6th International Building Physics Conference, IBPC 2015

Characterising the actual thermal performance of buildings: current results of common exercises performed in the framework of the IEA EBC Annex 58-project

Staf Roels[a], Peder Bacher[b], Geert Bauwens[a], Henrik Madsen[b], María José Jiménez[c]

[a] Building Physics Section, KU Leuven University of Leuven, Kasteelpark Arenberg 40 – box 02447, 3001 Heverlee, Belgium
[b] DTU Compute Dynamical Systems, Technical University of Denmark, Denmark
[c] Energy Efficiency in Buildings R&D Unit, CIEMAT, Spain

Abstract

Several studies have shown that actual thermal performance of buildings after construction may deviate significantly from that anticipated at design stage. As a result, there is growing interest in full scale testing of components and whole buildings. The IEA EBC Annex 58-project 'Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements' is developing the necessary knowledge and tools to achieve reliable in-situ dynamic testing and data analysis methods that can be used to characterise the actual thermal performance and energy efficiency of building components and whole buildings. The research within this project is driven by case studies. As a first simple case, an experiment on testing and data analysis is performed on a round robin test box. This test box can be seen as a scale model of a building, built by one of the participants, with fabric properties unknown to all other participants. Full scale measurements have been performed on the test box in different countries under real climatic conditions. The obtained dynamic data are distributed to all participants who have to try to characterise the thermal performance of the test box's fabric based on the provided data. This paper presents the first results obtained on the round robin experiment. It is shown how different techniques can be used to characterise the thermal performance of the test box, ranging from a simple stationary analysis to advanced dynamic data analysis methods.

Keywords: Integrated building simulation, mono-simulation, co-simulation, efficiency

1. Introduction

The rise of living standards, the scarcity of natural resources and the awareness of climate change resulted in an international pressure to significantly reduce the energy consumption of buildings and communities. In several countries more stringent requirements are imposed by energy performance

legislation and also an increased awareness for environmental issues in building codes can be noticed. Mostly, requirements and labelling of the energy performances of buildings is done in the design phase by calculating the theoretical energy use. Several studies showed however that the actual performance after realisation of the building may deviate significantly from this theoretically designed performance. Part of the deviations can be explained by user behaviour, but the other part has to be attributed to the physical features of the building and its systems. For the latter, building performance characterisation based on full scale testing – testing of building components or whole buildings under realistic dynamic conditions – could help to bridge the gap between theoretically predicted and real life performance of buildings. This is one of the reasons, why, together with an increased application of numerical simulations, a renewed interest in full scale testing can be observed. Though, despite the renewed interest, practice shows that the outcome of many on site activities can be questioned in terms of accuracy and reliability. The focus of nearly all full scale testing activities is on the assessment of the components and buildings, often neglecting the necessity of reliable assessment methods and quality assurance issues. Full scale testing however requires quality on both the test environment and the experimental set-up as well as on the (dynamic) data analysis methods to come to a characterisation with reliable accuracy and use of the results. As soon as the required quality fails on one of the topics, the results become inconclusive or might even be wrong. To this extent an international collaboration in the framework of the 'Energy in Buildings and Communities'-programme (former ECBCS) of the International Energy Agency has been set up. Launched in September 2011, the IEA EBC Annex 58-project works four years with international experts from all over the world on the topic of 'Reliable building energy performance characterisation based on full scale dynamic measurements'. The global objective of Annex 58 is to develop the necessary knowledge, tools and networks to achieve reliable in situ dynamic testing and data analysis methods that can be used to characterise the actual energy performance of building components and whole buildings. The present paper focusses on a round robin experiment performed within the project. In this experiment a test box – a scale model of a building – has been built by one of the participants, with unknown fabric properties for all other participants. The test box is shipped to different institutes (different climatic conditions) with the aim to perform a full scale measurement of the box under real climatic conditions. The obtained dynamic data are distributed amongst all partners who have to try to characterise the thermal performance of the test box based on the provided dynamic data. A description of the round robin experiment is given in the next section, followed by a presentation and discussion of the results of the experiment.

