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Methodology for evaluating the energy renovation effects on the thermal performance of social housing buildings: Monitoring study and grey box model development

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ABSTRACT

Grey box models are a solution for evaluating and quantifying the effect on building thermal performance of different energy saving measures. They are usually used to predict a building thermal performance, and applied to energy systems. This paper presents the application of a grey box model to evaluate the thermal performance of a reference social housing building, focusing on its potential to evaluate the thermal performance of building passive elements (building envelope). A methodology to be used by public administration (to evaluate the effectiveness of a given energy renovation work) is also proposed. Firstly, a monitoring carried out in an empty social housing dwelling during 3 months is presented. Afterwards, a grey box model development is carried out using obtained monitoring data. Model development as well as some general model results are presented and evaluated. Finally, a methodology proposal to be applied by public administration is presented. By monitoring and developing a grey box model of a social housing building, this research aims to explore the possibilities of grey box models as a tool to represent in an accurate way the thermal performance of a dwelling, focusing on evaluating building passive elements and their effects on building energy consumption.

1. Introduction

Buildings play an important role in energy consumption all over the world. Nowadays, the built environment uses over 40% of the final energy consumption in the European Union, where a significant part is used for fulfil their thermal demand [1]. For that reason, understanding the thermal performance of a given building is one of the aims of many references found in literature, both by means of monitoring studies such as [2,3], and/or by model simulations [4–6].

Knowing the thermal performance of a building allows predicting the effect of potential energy renovation measures, and then, identifying the optimal option in terms of energy, comfort or taking into account economical issues. In fact, amongst the main barriers of the penetration of new technologies in the market it can be found the uncertainties related to payback periods. Public administrations also found this problem frequently when they try to evaluate the effect on energy savings of a specific energy saving measure carried out with financial help from them.

Thus, literature shows how building models have been widely used with this aim as a useful tool in the last years, and many kind of models are devoted to analyze thermal performance of a dwelling [7]. Some tools to define that building models are currently widely spread and validated (such as TRNSYS or Energy Plus) [8–14]. However, this kind of models usually requires a significant computational time to perform yearly simulations and they need very detailed data related to the building characteristics.

Other type of simulation is the black box approach. It is commonly used when limited information is known about the building. It implies to define a mathematical function which represents the building thermal behaviour. To do that, measured data (input and outputs) are used to define the model parameters. Mathematical correlations which define the performance are identified based on mentioned measured data, and then, once those correlations have

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been fixed, model is fed using new input data, in order to obtain the corresponding output data. Many examples of this kind of models applied to different aspects related to energy performance in buildings can be found in literature, such as [15–18].

Finally, grey box models combine both approaches. A simple physical model is used and its parameters are fixed using measured data. Several designs and developments of grey box models applied to building environment (with very different objectives) are available in literature [19–22].

In addition, many researchers have shown differences between the expected and the actual performance of buildings, both in terms of energy consumption and indoor comfort, which are caused by faults in the building envelop and systems, and by the influence of occupants' behaviour in the operation of the building [23]. Faults in the building envelope or systems, which occur often during construction process, are usually not taken into account in simulations, which lead to inaccurate results. The influence of human behaviour is more difficult to predict due to the heterogeneity of the occupant typologies and the interaction between them and the building. As many studies in literature have shown (such as [24] for example), the human behaviour influences significantly the energy performance of the building, and it will be affected not only by indoor comfort, but also by different occupant's features (household incomes, culture, age...) as well as other external factors such as rebound effect [25–27]. For that reason, human behaviour and operating conditions are often included in building simulations using standardized profiles.

Then, for a better understanding of differences between expected and real performance of buildings, it is necessary to monitor the building thermal performance. Monitoring can be carried out in occupied or empty building (in order to avoid the user influence), long or short-term monitoring, and it can be focused on energy consumption, the behaviour of the occupants and/or the resulting indoor comfort. A profuse number of papers focused on monitoring studies (with different level of detail) can be easily found in literature. An interesting overview of data collection methods has been recently presented in [23].

