The Impact of Thermal Zone Resolution on the Energy Simulation Results of Complex Buildings

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Abstract

Strategic reduction of thermal zoning granularity in energy performance simulation may be advantageous in high-resolution queries involving large and complex-built objects in view of time and effort reduction potential. However, the proper choice of thermal zones' granularity is also dependent on the nature and purpose of performance queries. In this context, this paper explores the influence of the thermal zones' resolution on buildings' estimated heating and cooling loads. To this end, the illustrative instance of a multi-zone building is selected and made subject to varying levels of thermal zoning resolution.

1. Introduction and Background

Simulation of complex-built entities (e.g., large buildings with a multitude of differentially tempered zones, campuses, or entire urban neighbourhoods) requires considerable resources in terms of time, effort, and computing power. Hence, a number of past studies have explored various strategies to simplify or reduce the computational domain. However, the steadily increasing efficiency of computational algorithms and hardware means have been suggested to render such efforts less critical. Nonetheless, in certain instances, strategic reduction of the simulation models' complexity and the corresponding required computational resources may be useful, or even necessary.

This necessity seems less controversial in cases of vast simulation domains such as urban energy computing applications. Thereby, measures such as utilization of reduced models or the adaptation of the hour-glass methodology have been shown to have the potential to be effective (Ghiassi & Mahdavi, 2017). But reductive measures may be reasonable even in the less extensive case of complex multi-zonal building objects. Therefore, it is not only the spatial extension and complexity of the objects (size of the building, number of zones) that motivate reductive measures, but also the nature of more recent trends in simulating system dynamics and human behaviour (Malik et al., 2022). For instance, stochastic simulation routines and high-resolution agent-based modelling of occupants' movements and actions in buildings can result in a rapid increase of simulation models' complexity, which in turn leads to a surge of required computational load for data generation and processing.

Hence, strategic reduction of the simulation domain may be advantageous in simulation-based high-resolution queries that involve: *a)* large and complex built objects, *b)* multi-zonal thermodynamic processes, *c)* multiple dynamically operated control systems and devices, and *d)* complex patterns of occupants' presence, movement, and control actions.

A further reason to reflect on the granularity of simulation models relates to the fit-for-purpose discussion (Gaetani et al., 2023; Mahdavi & Tahmasebi, 2016). The idea is that the performance simulation strategies in general and the selected level of simulation model granularity in particular should take the nature and purpose of performance queries into consideration. Of relevance are here factors such as the stage of the design process (i.e., early versus late) and purpose of the query (e.g., demonstration of code compliance versus sizing of mechanical equipment for heating, cooling, and ventilation). Moreover, it has been also plausibly argued that the fidelity of simulation results does not necessarily improve in tandem with increased complexity and granularity of the simulation model. In fact, the relationship between detail level of

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simulation model input parameters and the uncertainty associated with simulation results is non-linear (Alonso, 1968; Magni et al., 2022).

In this context, the present contribution addresses one of the features of the simulation models of complex buildings that can influence the required time and effort for obtaining the target computational results. To this end, the focus is on the energy simulation domain and the influence of the thermal zones' resolution on the computed values of the building performance indicators, including those pertaining to buildings' heating and cooling loads.

The thermal zones in simulation models may have divergent thermally relevant characteristics, such as maintained ambient temperatures and illuminance levels, as well as occupancy-related assumptions (patterns of occupants' presence and behaviour in buildings).

To explore the implications of zonal resolution, the illustrative instance of a multi-zone building is selected and made subject to a full-domain and fairly detailed dynamic thermal simulation, thus establishing the benchmark case. Subsequently, multiple alternative models with varying levels of zonal fusion are generated and simulated. The process is repeated for multiple locations to obtain a first impression regarding potential dependencies of the results' variance on the external climatic conditions.

The results are compared to the benchmark using the respective values of the aforementioned performance indicators. Hence, the variation of obtained results can be studied, as smaller zonal units are successively fused into larger units.

The paper concludes with reflections on the degree to which the zoning granularity may be suggested to be worthy of critical consideration.

2. A Case Study

2.1 Overview

To explore the impact of thermal zoning granularity on the simulated values of typical energy performance indicators (i.e., heating and cooling loads), a generic office building was used as the case in point. Section 2.2. describes the building model (typical floor plan and basic construction properties). The examined zoning granularity levels are described in Section 2.3. Section 2.4. provides the details of the performed simulation runs.

2.2 The Building Model

Fig.1 shows the schematic illustration of the selected office building's regular plan. It consists of 16 double-occupancy office rooms, four central meeting and service rooms, as well as vertical (elevators, stairs) and horizonal (corridor) circulation areas.

The thermal transmittance of the building's external walls is assumed to be 0.3 $W.m^{-2}.K^{-1}$. Windows' thermal transmittance is assumed to be 1.0 $W.m^{-2}.K^{-1}$ and the window glazing is assumed to have a shading coefficient of 0.5.

