.4.

Table 178 KPIs calculated and planned for M8.1 (Stockholm)

1. Big Data Velocity and Volume	35 Mb / day, 215 Gb total
2. Big Data Variety	4
3. Big Data Energy Use and Emission	550 W / TBD
4. % Enabling Factor	100 %
5. Monitoring Accessibility	5
6. Number of enabled services	0
7. Number of enabled innovations	0
8. Number of insights	3
9. Type and number of customers that have accessed services	10

Additional details are presented in the following for some of the KPIs.

KPI #1. Big Data Velocity and Volume

Data per day:

- Vehicle passages: 11 Mb per day (~11 k passages / day)
- Wi-Fi pings: 23 Mb per day (~40 k pings / day)
- Event information: 1 kb / day
- Weather information: 50 kb / day
- *Sum: 35 Mb / day*

Total data:

- Main data lake: 115 Gb
- Object Storage: 100 Gb
- Weather data: 15 Mb
- *Sum: 215 Gb*

KPI #3. Big Data Energy Use

A range of services are used in the platform (see Table 179). For some of the services the hardware utilization is known but it is still virtual machines. For other services the actual hardware utilization is not known, these services have been estimated to a total of 5 virtual machines, since they handle relatively low amounts of data and are shared with other users of the service in the public cloud. The energy consumption of a virtual server has been estimated at 50 W based on public literature.

Emission data is still being investigated and will be added when available

Table 179 Energy use and CO2 emissions for the services used in the platform

Item	# servers	Energy / server	Total energy	CO2 Emissions
Datalake DB2	1	50 W	50 W	n/a
Kubernetes cluster	3	50 W	150 W	n/a
Watson IoT	2	50 W	100 W	n/a
Various services	5	50 W	250 W	n/a
Total	**11**	**50 W**	**550 W**	**n/a**

KPI #4: % Enabling Factor

Regarding KPI number 4, the intention is to enable real-time evaluation for all intended Measures. This will be confirmed as part of the final evaluation.

KPI #5. Monitoring Accessibility

Accessibility is defined as the amount of different options the users have to access the platform.

KPI #6 and #7. Number of enabled services / Number of enabled innovations

The result of this project has not yet concluded in any new services or innovations. But according to Tobias Johansson at City of Stockholm transport department these findings or similar projects will build the foundation for their work going forward. Examples of this can be implementations of environmental zones or rerouting of traffic.

KPI #8. Number of Insights

The number of insights obtained during this project are many and widespread, the main ones are:

1. The usages of Wi-fi sensors to obtain data regarding pedestrian traffic is not ideal.
2. The positioning of the cameras/sensors is crucial to obtain useful data and to facilitate maintenance.
3. The data gathered during this project is central in order to establish a modern and useful urban planning.

MetroLIVE Mobile Application

The purpose of the MetroLIVE application (Figure 154) is to help the arena visitor, to plan their trip based on the current traffic situation in the area. The application is based on the existing SL (Stockholm Lokaltrafik) API but differentiates in the detection of traffic congestion, traffic congestion alerts, heatmap of number of visitors on a map and estimated walk time based on the traffic situation. The application has the main focus on the visitor and provides the visitor with different trip alternatives.

The MetroLIVE application enables the event visitors to plan their trip based on real-time information regarding traffic congestion with a heatmap displaying congested areas and sends alerts on risk of traffic congestion in a specific area. The app also enables the user to check any disturbances of the trip and how the next departure from a stop is affected by traffic congestion. The application calculates walking time based on the real-time sensor data and can help the visitors to understand whether or not they will have enough time to catch the next train.

Figure 154 MetroLIVE Mobile Application that gives real-time updates regarding traffic information to event visitors

The Figure 154 above illustrates an event day, where the event has recently ended, and visitors are trying to navigate and plan their trip home. The application displays travel alternatives from the current location and displays the general time and new duration time based on the predictive walking time duration.

Technical feasibility (M8.1 Stockholm)

The implementation of the M8.1 is based on standard products and is technically feasible to implement and to use as intended. The main challenges have been around the sensor technology and the data quality received from the sensors.

- Implementation of new sensor systems can take time and this aspect should not be underestimated. This can be caused by lead time to reach agreements between physical facility owners to be able to mount devices, or to order and install necessary electricity.
- The Wi-Fi sensors can capture signals from phones within a radius of 75 meters in any direction and regardless of obstructions. By having a few of the sensors within a

distance of 140 meters from each other, this affects the ability to calculate the walk time as the individual is being registered on both sensors. The same applies to the vehicle sensors.
- The latency of the data registration from devices can in some cases be between 5-20 minutes. This limits the value of having real time sensors.
- There is an uncertainty with calculating the speed of passages to differentiate bicyclists from pedestrians. This is a result of vehicles passing by next to the bicycle lane. Therefore, it is relevant to add a feature with tracking velocity of passages on the sensors.

Economic feasibility (M8.1 Stockholm)

Implementation of a Big Data platform often impose a higher startup cost for the first use case. Adding additional cases or increasing the usage of the same use case can lower the cost per unit or use case. This effect is basically a result of services or labour costs. The IT related platform cost is consumption based and will have a low cost for the low volumes also at start.

The reason for this is that there are setup costs for the first use case. This setup cost is labour related. The cloud functionality in most cases have a price structure that is based on consumption which means that a low usage in the initial phases also means a low cost or even no cost during the development phase.

The Measure is economically sustainable when assumed that the foundation would be used for more cases or at a larger scale. The Measure is installed in a limited geographical area with few sensors connected which makes the relative cost per sensor higher.

The Measure's intent is to look at Big Data, and when the cost is compared to a traditional installation the increased cost for the IT platform itself is marginal, if any at all. The low scale implementation of sensors is not impacted by high IT running costs. This is a good example where cloud technology reduces the IT costs.

Social feasibility (M8.1 Stockholm)

The Measure is installed in a limited area of Stockholm with few users. A full evaluation of the social impacts was concluded after a longer demonstration period including three interviews. Observations from the user interviews have been used in the conclusions in this section.

One of the Measure's deliverables is an improved experience for visitors to the arena area, while this was not in the scope of the project, it was still a valuable side effectGiven that this will give the area an improved image it could result in a higher number of visitors. The experience is primarily focused on assisting the visitors coming to the area with public transportation. It could also mean that the vehicle traffic to and from the area would be reduced, helping decrease environmental stress. All these changes are considered to be marginal and not significantly change the access to the area, nor the local prices for real estate.

Upscaling and replicability of the Measure (M8.1 Stockholm)

All technologies used in this project are widely available. The cloud platform and weather data input can be used regardless of location. Sensors already installed can be used. If no sensor data is available, sensors must be installed to replicate the solution.

Big data and connected devices are getting more common. This project has aimed at showing a real example of how these could be used.

Replication criteria:

- *The number of data sources are expanding rapidly. It is important to use open data platforms which are designed to be flexible in terms of input, output and the ability to manage big data over time in a secure and safe manner*
- *Sensitive data need to be anonymized*
- *Data ownership is important and should be a decision criterion*
- *Implementation of new sensor systems can take time due to approvals needed and the need for connectivity and electricity*
- *Different sensors have different characteristics limiting their suitability for the intended use*

Conclusions (M8.1 Stockholm)

Big data and connected devices are getting more common. This creates opportunities for the city going forward to make its operation even more efficient but also to improve the experience for citizens and visitors. This Measure has had the target to show a real example of how this could look.

Other conclusions are:

- *It is important to have relevant stakeholders and user groups involved and that the development is aimed at providing real value for these groups*
- The number of data sources are expanding rapidly. It is therefore important to use open data platforms that are designed to be flexible in terms of input, output and the ability to manage data over time.
- Personal data are sensitive, and data needs to be anonymized.
- Data ownership is important. The data is collected for the benefit of Stockholm City, its citizens and visitors, and the ownership should be with the city.
- Implementation of new sensor systems can take time and this aspect should not be underestimated. This can be caused by long lead time to reach agreements between physical facility owners to be able to mount devices, or to order and install necessary electricity.
- The data has limitations in pattern recognition of unique visitors. The number of unique sensors per person is mostly one or two sensors. Usually the visitors are being tracked by the same sensor.
- The Wi-Fi sensors can capture signals from phones within a radius of 75 meters in any direction and regardless of obstructions. By having a few of the sensors within a distance of 140 meters from each other, this affects the ability to calculate the walk time as the individual is being registered on both sensors. The same applies to the vehicle sensors.
- The latency of the data registration from devices can in some cases be between 5-20 minutes. This limits the value of having real time sensors.
- There is an uncertainty with calculating the speed of passages to differentiate bicyclists from pedestrians. This is a result of vehicles passing by next to the bicycle lane. Therefore, it is relevant to add a feature with tracking velocity of passages on the sensors.
- The traffic congestion before and after an event affects the walking time from the arena area to the train station by doubling the time it takes under ordinary conditions.

Cologne (M8.1)

Industry partner	Contact person	Validation partner
UI	Stephan Borgert (UI)	KTH-SEED

The ultimate aim of Measure 8.1 in Cologne was to install, configure and improve an open urban big data platform that is able to store and process urban data in real-time in order to enable vertical and horizontal integration of data and services of the different infrastructures. Data of all departments of the City of Cologne can be integrated as well as data of Colognes municipal utility groups like Rheinenergie AG and KVB. Third parties like Colognes project partners Cambio and Ampido can also be included. This kind of platform is necessary for transforming a city into a smart city, thus it is supposed to support achieving the goals in GrowSmarter by integrating infrastructures on the ICT level. Furthermore it can be used as a planning and decision making tool for all planners and analysts within the city administration. The platform could also form a base for dialogue with citizens and the business community via a more transparent management and foster co-operation and co-creation processes.

The success of the big open data platform “urban pulse” installed in GrowSmarter depends on the datas that can be integrated and the people that uses them. Therefore, the potential for the enabling functionality is the main scope of the evaluation of these measure.

In the first projectphase 2015 a use case for mobility stations was developed which connects and enables all mobility solutions planned in cologne within the framework of GrowSmarter. Based on this, the required data was determined and initial disussions were held with partners on the provisions of the data. In parallel the necessary contracts and technical requirements for the construction of an urban data platform in the defined form have been developed.

At the end of the implementation phase 13 data sources have been included.
These are data with two different release forms:

a) open data, that is available at *offenedaten.koeln* and at the monitoring tool of the urban pulse (Urban Cockpit)
b) closed data that is only available for the projectpartners over the monitoring tool Urban Cockpit.

On top of the platform (Urban Pulse) two Monitoring Tools (Urban Cockpits) were implemented. One Cockpit for internal use with exclusive use of closed data (e.g. for authorities) and one cockpit for external use with released data, for example for citizens only as a demonstration tool.

After integrating, consolidating, aggregating and using existing and new sensor data from infrastructures, this cockpits will display information and generate a new base for innovation to support a new generation of management, control and policies. The aim is to eventually monitor the status and the impact of various measures in real time as well as simulate short and long term scenarios in more detail to improve the quality of decisions. The cockpit for the external use exists only as a mockup. The link to the internal tool was given to all projectpartners.

Figure 155 shows the architecture of Cologne’s Open Urban Big Data Solution Urban Pulse, which has been developed for the GrowSmarter project. The architecture consists of three main layers: Urban Sensors and Data (bottom), Data Storage and Processing (middle) and Apps and Data Platform (top). Data is produced in the bottom layer, is processed and stored in the middle layer and used on the top layer.

Baseline definition

A) Intention of the urban Pulse: Every city already has many data sources which produce urban data. Nowadays these data are stored and processed isolated from each other. In the context of GrowSmarter although the data from the partners should have been integrated in the platform to enable their meausures. The urban Pulse can associate these data sources with the Urban Sensors and Data level.
B) Open Data Platform of the City of Cologne *offenedatenkoeln.de*: The city of Cologne installed an Open Data Platform in 2012 (https://www.offenedaten-koeln.de/). This platform is depicted in the Apps and Data Platform layer of the architecture. It provides links and descriptions to APIs to some data sources of the Urban Sensors layer and also provides small static data, which can be downloaded directly from the platform. The APIs provide low refresh data of data sources like current available bikes of bike sharing stations. The refresh rate of this data source is 4 times / hour. The stored data are small data with an almost static refresh rate like points of interests of charging stations or bike sharing stations. These data are usually updated every 1 to 6 month.
C) The Difference between the urban Pulse and offenedatenkoeln.de: Receiving, storing, analyzing and processing real time data is not the purpose of this platform but the purpose of the platform, developed for GrowSmarter

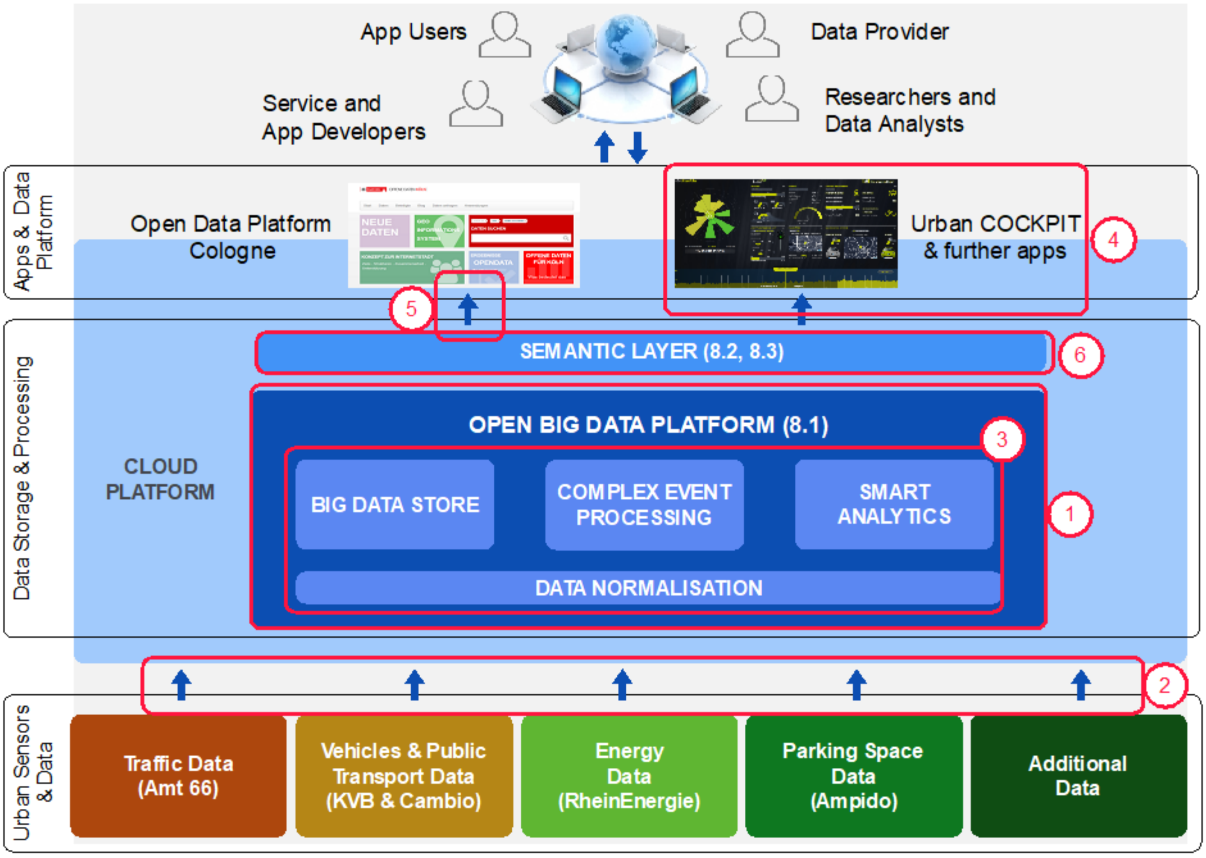

Figure 155 Architecture of Cologne's Open Urban Big Data Solution

Objective definition Urban Pulse

The architecture in Figure 155 shows the objective to be met for GrowSmarter. Currently isolated urban data are connected to the data storage and processing layer. New data sources will be integrated as well, such as Cologne's traffic systems data and public transport data, e.g. where the current vehicles of the public transport operators are located. These data sources provide data by a real-time refresh rate (3 times / sec to 1 event every 15 minutes) and produce big data streams. These streams can be stored and processed in real time as well. We installed the backend in Figure 155 (1) which consists of the components "Data Normalization", "Big Data Store", "Complex Event Processing" and "Smart Analytics" and integrated data sources Figure 155 (2).

Next to storing and processing, the analysis of the integrated data streams is important Figure 155 (3). Due to the integration of the isolated data to one backend, synergy effects can be produced by combination and analytics. The result is also called "smart data". This is essential for integrating different smart city infrastructures like private traffic, public traffic, smart parking and energy to enable a city to become a Smart City. For the smart data, outbound interfaces will be developed and described. The description will be published on the open data platform Cologne to stimulate new research and innovation activities.

The enabling factor of the urban pulse depends on the source and quality of data implemented and persons to whom the synergy effects can be presented/offered.

Figure 156 Urban Cockpit Main Page

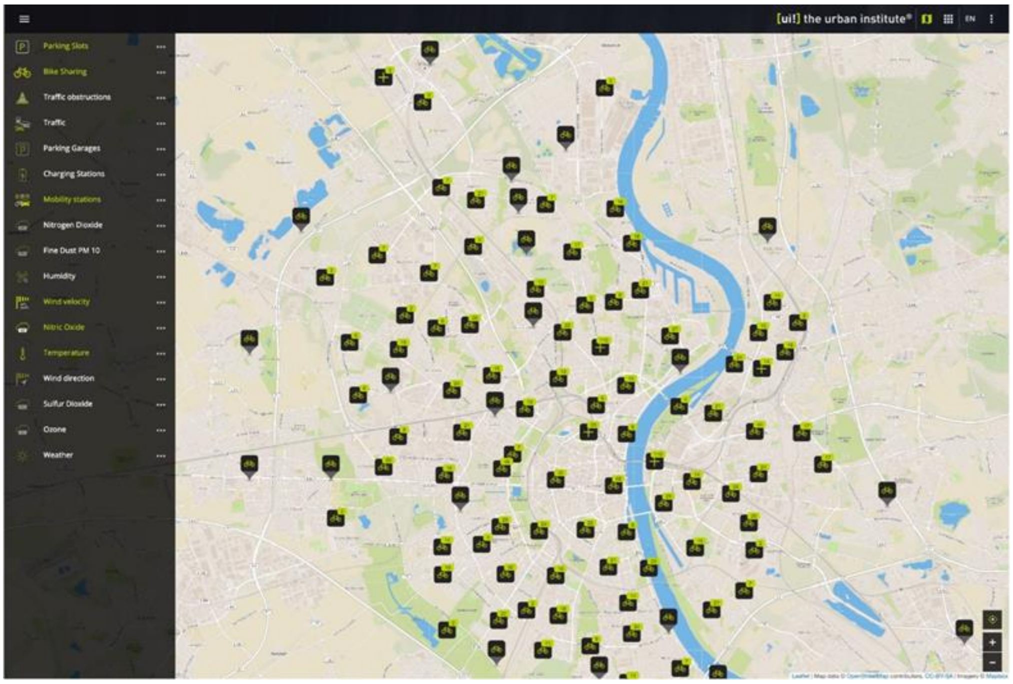

Figure 157 Urban Cockpit Map View

The Monitoring Tool of the Urban Pulse: The Urban Cockpit

On top of the urban Pulse a monitoring tool, the urban COCKPIT, was created (Figure 156 and Figure 157). With this the data sources and their optimization can be shown e.g. to get better knowledge about the city needs or what other value added information can be generated with the available data base. On the left side is pulsing and gives information of the current "pulse" of the city. In case of large traffic loads, much pollution, bad parking situations, high amount of non-regenerative energy consumption, etc. the pulse is very high which indicates the city suffers of a "stress". On the right side, different tiles or certain Smart City indicators are arranged. The Cockpit can be designed for in dependence on the user and the wished use cases. Currently it supports up to 9 different tiles. The event line on the bottom of the cockpit can be used to see when new events received into the COCKPIT.

Specification of methodology for evaluation (M8.1 Cologne)

In the implementation Phase the data platform required by the grant agreement was technically created and on top two monitoring tools were developed. The potential of the platfoms enabling function for the measures implemented in the GrowSmarter Framework was defined and presented by a use case for the mobility stations in 2015 and presented to all partners. Based on this discussions and workshops with all partners and some departments of the city of Cologne were held.
Since the required data has not been provided the platform cannot perform its enabling function. Therefore the evaluation can not be carried out in the way defined in the evaluation plan:

1. Qualitative surveys
2. Quantitative evaluation of metrics that describe how well the outcomes correlate with the described intentions

This came clear and was reported to KTH first at the General Assembly in Barcelona in 2016. And also in Cork 2017. In Cologne 2019 the General Assembly decided that each Meausure 8.x because of its enabling function can report its own KPI's depending if they work for this measure or not. The focus of the evaluation has to be qualitative:

1. What was done (see above)
2. Lessons learned/ what has to be done

Qualitative evaluation (M8.1 Cologne)

For the qualitative evaluation, the team had planned to conduct expert interviews with decision-makers and Smart City experts to be conducted continuously during the evaluation phase. The original objective was to sketch examples based on the numerous data in the open urban platform (OUP) and to ask the experts about the platform and the concrete benefits for their work area. This was intended to document the added value of the platform.
However, as described in detail in the Implementation Report, it was for various reasons not possible to obtain the data records described in the Grant Agreement. Especially the industrial partners (e.g. Ampido and cambio) were not able to provide the necessary real-time data to support the measures implemented in their workpackages for competitive and internal reasons. Ultimately, only closed data could be entered into the OUP, with the prerequisite that these may only be provided within the project framework. In addition, no integration of real-time data was possible (implemented real-time data is e.g. the availability of KVB Bicycles with an interval of provided data every 15 minutes).

It was therefore not possible to present the OUP in the scope as originally planned. As a result, the evaluation strategy also had to be adapted. The objectives of the expert interviews were redefined as follows:

- Carve out:
  - What are the concrete doubts and reservations against the use of an OUP
  - Which legal and internal reasons speak against the use of an OUP
- Interview:
  - Sensitize to & explain the potential of an OUP
  - Give the opportunity to think again about the potential benefits of an OUP for their field of work
  - Outline a positive scenario (we would be willing to use an OUP, if…)

The aim here is to enable Follower Cities to weigh whether an OUP can be set up or whether changes are required in advance. This supports the development of a "blueprint" required in GrowSmarter for Smart Cities.
New interview partners were defined on the basis of these questions. The focus was on

- Project partners from the municipal utility group
- Project partners from the industry
- Thematic services in the City administration of Cologne
- Interview partners with a scientific approach

With this reorientation, the City of Cologne, in cooperation with UI! set up a questionnaire for the planned interviews. It became clear that the preparation and execution of the interviews is more complex than assumed at the beginning of the project.
Main reason: Workshops and discussions with the project partners have already taken place during the implementation phase. The aim was to clarify which data they can make available to the OUP and in what form. In these meetings it became clear that the topic of data and its release and use is a very sensitive topic. Therefore, not only the content of the questions had to be carefully considered, but also the nature and framework of the questioning.
In order to differentiate the evaluation interviews from the meetings and workshops in the implementation phase and to be able to interview as impartially as possible, it became clear, that having the interviews conducted by third parties and at neutral locations will be best approach.
Ultimately, it was decided to call an external scientific support to ensure the quality and usability of the interviews. We chose the University of applied science in Cologne (TH) to be an appropriate partner.
Reason for this decision: There is a close cooperation between the TH and the City of Cologne in the field of sensor technology. Furthermore, the TH was involved in the candidature for GrowSmarter and is also supporting the WP2 Measure 3.1. in combination with Measure 5.3.
A first meeting with the TH took place in June 2018. The questionnaire prepared by the City of Cologne and the company UI! and a list of potential interview partners served as basis for this. Both were presented and discussed.
The TH proposed to focus on the project partners first before including some of the City of Cologne departments. The questions should focus on the potential benefits of an OUP for the partners, the desired framework conditions and the actual legal requirements.
With regard to the method the TH Cologne proposed to conduct workshops on the questions instead of interviews with individual partners. The advantage here is that the workshop participants can intensively deal with the topic and develop new ideas in a constructive environment. The workshops should ideally be conducted as a creative exchange in which the

participants motivate each other and possibly even develop common ideas. The City of Colognes experience from the implementation phase was passed on to the TH.
The workshops were designed and conducted by the TH. The composition of the workshops participants was also carried out by the TH.
The aim was to get Informations about what would be necessary to make a blueprint for an open urban big data platform run for the partners.
At last two workshops took place. One with the industry partners and one with employees of the departments of the City of Cologne.

Results of the Workshops:

11 proposals for data management:

- Connecting different mobility data
- Regionalising the mobility data
- Bringing mobility data to the mobility stations
- Generally improving parking space data
- Informing citizens about the Stegerwaldsiedlung success story
- Transferring the housing development management system to other city districts in a modified form (producer and consumer cooperatives)
- The city as a battery / swimming pools as an example
- Compiling environment and mobility data
- Compiling mobility data and local weather forecasting
- Not afraid of open data/take away fears of open data
- Define technical prerequisites

4 next steps to ensure to be regulated within the framework of a blueprint

- Definition of a trustworthly cloud infrastructure
- Definition of a binding discussion process
- Definition of a bundle of WEB Services
- Definition of specifications by the technical committees

4 proposals for action for the EU partner cities within the GrowSmarter project

- Definition of a common top level ontology in the fields of energy, mobility and environmental data
- Agreement on exchange formats for energy, mobility and environmental data
- Procedure models for the implementation of selected examples of WEB services
- Make timelybinding agreements with local companies about data exchange

In fact all partipiciants of the workshops agreeded that it makes sense to implement and use an urban platform. All of them has use cases from their own businesses. But everyone has fears and reservations to make their own data available for such a platform. In addition to legal protection concrete contractual regulations for the handling of data was desired.

The workshop confirmed the experiences from the implementation phase. It can be stated that all participitatians recognized the necessity of merging and optimizing data. The fears of regarding the handling of data prevent an opening in this topic.

<u>Quantitative evaluation (M8.1 Cologne)</u>

Table 180 presents the KPIs evaluated in Cologne for M8.1, following the scheme proposed in the Evaluation Plan D5.1.

Table 180 KPIs evaluated for M8.1 (Cologne)

1. Big Data Velocity and Volume	What size of data managed within the project (GB/Day and GB Total. A monthly detailed list of the technical accesses to the azue cloud is possible.Look at the end of the table.
2. Big Data Variety	Documentation of the different data sources integrated on the open data platform. = 13
3. Big Data Energy Use	Big Data Energy required for operation of the urban data platform (AZURE Cloude from Microsoft): No detailed Information can be given by Microsoft. They use 100 % Carbon neutral energy.
4. % Enabling Factor	What percent of intended GrowSmarter measures have been enabled for real-time evaluation? (%); 84 % (11 datasources out of 13 implemented sources)
5. Monitoring Accessibility	What percentage of policy makers, businesses, and researchers within the project has received satisfactory access to grow smarter data? The Urban Cockpit is only available for the projectpartners. 3 out of seven used it .
6. Number of enabled services	How many smart city services have been enabled due to the implementation of this measure? (Survey/Interview-based) Answer: **3** Look at the FactSheets to measure 8.1
7. Number of enabled innovations	How many innovations, if any, have been enabled due to the implementation of this measure? (Survey/Interview – based) Answer: **3** (GreenAir (up and running), Mobility Stations Service Bundle (partially), Smart Driving Assistance Service Bundle (partially))
8. Type and number of customers that have accessed services	How many insights that can lead to new policies and practices have been enabled or generated due to this measure? (Survey/Interview -based) Answer: **3** 1. Support For analyzing its good to use a meet in the middle approach: top-down and bottom-up. Bottom-up: Try to integrate as many open data sources as possible and analyze their quality and what value added information can be integrated out of them. Top-Down: Ask interest groups for their demands, develop solutions concepts with them in workshops and analyze what data is needed to fulfill the demand. Doing top-down and bottom-up in parallel is efficient since it turned out, capturing the state of digitalization of a city can be a very time consuming process. 2. This approach needs also to be explained to the partners to get data from in order to archive a better understanding and higher acceptance of what can be done with the new platform. This must be repeated several times, e.g. as workshops.

	3. A city needs to engage the entire community (citizens, but also corporations, organizations, universities, schools) to obtain a good support.
9. Number of insights	Numbers of end-users that have accessed generated data and services A) open data via offenedatenkoeln.de (April 2018 to March 2019): **4971** B) closed data for projectpartners via urban cockpit: **3 out of 7**

Dienstbeschreibung	Maßeinhei	Juni	Juli	August	Septembe	Oktober	Novembe	Dezembe	Januar	Februar	März	April	Gesamt
Azure App Service Basic Plan - B1	100 Hours	0.0000	0.0000	0.0000	0.0000	18.267	72.000	74.400	74.400	67.200	74.400	70.000	**450.667**
Azure App Service Free Plan - F1	1 Hour	0.0000	0.0000	0.0000	0.0000	0.2460	0.9677	0.9999	0.9999	0.9032	0.9999	0.9408	**60.574**
Bandwidth - Data Transfer In - Zone 1	10 GB	109.855	110.401	76.598	48.970	58.070	72.353	87.106	94.640	90.336	70.115	45.270	**863.714**
Bandwidth - Data Transfer Out - Zone 1	10 GB	0.7008	0.5527	0.5679	0.5089	0.7101	14.537	0.7099	10.897	0.9864	12.106	14.049	**98.956**
Event Hubs - Standard - Throughput Unit	100 Hours	572.800	595.200	595.200	576.000	595.200	576.000	595.200	595.200	537.600	593.600	542.400	**6.374.400**
Files - List Operations	10000000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
General Block Blob - Delete Operations	100000000	0.0009	0.0009	0.0009	0.0009	0.0010	0.0013	0.0013	0.0013	0.0012	0.0013	0.0008	**0.0118**
General Block Blob - GRS - Write Operations	100000000	0.0069	0.0071	0.0071	0.0069	0.0071	0.0069	0.0071	0.0071	0.0064	0.0071	0.0067	**0.0765**
General Block Blob - List and Create Container Operations	100000000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
General Block Blob - LRS Data Stored	100 GB/Month	0.0000	0.0000	0.0000	0.0000	0.0000	0.1348	20.097	47.631	65.959	80.451	89.423	**304.909**
General Block Blob - Read Operations	100000000	0.0319	0.0330	0.0325	0.0358	0.0404	0.0449	0.0499	0.0504	0.0455	0.0498	0.0392	**0.4533**
General Block Blob - Write Operations	100000000	0.0009	0.0009	0.0009	0.0009	0.0010	0.0088	0.0241	0.0242	0.0220	0.0215	0.0190	**0.1241**
IP Addresses - Basic - Dynamic Public IP	200 Hours	66.845	67.510	48.055	42.185	47.735	86.980	106.825	106.455	95.135	103.205	93.790	**864.720**
Queues - GRS - Class 1 Operations	100000000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
Queues - LRS - Class 1 Operations	100000000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
SQL Database Single Basic - B - DTUs	10/Day	30.042	30.792	31.000	30.000	31.000	29.958	31.000	31.000	27.958	31.000	28.667	**332.417**
SQL Database Single Standard - S0 - DTUs	10/Day	120.000	123.167	124.000	120.000	124.000	119.833	124.000	124.000	111.833	124.000	114.667	**1.329.500**
SQL Database Single Standard - S1 - DTUs	1/Day	600.833	615.833	620.000	600.000	620.000	599.167	620.000	620.000	559.167	620.000	573.333	**6.648.333**
SQL Database Single Standard - S2 - DTUs	1/Day	600.833	615.833	620.000	600.000	620.000	599.167	619.583	620.000	559.583	620.000	573.333	**6.648.333**
Standard HDD Managed Disks - Disk Operations	100000000	0.0000	0.0000	0.0000	0.0000	0.0039	0.0153	0.0165	0.0178	0.0230	0.0247	0.0249	**0.1262**
Standard HDD Managed Disks - S4 - Disks - EU West	1/Month	0.0000	0.0000	0.0000	0.0000	0.2379	0.9904	0.9999	0.9999	0.9999	0.9986	0.9626	**61.892**
Standard Page Blob - Disk Delete Operations	100000000	0.0272	0.0274	0.0266	0.0261	0.0270	0.0262	0.0273	0.0272	0.0250	0.0236	0.0193	**0.2830**
Standard Page Blob - Disk Read Operations	100000000	0.0129	0.0134	0.0131	0.0130	0.0134	0.0147	0.0139	0.0138	0.0126	0.0147	0.0125	**0.1479**
Standard Page Blob - Disk Write Operations	100000000	0.2419	0.2518	0.2457	0.2433	0.2508	0.2392	0.2357	0.2429	0.2210	0.2350	0.2117	**26.191**
Standard Page Blob - GRS - Disk Write Operations	100000000	0.1777	0.1826	0.1849	0.1779	0.1837	0.1808	0.1859	0.1837	0.1663	0.1857	0.1750	**19.841**
Standard Page Blob - GRS Data Stored	100 GB/Month	29.320	29.439	29.467	29.558	29.602	29.611	29.769	29.838	29.808	29.912	29.113	**325.436**
Standard Page Blob - LRS Data Stored	100 GB/Month	0.7610	0.7531	0.7668	0.7800	0.7989	0.8147	0.8230	0.8327	0.8602	0.9666	0.9506	**91.076**
Storage - Bandwidth - Geo-Replication Data Transfer - EU West	100 GB	23.222	23.247	24.137	23.098	23.864	23.848	24.008	24.355	21.970	24.102	23.243	**259.095**
Tables - Batch Write Operations	100000000	0.4725	0.5186	0.4107	0.5090	0.5785	0.7917	13.760	14.068	11.672	0.6159	0.2613	**81.083**
Tables - GRS - Batch Write Operations	100000000	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	**0.0032**
Tables - GRS - Write Operations	100000000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
Tables - GRS Data Stored	100 GB/Month	0.6864	0.6863	0.6863	0.6863	0.6863	0.6863	0.6863	0.6863	0.6863	0.6863	0.6619	**75.251**
Tables - LRS Data Stored	100 GB/Month	30.474	37.658	44.900	51.076	60.871	69.201	86.333	109.068	131.312	155.108	156.177	**932.179**
Tables - Read Operations	100000000	0.4724	0.5185	0.4106	0.5090	0.5784	0.7916	13.758	14.067	11.671	0.6157	0.2612	**81.071**
Tables - Scan Operations	100000000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0000**
Tables - Write Operations	100000000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0002**
Virtual Machines Av2 Series - A2 v2 - EU West	100 Hours	0.0000	0.0000	0.0000	0.0000	18.247	71.995	74.400	74.388	67.188	74.383	69.395	**449.997**
Virtual Machines Av2 Series Windows - A2 v2 - EU West	100 Hours	143.953	135.892	0.6227	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**286.072**
Virtual Machines Av2 Series Windows - A4m v2 - EU West	100 Hours	71.982	74.398	74.392	71.983	74.288	32.757	0.0000	0.0000	0.0000	0.0000	0.0000	**399.800**
Virtual Machines BS Series Windows - B8ms - EU West	10 Hours	0.0000	0.0000	0.0000	0.0000	0.0000	392.400	743.950	743.900	671.900	743.950	693.933	**3.990.034**
Virtual Machines D/DS Series Windows - D2/DS2 - EU West	10 Hours	2.879.450	2.975.867	2.974.767	2.879.567	2.975.634	2.883.417	2.975.500	2.974.834	2.685.684	2.975.634	2.771.767	**31.952.120**
Virtual Machines Dv2/DSv2 Series Windows - D3 v2/DS3 v2 - EU West	10 Hours	719.850	743.983	743.967	719.983	742.917	719.784	743.850	743.950	671.850	743.900	692.917	**7.986.951**
Virtual Machines Dv3/DSv3 Series Windows - D2 v3/D2s v3 - EU West	10 Hours	0.0000	128.933	1.425.583	1.437.917	1.485.600	1.439.800	1.487.700	1.487.750	1.342.250	1.487.817	1.386.917	**13.110.268**

Figure 158 Example of data usage collected through the Azure platform.

Technical feasibility, implementation issues (M8.1 Cologne)

The implementation of an urban data Platform is technically possible in all cities Depending on its size and requirements, the city has to check whether it will set up the urban data platform by their self or whether it had external provider create and/or operate the platform according to its individual needs.
The UrbanPulse platform is running on the Microsoft Azure Cloud and is easy to scale to big data streams of any urban domain. As already stated, a replication to other European cities can easily be done. Privacy was not an issue in GrowSmarter because we integrated only user independent data, but is also well supported by the platform.

Economic feasibility (M8.1 Cologne)

Platform consumer perspective (Cities): the introduction of an urban data platform and the integration of the existing urban data can create synergies that can improve the quality of life in the city and minimise costs in various areas. The benefit of an urban data platform depends on the available data and the willingness of the users to implement it. This has to be assessed individually for each city.

Platform provider perspective (UI!): The cost structure is modelled in such a way, selling of UrbanPulse licenses is leading to profit. However, the profit is small because the cloud costs for fast and reliable cloud infrastructures are high. To support the replication and selling of licences, customers can also buy reseller licences and developer licences. A developer licence is more expensive, but the customers get full access to all the source code.

Social feasibility (M8.1 Cologne)

During the implementation of the measure revealed that the handling of data raises significant fears and concerns among citizens, city employees and industry partners. As a result, the release of data was refused and the use of the data platform was not possible in the desired form. Here it is necessary to develop concrete courses of action topics such as data ethics and data security in order to counter these fears.

Reccomendations to replicate the Measure (M8.1 Cologne)

- Create a handling strategy for urban data with citywide validity on the topics of data sovereignty, data security, data protection, data ethics, robustness, protection of critical infrastructure, reliability, latency, quality assurance, contribution to innovation, added value, sustainability, current case law, public relations work and participation
- follow a meet in the middle approach by combining top-down with bottom up. Top-down: Establish integrated infrastructure visions that can be realized by using the platform to be able to concentrate on the required and essential data collection as soon as possible (e.g. parking management, bike paths etc.) Bottom-up: Start in parallel with capturing the state of accessibility of urban data and start integration the data soon in order to do a quality of data monitoring.
- Identify all required actors (e.g. city departments owning important data you need) and conduct workshops with them, teaching the ideas and goals and developing data scenarios in cooperation.
- Identify the necessary data sources and actors you have to cooperate with.
- Affected departments and agencies and/ or companies need to be included in the process at an early stage. This allows for early understanding and acceptance of the solution, time for discussion and individual special requests as well as including expert knowledge.
- The acceptance of sharing data is a task not to be underestimated.
- Redefine the objective of the evaluation on the basis of previous experience, the results of the implementation phase and the given prerequisites in order to achieve the best possible results.
- If possible, delegate the performance of the qualitative evaluation of difficult topics to independent third parties in order to include any reservations or fronts that may arise during the implementation phase in the result.

Conclusions (M8.1 Cologne)

- The potential of urban dataplatforms was recognized. Obstacles are concerns about data provision (ethics, security, value, ...) and legal design.Here it is necessary to define at first how the city will handle data.
- Solutions that are too large reinforce the fears of data owners for their data. Small solutions with mutual benefits are easier to implemnent (e.g Cambio and KVB realized a common App within the GrowSmarter Framework). The experiences gained in the technical, legal and communicative fields can be used for further projects.
- Better start with a concrete small use case, easy to handle and roll out the success to create bigger use cases.
- City administrations are structured hierarchical and not all city departments with necessary data are involved in the projects. For this reason it is important to start as soon as possible to meet with the departments' employees to give an overview about the project and the kind of data needed.

- Industrial project partners are also often not familiar with integration and combining urban data to develop value added data services. Therefore it is important to conduct workshops in order to teach the basic ideas and to develop all win solutions.
- Pursue contractual regulations with partners early on to share data with the city's open data platform.
- Open urban data of cities are mostly provided by the best effort principle and therefore often suffer from quality of data, which makes it hard to realize reliable smart city solutions.
- Understand what suitable data service APIs need to be in place or have to be developed
- Verify the legal requirements, especially regarding data protection
- Workshops conducted by specialized and independent third parties are a good solution for evaluation.

Barcelona (M8.1)

Industry partner	Contact person	Validation partner
Barcelona Supercomputing Center	Maria-Cristina Marinescu, BSC	KTH-SEED

The aim of Measure 8.1 in Barcelona is to offer an open data city platform that can allow exploring , querying, and visualizing the data integrated from the Barcelona measures. This data may be accessed not only directly via a REST API, but also via a metalevel which exposes the way data is conceptually connected. The advantages of such an approach are evident both immediately - e.g. new data is much more easily integrated without moving it around, relationships between different data types are exposed-, and over time – e.g. maintaining and customizing is easy, the metalevel (i.e. model) may be used as is in other cities.

Figure 159 below illustrates the Barcelona Big Open Data Platform architecture. A user wanting to use SIF to access the city data will pass his token to the SIF Web GUI to ensure following the same data protection mechanism as the one implemented by the Integrated Data Platform (M8.4). Conceptually, SIF can access data that resides in more than one repository. The testing phase is currently being carried out for crossing data from the IDP with other RDF-like sources stored in a Triple Store – such as the increasingly large number of public data sources that cities publish as open data.

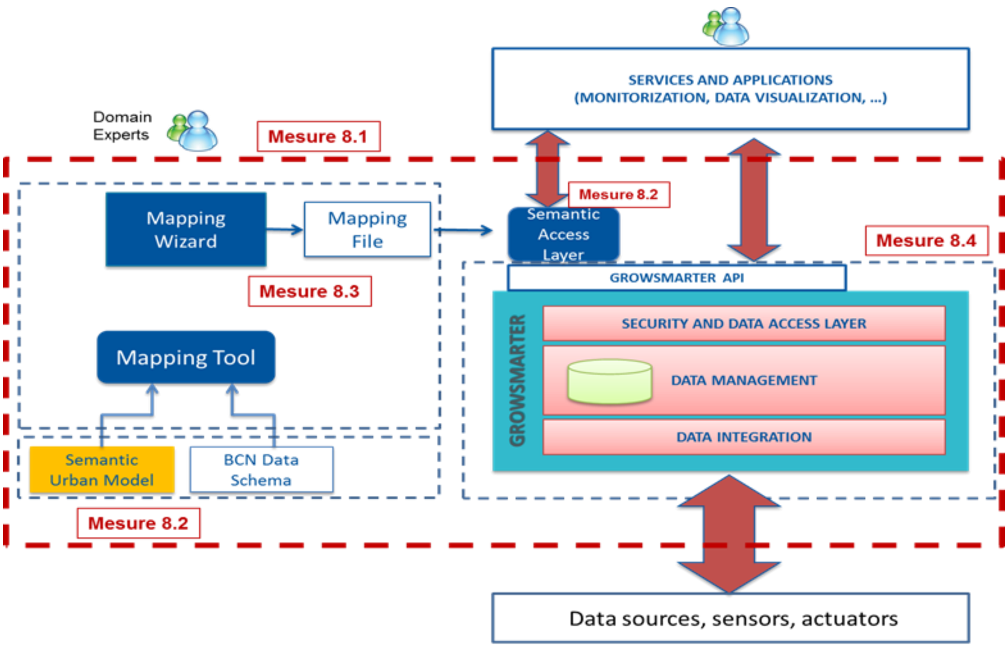

Figure 159: Scheme of SIF Web GUI (M8.1 Barcelona)

Measure 8.1 consists of the overall big data framework that includes the GrowSmarter integration platform (8.4) and the semantic model and tools for data access (8.2, 8.3). Users can access the city data in one of two manners: (1) Direct access via GrowSmarter platform, which allows querying the existing data independently using the filters offered by the API, within the concrete user permissions; and (2) Semantic access via the Semantic Integration Framework (SIF), that offers additional functionality which allows users to explore the ways existing data is connected (using natural language) and formulate complex queries involving the available data (using a visual and graphical interface).

The technical intentions of the Measure have feel fulfilled. Issues occurred with measures, services, and applictions that should use this platform, as some of the data and applications initially planned have not concretized.

This Measure does not directly offer data, but rather offers access to data provided by other measures, in the formats explained by measure 8.2 and 8.4.

Table 181 KPIs evaluated for M8.1 (Barcelona)

1. Data Velocity and Volume	1.8 GB.of data integrated in the GrowSmarter platform (M8.4) and access to a TDB of about 1.5GB.
2. Data Variety	The GrowSmarter platform integrates about 100 components and 700 sensors with different schemas, coming from different producers. These schemas are based on the templates that Cellnex proposed to all measure implementers in Barcelona, at the start of the project. These templates required information about the data that will be provided, and the use that the different partners will like to make of the integrated data via the GrowSmarter platform. In addition, a local TDB is available with data that may be crossed with the data from the GrowSmarter portal.
3. Data Energy Use	n/a
4. % Enabling Factor	All measures are enabled for evaluation given that they integrate the data via 8.4, and this data can be accessed. Since data is not updated in real-time, evaluation can occur at any time with the currently available data.
5. Monitoring Accessibility	Not known. A link to the Web tool is published. If a user formulates queries, these are translated to API calls and redirected to the 8.4 platform.
6. Number of enabled services	About 40.
7. Number of enabled innovations	n/a
8. Type and number of customers that have accessed services	13 GrowSmarter users.
9. Number of insights	n/a

The top level of the Open Data Paltform – i.e. the semantic exploration and query functionality - can be accessed at http://growsmarter.bsc.es/http://growsmarter.bsc.es:8080/UrbanPrototype/app/Home.

This is a Web interface that allows users to explore the Urban Model and access the interconnected data by formulating queries in an intuitive, graphical fashion. When a user formulates a query, this is translated to API calls and redirected to the 8.4 platform, or it is sent directly as a SPARQL query to the local TDB (Database).

The purpose of this plaform was to:

- simplify data integration, access, and maintenance
- enable users and application writers to develop services that are portable if they access the data via the Urban Model
- promote a reusable and customizable solution that can be easily adopted in other

cities, for instance in the Metropolitan area of Barcelona.

It is not trivial to evaluate quantitatively how well these goals were achieved. The table above shows some of the relevant numbers. Originally the data platform was intended to be a BIG Open Data Platform. Due to the problems that appear whenever a partner is supposed to share data, and the lack of a firm agreement about it at the very start of the project, the data that is integrated is not what one would necessarily call „big“ in the context of a city. To compensate this shortcoming thorough testing has been carried out together with complex queries against a dataset which includes a local TDB, not integrated via Measure 8.4.

The fact that the plaform does not integrate a very large amount of data is not a conceptual problem in itself, given that the purpose of the plaform was to offer a reusable, extensible manner to integrate the data; which ontologies do offer. In practical terms though, smaller quantities of data limits the usefulness of the approach and makes it harder to prove the necessity of a semantic approach with concrete complex examples. It is worth to mention that using this technology showed advantages over using fixed, brittle approches (such as the relational) that need re-architecting when schemas changes. This meant that it was possible to work incrementally without taking great risks of representing the data in the „wrong“ way.

One of the qualitative tests that were planned was to have at least one end-to-end application that uses this platform. The description of this application is in the following.

Use case of an urban-scale air quality model (M8.1 Barcelona)

This use case integrates activities of WP3 (Measures 5.2 / 8.1) and WP5 by deploying in the Barcelona site a monitoring and data collection infrastructure that provides data to an air quality nowcasting tool in urban environments. Figure 2 depicts the scheme used for the use case.

Real-time data from the monitoring nodes is used to initialize and validate an in-house CFD-based high-resolution (tens of meters, hourly output) urban-scale air quality model. This system has been developed at the Barcelona Supercomputing Center (BSC) in a joint collaboration with the Barcelona city council (IMI - Municipal Institute of Information) and the CAPTOR project, who provides the monitoring nodes that integrate the air quality and the wind sensors.

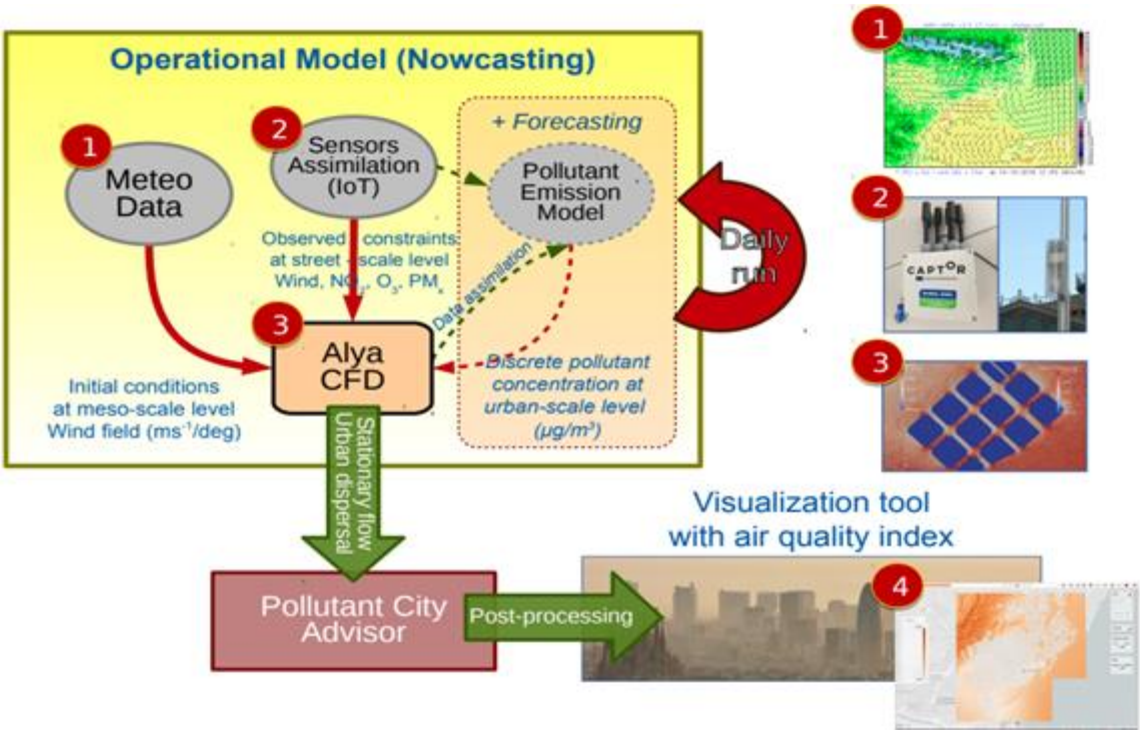

Figure 160 Scheme of the Urban-scale Air Quality Model infrastructure (Use Case)

By means of sensor nodes, the monitoring system provides wind fields (speed and direction) and air quality (NO2 and O3) parameters. These monitoring nodes have been installed in 4 Smart Towers in the 22@ district of Barcelona city. All the devices in this pack are designed to have a long-lasting life and high-endurance durability to reduce maintenance. This installation pack is composed of the components shown in Table 182.

