Assessment of the Energy Performance of building facades through different testing conditions and analysis techniques

G. Masy[1]*, S. Hincque[1], A. Dawans[2]

[(1)] UCLouvain, Louvain-la-Neuve, Belgium

[(2)] Jacques Delens s.a., Brussels, Belgium

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1. ABSTRACT

The building envelope interacts with its HVAC equipment and control, as well as with the electric grid. As the energy performance of the building envelope has a large impact on the energy costs and on the thermal comfort, being able to confirm that the predicted performance of the envelope is really achieved is an important issue.

In that context, UCL is developing methods to characterize the performance of building facades, in collaboration with Jacques Delens s.a.. Those methods can be applied on site during the construction phase, requiring a maximum of 9 days monitoring period, without occupancy.

Parallel experiments were conducted during summer 2017 on two pair of south oriented identical building units, including two types of boundary conditions: insulation or no insulation added on the internal side of the party walls, as well as two types of solicitations: co-heating with electric radiators at a constant set point, or free-floating internal temperature. The data are analyzed through stationary and dynamic methods in order to assess the external façade Heat Transfer Coefficient.

The results highlight the relevancy of the placement of internal insulation on the party walls. Such a boundary condition do not only allows to reach higher levels of indoor temperatures. It also reduces the heat losses to neighboring units and allows to reach faster the stationary state. Without placement of internal insulation on the party walls, the stationary state cannot be reached within the imposed time period of 9 days for the experiment.

When performed in apartment units, co-heating tests tend to magnify the influence of the internal thermal bridges effect, thereby leading to an overestimation of the external façade Heat Transfer Coefficient.

Keywords: Building Physics, Parameters Identification, Experimental Design

2. INTRODUCTION

A relevant characterization of the energy performance of a building envelope is important not only for taking into account the building's interactions with its heating, ventilation, air-conditioning and heating equipment, but also when considering the interactions potential between the building and the electricity grid. The design of an efficient building envelope is an important issue for three reasons. First, an efficient envelope reduces the energy and operating costs of the facility. Second, it provides comfortable environments at the building perimeter areas where the interface between the building envelope and the HVAC systems is crucial. Last, an efficiently integrated building envelope provides emerging opportunities of efficiency gains related to smart grid connectivity.

To ensure the positive impact of a well-designed energy efficient building envelope, it is crucial to verify that its predicted energy performance is really achieved. Bad workmanship for instance can result in difference between theoretical and achieved building performance which in turn induces higher energy cost as well as lower thermal comfort due to undersized equipment.

A common indicator to characterize the thermal performance of a building envelope is its Heat Transfer Coefficient, HTC (or Heat Loss Coefficient HLC), defined as the rate of heat loss from the whole envelope of a building, expressed in Watts per Kelvin of temperature differential between the internal and external environments.

A commonly referred method used to assess the building HTC is the co-heating test. In order for the co-heating method to be effective, there must be a significant internal-external temperature difference, a difference of at least 10 K is recommended (Bauwens & Roels, 2014; Jack, 2015; Janssens, 2016). This has restricted practical application of the co-heating test to the winter heating season (Johnston D., 2013; Wingfield J., 2010). The testing in building with attached spaces (such as semi-detached, terraced or apartment buildings) presents a problem in co-heating, particularly if it is not possible to access the adjacent space in order to install sensors (Stamp, 2016).

To overcome those restrictions, alternate measurement processes could be proposed, that should be suitable to summer weather conditions, and to building units that include common shared walls and floors.

Solar heat gains can be used as sole solicitation generating a free floating indoor temperature profile that can be dynamically analysed.

Internal insulation panels can be temporarily placed on the vertical and horizontal party walls in order to cut off the thermal mass effect, thereby increasing the internal-external temperature difference at the boundaries of the external facade. The later proposal also reduces the heat exchanges to the neighboring units.

Such alternate measurement methods have been tested on four south oriented building units, during the summer 2017. The data are analyzed through stationary methods and through dynamic grey-box modelling methods in order to assess the measured external façade Heat Transfer Coefficient. The HTC resulting from the data analysis are compared to the predicted HTC. When discrepancies are observed, investigations are made to determine if they are due to defects regarding the data analysis, such as underestimation of specific effects, or from real performance gap, i.e. a lower performance due to bad workmanship.

3. METHODOLOGY

The assessment of the HTC of a building unit requires the establishment of its complete heat balance, including the solar heat gains. Solar gains are the source of the most uncertainty, particularly in urban context where effects of mask and reflections occur. They must therefore be measured or carefully evaluated (Everett, 1985; Jack, 2015).

As measurements can be made on pairs of identical units, a methodology is adopted to get a reference value of the HTC that should not be affected by uncertainties related to the estimation of solar heat gains. This *reference HTC* can be obtained by considering the data collected on two identical units, with one submitted to a co-heating test and the other left in free floating temperature mode. A fictitious experiment then can be deduced from both experiments by subtracting the results of the free floating temperature experiment from the results of the co-heating experiment, provided the solar heat gains are assumed to be the same in both units (Fig. 1).

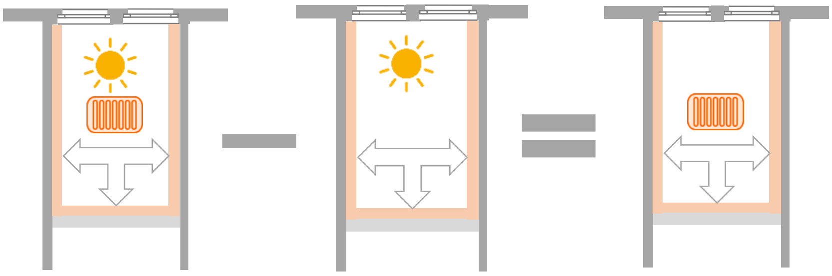

Figure 1: subtraction of the results related to the free floating temperature experiment from the results related to the co-heating test.

A second evaluation of the HTC can be obtained by analyzing the data collected on each separate unit. This step requires a reliable assessment of the solar heat gains inputs in the units.The HTC estimated by this way are called *confirmed HTC* as they are expected to confirm the reference value of the HTC. Results from the analysis of the units that are left in free-floating temperature mode are compared to the results from the units that are submitted to co-heating experiment.

4. EXPERIMENT

The experiment includes 9 days monitoring without occupancy. Ventilation inlets/outlets are sealed during the experiment. The ventilation system is off. Solar protections are removed when possible.

A difficulty is related to the presence of common walls and floors shared by adjacent units as it is not possible to gain access to all of the surrounding apartments or spaces when undertaking the tests. The temporarily placement of internal insulation on the party walls allows to overcome that difficulty in order to focus on the determination of the overall heat loss coefficient of the external facades (Fig. 2).

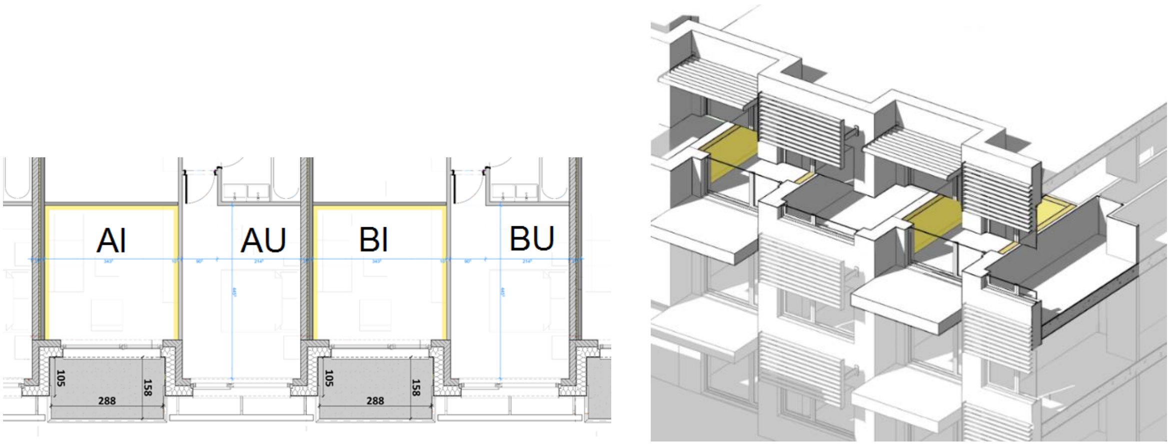

Figure 2: Layout (left) and perspective (right) of the apartments.

