# Thermal upgrade assessment of a multi-storey residential building based on in situ measurements

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**Abstract.** Within the framework of a renovation project in Stockholm area (Sweden), *in situ* measurements were carried out with the QUB/e method to (*i*) assess the actual thermal performance of the building fabric and (*ii*) validate the thermal upgrade measures implemented. Two consecutive QUB/e tests were performed in an apartment of a fully renovated multi-storey residential building. The average $U$-values were $0.64 \pm 0.04\,\mathrm{W\,m^{-2}\,K^{-1}}$ and $0.25 \pm 0.02\,\mathrm{W\,m^{-2}\,K^{-1}}$ for the glazings and the external walls, respectively. The measured values were in good agreement with the calculated values communicated by the municipality. A comparison of *in situ* measurements undertaken before and after the implementation of the thermal upgrade measures indicates that a three-fold decrease of the $U$-values (i.e., -67%) was achieved. This was consistent with the target set by the municipality (i.e., -60%). The thermal performance of the building fabric resulting from the thermal upgrade measures implemented (using off-the-shelf solutions) could thus be considered validated.

## 1. Introduction

The lack of fast and reliable *in situ* measurement methods often precludes the implementation of a systematic assessment of the thermal performance of the building envelope for both new-built and renovation projects. The QUB/e method [1, 2] is a dynamic measurement method developed to estimate the thermal performance of building envelopes (i.e., whole heat loss coefficient and $U$-values) in a single night without occupancy. The QUB/e method differs from other measurement method in its speed (one night compared to about two to three weeks for other existing methods). This makes it suitable for large-scale use by industry to test the actual thermal performance of buildings. The ability of the QUB/e method to provide reliable results was demonstrated in previous works (e.g., see [1, 2, 3, 4] and references therein).

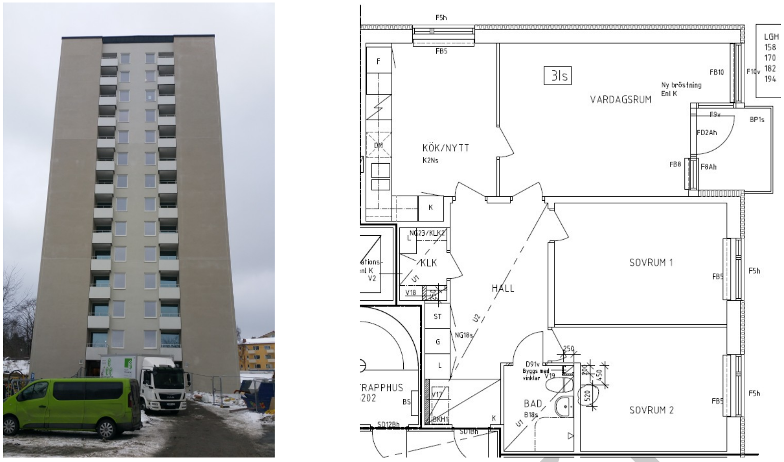
Within the framework of a renovation project in Stockholm area (Sweden), *in situ* measurements were carried out with the QUB/e method to (*i*) assess the actual thermal performance of the building fabric and (*ii*) validate the thermal upgrade measures implemented.

This paper is organised as follows. The materials and methods used in this study are described in Section 2. The results obtained from *in situ* measurements are presented and discussed in Section 3. Concluding remarks can be found in Section 4.

## 2. Materials and methods

### *2.1. Description of the building*

The measurements took place in an apartment on the $10^{\text{th}}$ floor of a circa 1960s multi-storey residential building located in Årsta (Stockholm area, Sweden). A view of the building and the layout of the apartment are shown in Figure 1.




(a) View of the external façade.

(b) Layout (sovrum = bedroom, kök = kitchen, vardagsrum = living room).

**Figure 1.** Overview of the apartment.

The wall construction is aerated concrete and the windows are double glazing units (DGU) with wood frames. The thermal upgrade measures involved an external wall insulation (EWI) system (Serporoc Premium/A system with glass wool from Isover and renders and other components from Weber) and the windows were made of quadruple glazing units (QGU) with aluminum frames (Domlux). The apartment has North – East orientation, floor area, attached area and net heated area of approximately $79\,\mathrm{m}^2$, $193\,\mathrm{m}^2$ and $241\,\mathrm{m}^2$, respectively. It should be noted that the window-to-external wall ratio is quite high (i.e., 27%) and the proportion of the net heated area in contact with the exterior is low (i.e., 20% of the total net heated area) but typical for an apartment in a multi-storey residential building.