Table 182 Components of the sensor node

Component	***Task***	***Provider***	***Picture***
Radome mount system	Provides camouflage with the environment, power supply, network connectivity and mounting space for sensors and control devices.	Barcelona city council	
Air-quality monitoring node	*Arduino* based node that controls and post-processes raw data coming from connected sensors. It includes low-cost Metal Oxide (MOx) sensors that measure O_3 and NO_2 pollutant concentrations ($\mu g/m^3$). Sensors are replicated to provide sensing data calibration.	CAPTOR project	
Wind sensor	*Davis* anemometer with a wind vane and a wind cup that provides wind velocity (m/s) and wind direction (degrees). This sensor is connected directly to the *Arduino* board.	BSC - CNS	

The data collected from sensors is sent to the Sentilo platform through the GrowSmarter API. This sensing data is being used by the air quality forecasting software (nowcasting) developed by BSC-CNS to predict wind fields and pollutant concentration in the streets with a 10 meter resolution in a hourly time basis (see Figure Figure 161). The output data obtained from this monitoring platform is accessible as open data through the GrowSmarter-Sentilo platform.

Table 183 presents the KPIs evaluated for the air quality use case.

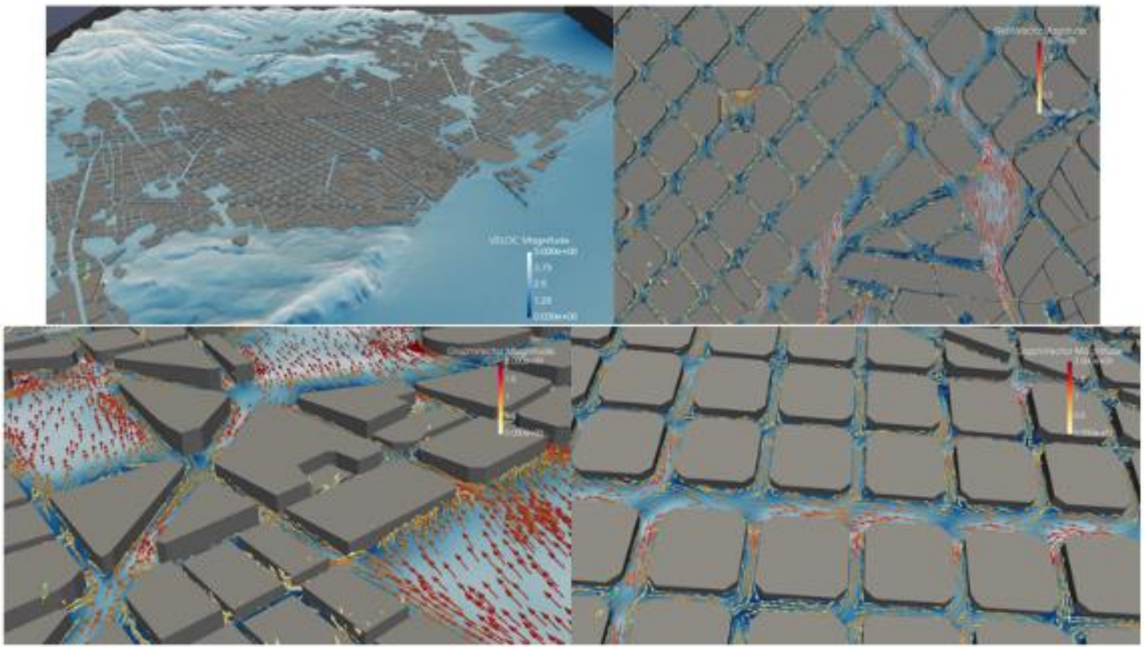

Figure 161 Snapshots of the urban area mesh (top-left), and closer views of vector wind results (top-right, bottom). Arrows represent the wind direction at the pedestrian level, and their color the wind velocity (ms^{-1}).

Table 183 KPIs evaluated for air quality model (Barcelona)

1. Big Data Velocity and Volume	The volume of data generated from the sensor network is not really big. Each monitoring node updates the information of 6 variables that are captured every 30 minutes, synchronizing them with the Sentilo platform. Every day, each node generates less than 10KB of data.
2. Big Data Variety	The monitoring node collects six different types of parameters: • Coordinates location (longitude/latitude) • UTC time • Temperature • Humidity • Pollutants: O_3 and NO_2 ($\mu g/m^3$) • Wind: velocity (m/s) and direction (degrees)
3. Monitoring Accessibility	Through Sentilo platform
4. Type and number of customers that have accessed services	GrowSmarter - Sentilo users.

The use case was implemented in terms of sensor node deployment and data acquisition in Sentilo infrastructure. Some CFD simulations using the gathered data from the sensor nodes were run, analyzed and studied internally at the BSC. However, the Air quality model for the urban area was not fully implemented in an operational way. The main reason was the computational cost of running these simulations, which are still quite demanding in a hourly basis scheme for a large urban area. It is known that the cost of running CFD-based simulations is not negligible, and requires high computational resources such as clusters or supercomputers, especially for large urban areas such as big cities. So, the technical and economical feasibility would depend in great extent on the city policy makers and their interest into using large computational resources.

On the other hand, air quality and associated impacts on public health are matters of growing concern in many urban areas. Public administration and health agencies are tasked to monitor the quality of air and, eventually, to make model forecasts to assist on the adoption of reacting measures and to warn on air pollution episodes affecting vulnerable groups of citizens. All the previous facts will facilitate the adoption and feasibility of these air quality models from the social point of view.

In order to replicate this measure in another urban area, three important steps have to be carried out in advance:

- First, a deployment of the monitoring network and data infrastructure must be performed. This step will include the installation of sensor nodes in specific urban points, and the retrieval and storage of certain metrics into a database system.

- Second, the generation of a fine grain geometrical mesh representing the urban area to be simulated in order to be used by the CFD model.

- Finally, before releasing an operational model for the new urban area, the Air quality model should be validated. This task includes the comparison of the model output against experimental results coming from auxiliary calibrated and installed sensors.

This use case is a clear example of synergies gained from integrating several GrowSmarter infrastructures. Moreover, it is also an example of collaboration among different entities and projects beyond the GrowSmarter project such as CAPTOR. The elaboration of this use case has entailed the following synergies:

- The Smart Towers provide support for the monitoring nodes and the communication infrastructure.

- The Sentilo platform provides the required data storage for the collected sensor metrics from the installed Smart Towers.

- The Air quality model is an example of a service developed on top of the GrowSmarter platform that provides air quality monitoring services.

Technical, economic and social feasibility (M8.1 Barcelona)

Using this integrated measure on part of application writers required them to use the exploration and query tool offered by 8.2 to formulate the queries and explore / visualize the data available. The exploration and query tool can technically work on top of any ontology (semantic model), and it targets domain users rather than IT people.

The approach based on semantic integration offers a dynamic, natural way to integrate data. Supported by the right tools, it can also offer a rich user experience. This technology makes it easier to maintain and evolve integrated heterogeneous dta sources, and makes applications built on top of the semantic layer portable between different cities, as they would refer to semantic concepts rather than directly to the actual data. This translates in an economically feasible solution.

Additionally, cities could easily measure where they stand in terms of the different quality of life, resilience, etc, indicators, and they could improve the ddecision making process based on such indicators – which can translate in better use of resources and better citizens services.

Data integration and access via an urban platform is at the beginning costly to implement, but quickly makes up for it if enough data is available that can be interconnected. Interconnection provides synergies and enables the development of analyses and applications that are otherwise not possible.

An important issue to try to solve from the beginning of the project is the availability of data. Data providers need to understand what will their data be used for, who and how will benefit from it, and what value they can get back as result of sharing data.

Upscaling and replicability of the Measure (M8.1 Barcelona)

This measure is based on measures 8.2 – 8.4. Measures 8.2 and 8.3 are easily replicable, given a data schema for the new city, the availability of a domain specialist that can guide the mapping process, and a new implementation of the Semantic Access Layer. See measure 8.4 for replicability of the city data portal.

Conclusions (M8.1 Barcelona)

Currently, each of the 3 lighthouse cities are developing their own Big Data Platform. This Measure could offer an alternative for an integrated solution for the whole GrowSmarter project at the semantic level, although several components would have to be in place to make this possible:

- Ensure that the ontology covers all concepts from all 3 cities
- Adapt the Semantic Access Layer to each city´s platform API
- Contribute to a standardization process based on the individual efforts already made by partners in the different citi

M8.2 – Semantic urban model

Introduction

The Measure involves building a model that reflects the structure, processes, and events specific to urban environments for the three vertical domains of interest: mobility, energy and integrated infrastructures. It may contain other more general concepts such as geopositioning, time, and KPIs, which are required by the modules computing e.g. carbon footprint and pollution. This data integration platform will provide semantic access for any service that wants to access Barcelona’s data (including the modeled domain-transversal data) - geo-positioned when available - either in raw form or in form of aggregated indicators.

The intentions of the Measure are:
1. To develop a digital semantic model representation of urban structure, processes, and events
2. To allow semantic access to data

Cologne (M8.2 and M8.3)

Industry partner	Contact person	Validation partner
UI	Stephan Borgert	KTH-SEED

Measure M8.2 and M8.3 are developed and driven in Barcelona. Originally it was planned that Cologne would support the evaluation by searching and discovering use cases in Cologne. As a result, there is at present and in the next few years no need for such solution in Cologne.

These measures are mainly developed and driven by Barcelona. Originally it was planned that Cologne supports the evaluation by searching and discovering use cases in Cologne.

A technical evaluation was always out of scope for Cologne. Barcelona sent query examples and questions to Cologne and Cologne answered them with the help of the participating project partners. In case of the Energy Ontology the project partners RheinEnergie AG and AGT were able to deliver input.

The objective was to find out which added value Barcelona's solution could have for Cologne and what actions would be necessary to apply Barcelona's solution on Cologne's UrbanPulse. As result, we discovered that there is no need for such solution in Cologne presently and in the near future. The main reason is, that only a small number of different real time data sources are available in Cologne right now and the advantages of the semantic layer cannot be used at present. On the other hand semantic urban models could also be useful in cases they are specified on another scope. Especially a taxonomy or categorization for urban data messages could be useful for our purposes as well as to support the integration of data sources into the UrbanPulse and to realise the connections among the different analytics and recommendation services of the UrbanPulse.

Hence, the UI! developed an integration concept and an ontology to support this. The data of the urban data sources must be made available in such a way that they can be integrated as easily as possible in the modelling of processes. In addition, the modelling language must be intuitive and understandable. Therefore Subject-oriented Business Process Management (S-BPM) was introduced. Data sources and applications were classified within domains and use cases have been chosen to apply the solution. For the management of heterogeneous data sources, Ontologies were chosen and for the description of processes S-BPM. A bridge between these two concepts was proposed with the OS-BPMO, which allows the description of things in other ontologies with the vocabulary of S-BPM and support instance mapping. The main focus was on the description of the messages exchanged between the subjects. It then described the evolution of the connector application and the components that extend the UrbanPulse platform.

The solution concept is documented in a report available online:
http://ui.city/images/download/2019/D_M82-M83_final.pdf

Barcelona

Industry partner	Contact person	Validation partner
Barcelona Supercomputing Center	Maria-Cristina Marinescu, BSC	KTH-SEED

The Urban Model was defined based on lengthy discussions with partners from WP2 (IREC) and WP4 (CENIT). It contains a generic high-level city model, to which the verticals of energy, mobility, and contamination monitoring, as well as relationships between concepts in the different domains have been added. The upper-level ontology is the ISMP city ontology by IBM and supports the integration of data from the different vertical domains by providing the semantic connections between these domains. Quality indicators are also represented as part of the ontology, and their calculation could be defined by domain specialists to assess and compare the various aspects of the urban fabric.

A list of competence queries has been gathered, which reflects the different ways users may query the ontology. The queries are those which will be returning data from the Barcelona IDP, but also queries that would be useful to ask assuming more complete and detailed data may become available. Discussions were held with Cologne to follow this query gathering process at their site in the future; a round checking out the energy queries from IREC with RheinEnergie has already occurred. This process is intended to be a test for the completeness and generality of the urban model. Due to different time priorities Cologne has not implemented the semantic solution.

This is an enabling functionality for any Measure and application that wants to use the semantic tool to easily cross data from different domains without having to know the underlying structure and port applications between cities without modifications (in case the relevant data does exist). Given the nature of this Measure, the performance baselines are covered in the enabled Grow Smarter Measures.

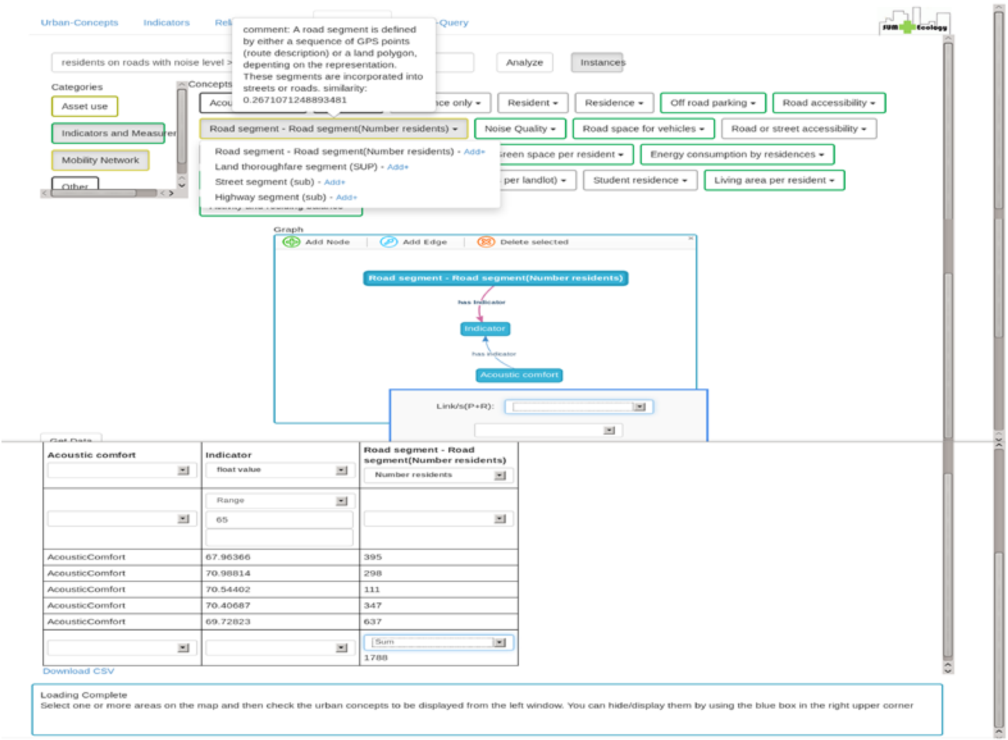

Figure 162 functionality of an exploration and query tool (M8.2 Barcelona)

The figure above shows the functionality of an exploration and query tool, which allows users see how concepts and data are connected and consult the data in a graphical fashion. This tool is based on an existing Web tool developed by BSC. It illustrates concept search, graphical query building, and returning the results. The query graph is built by adding concepts (entities

= nodes and relations = edges) in one of two ways: exploration and extension, or by using the tool to find paths (of several jumps) between existing nodes. All GrowSmarter measures – and other users - can explore and query the data via Web at http://growsmarter.bsc.es:8080/UrbanPrototype/app/Home.

The concrete evaluation procedure for the Measure consists of the following:

1) A final report describing how much of the urban environment has been modeled: BSC will be completing this report iover the next month. The three domains proposed are covered extensively by the model, although a lot of what would be useful data is not available, and therefore could not be integrated. Based on the availability of the applications that will access the data and the competence queries, we may be able to demonstrate with more examples the advantages of the semantic approach.

2) Big Data Integration: number of distinct Measures /applications using semantic access to exploit integrated data (without having to know how to integrate the isolated results otherwise returned by the API). Currently the Air Quality Simulator will use the SIF.

3) How many smart city services have been enabled due to the implementation of this Measure? Currently none; there isn´t a lot of data available yet to cross.

Worth mentioning, the Urban Model will become part of the Barcelona CityOS, the centralized platform that will enable anyone – citizens, administrations, and businesses – to access city data in an integrated fashion.

Table 184 KPIs evaluated for M8.2 (Barcelona)

1. Data Variety	-
2. Grow smarter measures enabled for monitoring %	All measures can explore and query the data via the semantic layer: http://redrock.bsc.es:8080/UrbanPrototype/app/master.jsp
3. Number of enabled services	We are in the process of migrating the tool to a more performant server, after which we will publish the new address on the project site.

The following gives a flavour of the types of queries that are facilitated by the semantic platform.

1) Report the number of parking spots in the metropolitan area of Barcelona. This is apparently a straighforward query, but only in the city of Barcelona it involves al least 5 types of public sources, 4 private sources, and various other types of individual owners and companies. These sources are independent and therefore updates don´t propagate. The extension of the use case from the city of Barcelona to the metropolitan area, involves not only the databases are different, but the types of parking places are classified differently and are associated possibly different rules.

2) Compute the ratio of hourly energy consumed by appliances in a building that comes from panels that are installed in these buildings. This is a rather complex query involving concepts from both energy and city structure domains. It involves 8 entities and 9 relationships, and it isn´t clear from the beginning that all of them need to be involved to correctly constrain (filter) the result. They are identified either by stepwise

expansion of concept nodes, or by inquiring for paths connecting two given concepts – which may introduce connection nodes

Technical feasibility (M8.2 Barcelona)

The Urban Model was implemented in a top-down fashion with a lot of support from domain specialists, particularly IREC and CENIT, and it may be re-used by any other city as is. It may also be specialized, although a domain specialist should help extending it with those concepts that may not have been modeled.

In terms of actual data integration through the model, a city re-using this measure should re-implement the Semantic Access Layer to adapt the query translation to their own city platform API.

If queries are to be targeted not only to the city platform, but also to other data in local TDBs, a correspondence table must be constructed that allows to match the concepts in the TDB / model to the corresponding data structures (e.g. column names) refered to in the API calls to the platform. This is necessary to be able to join the results of the partial queries (to platform and TDB) and construct the final semantic query result.

Assuming there are only 5 public sources, 4 private sources, and individual owners in form of companies, a public servant wants to compute the number of parking spots per type in the city of Barcelona.

The first step of this operation involves 9 queries to known databases. Usually there is no direct access to the data, and access is provided via an API. The step also involves getting a list of the private owners and contacting them to get the numbers from each of them.

As a second step, he needs to combine the results. This may involve a simple addition of the number of parking spots per type from the 9 sources + private owners, assuming the types cover the same set of possible values. This isn´t true in all databases, and especially so between different cities - for instance, of the same metropolitan area. If this is the case, the public servant needs to figure out how to report the possibly overlapping types.

If a second summary is needed that returns parking spots corresponding to another concept (e.g. Street, Neighbourhood, City Block, etc), the public servant would likely be in one of the following cases: (1) The APIs may provide this information directly for each of the separate databases. This is very unlikely given that API are generally simple and can´t ever cover the whole variety of possible user queries; (2) The APIs may not directly provide this information; multiple API calls may be necessary, togetehr with joining this information based on given keys that need to be published _somewhere_; or () direct access to the databases may be provided, which allows the queries to be formulated directly, with previous knowledge of what are the table keys to use in the joining operations.

In the case that data is integrated via the semantic model, data sources are already mapped to it and updates to any of them propagate when a query is launched. The only operation the public servant needs to perform is to create the semantic query using the exploration and query tool we provide in 8.2. While it may take a while to get used to it, the model will not change any further although the data sources may do so underneath. The query is launched and returns a result that already combines the data for all the entities requested - in this case nr of parking spots of each type, that correspond to whichever entity the semantic query specified (Roads, City Block, or any other combination of semantic concepts).

Economic feasibility (M8.2 Barcelona)

Once built, the urban model may be used by any city for integrating data in the represented domains. The Semantic Access Layer must though be re-implemented to adapt it to the existing city portal. Integrated data access is absolutely necessary for administrations or business that need to cross information between different vertical domains to get more precise results, or a better understanding of the urban reality.

A solution based on a semantic model, such as this measure advances, makes sense when integrating data from many heterogeneous sources. Integration via the model is in fact the only scalable approach if data changes often, access is not allowed to the actual data schema, data must remain where it is, or when it is sparse or incomplete.If this is not the case, and instead data changes very little or pertains to a single (or very few) stakeholders, than the effort involved in this approach may not be justified.

The features of our model and tool make our solution highly reusable, and therefore economically feasible. The social implications are immediate, as this model may be used to access city data across vertical domains and thus improve the understanding of city policy makers and the decision making processes.

Upscaling and replicability of the Measure (M8.2 Barcelona)

Replication involves the implementation of a new Semantic Access Layer, and possibly the extension of the model with new (unrepresented) concepts.

Conclusions (M8.2 Barcelona)

Recommendations for cities that want to take advantage of this approach:

- Cities can use the technology directly, although they need to re-implement the semantic access layer based on the way the data in their cities is accessed, and they need to use the mapping tool (8.3) to populate the model with data by choosing from the specific city recommended mappings.
- Make sure you have domain specialists to extend or customize the existing Urban Model with other domains or aspects typical of their environment.
- Make sure you will have enough data.

Identify partners that can commit to develop applications on top of your technology..

M8.3 – Semi automatic instance mapping

Barcelona

Industry partner	**Contact person**	**Validation partner**
Barcelona Supercomputing Center	Maria-Cristina Marinescu, BSC	KTH-SEED

The semantic urban model (M8.2) needs to be populated with actual data to take full advantage of the power of the approach. This step consists in the semantic mapping of the data to the concepts and is usually time consuming. Semi-automating this process is possible. New technologies can be enabled to semi-automatically map urban data to specific city. This problem is highly relevant when other want to populate the city model with their data. This requires finding correspondences between concepts and relationships embedded in the data, on one hand, and explicit in the ontology, on the other.

The intention of the Measure is to simplify (i.e. semi-automate) the process of introducing new and previously unmapped data.

A collaborative web interface was developed for instance mapping, based on LogMap (University of Oxford). The image in the figure below shows how, when selecting an ontology and a data schema, the web tool maps and visualizes the recommended mappings, together with those of other users. The idea is that many users can contribute to the validation of the desired mappings; one can simply use those mappings validated by another user, as well as compare his own choices with others.

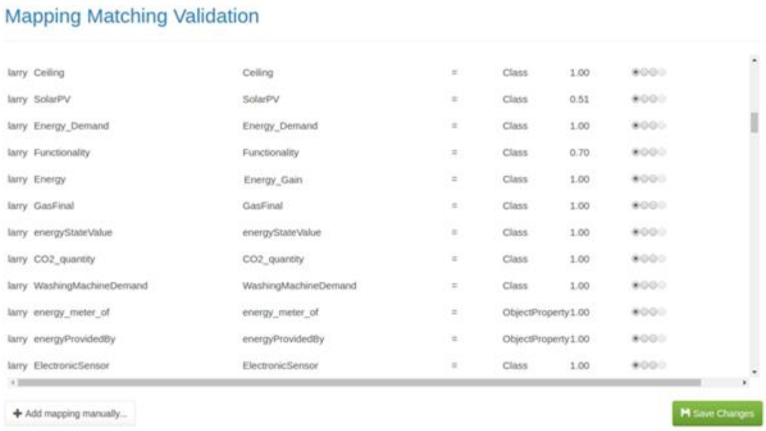

Figure 163 Example of results obtained through the instance mapping tool.

An existing visualization tool (VOWL) was integrated to support the user in the process of choosing and editing of the correct mappings from the ones suggested by the tool. Figure 164 illustrates the entities and relationships that hold in the GrowSmarter data schema (which are accessible through the GrowSmarter API). This visualization makes it easier to quickly explore the recommended mappings and take into consideration the connections between data to decide on the best mapping.

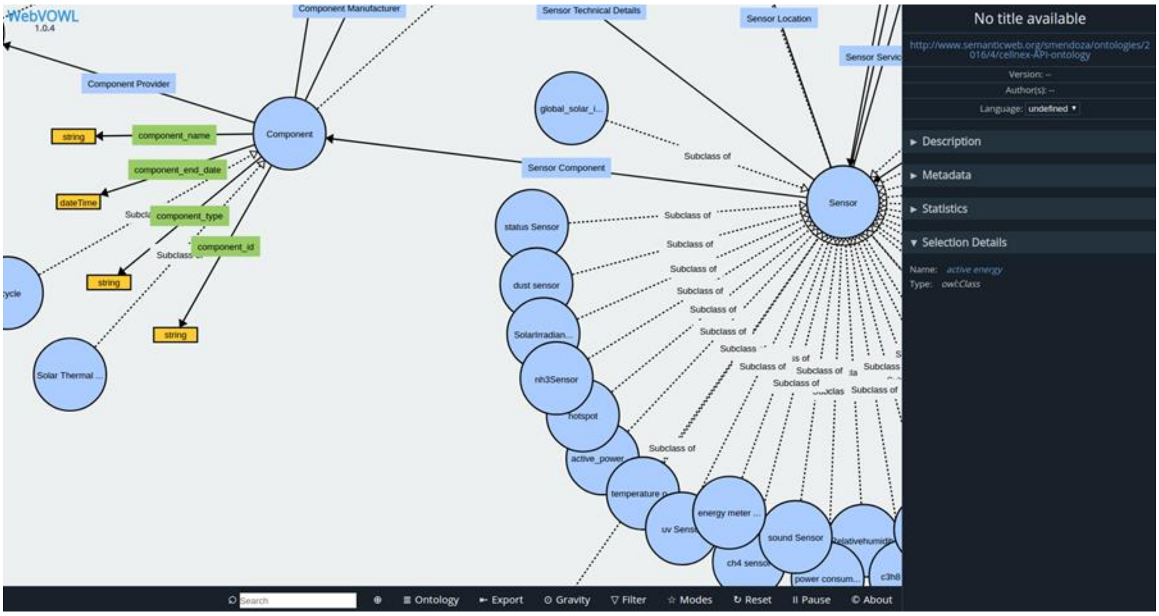

Figure 164 Example of data schema visualized through the adopted visualization tool (VOWL).

Measure 8.3 is an enabling functionality for Measure 8.2. Given the nature of this Measure, the performance baselines are covered in the enabled Grow Smarter Measures. One evaluation criteria could be how easy it is to decide on the actual mappings based on the recommended ones, although this is highly subjective.

One concrete issue that requires further study is that the current city schema is small and therefore the mapping tool finds few mappings to recommend. The finalized mapping tool will be tested and validated during the evaluation period to see how well the tool finds useful mappings with the existing data and to gather feedback from users.

Technical feasibility (M8.3 Barcelona)

Semi-automated mapping of data to model is not an easy task. Usually this is based on the existence of good labels and other annotations, and much less on other criteria – such as subgraph mapping. We have built our tool around the existing LogMap tool from the University of Oxford. To do this we had to provide not only the ontology, but also an .owl description of the data schema used by Measure 8.4. This translation was done manually, which allowed a good annotation of the schema. Good annotations are not a given and, as applications may want to integrate additional data from open (linked) sources, mapping may become more difficult.

Economic feasibility (M8.3 Barcelona)

The tool can find mappings between data and the urban model and it must involve domain experts, who need to evaluate the recommended mappings and choose the correct ones. If a schema does not exist for the data that needs to be mapped, this schema needs to be created. In the tool proposed, this schema must be in owl/rdf format.This process must be followed whenever new data types / sources become available, or when migrating the solution to a different city.

Mapping cannot be fully automated since it must incorporate human understanding about what a data set or data schema represents, beyond how it is stored or the names it uses. Using a mapping tool to recommend mappings - coupled with a visualizer – makes the process much faster and accurate. The fact that our tool is collaborative also helps due to being able to split the mapping between different experts, and benefitting from more than one single person´s experience.

A standard intervention would apply ETL technologies to the new data. Changes in data formats or schemas involve re-applying ETL to all the affected data. Additionally, applications built on top of the data may need to be updated as well to the new queries over the new schemas. On the other hand, the current measure (8.3) involved an initial effort not needed in the ETL approach.

Social feasibility (M8.3 Barcelona)

This measure simplifies the life of those actors that need to map the data and makes applications developed on top of it portable.

Upscaling and replicability of the Measure (M8.3 Barcelona)

The replicability of the Measure is possible under some conditions:

- the existence, or creation, of the city data schema (in owl/rdf)
- the availability of a domain specialist that can evaluate and choose between the recommended mappings

Conclusions (M8.3 Barcelona)

Measure 8.3 makes it possible to map, in a semi-automatic manner, actual city data to the Urban Model. As a result of this mapping, data from different vertical domains or sources can be more easily interconnected, without regard to their data schema (and leaving it where it is, if directly accessed rather than via the city portal). Changes in data schemas are naturally captured by this model. Every time new data types appear (not data in an already mapped source, but rather new sources) a domain expert has to manually select the correct mapping out of those suggested by the tool. If another city decides to reuse our solution, the Urban Model could be reused as such (with possible add-ons for concepts that were not present in Barcelona), but the actual data must be mapped to the model using our 8.3 collaborative mapper.

Cologne (M8.3)

Industry partner	Contact person	Validation partner
UI	Stephan Borgert	KTH-SEED

For Cologne, this Measure has been evaluated together with M8.2.

M8.4 – Integration of sensor data in a uniform standard-driven data format

Introduction

The Measure provides a platform for integration of sensor data coming from different producers (e.g. deployed sensors, data from proprietary platforms, open data repositories, etc.) and using different formats based on a uniform, standard-driven format. This platform provides a set of APIs to access the sensor data from the open linked city model, to manage the integrated data, either raw data or aggregated data. The Measure includes the development of a Web portal that can access and visualize raw and aggregated data from sensor infrastructures managed by the city of Barcelona and other trusted third parties, partners in this project.

The intentions of the Measure are to:
1. Facilitate new sensor deployment
2. Facilitate new sensor analytics/visualization

Barcelona

Industry partner	Contact person	Validation partner
Cellnex	Carmen Vicente, Cellnex	KTH-SEED

This Measure has implemented a horizontal platform to manage and share data from different Smart Measures that have been deployed in the City of Barcelona for the GrowSmarter project. The platform collects and standardizes different types of data with the aim to be offered in a common marketplace where the business applications can exploit the integrated data to provide added value.
Therefore, its main capabilities are focused on both, the urban data gathering, and the distribution of data services that allows third parties to exploit and create added value over the integrated data sets.

The solution implemented also allows to process and share in real-time large amounts of data to support decision making applications. In spite the wide range of heterogeneous urban data resources available in the city, the solution grants interoperability and a standard management.

The solution offers also a common marketplace of integrated data services, where the business applications, such us Business Intelligence algorithms, Monitoring Applications, City Dashboards, Semantic Layer, etc, can make use of the GrowSmarter integrated data. Through this marketplace of data services, M8.4 promotes the co-creation of new urban services and applications for the city and its inhabitants.

The platform (see Figure 165) provides a set of open secured standardized Application Programming Interfaces (APIs) to promote interoperability with the Business Applications that monitor and manage the smart city. The API offers methods for real-time queries, both for the current and the historical integrated data. Furthermore, the GrowSmarter API supports subscription methods that allows the business applications to get automatically updated data without using polling consultant algorithms.

Implementation of this Measure started in Dec 2015 and ended in Dec 2017. The main activities that have been carried out in this period have been:

- Meetings with stakeholders (data providers and data consumers)
- Definition of functional requirements and the common data model of the Integrated Data Platform.
- Design and definition of the computational architecture.
- Deployment of functional components and APIs.
- Platform set-up
- Data sources collection and integration
- Deployment of demonstration web applications for users

Although the implementation phase has ended, Retevision will still be working on it due the big dependence on the availability to integrate data from other Measures. Thus, Retevision will integrate data from new sources and provide also new features to the web portal.

Figure 165 . Measure M8.4 into the Big Open Data Platform (Barcelona site)

Since this is a technological enabling Measure, most of the evaluated parameters are related to Measure performance features of the platform, including:

- Heterogeneous data sources
- Integrated data
- Users
- Applications and API invocations

Evaluated data are classified in three main categories:

- *Inventory*: Monitors relevant items that have to be managed by the platform, such as number of users, data sources, integrated data elements and applications, etc.
    - Number of users and “type of organization” (Private Sector, Public Sector,

Research, University, and Other)
  - Number of “components” (a component represents a container of one or more sensors)
  - Number of “sensors” (a sensor represents an element that can provide digital Measures)
  - Number of “observations” (an observation represents a type of digital Measure provided by sensors)
  - Number of “data updates” (every time the sensor provides a new measured value, a data update is produced)
  - Number of “applications” (each application represents an external source that interacts with the GrowSmarter API)
  - Number of “API TIERS” (an API TIER represents the scope level among all the GrowSmarter integrated data. Although there is a global scope that represents all the GrowSmarter universe, the M8.4 platform provides also segmented scopes that are related to different data sets)
- *Integrated data*: Monitors the volume of integrated data stored into the platform.
- *API invocations*: Monitors the number of interactions between applications and data services provided by the GrowSmarter API.

M8.4 KPIs are measured from several specific operative processes of the Integrated Data platform. The platform operator has collected them manually from the involved modules. As a result, M8.4 provides monthly data. M8.4 monitored raw data provides monthly differential values. These values have been processed to show aggregated data, providing the overall screenshot of the platform at each month of the project.

From the technical point of view, Measure M8.4 has followed and improved the evaluation strategy, providing more quantifiable parameters than expected. While the original plan just monitors the number of incoming data sources and the number of users per affiliation, current parameters monitors also the number of updates, the volume of stored integrated data, and the API invocations. With the aim to provide an overall screenshot of the platform M8.4, the raw data have been processed to get aggregated data. M8.4 platform has a total of 12 users, and most of them are from the “Private Sector”.

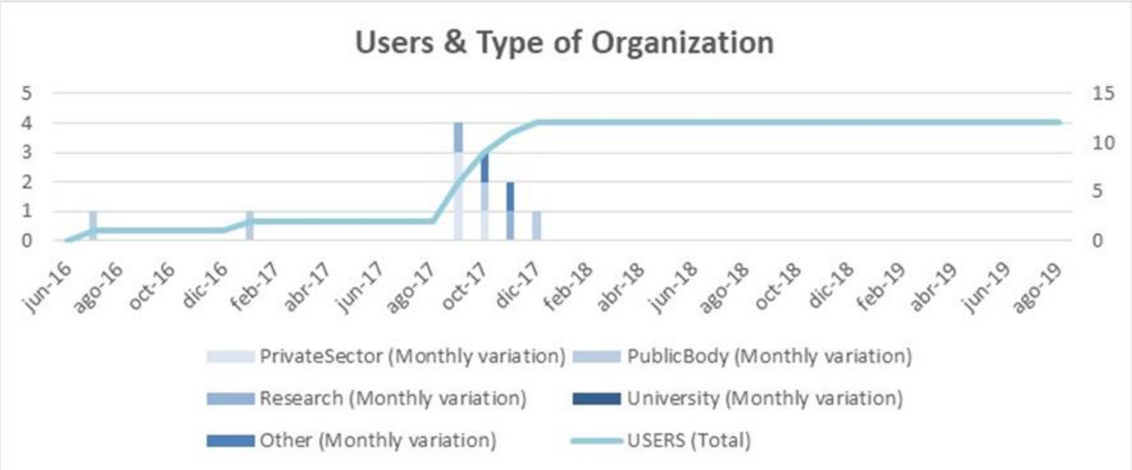

Figure 166: M8.4 - Users evolution

M8.4 platform is processing almost 120 components, 875 sensors and 6.500 data channels (observations).

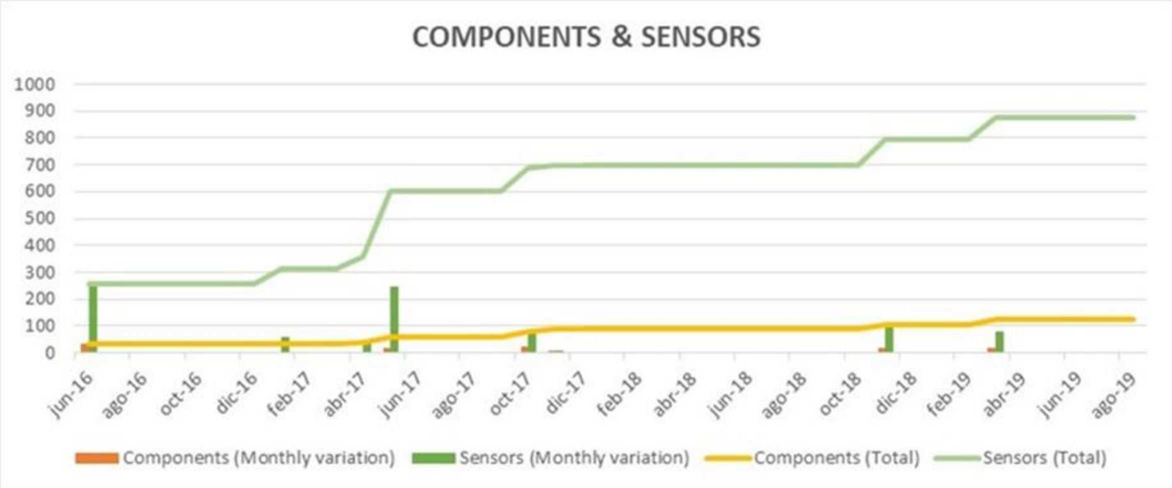

Figure 167: M8.4 – Components and Sensors evolution

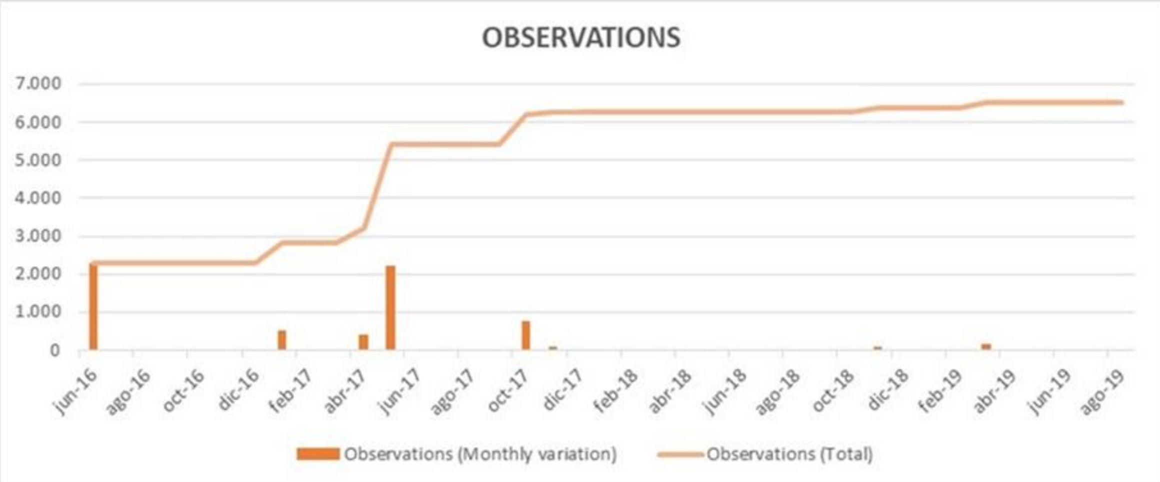

Figure 168: M8.4 – Observations evolution

M8.4 platform is processing an average of 880.000 data updates per month. Thus, the platform has managed nearly 4,8 GB of integrated data, as a total volume of Integrated Data from the beginning of the project.

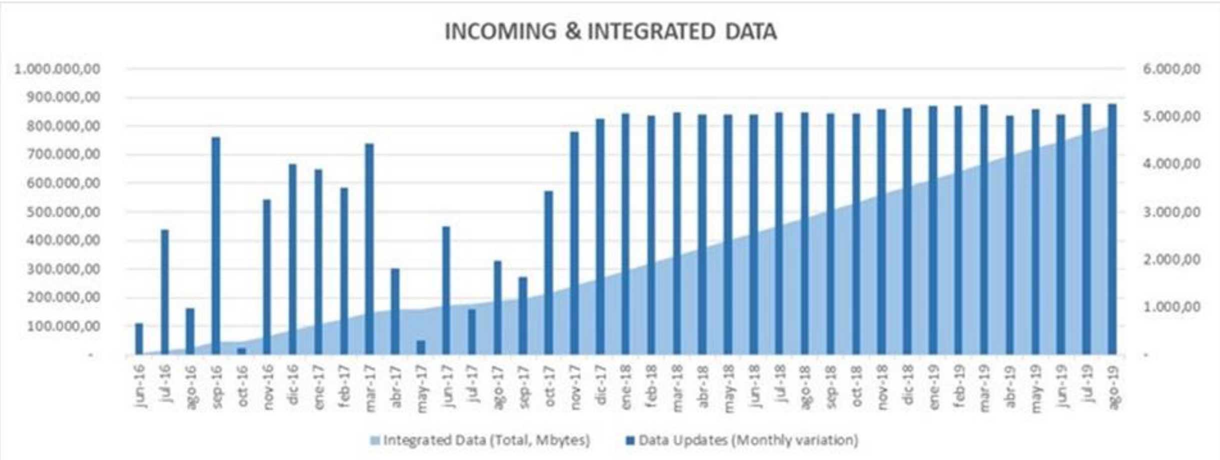

Figure 169: M8.4 – Data updates and Volume of Integrated Data evolution

M8.4 platform provides a total of 8 API TIERS. One of them, the TIER GrowSmarter, includes all the Integrated Data currently available in the city of Barcelona, whereas the other seven TIERs are a subset of the Barcelona GrowSmarter Integrated Data universe:

- TIER FreightDistributionSystem, provides data related with sensors of M9.2
- TIER BigBlue, provides data related with BigBlue sensors (M1.1)
- TIER SmartTaxi, provides data related with SmartTaxi measures (M12.6)
- TIER MSC, provides data related with M5.3
- TIER EnergyMeterGNF provides data related with NATURGY measures (M1.0, M1.1, M3.1, M4.2 and M6.2)
- TIER Library Les Corts, provides data related to the Smart Building that host the Library Les Corts (M1.0 and M1.1)
- TIER Building Monitoring, is a set of TIERS to provide data from several measures that are related with smart refurbishment of buildings in Barcelona. It is composed by TIER BigBlue, TIER EnergyMeterGNF and TIER Library Les Corts.

M8.4 platform has nearly 45 subscribed applications, most of them linked to the GrowSmarter TIER.

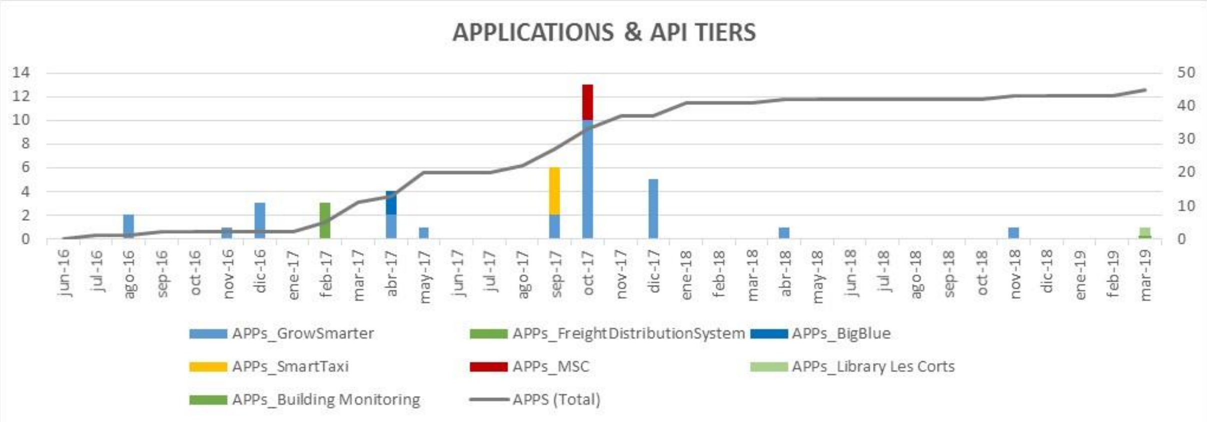

Figure 170: M8.4 – Applications per API TIER evolution

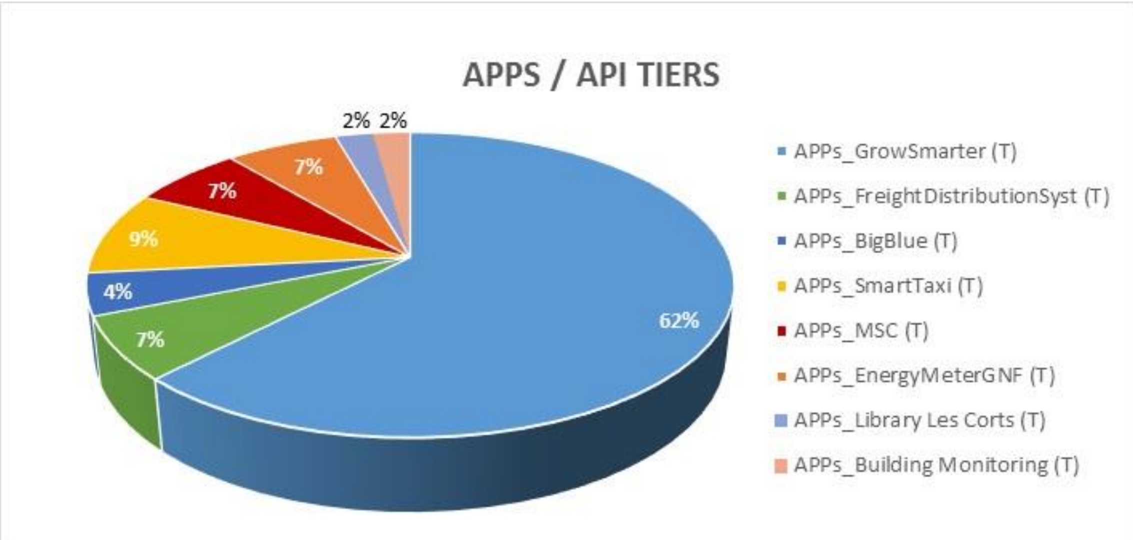

Figure 171: M8.4 – Applications per API TIER (Jan 2018)

Evaluated data shows API activity from the second half of 2016. From that time to the end of 2017, API monthly activity experiences a huge rise, following the evolution of the Growsmarter measures that have been deployed in the city of Barcelona. In fact, this time corresponds with the implementation phase for most of the measures.

Since January of 2018, API activity shows a more stable behaviour.

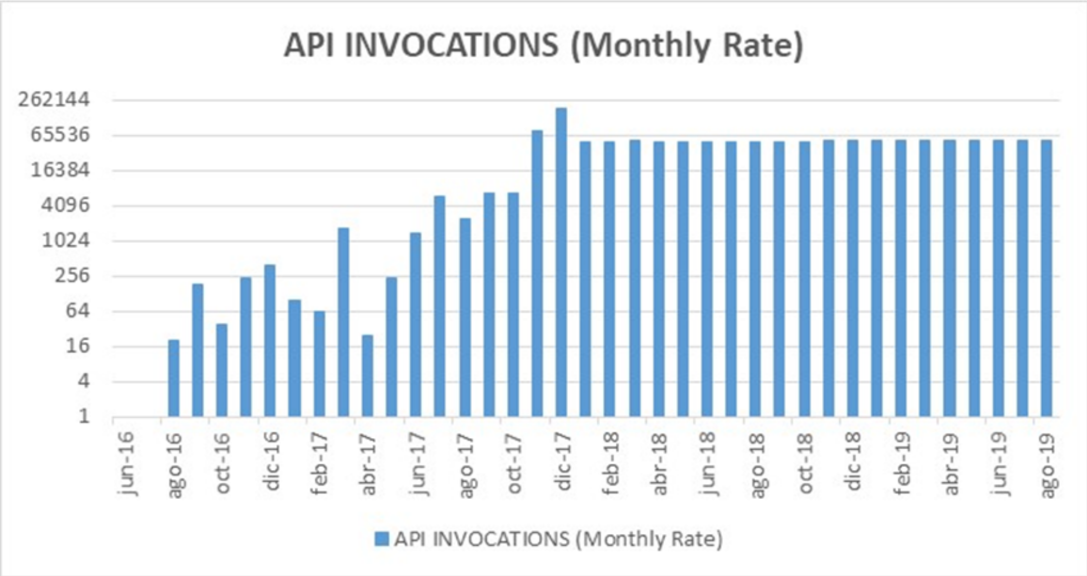

Figure 172: M8.4 – API Invocations evolution (logarithmic scale)

Technical feasibility (M8.4 Barcelona)

The horizontal concept of the platform allows to work across several vertical services. Besides, its modular concept allows to adapt its capabilities to any environment, helping to make feasible the implementation of the measure.

Economic feasibility (M8.4 Barcelona)

The value proposition has three main stakeholders: the platform Operator, data "Providers", and data "Consumers".
The solution has been devised as a Platform as a Service (PaaS), that proposes a modular cost system to be flexible with different needs and requirements.

- Freemium fee: Access to the platform and use of basic capabilities
- Premium fee: Use of extra-capabilities, O&M services
- Integration fee: Integration of new data sets into the platform

Social feasibility (M8.4 Barcelona)

The GrowSmarter Integrated Data Platform has been devised as a modular horizontal system able to work across different smart city actions. Its main value proposition is the provision of an interoperable marketplace of data services for business applications, which can take advantage of real time data correlation, data mining, data analysis, etc to support decision making processes.

The solution avoid vertical silos, whereas that supports interoperability across different technologies and legacy systems, together the provision of real-time information to support vertical services and decision making processes. Therefore, the solution improves the efficiency of business applications, that can better monitor and predict the behaviour of the city. In addition, city managers are able to run best polices that improve the quality of life in the city.

The marketplace of data services also drives innovation and the co-creation of new added value applications, boosting a sustainable economic development of the city.

Upscaling and replicability of the Measure (M8.4 Barcelona)

The solution is easily scalable and replicable to any other city. The Integrated Data has been devised as a horizontal platform composed by several functional modules, which are based on standards and open source components. Although it has been planned to support the GrowSmarter measures in the City of Barcelona, the solution is independent of specific data- sets and application domains.

The horizontal concept allows the platform to work across vertical services, whereas the modular concept allows the platform to provide new functionalities or to process new types of data sets, without disturbing the previous features.

Conclusions (M8.4 Barcelona)

From the technical point of view, M8.4 has followed and improved the evaluation strategy, providing more quantifiable parameters than expected. While the original plan just monitors the number of incoming data sources and the number of users per affiliation, current parameters monitors also the number of updates, the volume of stored integrated data, and the API invocations.

In Barcelona, measure 8.4 has demonstrate the benefits of horizontal platforms. They can work across different smart city frameworks and offer an interoperable marketplace of data services to allow third parties to exploit and to create added value over the integrated data sets, improving business applications and decision making processes. As a result, the marketplace of integrated data services promotes co-creation of new urban services and applications to improve the city and the quality of life of its inhabitants.

M8.5 – Sustainable Connected lighting to enhance Safety and Mobility

Introduction

The Measure aims to develop an API (Application Programming Interface) for smart lighting systems implemented by Measure M5.2 able to communicate the lighting management system with other applications (e.g. traffic management, weather systems) and software platforms in order to exchange data between systems. The solution will demonstrate a lighting technology agnostic system which means all kinds of luminaires (also third-party products and new future innovative light sources) can be connected to the management system by developing their own APIs.

The intention of the Measure is to facilitate integration of lighting management systems with other city services and infrastructures.

Barcelona

Industry partner	Contact person	Validation partner
Cellnex	Carmen Vicente, Cellnex	KTH-SEED

The lighting infrastructure will be managed by a system that will seamlessly connect to the GrowSmarter Platform or other SW platforms available in other cities using an API based on open standards. This means that lighting will be influenced not just by the decisions of the lighting system, but also by other systems managing other assets. The proposal seeks to motivate also a change of mind, realizing what the intelligent public lighting can do for cities when they become more interactive and create the base for novel services within the city.