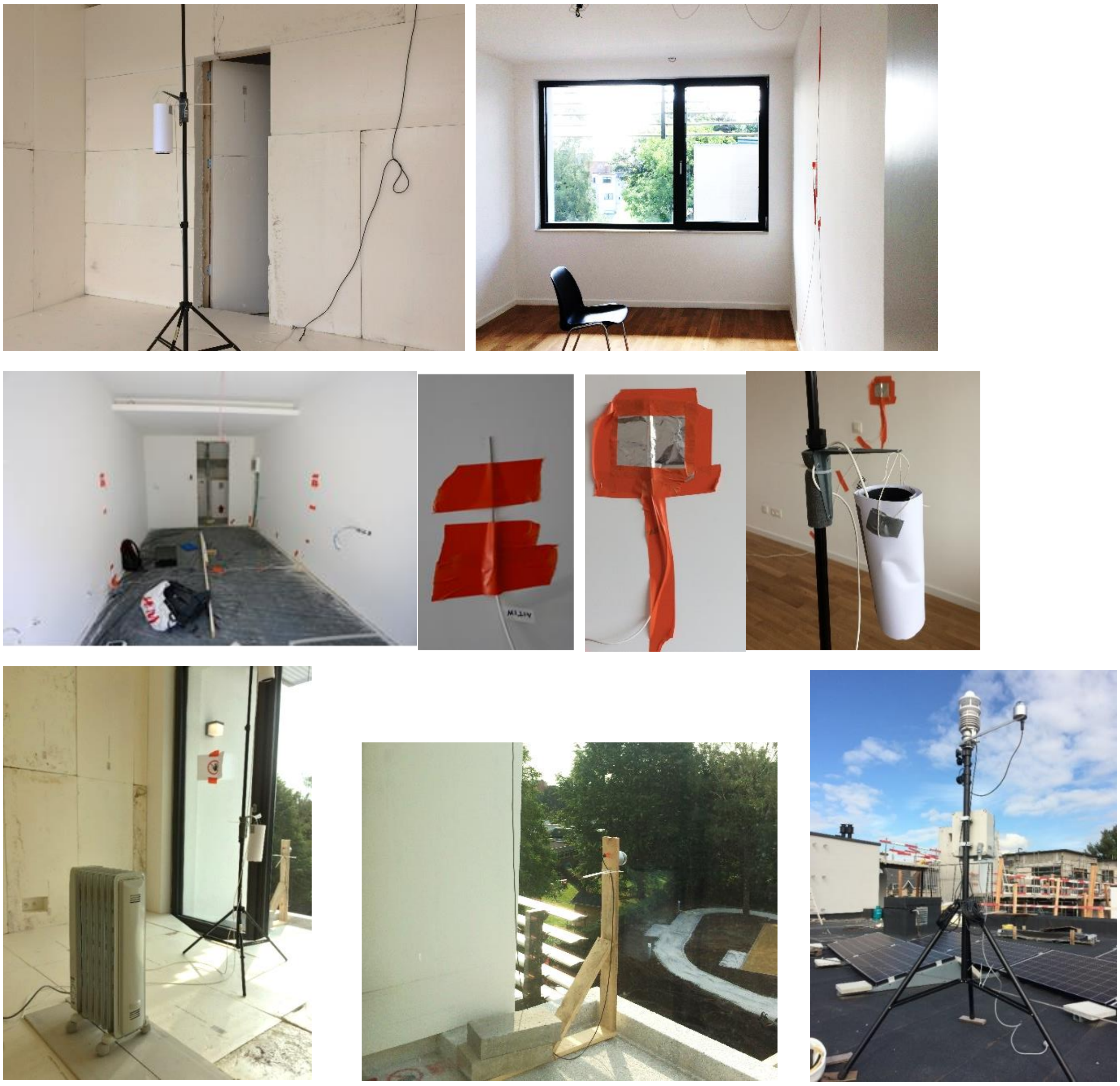

Figure 3: Experimental setup.
Row 1: Units covered or not covered with insulation panels.
Row 2: Temperature sensors at the interface of insulation layer before the placement of insulation panels (left and center left), at the surface of uninsulated walls (center right) and air temperature sensor protected from radiation (right).
Row 4: Experimental set-up for co-heating test (down left), external pyranometer (down middle), weather station located on the roof (down right).

A measurement campaign is performed on two South oriented apartments located in Brussels, from August to September 2017. The results concern two pairs of identical units, with one covered by inside insulation panels while the other is not (Fig. 2).

5. REFERENCE HTC

5.1 Results from stationary analysis

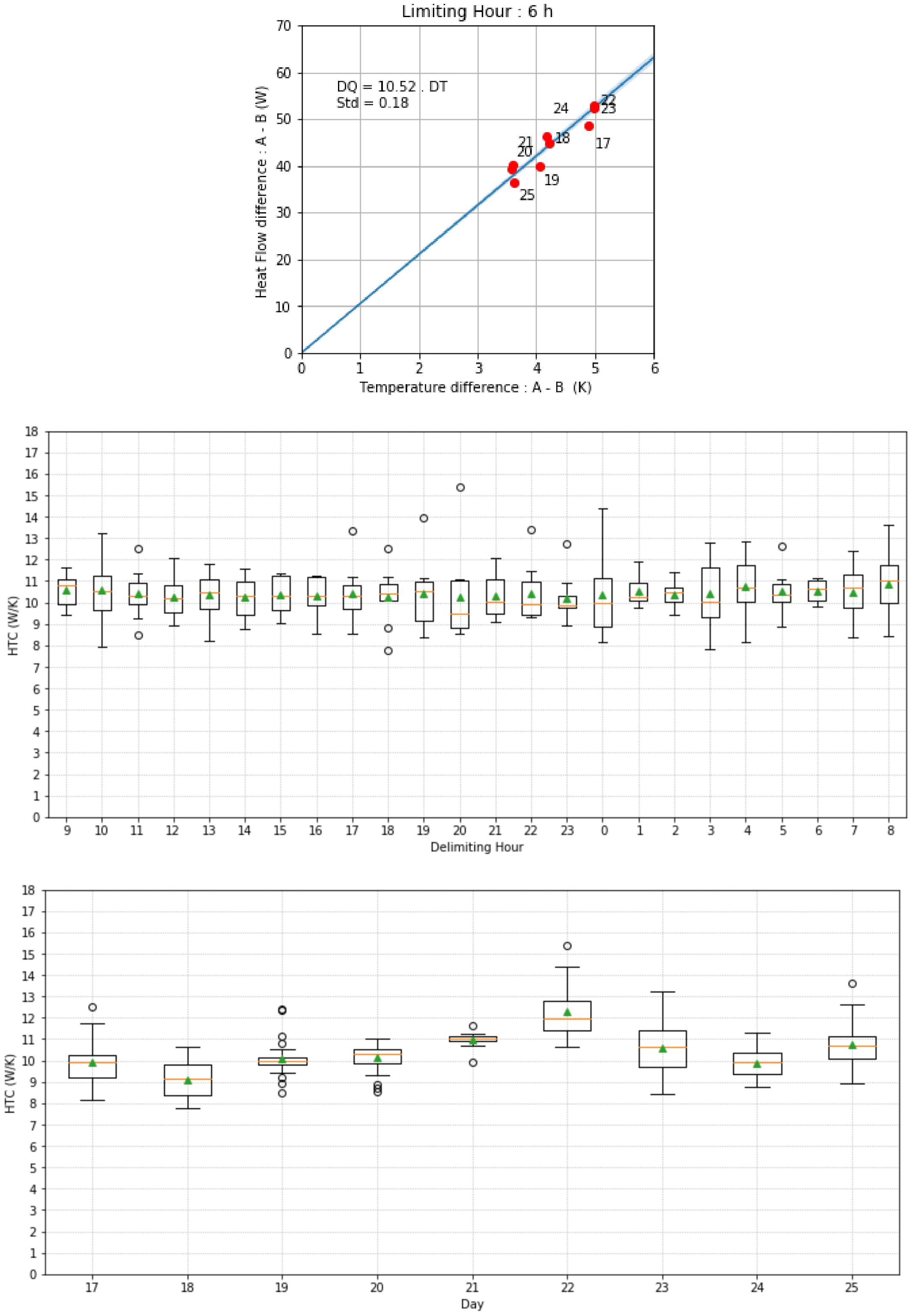

Figure 4: Correlation between daily means of heating powers and temperature differences between two identical insulated units (up), HTC obtained by shifting the aggregation intervals with delimiting hours ranging from 9 AM to 8 AM (middle), and daily average HTC values obtained by shifting the aggregation intervals (down). Averages represented by green triangles.

