# Impact of zoning strategies for building performance simulation

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**Abstract.** Building performance simulation (BPS) can provide detailed information on the thermal behaviour of buildings. Zoning is a key step in input data preparation for BPS. A simulation zone is typically composed of one or more rooms. Large spaces, such as open office spaces, may have multiple zones. Simulation zoning can be distinguished from HVAC zoning, which is a property of the HVAC system. An appropriate simulation zoning may depend on the simulation problem, and results from a trade-off between accuracy and simplicity. In current simulation practice, zoning is usually carried out based on the user's experience. This does not ensure consistency across modelled buildings and practitioners. This paper demonstrates how systematic bottom-up strategies can be applied to aggregate rooms into simulation zones. The impact of such strategies is investigated by applying them to several floors of residential buildings. Building performance simulation is carried out with either conceptual or detailed HVAC modeling. In the second case, variations in both simulation zoning and HVAC zoning are investigated. Simulation results are compared to those obtained with detailed one-zone-per-room models, to assess the deviations due to simulation zoning. A coarser simulation zoning is shown to cause significant deviations in certain cases. A fine simulation zoning may allow control inefficiencies due to coarse HVAC zoning to be quantified.

## 1. Introduction

Building performance simulation (BPS) can provide quantitative information on the processes that determine the energy consumption of buildings, notably in terms of heating, ventilation and air-conditioning (HVAC). The zone is a core concept in current BPS tools, and a central entity in their input models. Simulation zones determine the spatial discretization of the building model. Heat and mass balance is calculated for each zone. It is assumed that the air in a zone is perfectly mixed. As a consequence, heat transfer and storage surfaces, internal gains and air exchange rates are defined at the zone level (US DOE 2010). Outputs of simulated internal conditions also refer to zones. Geometrically, a zone is enclosed by a set of flat polygonal surfaces. One-dimensional heat conduction is calculated between the zone-facing side and the other side of these surfaces (Crawley et al. 2001). This other side may correspond to another zone, outdoor or ground conditions. Alternatively, it is sometimes assumed that there is no heat transfer across a boundary (adiabatic boundary), which allows the model to be simplified.

This papers deals with the impact of zoning strategies on BPS with either conceptual or detailed HVAC modeling. Zones, like rooms, are special cases of spaces. A space can be defined as a materially or theoretically bounded volume accommodating certain functions (Ekholm & Fridqvist, 2000). A room is a space which is typically enclosed by walls, floors, and ceilings. In the thermal domain, a zone is an aggregation of rooms related to a given purpose. We distinguish zones used in simulation from the zones defined in the context of HVAC systems. In the following, we refer to the former as simulation zones and to the latter as HVAC zones.

An HVAC zone, like a simulation zone, usually corresponds to a room or collection of rooms with common thermal characteristics, but it is defined in the context of HVAC design and operation, independently from simulation. ASHRAE (2013) defines an HVAC zone as a "space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat).” Others tend to define HVAC zoning on the basis of the actuator. For air-based systems, Platt et al. (2010) define an HVAC zone as a group of adjacent spaces “serviced by a common air-handling unit (AHU) or air-terminal device”. This definition leads to differences in meaning for various kinds of systems. Our distinction of HVAC zone and simulation zone broadly concurs with the ASHRAE (2013) distinction of HVAC zone and thermal block. The latter is “a collection of one or more HVAC zones grouped together for simulation purposes”.

The modeling of HVAC systems in BPS may take place at different levels of abstraction, which can be summarized as conceptual modeling, system-based modeling, component-based modeling and equation-based modeling (Trčka and Hensen 2010). The increasing level of detail of these approaches makes greater accuracy possible, while complicating input data preparation. Within a component-based model, each component may be assigned to a simulation zone, and their thermal interaction simulated.

When determining simulation zones, one faces a trade-off between the accuracy of the model on the one hand, and its size on the other hand. The drawbacks of a high number of zones include greater computation intensiveness, as well as difficulties in creating, checking and modifying models, and interpreting simulation results. From a simulation accuracy perspective, two extreme approaches are, respectively, to consider each room (or even room sections) as separate zones, and to consider the whole building as a single zone. It may often be the case that neither is appropriate. While zoning is often left to the intuition and experience of simulation users, simulation zones could also be consistently derived from the grouping of spaces according to well-defined criteria. This paper aims at demonstrating this possibility, and determining which attributes and rules can yield effective simulation zonings. To this aim, a systematic study for multiple floor plans is proposed, including simulation experiments with known as well as unknown HVAC zoning.

