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EXPLORING THE IMPACT OF MODEL CALIBRATION ON ESTIMATING ENERGY SAVINGS THROUGH BETTER SPACE HEATING CONTROL

D. Marini[1], L. H. Webb[1], G. Diamantis[1] and R. A. Buswell[1]
[1]Building Energy Research Group, Loughborough University, UK

ABSTRACT

It is widely accepted that simulation tools need to be carefully configured with appropriate inputs to yield good estimates of building performance. Having a good representation of a building's performance is particularly important when trying to generate a baseline against which energy savings are to be measured. This is especially challenging in residential buildings where there is a high dependency on occupant behaviour. Relevant data for domestic building is scarce and an option is to use existing guidelines published by organisations such as CIBSE or DOE. This paper considers the relative savings that might be expected by implementing several space heating control strategies, by evaluating the change in performance from a baseline model. The impact of calibrating the model on the results is given as is a description of the calibration approach used. It is demonstrated that potential energy savings can be *either* over *or* under predicted depending on the nature of the control strategy employed.

INTRODUCTION

In the UK space heating accounts for about 50% of the energy consumed in the home and nearly 90% of UK dwellings are centrally heated (Communities and Local Goverment, 2007). The introduction of better space heating controls through the implementation of ICT is being rolled out in the UK, and worldwide. These control systems are market on the basis that energy can be saved. In fundamental terms, the control systems can offer better scheduling to avoid wasted heat when spaces are not used, potentially better control of air temperatures and the possibility of zoning areas in the home to allow varying space conditions: savings of up to 28% have been demonstrated (Lu et al., 2010; Ericson and Cerpa, 2010). Evaluating the space heating options and potential savings is therefore of topical interest and increasingly the value of this is when a specific home is considered. A method of evaluating the savings is then needed, requiring some modelling approach on which to base the analysis.

Modelling and simulation are used to predict performance and whole building energy consumption, however studies show a gap between estimated and real building performance. For example, Branco et al. (2004) found that actual energy use was about 40% higher than the estimated energy use. Differences were attributed to the utilization of appliances and systems in the model and the real building as well as differences in actual/local weather conditions. A study by Staepels et al. (2013) compared measured energy consumption of several dwellings with estimated calculations and also found that both heating and hot water production were overestimated compared to actual energy consumption.

Issues with occupancy and human interaction with the building also need to be treated carefully in residential buildings. Zachary et al. (2010) carried out a detailed post-occupancy evaluation to investigate the energy performance of the buildings and the comfort of users. It was found that energy-efficiency behaviours account for about fifty percent of the variance in heat consumption. Hoes et al. (2009) showed that improving human behaviour modelling in simulation programs is one of the most important input parameters in reducing the gap between models and actual energy performance.

Calibrated models have been shown to reduce the gap between simulation and measurements results by systematically adjusting the input parameters (Raftery et al., 2011; Taheri et al., 2013; Mihai and Zmeureanu, 2013; Reddy et al., 2007). In addition, the implementation of dynamic schedules (e.g, occupancy, equipment, lighting and HVAC schedules) can be used to more closely represent the actual activity in the building, resulting in a more realistic set of inputs (Mahdavi, 2001).

In this paper, a simulation of a real home is developed and implemented using two models who's inputs are based on the design guides published by Chartered Institution of Building Services Engineering (CIBSE) and US Department of Energy (DOE). The simulation results are compared to real measured data from the building on a whole house energy basis including: gas, electricity and hot water consumption. A calibrated model was then created using high resolution monitored data and local weather conditions. During a systematic calibration process, the factors which influence error are identified. The three models were then used to evaluate three different heating control scenarios, with the aim to understand the effect of using the design guidelines over the calibrated model in estimating the potential energy savings for the specific property under the various space heating control strategies.