Stationary analysis uses time-averaged data inputs in order to remove the influence of the thermal mass. The values of the heat input rate and temperature difference are averaged over a period of 24 hours (Jack, 2015).

The average heating powers used for the analysis are corrected by the heat transfers through the party walls. Those transfer heat flows are computed from the measured temperatures either at the interface of the insulation panels, when the party wall are internally insulated, or at the party wall surface, when the party wall are not covered by internal insulation. The heat transfer coefficient of the boundary layer is assumed to be equal to 8 W/m2-K. This assumption strongly influences the estimated heat flows when the party walls are not internally insulated. When the party wall are not insulated, the thermal resistance of the insulation equals 2.80 m2-K/W so that the assumption regarding the boundary layer heat transfer coefficient has a little influence on the estimated heat flows.

The HTC can be visualized as the slope of the regression line representing the average heating powers as function of the average temperature differences between the two units (Fig. 4). The intercept of the regression line with the power axis is forced to a zero value.

The linear regression method ideally requires a spread of temperature difference conditions during the test, otherwise the data points are clustered together, limiting the accuracy with which the regression can be carried out. Such a spread of temperature differences is not reached for all the tests and that is the reason why the intercept of the regression line with the power axis is forced to a zero value.

The HTC is estimated from the heating power divided by the difference of temperature between the units. The error associated to the HTC decreases as the difference of temperature between the units increases, provided the errors related to the heating power and to the temperature difference are constant as function of the temperature difference. The reliability of the HTC resulting from a co-heating test thus increases as the temperature difference between the units increases.

An average $\Delta T > 10$ K is recommended for co-heating test. Such a temperature difference between the units is difficult to reach because a maximum temperature of 30°C was set in the tested units to avoid damaging them. A temperature difference of 4 to 5 K is observed during the experiment (fig. 4, up).

If there is any fraction of stored solar energy remaining in the heat balance, the stored solar contributions can be better captured by shifting the aggregation interval used to compute the 24 hours average values. A box plot showing the HTC obtained by regressions on 9 daily average values, for different delimiting hours, shows a stability of the HTC as well as the robustness of a dawn-dawn aggregation approach (fig. 4, middle). Day by day values of the HTC can also be plotted considering samples associated to different delimiting hours, for each day (fig. 4, down).

The linear regression between average heat power inputs and average temperature difference only holds in the stationary case, when no heat is being charged/discharged by building components.

Dynamic effect due to a step of internal temperature set point may be observed by considering the day by day evolution of the HTC, either when the party walls of the tested units are not internally covered by insulation or in presence of a massive external roof that is not internally covered with insulation (fig. 5). When such a day by day evolution of the HTC is detected, results from the stationary analysis should be considered as irrelevant and a dynamic analysis approach should be undertaken.

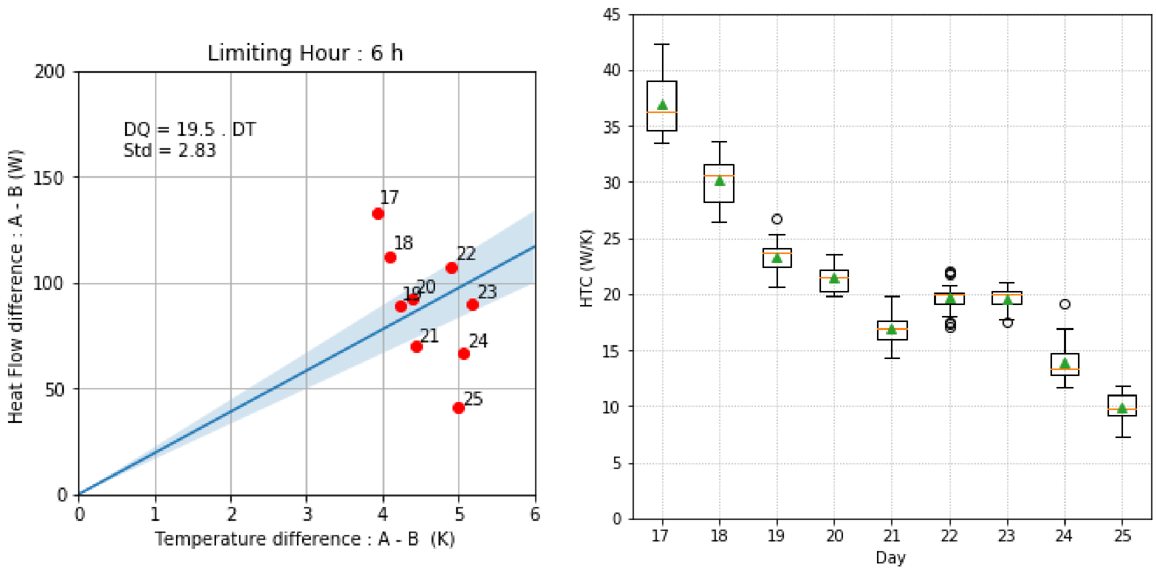

Figure 5: Correlation between daily mean heating power differences and temperature differences (left) and day by day evolution of the HTC (right), when party walls are not internally insulated.

5.2 Results from dynamic analysis

A literature review regarding dynamic heating experiments is included in Bauwens PhD Thesis (Bauwens, 2015). A common approach for analysis of dynamic data is to perform identification of the parameters of a grey-box model, constructed as lumped capacitance models, incorporating resistances and capacitances as well as introducing heat sources such as heating powers and solar gains (if any).

Application of grey-box modelling is based on prior physical knowledge of the building behaviour. The modeller starts from a simple model involving one capacity and interatively selects models of increasing complexity (fig. 6). The performance of the model is measured at each step through a given indicator, and the models are validated in both a statistical and physical context (Bacher & Madsen, 2010). Such an approach delivers a value of the HTC expressed as an equivalent resistance between internal and external temperature nodes.

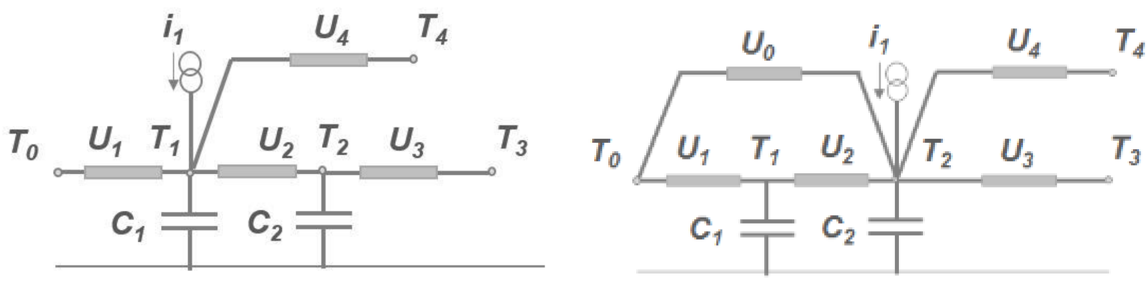

Figure 6: RC models used for insulated units (left) and uninsulated units (right). Temperature T3 is the temperature measured at the party wall surface and temperature T4 is measured in the adjacent zone of the same apartment.

The grey-box modelling approach is used to reproduce the time varying temperature difference between two identical units, when introducing the measured values of the heating powers differences. The performance of the model is quantified by the Root Mean Square of the error between the measured and the calculated temperature profiles (fig. 7). The corresponding RC networks are displayed on Fig. 6, where U represent conductance values. Table 1 displays the corresponding parameters of the RC models as well as their related HTC values.