## 2. Related work

The issue of building zoning for simulation has been addressed in various contexts, varying with the degree of definition of interior spaces. If interior spaces are not defined, as might be the case in conceptual building design, internal load properties cannot be considered. However, the building geometry may be discretized to account for differences in solar gains. ASHRAE (2013) recommends to divide floors into a core region and a perimeter region, and to subdivide the latter according to space orientation. Based on this recommendation, Dogan, Reinhart and Michalatos (2015) presented an algorithm to zone building massing models automatically.

If interior spaces are defined, a detailed building model can be created with one zone per room, and results of a simulation run with this model may allow zones to be grouped together based on their simulated behavior. Such an approach was followed by Georgescu, Eisenhower and Mezić (2012), as well as Giannakis (2015). With known interior spaces, thermal zones may also be determined without previous simulation run. In the context of a simulation project involving thousands of buildings, Ramirez et al. (2005) gave modelers the choice between three zoning schemes: one-zone-per-floor, perimeter/core and one-zone-per-activity-area. The last zoning was particularly recommended for restaurants, to account for differences between kitchen and dining areas. Looking at the influence of zoning on annual energy demand, Rivalin et al. (2014) concluded on the acceptability of large simplifications, including the grouping of rooms on different floors. For buildings with repeating floors, zone multipliers may also be used. Their use for the simulation of a high-rise building was shown to introduce very little error in annual cooling and heating energy (Ellis and Torcellini, 2005). The consideration of other performance indicators can lead to other conclusions. In a study of the performance of an office under climate change, De Wilde & Tian (2010) suggested that zonal resolution may significantly impact the predicted overheating risk, with coarser zoning likely to lead to an underestimation of this risk. Systematic studies investigating the influence of simulation zoning schemes in multiple buildings with defined interior spaces are not known to the authors.

## 3. Objectives and methodology

The objectives of the paper are to apply and extend an existing zoning method to simulation, and to evaluate this method in the context of automated BPS input preparation. This evaluation is to take place for two main cases, respectively with unknown and known HVAC zoning. In both cases, the deviations due to simulation zoning are evaluated, by comparing to results obtained with a detailed one-zone-per-room zoning.

In the first case, the zoning method is applied to a simulation of a building with unknown HVAC zoning. In this setting, simulation is carried out with an ideal HVAC system model, so that HVAC zoning is not taken into account, and no detailed HVAC model is used.

In the second case, the zoning method is applied to the simulation of a building with known HVAC zoning. In this case, we carry out detailed HVAC simulation with a component-based model, for the case of hydronic heating systems. This component-based model is derived from the zoned building model with the help of an automated method (Bres et al. 2017). While a simple decision in this case would be to use the HVAC zoning as simulation zoning, we investigate the impact of using a simulation zoning differing from the HVAC zoning.

## 4. Zoning method

Zones are generated based on a space aggregation operation that has been defined for a space modeling system (Suter 2013). A space model in this system consists of space layouts which model multiple views, such as architectural or pedestrian circulation views. Spatial relations between spaces and space elements (e.g. windows or walls) in a layout form a geometric network. In the space aggregation operation, spaces are merged based on their properties and connectivity (Suter et al. 2014). Space geometries are modeled as solids. Geometries of merged spaces are obtained by the solid union of original space geometries. Spatial inconsistencies due to operation processing are automatically detected and resolved. In case of space aggregation, doors and walls that separate merged spaces may not be included in the result layout.

The aggregation operation is used to define four simulation zone views that are derived from an architectural view (Table 1). All views are derived by merging spaces (rooms) in the architectural view based on the space adjacency relation. Different space properties are considered to group spaces in the architectural view. In the perimeter/core zone view, spaces are grouped if they are perimeter or core spaces (Suter 2015). External spaces are modeled explicitly in the space modeling system. A perimeter space is adjacent to at least one external space, whereas a core space is not. Core spaces are typically less exposed to solar radiation than perimeter spaces. In the functional zone view, spaces in the architectural view must be part of the same functional group (Suter 2015). Spaces belong to a functional group if they have the same primary space property, or if they share certain secondary space properties. For example, bathrooms and storage rooms belong to the group of service spaces. Similarly, there are groups for primary and secondary circulation spaces. Primary circulation spaces include publicly accessible stair cases and elevators. Secondary circulation spaces include hallways in spatial units with restricted access.