The measure is related to support an API solution to manage lighting systems involved in the SmartTowers solution (Measure 5.2 of Barcelona city). It was supposed to monitor the number of integrated lighting systems, or the number of SmartLighting APIs.

However, although it has not been possible to achieve an agreement with the managers of the lighting systems of the Barcelona Municipality, the measure was adapted to produce a SmartLighting API to interact with the two SmartTowers that were deployed in Cellnex premises.

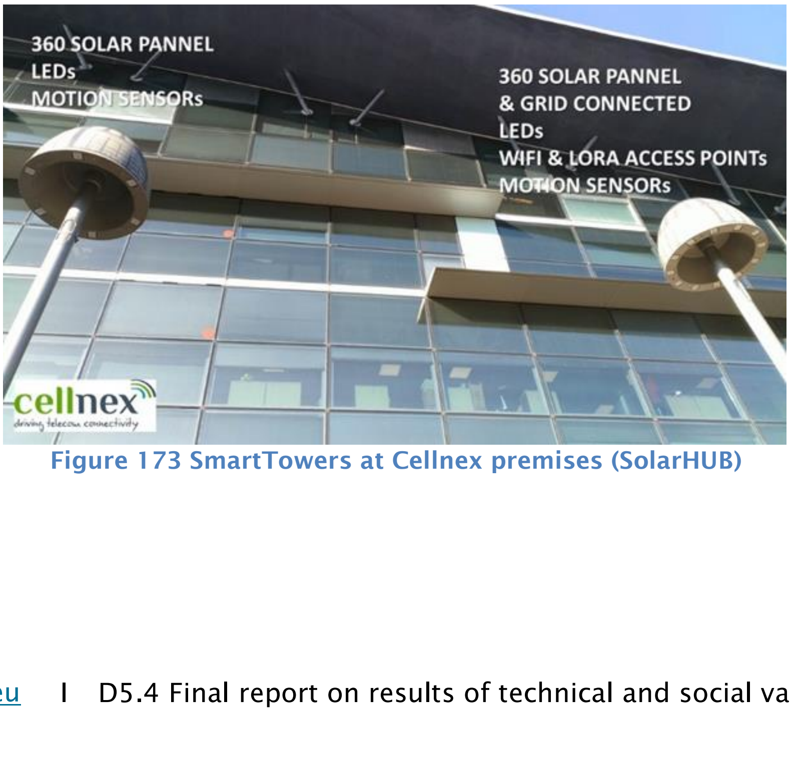

Figure 173 SmartTowers at Cellnex premises (SolarHUB)

Therefore, an agreement with the SolarHUB soltion provider has made it possible to develop a customized module that provides remote real-time management of the system by using the Sentilo platform.

Sentilo is an open source sensor and actuator platform which main goal is to allow an easy and interoperable management of different urban resources like sensors and actuators. Currently, there are several public administrations that has adopt and use the Sentilo solution to manage their urban devices.

Technical feasibility and implementation issues (M8.5 Barcelona)

To assure a feasible implementation, it is mandatory to involve street lighting service stakeholders (both operators, solution providers and the Municipality) in early stages of the project. Thus, they could define a smart solution that agrees with all of them.

It is also recommended to deploy city street lighting systems that allows remote management solutions through web services or APIs, in order to facilitate interoperability with other urban service management platforms.

Economic feasibility (M8.5 Barcelona)

Currently, interoperable cross-horizontal solutions are becoming more popular to improve decision-making processes. These type of solutions allow cross-sharing information to improve both, the productivity and the efficiency of the city, promoting also new business models through a shared marketplace of data services. The SmartLighting API compatible with Sentilo platforms is a clear example of a shared marketplace for new urban services.

Social feasibility (M8.5 Barcelona)

This kind of solutions, which are focused on improving the efficiency of the city, have also a high impact over the citizens, improving their quality of life.

Upscaling and replicability of the Measure (M8.5 Barcelona)

Despite the difficulty to make an agreement with the Barcelona City Council, the Smart Lighting API measure has been implemented for the two Solar Hubs deployed in Cellnex premises by the Smart Towers measure 5.2. Thus, Retevision has designed and developed a customized IoT solution that allows remote real-time management of both Solar Hubs via Sentilo. Then, the Smart Lighting API is a Sentilo “enabler” component that can work easily in any platform that implements the Sentilo solution, enabling horizontal management of different urban resources.

The solution is also easily scalable and replicable in other Smart city environments.

Conclusions (M8.5 Barcelona)

Barcelona is a big city with a complex city council. It has a lot of departments and the one that manages the street lighting service subcontracts several entities to perform the operation and maintenance of different city areas. So, in order to assure the quality of the street lighting service in the city, they refuse to collaborate working on open interfaces or connect with horizontal third parties’ Smart City management platforms.
The main conclusion is that the Smart Lighting API should be a requirement defined by the own street lighting service management area of the Municipality, in order to avoid mistrust when external actors propose the deployment of horizontal solutions to get interoperable management of several legacy systems, even when the solution is based on secured interfaces for systems inter connections.

3.4 Conclusions for Work Package 3

Work Package 3 (WP3) focuses on implementation of Smart Solutions 5-8, outlining the opportunities of integrated infrastructures to develop new services for citizens and to understand short and long term financial and technical implications to secure sustainability goals.

Concerning the Smart Solution 5; *Smart lightning, lampposts and traffic posts as hubs for communication*, it is suggested that electricity use may be reduced up to 32% (M5.1.1), 21% (M5.1.2), and 25% (M5.1.3). It is further proposed that such saving may be used for additional lighting in order to increase the sensation of security during dark hours in areas not earlier having night light, that the measures increase the attractiveness of any city, and that there is a good potential for these measures to be easily replicated in many European cities. However, the measures involve personal information, which means that data needs to be anonymized. For instance, regarding M5.2 in the Stockholm demo site, data was anonymized already in the sensor, so no personal data was handled or stored. To further ensure social acceptance, signboards have been installed in all entry points to the area and the public have been informed through a website about the technology used and how personal anonymized data were treated. Feedback from citizens shows that the general opinion is that people are satisfied to know that their personal integrity is not jeopardized. The solution has also been presented in different events, study visits, meetings and in media and also in these the social acceptance have been very positive.

Concerning Smart Solution 6; *New business models for district heating and cooling,* it is suggested that the measures are good examples of sustainable and economical feasible solutions which contributes to decreasing the use of fossil fuels and carbon emissions. However, concerning M6.1.1 and M6.1.2, Stockholm Exergi points out that the amount of available excess heat needs to be larger than what was the case in the supermarket in Stockholm in order for the measure to be economically feasible for the supplier. Moreover, implementation of the solutions at large-scale a district heating system is required to which a number of energy sources are connected. Recovering heat to the district heating system requires investment at the beginning but can be economically beneficial over the technical lifetime of the installation. Concerning social implications, the acceptance among residents and the City of Stockholm was relatively high. Feeding back energy to the district heating system means that Stockholm Exergi can offset the use of fuels with fossil content and in that way the scheme contributes to a more sustainable city.

Concerning Smart Solution 7; *Smart waste collection, turning waste into energy*, it is suggested that the system may lead to reduced CO_2 emissions of 46%. However, to grasp the full picture on a national or European level extrapolation to include transports to and from, among others, recycling plants, sorting facilities is necessary. It is further suggested that the system is technically feasible but that there are a few improvements that need to be introduced to increase the end user experience and to reduce energy usage, e.g. the waiting time for the user at the inlet is considered too long, and the idle energy consumption can be reduced substantially. Potential of standardization is medium to high depending on the local/regional availability of a recycling industry. As the measure intends to deploy a collecting system to send waste to a specific location where it is treated and recycled, the scalability of the measure depends on whether a city has a recycling plant to send the separated garbage bags. Hence, Scale Advantage is high for areas with an existing sorting facility and recycling industry, and if not, costs and benefits escalate proportionally to the area covered by the service, reducing the scalability.

Concerning Smart Solution 8; *Big open data platform for saving energy and improving the quality of life*, it is highlighted that it is important to have relevant stakeholders or user groups involved and that the development is aimed at providing real value for these groups. From the Stockholm site it is further suggested that: 1) the number of data sources are expanding rapidly, and it is therefore important to use open data platforms that are designed to be flexible in terms of input, output and the ability to manage data over time, 2) personal data are sensitive, and data needs to be anonymized, 3) the ownership should be with the city, and 4) implementation of new sensor systems can take time and this aspect should not be underestimated. In addition, concerning M8.1 in the Stockholm demo site, one of the measure's deliverables is an improved experience for visitors to the arena area and given that this will give the area an improved image it could result in a higher number of visitors. The experience is primarily focused on assisting the visitors coming to the area with public transportation but it could also lead to that the vehicle traffic to and from the area would be reduced, helping decrease environmental stress.

Recommendations from the Barcelona site include: 1) cities can use the technology directly, although they need to re-implement the semantic access layer based on the way the data in their cities is accessed, 2) domain specialists are needed to extend or customize the existing Urban Model with other domains or aspects typical of their environment, and 3) partners that can commit to develop applications on top of your technology should be identified. Recommendations from the Cologne side: the success of an open data platform depens on the datas that can be integrated and the people that uses them. Key point is communication. Start with small use cases. Identify all required actors (e.g. city departments owning important data you need) and conduct workshops with them, teaching the ideas and goals and developing data scenarios in cooperation. Identify the necessary data sources and actors you have to cooperate with. Affected departments and agencies and/ or companies need to be included in the process at an early stage. This allows for early understanding and acceptance of the solution, time for discussion and individual special requests as well as including expert knowledge. Create a handling strategy for urban data with citywide validity. This gives potential data users trust and security.

4 WORK PACKAGE 4: SUSTAINABLE URBAN MOBILITY

4.1 Introduction

The transport sector is currently acknowledged to be one of the toughest challenges regarding sustainable development. Local examples of how climate- and energy-efficiency targets can be fulfilled in the transport sector without compromising individual mobility will be critical as we approach tougher emission caps in the future. Besides the climate impact, there are many other negative consequences that need to be addressed, and that are part of sustainable travel planning perspectives. Examples are e.g. noise, ambient air pollution, traffic accidents and destruction of aesthetic and restorative qualities. The potential socio-economic savings from mitigating these uncontrollable traffic volumes through various travel demand Measures and mobility management are thus substantial.

Globally, frontier cities that demonstrate best practice solutions might have an advantage when the situation becomes more acute and the urge for disseminating know-how between cities increases. The issue is complex, since sustainable traffic planning and renewable energy supply need to encompass a multi-stakeholder process, involving potential shifts in individual travel behavior, the development of future vehicle technologies, and requirements on more efficient energy supply chains. One prediction can be made: the transition to a non-carbon society will place immense pressure on the limited, solar, wind and bio energy assets, as well as a conscious planning towards a more energy efficient individual travel behavior.

The GrowSmarter project is an attempt to create, implement, and evaluate a number of energy- and climate efficient solutions in three local city districts, with the aim of reaching 60% reduction of CO_2 and other pollutants at a concrete level in the transport system.

4.2 Evaluation methodology

Each Measure is categorized in what way it might contribute to one or more of the following efficiencies

A. Reducing traffic volumes
B. Transition to more energy/emission-efficient transport alternatives
C. Transition to renewable fuels
D. Improved traffic flows

For each site where the Measure is implemented, the site is defined according to

A. Number of people living in the site, potentially applying the Measure
B. Number of kilometers street/road links where Measure will be implemented

<u>Definition of baseline parameters for transports (collectively reported by each defined site in Stockholm, Cologne and Barcelona)</u>

A quantitative baseline need to be reported for each site based on the parameters given in the following tables.

Table 185 Example of site specific baseline parameters per travel mode per year

Site specific baseline parameters	Car (driver)	Car (passenger)	Car sharing	Park and Ride	Public Transport
Number of trips per travel mode					
Number of kilometers per travel mode					

Emissions per vehicle kilometer					
kWh per vehicle kilometer					
Emissions per person kilometer					
kWh per person kilometer					

Site specific baseline parameters	Train	Bus	MC/Moped	Bike	Walk
Number of trips per travel mode					
Number of kilometers per travel mode					
Emissions per vehicle kilometer					
kWh per vehicle kilometer					
Emissions per person kilometer					
kWh per person kilometer					

Table 186 Example of baseline parameters: heavy vehicles per year

Site specific baseline parameters	Heavy vehicles
Number of vehicles passing	
Number of vehicle kilometers	
Emissions per vehicle kilometer	
kWh per vehicle kilometer	
Average velocities during peak-hours	
Share of renewable fuels (% of energy)	

Specification of methodology for evaluation of each Measure should be defined using one or several of the following techniques:

a) Traffic flow measurements
b) GPS-technologies in vehicles or other data from transport actors
c) Simulation of traffic flows on specific road links
d) Travel surveys

Specification of quantifiable key performance indicators to be monitored over time
Quantifiable indicators needed for the evaluation are given in the following table:

Table 187 Example of KPI tables: Impact from Measure on personal transports

Measure	Number of people living in the site *potentially* using Measure	*Observed* number of users of Measure	Average emissions per person kilometer with private vehicles in the site (Kg CO_2/km)	Average energy use per person kilometer with private vehicles in the site (kWh/km)	Average emissions per person kilometer with private vehicles applying Measure (Kg CO_2/km)	Average energy use per person kilometer with private vehicles applying Measure (kWh/km)	Number of private vehicle kilometers shifting to cycling due to Measure (km)
Key indicators 60 months							

Measure	Number of private vehicle kilometers shifting to public transport due to Measure (km)	Number of private vehicle kilometers shifting to car sharing due to Measure (km)	Number of private vehicle kilometers shifting to renewable fuels or electricity due to Measure (km)	Total number of private vehicle kilometers reduced due to Measure (km)	**Total estimated reduction of emissions due to Measure based on indicators (Kg CO_2)**	**Total estimated reduction of energy use due to Measure based on indicators (% kWh)**	**Total estimated reduction of emissions due to Measure compared to baseline (% CO_2)**
Key indicators 60 months					Kg CO_2	% kWh	% CO_2

Qualitative key performance indicators

Qualitative key performance indicators of Measure will be based on interviews with users of the service and on the travel survey.

4.3 Measures of WP4

M9.0 – Sustainable delivery

This section presents the results of M9.1, M9.2.

M9.1 – Integrated multi-mode transport for light goods

Stockholm

Industry partner	Contact person	Validation partner
Carrier, Stockholmshem	Rasmus Linge	KTH-SEED

Two companies have been fondamental for the implementation of M9.1 that consists in the installation and test of a delivery room for light goods. One bike transport company (electric bikes) called “Move by Bike” (MBB) and a tech company that developed digital locks, called “Qlocx”.

The Measure has been deployed in Valla Torg, Stockholm, in a residential area with mostly senior tenants. Despite this, this Measure aims at demonstrating the feasibility of a delivery solution that can lead to better energy efficiency and an interesting business model.

<u>Baseline</u>

The baseline for this Measure is based upon the conventional distribution of packages via Post-Nord to its sub-post office at ICA-Supermarket Årsta (1,1km from Valla Torg 87), as shown in Figure 174. This also includes the tenant’s habits of using different sorts of transportation to get to the sub-post office.

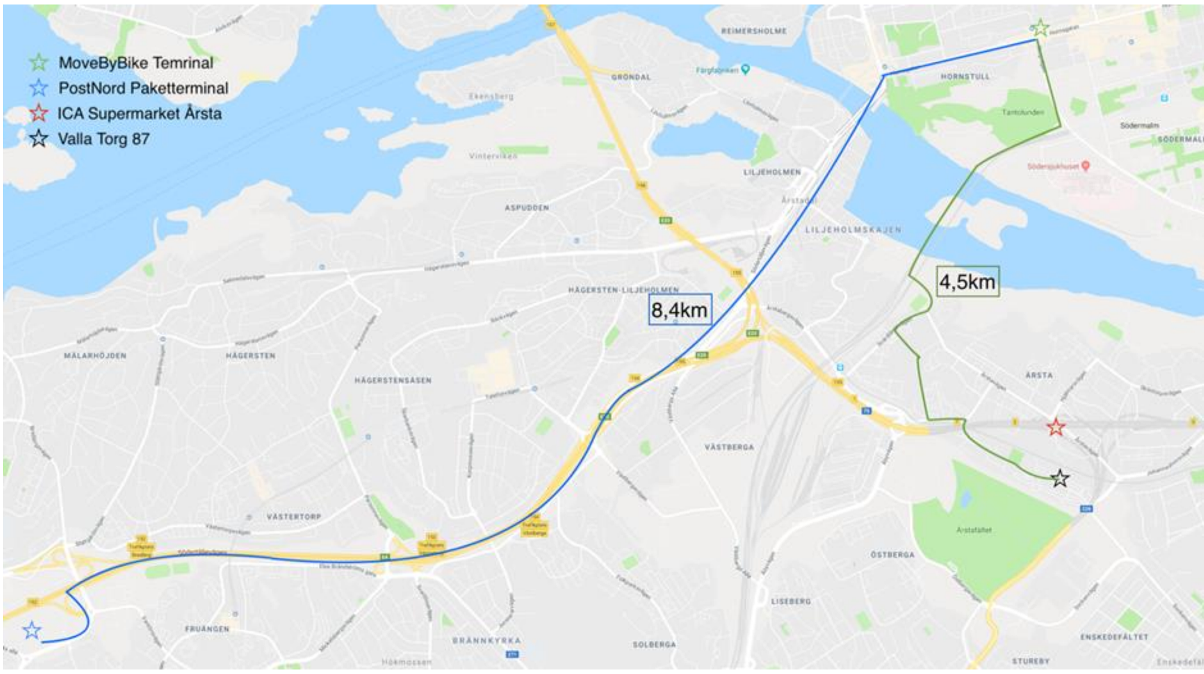

Figure 174 Implemented measure with road sections where Post-Nord deliver packages to MBB Terminal who’s transporting the goods by bike to the delivery room

The service was officially installed in April 2018. Several information efforts have been carried out by Stockholmshem to promote and inform tenants on how they can use the service.

MBB software for coordinating transports has been used to surveying all transports and Qlocx software has been used to gather all the information of goods entering and leaving the delivery room. The data from the actual deliveries has been compared with the ordinary way of getting packages home by picking them up at the local sub-post office at the supermarket.

The road sections travelled in the baseline scenario and after the implemented Measure have been analyzed to evaluate aggregated emissions, road minutes and energy usage according to quantifiable parameters below in Table 188 and Table 189.

Table 188 Average emissions and energy usage, M9.1 Stockholm

Vehicel parameters (TTW)	Average fuel consumption l/km	Average emissions kg CO2/l	Average energy use kilometer (Mj/km)
Light truck EN590 *	0,2	2,56	1,99
Car/private vehicle	0,08	2,56	0,80
Electric bike	0,29	0	0,02

Table 189 Road sections RM and Kilometers, M9.1 Stockholm

Road sections RM and Kilometers					
Road Section	Kilometers	Road Minutes			
From Post Nord Terminal to ICA	8,4	16			
From Post Nord Terminal to MBB	8,3	17			
From MBB to Delivery room*	4,5	16			
From Post Nord Terminal to Delivery room*	8,5	28			

Result summary

The following tables present the results in terms of average emissions and energy usage. In particular:

- Baseline, without delivery room, 11 deliveries with Post-Nord to ICA Supermarket (Table 190)
- Implemented Measure, 11 deliveries with Post-Nord via MBB to Post-Nord (Table 191)
- Comparison Base-line and implemented measure (Table 192)
- Upscaled scenario 35 packages a day, one consignment each day, 250 working days* Base-line Scenario (Table 193)
- Upscaled scenario 35 packages a day, one consignment each day, 250 working days* MBB picks up delivery at Post-Nord Terminal (Table 194)

Table 190 Baseline, without delivery room, 11 deliveries with Post-Nord to ICA Supermarket (M9.1, Stockholm)

Average emissions and energy usage*						
Vehicel parameters (TTW)	**Deliveries with Post Nord**	**Total number of km travel**	**Road minutes**	**Total fuel consumption l/km**	**Total emissions kg CO2/l**	**Total energy use (Mj/km)**
Light truck EN590	11	92,4	176	18,5	48	103,2
Car/private vehicle		4,1	11,2	0,3	0,9	4,6
Electric bike		0	0	0	0	0

Table 191 Implemented Measure, 11 deliveries with Post-Nord via MBB to Post-Nord (M9.1, Stockholm)

Average emissions and energy usage*						
Vehicel parameters (TTW)	**Deliveries to MBB/Delivery room**	**Total number of km travel**	**Road minutes**	**Total fuel consumption l/km**	**Total emissions kg CO2/l**	**Total energy use (Mj/km)**
Light truck EN590	11	91,3	176	18,3	47,5	102
Car/private vehicle		0	0	0	0	0
Electric bike	11	49,5	187	0	0	1

Table 192 Comparison Base-line and implemented measure (M9.1, Stockholm)

Average emissions and energy usage*						
Vehicel parameters	**Total number of km travel**	**Total emissions kg CO2/l**	**Total Road minutes**	**Total energy use (Mj/km)**		
Base-Line	96,5	48,9	187	107,8		
Implemented Measure	140,8	47,5	363	103		

Table 193 Upscaled scenario 35 packages a day, one consignment each day, 250 working days* Base-line Scenario (M9.1, Stockholm)

Average emissions and energy usage*						
Vehicel parameters (TTW)	**Deliveries to MBB/Delivery room**	**Total number of km travel**	**Road minutes**	**Total fuel consumption l**	**Total emissions kg CO2/l**	**Total energy use (Mj/km)**
Light truck EN590	250	2100	4000	420	1092	2345,7
Car/private vehicle		3273	8925	262	681	3656

If this quantity would be delivered according to the implemented measure, we would save 1% CO2 thanks to shorter distance to MBB from Post-Nord and 2% CO2 thanks to how much emissions could be reduced from avoiding travels to sub-postal office. The fundamental question should be "what would make this concept reach the strategic goals of reduction of CO2 by 60% and also creating an economically sustainable solution that tenants desire?". This is presented in Table 194 and elaborated further in the conclusions.

Table 194 Upscaled scenario 35 packages a day, one consignment each day, 250 working days* MBB picks up delivery at Post-Nord Terminal (M9.1, Stockholm)

Average emissions and energy usage*						
Vehicel parameters (TTW)	**Deliveries to MBB/Deliveryr room**	**Total number of km travel**	**Road minutes**	**Total fuel consumption l/km**	**Total emissions kg co2/l**	**Total energy use (Mj/km)**
Light truck EN590	0	0	0	0	0	0
Car/private vehicle		0	0	0	0	0
Electric bike	250	4175	11250	0	0	84

4.3.1.1.1 Technical feasibility, implementation issues

The implementation feasibility is in part dependent on the local structures for ordering and shipping goods online. If the Measurement is going to be fully implemented according to the scenario proposed in the conclusion new connections and interfaces between agents of transportation and logistics have to be developed and implemented.

4.3.1.1.2 Social feasibility

There are aspects of better urban environment for the whole community around the road sections used for the service. Most substantially the service is making the life easier for the consumer that is ordering goods online. In a long-term perspective, the service, if it is expanded on a very large scale, could affect the local labour market when the sub-postal office no longer is needed.

4.3.1.1.3 Possibility to replicate the Measure

The Measure would be possible to replicate but it will always be specific to demographic and infrastructure. Also, adaption has to be made to the structure of the actual housing company and delivery agents. This report is a groundwork-tool to evaluate and benchmark in an early stage before a similar solution is to be implemented.

4.3.1.1.4 Conclusions

In the results we can see that the implemented measure is not fulfilling the intended goals (reduction of emissions and easy to use, desirable service for tenants).

So, what would be a desirable scenario for the users, provider (Stockholmshem) and also advantageous in sustainable terms? This could be described in 3 strategic goals

- Free or almost free for tenants/housing company to use
- User friendly (no difficult extra step or external address when ordering online)
- Decreased emissions by >60% compared to base-line

To achieve these aims above we see 3 key steps to maximize the possibility for this service to be realized in that direction. 1) When A Delivery room order is made online, the transport option is per default to the delivery room when Post Nord is optional (no alternative address etc). This mean Qlocx must work together with for example Post Nord to create this connection. Discussions is currently going on, on this topic between Post Nord and Qlocx. 2) The usage of the delivery room(s) eventually needs an average turnover of around 35 packages a day. 3) MBB collects all the packages going to the delivery room that day at Post-Nords terminal and delivers them at the delivery room. Also Post Nord could use own electric vehicles to transport the parcels.

When the first step is achieved it would be more likely that MBB could pick up the consignments at the Post-Nord Terminal. MBB is currently discussing with Post Nord that in a case where the number of packages could reach at least 35 per day they could pick up that consignments of packages and deliver it to the delivery room. In that way Post-Nord could reduce their own transports and pay MBB for the service this will also mean that that the tenants or housing company doesn't have to be charge (or would be charge significantly less) for the service. To be more specific if the transport cost is neutral it's the maintenance of the delivery room and licence for software left to cover. In this approach emissions are reduced close to 100% (see table 6-7) thanks to the fact that all transport of the goods to delivery room is carried out by electric bicycles. The survey shows that what tenants is missing today is primarily a safe and easy to use function that is basically free. This developed method could potentially meet this requirement.

M9.2 – Micro distribution of freight

Introduction

This Measure aims at demonstrating the use of micro platforms or micro Urban Consolidation Centers (mUCC) where transport operators can store their goods and transfer them to electric tricycles for the last mile distribution, covering a designated area. Tricycles are equipped with sensors to monitor relevant parameters of the service, as well as relevant city environmental parameters. Furthermore, a dynamic routing algorithm is implemented. The results show the technical and social viability of the Measure, indicating the reduced emissions and reduced traffic in streets of the inner city. The work is carried out by CENIT, I2CAT, and Barcelona city council in collaboration with a subcontracted micro carrier.

According to the evaluation plan (D5.1), the intention of the Measure is to:
A) Reduce traffic volumes
B) Transition to more energy/emission-efficient transport alternatives
C) Transition to renewable fuels
D) Improve traffic flows

Barcelona

Industry partner	Contact person	Validation partner
CENIT	Paco Gasparín	KTH-SEED

The original plan was to implement the Measure in the San Martí Living Lab area, but in early 2016, an evaluation of the potential service demand in this area indicated a low level of parcel turnover. A a result, a new site close to the Estació de França railway station was selected for the implementation of the Measure.

As the demonstration is a pilot case, rather than procurement of services, the City Council granted an agreement to a delivery company (Vanapedal) serving the city's historic center Ciutat Vella and other areas of the city for the duration of the project. This company was chosen because it had experience with other European projects.The lease was granted on the condition that:

- the company agreed to deliver parcels on behalf of other companies, meaning that the operator should be market-neutral.
- the operator provides the Municipality with data about the delivery activities carried out each month.

Once the project is finalized, the City Council will decide whether to tender a concession or find a new model to support micro distribution platforms.

The service was launched in January 2017. The monitoring sensors, developed during 2016, were installed on three tricycles, enabling data collection over a two-year period. The sensors are powered by the tricycle battery and were installed under the tricycles to minimize the risk of robbery or vandalism. External antennas with long cables were used to enhance the coverage of the GPS and the communication links. A GPRS interface was also included in order to provide an alternative communication option should the municipal Wi-Fi corporative network not be reachable.

The micro platform started operations in January 2017. Since then data has been collected from the operator Vanapedal. The main aim was to collect data regarding:

- The number of daily operations
- The number of expeditions
- The amount of kilometers covered

The data collection was carried out by the cargo bikes in reference to the areas of the city in which these vehicles were performing deliveries. In February 2018, a new template was facilitated to Vanapedal in order to improve the data gathered in terms of precision. Despite this change, the data gathered in the period January 2017 to January 2018 was very useful for the determination of the impact of this Measure in the city.

The parameters gathered are (for each journey and cargo bike):

1. The number of operation hours
2. The expeditions sent
3. The number of expeditions delivered to the customer
4. The number of deliveries returned
5. The number of kilometers covered.

On days of peak activity, up to 14 or 15 cargo bikes have been running at the same time. All this information is collected for each cargo bike and each working day.

During a working day, each cargo-bike driver was handled a template with the data that was needed. Before starting the journey, the cargo-bike drivers wrote down the number of deliveries they had to do. Once the working day was over, on the return trip, the cargo drivers wrote down the undelivered parcels, the number of kilometers covered during that journey and the time needed to accomplish the route.

The structure of the template of the data collected can be seen in Table 195.

Table 195 Template for data collection (M9.2)

Day	Day
Month	Month
Year	Year
Driver	Name of driver
HOURS/WORKING DAY	Number of working hours
ROUTES	NUMBER OF DAILY ROUTES
VEHICLE	(tricycle1, bicycle4...)
SERVICE HOURS WITH VEHICLE	DURATION OF THE ROUTE
CLIENT	CLIENT NAME
MAIN DELIVERY AREA	ZIP CODE OF THE AREA
KM	KM COVERED PER ROUTE
EXPEDITIONS	TOTAL NUMBER OF EXPEDITIONS
EXP PROBLEMS	NUMBER OF RETURNED DELIVERIES
EXP EXIT	NUMBER OF DELIVERED EXPEDITIONS
EXP PER HOUR	EXPEDITIONS PER SERVICE HOUR

Q	PROBLEMS WITH DELIVERIES
Q2	% SUCCESS
average KM/EXP	AVERAGE DAILY DELIVERIES PER KM

The data in black is calculated from the data provided in the previous cells hence there was no need for the drivers to fill them in.

During the 26 months in which this data has been collected, every single time a tricycle left the micro platform to perform deliveries, a row with the information contained in the template was filled. Each row is a single journey. During this time period, a total of 207.064 journeys was made by the last mile operators.

Due to the way the data was collected, some of the data is partly missing for some tricycles. This can be explained with the fact that sometimes drivers forgot to worite down the data required after each trip. However, the data with complete rows represents more than 95%. Aside from the missing data, the rest of the data is considered to be accurate, but it is always trusted in the accuracy of drivers.

The data collected was put into a spreadsheet in order to find information through dynamic tables in excel. As a result, the number of kilometers covered by month, by driver, in total, etc was calculated. Furthermore, through dynamic tables, the monthly number of expeditions, the number of trips, the efficiency of deliveries (considering the undelivered parcels) and the average distance between expeditions were obtained. The aforementioned parameters were tha main ones that were calculated from the data provided by the company.

One of the benefits of the implementation of a transshipment terminal and delivery vehicles is the number of saved kilometers that are currently performed by vans or trucks in an area of the city. An approximation of the number of kilometers that could be saved by every full tricycle compared to a delivery made by a van was made.

CO2 reduction:

The reduction of emissions is calculated from the number of kilometers covered during the evaluation period by tricycles and number of deliveries. The following step was to calculate the energy required by tricycles and bicycles. This previous data was compared to the number of kilometers that would have been necessary for a delivery by van. The Catalan energy mix was used for the caluclations. Two conditions were taken into account for the calculations: the truck/van transportation produces local emissions; the production of electricity (for tricycles) does not generate local emissions (only at the energy production site, if any).

In order to understand the delivery routes of the logistic operators, there is a need for data which could not be accessed. Therefore, before using the micro platform services, certain assumptions were made to infer such information.

A transformation of kilometres performed by electric cargo bikes to the analogously kilometres that would have been carried out by standard courier services with the same deliveries was performed. Following the transformation, the CO2 emissions were calculated.

On the other hand, the amount of CO2 emitted by the electric cargo bike was calculated with the factor extracted from the National Commission of Markets and Competition (CNMC)[24].

Energy saving

The reduction of energy use was calculated using the first step of the calculation of the reduction in emissions. It is important to mention, that in order to get real values an interview with the last mile operator[25] was made in order to better understand the practices carried out by logistic operators and cope with the reality of the sector.

If the information on how the operators behaved had been available before using the micro platform services, it would have been possible to have more precise results. The possibility to interview the logistic operators was raised when the consideration that an error might have been introduced in the calculation of the reduction of vehicle kilometers was taken onto into account.

Noise reduction

The noise reduction was calculated assessing and comparing the noise a standard van would generate in average for each operation (approx. 80dB) with the noise generated by a cargo-bike (approx. 45dB). The number of cargo-bikes available was 15. Taking into account that approximately 1,5 bicycles of cargo are needed for each van, the number of vans would be 10.

The decibels are a logarithmic scale, therefore, an increase of 10 decibels (dB) is perceived as a doubling of noise volume. The number of decibels from multiple sources cannot simply be added to get the total number of decibels. If two trucks that produce 80 dB of noise each are passing the same location at the same time, they will produce a total of 83 dB, not 160 dB. Table 196 shows an approximative scheme for the calculation of the noise from overlapping of multiple sources. The table is accurate within 1 dB of the exact value.

Table 196 Example of calculation of noise.

Adding Decibel Amount differ by:	Add this amount to the higher value	Example
0 or 1 dB	3 dB	70 dB + 69 dB = 73 dB
2 or 3dB	2dB	74 dB + 71 dB = 76 dB
4 to 9 dB	1dB	66 dB + 60 dB = 67
10dB	0 dB	65 dB + 55 dB = 65 dB

[24] The National Commission of Markets and Competition (CNMC) estimates the information regarding the origin of electricity and its CO2 impact of all the trading companies participating in the Guarantees of Origin System (in accordance with Circular 1/2008, of February 7, "the National Energy Commission", consumer information on the origin of electricity consumed and its impact on the environment).

[25] As it was mentioned in the first page, the last mile operator is represented by a single company that delivers the parcel on behalf of the other companies.

Source: Hendricks, Rudy. Technical Noise Supplement: A Technical Supplement to the Traffic Noise Analysis Protocol. California Department of Transportation (Caltrans), October 1998.

Results

The following tables present a summary of the quantitative results obtained within M9.2.

Table 197 Baseline evaluated for M9.2, Barcelona

A) Number of people living in the site, potentially applying the measure	101387
B) Number of kilometers street/road links where measure will be implemented	4.49 km²

Table 198 KPIs evaluated for M9.2, Barcelona

Measure 9.2	Average emissions per heavy vehicle kilometre (Kg CO_2/km) *(since this Measure is not changing the emissions of heavy vehicles, we will give this figure for the baseline only)*	Average energy use per heavy vehicle kilometre in the site (kWh/km) *(since this Measure is not changing the energy used by heavy vehicles, we will give this figure for the baseline only)*	Number of heavy vehicle kilometres shifting to renewable fuels due to Measure 9.2 (km)	Number of bicycle/tricycle kilometres needed to perform the same deliveries due to Measure 9.2 (km)
Key indicators baseline	0.26	0.79kwh/km	101.778 km	0
Key indicators 26 months	-	-	0	72.183 km

Measure 9.2	**Total estimated reduction of emissions (Kg CO_2) due to Measure M9.2 based on indicators**	**Total estimated reduction of energy use (% kwh) due to Measure M9.2 based on indicators**	**Total estimated reduction of emissions (% CO_2) compared to baseline**	**Total estimated reduction of noise (dB) due to Measure M9.2 based on indicators**
Key indicators baseline	27.084 Kg CO2	80.970 kwh	-	115 dB
Key indicators 26 months	1.085 Kg CO2	97,55% kWh	95,99% CO2	90 dB

The difference in terms of emissions generated in kg of CO2 using electric tricycles instead of heavy vehicles is 95.9% CO2. Similarly, the energy reduction between these two types of vehicles is about 97.5% kWh. Moreover, the noise reduction is about 22% of dB.

During the period of 26 months when the data was collected (with the exception of June 2018), the number of deliveries has undergone large variations as can be seen in Figure 1. Despite the increase experienced during the first 6 months of the year 2017, the summer represented a difficult time for the company, since one of the main clients stopped using the micro platform. This fall was observed only for a few months, and as of October 2017, the expeditions raised up again. From this point of inflection, they have remained constant for a year. From October 2018 until now, a new company hired them resulting in a duplicated number of expeditions.

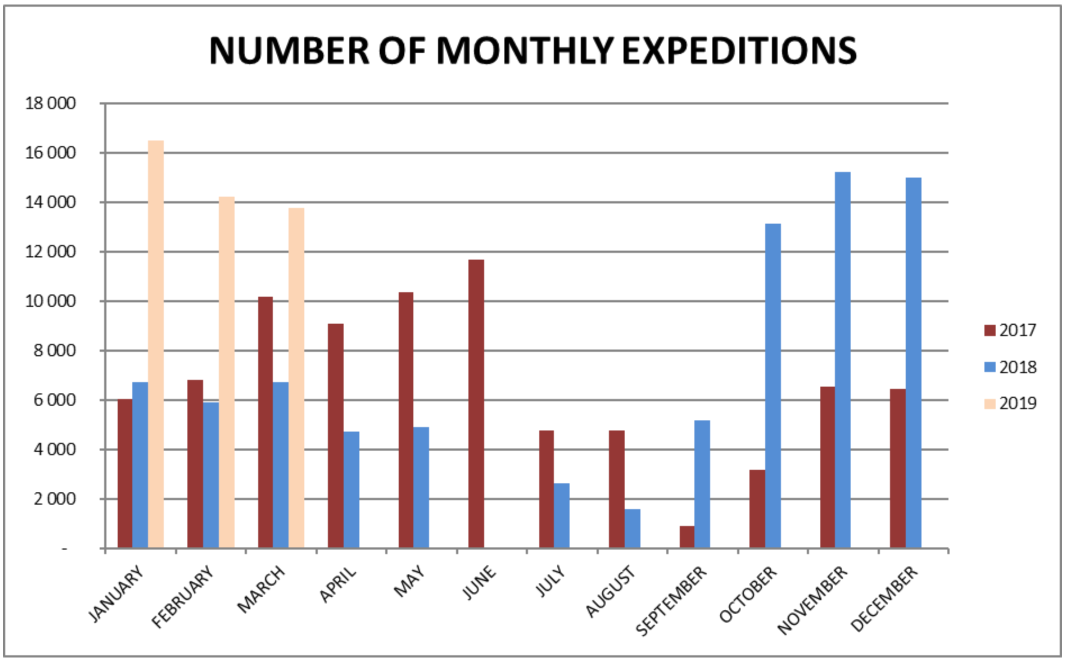

Figure 175 Number of monthly deliveries

The number of kilometers covered by the cargo-bikes during this time period is shown in Figure 176, in monthly distance. It follows a similar shape compared to the curve determined by the number of deliveries. October 2018 was the month in which more kilometers were covered, with more 5000 Km.

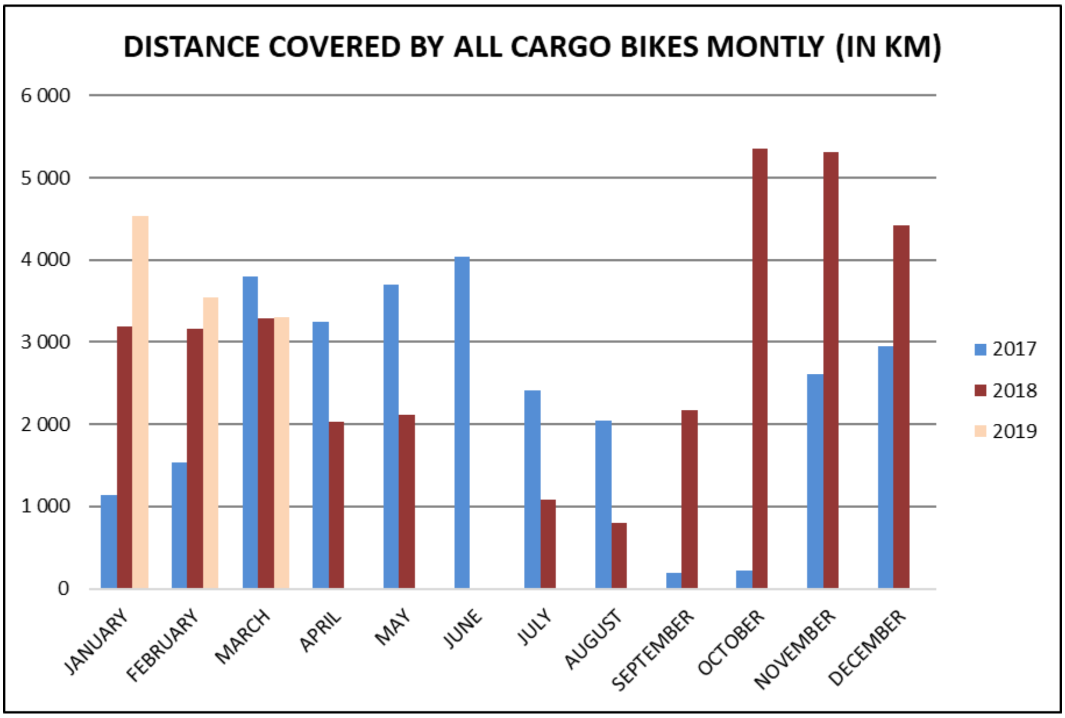

Figure 176 Total distance covered by all vehicles monthly

The daily number of kilometers is shown Figure 177. The average is 19.3km per day. The figure indicates the variations that have occurred over time.

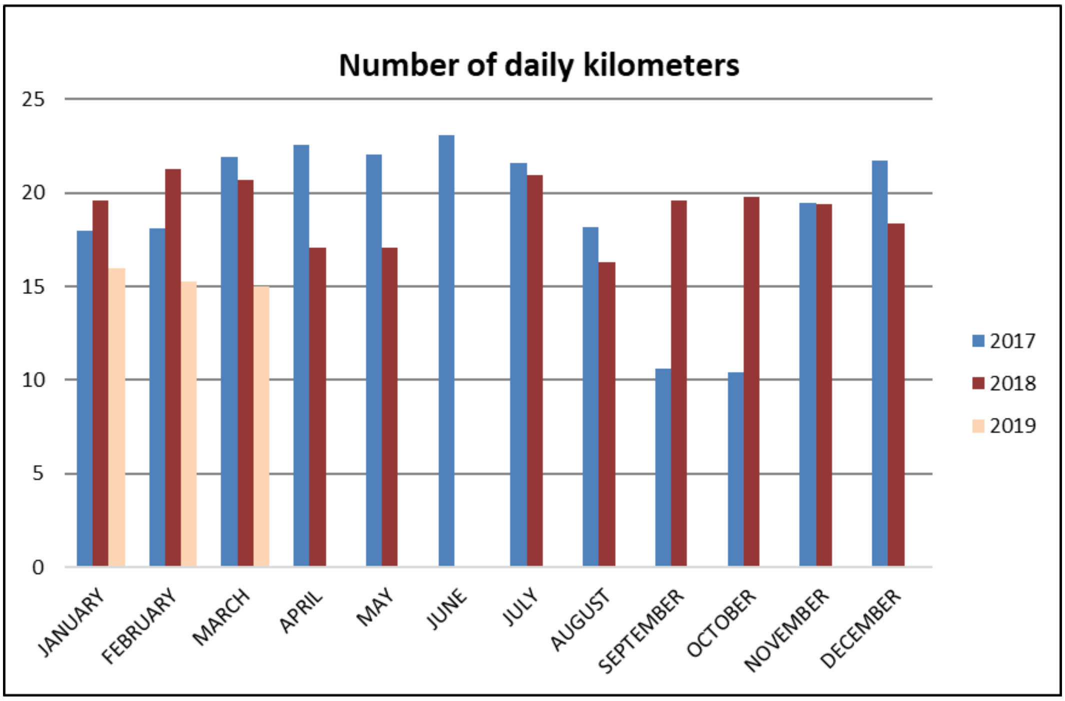

Figure 177 Number of daily kilometers covered

Finally, the deliveries per hour are plotted in Figure 178. It is worth noticing that there are some doubts about the reliability of the information shown. In the new template provided this year, this issue was cleared so as to make sure that the number of hours provided corresponds to the time needed for the journey, excluding the time required for the loading of the cargo bike, for example, at the beginning of the route or stops for lunch.

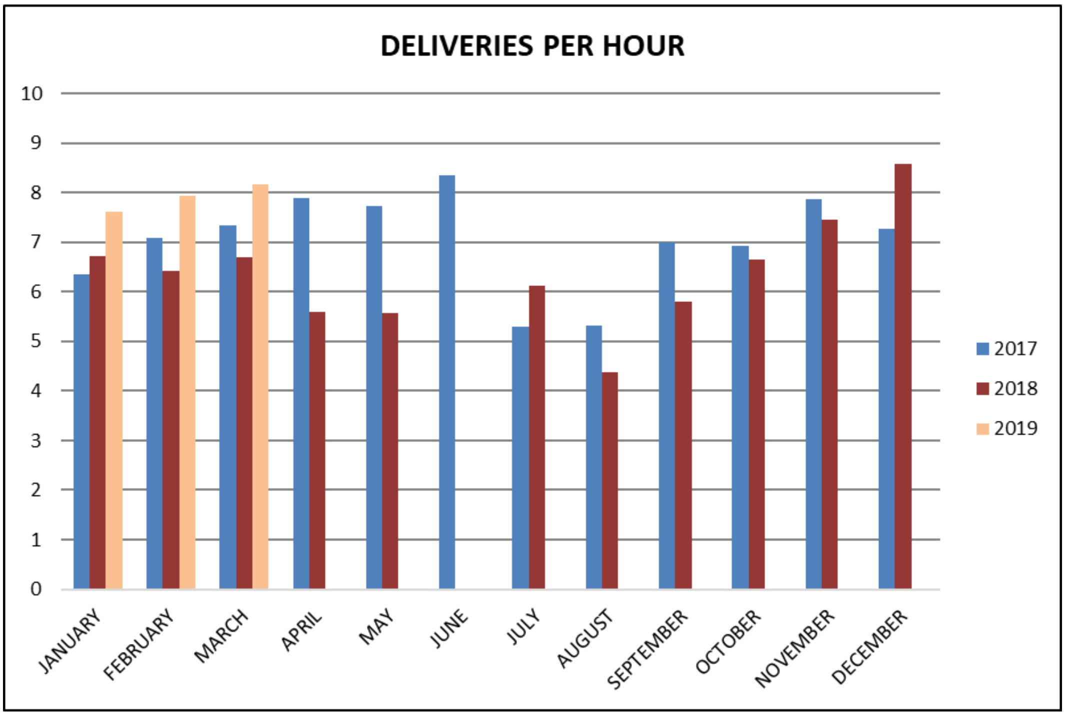

Figure 178 Deliveries per hour

The following Figures show the CO and noise (dB) indicators provided by the bike sensors in the first months of 2018.