The window to wall area ratio is assumed to be 40%. The air change rate in the office area during the occupancy hours is assumed to be 1 h^{-1}, otherwise 0.2 h^{-1}.

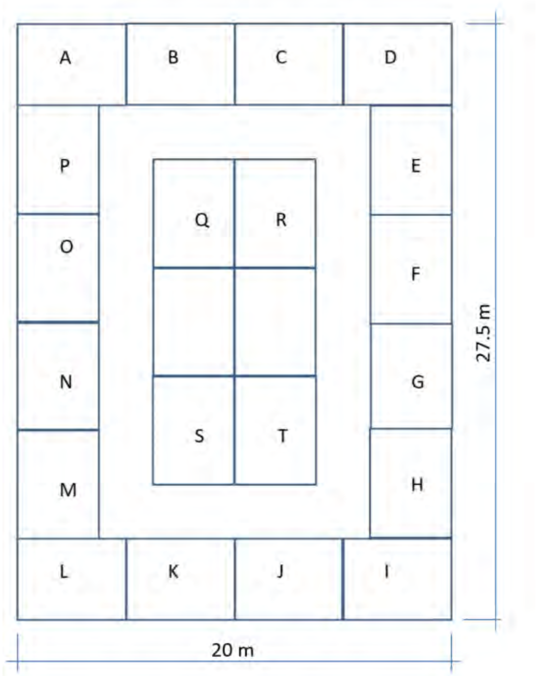

Fig. 1 – Schematic depiction of the regular plan of the selected office building

2.3 Four Levels of Zoning Granularity

Four thermal zoning schemes (labelled Z1 to Z4) are considered for the parametric simulation runs (see Table 1). In the case of the highest granularity (Z1), each of the 16 perimeter offices is assumed to have its own user-determined ambient temperature during the occupancy hours (ranging from 18 to 26°C). In the case of the next zoning scheme (Z2), adjacent offices were fused into one, resulting in a total of 8 office zones. The conditions in these zones (ambient temperature, reference task illuminance, air change rate, occupancy period) were assumed to represent the average values of the two zones they emerged from. This process was repeated in case of the zoning scheme Z3, resulting in four office zones. Finally, in the case of zoning scheme Z4, all office areas were fused into one uniformly conditioned zone.

Table 1 – Overview of the four thermal zoning schemes (Z1 to Z4) (see Fig. 1 for the room labels)

<table>
<tr><th>Z1</th><th>Z2</th><th>Z3</th><th>Z4</th></tr>
<tr><td>P</td><td rowspan="2">A + B</td><td rowspan="4">A + B + C + D</td><td rowspan="16">A + B + C + D
+
P + O + N + M
+
L + K + J + I
+
E + F + G + H</td></tr>
<tr><td>D</td></tr>
<tr><td>C</td><td rowspan="2">C + D</td></tr>
<tr><td>F</td></tr>
<tr><td>I</td><td rowspan="2">P + O</td><td rowspan="4">P + O + N + M</td></tr>
<tr><td>A</td></tr>
<tr><td>M</td><td rowspan="2">N + M</td></tr>
<tr><td>J</td></tr>
<tr><td>B</td><td rowspan="2">L + K</td><td rowspan="4">L + K + J + I</td></tr>
<tr><td>E</td></tr>
<tr><td>K</td><td rowspan="2">J + I</td></tr>
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<tr><td>H</td><td rowspan="2">G + H</td><td rowspan="4">E + F + G + H</td></tr>
<tr><td>O</td></tr>
<tr><td>L</td><td rowspan="2">E + F</td></tr>
<tr><td>N</td></tr>
<tr><td>R</td><td rowspan="2">Q + R</td><td rowspan="4">Q + R + S + T</td><td rowspan="4">Q + R + S + T</td></tr>
<tr><td>T</td></tr>
<tr><td>S</td><td rowspan="2">S + T</td></tr>
<tr><td>Q</td></tr>
</table>

2.4 Parametric Runs

Simulations were conducted for the aforementioned four zoning schemes. Three locations in Europe with different climatic conditions were considered as the site of the building. The motivation was to see if the impact of the zoning granularity is consistent across different climatic conditions. Toward this end, weather files for three cities were applied, namely Oslo (Norway), Vienna (Austria), and Palermo (Italy). Oslo and Palermo display rather high heating and cooling loads respectively, whereas Vienna has an intermediate position. Simulation results were expressed in terms of the values of annual heating and cooling loads.

3. Results and Discussion

Table 2 entails the numeric values of computed performance indicators (annual heating and cooling loads) for the four simulated thermal zoning schemes (Z1 to Z4) and the three locations.

To make the comparison of results for different zoning schemes easier, Table 3 includes the relative deviations of the results of the zoning schemes Z2, Z3, and Z4 from those of the zoning scheme Z1, which is used here as a kind of benchmark. As the values associated with zoning scheme Z1 are the highest in all cases, the values in Table 3 represent, in percentage, the underestimation of Z1 loads by zoning schemes 2 to 4.

The results, as summarized in Tables 2 and 3 warrant certain observations:

Computed values of performance indicators are different for different levels of resolutions. Specifically, the higher the resolution of the zoning scheme, the larger are the values of both heating and cooling loads.

Table 2 – Values of computed energy performance indicators (annual heating and cooling loads) for the four simulated thermal zoning schemes (Z1 to Z4) and the three locations

Indicator	Zoning	Vienna	Oslo	Palermo
Annual heating load [kWh.m^{-2}.a^{-1}]	Z1	75.0	108.6	22.0
	Z2	65.9	97.4	17.5
	Z3	62.2	92.3	16.3
	Z4	61.4	91.7	15.6
Annual cooling load [kWh.m^{-2}.a^{-1}]	Z1	24.0	9.2	77.0
	Z2	19.2	6.9	64.7
	Z3	17.4	6.2	61.0
	Z4	16.3	5.9	58.6

The magnitude of deviation that can be considered significant (or non-negligible) may be debatable.

But if one considers a threshold of 10% deviation as significant, then the results point to non-negligible degrees of deviation. One has to be of course careful when arguing based on relative deviation data, as respective percentages are typically higher for smaller absolute values of the commodity under consideration. For instance, in the present case, lower (i.e., 5 - 20), medium (i.e., 60 - 65), and higher (i.e., 90 - 95) absolute annual loads in $kWh.m^{-2}.a^{-1}$ correspond respectively to higher (i.e., 20 - 25), medium (i.e., 12 - 25), and lower (i.e., 10 - 15) relative deviations in percentage.

As the results in Tables 2 and 3 are purely simulation-based, it is not meaningful to evaluate them in terms of their "correctness" or accuracy. In fact, as it was alluded to before, higher zonal resolution is not necessarily constituent of more reliable predictions. However, this specific case study appears to suggest that the results obtained from a high-resolution zoning scheme are on the "safe side", as they are underestimated by the schemes of lower resolution.

There are multiple potential reasons and mechanisms responsible for the resolution-dependent discrepancies of the results. Despite the effort to normalize factors other than the zoning size, multiple details of the simulation models do inadvertently differ. In fact, it is difficult to preserve certain zone properties in the course of zonal fusion, including, for instance, the thermal mass effects of the partition elements between the zones as well as the schedule-dependent thermal loads associated with internal gains and ventilation loads.

Table 3 – Relative deviation (in %) of the computed energy performance indicators (annual heating and cooling loads) of zoning schemes Z2 to Z4 from the respective results of zoning schemes Z1 for the three locations

Indicator	**Zoning**	**Vienna**	**Oslo**	**Palermo**
Annual heating load	Z2	12	10	20
	Z3	17	15	26
	Z4	18	16	29
Annual cooling load	Z2	20	25	12
	Z3	27	33	21
	Z4	32	36	24

Nonetheless, the consistency of the observed tendency in the present study points to one potentially responsible factor for at least part of the observed deviations: Assignment of a thermal node in a numeric simulation model to a larger zone implies a within-zone thermal balance, hence effectively covering part of the required heating or cooling load provision. This masking effect yields seemingly lower load, which would not result in models with higher zonal resolution.

4. Conclusion

The investigation presented in this paper was motivated by the potential implications of the strategic reduction of thermal zoning granularity in energy performance simulation, particularly in case of large and complex buildings. Decisions on zoning resolution could be ostensibly informed by considerations related to both *i)* the efficiency and effectiveness of the simulation process and *ii)* the nature and purpose of performance queries.

To illustrate this matter, the influence of the thermal zones' resolution on the computed heating and cooling loads of an office building was studied via parametric simulation. The results point to non-negligible effects of the resolution of the building's thermal zones on computed annual heating and cooling loads.

The loads displayed, independent of the climatic context considered, higher values for simulation models with higher zonal granularity. Whereas this finding does not necessarily imply that higher zonal resolution translates into higher reliability, it does suggest that results obtained through such high-resolution models may be on the conservative side. Representing large thermal zones through single nodes in the numeric simulation increases the tendency toward within-zone thermal balance, thus resulting in lower estimation of required heating and cooling loads.

Future studies need to further examine and validate these results through consideration of a larger number and more detailed building models with regard to building typologies, environmental control systems, operation regimes, and contextual parameters. Likewise, a more comprehensive set of thermally relevant building performance measures must be taken into consideration, including energy use estimates and thermal state indicators relevant to passive mode of building operation. Moreover, studies of thermal zoning resolution and its implications for the building simulation results must take applicable practical considerations into account, including the orientation of building and the type and operation methods of the building's designated building systems. Finally, investigations of the kind presented in this paper have the potential to inform ongoing and future developments toward the automated generation of thermal zone configuration and the selection and sizing of environmental control systems and components.

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