METHODOLOGY

The building modelled is a typical UK family home, constructed in the mid 1970's. It is a two storey building covering 140m^2, has full cavity wall insulation and is double glazed throughout. Heating and hot water is provided by a condensing combi-boiler, serving radiators of varying size and style throughout the house. All radiators have manually controlled thermostatic radiator valves. The house is occupied by two adults and two children aged 11 and 8.

The models were created using EnergyPlus and data from the CIBSE and DOE: Table 1 lists the relevant parameters. The CIBSE model used input parameters are based on the following guidelines (CIBSE, 2006); energy efficiency in buildings (CIBSE, 2004) and building control systems (CIBSE, 2009). The DOE guidelines mostly are focused on non-residential buildings, however, (Hendron and Engebrecht, 2010) has significantly improved the guideline providing detailed information for modelling residential buildings.

Limitations exist in relation to assumptions made for the plant equipment performance and infiltration/ventilation design flow rates. To address these, additional input parameters were used in the DOE baseline model based on the (DOE, 2004) guidelines and (ASHRAE, 2010) standard for equipment performance and ventilation respectively.

The efficiency of condensing boiler was assumed to be 75% and 80% for the CIBSE and DOE models as based on respective guideline, while according to an experimental study the average annual efficiency for condensing boiler is about 83% (Kershaw et al., 2010). The performance of the boiler has been simulated as a function of return temperature and part load ratios performance curves based on respective benchmarks. The hot water consumption design levels are assumed 42 l/person/day and 58 l/person/day for CIBSE and DOE guidelines respectively.

Three simulations were run: based on CIBSE, DOE and the calibrated model. The weather file was derived by using a historical weather file and modifying the following parameters with actual measured data: outdoor dry bulb temperature; wind speed and direction; solar normal/diffused radiations. The same weather file was used in all three simulations.

Calibrated model

The input parameters were systematically calibrated and validated in individual steps. The time-varying input parameters were converted to schedule files which were later assigned to corresponding input parameters. The data used in the calibration included: windows and door movement; hot water flow rate; occupancy; heating control and patterns of power consumption.

The efficiency of the combi-boiler was estimated to be about 68% based on measured gas consumption and estimated heat supplied (Buswell et al., 2013). The heating operation schedule was calibrated based on the boiler heating programme schedule as defined by the householder, and was supported by monitored gas consumption data. The power consumption was measured at individual circuit level for lighting and electrical equipment. The load profiles were created by averaging the minutely measured power to hourly time-stamp. The highest measured power consumption point in any one hour over the period of simulation was used for the design level input.

For a more realistic estimation of infiltration and ventilation, the airflow network method was implemented providing the ability to simulate multi-zone airflows driven by real movement of openings (windows/doors) by occupants and wind speed/directions from weather data.

Error analysis

In general, statistical Mean Bias Error (MBE) method has been adopted in many practices for validation of the error between the predicted and measured data. The MBE measure how close the energy use predicted by the model corresponds to the measured data on a monthly or annual basis, however the estimations may be influenced by offsetting errors. Therefore, an index that captures offsetting errors so called Cumulative Variation of Root Mean Squared Error (CVRMSE) is considered as appropriate validation index (ASHRAE, 2002). In this work, both methods have been used.

Heating control scenarios

The CIBSE, DOE and calibrated model were used to evaluate three different heating control scenarios:

- occupancy based, preventing the heating of 'unused' space;
- the reduction of the air temperature in all areas to 18℃; and,
- reducing each zone temperature by 1℃.

The occupancy based zone heating control was determined by identifying which rooms of the home are occupied and when. In the occupancy based scenario, the control of the heating system is based on zone occupancy profiles by limiting the heat supplied to the zones during non-occupied hours. The heating system runs based on the operation schedule as defined in the models, but only the occupied zones are heated according to individual occupancy schedule profiles. In the all zone 18℃ scenario, the heating system is assumed to operate from 05:45 to 22:30 continuously and all zones are heated during this period however, all zones have an 18℃ heating temperature setpoint. In the all zone -1℃ scenario all zones have the same heating operation schedules but the heating design setpoint temperature is reduced by 1℃.