Many of the grey box models' developments (related to building environment) found in literature aim in general terms, to optimize the operation of the energy systems, but there are not many papers which using grey box models to assess the thermal performance of the envelope.

However, for all mentioned above, grey box methodology can be a very useful tool in order to quantify the real effect of a specific energy saving measure (global or partial) in a specific building. On the one hand, it has the advantages of the simulations (it makes possible to comparing two different scenarios, before and after retrofitting works, under the same operating conditions). On the other hand, it is necessary to carry out a monitoring in order to define the grey box model, and thus, aforementioned possible faults in envelope or systems will be implicitly taken into account, whereas they would be unnoticed when a typical simulation programme is used.

Then, this methodology can be useful in different sectors. In this case, it will be applied in social housing, as a tool to quantify the real effect of energy saving measures carried out with public funding, which allows identify the best energy renovation practices in order to define optimal long term strategies.

At the same time, having a quality data sets obtained in building monitoring is useful to develop, validate and calibrate different kind of models. However, experimental data often are not possible to obtain for different reasons (availability of a case study, availability of required equipment...). Besides, it is hardly found available this kind of data of a representative dwelling or building, so many model developers found an important problem to validate and adjust its model using experimental data, and data obtained by simulation tools (TRNSYS, energy plus...) are usually used. Taking into account these considerations, this paper aims:

- To provide high quality data sets of experimental data gathered in a representative empty dwelling during three months, which can be used as useful tool to validate and/or adjust the building model by means of comparison between monitoring data and calculated data. Moreover, data presented in this paper, may be useful when the objective of a research is to study the effect of a specific energy saving measure (thermal improvement of the envelope, a new heating system...) on a standard building, since this study provides enough data to define a model of the selected building and to validate it, regardless of the kind of model used.
- To explore the grey box models possibilities as a useful tool for tenants and public administrations to assess the real effect of energy saving measures focused on passive elements (although also is applicable to active ones) with two main objectives: identify the optimal solution amongst all the possibilities, or evaluate the real effect of a specific energy saving measure.

To reach these objectives, a reference dwelling was selected as case-study to carry out a monitoring and a grey box model of the selected dwelling was developed using the measured data. Firstly, selection and a detailed description of the dwelling are presented. Secondly, description of the monitoring is shown. Results of the monitoring are presented afterwards, and, the Grey Box Model development and calibration are described. Once the thermal performance is validated, just occupation profiles and operating conditions must be fixed in order to represent in a global way the energy consumption of the dwelling.

2. Case study and methodology

2.1. Building general description

A social dwelling located in a district of Bilbao was selected for this study. Selection was carried out taking into account a previous classification of the building stock presented in [28]. It is well known the complexity and heterogeneity of the building stock and the consequent difficulty to define a “standard building”. However, the chosen dwelling is quite representative in the region of a specific construction period of the 20th century, the 60s. A significant number of today's buildings were built up in that decade, especially in industrial cities.

The studied dwelling is located in a multi-family building built in 1959–1961, in the fourth floor. Some pictures are presented in Fig. 1 and the layout of the dwelling is shown in Fig. 3. The net floor area is 52.5 m^2 and the floor to ceiling height is 2.47 m. The considered dwelling has 3 external façades, orientated East, West and South, but only two of them (E and W) have windows. The following description of the construction features corresponds to the state of the dwelling when the monitoring period was carried out, in the first months of 2012.

2.2. Building construction features

External walls of the dwelling are composed by two layers of hollow bricks separated by an air gap. The indoor surfaces of walls are plaster over gypsum. The external surface is currently the result of renovation works carried out in 1987, when an addition of other façade layer was executed in the chosen building. The assumed addition of a new layer in façade is depicted in Fig. 2. The thickness of thermal insulation is very small, even negligible in some cases. Detailed section of the façade, as well as indoor partitions (both between two rooms and