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A Method to Calibrate Building Simulation Model Through Visual Inspection and Smart Meter

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Abstract: Several energy programs worldwide have used building inspection to overcome the lack of knowledge on technical parameter that are needed to upgrade existing buildings to make them more efficient. Due to the large amount of existing buildings that require to be renovated, energy policies have introduced energy certification as a way to increase the renovation rate, by providing information on several benefits such as energy savings, indoor environment improvements and financial support. However, these procedures are often simplified due to the high cost that field measurements represent. The most common procedure for residential buildings is a walkthrough or visual inspection and the use of statistical data from a sample of buildings to estimate key characteristics. These simplifications can be seen in certification or labelling programs in order to analyse the building performance and to propose energy conservation measures. This study uses a case study to propose a method that in combination with building inspection can provided accurate data of the building performance and technical parameters such as U-values, ventilation rate, infiltration and internal load. The method as a firsts step tailored the information gather during the walkthrough in order to be used in the second step which is a calibration based on collected data from the smart meter. The study case corresponds to a wooden terraced dwelling located in Oslo, the set temperature during winter are different in certain rooms of the dwelling as well their operational schedules. The results show that the uses of smart meter data can effectively improve the results from energy certificate and labelling in existing building, allowing to provide quality information to homeowners and policy makers.

1. Introduction

The renovation of the existing building stock is one of the main challenges worldwide and at the same time one of the main opportunities to achieve high energy efficiency and environmental objectives. For instance, the goal set by the Europe to reduce 20% of primary energy consumption by 2020 compare to projections (1). One mechanism that has been proposed, is the use of energy labelling as a way to inform building users about their building energy performance through a label or class that allows users to compare and assess prospective buildings. Energy labelling tends to be similar in terms of purposes, but they might vary from country to country due to their local climate, needs and expectations (2). Despite that energy labelling the energy performance of buildings is one of the main methods for promoting energy efficiency and see through buildings energy consumption (3), this tools has not reached the expectations. This issue is because of two factors, first energy labelling tools are tailored for new building, focussing predominantly on building design (4), and only adapted for existing buildings. Secondly, the strict technical requirements designed for the energy labelling are not enough to improve the energy efficiency single-handedly (5). Rating the energy performance of existing buildings represent a major challenge compare to new buildings. This is because, most of the information to correctly described existing buildings are difficult to find and most of the time the required inputs will be guess or based on statistical approach, leading to a large level of uncertainty. Additionally, in cases where the labelling system for existing buildings includes recommendations for improving the energy efficiency, such as the case for the Energy Performance Certificate (EPC) in EU, the recommendations and their underlying costs might not be accurate, in terms of expecting savings and the implementations cost, since they are based on normalised energy use and not real energy consumption. As a result of the lack of information, uncertainty of the actual building performance and its energy rating, stakeholders face several challenges to retrofit their buildings (6).

1.1. Performance gap

There are different types of energy labelling tools, for instance steady-state calculations or dynamic simulation methods are utilized to predict the energy consumption using standardized procedures to inform their performance and to verify that they fulfil the energy target. Both have their pros and cons, and despite their capabilities, they present issues to estimate the energy used(7). Classification schemes such as the EPC and standard calculation procedures for quantifying the energy use of a building have been reported to show significant discrepancies to measured energy use during occupation, which risk not achieving the defined targets (8). This phenomenon has been termed previously as “the performance gap”, research on this matters have suggested that actual energy consumption will be twice as much as predicted, highlighting the need for actual performance data (9). Research on this matters revealed there are several benefits of using realistic data (10). The use of real data become more important for retrofitting buildings since this task involves uncertainties related to benefits and costs, which often result in overlooking more than 50% of possible energy savings alternatives (11).