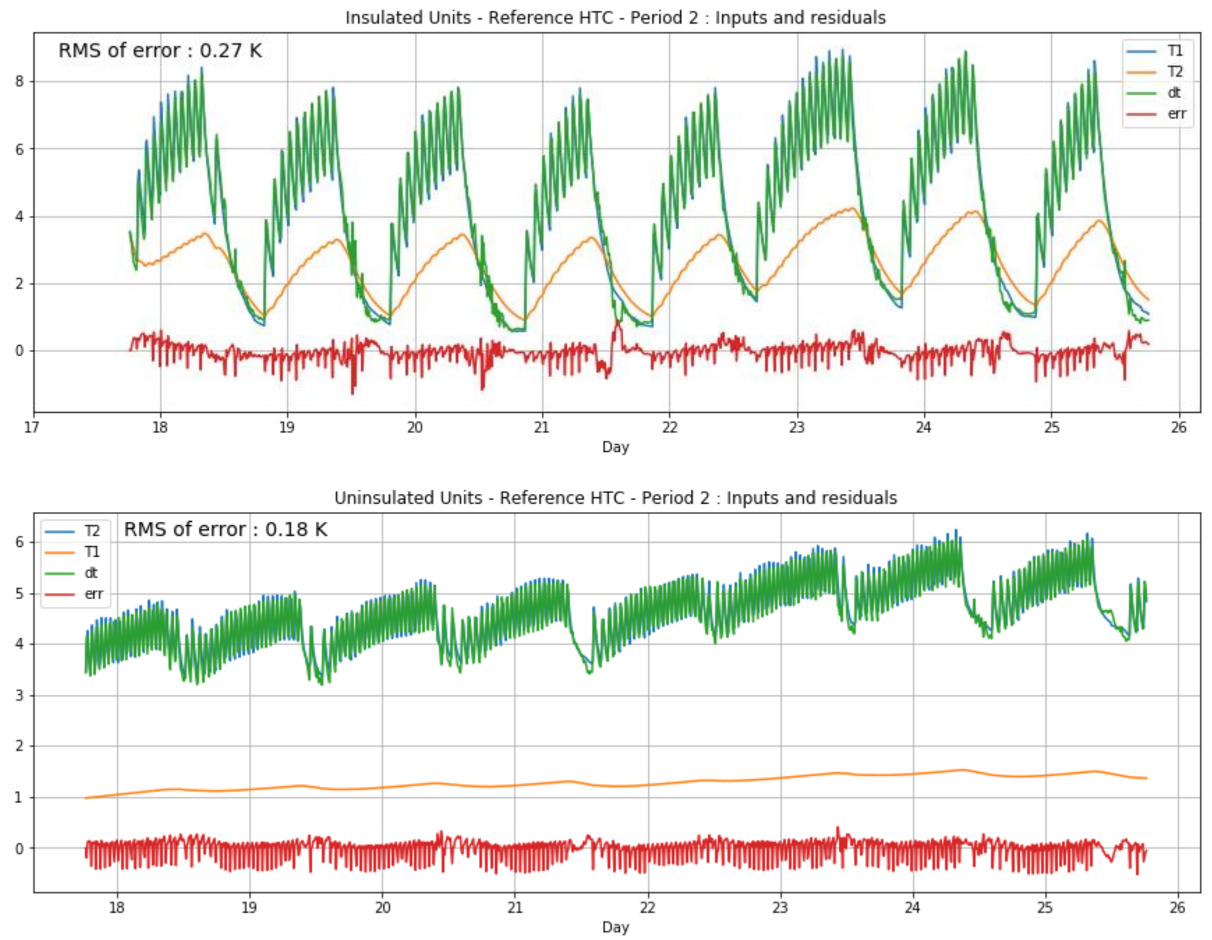

Figure 7: Measured indoor temperature difference between two identical units (green curve) and corresponding profile generated by grey box modelling (blue curve), in insulated units (up) and uninsulated units (down).

Table 1: RC models conductances and related values of the HTC in W/K.

Units	**U0**	**U1**	**U2**	**U3**	**U4**	**HTC**
Insulated	-	7.56	26.02	32.26	5.47	7.56 W/K
Uninsulated	10.59	20.36	8.08	485.45	82.23	16.37 W/K

The grey box modelling approach gives a HTC value of 7.56 W/K for insulated units, close to the predicted HTC of 6.58 W/K (Table 2). The HTC obtained for uninsulated units is 16.37 W/K. That value is close to the day by day evolution of the HTC displayed on fig. 5, but far from the predicted HTC of 7.40 W/K (Table 2).

6. PREDICTED HTC

The predicted values of the façade HTC are 6.58 W/K for insulated units and 7.40 W/K for uninsulated units (Table 2). The corresponding measured values are respectively 7.56 W/K and 16.37 W/K, showing a difference that can be explained by considering the heat transfers due to internal thermal bridges towards adjacent units (Fig. 8 and Table 3).

Table 2: Predicted HTC of the tested units.

	Through the facade				
Units	External walls	AU	Thermal Bridges	ψL	Infiltration Heat losses
	W/K		*W/K*		
Insulated	Glazing	3.09	Parapet	0.81	
	Frame	1.61	Screen anchorages	0.35	
	Opaque vertical walls	0.30	Balcony	0.10	
			Inward angles	- 0.15	
	Total	*5.00*	*Total*	*1.11*	*0.47 W/K*
Uninsulated	Glazing	1.99	Parapet	1.25	
	Frame	1.27	Screen anchorages	0.47	
	Opaque vertical walls	1.06	Outward angles	0.31	
	Roof	0.88	Inward angles	- 0.21	
	Total	*5.20*	*Total*	*1.82*	*0.38 W/K*

Table 3: Thermal bridges towards the adjacent zones.

	Towards adjacent zones	
Units	Thermal Bridges	ψL
Insulated	Single party wall	2.65
	Double party wall	1.83
Uninsulated	Single party wall	2.65
	Double party wall	1.83
	Ceiling-North party wall	1.30
	Ceiling-single party wall	1.56
	Ceiling-double party wall	2.11
	Ceiling-North party wall	1.12
	Ceiling-single party wall	0.93
	Ceiling-double party wall	1.63

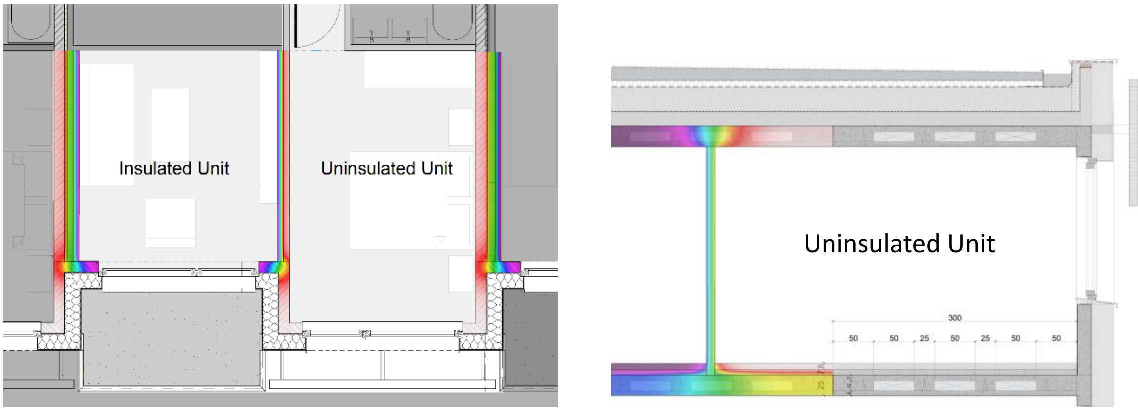

Figure 8: Thermal bridges towards adjacent zones.

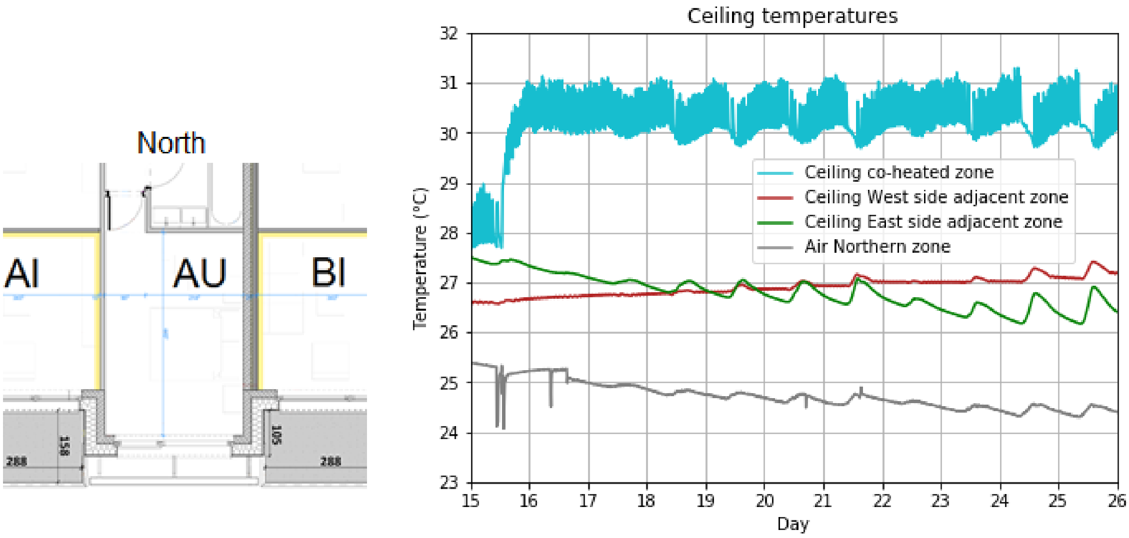

Figure 9: Temperature of the uninsulated unit at the ceiling (blue curve), at the ceilings of the adjacent zones (red and green curves), and in the Northern zone (grey curve), during a co-heating test.