Table 1: Zoning schemes.

| Scheme Id | Description |
|---|---|
| PZ | Perimeter/core |
| FZ | Functional zones |
| OZ | Orientation zones |
| OFZ | Orientation and functional zones |

The orientation zone view is generated based on the orientation of internal spaces relative to external spaces. Space orientation is determined in three steps. First, a convex decomposition of external spaces in the architectural view is performed. This accounts for changes in building orientation, e.g. at corners where facades meet. Second, connectivity of internal spaces with external spaces through transparent openings (such as windows) is determined. Spaces that are related to the same external spaces have the same orientation. Core spaces are not oriented to any external space. Third, connected spaces with the same orientation are merged.

The functional and orientation zone view is a combination of functional and orientation zone views. Conceptually, connected spaces in the architectural view that belong to the same functional group and have the same orientation are merged.

## 5. Simulation experiments

### 5.1 Overview

The zoning method is applied to multiple building floors, chosen to represent a variety of floor plan types possible in apartment buildings and summarized in Table 2.

Table 2: Buildings floors for case study.

| **Id** | D1989 | M1951 | K2010 | J1972A2 | J1972A5 |
|---|---|---|---|---|---|
| **Location** | Amsterdam, Netherlands | Chicago, USA | Chicago, USA | Stuttgart, Germany | Stuttgart, Germany |
| **Building year** | 1989 | 1951 | 2010 | 1972 | 1972 |
| **Architects** | Duinker, van der Torre | Mies van der Rohe | Krueck and Sexton | Jäger, Müller, Wirth | Jäger, Müller, Wirth |
| **Gross floor area ($m^2$)** | 321 | 649 | 650 | 340 | 398 |
| **Number of rooms** | 36 | 38 | 35 | 27 | 32 |

The corresponding apartment buildings were all built in heating-dominated climates. One representative floor per building is simulated, or two for the residential complex in Stuttgart. D1989 and M1951 represent the same building, before and after a renovation that changed the interior structure. Default constructions corresponding to the buildings' years of constructions are assumed. Weather data files for the respective locations are used. Internal loads and schedules follow the Swiss data sheet SIA Merkblatt 2024, which provides detailed schedules for bedrooms/living rooms, kitchens and bathrooms. This results in the creation of input building models for the BPS engines (Crawley et al. 2001) EnergyPlus and TRNSYS (Klein & Beckman 1976).

Table 3: Differentiation of internal loads and set points by space use.

| **Parameter** | **unit** | **Residential** | **Bathroom** | **Kitchen** | **Circulation** | **Duct** |
|---|---|---|---|---|---|---|
| Heating set point | °C | 21 | 24 | 20 | 18 | - |
| Area per person | m²/person | 50 | 5 | 5 | 100 | - |
| Heat gains from light and equipment | W/m² | 11 | 13 | 57 | 6 | 0 |

### 5.2 Experiments with unknown HVAC zoning

Simulation experiments are carried out to investigate the impact of the presented zoning strategies. Simulation models obtained from the application of the presented zoning strategies to the selected building floors are simulated with ideal HVAC system representation. Results are ideal loads, which represent the exact energy rate to be delivered in each zone by an HVAC system for set point conditions to be maintained.

We compare three different approaches to internal loads, summarized in Table 4. With interpolated internal loads, the sums of internal loads are preserved. The majority approach is simpler to implement, and probably more representative of actual practice.

Table 4: Internal load variations.

| **Id** | **Description** |
|---|---|
| Uniform | Same internal loads in all zones. |
| Majority | Internal loads corresponding to space use with largest area in aggregated rooms. |
| Interpolated | Internal loads interpolated (area-weighted) from aggregated rooms. |

### 5.3 Experiments with known HVAC zoning

With a more detailed HVAC model, it is attempted to question the relation between simulation zoning and HVAC zoning. This second group of simulation experiments is carried out only with interpolated internal loads. Variations of both HVAC zoning and simulation zoning are simulated, as illustrated in Table 6.