1.2. Calibration

Using Building Performance Simulation (BPS), despite that it has been used worldwide is a complex endeavour, many aspects need to be considered, where most of the models will be complex, with many parameters, state-variables and nonlinear relations (12). In many cases the results provided by the software will not be worth if the base case is not representing faithfully the thermal and energy behaviour of that building (13). Calibration techniques can be used to overcome the uncertainty of unknown inputs. Calibrated simulation is the process of using an existing building simulation computer program and “tuning” or calibrating the various inputs to the program so that observed energy use matches closely with that predicted by the simulation program (14). The benefits of using calibration techniques in existing buildings are, the increase of reliability on the most influential inputs, it can avoid the uses of experimental techniques, such as in-situ measurements, which are costly making an evaluation much more expensive. Calibration can also increase the confidence on the energy saving, and therefore, more reliable and insightful predictions can be made with statistical approaches, as well cost on renovation and their payback would have more support. As it was mentioned before, the calibration is an iterative process that aims to reconcile the model output with measure data. Even though, this is achieved, this not necessarily means that the inputs found are corrects, since similar results can be obtained by modifying the wrong parameters. As well the resolution of the measurements can also impact in the accuracy of the results. For instance, using small scale results (hourly or sub-hourly) it is more time consuming and much more difficult to calibrate than a large scale (annual or monthly basis), which can be affected by large errors (15). Another important aspect to consider is the calibration method to be used, where two approaches can be distinguished, manual and automated calibration.

Manual calibration: Manual and iterative calibration is performed until the criteria are met based on trial-and-error approaches, by means of an iterative manual tuning of the model parameters. Inputs are altered through the user’s experience and judgment about the building (16). Although this process can be considered essential for having reliable results, not all the specialist are capable to perform it (15). it is also the most commonly used in simulation applications.

Automated calibration: Automated techniques include all approaches that cannot be considered user driven and are built on sort of automated procedures (17). They can be based on mathematical procedures (e.g., Bayesian calibration) or analytical approaches (16). This process is similar to an optimization problem with the objective function being the minimization of the simulation energy use data, selecting automatically the parameters to tune and by how much (14).

The aim of this study is to present a simplified method to calibrate building energy model that can be used by certifiers as well as for energy auditors in order to improve the accuracy of the renovation decision to retrofit residential buildings. The proposed method considers the tasks that are currently been used to certify existing residential buildings incorporating simple in-situ measurements and monitored data from smart meters.

2. Methodology

The main target of the proposed method is to improve the energy labelling procedure, in specific, the estimation of the energy performance in existing buildings. In order to achieve this, the steps that are used in the EPC are consider, been the field- visit to the building the most important. Since the certifier should inspect the building in order to verify the level of maintenance and to corroborate the drawing of the dwelling, as well to obtain relevant inputs to be used in the labelling tool. However, no measurement will be made, most to of the gathered inputs will be based on the certifiers experience, knowledge or standards. Another important aspect to consider is that energy labelling use normalised parameters for some calculations, such as heating set point, occupancy and ventilation rate, which for this method should not be considered.

The first step proposed is to perform simple measurements during the field visit to the building in order to obtain a good starting point for the calibration. The measurement performed were ventilation airflow rate, IRT photography and air leakages detection.

Ventilation airflow rate: The ventilation rate was measure with a TSI 7575 Q-Trak and it was located in each exhaust vent.

IRT photography: A FLIR E4 camera was used during the winter season. The main purpose of this measurements was to have an estimation of the U-values for the envelope. This was done by applying a formula (18) that can roughly estimate the thermal characteristic of the walls.

Air leakages detection: A quick inspection was performed using a check list of typical air leakages in wooden houses, the leakages were sized and add up to the standardised airtightness value use for the labelling.

Seconds step of the method is to collect hourly electrical end use data from the smart meter and analyse its confidence level. This is because, often measurement from the smart meter present errors as well is necessary to identify unusual energy use. Third step is to identify the weather-dependent and weather independent energy use through a regression model. For this step it is also considered a monthly statistical analysis of the electrical data to identify the baseline as well the typical pattern of electrical load. The fourth step is to identify the model which gives the best representation of the heating energy use. Fifth step is to perform a sensitive analysis to reduces the number of parameters that are going to be considered into the calibration process, as well to organise in which order these parameters should be modified. Last step is to perform the simulations and assess the goodness-of-fit, for this case study, it was used Design Builder and RMSE.

2.1. Study case

A Norwegian dwelling was selected as case study for testing the method during a winter period (measurements). The building has timber as a main construction and it use as a heater system electrical radiator, which the user had adjusted in two groups, as it can be seen in figure 1. The energy consumption registered from the dwelling correspond to the entire year of 2018 and the weather data was obtained from the nearest weather station from the dwelling.