2. Round robin experiment

To determine the state of the art on full scale measurements and dynamic data analysis a round robin experiment has been set up in the framework of Annex 58. The global objective of the round robin experiment is to perform a well-controlled comparative experiment on testing and data analysis. To this extent, a test box (a scale model of a simplified building) has been built by KU Leuven. KU Leuven is the only partner within the Annex 58-project aware of the exact composition of the test box. After construction the box has been shipped to different partners (different climatic conditions and different acquisition equipment) with the aim to perform a full scale measurement of the test box under real climatic conditions. The obtained dynamic data is distributed to different institutes who have to try to characterize the test box based on the provided experimental data.

2.1. Description of the experiment

The investigated test box has a cubic form, with exterior dimensions of 120x120x120 cm³. The floor, roof and wall components of the box are all identical and have a thickness of 12cm, resulting in an inner volume of 96x96x96cm³. One wall contains an operable wooden window with overall dimensions of 71x71 cm² and a glazed part of 52x52 cm². A structure is provided around the box, so that the box remains free from the thermal influence of the ground. Hence, the box can be considered as floating in free air.

Winter 2012-2013 the test box has been tested at the premises of the Belgian Building Research Institute in Limelette, Belgium (50°41' N, 4°31' E). Afterwards the box has been shipped to Spain, where it was measured under summer conditions in Almeria (37.1° N, 2.4° W). In general, the weather conditions in Belgium are temperate, with a mild, but rainy, humid and cloudy winter. The weather at Almeria on the

other hand is dry and extremely hot in summer, with large temperature amplitudes between day and night. During day time, solar radiation is very high on horizontal surfaces and the sky is usually very clear. Figure 1 shows the test box at both sites.

Figure 1.Test box during winter at the measuring site at BBRI. Belgium (left) and during summer at the Plataforma Solar de Almeria, Spain (right).

At both sites, different experiments have been performed, ranging from co-heating tests with constant indoor temperature, over free floating temperature runs, to imposed dynamic heating sequences (ROLBS-signals). During the experiments, heat fluxes on all internal surfaces, together with internal and external surface temperatures, indoor temperature and delivered heating energy within the box have been measured. In addition, both test sites are equipped with an outdoor weather station, measuring all relevant boundary conditions (temperature, relative humidity, wind direction and speed, diffuse and direct solar radiation, long wave radiation,…). The measured data has been provided to all participants in the Annex 58-project. They are requested to characterise the thermal performance of the round robin test box as well as possible based on the provided dynamic data. Both stationary properties, e.g. the overall heat loss coefficient, and dynamic properties of the test box are aimed for.

3. Data analysis methods

Based on the provided dynamic data, different analysis methods have been used by the participants of Annex 58 to characterise the thermal performance of the test box. The techniques vary from simple stationary methods to advanced dynamic data analysis methods. In the next paragraphs a short description of the most important characterisation methods is given together with their main possibilities and limitations

3.1. Averaging method

Averaging methods are typically used in winter conditions to estimate the thermal resistance of building elements from in situ surface temperature and heat flux measurements (ISO 9869, 1994). The method assumes that the (average) heat flow rate and temperatures over a sufficient long period of time give a good estimate of the values in stationary conditions. By averaging the (dynamic) measured data the steady state values are calculated. This way, making use of the measured heat input and indoor/outdoor temperature difference, the overall (stationary) heat loss coefficient of the box can be determined. The method is only valid if the thermal properties and heat transfer coefficients can be treated as constant over the test period and if the effect of heat storage is negligible. As a result, it is clear that the method can be of use for the parts of the data measured during winter conditions in Belgium (when also the indoor temperature is kept constant and solar gains are negligible), but that the method loses his applicability for the Almeria data. Furthermore, only the stationary thermal properties of the box can be determined.

3.2. Simple and multiple linear regression

Apart from the averaging method, linear regression techniques are typically used to determine the stationary thermal properties. By fitting the linear correlation between the heat input and indoor/outdoor temperature difference, the overall heat loss coefficient can be determined. But while the averaging method makes use of detailed (short interval data) and the stationary values follow from the averaging technique, the linear regression typically makes use of daily averaged values, to cancel out short-term effects of thermal mass (Bauwens and Roels, 2014). Applying multiple linear regression, makes it possible to determine not only the overall heat loss coefficient, but also to gain some information on the solar transmittance. Major drawback is again that only the stationary properties can be determined and no characterisation of the dynamic thermal behaviour of the box can be made.