RESULTS AND DISCUSSION

The estimated gas, hot water and electricity consumption form simulation outputs of three models were

Table 1: The design input parameters used in the baseline models.

Design Parameter	Unit	Benchmark	Zones				
			Kitchen	Livingroom	Bedroom	Bathroom	Corridor
Heating setpoint	℃	CIBSE	19	22	19	21	20
		DOE	21	21	20	21	20
Infiltration	ac/h	CIBSE	1.5	1	0.5	1.5	1.3
		DOE	0.6	0.6	0.6	0.6	0.6
Ventilation	ac/h	CIBSE	1.5	1.2	1	2	1
		DOE	2	1.5	1.3	2.5	1.5
Equipment Power	W/m^2	CIBSE	3	3.9	3.6	1.7	1.6
		DOE	5.4	5.4	5.4	5.4	5.4
Lights Power	W/m^2	CIBSE	5	5	5	5	5
		DOE	3.8	3.8	3.8	3.8	3.8
Occupancy	people/m^2	CIBSE	0.017	0.017	0.03	0.019	0.016
		DOE	0.028	0.028	0.03	0.025	0.02

compared and validated against measured data for a typical day and whole month of February 2013.

Gas consumption

The measured gas volumetric flow rate is converted to energy assuming a calorific value of gas to be $39.5 MJm^{-3}$ (DECC, 2012) and are presented in Figure 1 alongside the simulation outputs. The top plot depicts the patterns of gas variability consumption while in the bottom plot, the cumulative gas consumption. The pattern of measured gas consumption (red line) shows that the heating system was operational from 05:45 to 08:00 and between 16:30 to 22:30. In the first running hour of both periods, the boiler runs continuously and gas consumption is at a maximum level. After the first hour the boiler turns on/off and the gas flow is modulated. The same heating schedule has been implemented for calibrated model (blue line), but the gas consumption pattern varies significantly only when the air temperature in central heating control zone reach the design setpoint and then boiler switch on/off to maintain the design setponit temperature.

The CIBSE/DOE models assume that heating system will run continuously for 24 hours with set back heating setpoints temperature of 15℃ for (CIBSE) and 12℃ (DOE) between 23:00 to 04:00. This results in more heat being stored in the thermal mass and therefore the heat demand is lower, and as a consequence gas consumption is also lower, even during certain hours in the midday the boiler switch off. Despite this, the cumulative plot shows that the gas consumption from baseline models are higher than calibrated model and measured gas consumption because the boiler has been running for more hours. From calibrated model it was estimated that the solar heat gains from transparent surfaces was about 1.2 kWh/m^2 contributing to about 5% of heat demand reduction as consequence gas consumption for simulated period.

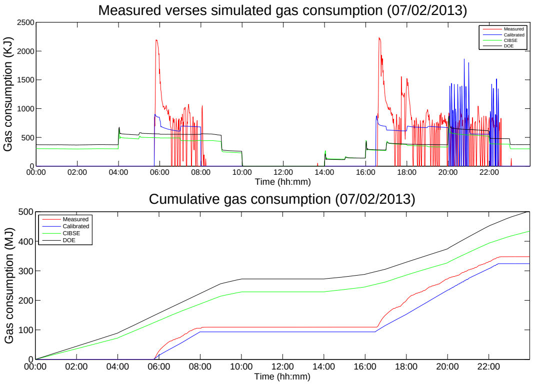

Figure 1: Gas consumption based on measured and predicted resuts from simulated models.