### *2.2. QUB/e method*

The principle of the QUB/e method [1, 2] is relatively simple: (*i*) the interior of a building is subjected to a thermal load modulation composed of two phases of equal durations and with a constant power (i.e., heating and free cooling) during the night and without occupancy; (*ii*) the temporal evolution of the dissipated thermal power, the ambient air temperatures and the heat flux densities are measured; (*iii*) the thermal transmission properties of the building envelope are then derived.

The QUB/e method makes it possible to measure both the overall insulation level of the building envelope (i.e., whole heat loss coefficient) and the local insulation level of building elements (i.e., $U$-values). For a detailed description of the QUB/e method and previous works, the interested reader should refer to [1, 2, 3, 4] and references therein.

### *2.3. Monitoring equipment and testing protocol*

The tests were carried out when the apartment was unoccupied between March 6$^{\text{th}}$ and March 9$^{\text{th}}$, 2018. Two consecutive QUB/e tests were undertaken at night. The mechanical ventilation and the heating system of the apartment were switched off during the QUB/e tests. Electrical heaters (i.e., fan heaters) were placed within the apartment in order to provide a uniform heating source for the QUB/e tests. The total duration of each QUB/e test was 13 hours (i.e., between 5.30pm and 6.30am).

Heat flux plates (Hukseflux HFP01) and type K thermocouples were used to monitor the heat flux densities on building elements and the air temperatures. A silicone paste was used to ensure a good thermal contact between the heat flux plates and the building elements. All sensors were connected to data loggers (Graphtec GL820). Weather conditions (i.e., temperature, relative humidity, wind orientation and speed, solar radiation) were recorded with a Davis Vantage Pro2 weather station installed on the balcony of the apartment. The data acquisition rate was set to one minute.

*In situ* measurements of heat flux density, from which *in situ* $U$-values are derived, were taken at 20 locations on the thermal elements (6 on the external walls, 5 on the internal walls, 4 on the floor, 2 on the ceiling and 3 on the glazings) of the apartment using heat flux plates (HFPs). Only measurements of heat flux density obtained from those locations that were considered not to be significantly influenced by thermal bridging at junctions with neighbouring thermal elements (typically at distances greater than 500 mm from the junctions) were used in the calculation of the *in situ* $U$-values. The appropriate locations were determined through a thermographic survey undertaken in accordance with EN 13187:1999 [5] (not reported here for the sake of brevity). It should be noted that HFPs were placed at the centre pane of the windows, i.e. the $U_g$-value of these glazing units could be derived from our measurements.

During a QUB/e test carried out in an apartment located in a multi-storey residential building, the heat exchanges do not only occur between the interior of the apartment and the exterior environment but also between the interior of the apartment and the neighbouring internal zones (apartments, corridor). The whole HLC needs to be corrected [1, 2, 4] in order to report only heat losses (or gains) to the exterior environment and have a sound comparison with theoretical calculations which assume a uniform temperature within a building (i.e., there are no heat losses/gains).

The HLC with respect to the exterior environment can be calculated with the following formula:

$$HLC_{ext} = HLC_{raw} - \sum_{j} U_{eff,\,j} \times A_j \qquad (1)$$

where $HLC_{ext}$, $HLC_{raw}$, $U_{eff,\,j}$ and $A_j$ are the HLC w.r.t. the exterior environment only (in $\mathrm{W\,K^{-1}}$), the 'raw' HLC (in $\mathrm{W\,K^{-1}}$) obtained from the standard QUB/e analysis, the effective $U$-value of the $\mathrm{j^{th}}$ internal element (in $\mathrm{W\,m^{-2}\,K^{-1}}$) obtained from the QUB/e method and the area of the $\mathrm{j^{th}}$ internal element (in $\mathrm{m^2}$), respectively.

The effective $U$-values derived from the measurements on the HFPs located on internal building elements (internal walls, floor, ceiling) exhibited rather large variations so that the heat losses (or gains) associated with each internal element had a large uncertainty. Besides, the proportion of the net heated area in contact with the interior being large (i.e., 80%) and the building envelope being highly insulated (i.e., $U$-values for the external walls smaller than $0.3\,\mathrm{W\,m^{-2}\,K^{-1}}$), the estimate of $HLC_{ext}$ would be associated with an uncertainty deemed not acceptable. We will thus only present and discuss the $U$-values of the external walls and the glazings in the next section.

It should be noted that the difficulty associated with the characterisation of the HLC of apartments in multi-storey residential buildings is not only related to the QUB/e method but to dynamic measurement methods in general. For quasi steady-state measurement methods (e.g., coheating method [6, 7]), if access to neighbouring internal zones can be arranged to control/monitor the air temperatures (i.e., by prescribing the same setpoint temperature in each zone), the HLC to the exterior environment can be estimated. This is seldom possible in practice.