Table 6: Simulated variations in thermal zoning and HVAC zoning. Each cell represents a simulation case, and cell color describes the relation between simulation and HVAC zoning. Identical zoning in green cells. Simulation coarser than HVAC zoning in blue if allowed by ASHRAE, otherwise in orange. Simulation zoning finer than HVAC zoning in yellow.

Compare to evaluate simulation zoning error

| HVAC zoning \ Simulation zoning | RZ | OFZ | FZ |
|---|---|---|---|
| **RZ** | RZ-RZ | RZ-OFZ | RZ-FZ |
| **OFZ** | OFZ-RZ | OFZ-OFZ | OFZ-FZ |
| **FZ** | FZ-RZ | FZ-OFZ | FZ-FZ |

Compare to evaluate control inefficiencies

The described zoning method is used to generate HVAC and simulation zonings. In the three considered HVAC zonings, only rooms with the same function, and hence the same set point temperature, are grouped together. For a given HVAC zoning of the modeled system, the simulation zoning may be equal to the HVAC zoning (green cells in Table 6). According to ASHRAE (2013), a simulation zoning coarser than HVAC zoning would only be acceptable if aggregated “HVAC zones have the same space use and orientation” (blue cell). On the other hand, a simulation zoning finer than the HVAC zoning (yellow cells) can be assumed to give more accurate results. In particular, it may allow the control inefficiencies deriving from a coarse HVAC zoning, i.e. local overheating or underheating, to be quantified. This cannot be simulated in EnergyPlus, where the simulation of air temperature and heat demand takes place at the same zone level. Thus, we resort to co-simulation for the simulation experiments in this section, with HVAC system simulation in TRNSYS. Air temperatures for each simulation zone are passed from EnergyPlus to TRNSYS, and heat delivered by each component is passed from TRNSYS to EnergyPlus. In terms of simulation, HVAC zoning is reflected only in TRNSYS, by modifying the temperature sensors controlling heat delivery in the HVAC control model. Temperature sensors in simulation zones corresponding to the same HVAC zone are replaced by a single temperature sensor. We assume this temperature sensor to be placed in the largest simulation zone of the HVAC zone.

## 6. Results

The results of the presented zoning schemes are examined in terms of their static structure and of the corresponding simulation results. In order to quantify deviations resulting from space lumping, we use the mean bias error MBE and the coefficient of variation of the mean square error CV(RMSE) (Equation 1), frequently applied to BPS calibration (Coakley et al. 2014). In all cases, the reference value is that obtained with the architectural view, i.e. with one zone per room. No particularly large or high room in the considered floor plans makes it necessary to further refine this most detailed simulation zoning.

$$MBE(\%) = \frac{\sum_{i=1}^{n} x_i - x_{Ref,i}}{\sum_{i=1}^{n} x_{Ref,i}} \qquad CV(RMSE)(\%) = \frac{1}{\sum_{i=1}^{n} x_{Ref,i}} \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - x_{Ref,i})^2} \tag{1}$$

### 6.1 Zone properties

We define the zoning factor as the number of rooms in the architectural view divided by the number of zones in the zoning view. The zoning factor indicates how many rooms in average a given zoning scheme aggregates into a single zone. As can be seen in Figure 2, the perimeter core zoning scheme tends to yield the highest zoning factors.