Electricity consumption

A comparison of model outputs and measured power consumption for a typical weekday are presented in Figure 2. The plot presents load curves of total power consumption from electric equipment and lights. The simulation results and measured power are normalized and presented in hourly timestamps. The power consumption for CIBSE/DOE models are calculated based on the input parameters presented in Table 1 and the input schedules as defined in the respective guidelines. The variation of the measured load curve depends on the appliances rated power and duration of time for which are used. These two different approaches lead to different load profiles of power consumption between measured and simulated models. The predicted power consumption were estimated 849 kW and 1102 kW for CIBSE and DOE models respectively, while the measure power consumption is 738 kW for that observed typical day. The patterns of power consumption (see Figure 2) from guideline models have higher level of consumption during morning (06:00 to 09:00) and evening hours (16:00 to 23:00). Similar trends have the measure power however in some hours it vary significantly. The calibrated power consumption based on hourly timestamp has a discrepancy of 4% referred to measure data. Calibrating the model for a shorter (minutely) timestamps the discrepancy decrease to about 1% however this calibration level is time consuming.

Hot water consumption

The CIBSE and DOE guidelines state that a typical family of four people on average are predicted to use about 160 l.day^{-1} and 230 l.day^{-1} respectively. The

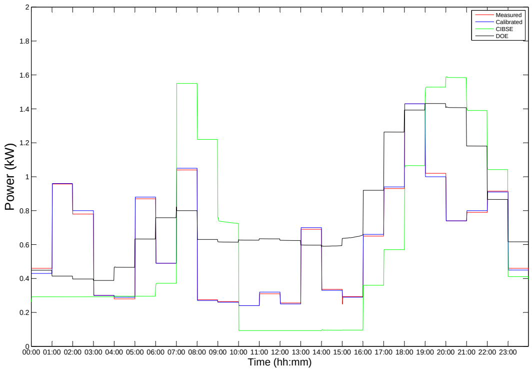

Figure 2: Comparison of power consumption during a week day.

measured data showed that, on average the hot water consumption was 96 $l.day^{-1}$ which is lower than the guidelines, but close to the reported consumption in the Energy Savings Trust report of 122 $l.day^{-1} \pm 18$ $l.day^{-1}$ (EnergySavingTrust, 2008). Figure 3 shows the hourly patterns of hot water consumption from CIBSE/DOE models and measured data during a day. The DOE model (blue bars) rates of hot water use starting from 06:00 to 24:00 have a range of 4 to 23 lh^{-1}, with highest levels of consumption during morning and evening hours.

The CIBSE model (green bars) shows the peak of use occur during two hours (08:00-09:00 and 22:00-23:00) having a rate of 48 $l.h^{-1}$. For the rest of the time, this model assume a lower hot water use ranging from 1 to 16 $l.h^{-1}$. The pattern of hot water use from measurements (red bar) is different compared to CIBSE/DOE models. The measured data had a high water rate of 70 litres during one hour in the evening (17:00-18:00) where possibly this could be attributed to the bathroom routine of the children in the household. For all other hours the hot water consumption is lower than 2 litres and could be considered as tap activities, except between 8:00 and 9:00am where consumption is 21 litres again highly likely to be linked to bathroom activities such as showering. In the calibrated model, the hot water consumption is modelled based on patterns of measured data. So that model does not overestimate or underestimate the gas consumption for hot water production.

Infiltration and ventilation

The CIBSE/DOE models control natural ventilation based on the indoor air temperature and occupancy schedule. If a zones air temperature decreases below 17°C then the air mass flow rate from natural ventilation is considered zero in order to avoid zones overcooling. The infiltration cannot be controlled based on indoor air temperature or a schedule, it always occurs. The calibrated model assumes the ventilation occurs when windows/doors are opened with a background infiltration.

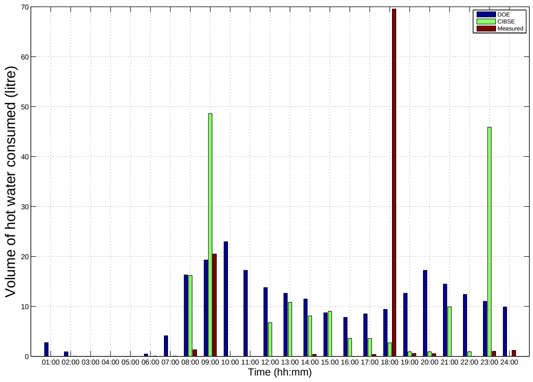

Figure 3: Hot water consumption patterns from baseline models and measured data.