## 3. Results and discussion

### *3.1. Local U-values*

Figure 2 shows the local $U$-values for the glazings and the external walls. Each boxplot corresponds to the $U$-values estimated for each QUB/e test for the glazings (3 different locations) and the external walls (6 different locations).

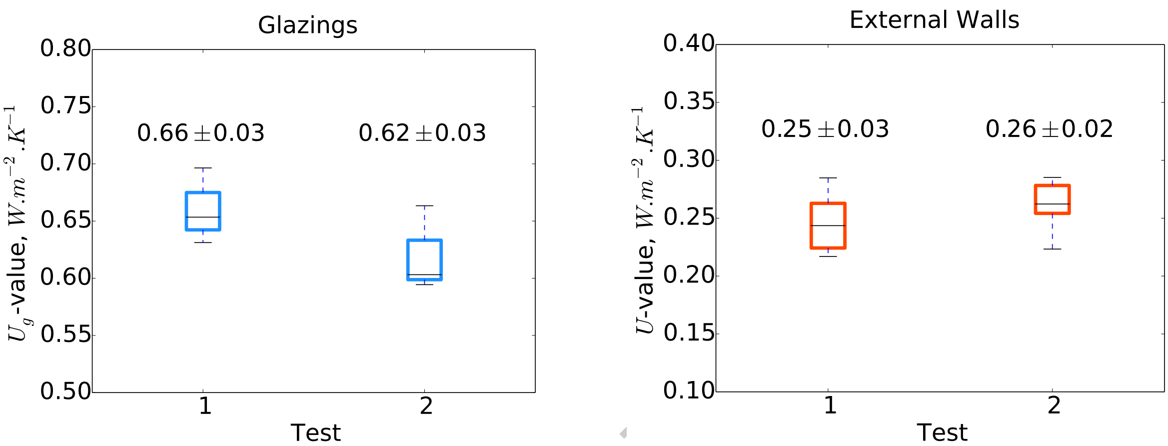



**Figure 2.** Local $U$-values. Each boxplot corresponds to the $U$-values estimated for each QUB/e test for the glazings (left) and the external walls (right).



The relative dispersion of the estimated local $U$-values was rather small (i.e., the coefficient of variation was smaller than 5% and 10% for the glazings and the external walls, respectively). This indicates that the building elements are fairly homogenous thermally-wise. This statement was backed-up by a thermographic survey undertaken in accordance with EN 13187:1999 [5] (not reported here for the sake of brevity).

The estimates obtained for both QUB/e tests are in good agreement (i.e., the relative differences are not significant) and demonstrate the robustness of the QUB/e method. The average measured $U$-values were $0.64 \pm 0.04\,\mathrm{W\,m^{-2}\,K^{-1}}$ and $0.25 \pm 0.02\,\mathrm{W\,m^{-2}\,K^{-1}}$ for the glazings and the external walls, respectively.

The measured values were in good agreement with the calculated values communicated by the municipality (i.e., 0.7 and $0.27\,\mathrm{W\,m^{-2}\,K^{-1}}$ for the glazings and the external walls, respectively). No 'performance gap' (e.g., see [8, 9, 10] and references therein) was observed (i.e., the relative differences between the target and the measured values were within the uncertainty bound of the measurements). The thermal performance of the building fabric resulting from the thermal upgrade measures (using off-the-shelf solutions) could thus be considered validated.

### *3.2. Thermal upgrade assessment*

A comprehensive set of *in situ* measurements was carried out in an apartment before the implementation of the thermal upgrade measures [4]. The measurements presented in this paper were conducted in a different building, part of the the same refurbishment project in Årsta, since the renovation of the previously tested building was not yet completed at the time the measurements took place. If we assume that the thermal performance of the building fabric is homogenous within these multi-storey residential buildings, we can assess the actual thermal upgrade of the building envelope and compare it with the target value.

Figure 3 represents the average $U$-values (derived from *in situ* measurements carried out with the QUB/e method) of both the glazings and the external walls before (baseline) and after (retrofit) the implementation of the thermal upgrade measures. A three-fold decrease of the

$U$-values (i.e., -67%) was achieved thanks to the thermal upgrade. This is consistent with the target set by the municipality (i.e., -60%).

