IMPACT OF MODEL SIMPLIFICATION ON ENERGY AND COMFORT ANALYSIS FOR DWELLINGS

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ABSTRACT

Carrying out building energy simulations is a valuable part of a decision-making process which helps designers to evaluate various building design options and their impact on energy consumption. However, it is also time consuming. This became even more obvious when many models have to be created, either as a part of an iterative design process, or for studying energy requirements (and implementation of potential energy conservation measures) of a housing stock. Model simplifications can mitigate this issue. One of the simplifications is to remove internal partitions (zoning) and to treat a single floor as a single zone. In the domestic houses, single floor can be treated either as a lounge or as a bedroom since these are two dominant zones where occupants spend the most of their time. The impact of a model simplification on dwellings heating demand, operational carbon emission, overheating risk and collective overheating risk is analysed in this paper.

INTRODUCTION

Creating detailed dynamic thermal simulation models for buildings is a time consuming and error prone process. Large amount of input details are required. These details include site, geometry, internal layout, construction, openings, usage and occupancy, equipment, lighting, HVAC and energy systems, and operational specifications. Although modern modelling tools such as eQuest, DesignBuilder and IES VE, amongst others, provide convenient methods for importing frequently used data sets to reduce the demand for manual input, a model creation remains the most labour intensive step that is responsible for the most quality issues. This situation becomes even worse when many models have to be created, either as a part of an iterative design process or for studying building clusters/stocks. A way to simplify model creation, with an acceptable compromise of accuracy in exchange for reduction in the level of details which have to be specified for a model, may be useful in certain applications.

One of the simplifications that can significantly reduce the amount of time required for modelling is internal layout of the building. The internal spaces of a large building are usually divided into different zones, differentiated by their usage and activity, heat gains and losses characteristics, and HVAC systems and operation regimes. For a small building, e.g. a domestic house or a self-contained unit in a large residential building, detailed zoning may not be necessary. The amount of work involved in a modelling will be significantly reduced if fewer zones have to be defined. So to the authors, it is of interest to see whether the error level caused by such simplification is acceptable or not. Potentially, such simplification, if acceptable, can pave the way to automated model creations on a large scale, e.g. using map and photographic information to create dynamic building performance models for building stocks.

Sensitivity analysis (SA) is a method of studying relative importance of the model parameters based on their impact on the model outputs. Several of sensitivity studies of building performance simulation models have been reported including Hopfe and Hensen (2011), Macdonald and Strachan (2001), Spitz et al. (2012) and Heiselberg et al. (2009). However, most of the studies on dynamic models used non-domestic buildings in design scenarios. As a result, internal layout or zoning has not been considered as an uncertainty variable. SA on domestic building energy models focused on energy performance assessment using steady-stated models (Firth et al., 2010), in which internal zones are not a concern either. Not been able to find answers in literature, we decided to conduct our own investigation.

This paper reports a study on the impact of zoning details of typical domestic house models on key building performance indicators such as annual heating demand, operational carbon emission, and overheating risks. We will first describe the method used in this study, and then discuss the results and findings.

METHOD

Since our interest is to test whether or not zoning details of dwelling models can be reduced, and to quantify the impact of such simplification on building performance analysis, the method chosen is a direct comparison of the two different approaches on a random sample of models representing a wide range of domestic houses. EnergyPlus v.7.2

(EnergyPlus, 2012), OpenStudio (NREL, 2012) and jEPlus (Zhang, 2009; jEPlus, 2012) were used for modelling and carrying out simulations.

Building models

Five modern house designs (UrbanArea, 2012 - see Figure 2) have been selected to form the base models of this study. House type 1 is a large four-bedroom detached unit with 151.38m^2 occupied floor area. House type 2 is a smaller two-bedroom detached unit with integral garage (92.58m^2). House type 3 comprises two semi-detached units, one with two bedrooms and the other with three bedrooms. Total occupied floor area is (171.44m^2). House type 4 is a large terraced property (117.88m^2, adjacent units not shown). And, house type 5 is a smaller terraced property (74.52m^2). Both terraced units have three bedrooms, although house type 4 has an integral garage on the ground floor. These five house types provide a good mix of sizes, forms and fenestration arrangements. Flats in an apartment block, or bungalows (single-storey houses) are not included in this study, as the internal conditions of different spaces in those dwelling types tend to be more uniform than multi-storey houses, therefore impact of zoning simplifications may be harder to detect.