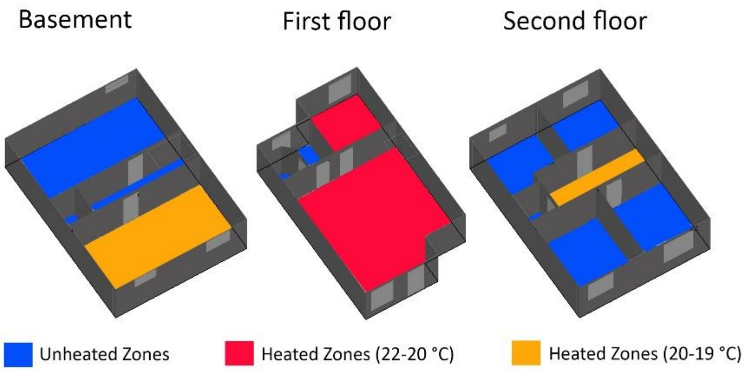

Figure 1. Floor plan of the dwelling and its heated zones.

3. Results

The field visit took around one hour which is the time that normally certifiers spend during the inspection, beside the measurement, other aspect where collected such as the heating set point and typical pattern of use of the building, which later will be use in the simulation. The data collected can are given in table 1.

Table 1. Impact of using standardised inputs compared with simple measurement in the simulation.

Input	Standard	Inspection
U-Value wall (W/m²K)	0.37	0.43
Airtightness (ACH)	4.00	4.60
ventilation rate (m3/h)	199	98.0
Heating set points (°C)	21-19	21-17

3.1. Electrical data from smart meter

The analysis from the electrical data showed that, outliers might affect the calibration, these can be seen in figure 2. The outliers were safe to remove since they a clear error from the smart meter since they have the same exact value for a wide range of temperature, missing data was also excluded. Another important aspect that was investigated was the variation of energy according to temperature, figure 3 shows that energy during summer conditions still present a slope indicating that electrical energy is used for heating, which it is very unlikely. This proved that it is necessary to distinguish the energy from heating and domestic use, from the unfiltered data, it was defined as base line 0.27 kWh and as change temperature 13.9 °C.

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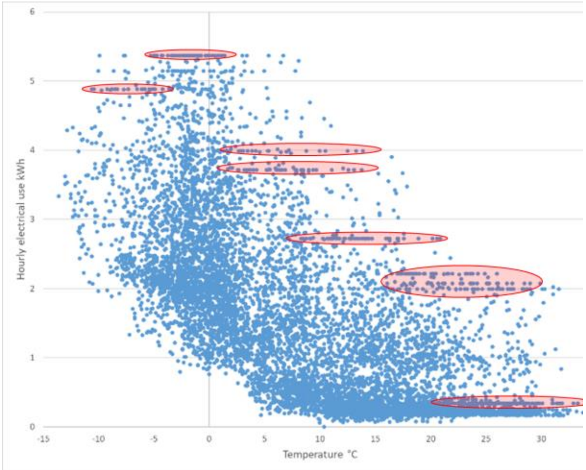


Figure 2. Outliers found in the electrical data.