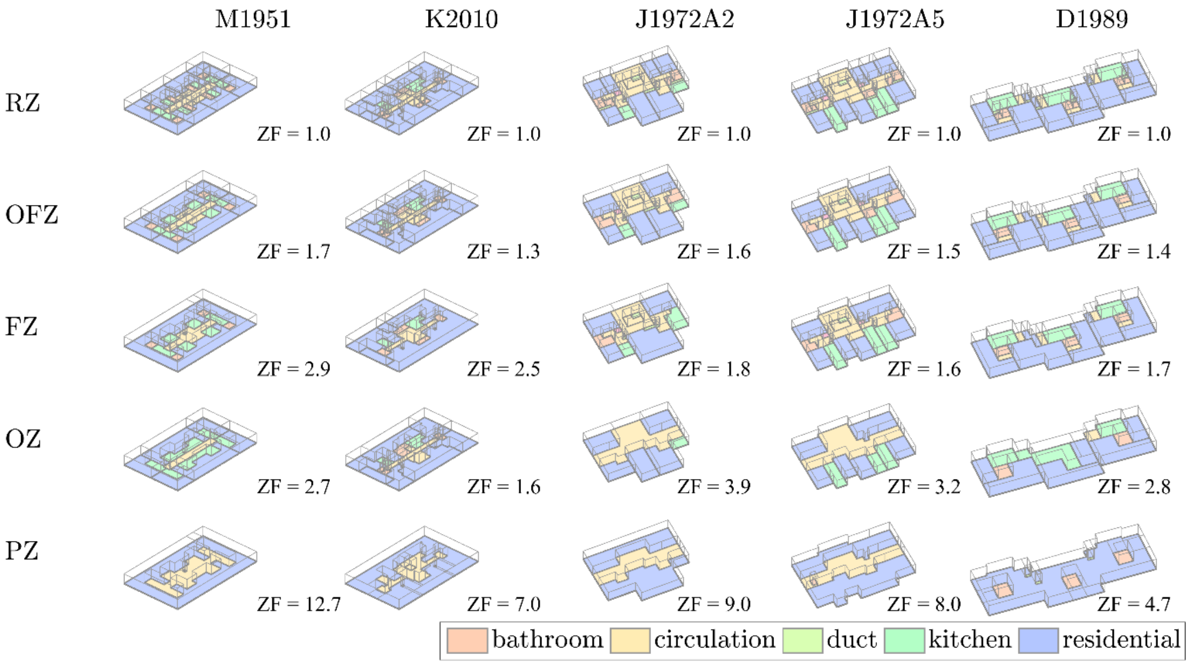


Figure 2: Resulting layouts for the selected floor models and zoning schemes, with the corresponding zoning factors (ZF).

### 6.2 Results with unknown HVAC zoning

Heating loads for a one-month simulation period in the peak heating month January are compared. As seen in Figure 3, the impact of the zoning schemes on heat load results can vary significantly for different floor plans. Only OFZ yields consistently lower deviations as the other zoning schemes. Also, results strongly depend on the way internal loads are treated. Uniform space uses result in the lowest zoning errors, especially for the orientation-conscious zoning. Indeed, zoning deviations with uniform internal loads are dominated by thermal interaction with the exterior. Also, uniform internal loads mostly lead to negative MBE values. These correspond to underestimating the heating load by having loads in spaces with different orientations compensate. On the contrary, with non-uniform internal loads, the bias can be positive as well as negative, as deviations due to internal loads are introduced.

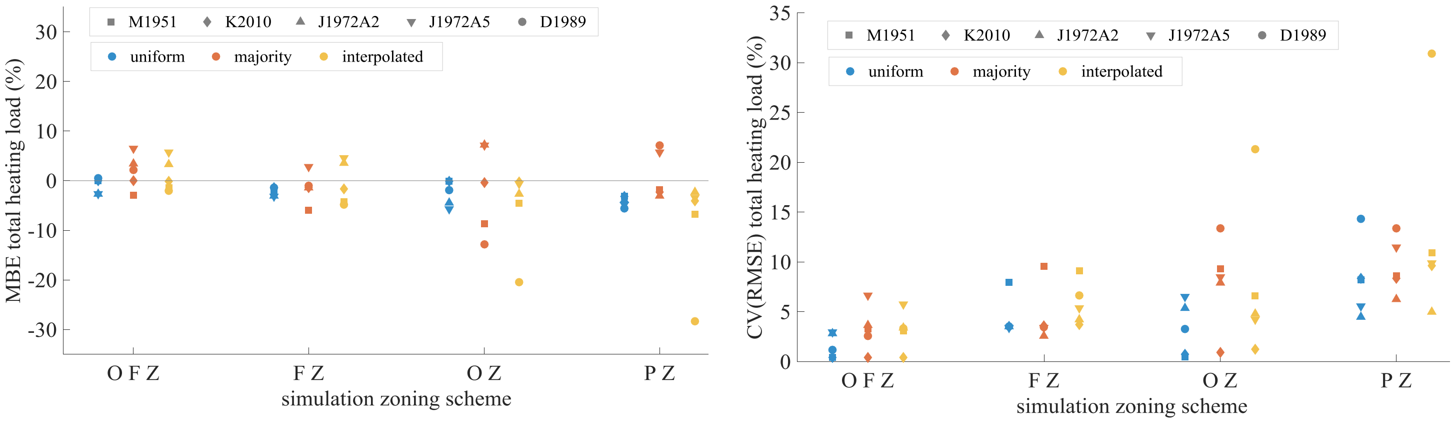


Figure 3: Error in total building heating load for buildings floors, zoning schemes and internal load variations relative to room-based zoning (RZ). Marker shapes represent building floors, and colors stand for internal load variations, as described in Table 4.