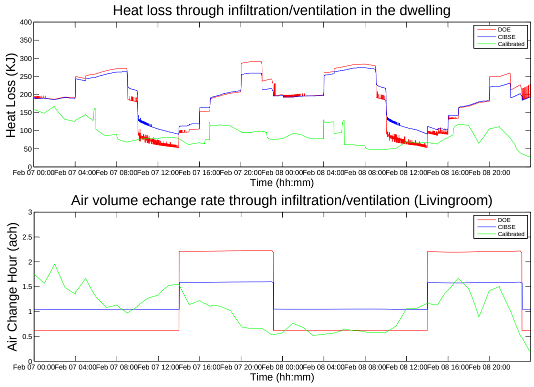

Figure 4: Heat loss and air change rate from infiltation and ventilation.

Figure 4 on the top plot shows the variation of heat lost in the building from infiltration/ventilation while the bottom plot shows variation of the air change rate for the livingroom as based on the results from the CIBSE, DOE and calibrated models. It can be noted that the heat lost from the CIBSE/DOE models (red and blue lines) are higher than compared to the heat lost in the calibrated model (green line). For CIBSE/DOE models, the heat loss varies from 50kJ to 300kJ. The heat lost during day hours (10:00 to 16:00) is lower for these periods due to infiltration. The base-line models calculate ventilation based on occupancy assuming 10 l/person fresh air. As consequence heat loss is higher during building occupied hours and varies based on zone occupancy schedules. For instance, the living room air change rate per hour for DOE model is 0.6(ach) during non occupied hours (23:00 to 16:00) and changes to 2.3(ach) during occupied hours (16:00 to 23:00). The calibrated model shows heat loss ranging from 30kJ to 160kJ which is lower than the CIBSE/DOE models. Also in the calibrated model the pattern of air change rate oscillates between 0.2(ach) to 2(ach) whereas in the CIBSE/DOE models it is constant during certain periods (see Figure 4).

Model Validation

The results from the three models are compared to real measurements for one month (February 2013)

Table 2: Models predicted results error compared to measurements.

Model	**CIBSE**		**DOE**		**Calibrated**	
Error (%)	MBE	CVRMSE	MBE	CVRMSE	MBE	CVRMSE
Gas	-26.3	27.4	-37.0	38.1	-1.6	2.4
Electricity	-12.6	13.9	-26.2	27.1	-1.2	1.7
Hot water	-44.3	46.2	-145.2	147.3	-0.7	1.1

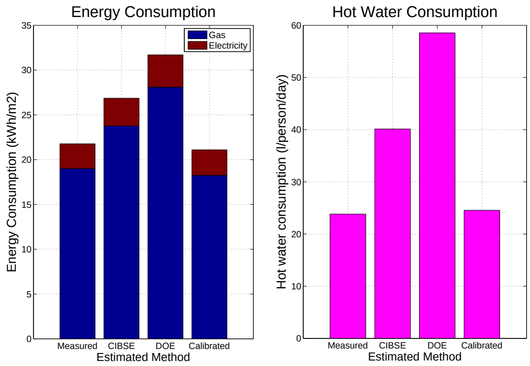

Figure 5: Comparision of estimated results from simulations and measurements.

and are presented in Figure 5. The evaluation of error between the models and the measurements are calculated and validated based on the calculation of MBE and CVRMSE values (see ASHRAE guideline 14 (ASHRAE, 2002)). Table 2 presents the evaluated errors that quantify the accuracy of energy and hot water consumption predicted by the base-line and calibrated models compared to measurements.