To provide a good coverage of the dwellings across the UK, three UK locations were selected. Weather files for London Gatwick Airport (South England), Finningley (North England) and Aberdeen-Dyce (Scotland) were used in simulations. Suburban terrain was assumed and no external shading by adjacent buildings or trees was considered. Orientation of the houses, rotated at 45 degree intervals, has been one of the parametric design parameters.

Building fabrics

The building envelopes are modelled in full details. Major construction elements in the domestic house design are exterior walls, ground floor, roof and glazing. While roof and ground floor elements were kept unchanged, three types of the exterior wall construction were included in the analysis. Exterior wall type one is heavy construction made of four layers: exterior brick layer, insulation layer, concrete block layer and interior gypsum plastering layer. Exterior wall types two and three represent light construction with the only difference in the exterior finishing layer. To be exact, wall type two has brickwork as a finishing layer while in the wall type three this layer is replaced with the wood. Rest of the construction is the same and has four additional layers: air gap, plywood sheathing, insulation layer with timber studding and gypsum plastering layer. Since the insulation layer in construction types two and three is made of insulation material and timber studding, its material properties were adjusted to reflect the presence of a timber. The timber fraction was set to 10% which is at the lower end of indicated values presented in the CIBSE Guide A (CIBSE, 2006).

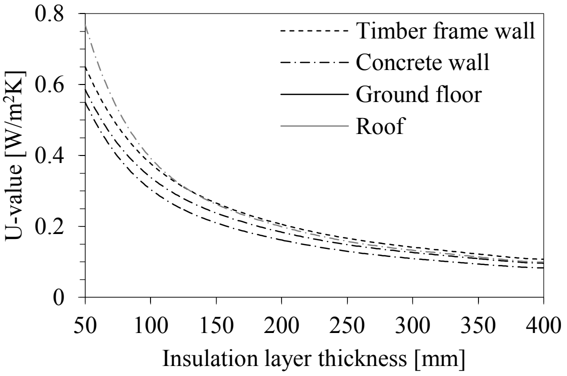
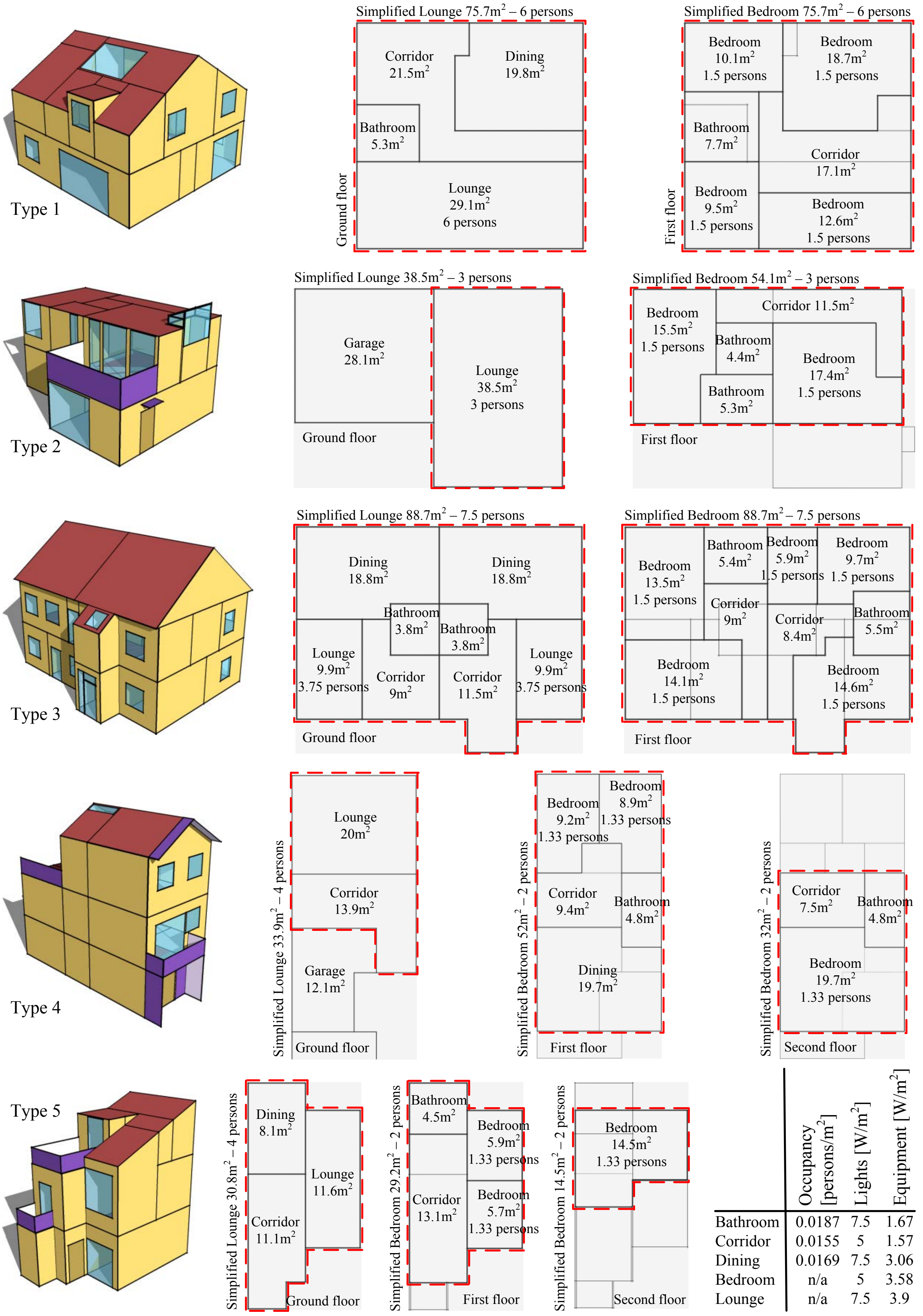