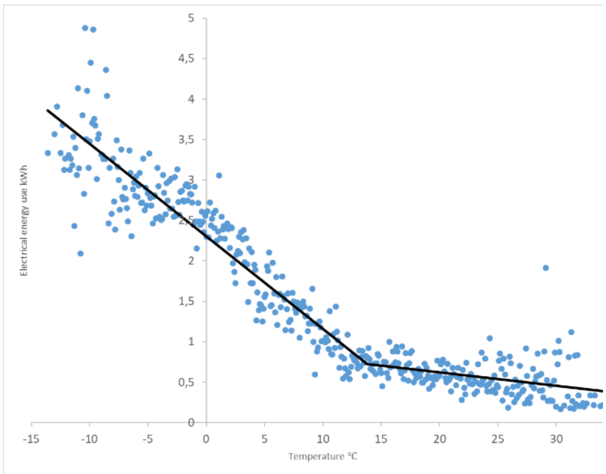
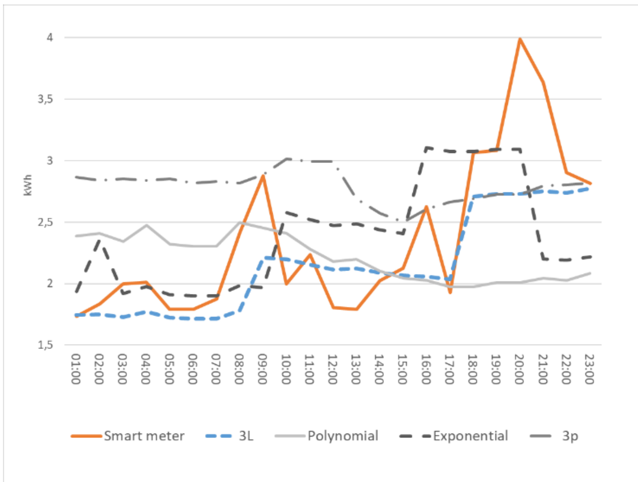


Figure 3. Energy behaviour during winter and summer.

3.2. Model comparison

In literature there are a great variety of model than can represent the heating energy used, from linear model to neural networks. However, the aim of the study is to propose a simple method, for that reason the model that has been used can be tested it in spreadsheet avoiding the uses of more complicated tools. Since the case study represent a challenge due to the multiple heating set points, it was performed a comparison of different model in order to define which will suit better the data. The results can be seen in figure 4. The model that present the best results was a three linear regression model which follow the variation of energy during the different changes of heating setpoints during the week, including the change of the set points during the weekend.



	3L	3P	Polynomial	Exponential
R^2	0.79	0.57	0.47	0.45
MSE	0.51	0.72	0.77	0.82

Figure 4. Performance of the different models

The model that better fit the data is the three linear regression model, which consider the different heating set point of the house, as well their schedule as it can be seen in equation 1. This might be the reason why the other model did not perform as good as it seen in other studies.

$$3L = \begin{cases} \beta_1 + \beta_2 T, t_1 < t_2 \\ \beta_2 + \beta_3 T, t_2 < t_3 \\ \beta_4 + \beta_5 T, t_4 < t_5 \end{cases} \tag{1}$$

Where:
β = Parameters
T = Temperature ℃
t = Time range used as a schedule

3.3. Sensitivity analysis

According to the results, the most relevant parameters where the heating set points, specially the heating set back point, this is due to the number of hours included, which correspond to one third of the day. The U values and the ventilation showed a similar impact. Ventilation measurement were performed. However, the variation used for the ventilation during the simulations were not in a great range as the one used for the U-values. Each parameter impact can be seen in figure 5.

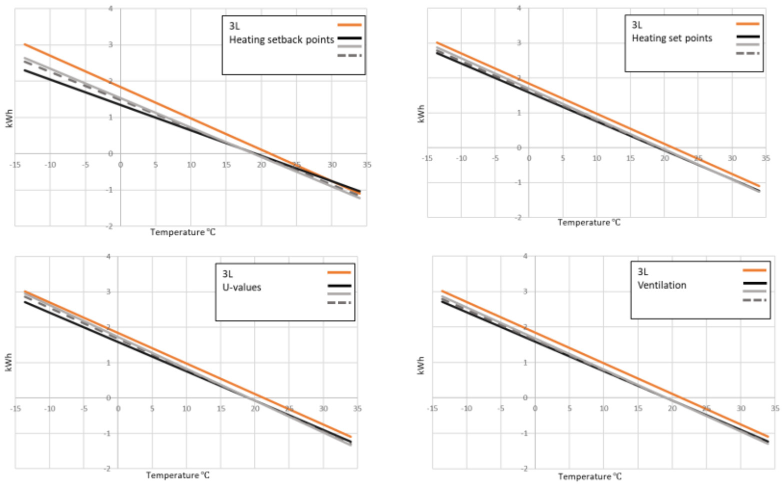


Figure 5. Impact of each parameter during the sensitivity analysis.