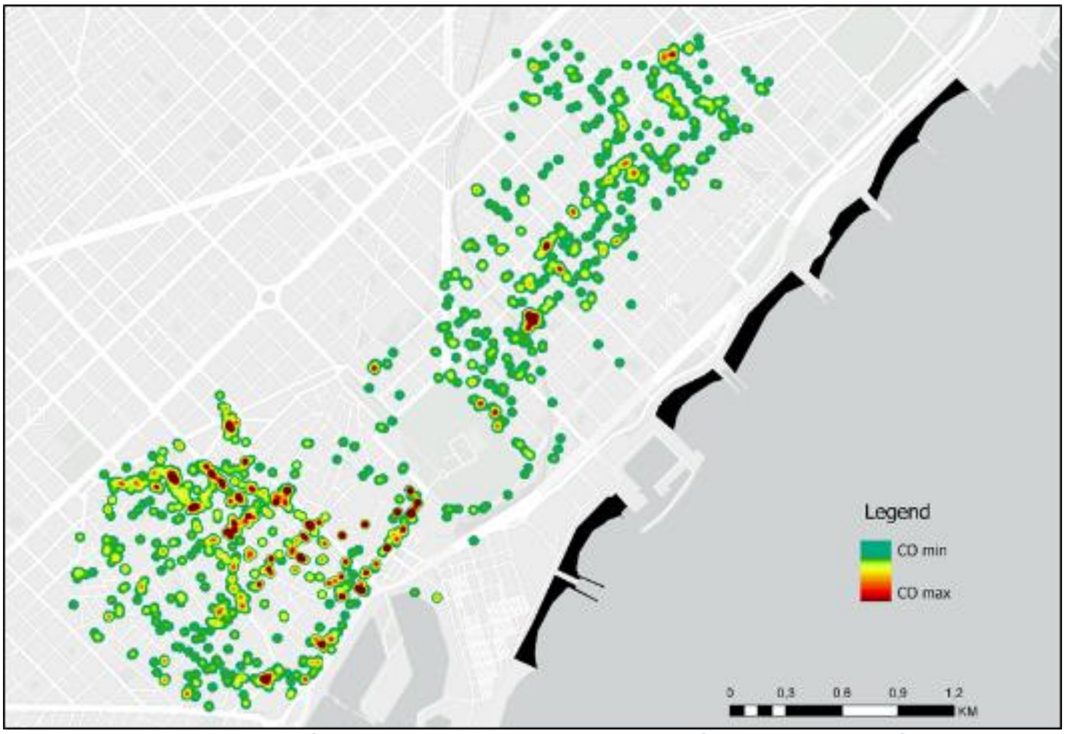

Figure 179 Representation of the CO sensor in the district of Ciutat Vella (left) and Sant Martí (right)

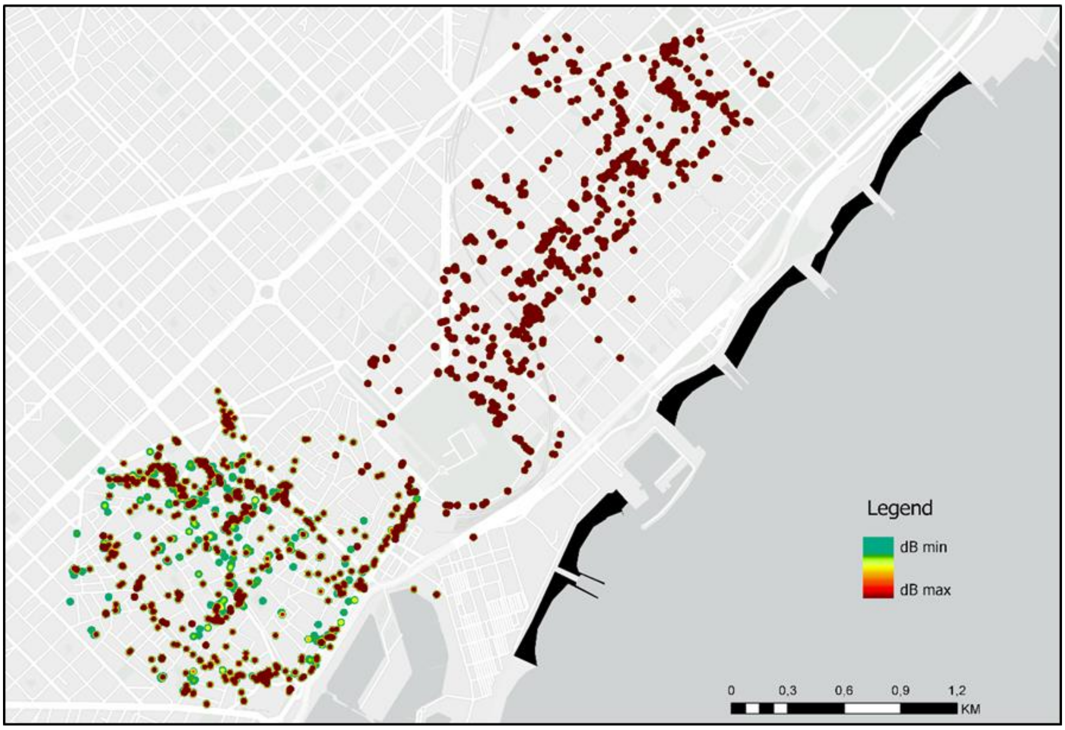

Figure 180 Representation of the sound sensor in the district of Ciutat Vella (left) and Sant Martí (right)

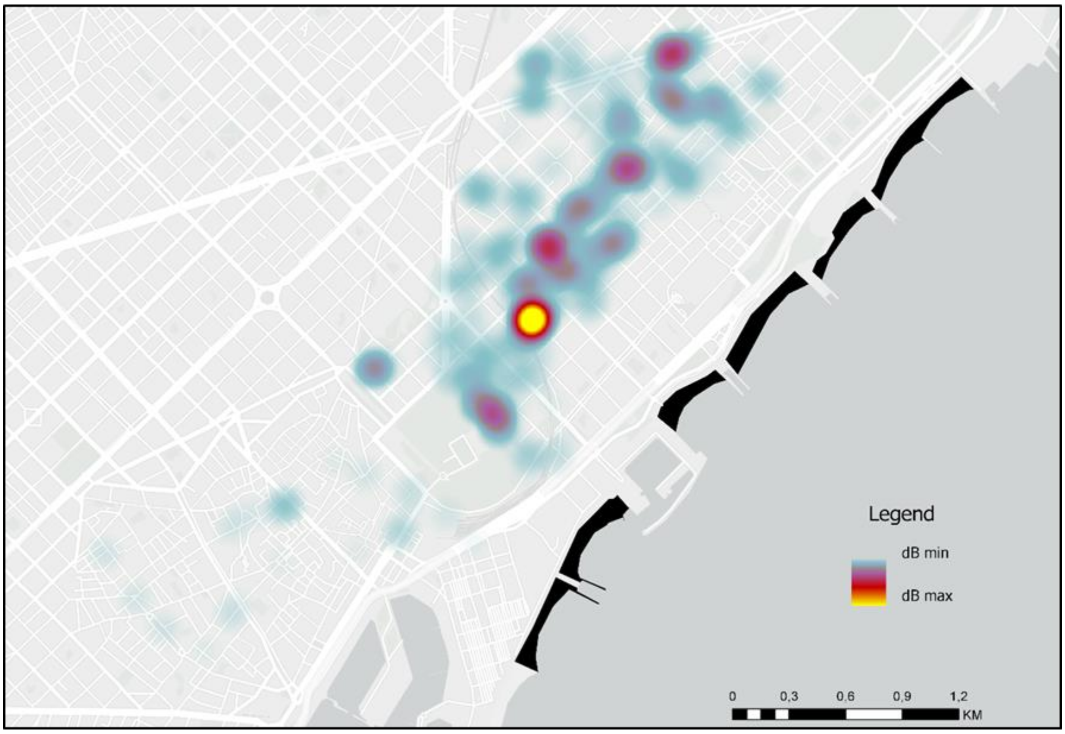

Figure 181 Representation of the sound sensor in the district of Sant Martí (right)

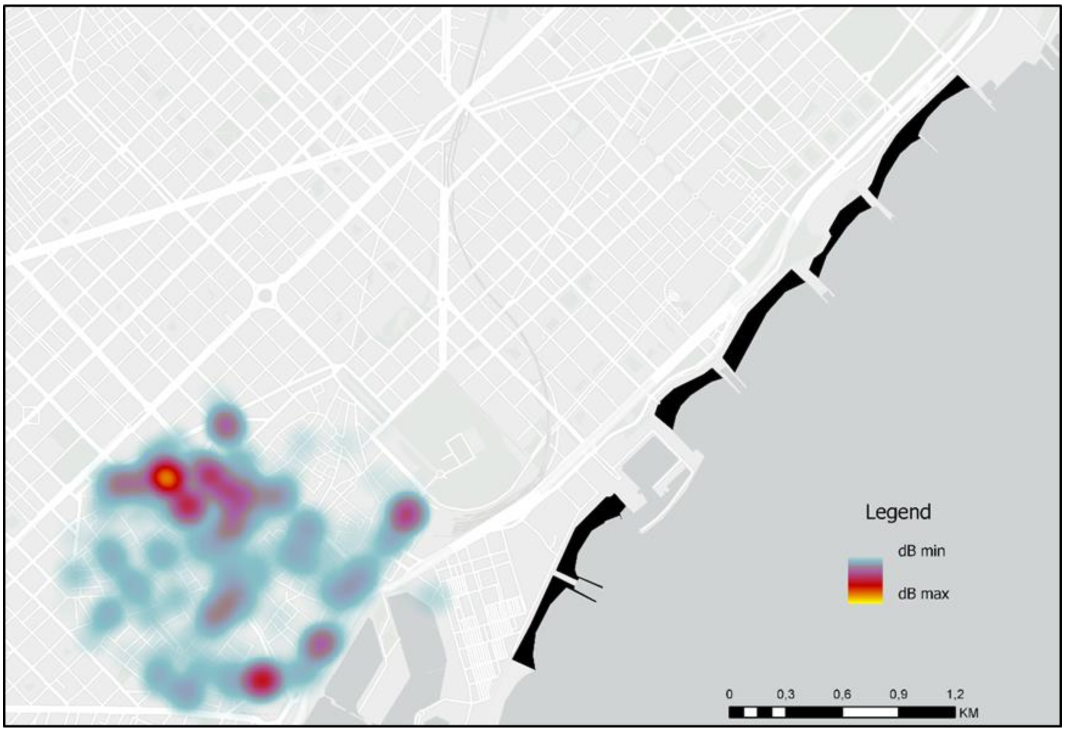

Figure 182 Representation of the sound sensor in the district of Ciutat Vella (left)

Potential for full scale implementation

Technical feasibility

This Measure does not present major problems in its implementation. The only potential technical problems were presented during the gathering of data and the development of the sensor set to be attached to the bikes. In this sense, the sensor boxes have presented several difficulties when being placed in the cargo bikes. Problems, with theft as well as with communications have occurred during their implementation.

The main problems raised during the implementation were mainly administrative and political. A favorable environment (such as narrow streets and pedestrianized areas that provided the last mile operator a competitive advantage against conventional companies) and companies willing to run their services from this micro platform helped with a smooth implementation.

Economic feasibility

Last mile delivery is an emerging market segment which needs creative support from city administrations. Cities need flexible spaces that can be used as premises for emerging businesses and the shared economy.

Municipal processes may need to speed up to keep pace with markets and clarify issues – such as the formal relationships between service providers, data ownership or the need for additional support mechanisms, such as restrictions on delivery times or use of delivery bays – in order to creatively change framework conditions in favour of sustainable parcel delivery.

Upscaling and replicability of the Measure

The measure has potential to be replicated in other cities with similar infrastructure requirements.

Conclusions

The results of this study show how a new approach for the deliveries can contribute to reduce largely the CO2 emissions, other pollutant substances derived from the use of conventional transport deliveries, and eventually to reduce drastically the energy consumed. In particular, the benefits of the new approach are more tangible and noticeable on those places where the traffic is restricted and/or acutely congested. Therefore, not only distributors and retailers might benefit because of the cost reduction, but also the final consumers' environment is enhanced in terms of healthiness and, thus it is possible to say that the nearby neighbourhood's roads would be more fluent and less likely to be overfilled.

As the results suggest, kilometres done by cargo bikes in relation to the same amount of deliveries carried out, are significantly lower than those of the common van delivery. This is presumably due to the fact that cargo bikes have a more flexible mobility in narrow and dense spaces than vans, since vans are not allowed to trespass pedestrian areas. As a result, bikes can make use of shortcuts through straighter ways to their delivery point by use of the public space, and are not determined by the need to park the vehicles in authorized spots to be able to proceed with loading/downloading operations. Thus, the efficiency of cargo bikes with respect to van and light trucks is demonstrated.

Besides the direct benefits previously stated and quantified in the study, some other underlying benefits arise by the use of the electric cargo bikes. For instance, cargo-bikes might help website retailers, by using common synergies, to continue growing while adapting the city to the new environment policies framework. Conversely, the trucks and vans used traditionally on those deliveries that now could be done by the cargo-bikes, can be used to supply bigger retailers or to supply larger distance door-to-door deliveries, where cargo-bikes would not be an option, and increase their efficiency.

In spite of considerable fluctuations in traffic passing through the micro-hub, over the 26 months of operation it is estimated that a monthly saving in CO2 of almost 1T is achieved. This is a useful contribution to the City Council's SUMP and other Air Quality Plan objectives.

M10.0 – Smart traffic management

This section presents the results of M10.1, M10.3 and M10.4.

M10.1 – Traffic management systems, Barcelona

Introduction

The objective of this Measure is to test the new theory on the existence of Macroscopic Fundamental Diagram (MFD) for the urban area (already proven by simulation in Barcelona) as a traffic management tool to assist traffic managers in making decisions on actions to avoid or alleviate congestion in dense urban areas by controlling the entry and evacuation flow rates. It allows the control of the street network performance and traffic state in a reasonable density domain, and the prevention of energy consumption and emissions.

Within GrowSmarter this measure is rather theoretical since no on-street implementation is foreseen. For the simulation of traffic behaviour is used a software platform (Aimsun). The main outcomes of the measure are specifications on how to manage traffic through traffic lights applying the theory of the macroscopic fundamental diagram.

According to the evaluation plan (D5.1), the intention of the Measure is to:
A) Reducing traffic volumes
B) Transition to more energy/emission-efficient transport alternatives
C) Transition to renewable fuels
D) Improved traffic flows

Barcelona

Industry partner	Contact person	Validation partner
CENIT	Paco Gasparín	KTH-SEED

Definition of the scope of the scenario.

The site that host the study is the Sant Martí district located in the north-east side of the city. Diagonal Avenue limits the area on one side; the other is limited by the sea forming a triangular-shaped quarter of the city. This area has a population of 70,000 inhabitants approximately and a density of 203.5 inhabitants/acre.

This urban area has an orthogonal layout of streets with traffic light regulation at each intersection. The aim is to validate that the regulation of the entrance of cars in the district, depending on density and flow, can improve the behavior of the area during peak hours.

The measure is deployed in a subzone (named 22@, Figure 183) constituted of 7500 inhabitants approximately, and a density of 185 inhabitants/acre. The area is around 41 acres and more than 11.5 Km of streets.

Figure 183: Scope of the simulation scenarios – The 22@ zone of Barcelona

Built the network

For building the scenarios, it is needed to define the network within the simulation tool. The first task is to introduce on the simulation tool the data that defines the structure of the streets: the different lanes that compose the streets (private vehicle lanes, bus and taxi lanes, bicycle lanes), their turns, their wideness, where the traffic lights are located and others.

It is important to remark that the intention is to work with traffic lights and how is the flow on the streets with micro detail and very detailed data is required on the streets configuration.

Figure 184 shows an example of how the turns are implemented. At street levels, the different lanes are configured using grey colour, and the different permitted movements for vehicles, represented by the black lines.

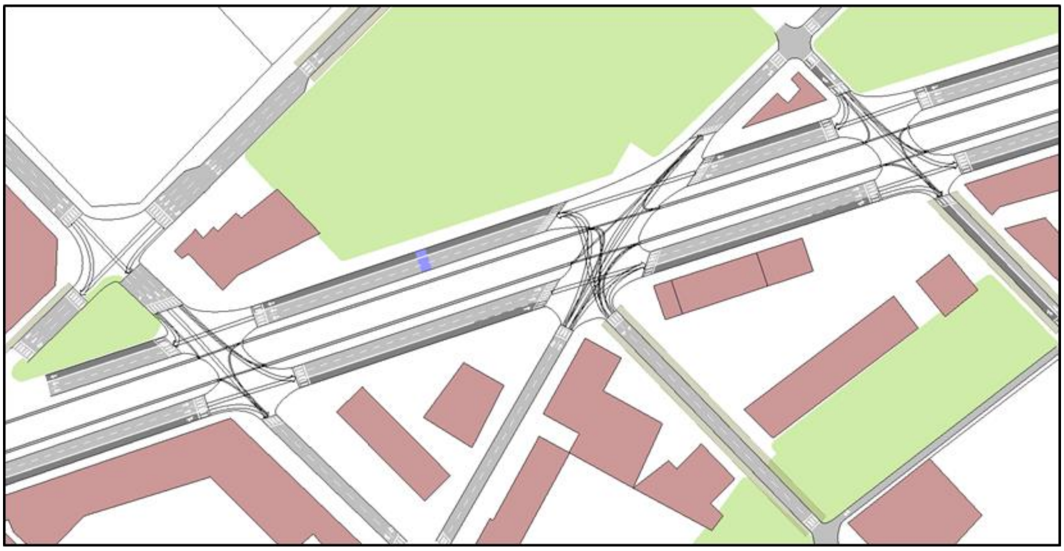

Figure 184: Traffic lanes and turns (example)

Figure 185 shows an example of the different lanes on the street, depending on the sort of vehicles that can run on them. Grey lanes are for private vehicles, dark grey lanes are for bus or taxi, and brown lanes are park areas. The narrow lanes are for bicycles.

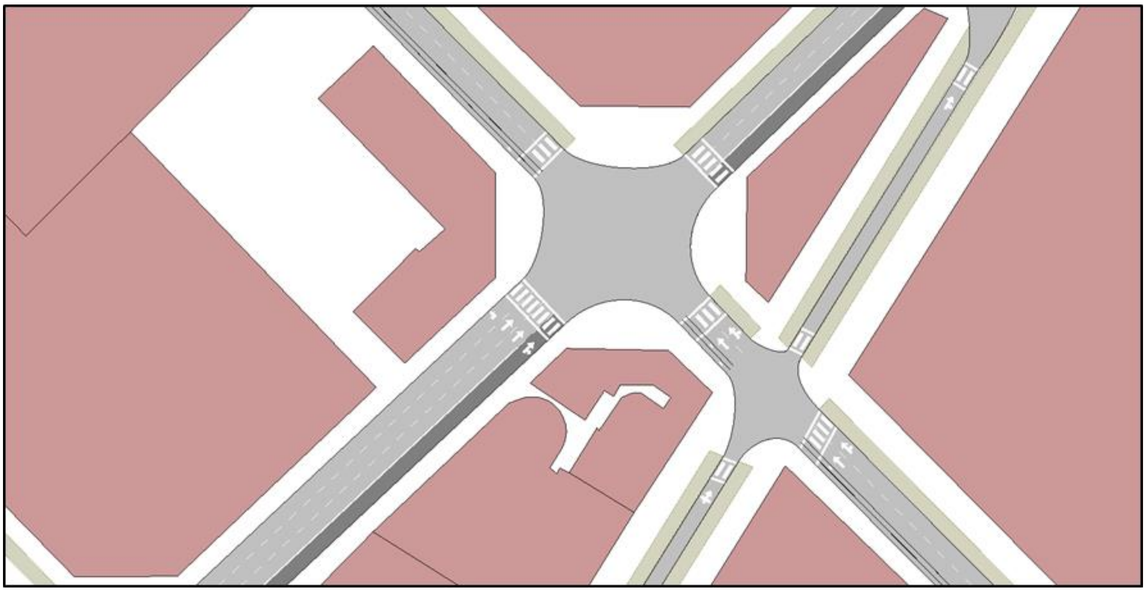

Figure 185: Different sort of lanes on the street (example)

Gathering real data

Real data has been used to feed the system and for defining the baseline scenario. The main data gathered includes:

- Vehicle flow, obtained from spires installed on the desired zone.
- Buses flow: line routes, stops location, theoretical frequency, and real data from the time the bus arrives at the different stops, to obtain more approximate information about the bus speed.

Figure 186 shows the representation of a bus stop on the map. The yellow marks correspond to s bus stops.

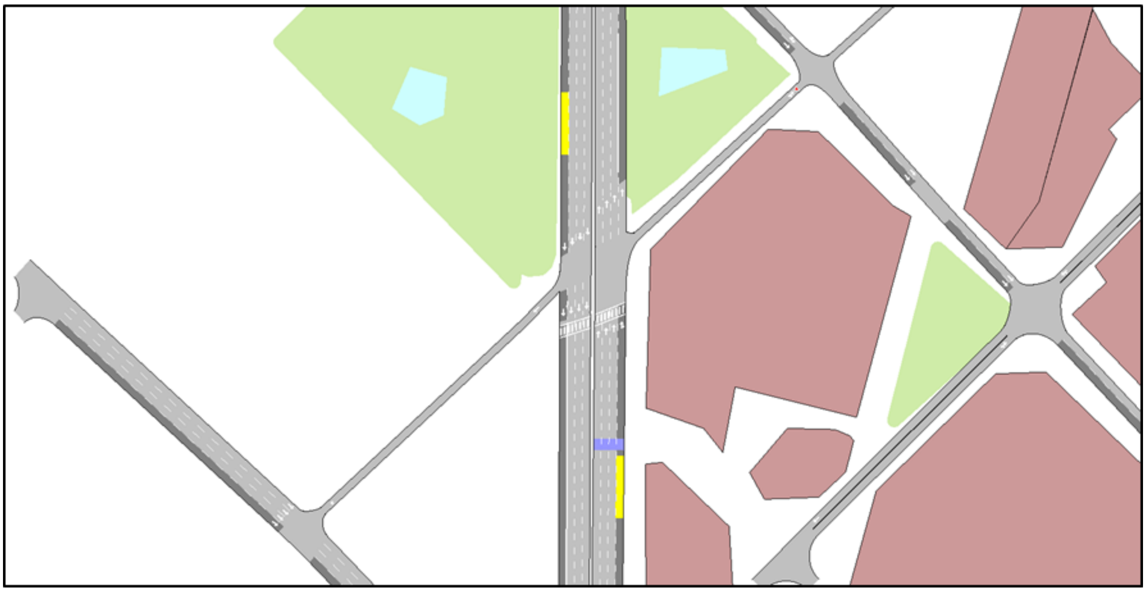

Figure 186: Locating bus stops (example)

Traffic lights

Data is available from all the traffic lights on the zone: their exact location and the different plans that govern the traffic light signalisation on the zone.

Figure 187 shows an example of a traffic light implementation on a cross: the green bars correspond to the green phase of every traffic light that governs the cross: for private vehicles, another specific for the bus if it is needed, bicycles.

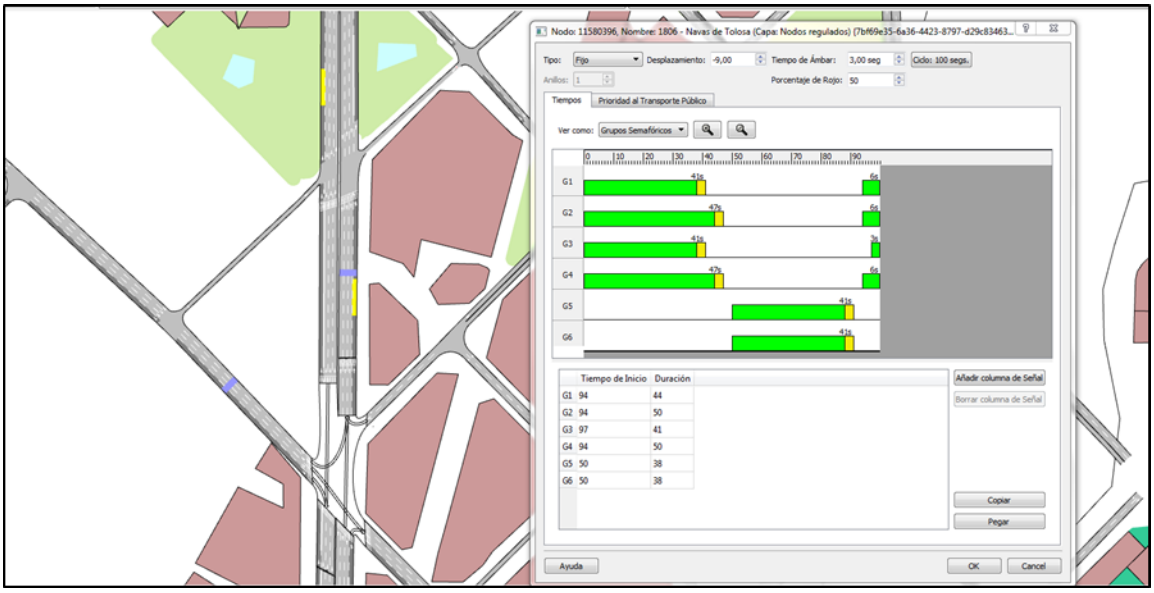

Figure 187: Traffic light plan on a cross (example)

Automatic procedures

Finally, automatic procedures are required to facilitate to update all the data used, because of the dynamism of the changes in the city that can affect the traffic behaviour.

Definition of the subzone

The simulation model was implemented with 22@ (Figure 188), but the results were not satisfactory. The flow-density curve was unrealistic, since model validation data is scarce in some areas. Then a sub-area (black area Figure 188) is selected where the MFD is performed. And the graphics and the baseline are made in this sub-area.

Figure 188: The sub-zone of 22@ in Sant Marti district in Barcelona

Controller Design for Gating Traffic Control

This is the second objective of the measure, optimize the area's semaphores. To perform this task, an input control is used in the subzone by obtaining traffic lights, called gating. This structure is explained in Figure 189 (M. Keyvan-Ekbatani, M. Papageorgiou and V. L. Knoop 2015).

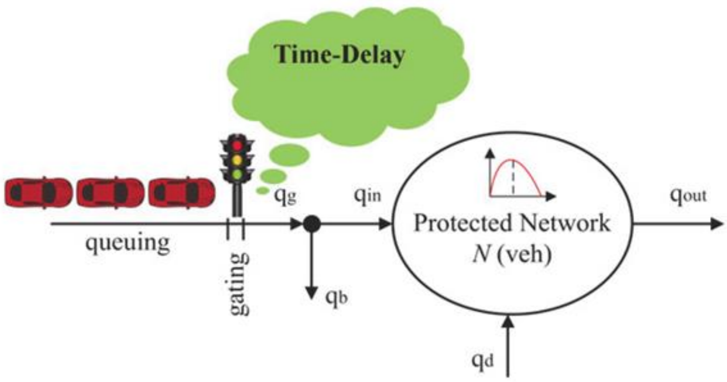

Figure 189: General scheme of gating

Definition of sets, variables and parameters in Figure 189:

- PT = Set of all the traffic lights in the PN boundary corresponding to the entrance sections to the network. Traffic lights set on exiting sections are discarded.
- P = Set of protected gates, which correspond to those traffic lights set up on those section with an entrance way to the network and that are intented to balance the flow.
- S = Non-protected gates. Defined as {PN} \ {P}

- L = Segments of the roads/streets
- T= Periods on which a decision must be taken.

- $N(t) \in \mathbb{R}^{|T|}$: Number of vehicles included in PN for each period t.

- Time-Delay (τ): is the travel time needed for gated vehicles to approach the PN. In this case, τ has been considered negligible.

- $q_g(t)$: gated flow. Reprensents the amount of flow that approaches or arrives to the PN vicinity and must be decided which quantity of this would be gated.

- $q_{in}(t)$: Part of the gated flow that enters the PN for each period t.

- $q_d(t)$: Others inflows (non-gated or internal) to the PN for each period t.

- $q_{out}(t)$: PN exiting flow for each period t.

Finally, an algorithm is constructed to perform the Gating traffic control, this task was carried out in two weeks. The validation of the simulation model has been difficult due to the few data that have been taken to perform it.

<u>Methodology</u>

The list of measured parameters in M10.1 included:

- flow of each section of the road
- travel production: product of the section flow and the length of the section
- weighted average flow of the network (22@ area)
- density of each section of the road:
- accumulation of the section: product of the section density and the length of the section
- weighted average density of the network
- average travel time of the network
- average speed of the network
- CO2 emissions
- energy consumption

The parameters have been evaluated through the implementation of microsimulation with the use of the Aimsun software. The input data, that have been used, are the measurements of the occupancy, evaluated through loop detectors put under the pavement of the street, collected on the 1st of March 2018. These measures have been used to adjust the input O/D matrix of the network, evaluated through the Transcad software.

The accuracy of the real data gathered through the loop detectors for the study area is not so good due to the lack of number of detectors placed in the study area. Since in this area the city of Barcelona has few installed sensors to collect data. In addition, these data collected from the loops have been filtered on the basis of the error: the measures of the occupancy have been taken each fifteen minutes and grouped each four fifteen minutes to have an hour, and then it has been seen, if only one of these has an error the whole group is considered not acceptable. Finally, once the real data have been filtered, the adjustment of the O/D matrix has been done in order to update the original O/D matrix on the basis of the new real data collected.

The model of the network has been created with the help of the Aimsun software.

Then the network has been calibrated with the traffic light configuration of each signalized intersection, with the all surface public transport lines that crosses the study area, with traffic state and traffic demand in order to create scenarios with experiment. The last one is needed in order to achieve a simulation of the traffic of the study area.

The scenario to be created is a dynamic scenario which generates the experiment type: the kind of test chosen is a Microsimulation with Stochastic Route Choice as assignment approach.

Finally, the simulation is done and the parameters are evaluated. The output data are gathered each 5 minutes from 6.30 to 9.00 in order to track the traffic in during the peak hour.

The scenarios that are created are:

- base scenario: in order to see how is the actual situation of the traffic in the study area;
- scenario with different demand factor: ones where the demand factor is increased and the others where it is decreased in order to forecast the growth of the traffic and the reduction of the mobility when some gating strategies introduced, respectively. For this process, an algorithm is used.

The algorithm involves for each period on which a decision could be made, in this case 5 traffic light cycles, which is equal to 8 min, to regulate the inflow of vehicles in order to maximize the amount of vehicles within the network while the network speed is preserved according the capacity of the network and the demand that request to enter to the PN area. It must be pointed out, that the decision taken in the period t, would affect all along the next period, which in fact is stochastic. Decisions are based upon the flows equated the actual flow. However, on the course of the simulation this flow changes along the period. Thus, an updating of the indicators for each of the controlled variables is performed in order to measure the state of the network for the next period.

The congestion of the network, in the MFD is given by relation between traffic flux (vehicles/hour) and the traffic density (vehicles/km). Hence, there is a relation with the number of vehicles that are in the network and the corresponding congestion.

The main idea is to obtain the total amount of vehicles within the system that are traveling in a given period, both gated and non-gated, in order to compute the q_{in}, on which the amount of vehicles, N(t), is the closest to the optimum in the PN. The vehicles variation rate is equal to the net flow. Thus, it is possible to define N(t) as:

$$\frac{dN(t)}{dt} = q_{in} + q_d - q_{out} \qquad (1)$$

Beforehand, it is not possible to know which are the actual $q_{in} + q_d$, since those depend on daily average intensity (DAI), therefore it is not possible to calcultate precisely its value in the evaluated interval.

Hence, those are considered constant for all along the interval. On the other hand, it is feasible to define exit flow q_{out}, as a function of the amount of vehicles within the system, since there is a straightforward relationship between the system density and its flow rate.

The function that states the relationship between these variables can be fitted linearly according whether the system is congested or not. This can be easily shown in the fundamental diagram flow below:

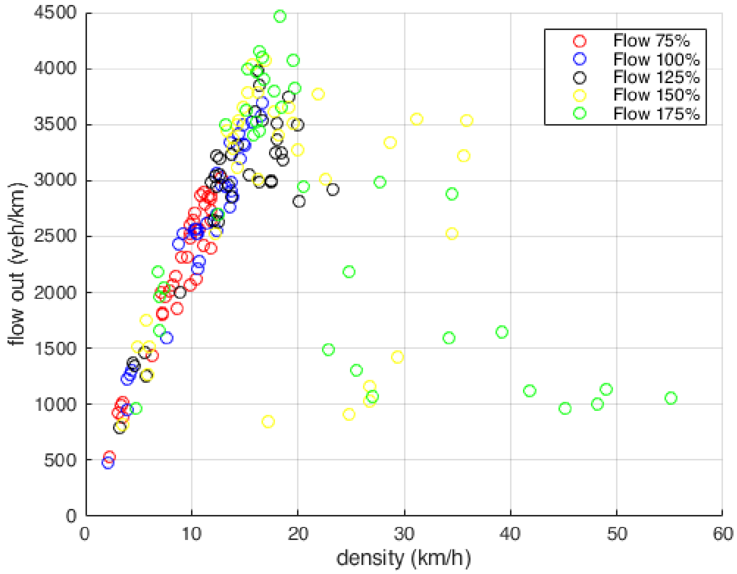

Figure 190: Macrofundamental Diagram for the PN selected

$$q_{out}(t) = \alpha_t + \beta_t \cdot N(t) \quad (2)$$

Once the change of variable is done in the equation before, this one turns out to be in the following ordinary differential equation:

Considering the following notation:

$$\frac{dN(t)}{dt} = q_{in}(t) + q_d(t) - (\alpha_t + \beta_t \cdot N(t)) \quad (3)$$

And with the aim of simplicity defining A as:

$$A = q_{in}(t) + q_d(t) - \alpha_t \quad (4)$$

The equation (3) results into:

$$\int \frac{dN(t)}{A - \beta_t \cdot N(t)} = \int dt \quad (5)$$

Once the differential equation is solved, the number of vehicles in function of time and the network flow for the given period is obtained. Finally, as a result of the differential equation, only must be computed the initial conditions in order to set the integration constant.

$$N(t) = \frac{Ce^{-\beta_t \cdot t} - A}{\beta_t} \quad (6)$$

Where C is the integration term.

$$N(t_0 = 0) = \frac{Ce^{-\beta_t \cdot 0} - A}{\beta_t} = N_0 \rightarrow C = N_0 \cdot \beta_t + A \quad (7)$$

$$N(t) = N_0 e^{-\beta \cdot t} + \left(\frac{e^{-\beta_t \cdot t} - 1}{\beta_t}\right) \cdot (q_{in}(t) + q_d(t) - \alpha_t) \quad (8)$$

Setting $N(T)$ being T as the interval length in which the decision would be made, 8 min, net flow in the sytem can be easily determined and the inflow that must be gated along the period is equation (2) can be transformed into:

$$q_{in}(t) = \frac{N_{opt} - N_0 e^{-\beta_t \cdot t}}{\left(\frac{e^{-\beta_t \cdot t} - 1}{\beta_t}\right)} + (\alpha_t - q_d(t)) \quad (9)$$

Lastly, in order to relate the actual inflow q_g gated and the flow $q_{in}(t)$ that must be gated into the network. The amount Φ, that relates the arrival flow with the actual inflow is given by:

$$\Phi(\mathrm{t}) = \frac{q_{in}(t)}{q_g(t)} \tag{10}$$

As stated before, this computations are done for each interval, the results obtained are send to the simulation in order to update the traffic light sequence and apply the corresponding gating policy reckoned. Once in the simulation the time of the interval is consumed a new decision, each 8 minutes, must be made, the correspoding parameters are updated and the desired sequence is again computed in order to balance the net flow.

Results

The results referred to the baseline, with density-flow, speed-density and flow-velocity graphs are shown in Figure 191, Figure 192 and Figure 193. The baseline density is 15,67 veh/km, speed is 34,8 km/h and flow is 365,4 veh/h.

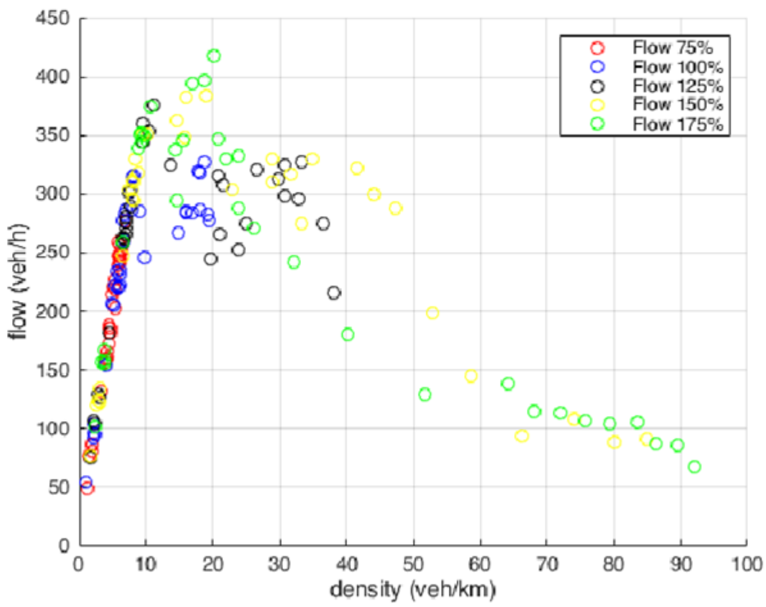

Figure 191: MFD for loading PN for all replications (density-flow)

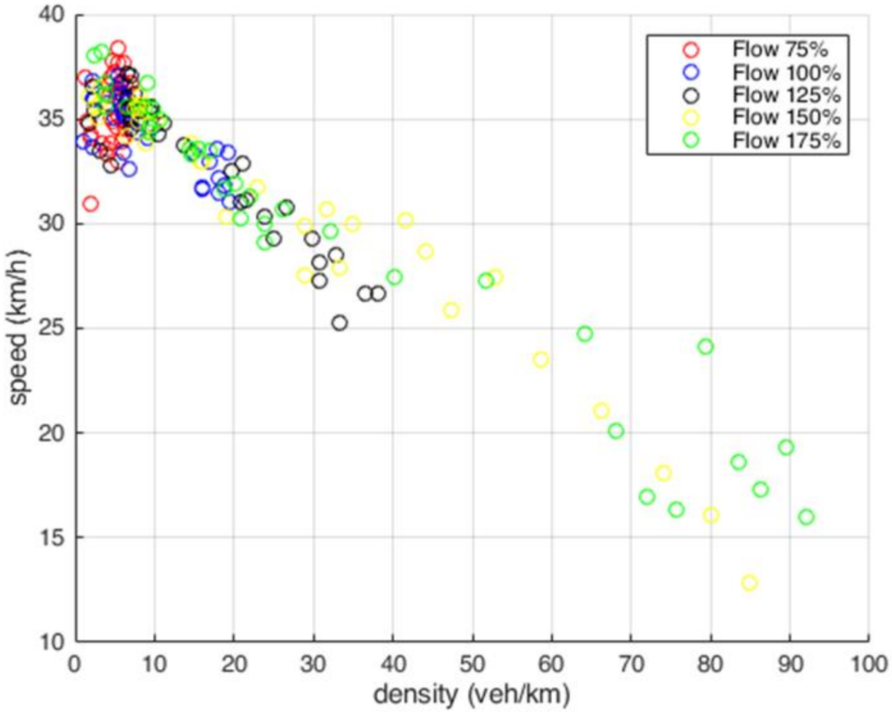

Figure 192: MFD for loading PN for all replications (density-speed)

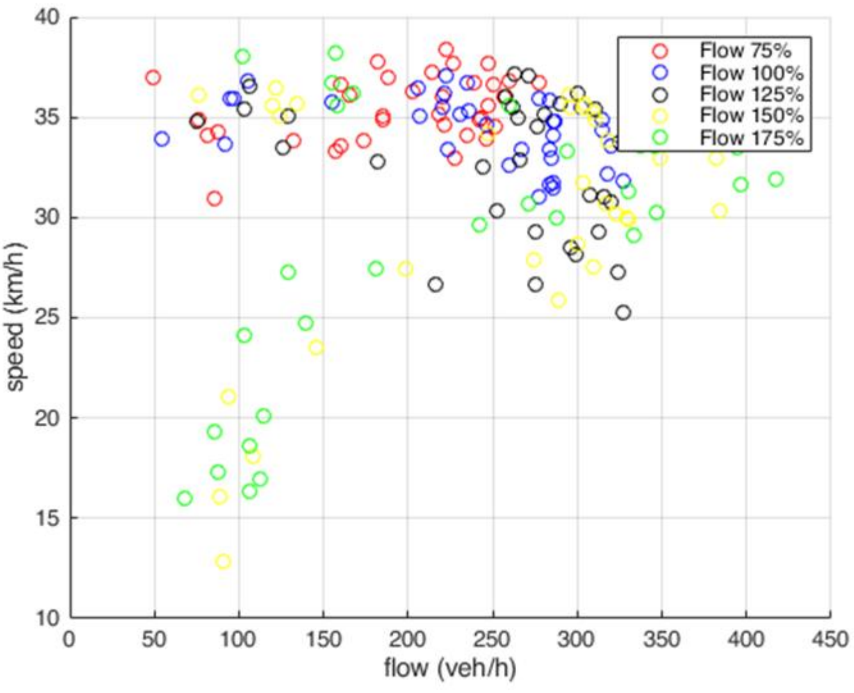

Figure 193: MFD for loading PN for all replications (flow-speed)

In order to analyse how the simulation evolves, both in the application of the gating measure and the current situation in which a flow control is not applied, some indicators are ilustrated in Figure 194.

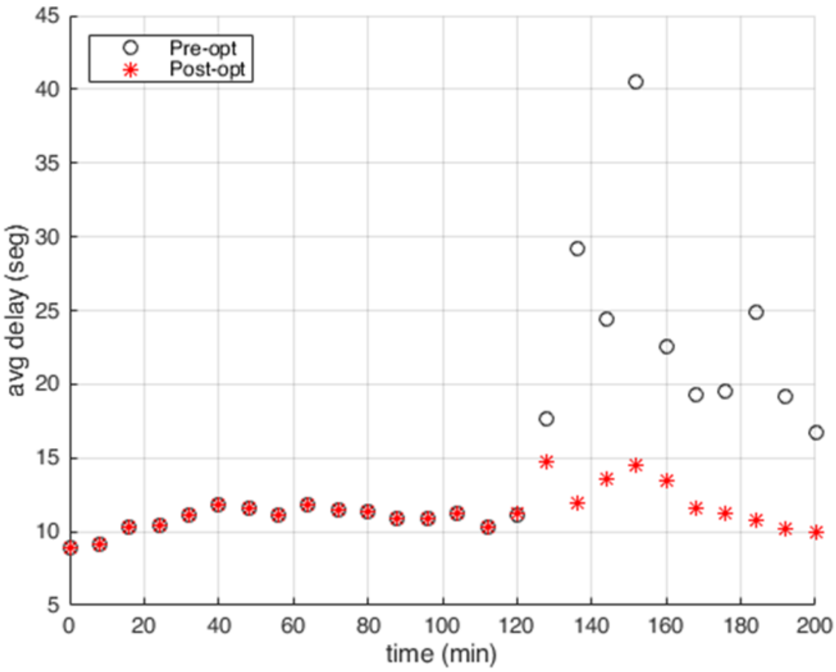

Figure 194: MFD average delay in seconds comparison between gating and non gating

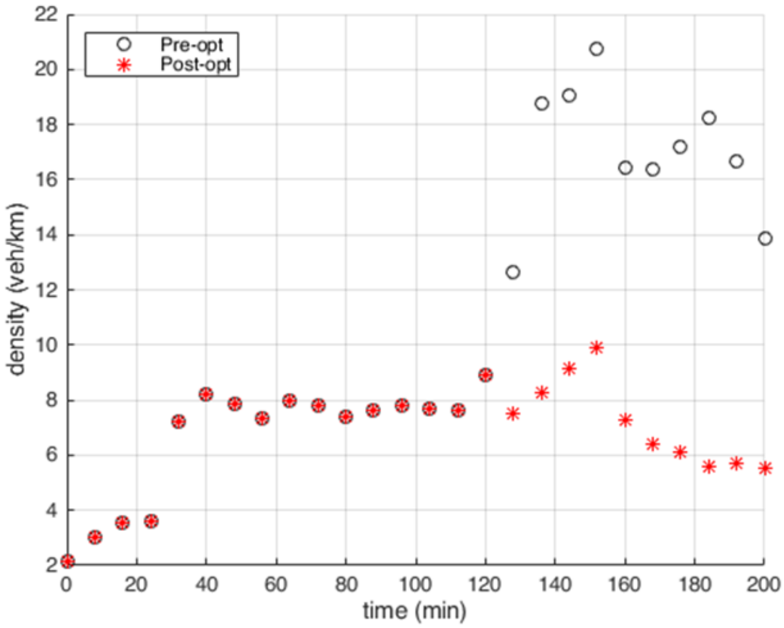

Figure 195: Density in the network along the simulation

The figures show a clear tendency in the reduction of density and the mean delay of the vehicles crossing the network.The results show a similar performance whenever the network is in a status where it can deal with the flow of vehicles i.e. the network is far from being collapsed and is not in a state in which it is close to the congestion threshold. Nevertheless, as longs as the number of vehicles increase, and thus the network starts to be in congested, or close to reach the peak of its saturation, the gating shows a clear way to improve the performance of the network by adjusting the traffic within the PN.

In terms of CO2 emissions (Figure 196), the average CO_2 in the non gating simulation is around 1089,3 g/Km. However, once the gating is applied the amount of emissions of CO_2 reaches a fall until 925 g/Km. Similarly, the amount of NO_X without gating measure is around 1.69g/Km, while the gating measure reduces this quantity until 1.42g/Km.

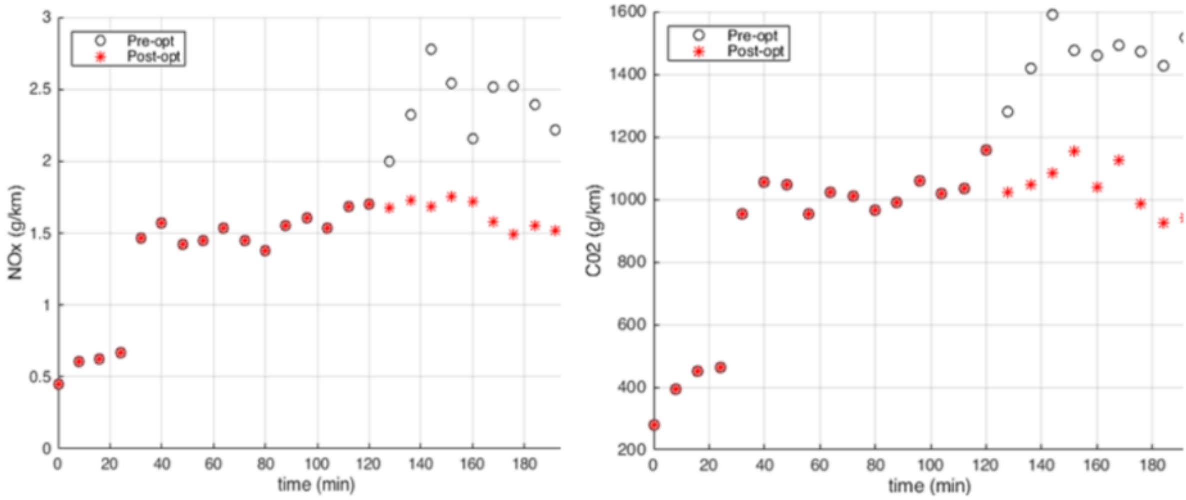

Figure 196: Emission reduction in terms of Nox and CO2

KPIs

Table 199 shows the KPIs evaluated for M10.1 in Barcelona.

Table 199 KPIs evaluated for M10.1, Barcelona

Measure 10.1	Total estimated reduction of emissions due to measure 10.1 based on indicators (Kg NOx)	Total estimated reduction of emissions due to measure 10.1 based on indicators (Kg CO2)	Increase in the average cruising speed for both inner and passing routes (km/h)	Average time savings for both inner and passing trips (aggregated time measurement)	Reduction in traffic density in the area of study(vehicle-kilometer)
Baseline (Non gating measure applied)	1.69 kg NOx	1089.3 Kg CO2	34.8 km/h	10.6 min	15.67 veh/km
Gating	1.42 kg NOx	925.2 Kg CO2	36.01 km/h	6.81 min	11.36 veh/km
% Difference between application	-16%	-15%	+3%	-35,8%	-27,5%

Potential for full scale implementation

Technical feasibility

Technically, this measure can have many problems for its implementation, since, it would be necessary to study what happens outside the PN. Sub-zone optimization can lead to serious problems in the rest of the city. The only way to know it would be to study the whole area, but we must create the entire simulation model for the remaining area. Which takes a lot of time and resources to create it.

Economic feasibility

The theorical implementation of the MFD is difficult to analyse concerning economic feasibility, because it is very complicated to really calculate the impact that it will have on the whole city, and not only focus on a sub-area of it.

Upscaling and replicability of the Measure

The MFD has some properties to apply, as already mentioned, another important feature is that the area to start the MFD must be no more than 10 km2. From here, if you study the area where you want to apply it could be feasible.

Implementation issues

Difficult to validate the simulation model.
The main difficulty is the validation of the simulation model. Since, if applied to large cities, it has to be defined by sub-zones (maximum of 10km2), where it will be formed by many entrances and exits to the city. To not let vehicles enter the studied area, will harm other areas of the city which we can not control. All this would not happen to small populations or areas of less than 10km2, because the entire area could be controlled. Another problem is that you need a lot of information at the micro level to be able to simulate the model. You also need to install many sensors and counters in the area you want to study.

Conclusions

A study of this style is very complex and requires many sources of information, and to validate the data empirically, real data of sensors are needed in the street. If these data are not available, the analyses are complicated, and in Barcelona, there is a deficit of data in this regard.

The optimization of the network in terms of MFD diagram adjusted is performed in a simulation of 200 min. The results show a good performance in reduction of all the parameters assessed, in speed/density, average speed and emissions reduction. The improvement of the network performance in terms of the KPI analysed, are widely proved for large amounts of demand over the capacity network established. It has been demonstrated empirically that, the larger the number the vehicles within the network, the greater the benefit for using the gating control. This is indicated by the indicator of density and the average trip time to the PN, where they have decreased by 27.5% and 35.5%, respectively.

Additionally, and as it should be expected, gating does not contribute to enhance oversized networks. Thus, a key-point in the gating control is to know accurately where the measure may be applied. Therefore, a previous analysis to assess which traffic lights could be appropriate to be candidates to be used for the gating control, not only in terms of capacity of the section to allocate the queue formed by the control, but also taking into account the potential demand attraction of section, is required.

This trend, in further analyses, should be to demonstrate whether for some point in which the demand is so huge, the queue formed by the gating could spoil the goodness of the measure. Furthermore, link capacity on those segments where the queues are formed by the gating have been considered limitless. A new model that incorporates the righteous and more realistic modelling constraints according the real capacity of the road would contribute to enhance the representability of the simulation and its respective results.

M10.3 – Travel Demand Management

Introduction

A smart phone application (based on an existing application called CERO Challenge) is developed to follow up changes in travel behavior among residents living in the area of Årsta. The smart phone application was also implemented on a test basis at the municipality Haninge in Stockholm county. The aim is to obtain a better real-time update of transport behavior in comparison to traditional travel surveys. This app can also function as a useful information channel regarding travel demand management Measures, as well as collecting data evaluation of transport measures.

This is an enabling measure, enabling services used in the other work packages. Therefore, this enabling functionality is the main scope of the evaluation of this measure.

According to the evaluation plan, the application will stimulate alternative emission/energy efficient transport modes through the idea of "gamification". The application can also provide key performance indicators of the day-to-day changes in travel behavior due to implementation of specific travel measures of interest.

Stockholm

Industry partner	Contact person	Validation partner
KTH, Stockholm Exergi	Markus Robèrt	KTH-SEED

The aim of this measure is to encourage and provide information about climate efficient forms of transport. In addition, the application of a travel app is also a way to test a new and potentially effective way of collecting day-to-day travel data for the evaluation of implemented transport measures in the area. A next challenge with the travel application is to encourage a high use rate among the tenants of Valla Torg.

A beta-version of a smart phone application (called CERO Challenge) was developed in order to obtain a better real-time update of transport behavior in comparison to traditional travel surveys. This will also function as a useful information channel regarding travel demand management measures, as well as an effective way of collecting data for the evaluation of transport measures in the area during the whole project period.

The travel app now incorporates a number of functions that aims at logging daily travel activity by use of GPS in modern mobile phones, and to encourage competitions among neighbors/friends and colleagues in reducing emissions and increasing physical activity in their daily travel. The app also incorporates a portal displaying services and transport modes reducing your emissions (which was the initial scope of measure 11.5 now merged with measure 10.3). Figure 197 below displays the first welcome/start-page of the app (the app is in Swedish).

Figure 197 Home screen (M10.3)

In order to track your daily travel activities, you need to define type of travel activity (work commute, business travel or leisure), and type of transport mode used. When pushing the green start button the trip is recorded and the app provides you with instant feedback on travel times, kilometers, velocities and emissions. All travel data is stored over time, in order to display changes in travel behavior over time (Figure 198)

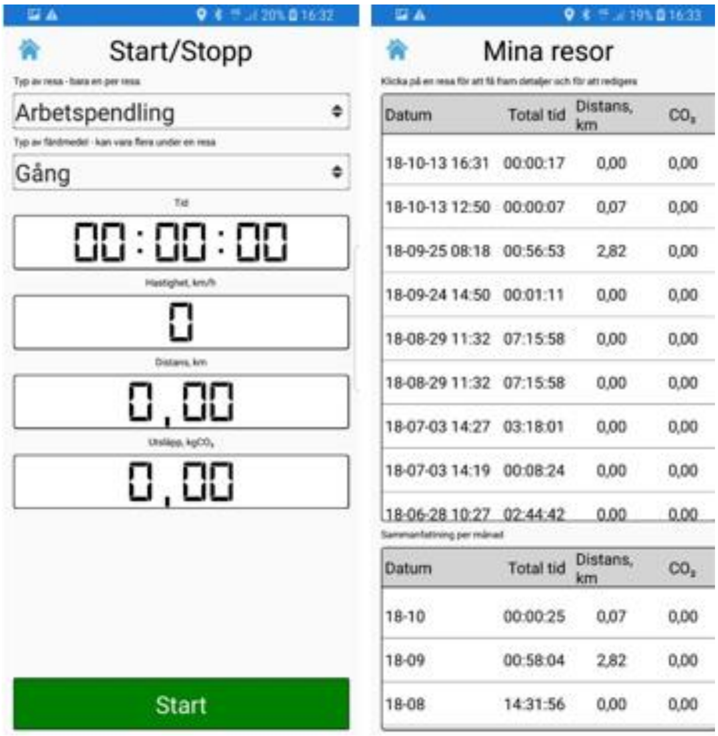

Figure 198 Logging of travel activities (M10.3)

To encourage low emissions and physical activity, the app allows users to challenge each other based on a) kilometers walking and cycling, b) minutes of physical activity, and c) emissions per kilometer. The three variables generate a ranking for each user. In order to compete, the users create a challenge (name and purpose), and choose a competitor (email address to another user of the app). All standings in present and past challenges are displayed when pushing the third button in the menu (figure 4).

