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# Impact of different thermal zone data simplification for model calibration on monitored-simulated performance gaps

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**Abstract**. The paper analyses the impact of different simplification approaches for model verification purposes considering a reference demo case of a municipality school located in Torre Pellice (Italy), which has been monitored with room detail since April 2021. The target variable of the calibration process is the indoor air temperature: firstly, results validity is checked on an unoccupied free-running period; secondly, occupied standard behaviours and adapted to real-use ones are adopted to test the simplification choices impact on indoor thermal comfort indicators (e.g. the Adaptive Comfort Model). Several model simplification actions on both building-level construction and zoning approaches are considered. Results of this demo case demonstrate the usability of simplified models, which can be adopted instead of more detailed and time-consuming full models for performance gap detections and other analyses.

## 1. Introduction

Building model verification with respect to monitored data from the field is a fundamental task for many applications, such as for example, the estimation of the performance gap between standard and actual behaviours, the proper definition of retrofitting scenarios and energy diagnoses, or for prediction purposes. This process is suggested to be essential to avoid considering the energy performance gap as only dependent on the differences between standard and real operational conditions, compromising energy efficiency and unnoticing real causes [1]. The recent advancements in building digital twins and building automation also underlined the need to produce reliable, verified models easily and quickly with respect to monitored results [2]. However, the model verification process is affected by several difficulties, from a general lack of defined methodology to unavoidable simplification assumptions both during the modelling phase and the parameters' choice [3]. As underlined in other studies, the definition of a model needs to be set in line with defined objectives, combining the required level of detail with the complexity of modelling issues. Error sources can be found during several steps of the process [4], for example coming from missing data from inspection or building construction details, the difficulty of performing sufficiently detailed monitoring campaigns, especially in residential buildings, the assumptions made during modelling phases, including scheduling definitions and the need to keep model complexity reasonable (considering e.g. zoning geometries or HVAC details) [5]. Several approaches are adopted in literature focusing on the calibration procedure itself; however, a fully manual approach based on building knowledge and different levels of on-the-field inspection is still widely diffused. Additional works in recent years underlined the need for more structured and automatable procedures that would allow better exploiting the available computation capabilities [6-7].

This paper analyses the impact of different simplification approaches for model verification purposes, considering as a reference demo case a municipality school located in Torre Pellice (Italy). The target variable of the calibration process is the indoor air temperature, which is verified exploiting an unoccupied free-running season to avoid the random impact of occupancy and natural ventilation behaviours. Then, occupied standards and adapted to real-use behaviours are adopted to verify the calibration choice impact on indoor comfort indicators (e.g. the Adaptive Comfort Model). Several model simplification actions regarding both building-level construction and zoning approaches are considered. In particular, the school building is considered in its completeness, hence a single model, and considering the different floors as separate construction models to speed up real-time multiple simulation usages. Moreover, different thermal zones' aggregations, going from room details to multi-space aggregations according to the orientations of windows and finally to floor averages, are also tested. The calibration procedure is run using semi-automatic parametrisations by changing EnergyPlus model inputs exploiting the new PREDYCE python library developed by the authors [8]. Results of the different tests analyse the calibration process complexity considering the needed elaboration time and data and the statistical feasibility of the calibrated model in representing the building behaviour at different granularity, both spatial (average building; single zones) and temporal.

## 2. Methodology

In the following paragraph, the considered case study and the different modelling solutions are described. Moreover, the adopted parametrical calibration procedure is presented.

### *2.1. Case study description*

The considered demo case is a municipality school in Torre Pellice, Italy. This school has been monitored with room detail since April 2021 inside the European H2020 project E-DYCE [9] with sensors and gateways based on the Capetti WINECAP™ system [10]. The four-story building of the 70s features construction characteristics in line with most Italian schools built in the same period. It shows a rectangular shape with a curved metal roof, and it consists of three floors devoted to middle school, plus an additional semi-buried floor devoted to kindergarten. The internal floors are organised with a stairwell in the northeast corner and a common circulation area along the north-facing façade, while classrooms and offices all face south – see Figure 1. A detailed inspection was carried out in the school to retrieve construction (e.g. exploiting the LSI U-value monitoring kits) and usage related information (e.g. occupancy schedules and ventilation habits).

Torre Pellice is a mountain municipality that can be representative of small municipalities in Italy since positioned 5357th in terms of population among the 7978 Italian Municipalities (ISTAT 2018). The climate is cold, classified as Italian zone F, and it is cloud monitored by a weather station composed of a Thies US climate sensor and a Class 1 Delta Ohm pyranometer.