An updated value of the HTC can be computed by including the extra heat flows due to the internal thermal bridges in the heat balance of the tested units. Those extra heat flows are evaluated from the predicted ψL values of the thermal bridges and considering the measured temperatures at their boundaries (Table 4). When a co-heating test is performed in one unit surrounded by unheated units, the temperature differences occurring at the connections of the vertical party walls with the ceiling is magnified by the stratification effect due to the co-heating (Fig. 9).

Dividing the difference of internal thermal bridges heat flows by the average temperature difference measured between both identical uninsulated units (4.60 K) during the co-heating test performed in one of them, the impact of the internal thermal bridges heat flows on the reference HTC is 8.72 W/K for the uninsulated units.

A similar approach applied to insulated units gives an impact of 3.59 W/K on the reference HTC, due to internal thermal bridges.

Table 4: Internal thermal bridges heat flows towards adjacent zones (Saints Pierre & Paul).

Units		Co-heated		Free floating temperature	
	Thermal bridges	ΔT *K*	Φ *W*	ΔT *K*	Φ *W*
Insulated	Single party wall	1.9	5	2.3	6
	Double party wall	6.5	12	-2.3	-4
	Total	(assumption)	*17 W*		*2 W*
Uninsulated	Single party wall	-1.9	-5	-2.3	-6
	Double party wall	2.3	4	0 (assumption)	0
	Ceiling-North party wall	4.9	6	0.5	1
	Ceiling-single party wall	3.4	5	-1.5	-2
	Ceiling-double party wall	3.7	8	0 (assumption)	0
	Floor-North party wall	4.9	5	0.5	1
	Floor-single party wall	3.1	3	0.1	0
	Floor-double party wall	4.7	8	0 (assumption)	0
	Total		*34 W*		*-7 W*

The difference between the predicted and the reference value of the HTC observed in uninsulated units (7.40 W/K and 16.38 W/K) is mostly explained by the effect of internal thermal bridges (8.72 W/K).

7. CONFIRMED HTC

The confirmation of the HTC by analyzing the data measured on the separate units requires a reliable estimation of the solar heat gains.

7.1 Solar heat gains assessment

Direct and diffuse solar irradiations are measured on a horizontal plane, with a pyranometer located on the roof of the building. Global irradiation is measured on a vertical plane parallel to the façade (Fig. 10).

Figure 10: Weather station, measurement of vertical irradiation and urban masks.

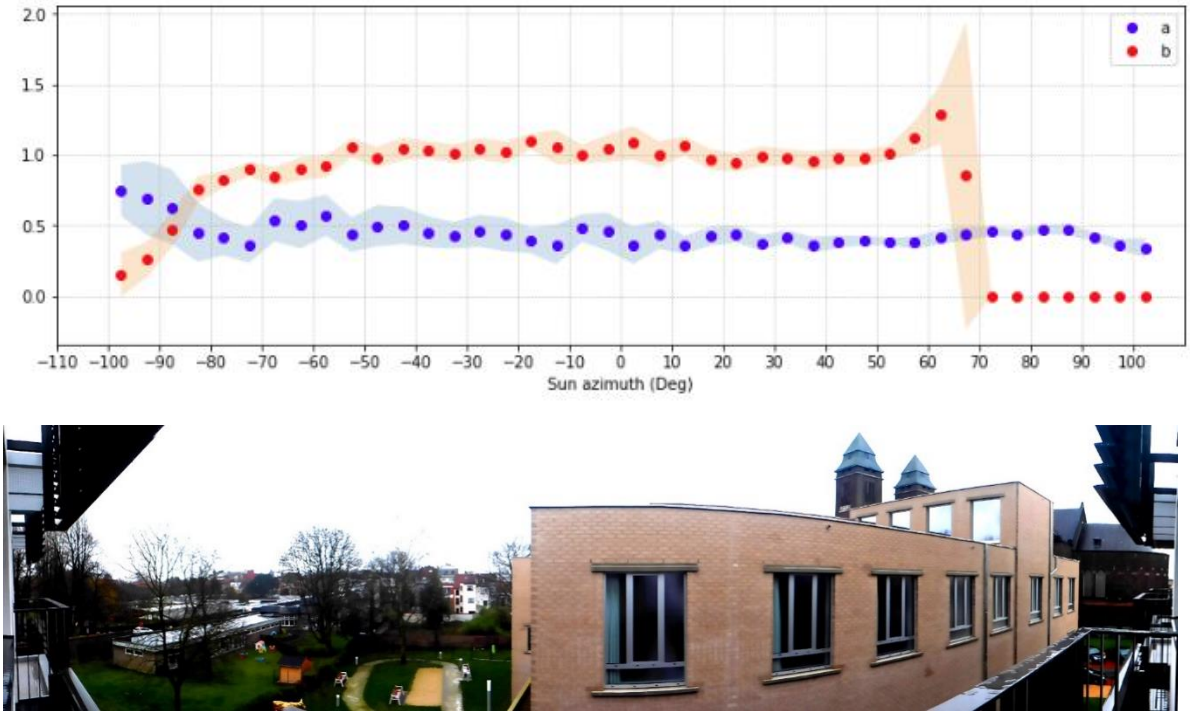

Figure 11: Decomposition of the vertical solar irradiation into its diffuse (a) and direct (b) components, with façade Azimuth = - 22°.

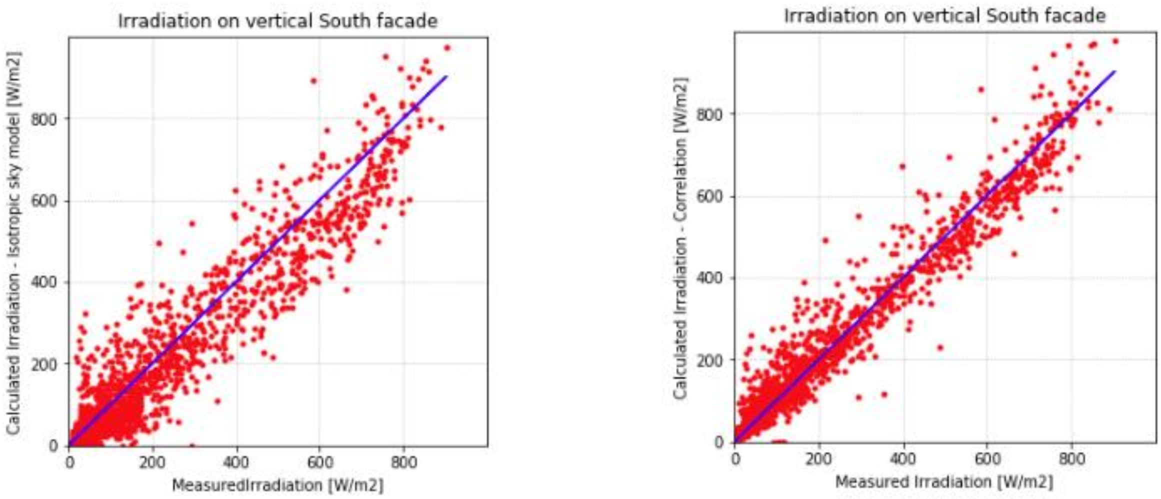

Figure 12: Vertical solar irradiation predicted by a conventional isotropic sky model (left) and by correlations (right), compared to measured values, with façade Azimuth = - 22°.

As measurement occurs in an urban site, the effect of the masks surrounding the building must be considered. The effect of the shading due to the screens surrounding the windows must be calculated as well.