Figure 199 User challenge feature (M10.3)

The travel app incorporates a portal of feasible ways to reduce travel emissions, such as:

- guidance to renewable fuel stations
- electric charging stations
- maps of cycle paths
- public transport planner
- car sharing operators
- ride-matching systems

Results

Quantitative results was collected since the first launch of the travel app (December 2017). Besides the tenants in Årsta, the app was also released on a test basis for employees in Haninge municipality which is a neighboring municipality in Stockholm County. In order to evaluate the use rate of the application and the functionality of the application, the following KPIs were useful:

- Number of users of the application: 87
- Number of trips logged in the application: 1114
- Number of trips logged in the area of Årsta: 22
- Test period: 2017-12-16 to 2019-06-10

These parameters have also provided evaluation material in order to test the precision of the app and to follow the travel activities of the first users of the app in the Area of Årsta. An example of data provided from the travel activities registered in the app is displayed below (travel activities in Årsta, each column provides variables of interest that are used for empirical analysis of the functionality of the app).

location_id	trip_id	UserId	Longitude	Latitude	Accuracy	Speed	distance	Accumulated	TimeStamp	TransportTyp	location_stat	transport_ty	gCO2Emissio	gCO2EmissionsAccumulated
56651	502	1035	18.02579821666	59.30010136666	5	27.16266666666	NULL	10086	2018-04-25 23:18	3	a	car (petrol)	NULL	2017.2000000
56652	502	1035	18.0254497	59.30027156666	5	27.05977777777	NULL	10113	2018-04-25 23:18	3	a	car (petrol)	NULL	2022.6000000
56653	502	1035	18.02513405	59.30042543333	5	27.00833333333	NULL	10138	2018-04-25 23:18	3	a	car (petrol)	NULL	2027.6000000
63487	586	1027	18.0744426	59.305902	10	1.615024685859	21	19771	2018-05-06 09:43	1	a	walk	0.0000000	0.0000000
63488	586	1027	18.0745285	59.3057132	10	1.593572497367	22	19793	2018-05-06 09:43	1	a	walk	0.0000000	0.0000000
63489	586	1027	18.0747244	59.3055488	10	1.769182205200	21	19814	2018-05-06 09:43	1	a	walk	0.0000000	0.0000000
63686	587	1015	18.07647096926	59.30521514737	10	2.170000076293	20	11203	2018-05-06 09:45	1	a	walk	0.0000000	0.0000000
63687	587	1015	18.07675721125	59.30459639528	10	1.309999942779	71	11274	2018-05-06 09:45	1	a	walk	0.0000000	0.0000000
63688	587	1015	18.07658647188	59.30421162402	10	0.379999995231	44	11318	2018-05-06 09:46	1	a	walk	0.0000000	0.0000000
63827	589	1027	18.0766166	59.3042102	37.23099899292	0	20	0	2018-05-06 13:18	1	a	walk	0.0000000	0.0000000
63829	589	1027	18.0765586	59.3046456	10	1.032414674758	49	49	2018-05-06 13:18	1	a	walk	0.0000000	0.0000000
78550	672	1015	18.07699609549	59.30428748024	10	1.720000028610	50	7648	2018-05-13 09:35	1	a	walk	0.0000000	0.0000000
78551	672	1015	18.07706868277	59.30410286882	10	1.809999942779	21	7669	2018-05-13 09:35	1	a	walk	0.0000000	0.0000000
78552	672	1015	18.07681236417	59.30393749387	10	0	24	7693	2018-05-13 09:38	1	a	walk	0.0000000	0.0000000
78553	672	1015	18.07701126674	59.30412105755	10	0.870000004768	23	7716	2018-05-13 09:41	1	a	walk	0.0000000	0.0000000
94806	742	1027	18.0743187	59.3058587	10	1.57153236866	21	19632	2018-05-27 09:53	2	a	bike	0.0000000	0.0000000
94807	742	1027	18.0744372	59.3056505	10	1.496253609657	24	19656	2018-05-27 09:53	2	a	bike	0.0000000	0.0000000
94808	742	1027	18.0746471	59.3054812	10	1.693943858146	22	19678	2018-05-27 09:53	2	a	bike	0.0000000	0.0000000
119932	1296	1060	18.0757388	59.3053714	10	1.367284893989	21	20445	2018-09-15 15:22	9	a	public transport	0.8400000	817.8000000
119933	1296	1060	18.0753702	59.305298	10	0.340392678976	23	20468	2018-09-15 15:23	9	a	public transport	0.9200000	818.7200000
119934	1296	1060	18.075004	59.3053342	10	0.987268567085	21	20489	2018-09-15 15:23	9	a	public transport	0.8400000	819.5600000
119935	1296	1060	18.0746847	59.3054461	10	0.991775810718	22	20511	2018-09-15 15:23	9	a	public transport	0.8800000	820.4400000
120306	1298	1015	18.07505330176	59.30525817090	8	0.194508954882	0	0	2018-09-15 15:23	1	a	walk	0.0000000	0.0000000
120307	1298	1015	18.07483235107	59.30533874014	6	1.000671744346	15	15	2018-09-15 15:23	1	a	walk	0.0000000	0.0000000
120308	1298	1015	18.07470135123	59.30542376270	6	1.191552519798	12	28	2018-09-15 15:23	1	a	walk	0.0000000	0.0000000
120460	1297	1060	18.0745245	59.3055283	10	0.461976259946	22	0	2018-09-15 15:24	1	a	walk	0.0000000	0.0000000
120461	1297	1060	18.0744205	59.3057001	10	1.010926842689	20	20	2018-09-15 15:24	1	a	walk	0.0000000	0.0000000
120462	1297	1060	18.0743628	59.3058808	10	1.326715230941	20	40	2018-09-15 15:24	1	a	walk	0.0000000	0.0000000
121155	1319	1034	18.0252808	59.2998515	10	16.83712577819	33	1258	2018-10-01 18:26	6	a	car (biogas)	0.9900000	37.7400000
121156	1319	1034	18.0259495	59.2995474	10	17.10805320739	51	1309	2018-10-01 18:26	6	a	car (biogas)	1.5300000	39.2700000
121157	1319	1034	18.0263912	59.299335	10	17.56687736511	35	1344	2018-10-01 18:26	6	a	car (biogas)	1.0500000	40.3200000
123129	1357	1068	18.07589479683	59.30558247278	4.000604136840	20.23327827453	20	401	2019-02-19 06:01	3	a	car (petrol)	4.0000000	80.2000000
123130	1357	1068	18.07579067751	59.30576046059	6.000906205260	20.25125122070	21	422	2019-02-19 06:01	3	a	car (petrol)	4.2000000	84.4000000
123131	1357	1068	18.07568390909	59.30592875971	8.001208273680	20.18481636047	20	442	2019-02-19 06:01	3	a	car (petrol)	4.0000000	88.4000000

In order to link information about the use of the travel application, and information about user groups, demographic segmentations, gender, age etc., a travel survey was conducted (which also included questions regarding all demographic variables, travel behavior etc.). Evidently, just one respondent of the 52 tenants answering the survey was using the application which made it impossible to draw statistical conclusions. However, as seen from the campaigns conducted, where the application was presented to the tenants, interest was very low for technologies such as this.

Potential for full scale implementation

Technical, economic and social feasibility

The measure is technically ready for large scale implementation and no further challenges remain regarding GPS-tracking or other development tasks.

The travel app has potential to create and strengthen a community actively adapt to future climate targets once all tenants have moved back to the refurbished houses. Sweden has a quite ambitious climate target, saying that we should aim for a fossil independent transport system at 2030. The travel app could potentially work as a positive trigger to reach this target at a local (and individual) level. The competition-part of the travel app is targeting involvement and positive “coopetition” among neighbors, friends and colleagues.

Upscaling and replicability of the Measure

The travel application is fully transferrable to other cities or regions anywhere in Europe. Adjustments need to be done regarding emission values for vehicles and the portal for energy efficient mobility management services needs to be adapted for local circumstances and providers of the specific services. During spring 2018 the app was presented at a large European mobility management conference (ECOMM), resulting in two Swedish municipalities that decided to implement the app as a nudging-tool to influence employees to more climate efficient travel behavior. This proves that the app has potential for transferability and replicability in other cities/organizations as a tool to trigger sustainable transport behavior.

Conclusions

The development of the travel application was quite challenging during the test-phase of the positioning system, where the development team had problems with providing sufficient precision in the tracking function, without draining the mobile telephone’s battery reserve (necessary feature for the tracking of individual travel behavior and emission impact from different travel modes). Once the positioning system was robust and not too energy consuming to the batteries, the next technical challenge was to make the application user friendly, and to develop the particular challenge/competition-feature to trigger social interaction and competitiveness. At present all functions work well together, and the application does what is expected from it. However, the attractiveness of the app would significantly increase if more users were registered and could potentially compete in low emission travel behavior. The integration of a smart-travel advisor (i.e. a portal of feasible sustainable travel alternatives in the area), will hopefully attract users to download the service. Once a sufficient use rate is reached (at least 1000 users), the plan is to develop a sustainable business model in order to manage future development and maintenance costs. One idea to discover further is to find partnerships with the different providers of mobility management services displayed in the app (car sharing companies, ride matching systems, bike stores, electric vehicle companies etc.).

A communication- and demonstration plan has been developed in cooperation with the landlord Stockholmshem in order to reach out to tenants and invite users to the app. The app was released and accessible for tenants 2017-12-16 and was presented in a first public launch to tenants April 2018. This is also a way to disseminate information about the new mobility management alternatives (the newly launched GrowSmarter measures) that are now available for the tenants. After the first test launch of the travel app, data was collected in order to evaluate the accuracy of the GPS-positioning, CO2-calculations of different travel modes, velocities and other technical functionalities essential to the app. One calibration was made regarding the interval of GPS-traction points, where we decided to limit the number of GPS-reports per time unit in order to optimize energy use of the mobile phones (phones ran out of battery when GPS-precision was high, i.e. we needed to reduce number of traction points per minute). Another modification needed was to improve the user friendliness of the interface.

A conclusion made after studying the demographic variables from the travel survey conducted initially, was that tenants in the area are dominantly elderly people, not too experienced with IT-services like this travel app (the low demand for mobile applications was also verified at the time of the first contact with tenants during the launch of the app in april 2018). 76% of the tenants in Valla Torg are older than 50 years, and 55% older than 65 years. Furthermore, only 17% of the tenants use private car for daily commute. Thus, even though the travel app was designed to be as simple, intuitive and user friendly as possible in order to match the criteria of not so app-experienced users, the demographic population was clearly not the ideal target group for this particular technology. A recommendation for future projects aiming at designing technologies and energy efficient travel alternatives for tenant districts or particular populations in the transport system, would be to conduct a thorough market survey before deciding which solutions are to be developed. The same conclusions could be made for all GrowSmarter-measures that involves development of mobile app technologies (such as the car sharing service, electric bike-sharing facility and the smart delivery room).

M10.4 – Traffic control system for passenger vehicles

Introduction

This Measure will use open traffic information data to find the traffic rhythm and route to allow for a smooth ride with as few stops and queuing as possible, thus reducing congestion. The equipment will be used on EVs to add an extra incentive for these cars.

According to the evaluation plan (D5.1), the intention of the Measure is to provide:
A) Transition to more energy/emission-efficient transport alternatives
B) Transition to renewable fuels
C) Improved traffic flows

The baseline is expected to be determined according to the tables provided in the evaluation plan (D5.1).

The key performance indicators for this Measure are expected to be determined according to the tables provided in the evaluation plan (D5.1).

Stockholm

Industry partner	Contact person	Validation partner
Insero	Jens Christian Loedberg	KTH-SEED

The evaluation of M10.4 has been carried out by Insero in collaboration with Stockholm Stad, Network of Automotive Excellence and KTH.

The measure was established with the vision of utilizing a smart traffic light assistance system (TLAS), which was and is being tested by several automotive OEMs around the globe. The target with the implementation of the system was to evaluate the potential improvement of the overall traffic flow in the city of Stockholm it could bring and explore the opportunity of turning it into an incentive for green vehicles by making it exclusive to plugin vehicles.

The measure was managed in collaboration between Network of Automotive Excellence (D) and Insero (DK), two organizations who have previously facilitated implementation of innovative technologies in collaboration with product and service providers. Stockholm Stad's traffic department played a central role in the implementation of the system as well as creating the best possible setup for testing. KTH have validated the test setup, the evaluation process and conclusions.

Previous theoretical evaluations of the system, showed a significant increase in flow of 4 % when 20 % of the vehicles were equipped with a smart TLAS and an increase of 17 % if all vehicles were equipped. This resulted in a reduction of energy consumption of 23 % according to previous tests in USA. The tests in measure 10.4 were done to investigate if similar results were realistic on a single vehicle level in Stockholm traffic.

Qualitative tests with non-experts were planned to investigate the average person in Stockholm's interest in the system and whether this could move people's interest in green vehicles, if the application was exclusive to this car group. In this measure, "green cars" are defined as Battery Electric Vehicle (BEV) only

Test setup

The initial test setup was constructed on a combination of quantitative and qualitative tests methods in order to be able to achieve valid conclusions on the three predefined key questions to answer with the measure:

· Will a TLAS for cars create a time saving for the individual vehicle driver?

· To what extent will a TLAS for cars reduce the energy consumption for driving, hence improve the TCO of the vehicle?

· Will a TLAS for cars have an effect on people's choice of propulsion method for their cars if it was only applied to BEVs?

The approach was structured as can be seen in Figure 200 with a combination of qualitative and quantitative phases.

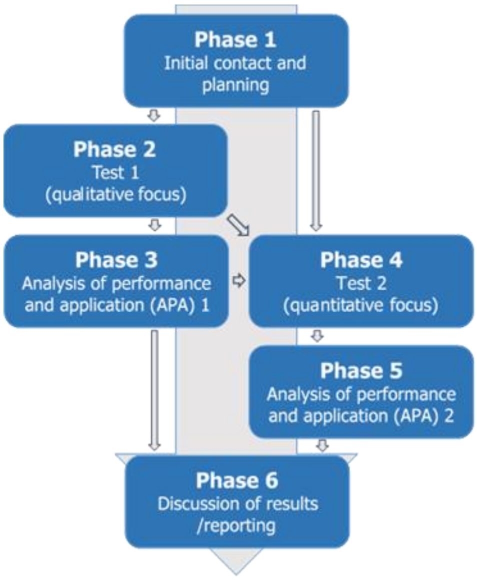

Figure 200 Test procedure for M10.4

Due to practical and legal issues with respect to the test vehicle provided and challenges with the technical integration, the test plan was shortly before the actual tests altered. Instead of starting with the qualitative phases, the initial tests of the system were used to gather quantitative data to reach higher efficiency on the data collection.

Another alteration to the original test plan was the number of vehicles being used for the test. Initially planned to be conducted with two cars, the test was reduced to one car due to not being able to compare data from the two vehicles when they traveled in opposite directions and because of lacking availability of resources from partners. In order to get as close a comparison between the traffic status, every second drive was made with the TLAS on and every second was made under normal conditions.

The route for the testing was chosen in collaboration between Stockholm Stad's traffic department and experts from the supplier of the Traffic Light Control System with the criteria:

· Good connection to signals

- Large deviation in flow of traffic during the day
- Possibility of having a circular route (natural turning points)
- 10 traffic lights on the route

Based on these criteria, it was chosen to conduct the test on the route of Ulvsundavägen in Bromma on the stretch from Travbanevägen to the intersection with Drottningholmsvägen, see Figure 201. The route contains 14 traffic lights with a combination of road intersections and pedestrian crossings. An important note is, that two of the traffic lights were not connected to the Traffic Light control system and could therefore not be displayed in the TLAS. These have been marked with yellow in the map of the test route.

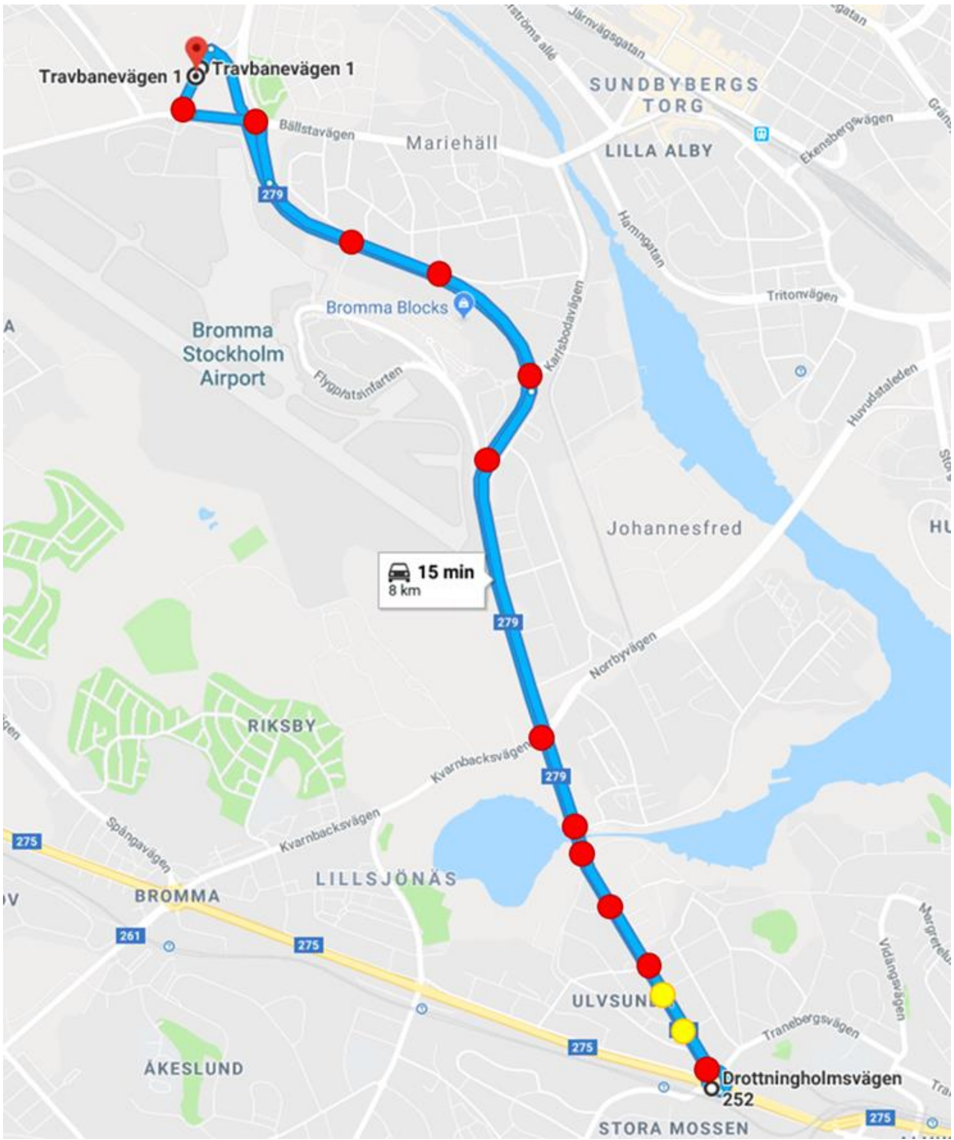

Figure 201 Choosen route for the testing (M10.4)

Since the test did not perform as expected, the test driver has written a test resume in order to explain and map the challenges and struggles from the driver's perspective and how this may have affected the quantitative test.

<u>Data processing</u>

During the tests of the system a total of 82 test drives were conducted, where 50 % of these were driven with the TLAS active. The test drives were, to the extent that it was possible, distributed evenly between the traffic congestions light, medium and heavy.

The analysis and evaluation of the tests, was conducted based on a test resume provided by the test driver.

Results

Test report by test driver

During the whole test, the same test driver was in place in the vehicle, hence the driver had the opportunity to test the system under all expected traffic situations and densities. After having conducted the planned test drives, a short test evaluation resume was written by the driver in order to evaluate the system and allow for adaptations before potentially starting the second test round – the qualitative test.

A total of 82 test rounds were driven passing 9 traffic lights, which accumulates to 738 crossings.

Two major issues were identified:

Quality of Data

- The data is unusable due to the extreme adaptivity of the traffic lights (144 crossings)
- In each test drive between 3 and 5 crossings were falsely predicted by the system or subject to frequent changes in predictions (30-55 %). This leads to mistrust in the system from the driver which resulted in disregard for the notifications

Non-connected traffic lights

- On the stretch there were at first 5 traffic lights, that were not connected to the system (reduced to 2 in the last days of the test)
- Whenever they were red, they influenced on the speed and consumption of the test
- The fact that the number of connected traffic lights were changed during the test, makes the data from the different periods incomparable.

These observations have led to the main conclusion that accuracy of traffic light forecasts and their predictability are, however, the key factors and the main prerequisite for such trials.

From this test report, it can be seen, that the validity of the tests conducted is very low, and analyses of the data from the sensors mounted in the car will not make sense, as the TLAS was not followed in the test due to very low reliability of the predictions. No results are available.

Quantitative data

As a part of the agreement with the partners involved in the demonstration of the measure, all data will not be made public, as they are to be considered as business-critical information.

A small analysis conducted by the company providing the Traffic Light control system - on the ability to predict the signal - showed that the predictability on some of the lights was very low on certain times of the day (see Figure 202 and Figure 203)

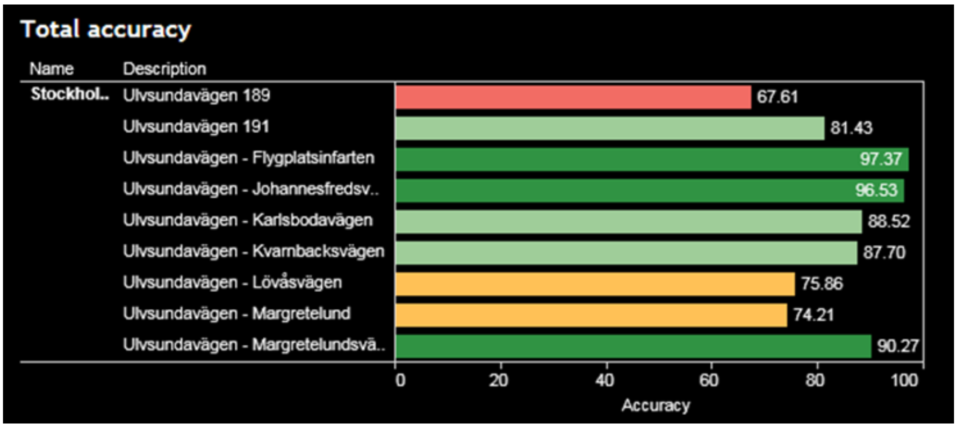

Figure 202 Predictability of traffic lights on weekdays between 15.00 and 18.00

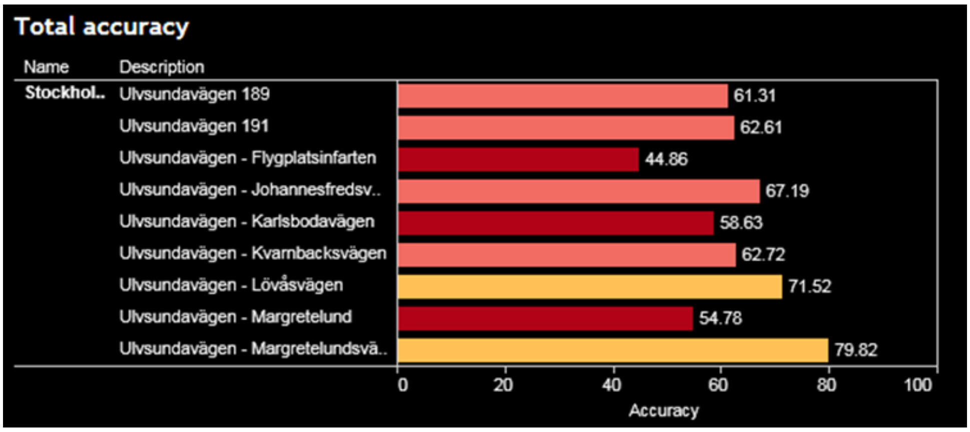

Figure 203 Predictability of traffic lights on weekends between 8.00 and 10.00

This predictability is important to keep as high as possible, as this is what will cause the projection on the screen for the driver and end up providing false information too often, if the predictability is too low.

From the analysis of the data it can be seen that the setpoint for acceptable data levels (dark green) has been set to +90% reliability, which is only achievable on three of the nine traffic lights analyzed during time of medium traffic (figure 2) and on none in rush hours (figure 3).

The reason for this situation, is that the traffic lights in Stockholm, in general, are controlled by the traffic through sensors built into the road. However, these sensors are placed in relatively close proximity to the traffic light providing only 1-5 seconds response time, which influences the predictability significantly.

Potential for full scale implementation

For cities considering how or if to implement the TLAS system, there are several antecedents for successful implementation, which have been organized and defined in Figure 204.

If cities are to invest in the technology, they must identify if a central control system is in place. This system must enable the bidirectional flow of data to ensure communication from the system to, and from, the central traffic light control system. The system must furthermore be accessible for the map operators and car OEMs, through an API or a similar functionality.

If a control system exists, they must identify the use of potential time and/or flow-controlled traffic lights in the relevant area.

If the data is insufficient in quality or quantity, the system must be optimized.

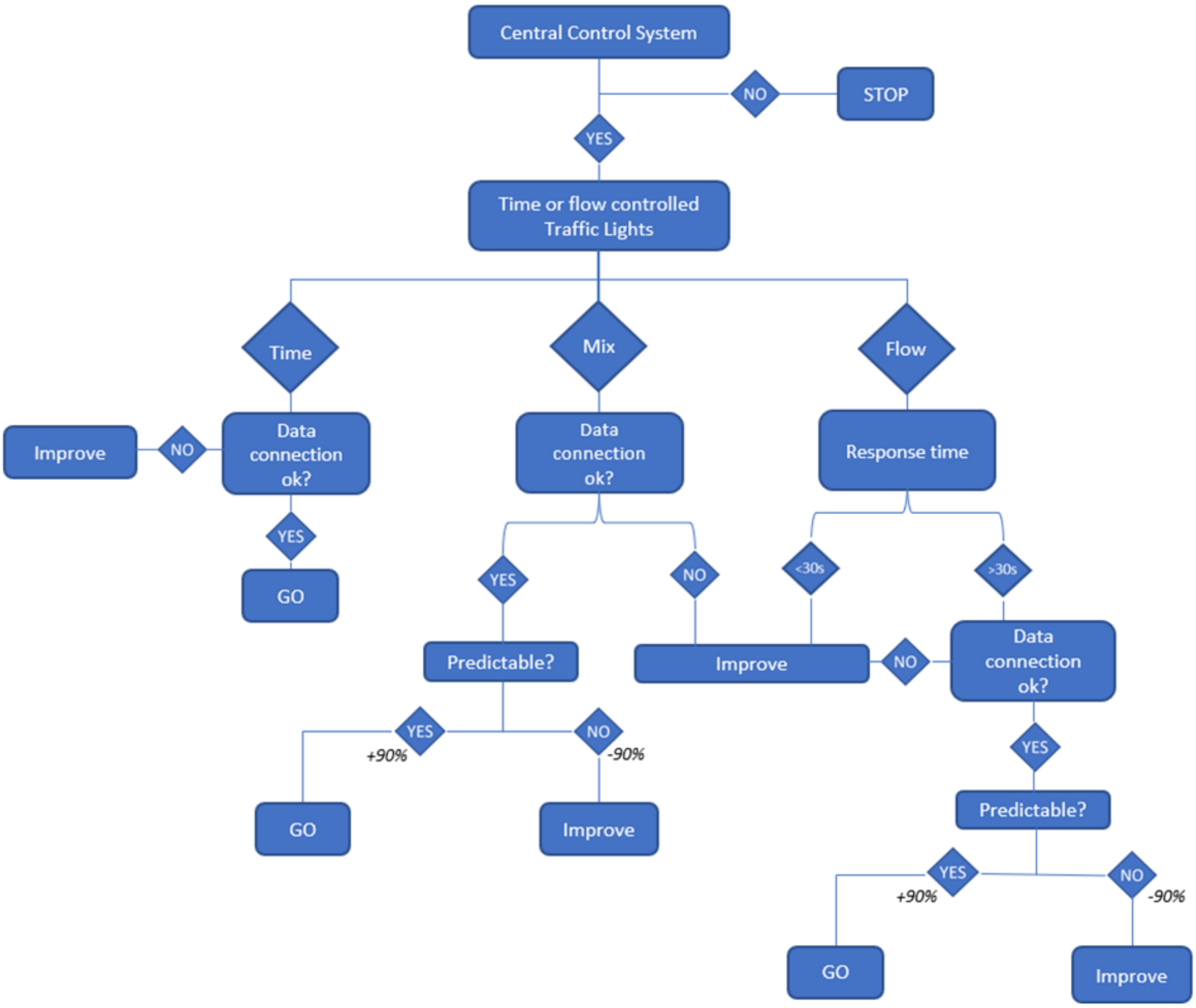

Figure 204 Flow diagram of necessary prerequisites for successful implementation

Conclusions

As can be deducted from above described evaluation; the test of the TLAS had several challenges in its completion, of which predictability was by far the largest. As a consequence, the system could not earn the trust of the driver.

This highly influenced the quality of the data from the test drives, making them non-reliable. No clear conclusion can therefore be made on either time saving through the system, the number of stops or consumption of the vehicle.

It is important to state that the conclusion of not being able to conclude anything is not a statement of the individual technologies performance, but specifically focuses on the tested stretch of road where the combination of the TLAS and the Traffic Light Control system was not able to perform as planned. This was a result of a very short response time from the individual traffic lights, which was caused by the placement of the road sensors that were in close proximity of the traffic light.

As a result of the above conclusions, no qualitative tests with regular inhabitants were performed, which resulted in it not being possible to conclude on the potential interest in the system and how this could move car ownership from regular cars to green cars under the previous stated conditions.

To summarize the conclusion, the following questions could not be answered at this stage:

- Will a TLAS for cars create a time saving for the individual vehicle driver?
- To which extent will a TLAS for cars reduce the energy consumption of driving, hence improve the TCO of the vehicle?
- Will a TLAS for cars have an effect on people's choice of propulsion method for their cars if it was only applied to BEVs?

M10.5 – Traffic signals synchronized to prioritize certain vehicles of movement of goods

Stockholm

Industry partner	Contact person	Validation partner
Carrier, Stockholmshem	Rasmus Linge	KTH-SEED

Measure 10.5 aimed to synchronise traffic signals along a route to enable the prioritisation of freight distribution using HVO (biodiesel)-fuelled vehicles. The measure aimed to reduce tailpipe emissions and improve transport efficiency by reducing the number of starts and stops for heavy vehicles, thereby creating an incentive for use of alternative fuels in freight distribution.

Carrier introduced HVO-fuelled vehicles into their fleet and, together with the City of Stockholm, worked to identify test routes. This proved complicated as various proposed routes could not be implemented due to their wider impact on congestion in the road network. Once a route was identified, the partners defined guidelines for the test and the traffic light network operator adapted their systems to enable the demonstration. Mobiles phones using special software were installed in the test vehicles to monitor vehicle movements along the route.

The collection of data was challenging. During spring-summer 2018, the test appeared to being running as planned. The City of Stockholm had reprogrammed the traffic lights to enable the test, and the traffic light network operator activated and deactivated the system on alternate weeks throughout the year, so that a comparison of operations with and without the prioritisation would be possible. Initial problems with the software were overcome and the partners ancitipated being able to analyse impacts. Nevertheless, when the partners tried to compile the data at the end of 2018, it became clear that the system had failed and had only recorded a small number of vehicle movements.

In early 2019, Carrier worked with the software provider to ensure the interface between traffic lights and mobile phone would function. However, when this was achieved, the partners learnt that the City of Stockholm had removed the equipment to restart the system from the traffic lights. This had to be reinstalled, and during summer 2019, the test was operational. However, the monitoring technique continued to deliver deceptive results, registering only a small number of the vehicle movements, and the attempt to enable comparison between periods with/without the system failed. In sum, this measure was implemented repeatedly, in several stages, yet was unable to deliver satisfactory data to enable validification of the results. One lesson is that the implementation required multiple actors, each of which were dependent on all other parts of the demonstration working in order to fulfill their obligations. Thus, every time there was a problem with one part of the test, it required multiple and parallel adjustments or corrections and create uncertainty or confusion between partners.

To conclude, this measure was implemented in full but resulted in unsatisfactory data. The implementation of the measure has resulted in significant learning for the partners involved. However, the techniques used did function to enable data collection, but were sufficiently unreliable to make validification of quantitative data impossible within the project lifetime.

M11.0 – Alternative fuel driven vehicles

This section presents the results of M11.1 and M11.2.

M11.1 – Charging infrastructure for EVs

Stockholm

Industry partner	Contact person	Validation partner
Stockholm Exergi	Rikard Norberg	KTH-SEED

Fortum delivered aggregated data for 2017 and 2018 for all of their charging facilities in Stockholm to the City of Stockholm for its annual report on charging statistics. This official report shows a range of parameters including energy transmission per charging session, time of charging session, total energy used, etc. Data specific to the fast charging unit in Årsta was also delivered to the city and shared with KTH, although KTH were not able to validate it, as the data was prepared outside of the project using a different methodology. In addition, Fortum and KTH maintained contact throughout 2019 concerning delivery of data for D5.3 and D5.4. Fortum made several submissions to KTH but the information submitted was incomplete and did not comply with the project evaluation methodology. KTH were unable to validate this data. However, as noted above, the City of Stockholm's official annual report on charging statistics includes aggregated data indicating the general trends observed at charging units across Stockholm.

Cologne

Industry partner	Contact person	Validation partner
RheinEnergie Cambio KVB City of Cologne	Christian Remacly Andreas Wolba	KTH-SEED

The goal of the solution is to promote the replacement of fossil fuelled vehicles. The charging infrastructure enables the tenants to charge their electric vehicles. In cooperation with the KVB, car-sharing company Cambio and the park-sharing company Ampido, the tenants will be offered various forms of E-mobility.

A total of 10 charging stations will be installed in the project area Mülheim.

The charging infrastructure for GrowSmarter is being implemented together with the e-mobility. RheinEnergie will implement those columns that are assigned in individual cases by WP4. Lots of planning, including coordination with all affected City departments and transportation agencies as well as North Rhine-Westphalian legislation has taken place and most of the mobility stations are now in place. All stations provide exclusively green electricity for charging.

Charles du Gaulle Platz

Four charging stations are installed here with two charging points each. Two stations are private (one for Cambio and one for Ampido) and two are public. (22kW max. charging capacity)

Figure 205 Charles de Gaulle platz charging station (M11.1 Cologne)

Bahnhof Mülheim

Two charging stations are installed here with two charging points each. Both station are for private use only. (22kW max. charging capacity)

Stegerwaldsiedlung

Two charging stations are installed here with two charging points each. One station is for private use (Cambio) and one for public use. (22kW max. charging capacity)

Figure 206 Stegerwaldsiedlung charging station (M11.1 Cologne)

Von-Sparr-Straße

One private (Cambio) charging station is installed here with two charging points. (22kW max. charging capacity)

Figure 207 Von-Sparr-Straße charging station (M11.1 Cologne)

Regentenstraße

One private (Cambio) charging station is installed here with two charging points. (22kW max. charging capacity)

RheinEnergie measures the number of charging loads for public charging stations as well as Cambio's. Furthermore, the kWh charge is measured from both charging stations types (public and Cambio's). The average charged kW is between 5 kW and 15 kW.

Results

Over 56.000 kWh were loaded at the 10 stations altogether in 2018. Considering an estimated consumption of 0,2 kWh/km and a emission of 0,15 kgCO2/km we have an reduction of 42 tCO2 in 2018

The monitoring of the charging processes show that the number of charging processes is constantly increasing.

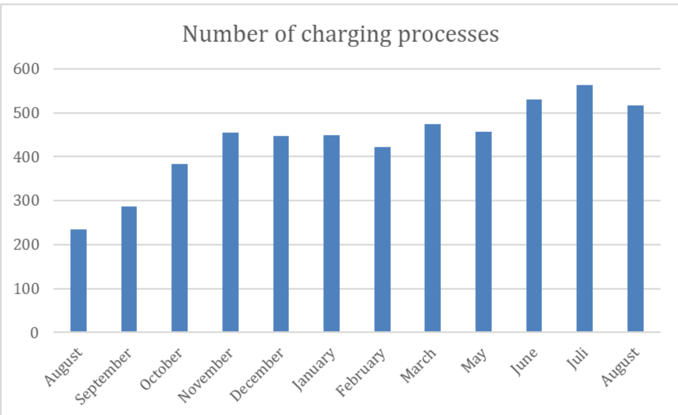

Figure 208 Charging processes (M11.1 Cologne)

In general, the system of charging infrastructure can also be developed and implemented in other cities. A good charging infrastructure is the prerequisite for a better integration of E-mobility.

M11.1-M11.2 – Developing charging infrastructures

Barcelona

Industry partner	Contact person	Validation partner
Nissan IREC	Xavier Pons (Nissan) Jordi Farre (IREC)	KTH-SEED

The measure has been deployed at Nissan headquarters and focuses on the integration of V2B applications with renewable energy generation in buildings. This has been done with the installation of V2X chargers integrated in the building, a photovoltaic (PV) module and an energy storage system.

This measure is built on the following elements:

- Installation of 2 V2X charging stations (10kW)
- Installation of a PV and energy storage system (ESS)
- Development and integration of an Energy Management System (EMS)
- Development and implementation of a SCADA system

Figure 209 Conceptual layout of Nissan solution

The EMS will optimize the energy management of V2X chargers, PV module and ESS installed in the building by communicating in real time and sending set points to the controllable elements. The EMS will manage the different elements based on external weather and energy price forecast and building energy load forecasts.

The deployment of the SCADA system will allow the building owner to control the performance of the installation with real time monitoring, historical data, alarms, etc.

Intentions of M11.1-M11.2 in Barcelona

A) Develop and integrate V2X charging Infrastructure.
B) Implementation of industrial SCADA system.
C) Installation of an EMS (Energy Management System) in charge of managing the Vehicle to Everything (V2X) charging infrastructure, PV module and energy storage system (ESS) in an optimal manner by reducing energy costs for the building. This optimization will allow the system to increase the use of renewable energy and the energy storage system.
D) Deployment of the integration of V2X as distributed energy resource (DER) in

buildings. The integration of this elements will allow to increase the self-consumed energy of the system.

E) Assessment of the environmental impact (CO2 emissions) of the system and evaluation of the decrease of building energy consumption from the grid and the decrease of CO2 emissions due to the inclusion of local renewable energy resources (PV), and the replacement of conventional combustion vehicles by electric vehicles.
F) Transition to more energy/emission-efficient transport alternatives
G) Reduction of the contamination of CO2 due to reduced fossil fuels
H) Increase energy efficiency via implementation of e-mobility in Public Transport
I) Provide new e-mobility services to EV customers
J) Improve the quality of life of the citizens and EV customers

Implementation

IREC started to work on the development phase for the SCADA and EMS system since spring 2018. Works on the PV installation and storage system started in October 2018. During June-July 2018, IREC performed the communication tests with the hybrid inverter in charge of controlling the PV and storage systems at IREC lab facilities. In August 2018, one of the V2G chargers and an electric vehicle was brought to IREC lab in order to start with the testing phase, which finished at the end of October 2018 (see Figure 210).

The installation of the PVs and storage system in Nissan's premises was finished in December 2018 (Figure 211).

The development of the Energy Management System and the SCADA was finished in Febreary 2019.

The commissioning of the PV, storage, and V2X chargers system was finished in February 2019.

On-site commissioning and testing of the overall system was done during February and March of 2019.

Figure 210 V2G Tests at IREC lab

Figure 211 PV system at Nissan office

Figure 212 V2G chargers at Nissan office

Baseline definition

The renewable energy resources penetration increment in electrical network creates a big challenge for distribution system operators. A possible solution for this challenge could be the use of bidirectional charging stations (so called Vehicle-to-Grid (V2G)) to dynamically regulate the system and therefore defer new investments in the network.

This technology offers to the end-user a significant economic benefit. The energy arbitrage, charging in low energy prices hours and selling energy/providing power in peak hours, could increase the return of investment of electric vehicles and in return, increase the penetration of EV.

Evaluation procedure

Figure 213 shows the architecture of the planned installation. Two V2G charging stations have been integrated in the already existing facilities of Nissan corporate building. Photovoltaic panels are intended to act as renewable energy source for the building. Also additional stationary storage has been installed in the Nissan facilities. The system has been monitored by a SCADA (developed by IREC) and managed by an EMS (developed by IREC) to minimize user cost which will derive in an increase of the use of renewable energy.

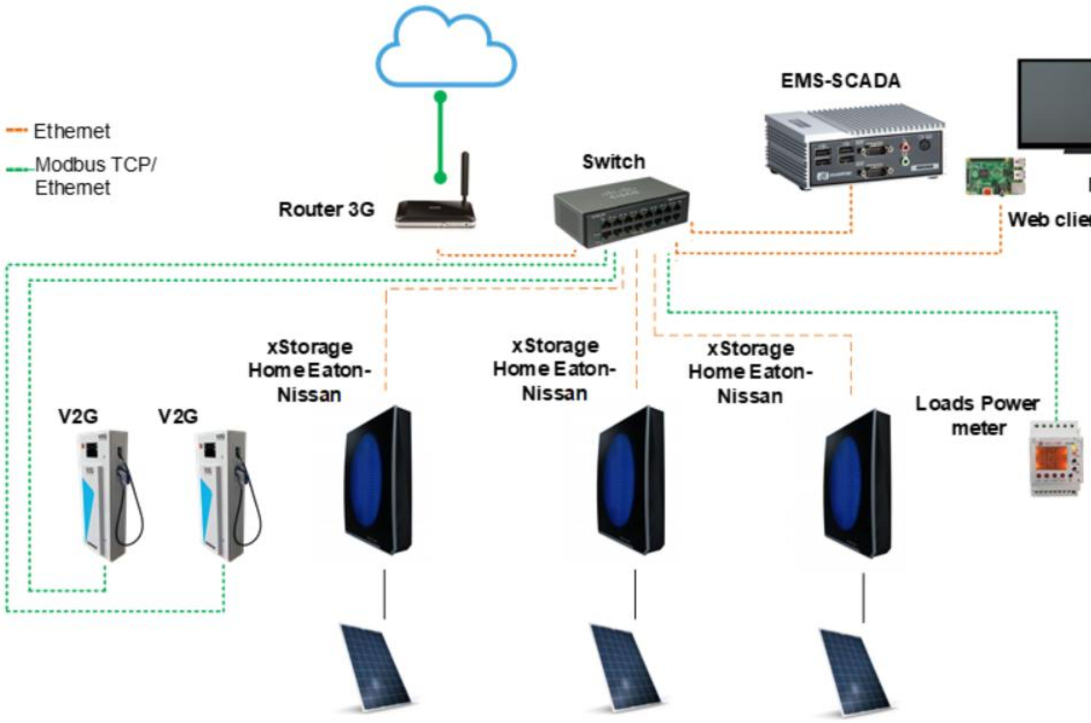

Figure 213 Architecture of the planned installation (Nissan solution)

CO2-Emissions

To evaluate Measure M11.2 all measurable parameters of the Nissan building have been monitored and evaluated. After collecting the available data, the evaluation has been carried out by comparing the estimated CO2 emissions of the four cases depicted in Figure 214.

In Case 1 the theoretical CO2 emission of a Nissan building loads and Nissan fleet consisting only of conventional combustion engine cars. The emissions of the conventional cars have been calculated by multiplying the total amount of km driven by the electric vehicles fleet with the average CO2 emission of gasoline/diesel cars. The emissions of the Nissan building loads have been calculated by multiplying the Energy consumed by the loads with the average emissions per hour of the Spanish energy mix.

The calculated emission of a conventional fleet and building loads of Case 1 will then be compared with the emission of the real EV-fleet in Case 2. In the case 2 the emissions of the cars have been calculated by multiplying the amount of Energy (kWh) used by the V2G chargers with the average CO2 emission of the Spanish energy mix during the charging period.

In Case 3 the influence of the PV-Panels has been evaluated. The amount of used energy by in the Case 2 minus the produced amount of renewable energy has been multiplied with the average CO2 emission of the Spanish energy mix during the evaluation period.

In Case 4 the energy storage system, the V2G and the functionalities of the developed energy management system have been evaluated. By optimizing the charge and discharge of both systems (ESS and V2G) the CO2-Emissions should be even lower than in the previous cases. The Case 4 the CO2-Emissions have been calculated by multiplying the amount of Energy (kWh) consumed from the grid with the average CO2 emission of the Spanish energy mix during the period.

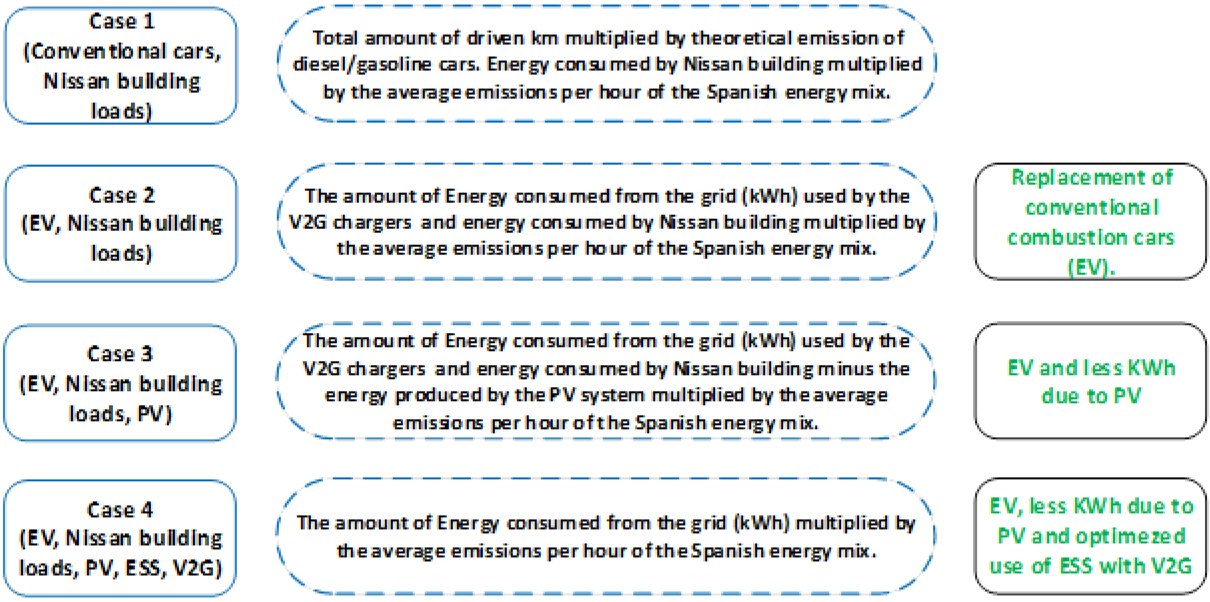

Figure 214 Evaluation cases

End-user energy costs

The EMS will allow the building owner to minimize the energy costs by mean of increasing the self-consumption and the usage of the storage systems. After collecting the available data, the evaluation has been carried out by comparing the estimated energy costs for the four cases depicted in Picture 6. The energy costs have been calculated in an equivalent way by means of multiplying the energy consumed from the grid per the energy cost per hour.

Results

Table 200 and Table 201 show the baseline and the quantifiable parameters evaluated for M11.1-M11.2. Table 202 shows the KPIs evaluated according to the Evaluation Plan and along the period from 26/02/2019 until 26/06/2019.

Table 200 Baseline values, M11.1-M11.2 Developing charging infrastructures, Barcelona

1.Number of EV users before the GrowSmarter Project per year (units)	20
2.Number of charging points before the GrowSmarter Project per year (units)	12
3.Number of charging events before the GrowSmarter Project per year (units).	-

Table 201 Quantifiable parameter, M11.1-M11.2 Developing charging infrastructures, Barcelona

Energy charged of bidirectional charge (kWh)	513
Energy discharged of bidirectional charge (kWh)	65
Charging time of bidirectional charge (min)	13320
Discharging time of bidirectional discharge (min)	2520
Energy imported from the mains (kWh)	29020

Energy exported to the mains (kWh)	115
Energy produced by the PV system (kWh)	2310
Energy charged in the ESS (kWh)	312
Energy discharged from the ESS (kWh)	381
Energy consumed by the loads (kWh)	30937

Table 202 KPIs evaluated for M11.1-M11.2 Developing charging infrastructures, Barcelona

Measure 11.2	Number of EV users per year (units)	Number of charging points per year (units)	Number of charging events per year (units)	Daily average charge per session of bidirectional charge (kWh/session)	Daily average discharge per session of bidirectional charge (kWh/session)
Key indicators baseline	20	12	No data available.	No data available.	No data available.
Key indicators 4 months	22	14	30	17,12	2,19

Measure 11.2	Total charging time per day of bidirectional charge (min)	Total discharging time per day of bidirectional charge (min)	Daily electricity charged of bidirectional charge (kWh/day)	**Daily electricity discharged of bidirectional charge (kWh/day)**	**Total estimated reduction of emissions due to measure 11.1/11.2 based on indicators (Kg CO2)**	**Total estimated reduction of energy use due to measure 11.1/11.2 based on indicators (% kWh)**	**Total estimated reduction of emissions due to measure 11.1/11.2 compared to baseline (% CO2)**
Key indicators baseline	-	-	-	-	--	--	--
Key indicators 4 months	111	21	4,28	0,55	1024	13,05 %	17,56 %

Measure 11.2	**Total estimated emissions (Case 1) (Kg CO2)**	**Total estimated reduction of emissions due to measure 11.1/11.2 based on indicators (Case 2) (Kg CO2)**	**Total estimated reduction of emissions due to measure 11.1/11.2 based on indicators (Case 3) (Kg CO2)**	**Total estimated reduction of emissions due to measure 11.1/11.2 based on indicators (Case 4) (Kg CO2)**	**Total estimated costs(Case 1) (€)**	**Total estimated reduction of costs due to measure 11.1/11.2 based on indicators (Case 2) (€)**	**Total estimated reduction of costs due to measure 11.1/11.2 based on indicators (Case 3) (€)**	**Total estimated reduction of costs due to measure 11.1/11.2 based on indicators (Case 4) (€)**

Key indicators 4 months	5834,63	534,52	948,48	1024,49	3166,30	242,21	463,56	505,71

The conversion factors used to estimate the CO2 emissions, energy and money savings here below is listed the references used for the calculations:

- In this measure, we didn't use the emission factors from the Ministry of Energy of Spain.
- We calculated the emissions based on the Spanish pool share at every hour of operation of the installation. In this measure, this is interesting as the Energy Management System is optimizing the use of the batteries and the EVs and decides when to charge and discharge it in a smart way.
- The reference of the emission factors used is: GaBi Professional Database from ThinkStep, using Spain Electricity generation datasets from different sources https://thinkstep.com/sustainability-data/lci-data/global-industrial-process-database based on data from IEA, OCDE, Dataset valid from 2014 until 2020
- The reference of the emission of diesel cars (city environment) used (205 gCO2/km) is: GaBi Professional http://www.gabi-software.com/index.php?id=8375 .
- The reference of the emission of diesel consumption (city environment) used (0.078 l/km) is: GaBi Professional http://www.gabi-software.com/index.php?id=8375 .
- The reference of the kilometer per Kilowatt-hour used (5.96 km/kwh) is from the publication: "*Sustainability analysis of the electric vehicle use in Europe for CO2 emissions reduction*" *by* Lluc Canals Casals, Egoitz Martinez-Laserna, Beatriz Amante García, Nerea Nieto.
- The reference of the diesel price used (1.2€/l) is from the Spanish Ministry for the Ecological Transition https://energia.gob.es/petroleo/Informes/InformesAnuales/InformesAnuales/Precios-Carburantes-Comparacion-2017-2018.pdf
- The reference of the calorific value of the diesel (10.17 kwh/l) is from the *World Nuclear Association* http://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx
- The reference of the electric energy prices for the mains had been taken from the actual tariff contracted by Nissan.