3.4. Calibration

Before the simulations process, it was studied the internal gain from domestic equipment and lighting. This was done by studying the energy behaviour during summer conditions. For this August and June were selected as representative, July was rejected since it was observed that no relevant pick of energy was occurring in the building, indicating that the occupants were away most of the time during the month. The data was compiled into a typical day which was used as internal gain in the simulation software. The internal load from equipment is showed in figure 6.

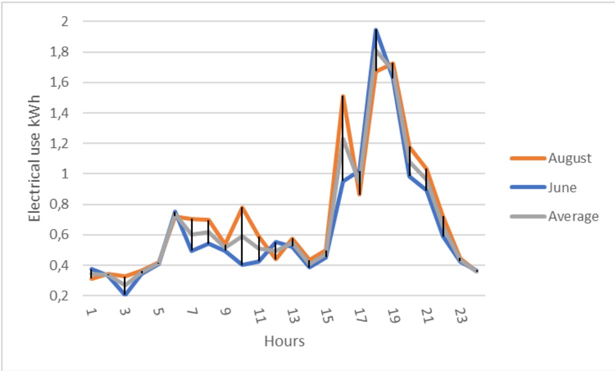


Figure 6. Internal load used in the simulation

The calibration process consisted in less than a hundred simulations performed manually, one parameter at the time, following the order from the sensitivity analysis. The calibrated model achieved a Root Mean Square Error variation of 3.6%. Figures 7 and 8 show the comparison between the smart meter data and the simulation. The resulting input can be seen in table 2.

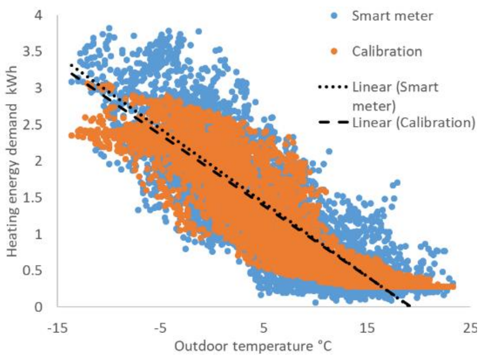


Figure 7. Scatter plot of hourly data during the heating season compared with the calibrated model.

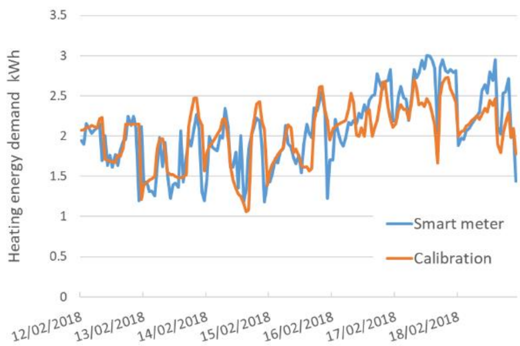


Figure 8. Hourly heating energy used during a week compared with the calibrated model.

Table 2. Results from the calibration

U-value wall (W/m2K)	U-value floor (W/m2K)	U-value ceiling (W/m2K)	U value windows (W/m2K)	Airtightness (ACH)	Ventilation rate (m3/h)	Heating set point (°C)	Heating set back point (°C)
0.33	0.18	0.17	1.91	*6.1	75.2	19	16

*Value obtained from the blower door test

4. Discussion and conclusion

Keeping in mind that in the most cases of building energy simulation and energy labelling, the experts are unable to execute measurements. This makes the calibration process difficult and doubtful. However every building has electrical loads that demands a constant power value or has a regular pattern of use (13). The results from the case study, showed that the uses of the simple measurements reduced greatly the amount of iteration needed to calibrate the model. The measurement an exception of the blower door test, are quick and do not required such an expensive equipment. For this reason, the use of simple measurement can help to introduce calibration into energy labelling. This study also addresses is that even when the model is calibrated, the major question is if the electric end-use of the building has been correctly represented by the model. Many regression models and techniques can be used, but it is important to verify that the results of the model have a reasonable behaviour, meaning that the pattern of electrical use from heating and equipment should be understood before the regression analysis begin. The advantage of using 3 linear regression for this case, were the good result obtained to model the main temperature changes in the dwelling (set-points). Which is the one that impacted the most during the calibration. The simple method proposed, can be effectively use for labelling purposes and should be a challenge to automatize the procedure into a calculation.

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