Figure 1 The building envelope U-values as a function of insulation thickness

The insulation layer thickness in the roof construction element, ground floor construction element and exterior walls constructions was varied from 50mm to 400mm in 50mm increments. The insulation thickness in the all construction elements was allowed to be varied separately to represent a variety of possible construction scenarios as well as a diversity of potential refurbishment measures such as insulating a roof/roof loft or upgrading insulation in exterior walls only. The effect of insulation thickness on a house envelope U-values is presented in Figure 1. Although three external wall constructions were included in the study, Figure 1 shows only two U-value curves for them. That is due to minimal differences in U-values between external wall types two and three where the only difference is the exterior layer. On the other hand, the presence of timber in the insulation layer in these wall types has significant impact and results in higher U-values than the exterior wall type one (Concrete wall in Figure 1).

In addition to the exterior wall types and the walls, roof and ground floor insulation layer thickness, eight glazing types were specified as a design option: two double-glazed units and six triple-glazed units. Double-glazed units are made from 4mm clear glass outer pane, 4mm low-emissivity glass inner pane and 12mm cavity between panes with the only difference in the type of gas used to fill the cavity; air or argon. Four of six triple-glazed units are made of 4mm glass panes and 12mm cavities between them, filled with either air or argon. Two of them have all glass panes made of clear glass, while other two have two low-emissivity inner panes. The last two triple-glazed units are made of 6mm glass panes and 13mm air filled cavities. Outer pane is made of clear glass in both units, while inner panes have improved characteristic which results in lower solar heat gain coefficient (SHGC). Although the SGHC is lower, the improved characteristics of inner panes have negative impact on the light transmittance (LT) which is decreased too. Basic properties of glazing types selected for the analysis (U-value, SHGC and LT) were presented in Table 1.



	Occupancy [persons/m²]	Lights [W/m²]	Equipment [W/m²]
Bathroom	0.0187	7.5	1.67
Corridor	0.0155	5	1.57
Dining	0.0169	7.5	3.06
Bedroom	n/a	5	3.58
Lounge	n/a	7.5	3.9

Figure 2 The five house types modelled: images from OpenStudio and floor layouts (table in bottom right corner presents the default values for occupancy density, lighting power and equipment power for individual zones)

Table 1 Glazing type properties

GLAZING TYPE	U-value [W/m^{2}K]	SHGC	LT
Double 4-12-4 Low-E Air	1.95	0.63	0.76
Double 4-12-4 Low-E Argon	1.84	0.63	0.76
Triple 4-12-4-12-4 Clear Air	1.78	0.66	0.72
Triple 4-12-4-12-4 Clear Argon	1.63	0.66	0.72
Triple 4-12-4-12-4 Low-E Air	1.05	0.49	0.65
Triple 4-12-4-12-4 Low-E Argon	0.89	0.49	0.65
Triple 6-13-6-13-6 Low-E(55) Air	1.14	0.31	0.46
Triple 6-13-6-13-6 Low-E(66) Air	1.15	0.36	0.54