Here below is shown the analysis of the KPIs of the table 197.

The number of EV users at Nissan Iberia offices increased a 10% and the number of EV charging points a 16,7% after the measure implementation.

Analyzing these four months of operation it can be seen that 30 charge events had occurred. There has been some issues preventing a higher number of charge events, specifically for some periods, the V2G chargers had been stopped due to a problem with the 4G router. The chargers itself were working correctly, but due to the connectivity problem, IREC wasn't able to do the supervision of the control system (EMS-SCADA) during the first few weeks. As we considered critical to supervise the system operation during these weeks Nissan and Irec agreed to postpone the commissioning of the V2Gs some weeks until the problem of connectivity had been fixed. It is also important to notice that during the first weeks of operation some EV users don't rely on this new technology and these users are afraid of have their EV discharged instead of charged once they leave the office.

It is expected that the number of charge events in the following months will increase due to the V2G chargers will be operating continuously. Also, the awareness and the trust in the system of the EV users will increase if the system doesn't present critical problems (It hasn't been the case until the moment).

If we analyse the energy charged and discharged per session the result 17,12kWh/session V2G charge on average and 2,19kWh/session V2G discharge on average. It is normal that the average of charging is much bigger than the V2G discharge since the main purpose is to have the EV with the battery charged when the EV user is leaving the parking place.

However, the V2G discharged energy per session is expected to increase during next months of operation. Since in the first weeks of operation we detected a problem in the machine learning algorithm for forecasting the EV presence of the EMS. The algorithm forecasted less time of EV presence than the EV stayed at parking place. That issue in consequence was limiting the opportunities to discharge the EV. The ML has been updated and for this reason it is reasonable to foresee an increment in the V2G discharged energy.

Regarding the other KPIs related to CO2, energy and money savings will improve in the coming months due to following reasons. The KPIs related to the use of EV instead of combustion engine (Case 2) cars will improve since it is expected a more intensive use of the chargers in the coming months. This is affecting also to case 4 since a more intensive use of the V2G chargers in addition to the corrections done at the machine learning algorithm will lead to an increase of the potential to do V2B services.

In the first weeks of operation also some problems with the hybrid inverters limited the PV production and the usage of the batteries. With these problems fixed the KPIs for the case 3 and 4 are expected to improve too.

Potential for full scale implementation

Technical feasibility, implementation issues

The implementation of the Measure has been completed successfully.

However, the measure had been challenging to implement due to the complexity of the solution, the lack of maturity of the V2G technology and all the technical challenges that have intrinsic the innovative solutions like the one implemented.

Figure 215 Two Nissan Leaf connected to the V2G chargers at Nissan offices

The implementation of the measure had faced many problems with the commissioning of the V2G chargers.

The measure implementation faced another technical issue. This issue was related to how to do the permitting process of the V2G chargers. Regarding the Spanish case, it is not regulated how to do the permitting process of a V2G charger in the electrical codes. The authority responsible of the permitting processes approved to do it as a normal unidirectional charger.

Grid-related policy frameworks in many countries do not recognize EVs or EVSE as a distributed energy storage resource capable of injecting power into the network. The grid interconnection and certification processes are, therefore, slow, expensive or often prohibited. In the example of Barcelona, acquiring the permits for a how a V2G charger was a first-time process, which was time-consuming.

4.3.1.1.5 Economic feasibility

Concerning economic feasibility, it is not demonstrated that business models using V2X technology are economically sustainable. Novel business models have to be tested to share benefits between stakeholders. Other factors, such as environmental responsibility (reduction of CO2 emissions, improvement air quality in cities, noise reduction…) and energy autonomy (Decrease dependency on fossil fuels) may also influence the V2X value proposition to end users.

A key issue, it will be to develop customer centered business models. Improve understanding of V2X value proposition to consumers and develop customer focused business models which distribute benefits and risk. It is widely believed that consumers are motivated by the TCO and ease of use of transport services. Therefore, V2X must demonstrate potential to reduce the

TCO of electric mobility whilst at the same time offering flexibility, reliability and ease of use to EV owners.

The energy price (fossil fuels and electric energy), the electrical tariff schemes and new actors in the electrical market able to give flexibility to the grid, e.g. the commercial aggregator, will be a key factor in the sustainability of the business models.

Other factors that will influence in the sustainability of the business models are the reduction of the investment and maintenance costs of the V2X equipment that nowadays are high. This is expected to improve in the future with the maturity of the technology and the economies of scale.

Also, political decisions can affect the content of strategies and policies and send signals to markets about the form of “mobility landscape”. These policies can lead to a more attractive scenario to V2X business models (e.g. new electrical tariff schemes, subsidies or tax exemptions…).

4.3.1.1.6 Social feasibility

Currently there is low levels of customer awareness of V2X technology and the value proposition to end users is poorly understood.

It will be necessary to promote the benefits of the technology to a boarded audience, as well as manage potential concerns, such as data security, battery aging and range anxiety.

They EV users need education and engagement programs to understand the impact of their driving behaviour in battery performance as well as the opportunities to maximize their benefits via V2X activities. Warranty implications of V2X activities is an essential factor for EV users as it will directly affect their TCO (Total Cost of Ownership).

Education and customer awareness of the V2X technology is key to the success of the implementation of these kind of measures. That’s the reason in the implementation of the measure Nissan included information panels close to the V2G chargers (See the figure 163). In these panels the user is informed about the consequences of parking and charge the EV in these parking places.

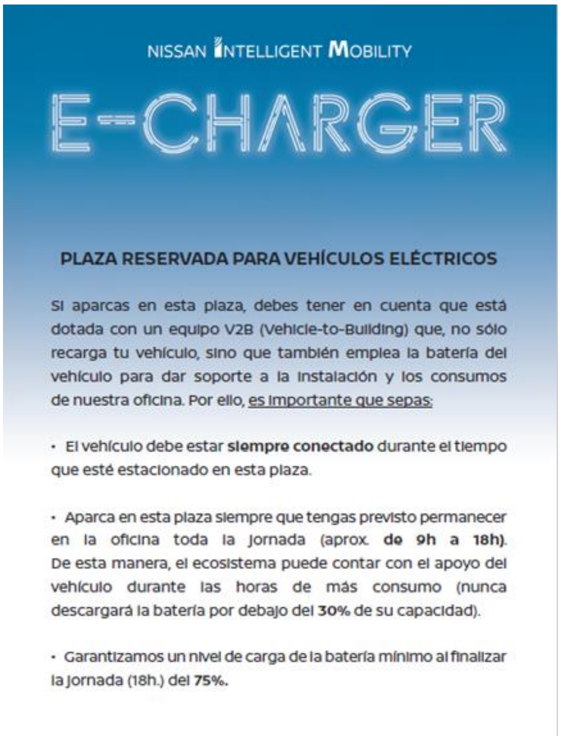

Figure 216 V2B Information panel in Nissan offices

In order to increase the awareness of V2B measure implemented in the Nissan offices between the Nissan EV users and other Nissan employees, two TV screens are showing some screens of the SCADA developed in the framework of the measure. In these screens it can be seen the current performance of the system, an explanation about how the system works and another one with the most relevant KPIs of the performance.

Figure 217 TV SCADA screen in Nissan offices

Possibility to replicate the Measure

The measure could be replicated in other cities in public or private buildings with EV fleets. Nevertheless, how this measure is replicated will depend on the context of the city and other factors explained below.

The main barriers for replication or up-scaling are:

- **Lack of hardware capable of V2X.** → Many issues during testing and commissioning and some other during the operation of the equipment.
- **Grid code lacks provision for V2X.** → Grid-related policy frameworks in many countries do not recognize EVs or EVSE as a distributed energy storage resource capable of injecting power into the network. The grid interconnection and certification processes are, therefore, slow, expensive or often prohibited.
- **Building not exposed to price signal. (Electricity tariffs).** → Electricity tariffs are essential to have sustainable BM.
- **Low levels of customer awareness.**
- **Business Models** - It is not clear that business models using V2X technology are economically sustainable.

The main enablers for the replication that would allow the replication of the measure are:

- **Improvement of the maturity of the technology; Standardization and harmonization** → Global standard for V2X technology and harmonization these with existing power, transport and communication systems. Agreement and application of global standards is a route to reduce costs, mitigate negative impacts and encourage participation by manufactures and service providers.

- **Inclusion of V2X in grid codes**
- **New electrical grid scenario including flexibility** - Redesign energy tariffs to better reflect the real-time value of energy and capacity in the power system. This will enable buildings with smart flexible resources, such as V2X, to optimize charging and discharging. The synergies with renewable energy sources, storage systems and other systems could play a key role in this new scenario where the electrification of the demand will be increased in the coming years.
- **Development of customer centered business models** – Improvement of the understanding of V2X value proposition to consumers and development of the customer focused business models which distribute benefits and risk. It is widely believed that consumers are motivated by the TCO and ease of use of transport services. Therefore, V2X must demonstrate potential to reduce the TCO of electric mobility whilst at the same time offering flexibility, reliability and ease of use to EV owners. Also, synergies among V2X bidirectional chargers, EV fast chargers, local DERs and local energy storage systems can improve the business models and therefore empower the market uptake for V2X technology.

Considering all these points, further work should be done in order to reach the full potential of the V2X technology and up-scaling the solution.

Conclusions

The implementation of the measure has been completed successfully. The concept of EVs in conjunction with the V2G chargers providing services to the building has been a successfully demonstrated, which is not easy considering all the technical challenges involved in the implementation of the measure.

This measure is one of the first pilots providing these kind of services to buildings with EVs. This prove of concept could help improve energy efficiency of the buildings and increase levels of sustainable urban mobility. In addition, in economic terms it can help reduce electrical bill costs and TCO of the EVs.

Nevertheless, it is not clear that business models using V2X technology are economically sustainable. Other factors, such as environmental responsibility and energy autonomy may also influence the V2X value proposition to end users.

In addition, regarding the social adoption of the technology, it will be necessary to promote its benefits to a boarded audience, as well as manage potential concerns, such as data security, battery aging and range anxiety.
Concerning the replicability of the measure, further work should be done with the aim of reach the full potential of the V2X technology and up-scaling the solution.

M11.1-M11.2 – Fast charging infrastructures

Barcelona

Industry partner	Contact person	Validation partner
Barcelona	Gonzalo Cabezas	KTH-SEED

Within GrowSmarter, Endesa Energía and the Barcelona City Council provided the smart charging infrastructure for electric vehicles in Barcelona. This infrastructure is composed of 5 fast charge stations for electric vehicles.

An e-mobility charging system was deployed in order to manage the charging infrastructure in Barcelona. The charging infrastructure is monitored in order to extract the usage data and study the impact of the measure. New functionalities and services for the customer will be studied, as well as a plan for deployment of the charging infrastructure at city level.

Charge points are electricity supply points for electric vehicles installed as per current legislation and standards. There are different types of charge points, depending on their location, accessibility, use and supply technical specifications. Each type is conceived to meet the needs of different vehicles and to supply a certain service.

It is important to foster the availability of charge points in places where any electric vehicle is habitually parked. Electric vehicle users should also be able to have at their disposal and easily locate public charge points for semi-fast and fast charging in the event of an emergency or specific need.

The first phase of the measure consisted in the definition of the locations of the stations to be installed. The locations were selected based on the city strategy to deploy the fast charging stations grid. At present, in the city of Barcelona there are 17 fast charging stations, 5 of which installed within GrowSmarter, and more than 300 standard charging stations (slow and medium speed). The fast charging stations are deployed at a specific distance from each other to be reached in less than 6min driving (see Figure 218).

In particular, the 5 charging stations are installed in:

- Passeig de Gràcia 5
- Provença 447 (Sagrada Familia)
- Av. Del Paral.lel 55
- Roc Boronat 122
- Plaça Pla de Palau

All the stations are connected to the mobility control center (NOC) where the general management of the EV service is managed (by the council and a subcontractor). The management includes the infrastructure operation, EV user management and incident reporting.

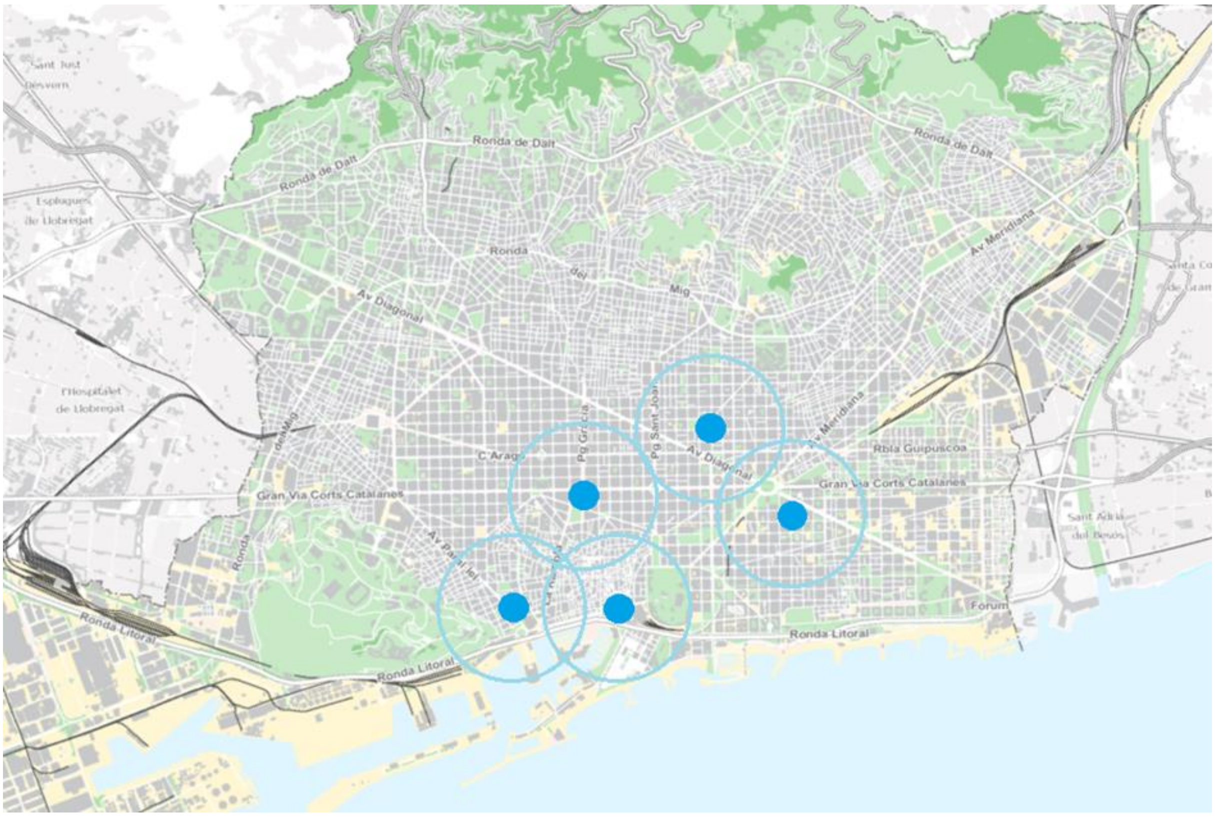

Figure 218 Location of the 5 fast charging stations (M11.1-M11.2)

Results

The most relevant KPI is the number of charging events provided by the stations. Together with the power delivered to the vehicles, this can be translated to the standard CO2 emissions as if that energy were used by conventional fuel driven cars.

The evolution of electric vehicles registered in Barcelona since the beginning of the project (2015) has been increasing from about 1500 to more than 5000 vehicles at present. As shown in Figure 219, in 2018 the number of electric vehicles has increased exponentially, and so the use of the charging stations in public space.

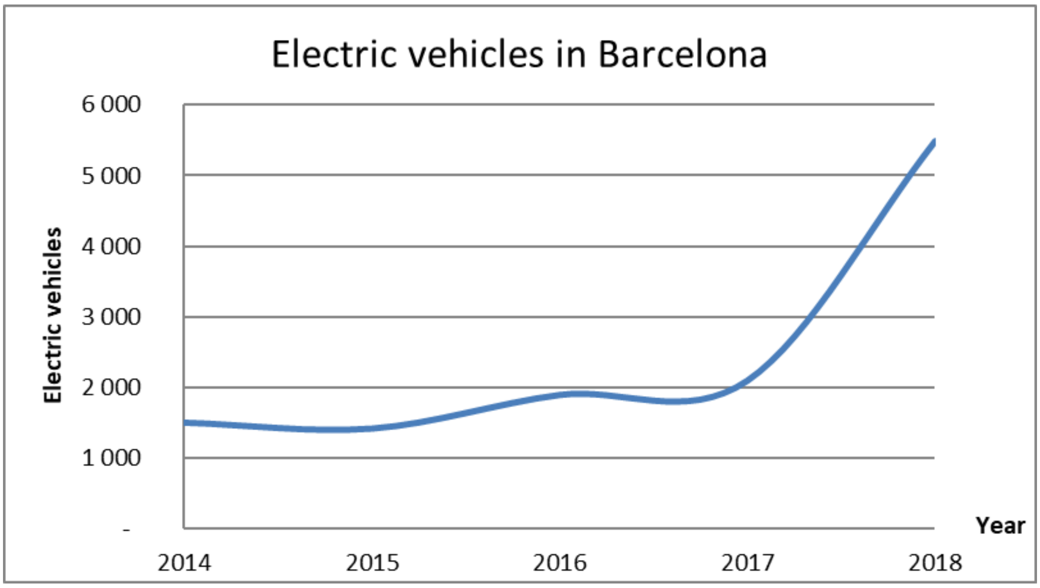

Figure 219 Electric vehicles in Barcelona (M11.1-M11.2)

Table 203 Baseline for M11.1-M11.2 (Barcelona)

1.Number of EV users before the GrowSmarter Project per year (units)	1504
2.Number of Fast charging points before the GrowSmarter Project per year (units)	12
3.Number of charging events before the GrowSmarter Project per year (units)	None

With reference to Figure 219, it is worth mentioning that the data gathered in this report applies only to the 5 charging stations installed within GrowSmarter. As the charging stations have been implemented where no other charging stations where placed, no data is available before the project.

At present, recharging electric vehicles in Barcelona public space is free of charge. There are still different HW providers so that the maintenance tasks may differ depending on the equipment. Besides the communication of the different HW providers to the management platform is also very HW dependant and is still under revision.

During the first reporting period, the data files provided to KTH describe the operation for 4 out of 5 stations. The connection of Roc Boronat station had a connectivity issue and couldn't provide the requested data for the period.

The evolution of the charging events per day and per charging station indicator has been increasing during 2018 and early 2019. With an average of 2 events in January 2018 to 3.74 in November 2018, to the figure of 5.04 in early 2019 (Figure 220).

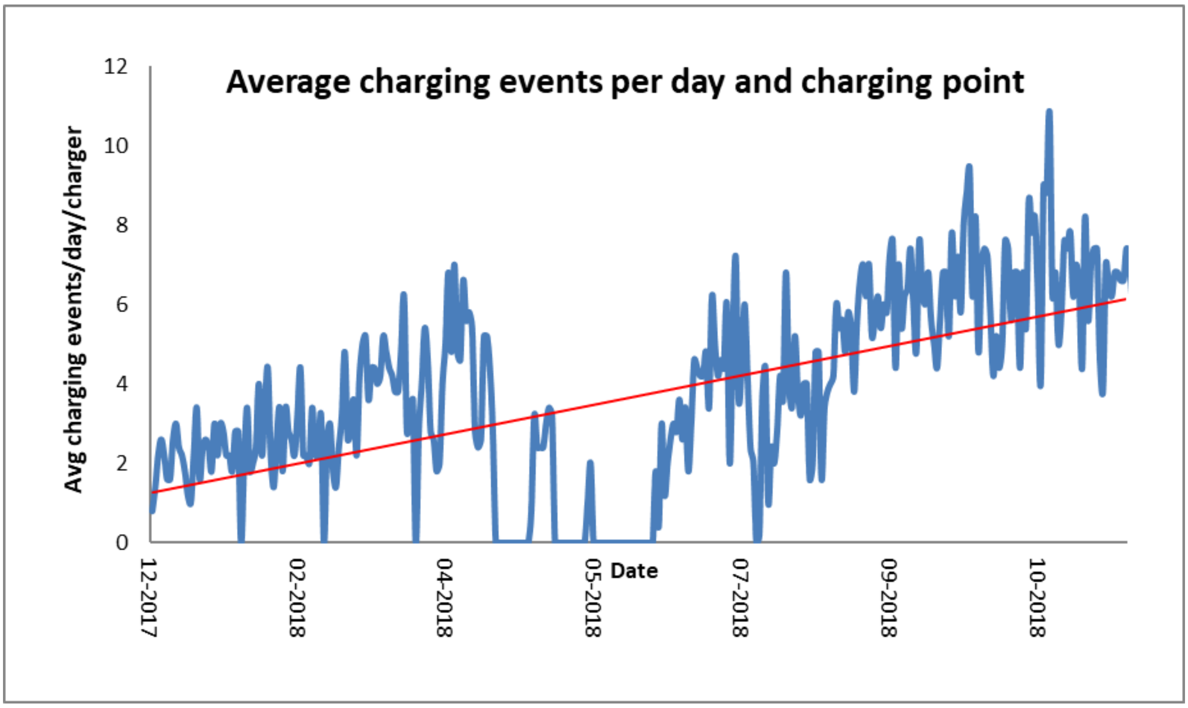

Figure 220 Average charging event per day and charging point (M11.1-M11.2)

It is noticeable the periods where there was a gap of data due to technical issues on the EV management system that where repeated at specific days.

In terms of energy, the total energy provided by the GrowSmarter stations has been about 91932KWh corresponding to an equivalent amount of about 68 tons of CO_2 emissions (evaluated considering an estimated consumption of 0,2 kWh/km and a emission of 0,15 kgCO2/km).

Incident reporting

Together with the operational data provided to KTH, the measure is periodically reporting all the incidents associated to the service. These incidents include paintings, broken connectors, vandalism actions, network and weather issues.

Figure 221 Examples of vandalism incidents (M11.1-M11.2)

The incidents are reported to calculate the total economic costs of the measure. These costs have to be calculated after each financial period and added to the monthly base fee that includes general maintenance tasks.

Table 204 shows the KPIs prescribed by the Evaluation Plan D5.1 regarding the fast charging stations within M11.1-M11.2.

Table 204 KPIs for M11.1-M11.2, impact on personal transports (Barcelona)

Measure 11.1/11.2	Number of EV users per year (units)	Number of charging points per year (units)	Number of charging events per year (units)	Daily average charge per session of fast charge (kWh/session)	Daily electricity charged of fast charge (kWh/day)	Average charging time of fast charge (min)
Key indicators baseline	1504	12	-	-	-	-
Key indicators 12 months	1436	12+3	-	-	-	-
Key indicators 24 months	1597	12+5	-	-	-	-
Key indicators 36 months	2209	12+5	Paral·lel: 43 Provença 576 Pla Palau 502 Pg Gracia 174	Paral·lel: 9.77 Provença 11.84 Pla Palau 14.86 Pg Gracia 12.7	Paral·lel: 24.5 Provença 63.93 Pla Palau 56.74 Pg Gracia 89.73	Paral·lel: 24.3 Provença 25.7 Pla Palau 32.15 Pg Gracia 27.66

			Roc Boronat:- Total:1295	Roc Boronat:- Avg: 12.29	Roc Boronat 65.15	Roc Boronat:-
Key indicators 48 months	5489	12+5	Paral·lel: 833 Provença: 1567 Pla Palauç: 1725 Pg Gracia: 1361 Roc Boronat: 761 Total:6247	Paral·lel:10.00 Provença:10.96 Pla Palau:11.00 Pg Gracia:9.00 Roc Boronat:7.00 Avg: 9.59	Paral·lel: Provença: Pla Palau: Pg Gracia: Roc Boronat:	Paral·lel:24 Provença 22 Pla Palau:27 Pg Gracia:22 Roc Boronat:23
Key indicators 60 months	6829	12+5	Paral·lel: 1169 Provença: 3006 Pla Palauç: 1713 Pg Gracia: 2968 Roc Boronat: 1203 Total:10060	Paral·lel: 9,06 Provença: 9,79 Pla Palau: 9,59 Pg Gracia: 8,95 Roc Boronat: 6,68 Avg:8.81	Paral·lel: 22,81 Provença: 94,58 Pla Palau: 69,71 Pg Gracia: 24,92 Roc Boronat: 37,83	Paral·lel: 26.8 Provença: 27.13 Pla Palau: 43.68 Pg Gracia: 24.05 Roc Boronat: 25.46

Potential for full scale implementation

Technical feasibility

The implementation of the Measure has been completed with no issues.

Economic feasibility

Aggregated analysis on economic sustainability will be carried out in WP6. However, it is relevant to indicate that, at present, recharging electric vehicles in Barcelona public space is free of charge. Therefore, the economic sustainability can only be understood by the willingness of the council to foster the introduction of these technologies in the city rather than obtaining a profitable business model. In the near future, once the sector will be more mature, there might be a charging fee, still to define.

Possibility to replicate the Measure

The measure has potential to be replicated in other cities with similar infrastructure requirements.

Conclusions

Electric mobility brings energy, environmental and economic advantage; it does not generate emissions or particles with local emissions and reduces noise pollution. To promote the use of alternatively powered vehicles it is essential to have an infrastructure of battery charging and supply points which is wide enough, operational and easy to find.

The evaluation from the GrowSmarter stations has demonstrated the positive impact in emissions. In terms of energy, based on the the total energy provided by the GrowSmarter stations during the monitoring period, the EV stations have provided 91932KWh corresponding to an equivalent amount of about 68 tons of CO_2 emissions.

In terms of usage, the increase of the use of the EV stations since the beginning of the project raised from 2 to 6 events per day and station in average. Of course, the increase of the usage of the charging infrastructure is linked to the increase in the number of EV users (figure 155) and that has to be analysed under the umbrella of all the measures the council has implemented to foster the use of electric vehicles in the city. These measures include:

- Discount on road tax (IVTM in Spain)
- Free access to toll roads
- Reduced rates on toll roads
- Reduced parking costs in regulated areas
- Discount on the use of charge points in underground parking spaces
- Discount on the use of public roadside charge points
- HOV lanes

M11.4 – Refueling facilities for renewable fuels for heavy duty vehicles

Introduction

Following the work started in the Life+ project CleanTruck, Stockholm, together with the distribution companies, agreed to set up at least 10 new stations for ED95, LBG, or HVO, operate the logistic center on these vehicles, require increased rates of renewable fuels in the city's procurements of transport, and encourage business to put the same requirement on their deliveries. Industrial companies such as the different fueling station companies i.e. IDS and AGA together with Stockholm Gas AB have been involved in the realization of this Measure as associated partners to the project.

According to the evaluation plan (D5.1), the intention of the Measure was to define:
A) Number of renewable fueled trucks in Stockholm at present
B) Potential number of renewable fueled trucks in Stockholm using these facilities
C) Number of liters of renewable fuel sold in Stockholm at present
D) Potential number of liters of renewable fuel sold at these stations

Stockholm

Industry partner	Contact person	Validation partner
City of Stockholm	Per Erik Österlund	KTH-SEED

There is significant demand for fuel stations providing renewable fuels in the Stockholm region. Unfortunately this creates a conflict with urban development programmes, infrastructure investments and for physical space for fuel stations serving heavy goods vehicles. Achieving acceptance that large spaces must be reserved for fuel stations takes time and is not prioritised. GrowSmarter has achieved some success with five new fuel stations in operation and delivering renewable fuels, primarily HVO. It is hoped that a further three fuel stations will be launched in 2019.

The measure has been implemented as planned. Compared to the initial intentions of the Measure, the following points are worth to notice:

A) Number of renewable fueled trucks in Stockholm: increase from 356 renewable fueled trucks in Stockholm County (2016) to 392 in 2018. However these figures exclude trucks operating on 100% HVO, for which there are no national statistics. We see a significant increase in use of 100% HVO from 2016 to 2018, suggesting many more trucks are operating on renewable fuels in Stockholm County.

B) Potential number of renewable fueled trucks in Stockholm: potential is equivalent to number of trucks in region, 13615 in 2018 (up from 12381 in 2016)
C) Number of liters of renewable fuel sold in Stockholm: the total share of renewable fuels in fuel sold to trucks is 28,4% in 2018. Detailed figures per type of renewable fuel and blend are available.

The major challenges for implementation concern the speed of public planning processes where multiple stakeholders and interests are involved and at times in conflict. This can cause significant delays to the start of building works. Otherwise this measure is a commercial venture for which no additional investment support has been necessary – all investments occur on a commercial basis and in line with the fuel providers' own business models. The increase of alternative fuelled HGVs in the Stockholm area indicates that the increased availability of alternative fuels does have an impact on transport companies' purchasing behaviour (for vehicles and fuels).

The number of Heavy Goods Vehicles (HGVs) operating on alternative fuels ("clean" HGVs) has increased. However, Stockholm – both the city and surrounding region - is expanding rapidly and there is an ongoing boom in the construction sector, with large infrastructure projects, new-build residential or commercial properties, and renovation of existing premises accounting for an increase of 11% in the number of HGVs registered in the region.

For this reason, the share of "clean" HGVs as a proportion of all registered HGVs in Stockholm has decreased even as the total number of "clean" HGVs increases. There has been an increase in the use of 100% renewable fuels and a rapid increase in the volume of biogas (bio methane) and RME being used. Despite this, there has been a 20% increase in CO2 emissions from HGVs operating in Stockholm and a 17% increase in the sales of fossil diesel. In addition, the share of renewable blends in conventional diesel has decreased from 38% to 29% due to changes in national tax regulations from 1 July 2018 (that have increased the renewable share in other parts of Sweden, yet reduced the share in Stockholm).

As noted above, the construction boom is a key driver of this trend. The share of low-value goods in transit (e.g. stone, gravel, sand, cement, ballast, soil, etc.) is increasing and there are few sustainable alternatives for transporting such goods. The City is working to identify alternatives, such as barge-based solutions, but the general increase in HGV traffic is likely to continue for some years (even as the total number of HGVs in Sweden decreases). Another driver is internet retail, which has increased dramatically and is not always associated with transport efficiency. There are signs that different consumer groups (or other transport purchasers) may be willing to pay for "clean" transport services, but transport is usually priced according to the fossil-fuel index.

Other drivers include the biofuel production. There is high demand for HVO and willingness to produce the fuel, yet EU regulations and a lack of raw materials are holding back production. There has also been a limited range of alternatives to diesel HGVs on the market. A new range of gas-powered HGVs is now on the market and the Swedish Government has approved grants for infrastructure for LNG/LBG and CNG/CBG. It may thus be possible to further increase the number of HGVs using biogas in the near future.

A number of steps are required to accelerate the shift towards "clean" HGVs:

1. More efficient vehicles and combinations of vehicles (local traffic rules are a

barrier)

2. Swedish health and safety rules prohibit use of petrol, ethanol and "gas" at underground workplaces. However, these rules are ill-defined and could be challenged or amended.
3. Barges must be used both for inland waterways (Mälaren) and the Baltic
4. The City should permit night deliveries on a permanent basis
5. The price difference between "clean" HGVs and fossil HGVs must be reduced or inverted (gas HGVs cost 400 000 SEK more than diesel; 15-tonne electric HGVs cost 2 million SEK more than diesel).

From 1 July 2018 fuel companies must include at least a 19.4% renewable blend (well-to-wheel) in diesel and comply with fuel quality standards for MK1 diesel (in practice 25% renewable share in volume). This will provide positive results at the national level, but negative results for Stockholm and the project (both now and in the coming two years) unless there is a clear shift to biogas or ethanol (because Stockholm had a higher share of renewables before the new rule, and now has a lower share, whereas the opposite applies for Sweden as a whole). For this reason, the City continues to support efforts to improve infrastructure for biodiesel (FAME, HVO), diesel-ethanol ED95, gas, and rapid-chargers for HGVs.

Potential for full scale implementation

Economic feasibility

The City of Stockholm will be fossil-fuel free as an organisation by 2030 and as a whole by 2040. This means fossil fuels must be phased out and replaced with renewable alternatives. For fuel providers, this may mean short-term loss of revenues and longer writing-off periods, as the share of liquid fuels is expected to decrease as more electric propulsion is used. This means that existing fuel providers must adapt to a shrinking market (in volume) and seek to replace lost revenues with other income streams, such as car rental, service, shopping, other mobility services, etc. Many fuel stations have good locations and can adapt to such a transition. The challenge for fuel suppliers to vans and heavy goods vehicles is that most experts expect an increase in logistics flows in urban areas, meaning these fuel stations must be equipped with renewable fuel pumps.

Social feasibility

The measure is socially accepted among relevant stakeholder groups. Fuel station operators, fuel providers, logistic firms, etc have been engaged in the development of the measure.

Upscaling and replicability of the Measure

The Measure is completely possible to replicate.

Conclusions

The use of renewable fuels in heavy goods vehicles is a proven solution for reducing greenhouse gas emissions and air pollution. Significant efforts should be made by national governments and cities to promote the use of renewable fuels. The City of Stockholm has shown that informal cooperation between stakeholders can help overcome first-mover problems and ensure that when fuel stations are installed, distribution companies acquire appropriate vehicle models and their customers demand sustainable logistics services, thereby ensuring demand for the fuels. Nevertheless, the technicalities of planning processes can slow implementation and the transition to alternative fuels, even in cases where all stakeholders are working towards shared goals.

There is enormous potential for a shift to LNG/LBG and CNG/CBG fuels across Europe, and in some contexts, local distribution may be well-served by diesel-ethanol (ED95) or electric HGVs. HVO and RME may be best used as low blends in fossil diesel and perhaps for Non-Road Mobile Machinery (for which there are currently no non-fossil alternatives on the market). All cities should strive to achieve a technical shift away from fossil fuels, but as the future supply of biofuels will remain limited without significant shifts in agricultural policy, cities must prioritise which fuels and types of service they wish to provide with biofuels and work strategically to achieve these aims.

M12.0 – Smart mobility solutions

By offering membership in a car pool, property owners are able to reduce the number of parking spaces attached to the buildings (green parking index) drastically. By reducing the available number of parking spaces it gets less attractive to own a car which will act in favor of other modes of transportation such as public transport or bike and by offering a car pool it is easier for people to drop the car completely because they have the option to borrow a car when they really need to.

This section presents the results of M12.1, M12.2, M12.3, M12.4 and M12.6.

M12.1 – Green parking index in combination with car sharing pool with EV

Introduction

As a measure in the project Grow Smarter, a public electrical car-sharing service has been introduced in Stockholm at Valla torg. Tenants at Valla torg gets free membership access to a car sharing service stationed close to their homes. Other members of the car sharing service also has access to the cars stationed at Valla torg.

The private company Move About conducts the car sharing service. There are two vehicles stationed at Valla torg. All tenants in the buildings that are part of the Grow Smarter project gets the membership for free and only pay a fee while using the service.

The car sharing service was launched in February 2018, it has been operational for over one year and it is frequently used and successful.

By offering membership in a car pool, property owners are able to reduce the cost and number of parking spaces attached to the buildings (green parking index) drastically. By reducing the available parking spaces it gets less attractive to own a car, this may act in favour of other modes of transportation such as public transports or bike and by offering a car pool. It is then easier for people to drop the idea of owning a car because they have the option to share one and use it when they need to.

According to the evaluation plan (D5.1), the intention of the Measure was to:
A. Reduce traffic volumes
B. Promote the transition to more energy/emission-efficient transport alternatives
C. Promote the transition to renewable fuels
D. Improve traffic flows

The baseline is expected to be determined according to the tables provided in the evaluation plan (D5.1).

The key performance indicators for this Measure are expected to be determined according to the tables provided in the evaluation plan (D5.1).

Stockholm

Industry partner	Contact person	Validation partner
Stockholmshem	Olle Krönby	KTH-SEED, IESE

The car sharing service was launched in February 2018. The daily collected data makes it possible to evaluate the use of the car sharing service. To be able to draw any conclusions regarding the intensions of the measure it is necessary to make some assumptions.

There is not sufficient data to draw any certain conclusions of the realisation of the intention regarding “reduced traffic volumes and improved traffic flows”. However, it is possible to make some assumptions out of available data.

Regarding the intention to contribute to more energy/emission-efficient transport alternatives, we can draw some conclusions on available data by making some assumptions. CO2 emissions is calculated according to the calculation tool at “Utsläppsrätt.se”.

Table 205 KPIs evaluated for M12.1 in Stockholm

Measure 12.1	Key indicators 36 months	Key indicators 48 months	Key indicators 60 months
Number of people living in the site potentially using measure 12.1	150	Approx. 500	Approx. 500
Observed number of users of measure 12.1	25	29	54 (30 tenants in the pool)
Average emissions per person kilometer with private vehicles in the site (Kg CO2/km)	0,2 kg CO2/km	0,2 kg CO2/km	0,2 kg CO2/km
Average energy use per person kilometer with private vehicles in the site (kWh/km)	7,92 kWh/km	7,92 kWh/km	7,92 kWh/km
Average emissions per person kilometer with private vehicles applying measure 12.1 (Kg CO2/km)	0,017 kg CO2/km	0,017 kg CO2/km	0,017 kg CO2/km
Average energy use per person kilometer with private vehicles applying measure 12.1 (kWh/km)	0,15-0,2 kWh/km	0,15-0,2 kWh/km	0,15-0,2 kWh/km
Measure 12.1	Key indicators 36 months	Key indicators 48 months	Key indicators 60 months
Number of private vehicle kilometers shifting to car sharing due to measure 12.1 (km)	N/A	1942 km	43 809 km
Number of private vehicle kilometers shifting to renewable fuels or electricity due to measure 12.1 (km)	N/A	1942 km	43 809 km
Total number of private vehicle kilometers reduced due to measure 12.1 (km)	N/A	1942 km	43 809 km
Total estimated reduction of emissions due to measure 12.1 based on indicators (Kg CO2)	0 Kg CO2	370 Kg CO2	8336 Kg CO2
Total estimated reduction of energy use due to measure 12.1 based on indicators (% kWh)	0 % kWh	98,11 % kWh	98,11 % kWh
Total estimated reduction of emissions due to measure 12.1 compared to baseline (% CO2)	0 % CO2	N/A % CO2	2,5 % CO2

The tenants at Valla torg shared their experiences of the car sharing service and their travel behavoirs in a survey. The survey was executed in June 2019.

Since the launch of the car sharing service in February 2018 until 31st March 2019, the vehicles at Valla torg have been used for a total of 43 809 km. Assuming that this distance have been done in an electric car *instead* of a medium size petrol car, the CO2 emissions have been reduced by 8 336 kg[26]. Under the same assumption, the CO2 emissions per kilometre has been reduced by 90%.[27]

Data presented in the above tables are under the assumption that all kilometres used in measure 12.1 have replaced the use of a private car running on fossil fuels. After the survey in June 2019, we will be able to draw more accurate conclusion regarding the number of tenants shifting modes of transportation and therefore have a better understanding of the effect of the measure.

Results

Private individuals mainly use the car sharing service at Valla torg. Peak usage is during evenings and especially during weekends, when the service often is fully booked.

- *Beläggningsstatistik Valla Torg 2018*
- *Beläggningsstatistik Valla Torg 2019*
- *Statistics carpool Valla torg*

Furthermore, a company with an eco-friendly business profile has also used the cars. There is no data regarding to what extent the service has reduced CO2 emissions, although the frequent use of the car sharing service suggests that it has contributed to reductions of CO2 emissions in the area. As previously stated, under the assumption that the total distance of 43 809 km traveled by car-pool would have been done using a medium size petrol car, the CO2 emissions would amount to 8 336 kg.

- [26]Utsläppsrätt.se, *Beräkning av utsläpp från bilar.* Emisso (http://www.utslappsratt.se/berakna-utslapp/berakning-av-utslapp-fran-bilar/ accessed 2019-04-30)
- [27]With an average of 0,2kg CO2/km for a regular car and 0,02kg CO2/km for electric car sharing. (VTI 1999. Energiförbrukning och avgasemission för olika transporttyper)

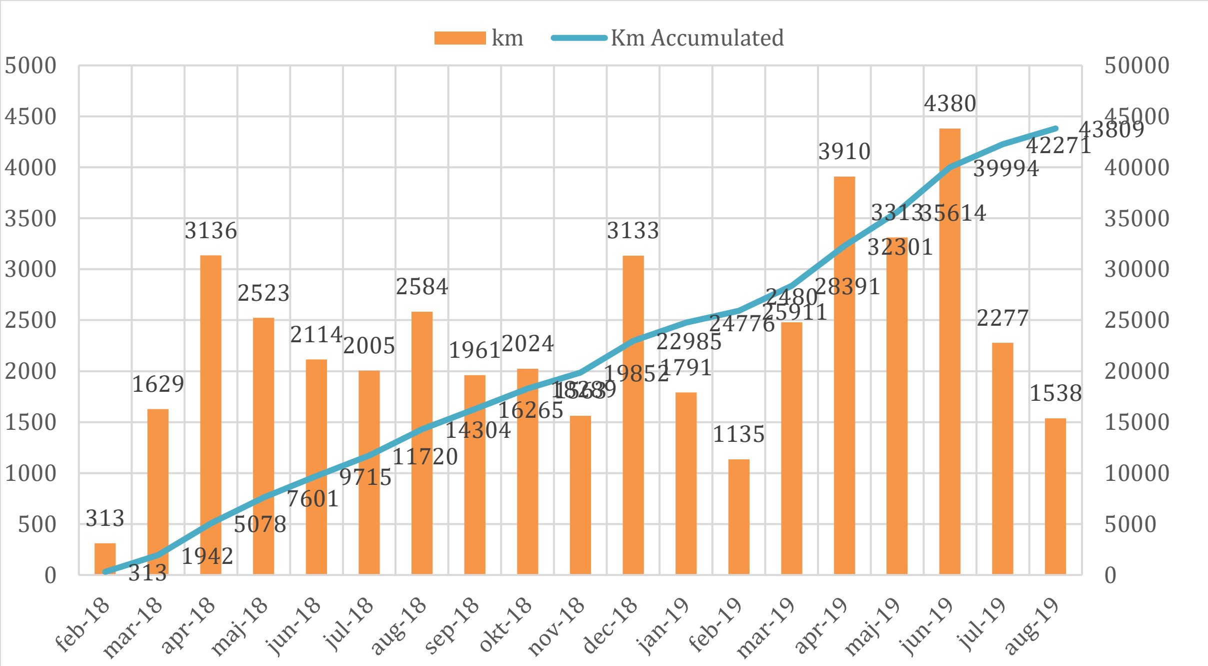

Figure 222 Distance traveled per month (both cars), M12.1 Stockholm

As information about the car sharing service is spreading, members living in other parts of Sweden have started using the car sharing service at Valla torg when travelling to Stockholm using public transportation. In the same way, members of the car sharing service living at Valla torg can use Move Abouts vehicles in other parts of Sweden. Access to cars in different parts of Sweden in combination with good public transport between these spots can reduce long distance travelling by car. The data available does not make it possible to evaluate to what extent long distance travelling by car has been reduced, nor to what extent CO2 emissions have been reduced.

Potential for full scale implementation

Technical feasibility

There has been no problem implementing the service. However, there is a discussion whether the power grid in Stockholm will be sufficient for heavy use of electricity in the future.

Economic feasibility

The investment cost for the carpool amounts to (1€ ≈ 10.7 SEK):

- 40 852 SEK - charging station
- 45 707 SEK - communication, decor etc.
- 37 475 SEK - starting cost
- 124 034 SEK total

The operating expenditure amounts to (excluding electricity):

- 11 138 SEK – monthly fee for two cars
- 2 130 SEK – monthly loss of revenue for 2 parking spaces
    - *New rents for parking spaces 2018*
- 13 268 SEK/Month total

The expected cost for Stockholmshem when producing parking spaces is approximately 400 000 SEK in a garage (more common in new construction) and 75 000 SEK outdoors per spot. The car-pool combined with a subsidized public transport-card, improved facilities for bikes and an electric and/or cargo bike-pool, can give a landlord a 15% discount on required parking spaces in new construction of houses. Hence, the measure can be economically feasible in areas with newly constructed housing.

There is business potential in electrical car sharing services in existing residential areas. The example at Valla Torg shows that there is a potential market outside the city center, if it is in close connection to the city center and has good public transports (which is the case at Valla torg). Having an eco-friendly profile and using electrical vehicles adds value for customers interested in climate and environmental issues. The car sharing service at Valla torg is subsidized during the project period as the tenants get free membership and the electric charging is free for the company. Furthermore, Stockholmshem takes the cost of the service, including the cars and booking-system.

As the car sharing service at Valla torg is successful, there is potential for good business opportunities even without subsidies at Valla torg or similar places. The preferred business model for a continued success is without Stockholmshem having to pay for the service and rather only offer parking spaces to the car pool company.

Social feasibility

According to Bilsvar[28], the cost of owning a popular mid-size car[29] is 4000 SEK per month excluding parking. In comparison, a membership in the car pool (subsidized for tenants during the project) costs 124 SEK per month and 79 SEK per hour. Therefore, a household can use the car pool for approximately 49 hours before it becomes economically beneficial to own a car. Households that only uses a car sporadically can therefore drastically reduce their monthly costs of transportation by switching to the car pool service.
An evaluation of social aspects of the measures in Grow Smarter have been executed in June 2019. The tenants got the opportunity to share their experiences in a survey. Unfortunately only 1 of the 77 tenants who participated in the survey had used the measure, therefore it is not relevant to evaluate what tenants think of the solution. But the survey gave other answers, for example 35,2 % of the respondents are interested in testing the carpool and 16,3 % have decreased interest in owning their own car. Only 8 % of respondents had been members in a mobility sharing service before, hence the experience amongst users is low. The majority of tenants in the area is above middle age, as represented by respondents in the survey, which may lead to a lesser interest in technical, app-based solutions such as the car sharing service.[30]

Upscaling and replicability of the Measure

Until recently there has been a struggle for survival for car sharing companies in Stockholm. However, the market is changing rapidly and in the central parts of the city there is now an established market for car sharing. Most of the companies are not offering electric vehicles, but are contributing to reducing the number of cars in the city center. Outside the city center there has been less interest in car sharing. Valla torg, which is situated south of the city center is however an example of a potentially broadened market for car sharing. However, the project

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- [28] Bilsvar, Hallå konsument!, *Oberoende vägledning genom Konsumentverket* (https://www.bilsvar.se/sv/sok-bil/bildetaljer/volkswagen_golf_2019_bensin_automat_kombi-sedan_framhjulsdrift_110?brand=VOLKSWAGEN&model=GOLF&fuelgroup=Bensin&fromsearch=true Accessed 2019-04-29, 13.00)
- [29] Volkswagen Golf 2019, 1.0 TSI DSG7 Kombi-Sedan (110hk), Automat
- [30] Growsmarter survey at Valla torg, executed in June 2019 https://www.esmaker.net/analyze/Report/public/?guid=fb51166e-0873-4344-bebd-3fbd5a1c3728

Grow Smarter is subsidizing the car sharing service at Valla torg, as the tenants get their membership for free and the electric charging as well as parking space is free for the company. The measure can be successful in replication. However, to reach an even better result, the target areas demographics can be analyzed so that the target group better match the measure. As seen in the social evaluation[31] for the smart solutions in Valla torg, the majority of tenants are older and may have an effect on usage. A better result is possible in newly produced houses with higher rent and younger residents who are keener on using digital solutions and can financially benefit even more from the measure.

Conclusions

The car sharing service at Valla torg was launched in February 2018. It is frequently used and is successful. There is potential to duplicate the service in other areas as there is economic potential in the business and landlords have an interest in providing their tenants with car sharing services in order to reduce the number of parking spaces. However, the business model for the car sharing at Valla torg needs to be developed after the project period. There will probably be different business models in different areas depending on the market situation for car sharing in each specific area.

M12.2 – Electrical and Cargo bike pool

Introduction

The cargo bike pool launched on the 17th of April 2019. Communication efforts has been done aimed at tenants and a formal launch of the cargo bikes were held. At this event, tenants were introduced to the service and were able to try the bikes around the neighbourhood.
There are two electric cargo bikes in the pool at Valla torg. They are available for tenants living in the buildings that are part of the Grow Smarter project. A private company conducts the electric cargo bike pool. The company deliver user data of the electric cargo bikes.

Stockholmshem has performed an evaluation of social aspects in June 2019. The tenants got the opportunity to share their experiences in a survey. The survey contained questions regarding the tenant's travel behaviour, so the survey will give us information regarding climate impact and the potential of the cargo bike sharing service.

Stockholm

Industry partner	Contact person	Validation partner
Stockholmshem	Olle Krönby	KTH-SEED, IESE

The Electrical and cargo bike pool was launched in April 2019. By offering membership in an electric bike pool, property owners are able to reduce the number of parking spaces attached to the buildings (green parking index) drastically. By reducing the available number of parking spaces it gets less attractive to own a car which will act in favor of other modes of transportation, such as public transport or bike. By offering an electric cargo bike pool it is easier for people to drop the car completely because they have the option to borrow a bike

- [31] Growsmarter survey at Valla torg, executed in June 2019 https://www.esmaker.net/analyze/Report/public/?guid=fb51166e-0873-4344-bebd-3fbd5a1c3728

when they need to. Because the bikes can carry cargo or another person, it is possible to replace most errands done with a car.

The cargo bike company Cykelpoolen collect data from users of the service. The data makes it possible to evaluate the usage of the bikes.

Furthermore, the tenants at Valla torg will get the opportunity to share their experiences of the cargo bike service and their travel behaviour in a survey. The survey took place in June 2019.

Results

Since the launch in april 2019, the electric cargobikepool has been used for approximately 51 hours by 10 individual users. The distance travelled with the bikes amount to 173 km. 7 of the journeys made have been over 10 km and the longest ride so far is 28 km (see Figure 223). Assuming that these 173 km have been done with the electric cargo bikes instead of a medium size petrol car, the CO2 emissions have been reduced by 33 kg. Under the same assumption, the CO2 emissions per kilometre are reduced by almost 100% (see Table 206) as the electricity bought is only from renewable sources.