The estimated error with negative values (MBE) means that results from models are higher than results from measurements and vice-versa for positive values. The CVMRSE values are always positive despite the fact that predicted results could be higher than measurements. For example, the gas consumption from the CIBSE model is about 27% higher than compared to the measured gas consumption. Gas consumption from the DOE model is 38% higher than compared to measurements. The validated error of electricity consumption for base-line models is slightly lower than for gas, but still predicted results are overestimated compared to real measured power. Hot water use is overestimated significantly from both base-line models, especially for DOE model the overestimation is 147%. Overall, the calibrated model significantly enhances the accuracy of model predictions for gas, electricity and hot water use. For example, the gas consumption from the calibrated model at final stage of calibration is 2.4% lower than measured gas consumption. The underestimation from calibrated model can be attributed to a high gas flow rate during the boiler start up period (real system) and for some zones for certain periods, the measured temperatures were slightly higher compared to zones temperatures in the calibrated model.

In order to estimate the most important factors which influence the discrepancy of predicted results from base-line models, the design input parameters and operation schedules are replaced with those of the calibrated model and run in individual steps. Results are compared with the original base-line models output and error gap was estimated for each step. Table 3 shows an analysis of estimated error for base-line models relating to the prediction of gas consumption. The errors are defined for individual calibration issues. From Table 3 can be seen that two of the parameters (parameters with MBE positive values) have an influence in reduction of gas consumption. The boiler efficiency defined from guidelines are higher than the calculated efficiency that was evaluated for this study, as consequence this lead to underestimation of gas consumption of 7% and 12% for CIBSE and DOE models respectively. The power consumption from electric equipment and lights are overestimated for both base-line models as compared to real measurements, this leads to higher heat gains and as consequence lower predicted gas consumption. Heat loss from infiltration and ventilation has a significant impact on the estimation of predicted gas consumption. The gas consumption was overestimated to about 32% and 35% for CIBSE and DOE model respectively as consequence of overestimation of heat loss from infiltration and ventilation. Another factor which has a significant impact on the error gap between measured and predicted gas consumption from base-line models is the operation schedule of the heating system. As described in the gas consumption subsection, the heating system for base-line models operates for more hours than the measured system. The operation schedule of the heating system overestimates the results by 12% for the CIBSE and 17% for the DOE model. In addition the heating design setback temperature is higher, and therefore the predicted gas consumption is higher. The overestimation of hot water use from base-line models also impacts on the estimated gas consumption. The error gap as consequence of overestimated hot water use was evaluated at 5% and 18% for CIBSE and DOE models respectively. For power consumption the error gap is affected by two main factors maximum power input (design level) and the operation schedules. The design level for the base-line models (Figure 2) are lower than measurements and also the load curves are different. A lower design level and a more flexible operation schedule (time of use) would decrease predicted power consumption and as consequence a lower error gap between base-line models and measurements. The measured hot water consumption has a higher design level but hourly patterns of base-line models apparently influence the overestimation of hot

Table 3: Analysis of error for base-line models on prediction of gas consumption.

	CIBSE		DOE	
Calib. issue	MBE	CVRMSE	MBE	CVRMSE
Efficiency	7.0%	7.2%	12.0%	12.3%
Heat gains	7.6%	8.9%	13.3%	14.1%
Inf/vent.	-31.5%	32.4%	-33.4%	35.1%
Schedules	-11.2%	-12.4%	-16.2%	17.5%
Hot Water	-4.3%	-5.4%	-11.2%	12.8%

water use.

Impact of occupancy based zone heating control

The three models were used to evaluate three different zone heating control scenarios, described previously. The monitored case study is a home with a central heating system, where all the rooms (zones) are heated during the scheduled boiler running period. In order to investigate which zones were not occupied during the heating period it was necessary to develop an occupancy profile schedule based on the monitored data. During the process of identifying which rooms and when they were not occupied, the measured data showed that except at specific times of day and in specific zones, rooms were not necessarily 'occupied' but were still 'in use'. Most zones in the house have transient occupancy, people move from one area to another. Some zones have longer periods of occupancy such as the living room, whilst other zones have much shorter periods i.e. are much more transient such as a downstairs toilet, or a hallway. Rooms such as kitchens have a mixture of longer and shorter in use periods.