Internal conditions and HVAC operation

The national calculation methodology (NCM) recommendations (BRE, 2012) were used to set a default occupant's density, equipment loads and lighting loads for each individual zone (bedrooms, lounges, kitchens, dining areas, corridors and bathrooms). However, the recommended values were parameterized to better represent the variety of household activities. Two additional values of occupant's density were included: 50% less occupied and 50% more occupied. Also, both the equipment loads and lighting loads were varied from half of the default values up to twice higher values. In addition, two types of schedules, reflecting the occupancy pattern and equipment/lighting use, were developed to represent working family household and constantly occupied property. Further impact on the level of internal gains was obtained by introducing the daylight control in lounge and bedroom zones. Although it is not common to have daylight control in domestic properties, it has been included as a design parameter to represent highly possible scenario of reducing lighting level by switching lights off when there is enough natural light.

The houses heating demand was determined assuming an ideal system is installed which delivers sufficient amount of energy to maintain a desired indoor temperature all the time. Heating setpoint temperatures in lounge areas, bedrooms and the rest of the house were also parameters in the study and they were varied between 18 and 22°C in lounge zones and between 16 and 22°C in all other zones. In addition to the heating setpoint temperature values, the heating demand was varied by introducing two types of heating system control strategy: cycling and continuous operation. In the cycling operation mode, the heating setpoint during unoccupied period was set to 12°C and the system was not in operation unless the indoor temperature drops below the setback value. On the other hand, in the continuous operation, the heating setpoint temperatures were constantly kept high which resulted in longer operating hours and, as expected, higher heating demand.

The uncontrolled flow of outdoor air into a house through cracks and other unintentional openings, also known as infiltration, has been selected as a simulation parameter as well. The infiltration level was varied from 0.05 to 0.95 air changes per hour (ach) in 0.1ach increments in order to include a range of homes from very tight to extremely leaky. Fresh air requirements were fulfilled by allowing the distribution of 10l/s per person of outdoor air to the occupied zones. The natural ventilation as a measure which can reduce overheating was also included in the analysis. Whenever the outdoor air temperature rises over 22°C during occupied period, the additional amount of outdoor air was introduced to the lounge and bedroom zones. This amount was varied between 0 and 24ach in 6ach increments and represents the various levels of opening windows (or kept closed if value is equal to 0ach).

Parameters used for defining the parametric design space of the houses are summarised in Figure 3. The total number of all possible scenarios is just under 6.94×10^{12}. To run the whole set of scenarios would be infeasible and unnecessary. Instead, the Latin Hypercube Sampling (LHS) method provided by jEPlus was used to select a random sample of 2,000 simulation scenarios. These 2,000 cases were simulated twice, with detailed zoning and simplified zoning respectively. This allows us to compare the difference between two modelling approaches case by case.

Detailed and simplified zoning

In modelling, the number of zones and the level of zone details increase both model preparation time and simulation time. Zoning is often necessary for large buildings, such as offices, schools and hospitals. For dwellings, however, the level of details required is subject to the applications of the models. Creating models easily and rapidly is useful in the early design stage of a building, or for energy evaluation of building clusters, such as an urban area. The question is how much simplification of zoning in domestic house models may affect model accuracy.

The five house types described above were modelled in full zoning details first. Each and every functional space in the house was defined as a separate thermal zone, where different occupancy patterns, internal gains and control settings apply. Since we want to use this case as an example of maximum zone separation, inter-zonal airflow is prohibited by not including holes (doors, for example) in partition walls. This can be seen as the internal doors in the house are kept shut at all times. From Figure 2, you can see five zone types defined in this study. These are bedroom, corridor, bathroom, kitchen and dining, and lounge area. Each bedroom also has its own number of occupants; therefore the occupancy density varies between bedroom zones, depending on their floor areas. In this way, we can make sure the total number of occupants in the house remains the same, disregarding whether detailed or simplified zoning is used.