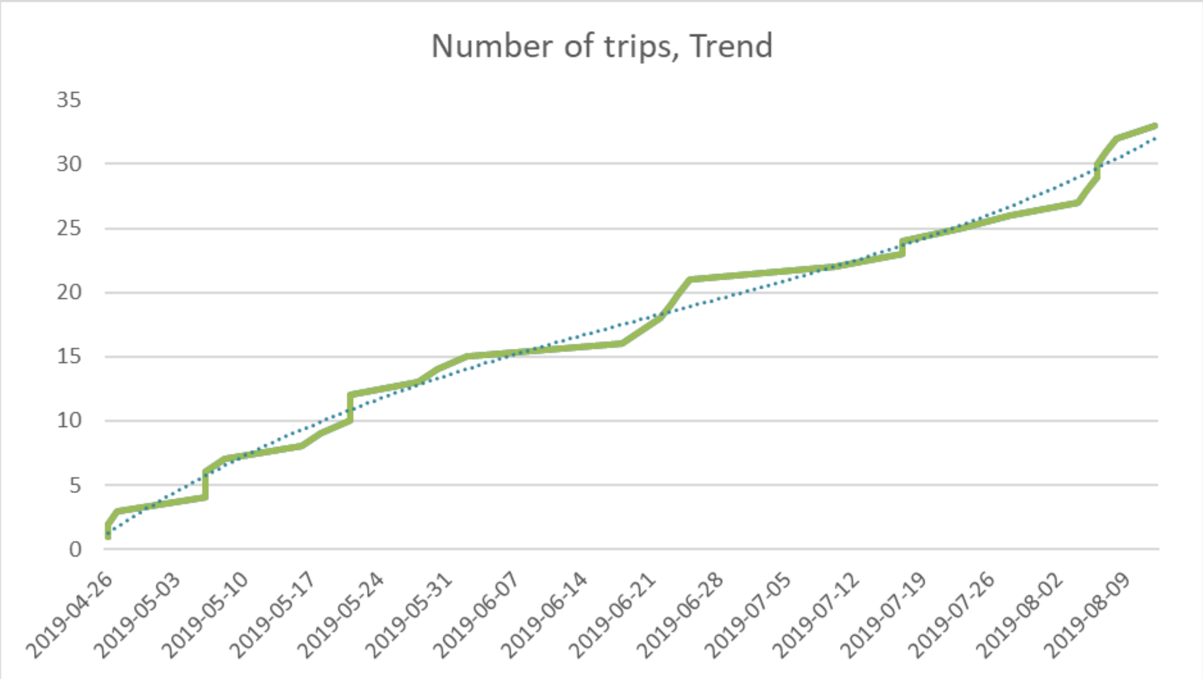


Figure 223 Number of trips since implementation. Cykelpoolen 2019

Table 206 KPIs evaluated for M12.2 in Stockholm

Measure 12.2	Key indicators 36 months	Key indicators 48 months	Key indicators 60 months
Number of people living in the site potentially using measure 12.2	150	Approx. 500	Approx. 500
Observed number of users of measure 12.2	N/A	N/A	10
Average emissions per person kilometer with private vehicles in the site (Kg CO2/km)	0,2 kg CO2/km	0,2 kg CO2/km	0,2 kg CO2/km
Average energy use per person kilometer with private vehicles in the site (kWh/km)	7,92 kWh/km	7,92 kWh/km	7,92 kWh/km
Average emissions per person kilometer with vehicles applying measure 12.2 (Kg CO2/km)	0	0	0
Average energy use per person kilometer with vehicles applying measure 12.2 (kWh/km)	0,004-0,008 kWh/km	0,004-0,008 kWh/km	0,004-0,008 kWh/km
Number of private vehicle kilometers shifting to cycling due to measure 12.2 (km)	N/A	N/A	173

Measure 12.2	Key indicators 60 months
Number of private vehicle kilometers shifting to public transport due to measure 12.2 (km)	N/A
Number of private vehicle kilometers shifting to public transport due to measure 12.2 (km)	N/A
Number of private vehicle kilometers shifting to car sharing due to measure 12.2 (km)	173 km
Number of private vehicle kilometers shifting to renewable fuels or electricity due to measure 12.2 (km)	173 km
Total number of private vehicle kilometers reduced due to measure 12.2 (km)	33 Kg CO2
Total estimated reduction of emissions due to measure 12.2 based on indicators (Kg CO2)	99,95 % kWh/km
Total estimated reduction of energy use due to measure 12.2 based on indicators (% kWh)	0,0099 % CO2
Total estimated reduction of emissions due to measure 12.2 compared to baseline (% CO2)	N/A

Potential for full scale implementation

4.3.1.1.7 Technical feasibility

There has been some difficulties in implementing the measure. Firstly, there was a lack of companies delivering the service. Secondly, when a company was found, negotiations stranded and an agreement of terms could not be struck, hence the launch of the service was delayed. The technical implementation has not had any major complications other than the need to secure the bikes from theft. Therefore, they are placed in a bike cage with electronic locks. This solution limits the service to Stockholmshems tenants and is not yet open to the public due to technical- and security issues.
Unfortunately the cages containing the bikes have been broken in to twice since the launch. Equipment belonging to the bikes and the cage have been stolen, hence the bikepool have been shut down for limited periods of time due to repairs.

4.3.1.1.8 Economic feasibility

The cost of implementing the electric cargo bikepool and operating it for 1 year amounts to 12 347 €. This does not include the cost of the bike-cage nor the electric charging station, as both of these are included in the bigger refurbishment of the area. The cost for reconstruction of the bike cage is due to the break in.

Table 207 Summary of the costs for M12.2

Investment costs	SEK	Euro	**Operating expenditure**	SEK	Euro
Electric locks	61 181,00 kr	5 691,26 €	Monthly fee for 2 bikes	4 000,00 kr	372,09 €
Communication, decor etc.	9 875,00 kr	918,60 €			
Bike cage		0,00 €			
Bike cage reconstruction	13 675,00 kr	1 272,09 €			
Sum	84 731,00 kr	7 881,95 €	**Sum**	4 000,00 kr	372,09 €
Total (1 year)	132 731,00 kr	12 347,07 €			

The expected cost for Stockholmshem when producing parking spaces is approximately 37000€ in a garage (more common in new construction) and about 7000€ outdoors per spot. The car-pool combined with a subsidized public transport-card, improved facilities for bikes and an electric and/or cargo bike-pool, can give a landlord a 15% discount on required parking spaces in new construction of houses. Hence, the measure can be economically feasible in areas with newly constructed housing.

At the moment, we do not see the solution as economically feasible due to low usage of the cargo bikes. During the project, the solution is subsidized and tenants only pay about 1.5€ per hour when they use the bikes. There is no monthly fee. For the solution to be economically feasible the price for the service must be higher or usage must increase drastically.

4.3.1.1.9 Social feasibility

According to Bilsvar[32], the cost of owning a popular mid-size car[33] is 4000 SEK per month excluding parking. In comparison, a membership in the cargo bike pool costs 15 SEK per hour. Therefore, a household can use the bikes for approximately 277 hours before it becomes economically beneficial to own a car. Households that only uses a car sporadically can therefore drastically reduce their monthly costs of transportation by switching to the cargo bike pool.

An evaluation of social aspects of the measures in Grow Smarter have been executed in June 2019. The tenants got the opportunity to share their experiences in a survey. Unfortunately only 2 of the 77 tenants who participated in the survey had used the measure, therefore it is not relevant to evaluate what tenants think of the solution. But the survey gave other answers, for example 35,2 % of the respondents are interested in testing the bikepool and 16,3 % have a decreased interest in owning their own car. Only 8 % of respondents had been members in a mobility sharing service before, hence the experience amongst users is low. The majority of tenants in the area are older, as represented by respondents in the survey where 71 % of the tenants are 51 years old or more, which may lead to a lesser interest in technical, app-based solutions such as the electric cargo bikes.[34]

4.3.1.1.10 Possibility to replicate the Measure

The measure is possible to replicate. Unfortunately, the measure is not sufficiently successful in Valla torg but there are certain improvements that are possible in replication. To increase the economic and technical feasibility of the measure, the bikepool must be open to the public and therefore have a potential bigger group of consumers. Furthermore the bikes should preferably be placed inside a building for easier electric charging and less risk of theft/burglary.

Conclusions

The electric cargo bikepool at Valla torg was launched in April 2019. It is being used but not at a satisfactory amount. One possible explanatory factor for the low usage of the bikepool is the age of tenants. According to the survey made in June, a majority of tenants in the site are above middle age and 51,3 % are older than 60. Stockholmshem together with the bikepool-company will work actively to increase usage of the measure for the remainder of the project. For example, the electric cargo bikes placed in the pool today have 2 wheels, which is not suited for an older target group. We will therefore aim to replace one of the bikes with a 3-wheeled version to accommodate the tenants needs.
There is potential to replicate the measure in other areas but there is need for some improvements for the measure to be feasible, both economically and technically. In newly produced areas, the measure is more likely to be replicated due to the possibility to reduce the required amount of parking spaces, hence lowering the production cost. Furthermore, in replication, the measure must take the age of the target group into consideration.

- [32] Bilsvar, Hallå konsument!, (https://www.bilsvar.se/sv/sok-bil/bildetaljer/volkswagen_golf_2019_bensin_automat_kombi-sedan_framhjulsdrift_110?brand=VOLKSWAGEN&model=GOLF&fuelgroup=Bensin&fromsearch=true Accessed 2019-04-29, 13.00)
- [33] Volkswagen Golf 2019, 1.0 TSI DSG7 Kombi-Sedan (110hk), Automat
- [34] Growsmarter survey at Valla torg, executed in June 2019 https://www.esmaker.net/analyze/Report/public/?guid=fb51166e-0873-4344-bebd-3fbd5a1c3728

The business model for the bikepool at Valla torg needs to be developed after the project period.

M12.3 – Mobility station Cologne

Introduction

Cologne has established three mobility hubs for up to 20 EV and 50 pedelecs including a larger number of electrical pedelecs, which will be available both as standard bikes or cargo bikes. Additionally, public parking spaces can be reserved beforehand by car-drivers, combined with dynamic pricing according to traffic volume in order to reduce traffic and CO_2-emissions.

According to the evaluation plan (D5.1), the intention of the Measure was to provide:
A) Reducing traffic volumes
B) Transition to more energy/emission-efficient transport alternatives
C) Transition to renewable fuels
D) Improved traffic flows

The targets for the mobile stations were defined as follows:
- This solution will reduce carbon emissions and improve air quality
- Mobile stations reduce the need for private car or bike ownership
- Mobile stations make a visible contribution to reducing emissions in the city of Cologne

Cologne

Industry partner	Contact person	Validation partner
Cambio KVB Ampido RheinEnergie	Carsten Rickers	KTH-SEED

Ecomobility has become more and more a component of transport policy and traffic planning of German towns. Ecomobility calls the group of "environment-friendly" means of transportation: Not motorized carriers of traffic (pedestrian and public or private bicycles), public means of transportation (road, coach and taxis), as well as car sharing and carpooling center. The aim of ecomobility is to enable road users to travel their routes within the environmental network and to rely less on their own car. A logical conclusion for Cologne was to set up mobile stations in the GrowSmarter project that would link the different types of mobility. It was intended to setup three large mobility stations, which offer different modes of transport at larger public transport hubs.

During the implementation phase, it quickly became clear that there were problems in finding good locations. These are essentially based on legal requirements, which, for example, prevent these stations from being built on publicly dedicated areas. In the end, 3 larger stations were built. In addition, there are several smaller stations that were set up in M12.4 as car and bike sharing stations. These were included in the analysis, as the term mobile stations has meanwhile been used in North Rhine-Westphalia to include small stations, too.

At the present time (one year after the start of the evaluation) only preliminary results are available. The available figures point to a positive development in the reduction of emissions.

This is strongly supported by the CO_2 reductions at the car- and bike sharing stations of Cambio and KVB. For more details, M12.4, in which CO_2 savings of more than 70% were achieved at the stations. Parking space reservations could also contribute to this if they are introduced in places where there is heavy traffic looking for parking space.

What has also become clear are the different user requirements at the stations. At the large mobile stations such as Charles-De-Gaulle-Platz and Mülheim railway station, it is primarily the possibilities of switching to buses, trains and the KVB bicycle that are used on a daily basis. At all stations, customers primarily use the car sharing service for journeys that cannot be made by public transport or for business trips.

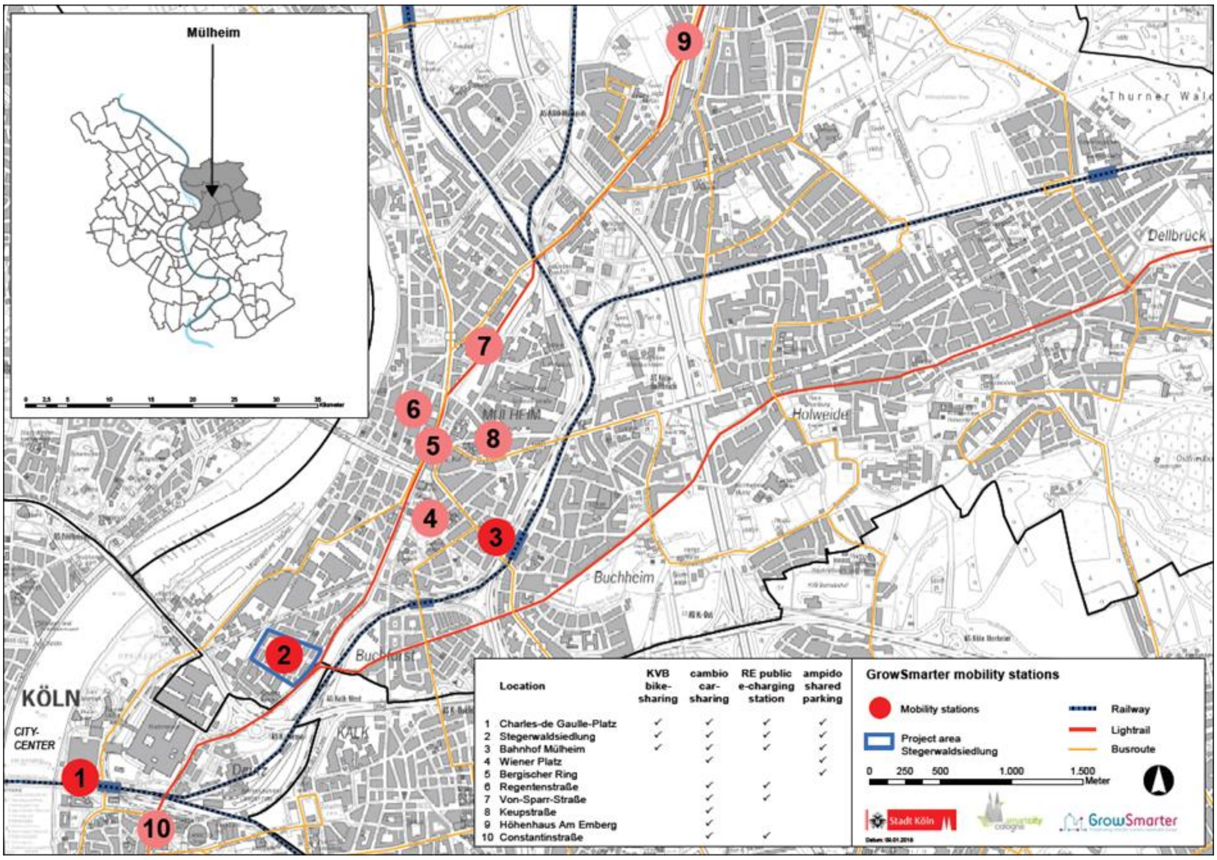


Figure 224 Overview plan: Mobile stations in the project area for M12.3

In the GrowSmarter project, work package 4 for Cologne which included mobility, the construction of 3 large mobile stations with (e-)car-sharing, (e-)bike-sharing, public charging infrastructure and the possibility of reserving parking spaces via an app were defined. In the course of the project, a mobile station was defined and classified for the entire federal state of North Rhine-Westphalia. Afterwards, "small" units were also defined as mobile stations even though there are only individual offers and these stations are not located at large junctions to public transport.

According to this definition, mobile stations with fewer services were also set up within the framework of the project. In order to obtain information about the effect of these mobile stations, they will also be examined within the framework of the evaluation.

During the installation of the stations, various obstacles emerged, which were described in more detail in M12.4 for car and bike sharing and in the annex to this report for car park reservation. Essentially, there was an elaborate search for suitable locations due to legal regulations.

The "ideal" locations for the large mobile stations would certainly be directly in front of the junctions with direct access to / from public transport. In all cases, however, these locations are so-called publicly dedicated areas that could not be used for legal reasons. Only one station is ideally located directly at the Mülheim railway station. However, this is private land owned by Deutsche Bahn AG, with which the project partners had to conclude individual contracts. A use of the areas by Ampido was rejected by the Bahn AG. Only Cambio (car sharing), KVB (bike sharing) and RheinEnergie (e-charging stations) received a usage contract.

The 3 large mobile stations (Bahnhof Mülheim, Charles-De-Gaulle-Platz and Stegerwaldsiedlung) were equipped with information signs (stelae) by the city of Cologne to show the respective offers. Information signs from public transport to the offers of the stations are currently still being discussed, but will probably be implemented at the KVB stops in the near future.
The administration had to obtain a political decision for the permits to be granted or for the contracts to be concluded. A total of 41 organizational units had to be involved in the internal administrative participation procedure, which considerably delayed implementation.

The savings potential for CO_2 emissions could be calculated very precisely. The charging infrastructure is described in M11.1.
More complex is the evaluation of the general impact of the stations. The figures of the registered motor vehicles, divided according to the respective pollutant class, are only collected once a year by the City of Cologne
Since this is a statistical analysis, assumptions must be made for the values where no data are available.
The actual pollutant emissions are not determined here, but a calculated value that refers exclusively to the passenger car vehicles registered in the respective area. Thus also the motor vehicles, which commute daily to Cologne, or which cross the Cologne city area, are not considered, since there are no qualified numbers for this.
Only passenger car vehicles are considered, since the owners could use the target group for a mobile station with car sharing, bike sharing, public transport and taxis.
The Federal Motor Transport Authority publishes the annual average car mileage for the federal territory, which is currently available for the years 2014-2016 inclusive. For 2017 the value was extrapolated. There are no concrete figures for Cologne, which is why this calculation model assumes that the nationwide value also applies to Cologne; no better figures are available.
The exhaust gas limit values are regulated in the respective Euro standards; the respective permissible maximum value is assumed here in the further calculation. Where no exhaust gas limit value is defined, this is either extrapolated or assumed.

The following qualified estimates are made for the "special vehicles" as no findings are available:

- Electric vehicles 5 % of EURO 6, petrol
- Gas vehicles 30 % of EURO 6, petrol
- Hybrid vehicles 80 % of EURO 6, petrol
- Oldtimer EURO 1

Based on the annual mileage multiplied by the permissible limit value in the respective pollutant class, the annual pollutant output is then calculated, broken down by pollutant class. In the tables [Calculation CO], [Calculation HC + NOx], [Calculation NOx], [Calculation PM particulate matter] and [Calculation CO2] the respective areas are first described in line 2. Thus, a radius of 800 meters was drawn around each mobile station, since it is assumed that a maximum of 800 meters represents a reasonable walking distance for the user.

Line 3 indicates the start time for Car-Sharing, the stations marked with a red X have not been put into operation; however, they are also considered below in order to draw conclusions about this calculation methodology. For each area and the years 2014-2018, the reported passenger car vehicles were now multiplied by the annual pollutant emissions; further down in the table, the respective change per year is shown in the summary; the change from 2014 to 2018 is also shown.

In the catchment areas "Von-Sparr-Str.", "Berliner Str./Steinkauler Str." and "Carlswerk" there was a significant increase in the number of passenger cars in 2016 and 2017. The reason is obviously the offer of a company that offers cars as "Auto Flat rate" (permanent rental cars). The cars are registered at an address that is included in all three above-mentioned areas. This results in falsifications of the evaluability of these 3 locations.

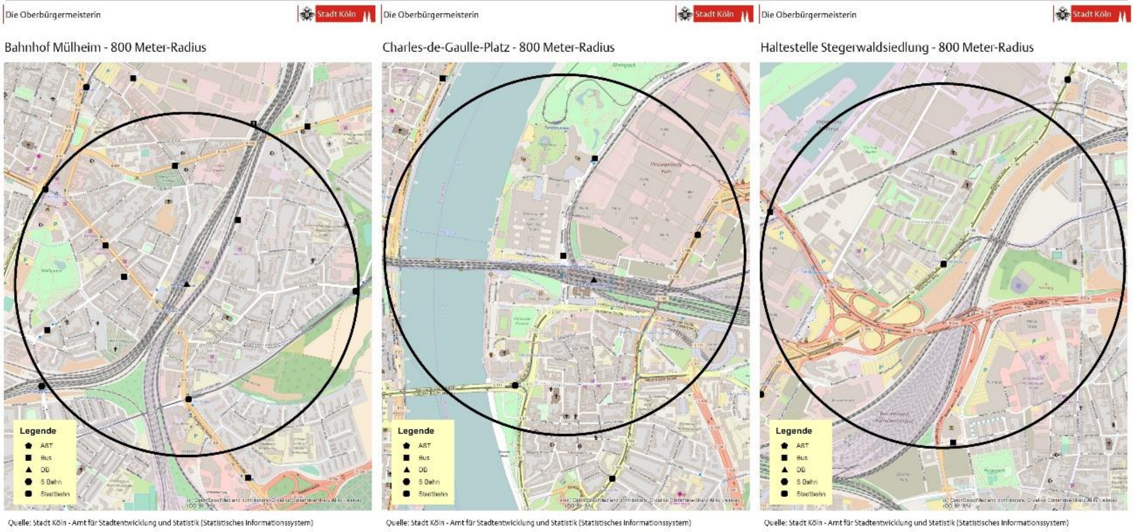
Results

The results show that the reduction of pollutant emissions at the mobile stations is significantly higher than in the city as a whole. Since the calculation model is uniform and therefore comparable, the other boundary conditions that occurred during the observation period, such as the diesel scandal, are not reflected.
Individual values for CO2 emissions, in kg and percentages, can be taken from the following table, which only shows the summary of the evaluation in the Excel file.
In the EURO standards 1-6, where the respective pollutant emissions are regulated, only CO emissions are defined. When the carbon monoxide (CO) is emitted by the combustion engine, it comes into contact with air and burns together with the oxygen (O) present there to form carbon dioxide (CO2). The specific weight of carbon monoxide (CO) is 1.2506 kg/m³, of carbon dioxide 1.9767 kg/m³. Thus the determined weight increases by the factor: 1.9767/1.2506=1.58060131.
The second table [Brief summary] summarizes the values for GrowSmarter. The savings potential for the entire Mülheim project area is presented here on the basis of the given table contents. For Car Sharing we have taken the average CO2 values from Measure 12.4. The KVB's bikes or e-bikes represent an offer for "the last mile". The users are primarily persons who would otherwise have ridden their own bicycle or walked. However, they are also used for errands and excursions and then lead to CO2 savings, which are unfortunately not measurable, as in these cases car journeys are often replaced. The parking spaces used by ampido (details in the facility) are not within the catchment area of the mobile stations, with the exception of the three large stations.

The table below shows that the two stations in the district 9/ Mülheim (Bahnhof Mülheim and Stegerwaldsiedlung) have a better reduction than the district, also the Charles-de-Gaulle-Platz in the district 1/ Innenstadt.

Table 208 Comaprison between different districts (M12.3)

Theme/Topic	Location - 800 m Radius			District		Köln
	Bahnhof Mülheim	Charles-de-Gaulles-Platz	Stegerwald-siedlung	1/Innenstadt	9/Mülheim	
Start	01.04.2016	01.08.2016	01.08.2017			
Emission of Hazards						
Reduction 2014-2018:						
kg	32.357 kg	7.459 kg	9.414 kg	174.880 kg	201.730 kg	1.666.660 kg
Procent:	20,70%	14,23%	14,99%	14,40%	13,59%	14,61%
g/ inhabitants	2.106 g	1.827 g	1.639 g	1.613 g	1.833 g	2.189 g
Procent:	22,17%	15,92%	17,53%	15,29%	14,99%	17,04%



The table above clearly shows that Mülheim railway station has the largest CO2 reduction. At this location there is a subway station as well as several bus lines in addition to the station itself. In addition to the residential buildings, a shopping street is also within walking distance. At Charles-de-Gaulle-Platz there are also the public transport offers, but this location is a rather bad location, because it is behind the actual train station.

The Stegerwaldsiedlung has the next public transport offer with a tram stop only approx. 450 m walking distance away. Within the Stegerwaldsiedlung there is only a pure residential development, no shops.

The same tendency can be found in Measure 12.4

Table 209 Summary oft he KPIs evaluated for M12.3

Measure 12.3 until 2018	Year	Number of people living in the site Mülheim *potentially* using measure 12.3	*Observed* number of users of measure 12.3			Average energy use per person kilometer with private vehicles in the site	Average emissions per person kilometer with private vehicles applying measure 12.3 car-sharing	Average energy use per person kilometer with private vehicles applying measure 12.3	Number of private vehicle km total	Number of private vehicle km per person older then 18 years	total CO2-emission (kg)	CO2-emission (KG) per person older then 18 years	Average emissions per person kilometer with private vehicles in the site	Total estimated reduction of energy use due to measure 12.3 based on indicators	Total estimated reduction of CO2 emissions due to measure 12.3 compared to baseline
		inhabitents > 18	bike-sharing	car-sharing	parking space	kWh/km	Kg CO2/km	kWh/km	km	km	CO2 (kg)	CO2 (kg)	CO2 (g/km)	% kWh	% CO2
Key indicators baseline	2014	121.416	0	0	0		0,000		775.822.780	6.390	1.485.966	12,239	1,915		0,00%
Key indicators 12 months	2015	122.908	0	0	0		0,000		782.592.310	6.367	1.433.686	11,665	1,832		-4,69%
Key indicators 24 months	2016	123.389	0	7.011	311		0,087		796.660.653	6.456	1.396.102	11,315	1,752		-3,00%
Key indicators 36 months	2017	123.208	11.684	12.949	1.778		0,083		831.875.734	6.752	1.350.489	10,961	1,623		-3,13%
Key indicators 48 months	2018	123.422	27.217	15.308	1.812		0,087		835.233.042	6.767	1.348.311	10,924	1,614		-0,33%
Key indicators 60 months	2019 (until 03/2019)	123.422	12.996	3.955			0,085								
Key indicators 2014-2018															-10,74%

The figures for 2019 will be avilable only during the second quarter of 2020 at the earliest

Conclusions

As can be seen from the second table, CO2 emissions - despite an increase in the number of vehicles - are steadily falling in the city of Cologne. This is mainly due to the newly registered vehicles, but also to the reduction in the annual mileage per private car. But mobile stations also seem to have an influence here. The annual reduction in CO2 emissions at the mobile stations is often higher than the reduction in the Mülheim project area or in the entire urban area of Cologne.
It can also be seen that an increased offer of car sharing can contribute to considerable reductions in emissions. Customers see car sharing "only" as a service and receive only the costs of the respective journey.

- They no longer invest a one-off (high) sum in a beautiful, expensive, highly motorized vehicle and then calculate this "positively" by only estimating the kilometers driven with the petrol costs.
- They buy:
  - no longer the car for maximum use (to go on holiday 1x a year),
  - no longer the highly motorized car
  - but pay attention to costs and benefits.

Car sharing operators can therefore also pay very close attention to the emission values of vehicles and influence total emissions solely through this. The increased purchase of e-cars is also contributing to this, even though they are still being used in a very wait-and-see manner at present.
In terms of figures, a comparison with the figures for the city of Cologne but also with other studies (see M 12.4) shows that one car sharing vehicle replaces about 12 private vehicles. However, this only applies to station-based sharing, where the vehicles are returned to the location again and again. The so-called "free-floaters" mathematically replace only about 3 vehicles.
This suggests that mobile stations in the city of Cologne should be supported more with bikes and station-based car sharing. However, the city of Cologne is relying on the mix here, also for competitive reasons.

In this project, ampido was granted a special permit by the district government of Cologne as the upper road traffic authority in coordination with the transport ministry of the state of North Rhine-Westphalia. However, this meant that only two parking spaces could be provided in each case in the publicly legally dedicated street area (Bergischer Ring and Montanusstraße opposite Mülheim station) and only for the project period, i.e. until the end of 2019. A meaningful technical evaluation was not possible under these boundary conditions!
As explained in the annex (ampido), the locations for car park reservations are rather the central shopping streets with a lot of car park search traffic. These are not the locations of the mobile stations. In the ideal locations, high CO2 savings could certainly be achieved.

Operator model
The City of Cologne has a fundamental interest in keeping all pollutant emissions as low as possible or, where possible, to reduce them, also against the background of public welfare. Nevertheless, the City of Cologne cannot act as the operator of a mobile station and thus become actively involved in the improvement of environmental values. The associated consideration is very complex, but is also briefly outlined here in order to make the connections clear:
The division into the various measures 11.1, 12.4 and 12.3 is actually counterproductive for the technical and economic evaluation.
Due to the different modules (offers of the participating industrial partners), the economic risk (risk and profit) lies exclusively with the providers, not with the City of Cologne. The legal problems of online parking space management (ampido module) have been sufficiently pointed out.
So it is indeed worth thinking about discussing an operator model, according to the wish of the partners the operator is then the property owner. For legal reasons, the public sector may not act as such a profit-oriented operator! On the other hand, the municipality is bound by legal regulations regarding the use of public areas. The permission of exclusive use public areas to private companies is regulated by law. In the project we have besides also different property owners:
Charles-de-Gaulle-Platz: City of Cologne, Office for Real Estate, Surveying and Cadastre
Stegerwald settlement: DEWOG
Station forecourt Mülheim: Deutsche Bahn AG
Other locations: City of Cologne, Office for Roads and Traffic Development
Outside the project, other property owners in the city of Cologne are also conceivable in semi-public or public space:
City of Cologne, Office for Landscape Conservation and Green Areas
Landesbetrieb Straßenbau NRW (e.g. as owner of the P+R-Platz Weiden etc.)
When such an operator model is implemented, the respective property owner would also have to order and pay for the respective service from the industrial partner or there is a profit from the business itself. For the implementation an operator model, the administration believes that at least one political mandate, combined with the securing of deficit compensation from public funds.
As a rule, the industrial partner currently submits an application for land use to the landowner, and this application is then decided either positively or negatively.
The municipality has no legal means of entering into corresponding contract negotiations with (private) third parties, as it does not appear as a contracting party. It can support at most accompanying or there is a possibility of contractual agreement with investors in connection with the law. Application of national or local laws or statutes make this possible.

Also due to the fact that each of the mobile stations set up in the GrowSmarter project has different conditions, be it geographical conditions, different number of modules, type and size of the required areas, property conditions (see above), different starting times and much more, a technical and economic overall view of a mobile station is not possible, but it is possible for each selected partner.

M12.4 – Electrical and Conventional car sharing

Introduction

This Measure proposes a car sharing service with a range of different cars to be able to cater to everybody's need in different situations. To completely be able to not own your own car it is necessary that carpools can offer different car for your different needs. An electrical vehicle might be suitable for shorter trips in the city but when travelling longer distances with a big family an electric vehicle might not fit the needs and it is therefore important to offer alternatives. This Measure has been implemented by Cambio. Rentable e-bikes are provided by KVB.

According to the evaluation plan (D5.1), the intention of the Measure is to
A) Reducing traffic volumes
B) Transition to more energy/emission-efficient transport alternatives
C) Transition to renewable fuels
D) Improved traffic flows

Cologne

Industry partner	Contact person	Validation partner
Cambio KVB	Holger Kahl, Tanya Bullmann (Cambio), Thomas Bischof (KVB)	KTH-SEED

The individual data as well as the sum and average values are presented in the summary table at the end of this section. At August 2019, the CO2 savings potentials 51% for 2019 have been achieved by using car-sharing vehicles.

About 46% of cambio customers stopped using their private car All in all, the savings potential for CO2 is 73% or 371 tons due to the private kilometres not driven. These customers only use bicycles (private or KVB bicycles - with about 10% of the abolished private car kilometres - for the last mile) and/or public transport. For special needs, cambio's carsharing service is used. A cambio carsharing car in Cologne can replace about 12 private cars. Also, the average CO2 emissions of carsharing vehicles (0.085 kg/km) are only about half as high as those of the vehicles in the GrowSmarter project area, Mülheim (2018: 0.164 kg/km).

Among the 8 stations, one station unfortunately had to be closed on 15.05.2018 after 9 months of operation, 45 413 users covered a total of 2 297 953 km with Carsharing vehicles until the end of August 2019. Of these, 12% or 275 333 km were covered with e-vehicles. By August 2019, 18% of the kilometres had already been covered electrically. In 2018 as a whole, this was still 14%. That means an increase of 100% compared to 2017 (9%). The increase in the use of electric vehicles since the start of the GrowSmarter project has continued.

The electricity is supplied by RheinEnergie AG in Cologne (M11.1) free of charge as renewable energy ("green electricity").The Life-cycle assessment (LCA) factor has been defined by RheinEnergie equal to 0.010 kg CO2/kWh. Considering this factor, the above-mentioned CO2 savings would be reduced from 73% down to approx. 70%.

In 2018, a total of 12 772 kWh was loaded from the eVehicles. This corresponds to an average of 0.13 kWh per kilometer (103 335 driven km). By August 2019, this had been 12640 kWh with an average consumption of 0.14 kWh (91 993 driven km). The fact that the M11.1 will exclusively provide "green" electricity results in a direct CO2 saving through the electric vehicles of 10.2 t in 2018 and of 9.1 t for the year 2019 until August. The e-vehicles used in the project are exclusively Renault ZOE. Basis for the calculation is the Fiesta with 0.099 kg/CO2 per km, as the most used vehicle at cambio Cologne..

The eTicket, introduced at the end of 2017 in the GrowSmarter project (use of public transport, bikes and carsharing with one ticket), is enjoying great popularity.

- Since the introduction of the integrated solution in October 2017, the proportion of new cambio customers per month who have purchased an eTicket has remained constant at 30%. There are almost 2500 existing cambio customers on the road with the eTicket, which corresponds to 10% of the total number of customers.

- A further 1,260 cambio customers have an old public transport discount with preservation. That is approx. 5% of all Cologne users. In addition, there are 4840 customers with student discounts who are also permanent KVB users with a proportion of approx. 60%. This amounts to at least a further 11%. This means that at least 26% of all cambio customers in Cologne travel with a public transport advantage.

- 80% of KVB's bike users (are also eTicket customers.

The number of bicycle rentals and returns for bike sharing in the entire city of Cologne was around 3.86 million from May 2015 until August 2019, of which more than 370 thousand transactions are located in the Mülheim project area. It should be noted that only a small part of this district is covered by bike sharing.

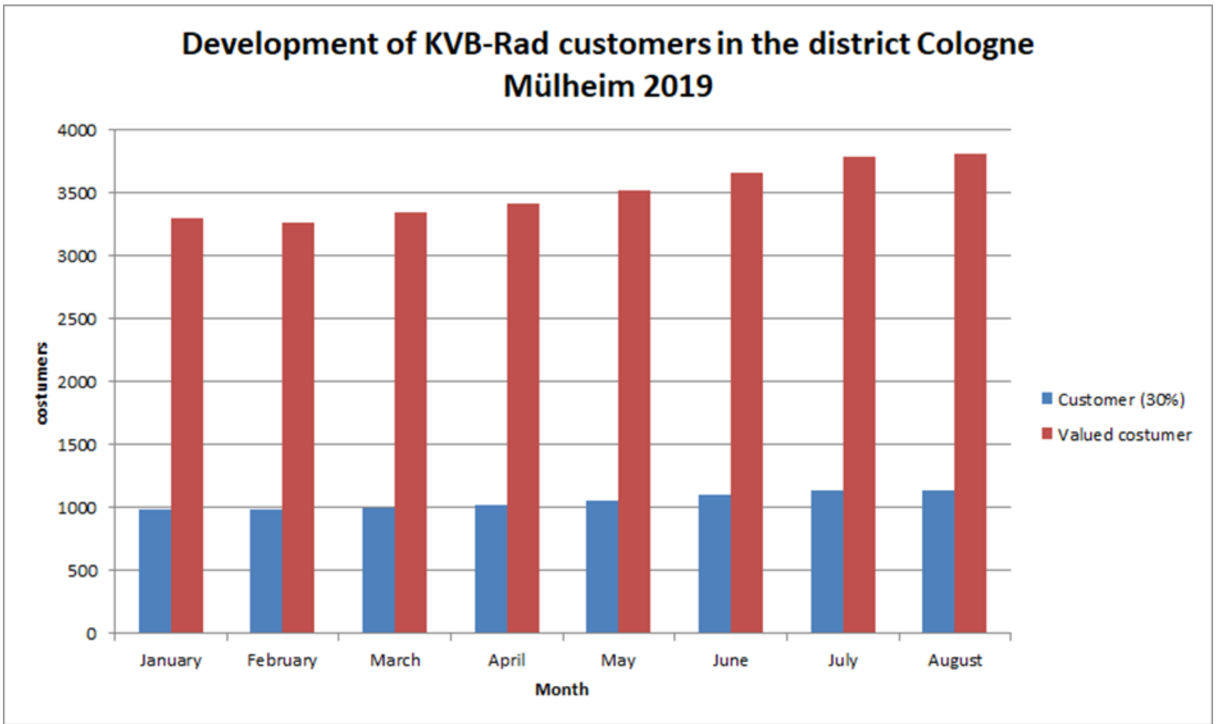


Figure 225 Development of KVB bike customers in Mülheim district in the year 2019.

At the 8 stations, 66087 users covered a total of 98638 km with bike sharing by the end of August 2019. In the case of the bikes, a significant increase in use can be seen in the 100 m area around the stations. With reference to it is worth noticing that the customer information currently available is not complete. Only know the postal code or the city district of about 30% (blue) of the customers was known during the Project. For these reasons the value has been extrapolated to 100% (shown in red)

Due to a delayed certification of the pedelecs and the newly designed stations by the Technical Supervision Association (TÜV), these could only be put into operation at the beginning of February. The average distance travelled cannot be indicated for the pedelecs, as a return/rental can only take place at the fixed stations and no continuous tracking takes place. Therefore, no air line evaluation is possible as a substitute. An exact evaluation regarding the number of rentals/returns is difficult at the beginning, since many rentals only take place "briefly" (<10 min) and are often provided with the comment "accidentally rented", "did not know that it is a pedelec" etc. These comments suggest that the lending was not intended and have therefore not been included in our figures. The measurement at the end of August 2019 show more detailed results and projection possibilities for one year. At the 3 stations, there has been about 763 transactions with pedelec sharing from February until the end of August 2019. Projected to one year, this will be 1 300 pedelec users.

The two drawings below show the transactions for bicycles (May 2015 – Aug 2019) and pedelecs (Feb 2019 – August 2019) at the three large mobile stations

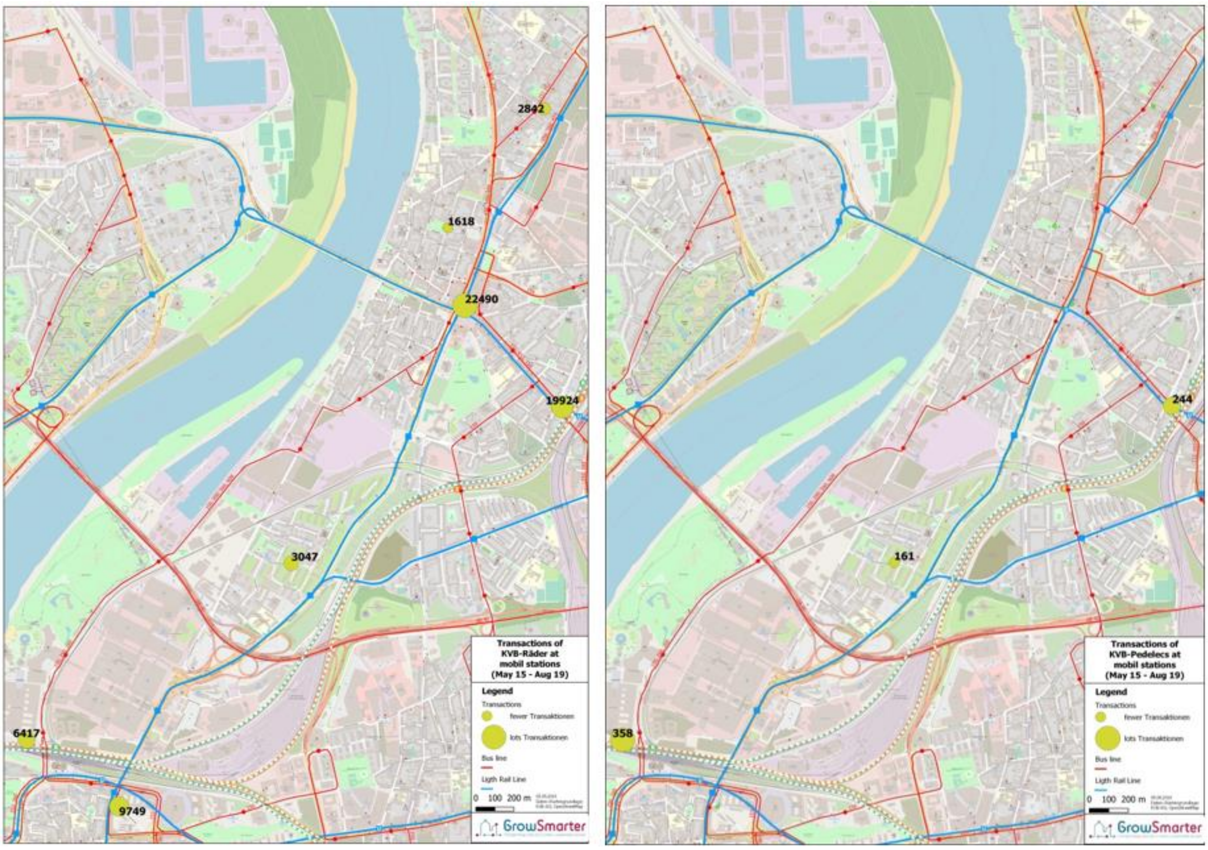


Figure 226 Transactions for bicycles and pedelecs at the three large mobile stations

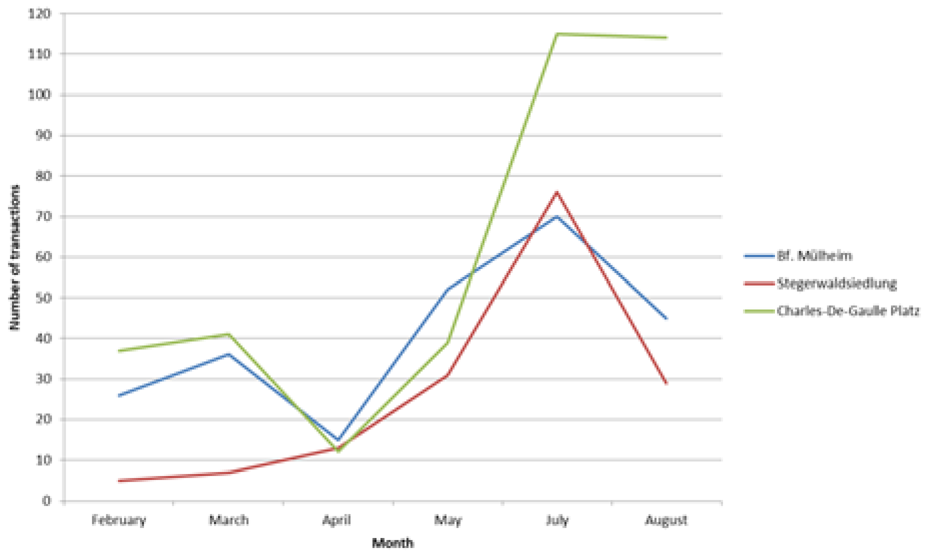


Figure 227 Transactions of pedelecs at mobile stations in 2019 (January – August)

A customer survey by KVB in April 2018 revealed that 58% of respondents considered the KVB bicycle to be a substitute for their own bicycle, public transport or car. 42% already use the rental bicycle multimodally, e.g. after or at the beginning of a public transport ride. The conclusion is that CO2 can also be saved by sharing bicycles through less use of private cars. Unfortunately, it is not possible for us to quantify this by measurements.

Conclusions

The economic view shows that for the time after the GrowSmarter project a just balanced result of the car and bike sharing stations installed in Mülheim can be expected. This is partly due to the high proportion of expensive e-vehicles that are still badly accepted by customers (16 of a total of 40, corresponding to 40% of the GrowSmarter fleet). The usual share at cambio in Cologne is 5%.

On the other hand, the stations Charles-de-Gaulle-Platz (away from the station Köln-Deutz) and Stegerwaldsiedlung (also away from the next stop) are highly uneconomical. This represents 25% of the total of 8 stations. Such a high rate cannot be supported by the 6 economic stations. These inefficiencies are due to the bad location of these stations, which in Measure 12.3 are also listed as large mobility stations.

Some problems were identified in the implementation of the measure. The initially statements that all hubs should be located in public spaces, with the exception of Regentenstr. and Von-Sparr-Str., could not be fulfilled. The other stations have all been built on private or fiscal land. There was also no questioning of the citizens where they intended to position the stations, especially the large mobility stations. Instead, they had avoided dealing with citizens and flexible solutions (train station Mülheim and Stegerwaldsiedlung) by requiring the project partners cambio and -in M12.3 also ampido- to sign individual contracts with Deutsche Bahn or DEWOG. Deutsche Bahn even denied a contract for ampido. Because the stations are mobility stations of the Municipality of Cologne, it would have been more effective if the Cologne Municipality had rented the spaces.

In addition, there were coordination problems between the individual departments of the administration (Municipality of Cologne), which, among other things, made it impossible to set up a station at any other train station (e.g. S-Bahn-Dellbrück).

The municipality of Cologne has a big problem with the considerable exceedances of the emission limit values. Due to a court ruling, the use of diesel vehicles (lower than EU Standard V) will soon be prohibited in large parts of the city. It is necessary to do something about the strong traffic in the city. In addition, cyclists are still “second-degree road users” and are strongly disadvantaged compared to cars, e.g. because of missing cycle paths, unseparated cycle paths on the roads and much too small paths.

Technically it is possible to implement car and bike sharing stations all over Cologne and in other cities. Especially suitable are residential and mixed areas with a good local infrastructure and good connections to public transport as well as a good cycle path network. This would be a good opportunity for the City of Cologne to drastically reduce private car traffic, setting up more such car sharing stations. In addition, private vehicles are only used on average for a maximum of 20% of the time. Most of the time they are only parked occupying space wherever public areas are available. These areas could be used much more sensibly for cycle paths or wider footpaths.

The number of parking spaces to be created by developers is regulated by the building regulations of North Rhine-Westphalia (NRW). The Municipality of Cologne has introduced a law on the payment of transfer fees, according to which the number of parking spaces can already be reduced today if the developer offers replacement measures. These are always individual case decisions on the construction measures in question and there is no fixed index. It would be possible, for example, to install of car sharing stations so that 11 private parking spaces could be dispensed per one car sharing vehicle. This is the accredited factor, described above, for station-based car sharing. This value was also underlined by the GrowSmarter project.

Table 210 Measurements for M12.4, Cologne

KPI	Baseline	12 months	24 months	36 months	48 months	60* months
Number of private vehicle kilometers shifting to public transport due to measure 12.4 (km)	121416	122908	123389	123208	123422	123422
Number of users (pedelec)	-	0	0	0	0	192
Number of users (pedelec)	-	0	0	11684	27217	12996
Number of users (pedelec)	-	0	7011	12949	15308	10145
Average emissions per person per kilometer with private vehicles (kg CO2/km)	0.173	0.173	0.173	0.173	0.173	0.173
Average emissions per person per kilometer with private vehicles applying M12.4 (kg CO2/km)	-	0.0	0.087	0.083	0.087	0.085
Average energy use per person per kilometer with private vehicles applying M12.4 (kg CO2/km)	-	-	-	-	-	-
Number of private vehicle kilometers shifting to cycling due to M12.4 (km)	-	0	32166	56905	61963	43580
Number of private vehicle kilometers shifting to public transport due to M12.4 (km)	-	0	289431	512148	556795	392221
Number of private vehicle kilometers shifting to car sharing due to M12.4 (km)	-	0	377597	669015	740748	511592
Number of private vehicle kilometers shifting to renewable fuel or electricity due to M12.4 (km)	-	0	19222	60843	103335	91933
Private vehicle kilometers reduced thanks to M12.4 (km)	-	0	321457	569051	618629	435801
Estimated reduction of emissions thanks to M12.4	-	0	50973	105675	117436	80325

(kg CO2/km)						
Estimated reduction of energy use thanks to M12.4 (kg CO2/km)	-	-	-	-	-	-
Estimated reduction of emissions thanks to M12.4, compared to baseline (kg CO2/km)	-	0	73	74	73	74

*until August 2019.

M12.6 – Smart taxi stand system

Introduction

Taxis represent an important mobility agent in cities, providing fast and door-to-door services to users. In this measure, different scenarios can happen if taxi drivers use more stops through a mobile application. The main interest of the measure is to encourage taxi drivers to wait in the assigned stops when they have no clients, thus reducing the unpredictable mileage in a vacancy and the consequent congestion, fuel costs, energy consumption and polluting emissions.

The purpose of the measure is to study what would happen if the use of assigned stops increased. This would be done by creating different scenarios, and relating them to the reduction of costs and externalities (pollution) that result from the unproductive mileage of taxis.

According to the evaluation plan (D5.1), the intention of the Measure is to provide:
A) Reduction of traffic volumes
B) Transition to more energy/emission-efficient transport alternatives
C) Transition to renewable fuels
D) Improved traffic flows

The evaluation of this measure will allow quantifying the reduction of kilometres and pollution from a greater use of the stops. The scenarios will be created based on the data collected from the use of the stops at the moment (baseline), and the hypothesis on increasing the occupation rates until total occupation of stands (scenarios). The results obtained from the calculation of the scenarios will be compared to the baseline.

The key performance indicators for this measure are expected to be determined according to the tables provided in the evaluation plan (D5.1).

Barcelona

Industry partner	Contact person	Validation partner
CENIT	Paco Gasparin	KTH-SEED

This study intends to analyze how a proper use of taxi spot stands could contribute to improve taxi providers' efficiency and customers' service satisfaction.

Discussions with the Regulatory Institute for Taxis were held and taxi operators were informed about the Measure and the temporary closure of taxi stands during installation of the sensors (one day per site). A driver survey indicated strong support for the Measure (77,9% in favor). However, the physical implementation of the Measure – installation of sensors into road surfaces and repainting of road markings at taxi stands to ensure accurate parking – was considerably less complex than the data management issues related to the Measure.

Inaccurate parking by taxi drivers and the layout of taxi stands impacts upon the amount and quality of data received by the IT system. The availability of a communication link to send the data also varied in different districts, meaning not all sites that were identified as theoretically possible for implementation were actually viable. As with other measures, the process of obtaining permits for physical works may take time. Similarly, the costs of network access and system use, and issues related with data costs (free for the City administration during the project phase) must be resolved in the long-term. Another challenge is that, from the time the GrowSmarter proposal was written, there has been a rapid increase in the use of proprietary applications by taxi companies, meaning customers increasingly prefer to be collected at, for example, their residence or office. Thus, the impacts of the Measure of taxi use may be hard to discern - this challenge has been evaluated in the demonstration phase.

In this measure, three taxi ranks have been monitored. In each taxi rank 13 taxi parking spaces will have sensors in order to detect the presence of a vehicle. This figure is not very representative when compared to the 354 taxi stands with 2,315 places that currently exist in Barcelona. Considering this fact, it is difficult to evaluate a significant change in behavior of users and taxi drivers since the impact will be relatively low.