Interpolating internal loads from original rooms often yields lower errors than just deriving internal loads from the dominant space use. Sometimes it does not, as the deviations introduced by majority use internal loads may offset other deviations caused by lumping. This is especially the case with building D1989, which represents an outlier with the highest errors. Indeed, we can see that the majority approach for internal loads introduces a positive bias which compensates the exterior-dominated deviation assessed with uniform internal loads, whereas such compensation does not happen with the interpolated approach.

### 6.3 Results with known HVAC zoning

For the experiments with known HVAC zoning, heating control is not ideal, and temperatures can deviate from set point. The proportion of room temperatures below set point is shown in Figure 4. This indicator of underheating consistently increases with coarser HVAC zonings. The results with RZ simulation zoning, on the left third, are assumed to be the most accurate. Accordingly, the coarsest HVAC zoning, FZ, leads to unacceptably high proportions of underheating, particularly for the two Chicago floor plans. This can be detected with RZ or OFZ simulation zoning, but not when simulation zoning is as coarse as HVAC zoning.

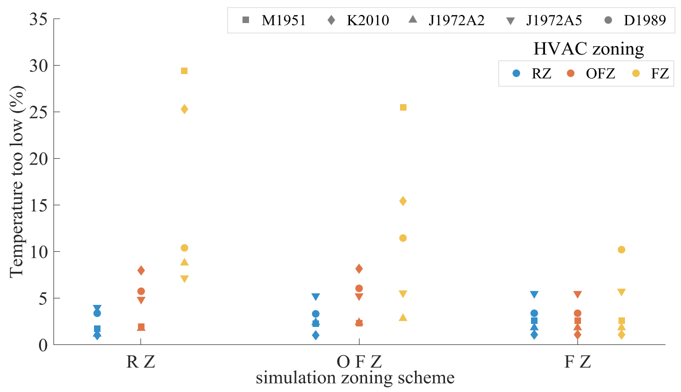


Figure 4: Proportion of time (during the simulation period January) and floor area in which simulated temperatures are lower than set point. Colors stand for HVAC zoning schemes.

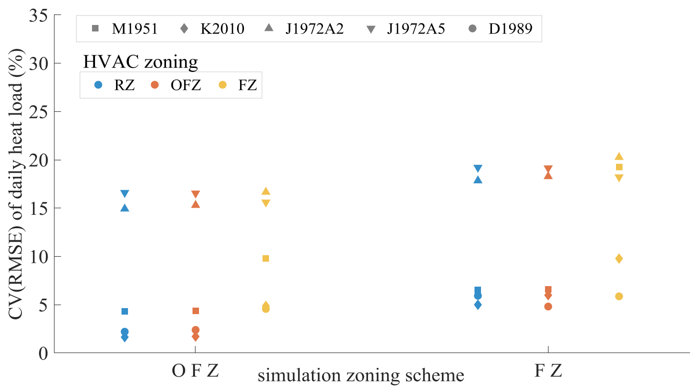


Figure 5: Errors in total heating load with several simulation zonings and HVAC zonings relative to room simulation zoning (RZ). Colors stand for HVAC zoning schemes.

Deviations in simulated heating load relative to room simulation zoning are illustrated in Figure 5. The more granular simulation zoning OFZ does result in lower errors than the FZ simulation zoning, but the difference are rather less marked than with ideal load simulation. This could be partially explained by interfering variations in achieved temperatures, as seen in the previous figure. Outliers with higher errors correspond to the two Stuttgart floor plans. It can also be seen that the errors due to simulation zoning rather tend to increase with coarser HVAC zoning. Like the temperature results, this contradicts the view that simulation zoning should correspond to HVAC zoning.

## 7. Discussion

Applying the presented method to selected floor plans and with several sets of parameters reveals that the effects of zoning schemes on simulation results may vary widely. Aggregating rooms with different uses into zones may lead to large errors, especially when grouping conditioned and non-conditioned (for instance circulation) rooms. The observation of outliers in the presented simulation experiments seem to indicate that building particulars play an important role.