To identify a typical daily occupancy, a months data was normalised to give a daily usage of rooms binned in sequential 30 minute units. If there was no activity in this 30 minute period, it was assumed that the room was unoccupied and not in-use. Rooms which were only occupied for a few moments at a time such as a toilet or hallway, still had time periods within which they were used more and time periods when not in use at all, thus when the data was normalised a time period of use could still be identified. For example the downstairs toilet showed periods of use as follows 06:30 9:00, 15:30 18:30 and 21:00-24:00, obviously this is not continuous occupancy but short 5 minutes in use for example. These in use periods were used to produce an occupancy profile for each zone. Figure 6 shows heating on time and room occupancy. It can be seen that there are unoccupied zones which are being heated, in addition there are periods of zone occupancy during which the heating is off. These areas of conflict generally relate to the bedroom areas, but also occur for the bathrooms and at times for the downstairs living spaces. In order to estimate the impact of zone heating control, the on/off of the thermostatic radiator valves (TRV) of the model have been adjusted stopping heat being supplied to the non-occupied rooms.

Figure 7 presents gas consumption patterns and cumulative consumption using the calibrated model for zone based heating and reduced heating setpoint temperature simulations. The pattern of gas consumption based on occupancy zonal heating control (green line) shows lower consumption than compared to the calibrated model(red line) during the first hour of operation in the morning. The lower consumption occurs as a result of stopping the heat supplied to kitchen/dinning room (which are combined to make 1 zone) and living room for non-occupied hours, when the heat is supplied to these zones (07:00 - 08:00) the gas consumption is higher than compared to the calibrated model. The difference in gas consumption between calibrated and zonal heating control models occur as consequence of supplying heat to bedrooms, kitchen/dinning and bathrooms only during occupied hours. Limiting heat supplied to these zones reduces overall gas consumption.

Figure 6: Rooms occupancy and heating system operation profiles.

Table 4: Estimated potential savings based on zone's heating control.

Zones Control Method	**Savings (%)**		
	CIBSE	**DOE**	**Calibrated**
Occupancy based	35	39	19
All zones 18 ℃	11	16	10
All zones 1 ℃ lower	7	9	12

Compared to the calibrated model as shown in Figure 7 (bottom plot) the gas consumption is reduced for all three heating system control scenarios. Controlling heating systems based on zones occupancy profiles can reduce gas consumption more than decreasing the zones heating setpoint temperatures.

Table 4 presents the potential savings of gas consumption as estimated for the base-line and calibrated model. It can be noted that for occupant based control, the base-line models predict to save significantly more energy than calibrated model. The significant difference is because the baseline models assume that most of the zones are occupied during the day time hours (09:00- 16:00) while the monitored data shows that during this period the zones are almost not occupied. The savings are higher for the DOE model decreasing for all zone design setpoint temperature to 18℃ because some zones (bedrooms and kitchen) have a higher setpoint temperature than compared to the CIBSE and calibrated model. Decreasing the heat-