The global solar irradiation measured on a vertical plane is shared into its direct and diffuse components by the following correlation, involving both horizontal diffuse and direct irradiations, with the direct component being projected from the horizontal to the vertical plane:

$$I_v = a(\gamma)\, I_{dh} + b(\gamma)\, I_b \qquad (1)$$

I_v Global irradiation on a vertical plane facing surrounding masks *W/m*^{2}

I_{dh} Diffuse irradiation on a horizontal plane located in an open space *W/m*^{2}

I_b Direct irradiation on a vertical plane, computed from the direct irradiation measured on an horizontal plane located in an open space *W/m*^{2}

γ Sun azimuth *degree*

The correlations are done for given ranges of the sun azimuth (Fig. 11).

The vertical irradiations predicted by the correlations (1) can be compared to the vertical irradiations predicted by a conventional isotropic sky model (2):

$$I_v = \frac{1+\cos p}{2}\, I_{dh} + \frac{1-\cos p}{2} \rho\, I_{th} + I_b \qquad (2)$$

I_{dh} Diffuse irradiation on a horizontal plane located in an open space *W/m*

I_{th} Global irradiation on a horizontal plane located in an open space *W/m*^{22}

ρ Ground refection factor (ρ set to 0 to fit better with the measured values).

p Slope of the plane *degree* (90° for a vertical plane).

The agreement provided by the correlations is better than that provided by the conventional isotropic sky model (Fig. 12). The RMS of the predicted irradiation error drops from 50.2 W/m^2 for the isotropic model until 31.9 W/m^2 for the correlation model. In an urban context, the correlation model is more likely to capture the effect of masks due to the elements facing each other (buildings, trees).

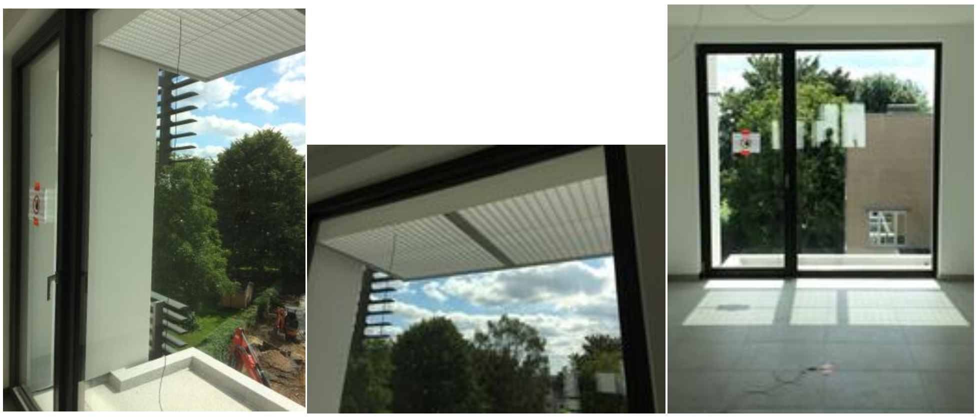

Figure 13: Effect of shading screens surrounding windows.

The calculation of solar heat gains includes the assessment of the solar factors from the sky (diffuse solar radiation), the assessment of all the shadings on the glazing (direct solar irradiation) and the assessment of reflected radiation (balconies and lateral walls). The assessment of the shading due to the screens surrounding the windows is an important issue (Fig. 13).

Considering the previously calculated reference HTC, a comparison can be made between the daily average values of the calculated solar heat gains and the average solar heat gains required to balance the heat losses of the units when computed from the units reference HTC. Such a comparison is shown on fig. 14 for the two insulated units with stationary reference HTC equal to 10.52 W/K.

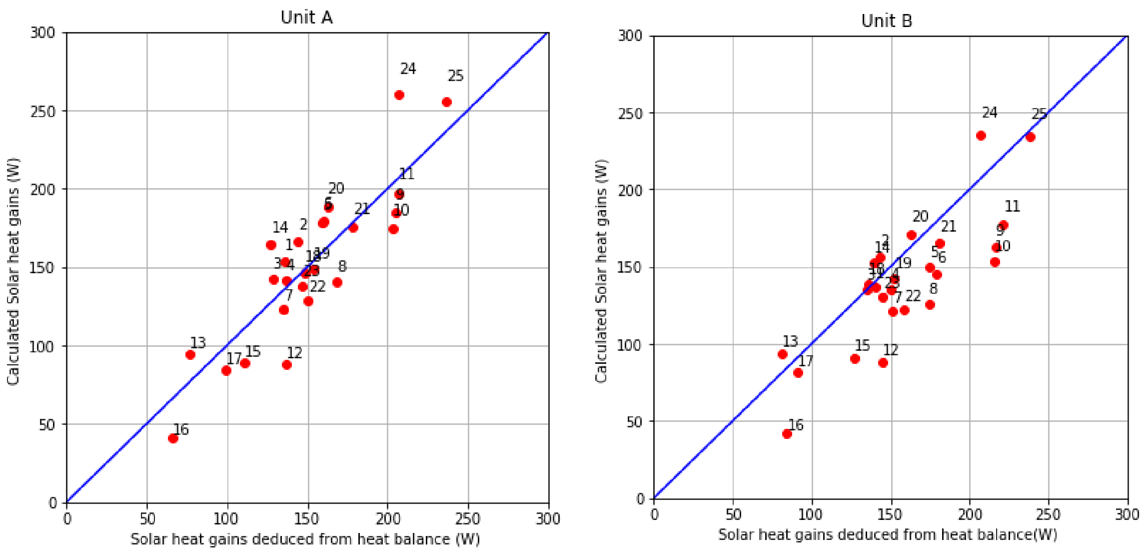

Figure 14: Calculated solar heat gains compared to the heat gains required to balance the heat losses associated to the reference HTC of insulted units.

7.2 Uncertainty assessment

The probable uncertainty of the HTC is calculated on the basis of the chi-square merit function, defined for a unitary standard deviation. A confidence interval of the HTC is calculated by considering the variation of the chi-square as function of the HTC, around its minimum, with the rest of the parameters being chosen to minimize the chi-square. The asymmetric limits of a confidence interval are defined for a variation of chi-square (fig. 5):

$$\Delta\chi^2 = \chi^2 - \chi^2_{min} = \chi^2_{min} \quad (3)$$

7.3 Results from stationary analysis on separate units

Results from stationary analysis on separate units are presented on fig. 15 and 16 and summarized on Table 5.

Table 5: Results from stationary analysis on separate units

Unit	**Test**	**HTC** *W/K*	**INTERVAL** *W/K*
Insulated	T° 29°C	10.46 ± 0.37	–0.72 + 1.12
Insulated	Floating T°	9.68 ± 0.39	–0.74 + 1.26
Uninsulated	T° 29°C	10.54 ± 0.29	–0.65 + 0.78
Uninsulated	Floating T°	6.82 ± 0.79	–1.19 + 3.31

The HTC values obtained in the identical insulated units are similar (HTC values of 10.46 and 9.68 W/K) while the values obtained for identical uninsulated units are different (HTC values of 10.54 and 6.82 W/K). Co-heating test results show increasing HTC values, particularly when performed in uninsulated units.

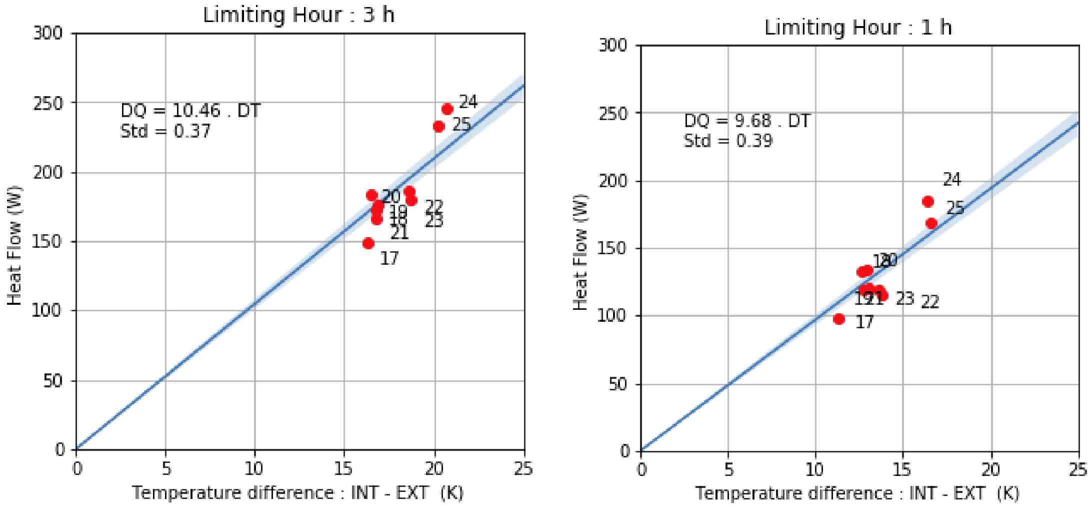

Figure 15: HTC obtained for two identical insulated units tested in parallel, with one co-heated at 30°C (left), and the other left in free floating temperature (right).