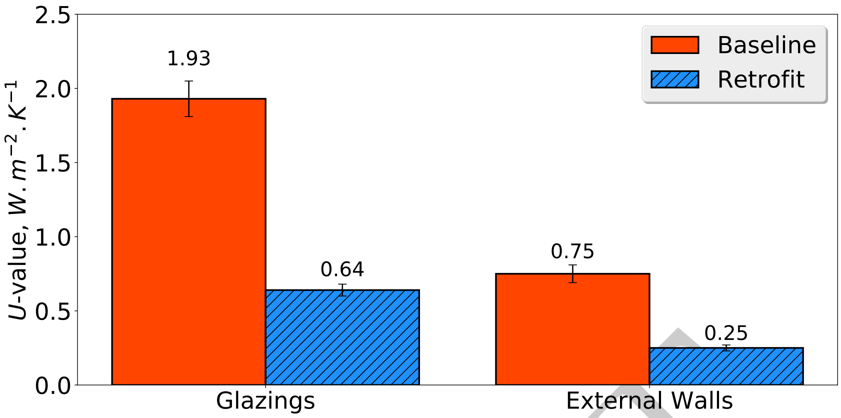



**Figure 3.** Average $U$-values before (baseline) and after (retrofit) the thermal upgrade measures.

## 4. Conclusion

The findings from a series of *in situ* measurements in a fully renovated multi-storey residential building were presented in this work. The objectives of the measurements were to (*i*) assess the actual thermal performance of the building fabric and (*ii*) validate the thermal upgrade measures implemented.

Two consecutive QUB/e tests were performed in an apartment located in Årsta (Stockholm area, Sweden) after its full renovation. We obtained robust estimates of the local $U$-values. The measured values were in good agreement with the calculated values communicated by the municipality.

A comparison of *in situ* measurements undertaken before and after the implementation of the thermal upgrade measures indicates that a three-fold decrease of the $U$-values (i.e., -67%) was achieved. This is consistent with the target set by the municipality (i.e., -60%). The thermal performance of the building fabric resulting from the thermal upgrade measures (using off-the-shelf solutions) could thus be considered validated.

This work also demonstrated the relevance of the QUB/e method for wider uptake of quality assurance practices by the building construction industry.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## References


[1] Meulemans J, Alzetto F, Farmer D and Gorse C 2016 QUB/e – A novel transient experimental method for in situ measurements of the thermal performance of building fabrics *International SEEDS Conference 2016: Sustainable Ecological Engineering Design for Society* ed Gorse C and Dastbaz M (Leeds, UK) URL https://hal.archives-ouvertes.fr/hal-01589176

[2] Meulemans J, Alzetto F, Farmer D and Gorse C 2017 QUB/e – A Novel Transient Experimental Method for in situ Measurements of the Thermal Performance of Building Fabrics *Building Information Modelling, Building Performance, Design and Smart Construction* ed Dastbaz M, Gorse C and Moncaster A (Springer, Cham, Switzerland) URL https://doi.org/10.1007/978-3-319-50346-2_9

[3] Sougkakis V, Wood C, Meulemans J, Gillott M and Cox T 2019 QUB/e: Validation of a transient method for determining whole building thermal performance and building element U-values in situ under actual operating conditions *Proceedings of the 17$^{th}$ International Conference on Sustainable Energy Technologies – SET 2018, 21–23 August 2018, Wuhan, China: Sustainable Energy Technologies for Eco Cities and Environment* vol 3 ed Riffat S, Su Y, Liu D and Zhang Y (University of Nottingham, Nottingham, UK) pp 174–184 URL https://nottingham-repository.worktribe.com/output/1607959

[4] Meulemans J 2019 An Assessment of the QUB/e Method for Fast In Situ Measurements of the Thermal Performance of Building Fabrics in Cold Climates *Cold Climate HVAC 2018* Springer Proceedings in Energy ed Johansson D, Bagge H and Wahlström A (Springer, Cham, Switzerland) pp 317–326 URL https://doi.org/10.1007/978-3-030-00662-4_27

[5] BS EN 13187:1999 Thermal performance of buildings – Qualitative detection of thermal irregularities in building envelopes – Infrared method

[6] Johnston D, Miles-Shenton D, Farmer D and Wingfield J 2013 Whole House Heat Loss Test Method (Coheating) Technical report Leeds Metropolitan University

[7] Bauwens G and Roels S 2014 *Energ. Buildings* **82** 163–72 URL https://doi.org/10.1016/j.enbuild.2014.04.039

[8] Stafford A, Bell M and Gorse C 2012 Building Confidence – A working paper Report 008 The Centre for Low Carbon Futures

[9] Johnston D, Farmer D, Brooke-Peat M and Miles-Shenton D 2014 *Build. Res. Inf.* 1–14 URL https://doi.org/10.1080/09613218.2014.979093

[10] Johnston D, Miles-Shenton D and Farmer D 2015 *Build. Serv. Eng. Res. Technol.* **36** 614–27 URL https://doi.org/10.1177/0143624415570344