3.3. ARX- and ARMAX-models

Compared to the previous methods, ARX and ARMAX -models allow the dynamics of the system to be included. In the abbreviation AR stands for AutoRegressive: the current output is related to the previous values of the output; MA (Moving Average) refers to the noise model used and X for the fact that eXternal inputs are used: the system relies not only on the current input value, but also on the history of the input. For identifying generic systems AR(MA)X-models are the standard methodology. The most used ARX model structure is the simple linear difference equation which relates the current output at time *t* to a finite number of past outputs and inputs. ARX and ARMAX models have among others been applied by Jimenez and Heras (2005) and Jimenez et al. (2008) for modelling the heat dynamics of buildings and building components. The main problem when applying AR(MA)X-models on the data of the round robin box is first of all the selection and validation of the model, but then also how to interpret the model to get information on the thermal characteristics of the test box. Steady-state physical parameters are usually obtained by comparing the steady-state energy balance equation of the considered system and the AR(MA)X model. An important step in this process is to select inputs and outputs that make this comparison possible. Bacher and Delff (2013) show that by stepwise increasing the model order until most significant autocorrelation and crosscorrelation is removed, a reliable modelling of both stationary and dynamic properties of the box is feasible.

3.4. State space models

A final methodology to characterise the round robin box is making use of state space or so-called grey box models. State space models making use of simple resistance/capacitance schemes can be used to simulate the dynamic behaviour of the box. Mostly a forward selection approach is used. In this approach the analysis starts with fitting a very simple model, which is then stepwise extended until the loglikelihood no longer increases significantly compared to the previous model and the model validation shows that the residuals (the difference between the measured and predicted output) correspond to white noise. As both the initial model as well as all possible extensions are expected to represent a simplified version of the round robin test box, this requires – in contrast to the ARMAX-model – some prior physical knowledge. That is why state space models are often also referred to as grey box models. Figure 2 shows as an example a two-state grey box model for the round robin test box, taking into account heat input by heater and solar radiation, capacity of the interior and walls of the box and (conductive) heat flow through the walls of the box. To identify all relevant dynamic characteristics of the box, preferably a predetermined heating power signal (e.g. ROLBS- or PRBS-signal) is imposed to excite the box around its expected time constants, whilst remaining uncorrelated with outdoor weather conditions.
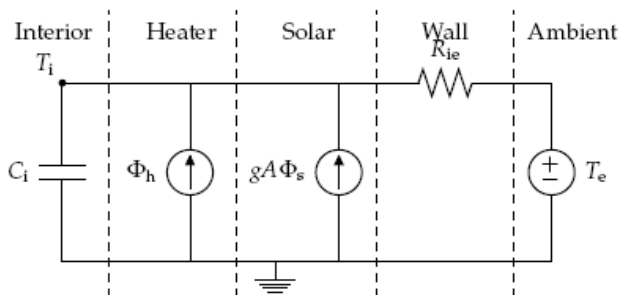
Figure 2.Example of a two-state grey box model applied by one of the participants to characterise the round robin test box (Bacher and Delff, 2013)