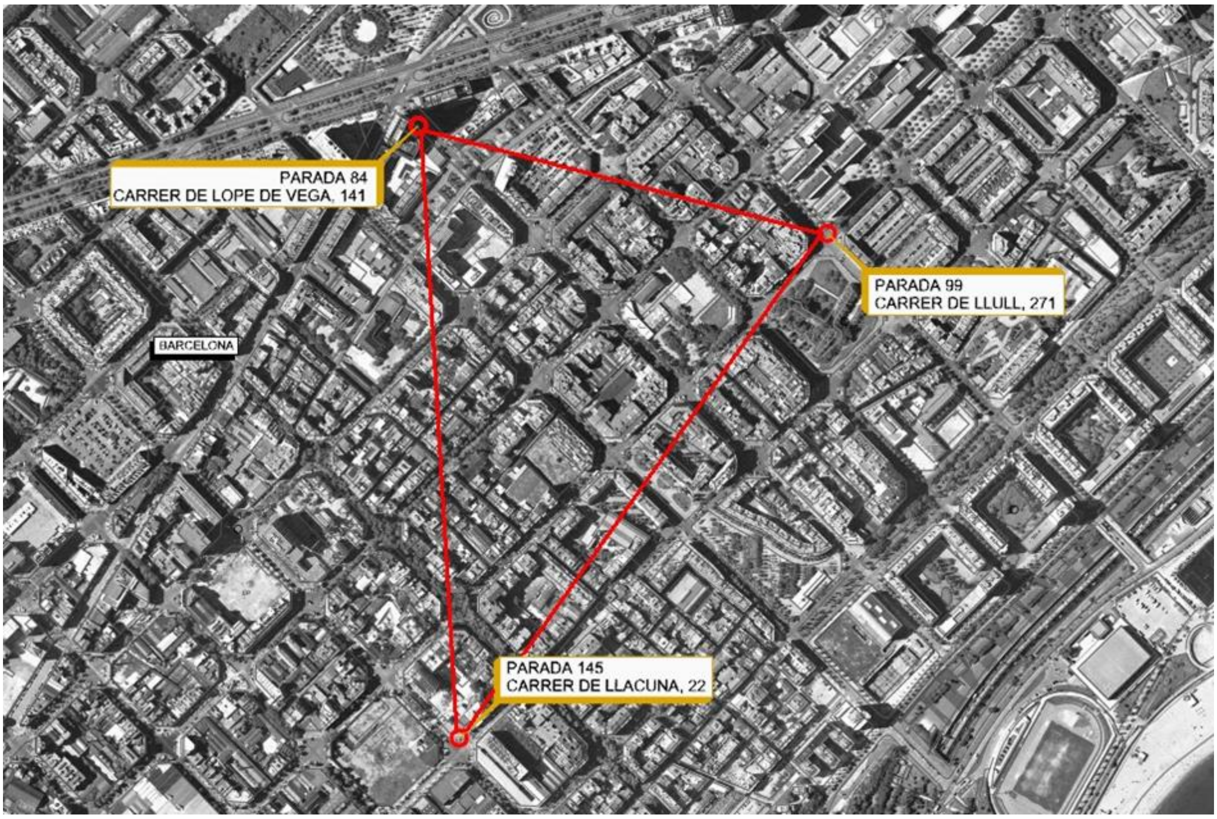


Figure 228: Localization of the three taxi stands

In the year 2018, according to studies at the Taxi Observatory (is an annual report that carries out an analysis of the Taxi sector in Barcelona carried out by CENIT with the Metropolitan Institute of Taxi), the average degree of occupation of the mileage of a taxi was 59% (at night the rate is lower, since taxis should spend more time to look for a client). In addition, the average CO2 produced for each taxi was 7,294 kg. As an annual average, a taxi covers 11.74 km per hour of service with a client and 8.14 km per hour of empty service. In addition, taking into account time, a taxi passes only 27.5 minutes every hour with the clients on board, the rest of the time is unproductive.

These figures are general and describe the sector as a whole and it is unlikely that they change with the implementation of measure 12.6 due to its limited impact. Currently, 30 taxis (sample of taxis used in the Taxi Observatory 2018) in Barcelona provide all data generated by their taxi rides. From this information, the number of taxi rides originated at taxi stops is inferred and the following information is obtained:

<u>Taxi stand number 84</u>

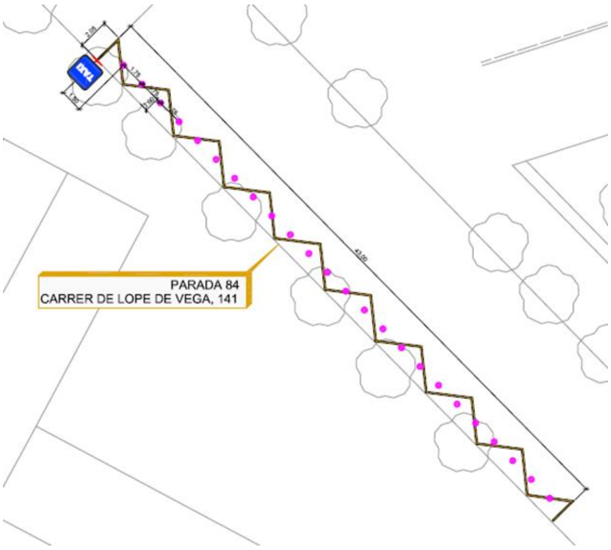


Figure 229 Taxi stand 84 (M12.6)

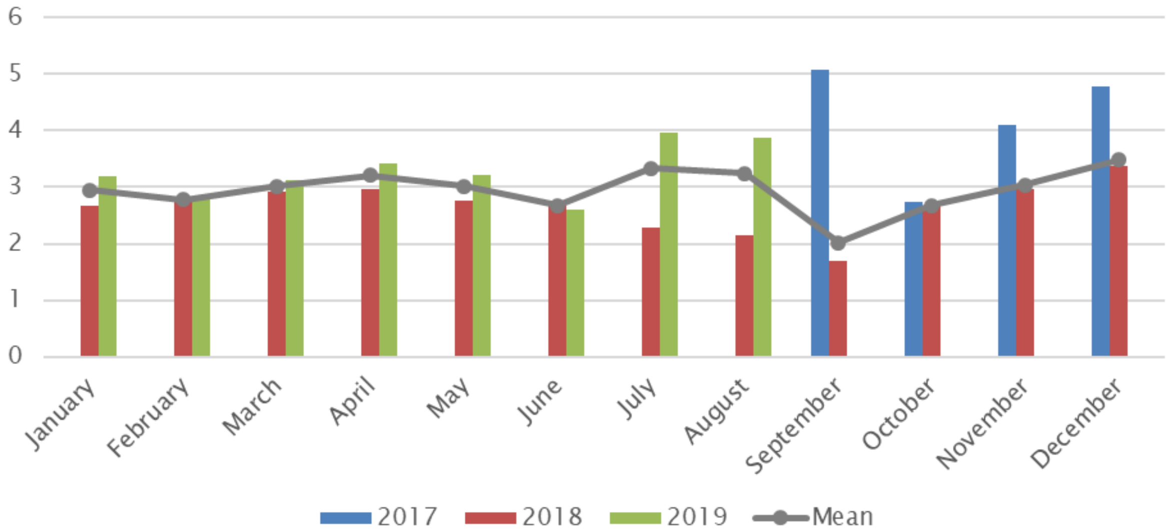


Figure 230 Taxi stand 84: evolution of free spots (M12.6)

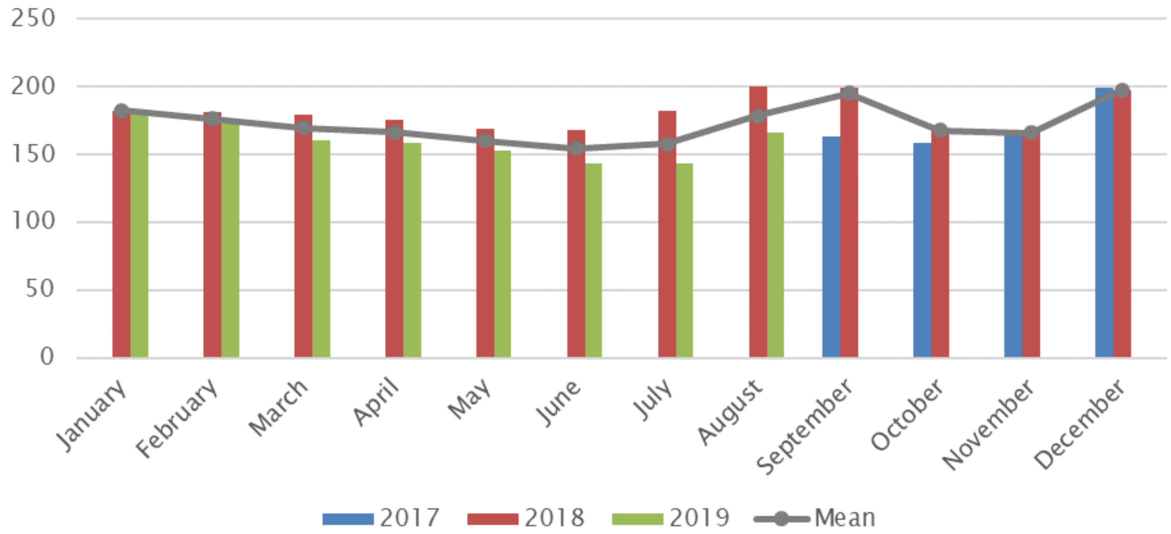


Figure 231 Taxi stand 84 evolution of time (s) between two taxis changes

This stop in the indicated period had 628,002 registered races. However, it can be noted that free taxi spots in stand 84 of the period indicated is 2.99 (Figure 230), and the time between two taxis is 170 seconds (Figure 231).

Taxi stand number 99

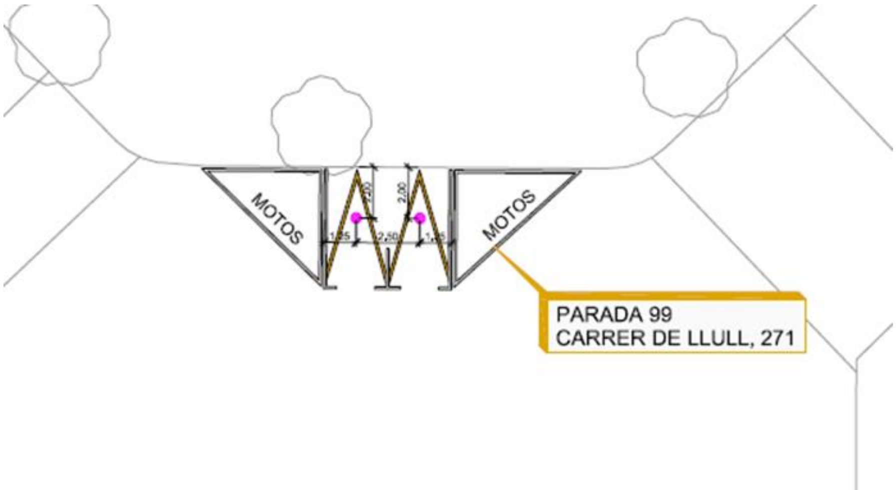


Figure 232 Taxi stand 99 (M12.6)

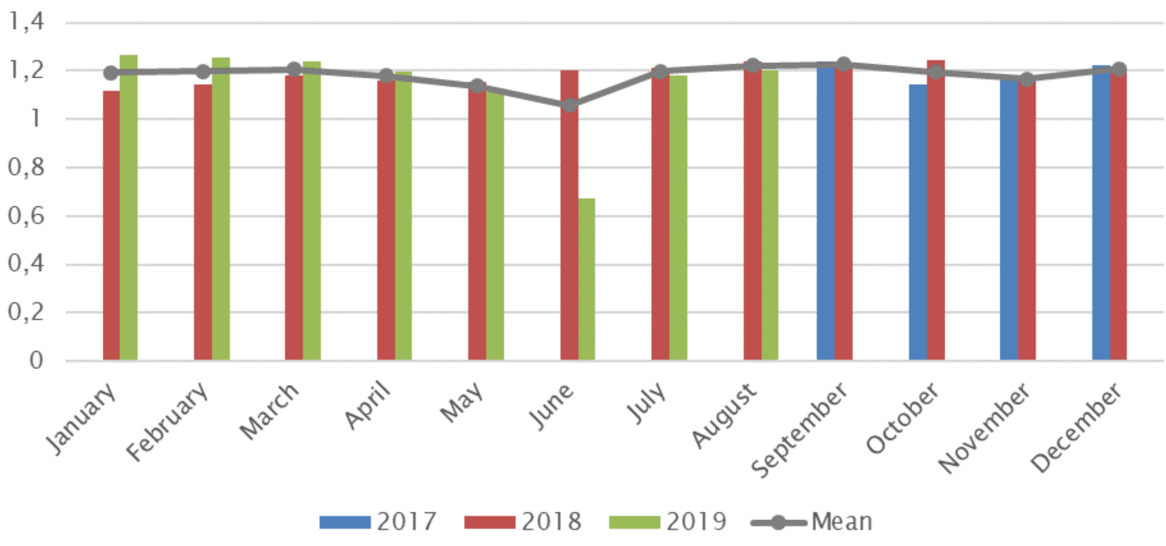


Figure 233 Taxi stand 99: evolution of free spots (M12.6)

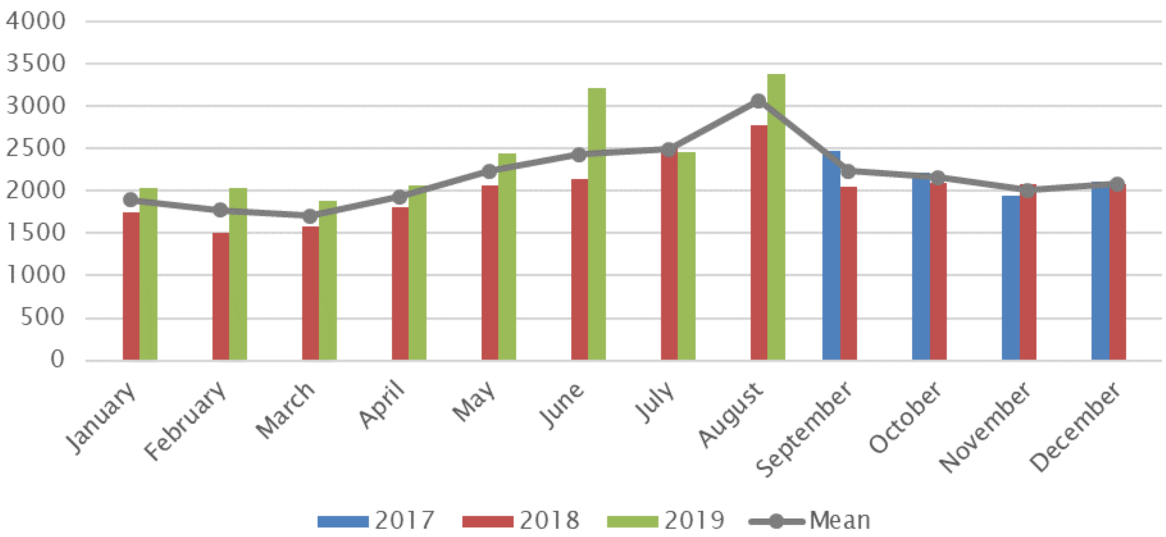


Figure 234 Taxi stand 99 evolution of time (s) between two taxis changes

The total number of races has been 23,516. The average value of free spots for this period is 1.18 (Figure 233) and time is 2123 seconds (Figure 234).

<u>Taxi stand number 145</u>

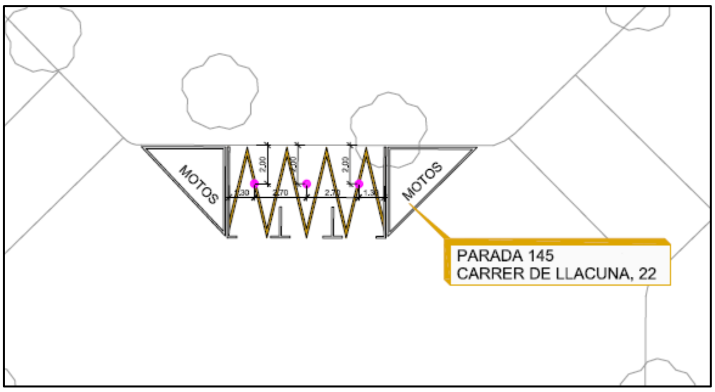


Figure 235 Taxi stand 145 (M12.6)

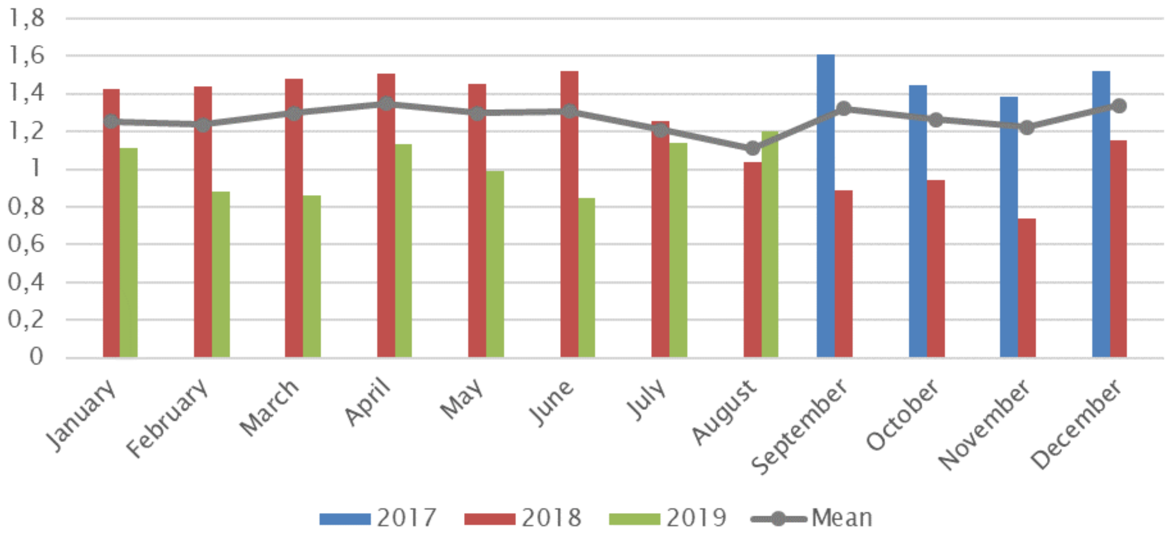


Figure 236 Taxi stand 145 availability trend (M12.6)

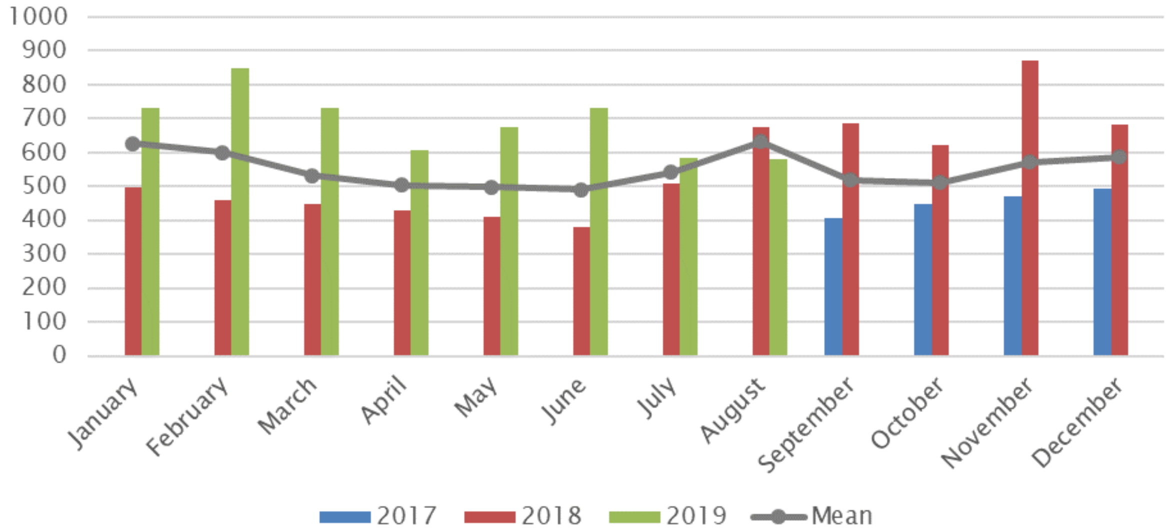


Figure 237 Taxi stand 145 evolution of time (s) between two taxis changes

This stop has registered 117,117 races for two years. The average value of free spots for this period is 1.27 (Figure 236) and time is 549 seconds (Figure 237).

Calculating the number of reduced kilometers travelled by the vehicles because of this measure, is very complex, unless we monitor all taxis and survey all taxi drivers. Since this is impossible, data from the Taxi Observatory of 2018 have been taken to estimate the kilometers. To understand the procedure of the calculation, several considerations were made, which are:

- Selection of the data from the 2018 Taxi Observatory which are kilometers without clients in one hour, during workday and the total days worked per month.
- The occupation index of each one of the stops is calculated as an average per month and it is also assigned as if it were the same value in one hour.
- It is considered that if a taxi is at the stop, it does not circulate in the urban area without a client. Thus, meaning that it does not travel without clients.

Taxi App

The last stage has been the design and development of an application (Figure 238 and Figure 239). The app displays the information that includes the real time availability of spaces or taxis and includes a color to indicate the chances of getting a space / taxi.

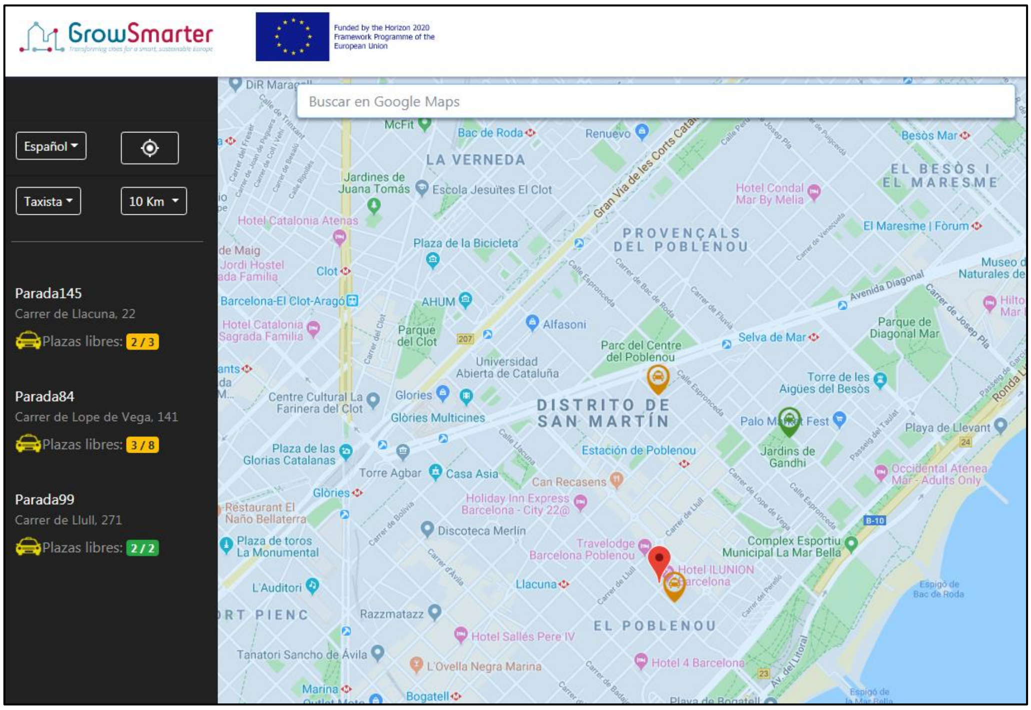


Figure 238 Application tab for taxi driver

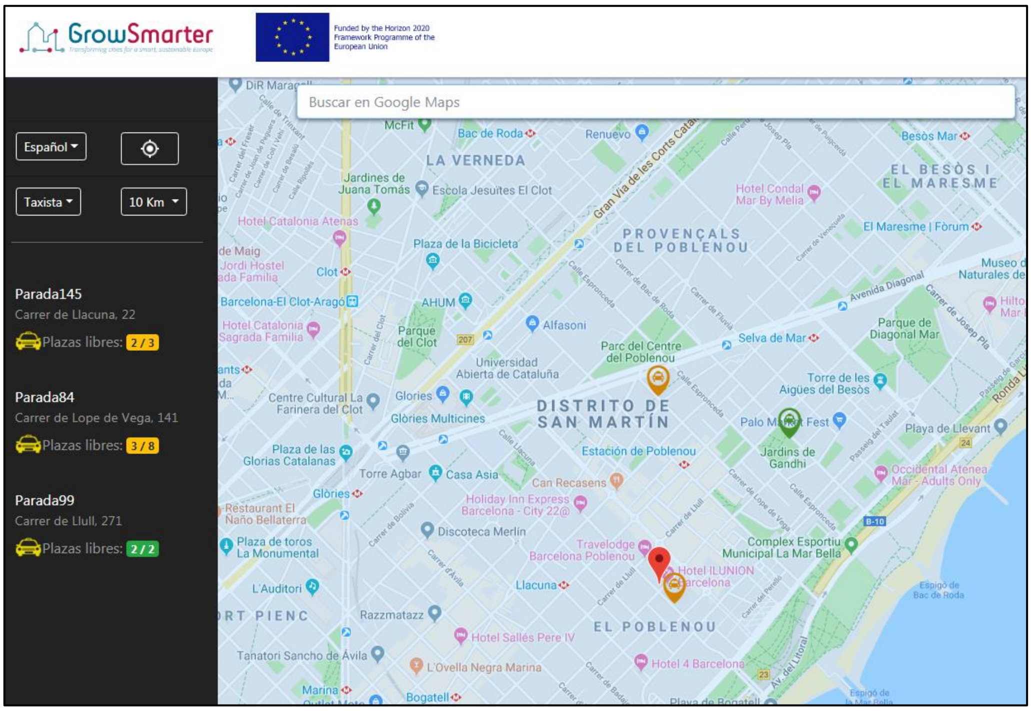


Figure 239: Application tab for user

Evaluation procedure

All data needed to perform the study, has been collected through magnetic sensors installed on the pavement of the taxis stands. These data are sent along the Sigfox network owned by Cellnex and stored at the platform of the Growsmarter project.

The three monitored taxi stands have been collecting data from September 2017 to August 2019. The parameters that can be measured are the availability of points at the stops of monitored taxis and the time between two movements of the sensors.

Data accuracy is difficult to measure since, for instance, stand 84 has a capacity of 8 taxis and its layout is in line. Besides, the stand is very close to a traffic light, fact that may cause some disturbances.

The data gathered from the stants will provides the taxi stands' occupancy for a given time. The list of events is updated once a sensor changes its status. The gathering and grouping of all the data collected for a period of time, for instance 1 month, will be analysed giving the average values of occupancy as output.

Four scenarios have been taken into consideration to predict the use of the application and show how it could affect the reduction of emissions. These theoretical scenarios have been evaluated as the application didn't reach the expected usage due to technical delays in the development, its distribution among taxi drivers and the small impact of the monitored taxi stops compared to the total number of taxi stops. The scenarios take into account each of the stops increasing by 25%, 50%, 75% and 100% of occupation which will be then be compared to the baseline.

The calculation of the CO2 reduction thanks to the use of taxi stops has been carried out through the following steps:

- Using sensors data to extract the available sites from each of the stands. Then, with the total number of places in each of the stops, the occupied places can be obtained. These data are extracted for each month and rank.
- From the Taxi Observatory 2018 can be derived the average number of kilometers in which taxis circulate without a customer in one hour (8,14km), during working hours (10.71h) and the days they work every month (rests two days each week , one day at the weekend and the other on a business day, that is, between 20 and 23 days per month).
- Once the employment data is obtained, the data provided by the Taxi Observatory are multiplied among them to obtain the total kilometers reduced. This procedure is carried out for each one of the scenarios.
- Finally, the CO2 is calculated from the saved kilometers and the kg CO2 of all the stops are added.

The calculation of CO2 is carried out with the following procedure:

- The calculation of the volume of emissions emitted by a taxi per year is made on average taking into account the number of kilometers saved through the use of stops. From a table that has the frequencies corresponding to the type of taxi in relation to the year of enrollment and the type of fuel it uses (that is, the entire taxi fleet of Barcelona) is taken into account. The table corresponds to:

- 7 different types based on the year of production of the vehicle: Conventional (<1992), Euro I (1992-1995), Euro II (1996-1999), Euro III (2000-2004), Euro IV (2005-2010), Euro V (2011-2015) and Euro VI (2015-2018).
- Type of technology: Diesel, GN (natural gas), BD-GLP (biodiesel - liquefied petroleum gas), LPG hybrid, GN hybrid (natural gas), electric and gasoline.

- Another table that resulted very suseful was the one indicating the grams emitted for each km traveled according to the year range, the production of the vehicle and the type of energy source it uses (gasoline, hybrid, etc...). The value obtained by the table is multiplied by the number of kilometers of each taxi and subsequently the desired mass parameter is obtained. In this case, the value is divided by 1000 to obtain the kg/km. The calculation per type of vehicle and production time was carried out as follows:

- the results were gropued per all the available ranges, by dividing respectively the frequency of vehicles in each range by the total number of the taxis in Barcelona categorized per type of vehicle. These values were analyzed and then multiplied by the previously obtained emission values.

<u>KPIs</u>

Table 211 shows the KPIs evaluated for M10.1 in Barcelona.

Table 211: KPIs evaluated for M12.6, Barcelona

Measure 12.6	Total number of private vehicle kilometers reduced due to measure 12.6 (km per year)	Total estimated reduction of emissions due to measure 12.6 based on indicators (Kg CO2)	Total estimated reduction of emissions due to measure 12.6 compared to baseline (% CO2)
Key indicators baseline	176.168 km	26.940 Kg CO2	-
Key indicators scenario 25% occupation increase	220.210 km	33.675 Kg CO2	20% CO2
Key indicators scenario 50% occupation increase	264.252 km	40.410 Kg CO2	33% CO2
Key indicators scenario 75% occupation increase	308.294 km	47.145 Kg CO2	43% CO2
Key indicators scenario 100% occupation increase	352.336 km	53.880 Kg CO2	50 % CO2

It is important to keep in mind that the results (percentages) showed in Table 1 indicate the reduction of CO_2 that could be obtained by the hypothesized usage of the stands compared to the baseline which indicate the current occupation of the stand. Therefore, a further reduction of 50% of CO_2 (with respect to the current situation) could be obtained if the stands are always occupied.

Potential for full scale implementation

Technical feasibility

The installation of the sensors was performed correctly, but there have been problems with the batteries and the overexploitation of the technology with the use of sigfox. Since the stops had a huge amount of movements, the batteries discharged faster than expected. The part of the application has given typical development problems. Another issue encountered was when dealing with third parties (IMET) and the application could not be deployed with guarantees and in time.

Economic feasibility

Aggregated analysis on economic sustainability will be carried out in WP6. However, it is relevant to include, within WP5, considerations on the economic sustainability of each Measure.

Taxi stops need to be promoted to favour urban mobility. This will reduce the pollution and travel time of taxi drivers without a client.

Upscaling and replicability of the Measure

This measure would be replicable and upscaled if there were a suitable technology and with a great duration to perform the analysis of the utilization of the taxi rank. A first approach would be to apply it to the rest of the city of Barcelona and then move on to other cities.

Implementation issues

One of the main issues was the low durability of sensor batteries, as there are many movements during the day at the stops. The main problem, however, was the delay in the deployment of the application; as a result, taxi drivers could not use it, thus the need to evaluate with different scenarios. Although, it is important to note that if data were obtained by the application they would not be sufficiently relevant due to the low number of stops (3).

Conclusions

Fostering the use of taxis is a good way to reduce congestion and pollution in the city. In this case, only three stops could be studied in the 22@ study area. Therefore, the impact in the city is very low compared to what impact it woukd have had if all 354 stands were studied.

The average occupation of all stands was around 50%. The detection time of two changes depends on the characteristics of the stop: the number of places and the type of parking (in-line or in battery), that is, more places mean more movement. Furthermore, when taxies park in line, there is more movement than when it is in battery.

As we could not extract data through the application to see the use of taxi stops, both for taxi drivers and clients, it has been decided to create different scenarios to see what would happen with the launch, from a very optimistic stage to a stage like the current one. From these scenarios, the reduced kilometres and CO2 were calculated, where CO2 savings range from 20% to 50% less than the current scenario. But if we observe the kilograms of CO2, it can be noted that their impact is very small, from 33,675 to 53,880. Therefore, the impact in the city, when studying only three stops, is very low. However, if applied to the whole city, there would be enough values to say whether the impact was high or not.

One of the problems of this measure was the technology used to detect the movements of the taxis, since the batteries of the sensors have a small lasting period. In this data collection period, one of the sensors was hanged and another was drained. Therefore, there is a need to find or research another more appropriate technology to study taxis stops.

In conclusion, this measure has had little impact, but the results obtained from the analysis of the scenarios show that it could have a much higher impact at city level if it were implanted all over the city area. Furthermore, the sensor technology has not been the most appropriate to collect the data due to the battery life. Therefore, it would also be interesting to study other technologies that can be used in the entire area of Barcelona to scale up the solution and increase the impact in the city.

4.4 Conclusions for Work Package 4

All measures of WP4 have been evaluated from one or several of the four alternative forms of data acquisition:

a. Traffic flow measurements
b. GPS-technologies in vehicles or other data from transport actors
c. Computer simulations of traffic flows on specific road links
d. Travel surveys

Experience from the evaluation process of the WP4 measures show that there is often a challenge to gather accurate and useful data. In some situations travel data has been collected at a city level, and transformed to a city district level.

In order to evaluate if the emission- and energy saving potential of the measures developed and implemented in WP4 actually fulfill the GrowSmarter project target of 60% energy- and emission reductions, we need to make a distinction between three systems perspectives:

a) *The direct substitution effects*

This is given by the CO2- emission reductions from substitution of present (fossil fueled) vehicle kilometers with private vehicles and trucks, in comparison to the more energy- and emission efficient transport alternatives developed in the WP4 measures of GrowSmarter. In general, the direct substitution effect of the GrowSmarter WP4-measures fulfill and exceed the 60 % energy- and emission reduction target (e.g. X number of kilometers with a petrol car, transferred to use of an electric vehicle charged with renewable energy sources).

b) The effects from a user perspective

In order to derive the overall effect from implementing the GrowSmarter measures in a certain population of citizens in the transport system (e.g. the tenants in a particular housing district), we need to also include travel behavior and the adoption rate of the specific travel alternatives. Here, emission- and energy saving potentials are strongly dependent on the specific demographic distribution of the population that would need to adopt a new travel behavior using the particular travel alternatives developed. An experience in the GrowSmarter project (in particular from the test-site Årsta in Stockholm) is that the selection of “early adopters” strongly influences the adoption rate of the new transport services developed. A conclusion made after studying the demographic variables from the travel survey conducted initially in Årsta, was that tenants are dominantly elderly people, not too experienced with IT-services and new mobility management alternatives. As shown in the travel survey conducted in the area, 76% of the tenants in Valla Torg are older than 50 years, and 55% older than 65 years. Furthermore, only 17% of the tenants use private car for daily commute. Thus, a recommendation for future projects aiming at designing technologies and energy efficient travel alternatives for early adopters in tenant districts or particular populations in the transport system, would be a thorough market survey before deciding if the population is appropriate as early adopters of the solutions at hand.

None of the measures developed in GrowSmarter has reached an impact on the daily travel behavior (of early adopters of the transport services) that would correspond to a 60% energy- and emission reduction impact from a user perspective.

c) The broad scale system effects in the transport system

To derive the system effects from a future broad scale implementation of the GrowSmarter measures in the transport system, assumptions need to be made regarding future adoption rates of the transport services developed, how they are interlinked, route optimization if logistic services reaches certain user-threshold levels, implementation of charging infrastructure and more. None of the measures developed in GrowSmarter has reached an impact of the magnitude that it would correspond to a 60% energy- and emission reduction impact from a systems perspective. However, some of the GrowSmarter measures are elaborating on “what-if-scenarios” showing the potential of the particular measure from a broader future systems perspective where the potential of reaching the 60% energy- and emission efficiency target is discussed.

Furthermore, there are numerous exogenous factors that might stimulate future applicability and dissemination of the travel measures developed and implemented at a local level of WP4, which are not evaluated in this report, but which need to be addressed. Examples of such are e.g.:

- Relative price difference on fossil fuels in relation to renewable fuels
- Price on electric vehicles in relation to traditional combustion engines
- Development of electric charging infrastructure and battery technologies
- Infrastructure planning (which could prioritize bicycles, public transport, and other forms of sustainable transports to a higher extent than at present.
- Road pricing and future taxation of emissions in the transport system
- Potential adoption rate of the mobility management services in *other* tenant districts than the ones selected for the GrowSmarter project.

Most of the exogenous factors listed above determine the future impact of new technologies and mobility management services such as the ones developed at a test basis in the GrowSmarter project.

5 OVERALL CONCLUSIONS

5.1 Introduction

GrowSmarter has been a very large project, with a budget of 25M€, and a large number of Measures divided into 12 Smart Solutions, spread over three Lighthouse Cities from north to south Europe and also incorporating several follower cities, in many cases reproducing the Measures implemented in the Lighthouse cities. The Measures have been spanning Low Energy Districts, Integrated Infrastructure and Sustainable Urban Mobility. In the chapters above, the validated reports from each of the Measures have been presented. For each of the three main areas, some general conclusions have been drawn. It is the purpose of the present chapter to summarize the conclusions and evaluate the results in a broader sense, and to try to answer the question to what extent the project has reached the goals set up for the project from the beginning.

The overarchin goal of GrowSmarter is to contribute to fulfilling the climate change and energy targets of the EU, which is, by 2020, to decrease the greenhouse gas emissions by 20% (compared to 1990), to have 20% of the energy supply from renewables, and to increase the energy efficiency by 20% . During the course of the project, the Paris Agreement was adopted, stating the aim to limit global warming to less than 2 deg C, and preferably less than 1,5 deg C. Further, the EU has been highly involved in the formulation of the UN Sustainability Goals expressed in the 2030 Agenda for Sustainable Development. GrowSmarter is thus a vehicle for the EU to reach the ambitious, but necessary, goals agreed on for the future.

It is important to note that the goals are not restricted to environmental sustainability, but include also goals concerning social and economic sustainability, targeting the quality of life of EU citizens. Measurable targets to this end is that 75% of the population in the age 20 to 64 should be employed, and that the number of people in risk of poverty and social exclusion should be decreased by 20 million to the year 2020.

Citing the Evaluation Plan of GrowSmarter, the goals of GrowSmarter, as expressed in the Grant Agreement, are to a large extent reflecting the goals of the EU stated above. First, the quality of life of the European citizens should be improved by

1. “…better options for urban transport and better deliveries of goods with improved service towards citizens…”

2. “Cost efficient refurbishment … of existing residential and commercial buildings in cooperation with the tenants “

3. “Improvements in the street environment with smarter lighting and better communication facilities ….”

4. “… better economy by both lower energy costs and increased economic growth and job-creation…”

5. “The project is expected, on the demonstration level … to create as much as 1500 jobs.”

Second, the goal is to reduce the environmental impact and need of energy:

6. “The aim for reduction of energy is 60 % on the demonstration level compared to levels before the project was implemented.”

7. “The reductions of Greenhouse-gases are slightly higher [than 60%] through the extensive use of waste heat and renewable energy sources.”

8. “The project aims to reduce the emissions from transport by 60% in the chosen districts by smarter sustainable transport solutions.”

Additionally, in the project summary, it is stated that

9. “GrowSmarter demonstrates the cost efficient renewal of 100.000 square meters of Nearly Zero or low energy districts reducing energy demand by 70-90%.”

In the description of the Expected Impact it is also stated that

10. [the GrowSmarter project will] “Reduce the … local emissions from transport esp NOx by 60% of the chosen districts.”

The third and final goal is to contribute to a sustainable economic development:

11. “… the project aims at saving energy with quantitative reductions in capital costs as well as reduced costs for energy and maintenance.”

12. “The project aims at saving 60 % of the energy needs for the demonstrated smart solutions thus significantly reducing the cost of energy.”

13. “The project aims to contribute to European economic growth by the integrated Smart Solutions demonstrated.”

These are the goals expressed in the Grant Agreement against which the results should be compared. The present report focuses on the technical and social goals, leaving the goals related to economic issues to the final report of WP6.

As was noted in the Evaluation Plan, a few of the goals above are stated in terms of a qualitative change to the “better” (c.f. goal 1, 2, 3, 4, 11, 13) while the remaining 7 are partly overlapping. In conclusion, the quantitative goals which can be evaluated are the following:

- Creation of 1500 jobs.
- Reduction of energy use by 60% on the demonstration level
- Reduction of CO_2 emissions by more than 60%
- Reduction of emissions from local traffic, especially NOx by 60%
- Reduction of energy use in 100.000 m2 of buildings by 70 – 90%.

The reductions should, in general, be based on the levels before the measures were implemented.

5.2 Key findings

Conclusions concerning each work package were already presented at the end of Ch. 2, 3 and 4. In the following, parts of the conclusions are highlighted again and further discussed.

WP2, Low Energy Districts

The goal for the energy use is, according to point #6 above, a reduction by 60% on the demonstration level. As shown in Ch 2, this goal has been met in some buildings where several means of energy savings have been combined. In other buildings, only selected measures have been implemented and high energy savings cannot be expected. In these cases, the results are still highly interesting and relevant as the effect of only one- or a few, measures can then be evaluated more in detail.

In some cases, the measured savings are less than expected from the calculations done at the beginning of the project. As noted in Ch 2, it is not uncommon that the measured energy use is higher than calculated beforehand. The causes may be problems with the quality of the refurbishment or the components used, but also that the tenants living in, or using, the buildings do not behave as expected (e.g. sleep with the window not properly closed, or washing dishes under running hot water).

In general, the conclusion from WP2, as presented in Ch 2, is that an energy saving of 60% after refurbishment is possible, if a sufficient number of Measures are implemented. The goal of 60% savings have thus been demonstrated for certain buildings, and the possibility of reaching this goal for buildings in general has been demonstrated as well.

In the buildings with the highest energy savings, use of renewable energy sources have been part of the solution. Two such sources should be stressed: Solar energy collected by PV panels and energy from the ambient collected by use of heat pumps. PV panels reduce the need of bought electricity, particularly in the summer time when the insolation is higher. The advantage of PV is highest in hot climates where electric energy is needed for cooling in the summer. Heat pumps, on the other hand, increase the need for electricity, particularly in the winter time and in northern countries where and when solar energy is scarce. From an environmental point of view, it is important to take the local (national) CO_2-emission factors into account when considering implementation of heat pumps. As their coefficient of performance is typically well above 3, heat pumps will drastically reduce the need of bought energy, but depending on local conditions the benefit for the environment will be different. In Sweden, almost all electricity is generated without use of fossil fuels, and in this case heat pumps is an environmentally friendly way of heating. As a matter of fact, the CO_2 emissions related to 1 kWh of electricity is lower than that of 1 kWh of heat from district heating in Stockholm. In a future, when fossil fuels are no longer used for electricity production, heat pumps will be the natural choice of heating buildings, either directly, as done in GrowSmarter, or indirectly, through large heat pumps in district heating systems.

Even though it has been demonstrated that energy savings of 60% is within reach in refurbishment of buildings, there may be other factors than purely technical which may prohibit this to be reached. Buildings are not only dwellings for the inhabitants, they are also creating the visual impression of a city. For this reason, there are often limitations to what can be done to the façade or the roof of a building. This can be exemplified by at least one building in Barcelona, where it was not allowed to add insultation to the façade towards the street. Likewise, it is well known that it is presently not allowed to put PV panels on rooftops without special permission. For the future, there is a need for development of technological solutions which do not influence the visual appearance of buildings. Perhaps, also, the limitations based on aesthetic arguments need to be relaxed to allow the cities to develop in a more sustainable direction.

The effect on the energy use and CO_2 emisions of the refurbishment done within GrowSmarter was calculated considering only the buildings which were completely refurbished. The results were shown in Table 146. For these 30 buildings, the total annual energy savings were 5.8 GWh, representing an energy saving of about 39%. The corresponding total annual reduction of CO_2 was 1437ton, or about 44%. The highest reduction of energy use was for the six buildings in Stockholm, with an average energy saving of about 64%. The reduction of CO_2 emissions was about 57% both for the buildings in Stockholm and the sixteen completely refurbished buildings in Cologne.

For Stockholm, the effect of upscaling of some of the Measures was investigated in particular. The reason for focusing on Stockholm was that data concerning the building stock is easily available. Using public data and making assumptions based on general knowledge of building regulations etc. the effect of five independent measures on the relevant building stock in Stockholm was investigated in some detail. As the Measures are not affecting each other, the effects of each one can be added, and the combined effect can be estimated. The investigation indicates that introduction of exhaust air heat pumps would decrease the energy use by 38%, exchanging old windows for the type used in Årsta in GrowSmarter would decrease the energy use by 14%, heat recovery from the waste water would decrease the energy use by 13%, decreasing the losses from the DHW circulation would decrease the energy use by 3% and increasing the air tightness to the levels achieved in GrowSmarter would decrease the energy use by about 2%. All these measures could be implemented in a large number of buildings in Stockholm and would then result in a total saving of about 61% of the energy used for heating in Stockholm.

WP3, Integrated Infrastructure

Several of the Measures within WP3 are what is called *enabling measures*. This means that they could not by themselves be expected to save energy or reduce environmental impact. Instead, they contribute to the infrastructure on which other Measures may rely. Examples may be communication equipment and data management systems making it possible to track traffic flows, follow energy use of buildings or manage settings of indoor temperatures from a distance. In general, many of the solutions or Measures implemented within GrowSmarter, both related to Urban Mobility and Low Energy Districts are based on new or developing infrastructure and mobile communication. The importance of this infrastructure cannot be underestimated and it can be expected that it will allow the development of new efficient and easy to use services which will help to develop society in a sustainable direction. An important concern is the protection of the personal integrity. During the course of the project, the European *General Data Protection Regulation* (GDPR) was implemented and this resulted in additional constraints to the collection of data, and may have prohibited some technical solutions which may have been beneficial for reducing energy use or increasing quality of life.

Some examples of applications of an integrated infrastructure have been implemented within GrowSmarter and demonstrated to have the potential to increase the quality of life of the citizens and to decrease energy use. A good example is the implementation of Smart Lighting, allowing the reduction of light intensity outdoors or indoors during periods when people are not present, thus reducing energy use. Alternatively, the savings could be used to increase the light intensity during periods when people are present, thereby increasing the sensation of safety. It was suggested by the measurements that Smart Lighting could save as much as 45% of the energy use. However, this figure will depend heavily on where the Measure is implemented. In an area where people are constantly passing, the savings can be expected to be low, while in rarely visited areas the savings would be very high.

Another Measure in WP3 was related to energy recovery from data centers and supermarkets to the district heating system through the use of heat pumps. This requires of course that district heating is well established, which is the case in Sweden and some othe countries in northern Europe, but not further south. In general, a district heating system allows the distribution of heat from co-generation plants, waste incineration plants as well as other heat sources, but due to the high investment costs it is mainly of interest in cold climates. The experience from this Measure within GrowSmarter was that the income from heat sold was in some cases not sufficient to motivate the necessary investment in the heat recovery equipment. Regulations of the market may make it more profitable for small suppliers of heat to connect to the district heating systems in the future.

As for the Smart Waste Collection, it was found to lead to less traffic in between the buildings, but for the overall feasibility it is important that the infrastructure is available for handling the sorted waste. A large scale implementation would be beneficial for the success of the Measure.

WP4, Sustainable Urban Mobility

As stated in the conclusions of Ch 4, the measures in WP4 have been evaluated through at least one of the following four modes of data acquisition:

a. Traffic flow measurements
b. GPS-technologies in vehicles or other data from transport actors
c. Computer simulations of traffic flows on specific road links
d. Travel surveys

In general, it has been a challenge to collect accurate and useful data. To evaluate if the goal of 60% energy and emission reductions have been reached, three different perspectives were considered.

a. The direct substitution effect considers the effect of substituting the vehicle used today with an alternative vehicle running on e.g. (renewable) electricity. In this comparison, the reductions are typically well above 60%. This perspective is useful to apply when for example comparing energy use by delivery vehicles.
b. When new alternatives for travel are offered, a user perspective is necessary. It was concluded that the effect of a certain Measure in this case is highly dependent on the demographic distribution of the people living in the area. In Valla Torg (Stockholm), 76% of the tenants were found to be above the age of 50, and the interest for using bikes from the bike-pool were naturally found to be low. In general, none of the measures intended to influence the daily travel behavior resulted in energy or emission reductions of 60% as was targeted.
c. A third perspective is to look at the broad scale system effects in the transport system of implementing the GrowSmarter solutions. It is concluded that none of the measures tested within GrowSmarter would by themselves reach the goal of 60%

reductions if implemented broadly within the cities.

It should be pointed out that there are several exogenuos factors which are expected to have a large influence on the interest for the solutions developed within GrowSmarter. Examples of such factors are price difference between fossil and renewable fuels, between electric and fossil fuel vehicles, availability of charging infrastructure etc.

5.3 Possibility of upscaling and transfer of technology

The GrowSmarter project has been financed in order to demonstrate available solutions for reducing energy use and environmental impact related to living, working and travelling in the urban environment. The Smart Solutions of the project have been implemented in three Lighthouse Cities, while Follower Cities have had the opportunity to study the implementation. An important factor in the evaluation of the project results is therefore if the implemented Solutions can be transferred to other cities and regions within Europe.

When considering the applicability of a specific solution to a different location there are several conditions which should be considered and some of them will be discussed briefly here.

- The climate is naturally important when considering refurbishment or implementation of energy saving measures in buildings. As an example, the thickness of the insulation of a building has an economic optimum, determined mainly by the cost of depreciating the installation of the insulation and the savings due to reduction of costs for heating and/or cooling. In a warmer climate, thick insulation and triple glazed windows cannot be as easily motivated as in a cold climate with long winters. For this reason it is not straightforward to draw conclusions about this type of energy saving measures between cities. Estimates are necessary concerning the possible savings in the new climate, and the resulting economic savings.

- The origin of electricity, and the corresponding CO_2-emission factors differ greatly between countries. In Sweden, electricity is produced almost exclusively by hydropower, wind power and nuclear power, and the emissions related to the generation of electricity is thus very low. In other parts of Europe the situation is different. In Poland, electricity is mainly produced in coal fired power plants, and CO_2 emissions related to generation of electricity is very high. When considering different options for heating, this should be considered. What may be an environmentally good solution in one country could be less so in another. By using the CO_2-emission factors or similar, it is easy to compare the environmental effects between countries when considering a switch from one energy source to another.

- A related issue is wheter electricity could be considered to be from renewables under certain conditions. In some countries it is possible to specify that the electricity a customer buys from the utility should be from renewable sources. In general, this is positive as the market will set a higher price for electricity from renewables as compared to electricity from fossil fueled plants. However, this is calculated on an average only, and there is no guarantee that the utility can deliver electricity from renewable sources at each instant around the year. Normally this is not considered when evaluationg the environmental effects of energy use. In a future, when smart meters are adopted, modes of tracking the origin of the electricity over time may be developed allowing a true accounting of the renewable energy.

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GrowSmarter
Transforming cities for a smart, sustainable Europe

ABOUT GROWSMARTER

GrowSmarter (www.grow-smarter.eu) brings together cities and industry to integrate, demonstrate and stimulate the uptake of '12 smart city solutions' in energy, infrastructure and transport, to provide other European cities with insights and create a ready market to support the transition to a smart, sustainable Europe.

GrowSmarter project partners

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