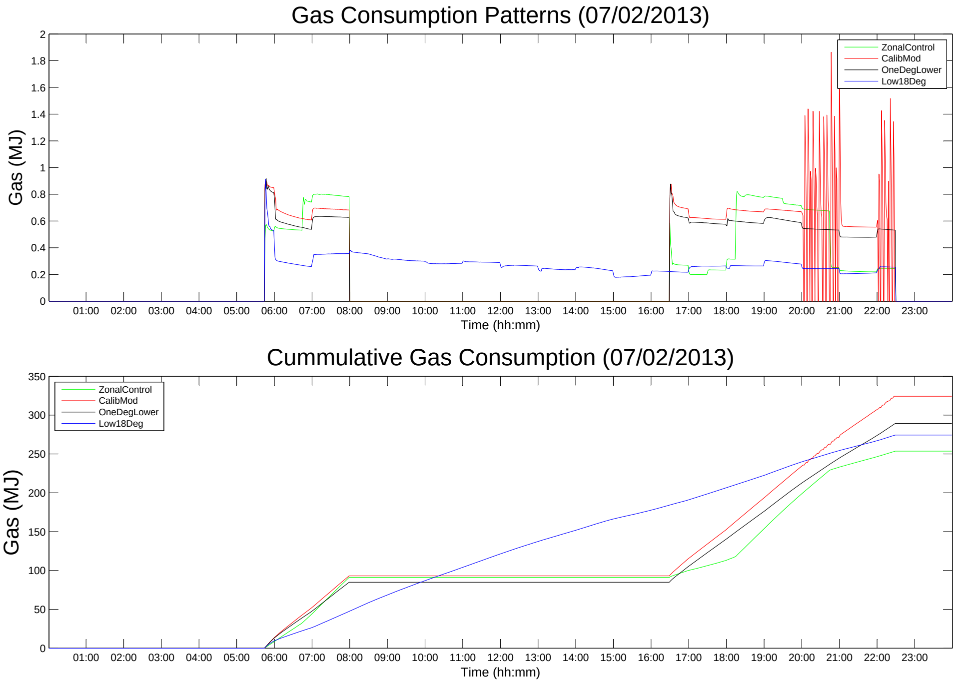

Figure 7: Impact of zone occupancy based control and design heating setpoint on gas consumption.

ing setpoint temperature 1K resulted in higher savings for the calibrated model. This might be attributed to the heating system schedule which operates during the hours when the outdoor temperature is lower; hence decreasing indoor set-point temperature for this periods might lead to reduce energy consumption. In this context, calibration process is important in order to estimate reliable results regarding to potential energy savings.

It was estimated that controlling heating system based on zone's occupancy profile can be saved 19% of gas consumption. Although the heating system run for a longer period (05:45 to 22:30) the gas consumption can be reduced by 10% if the heating design setpoint temperature are decreased to 18℃ for all zones. This control scenario for example could be especially convenient during weekend (most of the time people are home) and during the days when outdoor air temperate is not very low. Meanwhile, decreasing the heating design setpoint temperature one degree celsius, the gas consumption could be reduced by 12% as estimated from calibrated simulation results.

CONCLUSIONS

Recognising the importance of realistic design inputs into simulation tools to yield good predictions, this work developed two baseline models based on CIBSE and DOE guidelines and a calibrated model of a UK family dwelling.

Overall gas consumption in the CIBSE and DOE models was overestimated. The over estimation was attributed to three factors: high assumed flow rates of infiltration and ventilation; unrealistic heating system operation schedules; and an overestimation of predicted hot water use. Two factors in the CIBSE and DOE models underestimated the gas consumption, these were the boiler efficiency and heat gains from power consumption.

Through a calibration process a model was developed which significantly reduced the scale of discrepancy from that of the CIBSE and DOE model when compared to real measurements. Furthermore, the calibrated model represented a more realistic thermal building behaviour and as a consequence more reliable results were estimated from heating control scenarios.

Rather than 'occupancy' profiles, the monitored PIR based 'activity' data was used to create 'in use' profiles identifying the periods when rooms ought to be heated. This was to account for the intermittent occupancy observed in domestic spaces. These 'in use' profiles were then utilised to in two of three scenarios which were explored with regards to their impact on energy reduction.

The typical control of central heating systems often means that heat is supplied to zones that are not in use: turning off the heat supply in those zones has a considerable impact on reducing gas consumption. The results also showed that decreasing heating design input temperatures by 2K - 3K (i.e. from 21℃ to 18℃), the energy consumption can be reduced despite the heating system running continuously during daytime hours. It was found also that considerable energy savings can be achieved by decreasing the zones heating setpoint temperature by one degree celsius.

Of note, however, was the variation in under or over estimation of savings which are apparent between the CIBSE/DOE and calibrated models: the lack of consistency is dependant on the modelled differences between the base-line and the secondary model. Care is therefore required when attempting to evaluate potential savings from different demand reduction strategies using simulation based approaches.

ACKNOWLEDGEMENT

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