4. Characterisation of the test box – discussion of the results

Figure 3 collects the results for the overall heat loss coefficient HLC and the solar transmittance gA obtained by different IEA EBC Annex 58 participants.
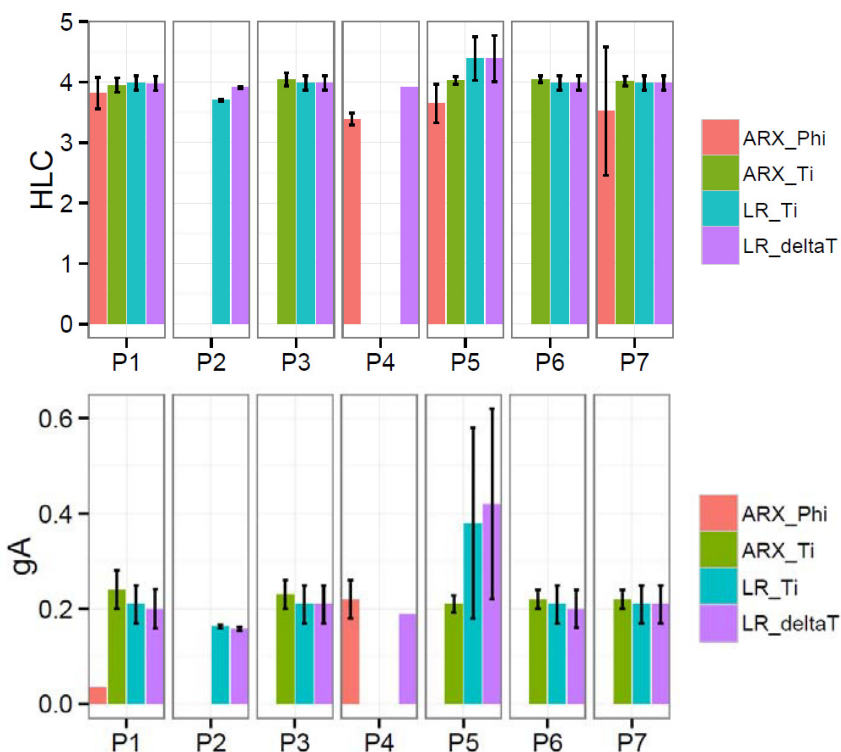

Figure 3.Top: overall heat loss coefficient HLC (W/K) and bottom: solar aperture gA (m²) of the round robin test box as determined by different participants (P1 to P7) and different analysis methods (ARX and linear regression LR).

Comparing the estimates in Figure 3, it can be seen that overall, a rather good agreement is found. The obtained values seem to hover around 4 W/K for the HLC and 0.2 m² for the solar aperture. A more in depth analysis and comparison of the results pointed out that care has to be taken when choosing the sampling period. The very narrow confidence interval obtained by participant P2 is due to the use of too short sampling periods. As a result, the residuals are correlated which results in erroneous estimates of the confidence interval. On the other hand, applying a too large sampling period (as was done by participant

P5) results in a large spread in the obtained estimates for both HLC and gA-value. Other minor differences in the assessment results can be attributed to small differences in modelling assumptions, such as the sampling period, the choice of the model order in the case of ARX modelling, and the strategy in selecting which inputs are lagged, which are not, and to which order.

5. Conclusions

The Annex 58-project of the IEA EBC-programme shows that there is currently a larger international interest in full scale testing and dynamic data analysis. This can be explained by the fact that full scale testing allows evaluation and characterisation of the thermal performance of building components and whole buildings in reality. To illustrate this, as a first step a round robin test box experiment has been performed within the framework of Annex 58. The global objective of the round robin experiment was to perform a well-controlled comparative experiment on testing and data analysis. It is shown how different techniques can be applied to characterise the thermal performance of the test box ranging from (quasi)stationary techniques towards dynamic system identification. Where the first ones are only able to estimate the steady state properties of the box (e.g. overall heat loss coefficient), the latter can give additional information on the dynamic behaviour of the box and can be used to simulate the dynamic response of the box in a simplified way. In a next step the investigated methods will be applied tocharacterise real buildings.

Acknowledgement

References

[1] Bacher P. and Delff P. 2013. IEA EBC Annex 58 Common Exercise 4: ARX, ARMAX and grey-box models for thermal performance characterisation of the test box. Internal report.
[2] Bauwens G. and Roels S. 2014. Co-heating test: a state of the art. Energy and Buildings 82: 163-172.
[3] ISO 9869. 1994. Thermal insulation. Building elements. In-situ measurements of thermal resistance and thermal transmittance (ISO 9869:1994(E)). International Organization for Standardization ISO.
[4] M.J. Jimenez and M.R. Heras. 2005. Application of multi-output ARX models for estimation of the u and g values of building components in outdoor testing. Solar Energy, 79(3):302–310.
[5] M.J. Jimenez, H. Madsen, K. Andersen. 2008. Identification of the main thermal characteristics of building components using matlab. Building and Environment, 43(2): 170–180.