Parameter			No.
Climate		London-Gatwick; Finningley; Aberdeen-Dice	3
House types			5
Orientation		0 – 345° step 45°	8
Exterior wall type			3
Insulation layer thickness	Exterior wall	50 – 400mm step 50mm	8
	Roof		8
	Ground floor		8
Glazing type			8
Infiltration		0.05 – 0.95ach step 0.1ach	10
Natural ventilation		0 – 24ach step 6ach	5
Heating setpoint	Lounge	18 – 22°C step 1°C	5
	Bedrooms	16 – 22°C step 1°C	7
	Other		7
Load fraction	Equipment	0.5 – 2 step 0.5	4
	Lighting		4
Occupant's density fraction		0.5; 1; 1.5	3
Schedules		Working family; Constantly occupied	2
Daylight control		No; Yes	2
Heating operation		Cycling; Continuous	2

Total number of combinations ≈ 6.94 x 10^{12}

Figure 3 List of parameters

The two dominant activities in the domestic houses are the lounge zones and bedroom zones. The occupants spend most of their time in these two zones when they are at home. Due to that, the models with simplified zoning are composed of lounge zones and bedroom zones only. Each floor of a house is treated as a single zone, either as a lounge or as a bedroom. This method is consistent with the methods found in most commonly used steady-state energy models such as BREDEM (Anderson and Chapman, 2010). We did not normalize the equipment/lighting density of the corresponding zone types to achieve equal total gains in both detailed and simplified zoning approaches. The assumption is that, to create a model with simplified zoning the modeller does not have to have details on the internal layout and the activities of the spaces other than lounge and bedrooms. This naturally causes error in the overall equipment and lighting consumption calculations, as shown in Figure 4 below.

Building performance indicators

The proposed method of model simplification has little impact on construction cost and embodied carbon emission calculations of the building. The availability of natural lighting is determined by the geometry of the building and the opening in the building envelope; therefore it is not affected by internal layout. However, internal partitioning and space use would have an impact on lighting requirement, which will be captured by the carbon emission from electricity consumption. Heating energy consumption of dwelling is a main concern in the UK. Thermal comfort is another key area of interest, especially the overheating risks during the summer. As a result, the key performance indicators of domestic houses calculated in this study are the following:

- Annual heating energy demand, normalized by total occupied floor area of the building [kWh/m^2/yr]. Ideal load heat system is assumed in all building models.
- Annual operational carbon emission, normalized by total occupied floor area of the building [kg/m^2/yr]. This figure includes electrical equipment (including cooking) and lighting, and gas heating emissions.
- Overheating risk [hr/yr], measured by the total number of occupied hours that internal temperature is above certain threshold in each zone, in particular in bedrooms and in the living areas in this case. Temperatures over which the overheating risk were counted were specified based on the benchmark values presented in the CIBSE Guide A (CIBSE, 2006) and the Technical Manual 36 (CIBSE, 2005) and these are 28°C and 26°C for living areas and bedrooms, respectively.
- Collective overheating risk [person x hr/yr], measured by occupied hours multiplied by the

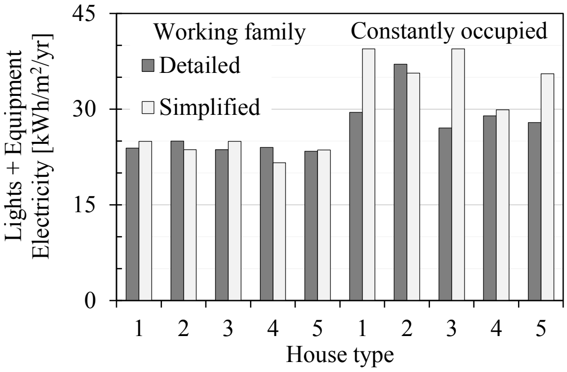


Figure 4 Comparison of detailed zoning models and simplified zoning models electricity consumption

number of occupants in the corresponding zone during the overheating period. The collective overheating risk measure shows how many person-hours that occupants suffer collectively from overheating. This figure is calculated using EnergyPlus' EMS function.

RESULTS

Scatter plots in Figure 5 show the correlation between detailed zoning model simulation outputs and simplified zoning model simulation outputs. Predictions of the overheating risk and the collective overheating risk presented in charts on the right side are plotted using the logarithmic scale since the ranges of results are quite high while the majority of values are at the lower end. From the charts itself it can be seen that simplified zoning model outputs correlate well to detailed zoning model outputs. However, further analysis is required to quantify the difference in simulation results between these two modelling approaches.