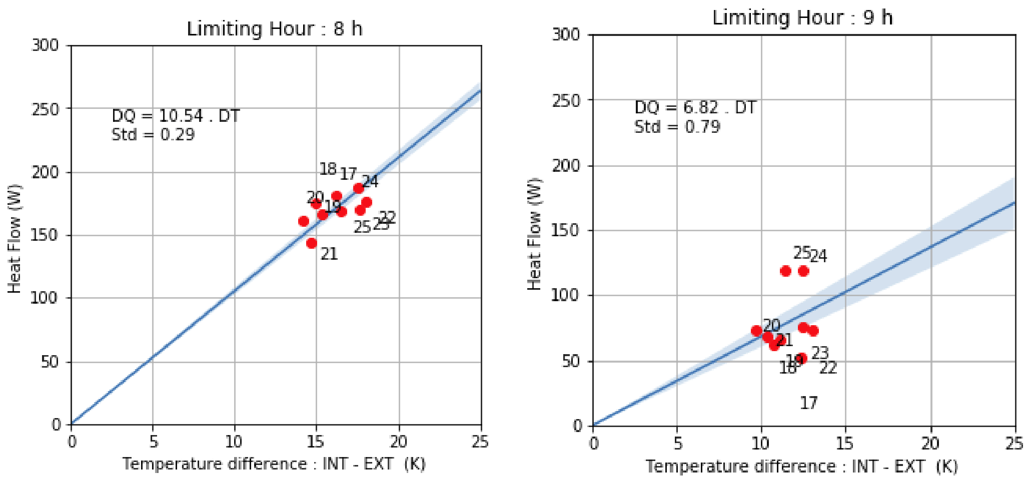

Figure 16: HTC obtained for identical uninsulated units tested in parallel, with one co-heated at 30°C (left), and the other left in free floating temperature (right).

7.4 Results from dynamic analysis on separate units

Results from dynamic analysis on separate units are presented on fig. 17 and summarized on Table 6.

Table 6: Results from dynamic analysis on separate units.

Unit	**Test**	**HTC** *W/K*	**INTERVAL** *W/K*
Insulated	T° 29°C	6.43	– 1.05+ 1.14
Insulated	Floating T°	7.55	– 0.90 + 1.17
Uninsulated	T° 29°C	10.93	– 4.10 + 4.74
Uninsulated	Floating T°	7.00	– 3.54 + 4.04

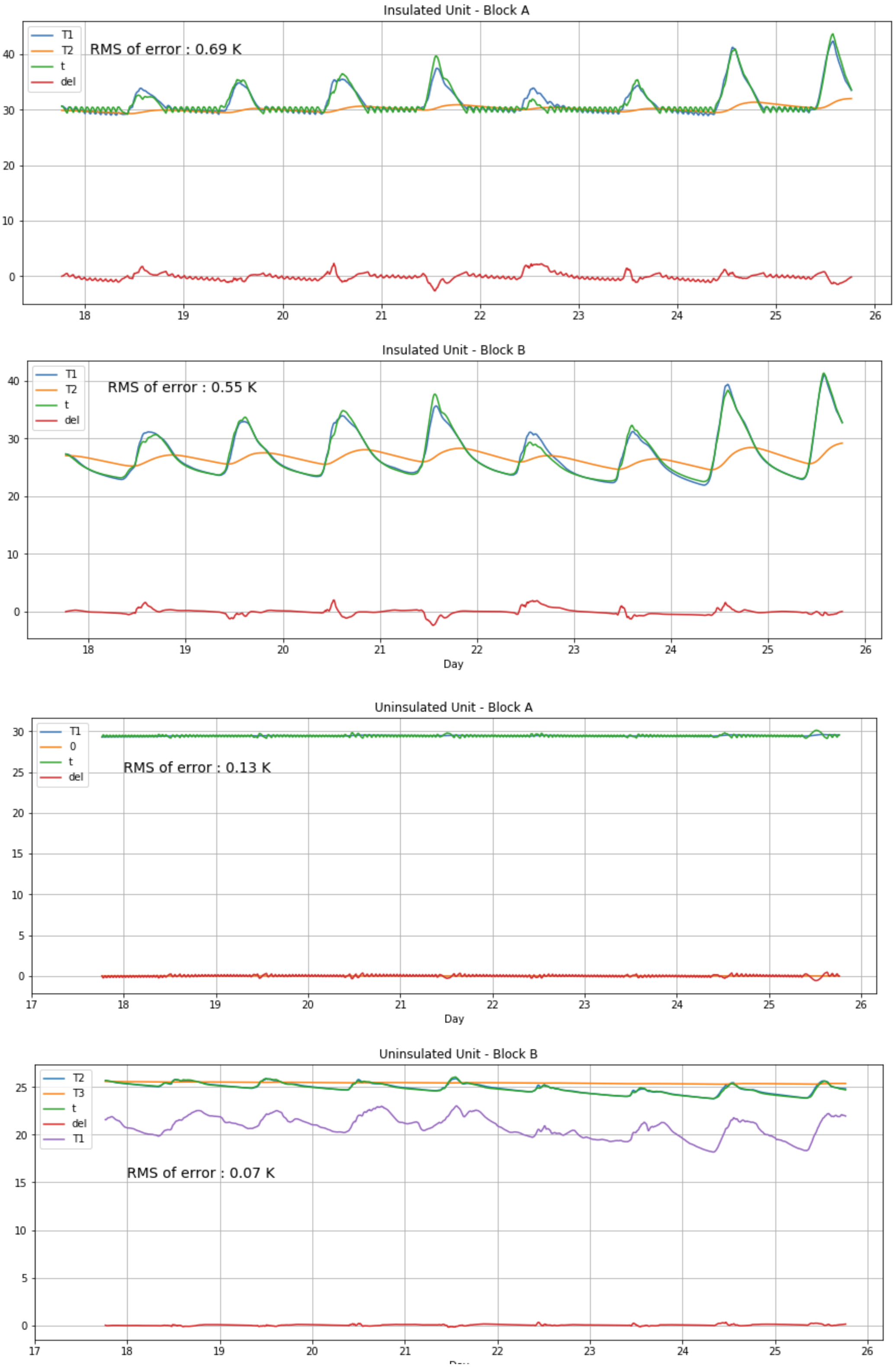

Figure 17: Indoor temperature profiles generated by grey-box modelling (blue curves) compared to measured temperatures (green curves) for identical ***insulated*** *units tested in parallel with one co-heated at 30°C (up), and the other in free floating temperature (up middle), and for identical* ***uninsulated*** *units tested in parallel with one co-heated at 30°C (down middle), and the other in free floating temperature (down).*

The HTC values obtained in the identical insulated units are similar (HTC values of 6.43 and 7.55 W/K) while the values obtained for identical uninsulated units are different (HTC values of 10.93 and 7.00 W/K). Co-heating test results show increasing HTC values, particularly when performed in uninsulated units. The associated confidence interval indicates more reliable results when the units are internally insulated.

Fig. 18 shows a comparison of the resulting HTC with the confidence intervals.