A simulation zoning finer than the HVAC zoning may allow load differences due to coarse HVAC zoning to be evaluated. However, these differences can be expected to vary significantly with HVAC system, control scheme and sensor location. Also, at this level of detail, differences in thermal comfort should be taken into account. A coarse HVAC zoning should not lead modellers to choose an equally coarse simulation zoning, as this might result in significant errors in the evaluation of energy use and/or thermal comfort. Moreover, the amplitude of these errors is difficult to predict, as it was shown to vary strongly in the studied floor plans.

## 8. Conclusion

Systematic strategies for thermal zoning in the context of building performance simulation are presented and applied to multiple buildings. The method allows this aspect of model creation to be treated more consistently. Simulation experiments with multiple buildings show that the impact of zoning schemes on simulation results varies with individual buildings and parameters. Aggregating rooms with non-uniform internal loads can lead to significant errors. More experiments would be needed to investigate the trade-off between model accuracy and complexity on a more general basis. The presented method could also deal with cross-floor room aggregation. This has not been considered in the case study, which dealt only with floor plans. In the future, one could compare results obtained with floor-internal and cross-floor room aggregation, as well as with zone multipliers for zones on different floors. Zoning criteria have been built on parameters with discrete or nominal values. Zoning criteria based on quantitative and continuous values, such as window to wall ratio or shading ratio, could be introduced and used within a clustering approach.

## References


ANSI/ASHRAE/IES Standard 90.1–2013. (2013). Energy Standard for Buildings except Low-Rise Residential Buildings, Appendix G. 2013. Atlanta, GA: The American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Bres, A., Judex, F., Suter, G. & de Wilde, P. (2017). A Method for Automated Generation of HVAC Distribution Subsystems for Building Performance Simulation. *Submitted to Building Simulation 2017*.

Building Energy Codes Program (2017). “Glossary.” Available from: https://www.energycodes.gov/resource-center/glossary/ [Accessed 1st March 2017].

Coakley, D., Raftery, P., & Keane, M. (2014). A review of methods to match building energy simulation models to measured data. *Renewable and sustainable energy reviews*, 37, 123-141.

Crawley, D. B., Lawrie, L. K., Winkelmann, F. C., Buhl, W. F., Huang, Y. J., Pedersen, C. O., ... & Glazer, J. (2001). EnergyPlus: creating a new-generation building energy simulation program. *Energy and buildings*, 33(4), 319-331.

Dogan, T., Reinhart, C. & Michalatos, P. (2015). Autozoner: an algorithm for automatic thermal zoning of buildings with unknown interior space definitions. *Journal of Building Performance Simulation*, 9(2), 176-189.

Ekholm, A., & Fridqvist, S. (2000). A concept of space for building classification, product modelling, and design. *Automation in Construction*, 9(3), 315-328.

Ellis, P. G., & Torcellini, P. A. (2005). Simulating tall buildings using EnergyPlus. *Proceedings of Building Simulation 2005*, 279-286.

Georgescu, Michael, Bryan Eisenhower, and Igor Mezic. (2012). Creating zoning approximations to building energy models using the Koopman operator. *Proceedings of IBPSA-USA’s SimBuild 2012 conference*. Madison, Wisconsin.

Giannakis, G. (2015). *Development of Methodologies for Automatic Thermal Model Generation using Building Information Models*. PhD thesis. Technical University of Crete.

Klein, S. A. & Beckman, W. A. (1976). “TRNSYS – A transient system simulation program”. *ASHRAE Transactions*, vol. 80.

Platt, G., Li, J., Li, R., Poulton, G., James, G., & Wall, J. (2010). Adaptive HVAC zone modeling for sustainable buildings. *Energy and Buildings*, 42(4), 412-421.

Ramirez, R., Sebold, F., Mayer, T., Ciminelli, M., & Abrishami, M. (2005). A building simulation palooza: the California CEUS project and DrCEUS. *Proceedings of Building Simulation 2005*, 1003-1010.

Suter, G. (2013). Structure and spatial consistency of network-based space layouts for building and product design. *Computer-Aided Design*, 45(8), 1108-1127.

Suter, G., Petrushevski, F., & Šipetić, M. (2014). Operations on network-based space layouts for modeling multiple space views of buildings. *Advanced Engineering Informatics*, 28(4), 395-411.