Following statistical parameters were computed to support the analysis: coefficient of determination (R^2), root mean square error (*RMSE*), coefficient of variation of *RMSE* (*CV*(*RMSE*)), mean absolute error ($\overline{|e|}$), 95th percentile of the mean absolute error ($|e|_{95\%}$), mean absolute relative error ($\overline{|\delta|}$) as well as 95th and 80th percentiles of the mean absolute relative error ($|\delta|_{95\%}$, $|\delta|_{80\%}$). Coefficient of determination is computed as presented in equation 1.

$$R^2 = 1 - \frac{\sum_{i=1}^{N} e_i^2}{\sum_{i=1}^{N} (y_i - \bar{y})} \tag{1}$$

Where y_i is the observed value (calculated by the detailed zoning model), $\bar{y}$ is the mean of the observed values and e_i is the error defined as the difference between the observed value y_i and associated value predicted by simplified zoning model $\widehat{y_i}$ as presented in equation 2.

$$e_i = y_i - \widehat{y_i} \tag{2}$$

The *RMSE* is defined as the square root of the mean square error (equation 3), while the *CV*(*RMSE*) is defined as the *RMSE* normalized to the mean of the observed values (equation 4).

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} e_i^2} \tag{3}$$

$$CV(RMSE) = \frac{RMSE}{\bar{y}} \tag{4}$$

The mean absolute error is computed to show the overall differences between outputs from the

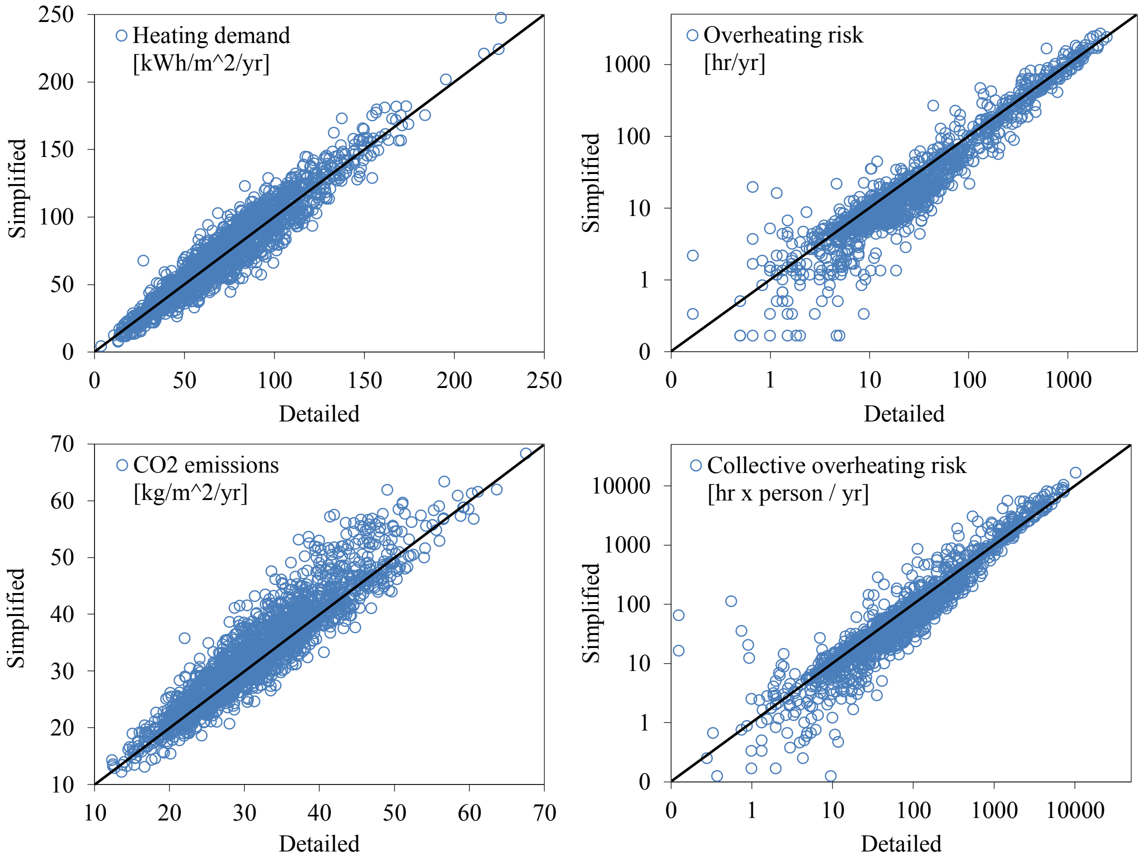


Figure 5 Detailed zoning model vs. simplified zoning model simulation predictions

simplified zoning model and outputs from the detailed zoning model (equation 5).