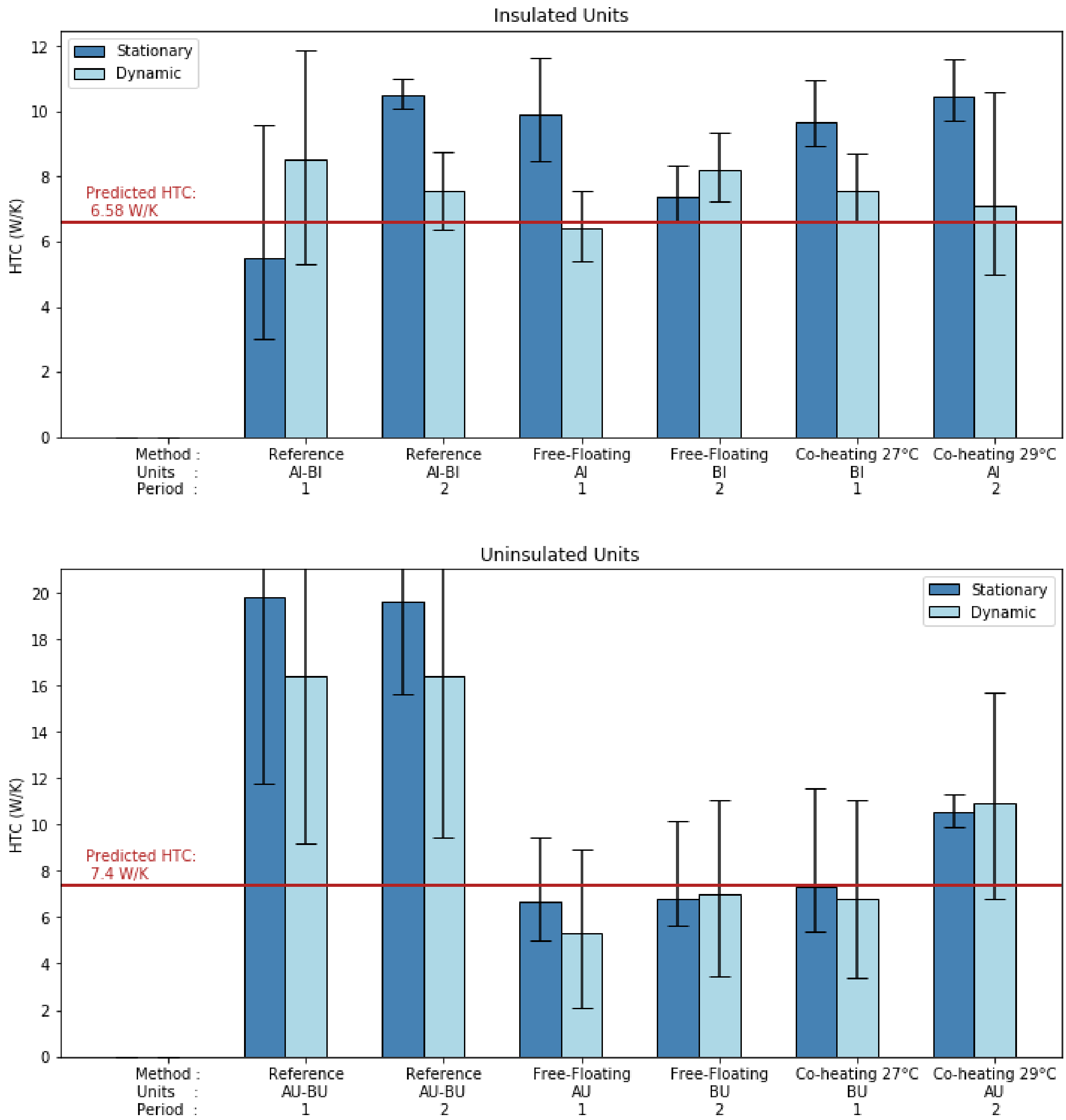

Figure 18: Predicted HTC, Reference HTC and confirmed HTC values obtained by stationary and dynamic analysis on insulated (up) and uninsulated units (down).

For the insulated units: The mean values of the HTC are close to the predicted value when obtained by dynamic approach, showing a maximum gap of -1 W/K (-13%). This gap increases up to +3 W/K (+41 %) when the analysis is performed trough a stationary approach.

For the uninsulated units: The mean values of the HTC obtained by either stationary or dynamic approaches confirm the predicted HTC, provided the test is performed in floating temperature mode (maximum difference of 19 %). This is also true for the co-heating test performed at 27°C as this set point was too low to start the heating system.

The uncertainty associated to the HTC is much higher when the tested units are not covered by inside insulation panels, whatever the testing method (free floating temperature vs co-heating) or the analysis method (stationary vs dynamic).

When using internal insulation panels to perform the test, the uncertainty is divided by 2 on average in case of stationary analysis of the data (interval reduced from 63 to 30% of the HTC), and by 3 in case of dynamic grey-box modelling approach (interval reduced from 117 to 41% of the HTC). The placement of inside insulation on party walls is a relevant solution to increase the reliability of the assessed HTC.

8. CONCLUSION

A methodology is proposed to identify a reference value of the HLC in case of parallel experiment on identical units. Data measured in parallel on identical units can be used to generate fictitious experiments by subtracting the results of the free floating temperature experiment from the results of the co-heating experiment, in order to asses a reference HTC.

Confirmed values of the HTC are then obtained by considering the heat balance of each unit separately, each of them being provided both with the heat inputs due to the calculated solar heat gains and the measured powers from electric radiators.

The methodology is applied on 4 apartments units. Two solicitations are used (free floating temperature due to solar gains vs co-heating at constant set point) with two types of boundary conditions (with and without placement of internal insulation panels on common party walls) . The data are analyzed by stationary and dynamic approaches. The stationary approach uses 24 h average data while the dynamic approach is based on grey-box modelling. An uncertainty indicator is used to provide a confidence interval to the results.

When coupled with the placement of internal insulation on party walls, the grey-box modelling approach is able to predict the HTC with a maximum discrepancy of 13 %, according to our uncertainty indicator. The discrepancy increases until 41 % when a stationary analysis is performed on the same measurement data.

When the party walls are not covered by internal insulation panels, a reliable assessment of the HTC can only be performed for free floating temperature conditions, either by a stationary or by a dynamic approach. A reliable assessment of the HTC is not possible in case of a co-heating test, whatever the analysis method, either stationary or dynamic. This lack of reliability is due to the effect of internal thermal bridges. The heat exchanges through those thermal bridges are magnified by the increase of temperature differences at their boundaries, due to the co-heating experiment.

The methodology used to obtain a reference value of the HTC on basis of the results with and without co-heating on identical units, is corrupted by the effect of internal thermal bridges. This effect entails an overestimation of the reference HTC. It mostly explains the discrepancy observed in insulated units (10.5 W/ instead of 6.58 W/K, K by stationary approach) and in uninsulated units (16.4W/K instead of 7.40 W/K, by dynamic analysis).

The relevancy of the placement of inside insulation on common party walls is assessed on basis of our uncertainty indicator. With the use of inside insulation panels to perform the test, the uncertainty indicator is divided by 2 on average in case of stationary analysis of the data, and by 3 in case of dynamic grey-box modelling approach. The placement of inside insulation on party walls can be considered as a relevant solution to increase the reliability of the HTC assessment. A rough estimation of the cost related to the placement and the removal of the insulation panels including repair (patching of the ceiling) is about 2000 EUR per tested unit including VAT.

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REFERENCES

Bacher, P., & Madsen, H. (2010). *Procedure for identifying models for the heat dynamics of buildings: Financed by The Danish Electricity Saving Trust and Vind i Øresund-Interreg 4A*. Retrieved from

Bauwens, G. (2015). In Situ Testing of a Building's Overall Heat Loss Coefficient-Embedding Quasi-stationary and Dynamic Tests in a Building Physical and Statistical Framework.

Bauwens, G., & Roels, S. (2014). Co-heating test: A state-of-the-art. *Energy and Buildings, 82*, 163-172. doi:10.1016/j.enbuild.2014.04.039

Everett, A. (1985). *RAPID THERMAL CALIBRATION OF HOUSES*. Retrieved from

Jack, R. (2015). *Building diagnostics: practical measurement of the fabric thermal performance of houses.* © Richard Jack,

Janssens, A. (2016). *International Energy Agency, EBC Annex 58, Reliable building energy performance characterisation based on full scale dynamic measurements, Report of Subtask 1b: Overview of methods to analyse dynamic data*. Retrieved from

Johnston D., M.-S. D., Farmer D., Wingfield J., Miles-Shenton D., Bell M. (2013). *Whole House Heat Loss Test Method (Coheating)*. Retrieved from

Stamp, S. (2016). *Assessing uncertainty in co-heating tests: Calibrating a whole building steady state heat loss measurement method.* UCL (University College London),

Wingfield J., J. D., Miles-Shenton D., Bell M. (2010). *Whole House Heat Loss Test Method (Coheating)*. Retrieved from CeBE Centre for the Built Environment: