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Model simplification of geometry and facilities, for energy and indoor environment towards more reliable energy labelling

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Abstract. Reliable building energy and indoor climate performance assessment require adequate and often time-consuming modelling. Currently, energy performance certification (EPC) is carried out in Member States (MS) using simple steady-state tools. These tools simplify not only building geometry but also HVAC systems, boundary conditions, and building loads. These simplifications can cause the so-called "performance gap", which is the difference between modelled prediction and actual operation. This creates a lack of trust in the EPCs and scepticism. This paper is scouting toward shifting to dynamic models of different detail levels, considering the zoning, heating and ventilation facilitie's complexity. In the scope of this dynamic thermal simulation study, a residential multi-apartment building located in Denmark is investigated. The thermal zone simplification has 5 levels of complexity, from modelling each room as a thermal zone to the whole staircase as one thermal zone. The heating system was modelled as: i) ideal loads, ii) electrical radiators, iii) water radiators. Ventilation was modelled as i) zone ventilation, and ii) airflow network. Modelling results are evaluated for heat demand, thermal and atmospheric comfort.

1. Introduction

For the last 20 years, energy performance certificates (EPCs) have proven their place for labelling energy performance of buildings. Still, there is significant scepticism about the reliability of their results which is often questioned in numerous publications [1-3]. Today's major challenges are related to the inability of steady-state EPCs to capture the dynamic conditions of building operation, mainly because tools are based on steady-state, often monthly, calculations. One could claim that labelling purpose is primarily to compare energy performance between buildings and therefore boundary conditions and simulations could be simplified. On the other hand, even if labelling is about the comparison of buildings, still it is valid whether comparison should be based on more realistic assumptions and by using methods that in a better manner could capture dynamic building nature. Moreover, labelling responsibility is also to provide renovation recommendations. It is claimed in [4] that simplified methods could provide false expectations from the renovation actions and therefore contribute to the growing mistrust in the labelling scheme.

Shifting from steady-state modelling to dynamic is not consequences-free. More detailed modelling requires more resources, not only to develop models but also to analyse data, and therefore could cause an additional financial burden for the building owner. It is, therefore, necessary to investigate the consequences of model simplification, both concerning zoning, system modelling and required evaluation results; energy and indoor climate.

The ground for the shifting from steady-state to dynamic modelling is already laid in the set of EN ISO 52000 standard family that received a mandate M/480 [5] from European Commission to support updated Energy Performance of Building Directive (EPBD) EPBD:2018 [6]. The family of EPB standards is well described in [7] in which authors explained EN ISO 52000 holistic approach that addresses all types of energy use in buildings, outdoor boundary conditions, indoor climate requirements and the dynamic interplay and complexity of these all aspects. What is more, [7] highlights the need for dynamic calculations to be able to properly quantify the energy performance of buildings and building systems (solar blinds, thermostats, needs, occupation, accumulation, mechanical ventilation, night-time free-cooling-ventilation, weekend operation, heat pump, solar panels) which all dynamically interplay with the outdoor condition. Among five primary EPB standards, special attention and relevance to the work presented in this paper should be paid to EN ISO 52016-1. In EN ISO 52016-1 can be found, among others, a general description of the hourly calculation method, input lists for geometry, thermal properties of building and elements, condition of use of technical building systems, climatic input data, and internal gains.

Building geometry modelling is a topic that has been studied and presented in several publications. As stated in [8], three common simplifications can be identified: i) modelling a typical floor and multiplying the calculated load by the number of floors, ii) simplification of fenestration (many windows into one), iii) reduction of thermal zones and building internal thermal mass. For instance, predictions based on detailed models (every room as a zone) were compared to those from simplified models (each floor as a single zone) for five types of UK residential buildings by [9] resulted in a mean absolute average error of 10.6% for annual heating demand and 8.6 % for CO2 total emission while simulation computing cost was reduced by 30% on average. The authors concluded that the impact of model simplification was low on heating demand and CO2 emission outcomes. The overheating issue was discovered more complicated, and the issue was highlighted for further research. Picco and Mareno in [10] assessed different simplifications of model construction, among others zoning and building obstructions. Strong simplifications did not significantly influence the results. Another study presented in [11] for residential buildings in UK considered the simplification of thermal zones reduction to one per floor and one per entire house. The annual heating demand was underestimated by 17% and 26% respectively. In [12] authors studied the consequences of model simplification, such as the reduction of thermal zones, internal walls, and shading removal. Results showed that shading exclusion in south-facing zones must not be carried out due to significant output influence. There exist more studies with similar scope of the investigation and valuable results, but the shortcoming is that they focus on model geometry simplification in energy simulation. As stated in [13] impact of modelling simplification on thermal comfort and indoor environment is usually not investigated. The other shortcoming is that majority of studies focus on geometrical model simplification but overlook the modelling of HVAC. This study contributes to the lack of studies on both zoning and system modelling together and studies on energy and the indoor environment (thermal and atmospheric).

2. Method

This section presents the studied case building and elaborates on the model's development carried out in Energy Plus software. Five zoning complexity levels are created and 3 models for each heating and ventilation facility are considered, See Fig. 1 and Table 1.

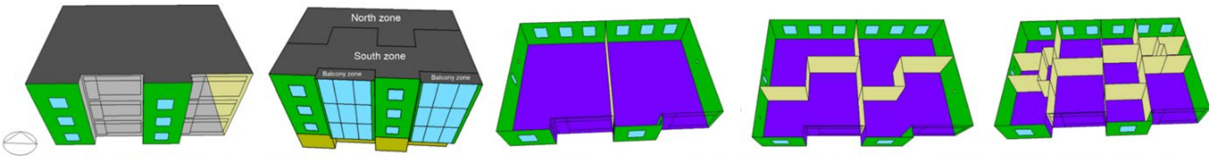
2.1. Building properties

The studied case building is a three-storey residential building which is located in Aalborg, Denmark. It was built in 1964 and partly renovated in 2012. The analysis considers one staircase with a total of 6 apartments. The major orientation of the building is north/south. The building is not influenced by the shadow of other buildings. The building is heated by district heating by radiators and is naturally ventilated. The developed models follow EN ISO 52016, namely, envelope elements contain individual information about their U-values, size, orientation and thermal mass.

2.2. Models geometry, facilities and other required input data

The process of the definition of thermal zones in dynamic models represents new complexity that is often not present in monthly calculation methods. This study considers building geometry in five different levels of zoning complexity as presented in Fig 1. In the simplification process, internal partition walls are simplified, and all the internal partitions are added as additional thermal mass.

The building has an unconditioned underground basement, which is simulated as a building component for heat transfer calculation and is separated from building zones. The balcony and staircase are not conditioned and thus are also separated from building zones. The west, north, and south façades are external walls and are exposed to sun and wind. The east façade is made of internal walls adjacent to another staircase.



Level 1. One zone per staircase **Level 2. Two zones per staircase.** **Level 3. One zone per apartment.** **Level 4. Two zones per apartment.** **Level 5. One zone per room.**

Figure 1. Model zoning levels.

The ventilation airflow rate is 30 m^3/h/person according to standard DS/EN 16798-1:2019. The ventilation system is modeled in two different ways, see Table 1; 1. as Zone Ventilation, which is the purposeful flow of air from the outdoor environment directly into a thermal zone in order to provide some amount of non-mechanical cooling. This ventilation is intended to model “simple” ventilation as opposed to the more detailed ventilation investigations that can be performed with the Airflow Network model [14], 2. As Airflow Network model in combination with exhaust fan ventilation, which is a more detailed ventilation system defining the airflow between zones and airflow due to natural ventilation (e.g., open windows) or mechanically-induced ventilation (e.g., exhaust air fans).

The heating system is modeled in 3 different ways, see Table 1; 1. as Ideal Loads HVAC system, which is used to calculate loads without modelling a full HVAC system. It can be thought of as an ideal unit that mixes zone air with the specified amount of outdoor air and then adds or removes heat and moisture at 100% efficiency to meet the specified set points. 2. as Electric Radiators, which define electric baseboard heaters. Radiant heat is calculated by the user-defined fraction from the heating capacity of a baseboard unit. The remaining convective gains from the unit are evenly spread throughout the space thus having an immediate impact on the zone air heat balance which is used to calculate the mean air temperature within the space, 3. District heating and water radiators, which provides heating to the zone by water radiator with a radiation factor of 0.3 to the internal surfaces. In addition, it accounts for the pipe model with transport delay. In this simulation, the pipes are set as adiabatic. Heat is transferred from the water inside the pipe, through the tube and fins. Heat is transferred from the radiator by convection to the surrounding air and radiation to the surfaces and people within the zone.

Regarding required input data, for example, condition of use, scheduling, accessibility of hourly weather conditions, the detailed construction of building models together with the decision about the definition of models to simulate facilities reflect a significant additional effort that is not present in monthly calculations. The operation time, set points, internal loads and schedules are taken from DS EN 16798-1, including the occupants, appliances, and lighting.

Table 1. Models complexity, zoning and facilities

	Complexity level	Description/comments
Facility 1	1	Zone Ventilation
Ventilation	2	Airflow Network
Facility 2	1	Ideal Loads HVAC system
(Heating)	2	Electric Radiators
	3	District heating and water radiators
Zoning	1	One zone per staircase
	2	Two zones per staircase (south and north)
	3	One zone per apartment
	4	Two zones per apartment (south and north)
	5	One room as a zone

The model naming method is following, X-Y-ZoningZ, where X is ventilation, Y is heating and Z is zoning complexity level as in Table 1.

3. Results

Due to the space limitation of this paper, only the selected results are presented. Fig. 2 (left) shows the monthly aggregated heating demand of all the combination of the complexity of modelling ventilation and heating facilities and zoning while in Fig. 2 (right) charts present the same results but from a statistical perspective (mean, median, minimum, maximum, 75 and 25 percentile).

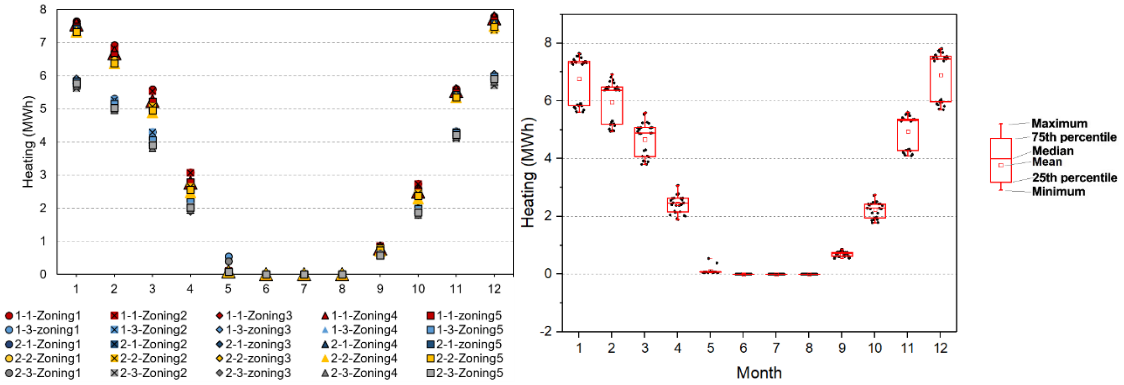


Figure 2. (left) The monthly space heating demand for different model complexity combinations, (right) the standard deviation of monthly heating demand of all model combination complexity, black dots represent each model results of modelled heating demand.

Fig. 3 shows the comfort, thermal and atmospheric, during the heating season and non-heating season evaluated as a number of hours within a specific comfort category within each month. Predicted mean vote PMV, is calculated according to ISO7730 and used to evaluate thermal comfort for the heating season and adapted comfort classes (CEN_cat1-CEN_cat3), according to ISO EN 16798 is used for the non-heating season as the building has no mechanical cooling. Moreover, evaluation includes the number of hours with overventilation ($CO2<600$ ppm) and underventilation ($CO2>900$ ppm) and hours above 26 °C (H26). In Fig. 3 PMV_out means outside PMV category 1-3 and CEN_out means hours outside CEN categories 1-3.

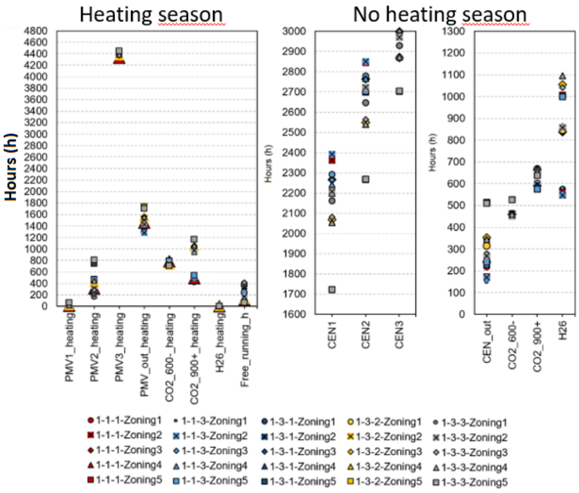


Figure 3. Comfort, thermal and atmospheric, (left) for heating season using PMV, CO2<600 ppm and CO2>900 ppm, H>26 hours above 26 degC, and (middle & right) for non-heating season using adaptive comfort classes I-III, CO2<600 ppm and CO2>900 ppm.

4. Conclusion

This modelling study indicates that zoning, detailed or simple, has an insignificant impact on calculated space heating demand. The relative differences between the results for different zoning of the model are rather small. The average deviation of the 5 zoning methods is 2.08% for heating demand. It is important to note that the "dynamic loads" in the models are defined identically for all the zones and the set-point temperature in thermal zones was defined according to ISO16798-1. Therefore, these modelling assumptions have already a limited influence on the impact of geometry on heating demand outcomes. If the "dynamics" of the building were properly introduced in the modelled thermal zones, then different results could be expected. This discussion adds to the need of moving from "standard" boundary conditions used in EPC to more realistic, operational ones. Still, it can be concluded that model zoning simplification might be a valid strategy to ease dynamic modelling. Moreover, to perform an operational assessment that would be compatible with modelling studies, the space heating measurement, should be preferably monitored at the apartment level and if that is not possible then at the staircase level and supplemented by detailed temperature measurements from the apartments to better understand the reasons behind the potential performance gap. The authors wish to highlight that conclusions are valid for the studied building typology, its climatic location – heating dominated climate, and when the primary focus is on space heating energy use.

The observed deviations in results are mainly caused by the additional loss accounted by the detailed modelling of the systems and the modified perception of thermal comfort for the occupants, particularly regarding the radiative/convective share of the heat load from the radiators in the thermal zones.

Moreover, results indicate that the heating and ventilation facility modelling methods have a more significant influence on the heating demand evaluation. The standard deviation for zoning levels 1 to 5 for all the considered combinations of facility modelling is 26.29%.

A thermal comfort study is also performed outside the heating season when the case building is in free operation mode. The thermal comfort is sensitive to both the zoning method and the ventilation model. With the detailed ventilation model (airflow network), the deviation of thermal comfort among different zoning methods is even bigger. In general, the detailed ventilation model results in lower thermal comfort. For air quality, the zoning method seems less important, while the ventilation model only affects underventilation, and the detailed ventilation model results in higher underventilation.

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