$$\overline{|e|} = \frac{1}{N}\sum_{i=1}^{N}|e_i| \tag{5}$$

The relative errors between two simulation outputs datasets were computed to provide additional information about the accuracy of simplified models although this approach has limitations since relatively small absolute errors can cause large relative errors. Nevertheless, the mean absolute relative error is calculated as presented in equation 6 (multiplied by 100 to present it in percentages).

$$\overline{|\delta|} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{e_i}{y_i}\right| \cdot 100 \tag{6}$$

Table 2 shows the summary of statistical parameters for each of four simulation outputs (heating demand, CO_2 emissions, overheating risk, and collective overheating risk). It can be seen that the means of both samples (outputs from detailed zoning models and simplified zoning models) are very close to each other, except in the case of the collective overheating risk. Coefficient of determination is slightly above 0.8 for both CO_2 emissions and collective overheating risk, while for the heating demand is 0.91 and for the overheating risk is 0.94. The heating demand *RMSE* is 9.3 kWh/m^2/yr while the CO_2 emissions *RMSE* is 3.47 kg/m^2/yr. This results in the coefficient of variation of *RMSE* of only 13% and 11% respectively. On the other hand, overheating risk and collective overheating risk root mean square errors are much higher.

Mean absolute errors of all analysed outputs are relatively small. In addition, the 95th percentiles of mean absolute error show the same trend. The value of 306 for the collective overheating risk might sound quite high but the range is also large.

The relative errors analysis gives more information about the simplified zoning models accuracy. It is important to mention that the overheating risk and collective overheating risk relative errors were adjusted by introducing the minimum of 10 overheating hours, which means that all records in the simulations outputs lower than 10 hours were replaced with 10 hours (or 10 hour x person). By introducing this artificial lower end, we were able to partially mitigate the sensitivity which relative error has when the denominator is a small number.

The mean absolute relative errors for heating demand and CO_2 emissions are around 10%, for the overheating risk about 15%, while for the collective overheating risk is slightly larger and amounts close to 24%. 95th percentiles of the absolute relative error show that the simplified zoning models prediction of heating demand and CO_2 emissions is acceptable with 27.5% and 22% relative errors respectively. Opposite to this, overheating risk and collective overheating risk have much higher 95th percentiles of absolute relative errors: 58.2% and 68.8%. Even the 80th percentiles for these two outputs are large, having 58% absolute relative error for former and 69% absolute relative error for latter.

DISCUSSION

The main benefit of simplified models is that the both preparation time and simulation time can be considerably shortened. While it may be difficult to evaluate accurately the modelling time, which largely depends on models and users' skills, the fact that the required zone types are reduced from five to two, therefore remove the need for specifying occupancy, equipment and lighting schedules and HVAC set points for three zone types, is significant. More importantly, the simplified models do not require the internal layouts of the buildings to be known, which opens door to automated model creation by boundary geometry alone.

On the other hand, saving in simulation time can be easily measured. Figure 6 shows the comparison of

Table 2 Statistical measures of simplified zoning model outputs when compared to detailed zoning model outputs

	HEATING DEMAND	**CO_2 EMISSIONS**	**OVERHEATING RISK**	**COLLECTIVE OVERHEATING RISK**
Mean – detailed	72.65	32.16	87.36	251.28
Mean – simplified	73.19	33.32	84.12	290.07
R^2	0.91	0.82	0.94	0.81
RMSE	9.30	3.47	62.04	336.62
CV(*RMSE*)	0.13	0.11	0.71	1.34
$\overline{\lvert e\rvert}$	7.15	2.53	19.11	79.19
$\lvert e\rvert_{95\%}$	18.80	7.42	96.59	305.99
$\overline{\lvert\delta\rvert}$	10.59	8.00	15.08	23.43
$\lvert\delta\rvert_{95\%}$	27.55	22.06	58.20	68.77
$\lvert\delta\rvert_{80\%}$	16.62	12.81	31.57	41.18

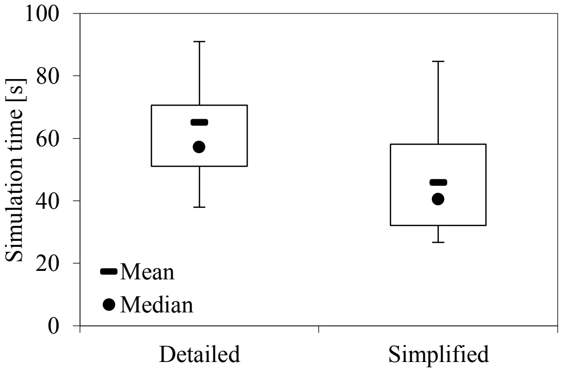


Figure 6 Simulations computational time

simulation times of the detailed zoning models and the simplified zoning models using box plots. It is clear that the average simulation time (on Intel Xeon E5440 processors) of the detailed zoning models is 65.13 seconds, while the average simulation time of the simplified zoning models is 45.9 seconds. The total simulation time for 2,000 EnergyPlus simulations is 36.2 CPU hours for the detailed zoning models, and 25.5 CPU hours for the simplified zoning models. By simplifying zoning, the computing cost is reduced by 30%.

The errors calculated from comparing simplified zoning to detailed zoning approaches, indicate the relatively low impact of zoning simplification on heating energy consumption and overall carbon emission of the houses. Mean (absolute) relative errors across diverse building models in various UK climatic conditions are 10.6% for heating and 8.0% for total CO_2 emission, respectively. The errors can be largely explained by the difference in total internal gains and electricity consumption from equipment and lighting. Some effort in matching equipment and lighting gains in detailed and simplified models would help in reducing the errors.

For thermal comfort and overheating evaluation, the situation is more complicated. For the simple overheating hours above threshold in occupied zones (lounge and bedrooms), zoning simplification results in fewer large zones in the model, which help reduce the frequency that overheating happens. However, when the number of occupants in each zone is taken into account, the trend is reversed. Zoning simplification causes more persons suffer from overheating, compared to detailed zoning. Why this phenomenon should happen deserves further investigation. On the other hand, we have to admit that we have not found the most suitable metric for evaluating thermal comfort level in dwellings, as the ASHRAE 55 comfort standard calculated by EnergyPlus does not apply to domestic applications. Further research in this area is necessary.

Whether or not zoning simplification can be used depends on the applications. For stock modelling of heating and electricity consumptions in dwellings, simple steady-state models (such as BREDEM) are typically used. Steady-state models cannot be easily ported to different applications beyond their original purpose and modelling context. For example, they may not be suitable for analysing dwellings in a different climatic zone, or to incorporate a different assumption on occupants' behaviour. Dynamic models can reveal much more details of building performance than steady-state models. Such details will help designers and stakeholders alike understand better their buildings, and experiment in different scenarios, such as applying different retrofitting strategies and energy conservation measures, and investigating the impact of climate change.

Readers of this paper should note that in this study, "extreme" cases are used to contrast simplified zoning method against detailed zoning. For example, it is extremely rare in any residence that doors are kept shut all the time, therefore prevent air circulation between zones. If some amount of inter-zonal circulation is allowed, temperature distribution in the house will be more uniform compared to what the detailed models predict. This will consequently reduce overheating risk.

The second point readers should aware is that we do not assume that models with detailed zoning are closer representation of reality, in other words, more accurate than simplified zoning. In real world applications, uncertainty exists in internal layouts, occupancy schedules and other zone-specific inputs. Assumptions and guess works are common for filling in missing details. Unfortunately, we have not found any uncertainty analysis in this area from literature. As a result, whether or not 10% relative error is acceptable cannot be answered at this stage. Further research is required.

CONCLUSION

This paper analysed the impact of domestic house models simplification on annual heating demand, operational carbon emission and overheating risk in dwellings. Firstly, detailed models of five house designs were developed to form the base models in this study. Each functional space in these models was defined as an individual thermal zone with associated occupancy patterns, internal gains and control settings. Models were then simplified by treating each floor of a house as a single thermal zone, either lounge or bedroom. These two zone types were selected due to the occupants spend the most of their time in them.

Diversity of the domestic building stock was captured by varying a large set of parameters including the site, orientation, construction elements, activity levels, operational specifications, etc., to mention just a few. A random sample of 2,000 simulation scenarios was selected from the large simulation space ($\approx 6.94 \times 10^{12}$). Sampled cases were simulated with both detailed and simplified zoning in order to evaluate simulation outputs on a case by case basis.

The results were analysed using the descriptive statistics. Mean absolute relative errors between detailed zoning models and simplified zoning models are 8% for annual operational carbon emissions, 10.6% for annual heating demand and 15% for overheating risk. The collective overheating risk has a slightly larger mean absolute relative error which amounts 23.4%. Whether or not these relative errors are acceptable is debatable, the clear benefit of simplified zoning models, which is a reduced preparation and simulation time, should not be questionable. By simplify zoning, the simulation time decreases by 30% on average.

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