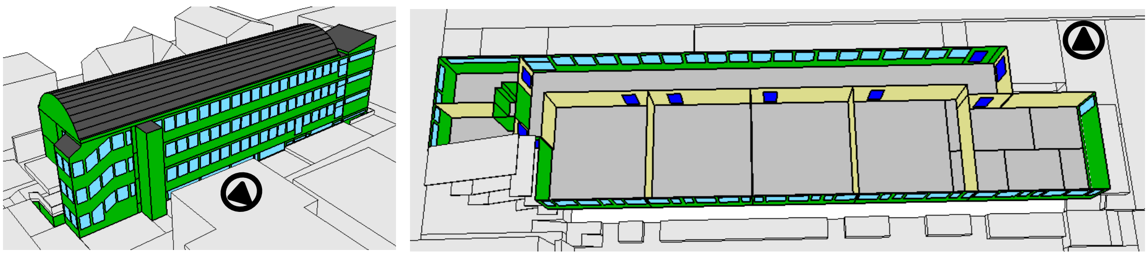

**Figure 1**. Model of the school with full view and insight on the first floor (3° level).

### *2.2. Modelling solutions*

Different modelling solutions were adopted in this paper to compare their impact on final indoor temperature calibration results. Considering thermal zone aggregations, three versions of the full model (with all the floors and surroundings) were considered – see Table 1. Starting from the full model, four separate models for each floor were extracted, setting boundary conditions of floors and ceilings as adiabatic: the ground floor is selected as the main example. Finally, considering the ground floor, it was considered the case in which very limited information on the building construction was available, adopting as a starting point information retrieved by the Tabula dataset [11].

**Table 1**. Model settings and EnergyPlus simulation running time considering a yearly simulation.

| Model setting | Description | Simulation Time (s) |
|---|---|---|
| Full model I | separate thermal zone for each room | 1765 |
| Full model II | aggregation based on windows orientation N-S | 1599 |
| Full model III | unique thermal zone for the whole floor | 1524 |
| Single floor – realistic | separate thermal zone for each room | 148 |
| Single floor – Tabula | separate thermal zone for each room | 148 |

### *2.3. Calibration procedure*

The adopted methodology for model verification has its main reference in [12]. It consists in minimising the combined error measure composed of RMSE (Root Mean Square Error) and MBE (Mean Bias Error) on a given variable (1). This allows defining a precise target to be optimised through massive automatic simulation runs. The target variable is the average monitored temperature on the main zones of interest, including corridors and classrooms on each floor.

$$\mathrm{Error_{tot}} = \sqrt{\mathrm{RMSE}^2 + \mathrm{MBE}^2} \qquad (1)$$

Different editing actions are applied automatically and parametrically to the building model. Particularly, the considered set of actions includes variations on the following steps: i.) internal mass; ii.) opaque envelope U-Value (basement floor, walls and roof); iii.) windows U-Value and Solar Heat Gain Coefficient; and iv.) air infiltration. Variation ranges are defined according to inspection to keep results realistic, except in the last modelling scenario where Tabula-based values were used as the starting point. In this case, the envelope U-value variation range was set considering the Tabula suggested values for the previous and following periods (from 1.7 to 0.7 W/m$^2$K).

The calibration signature, described in [13], is computed according to (2). The parametric actions applied to the models allow to shift of the curve (e.g. by acting on infiltration), change coefficient and inclination, and modify amplitude variations (e.g. by acting on internal mass). Figure 2 shows a generic example of calibration signature evolution during the calibration procedure, from the starting point to the best-obtained result in $\mathrm{Error_{tot}}$.

$$\text{Calibration signature} = \frac{\text{measured } T_{\mathrm{db}}^{\mathrm{i}} - \text{simulated } T_{\mathrm{db}}^{\mathrm{i}}}{\max \text{measured } T_{\mathrm{db}}^{\mathrm{i}}} \cdot 100\% \qquad (2)$$

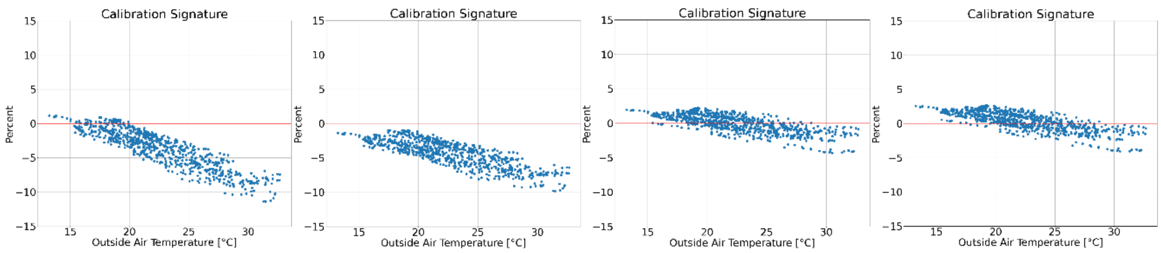


**Figure 2**. Calibration signature evolution through the different calibration steps for the full model.

## 3. Results

In the following paragraph, first results of the calibration procedure on the selected unoccupied period are presented, then the calibration strength over time on occupied free-running periods is tested through performance gap analysis of temperature and thermal comfort indicators.

### *3.1. Calibration results in the unoccupied free-running period*

The chosen calibration period goes from 15/07 to 15/08 2021, during school closure. Figure 3 shows the final calibration signatures for the tested modelling solutions. Table 2 reports the errors obtained after the calibration process. In all cases, a satisfying result inside a 5% error range is reached, in line with ASHRAE reference suggestions for model calibration [14]. Concerning the full models, the floor aggregation shows the best performance, while the North-South one is the worst. Although, the specific building typology may influence the latter. Focusing on the computationally faster model of the ground floor, it is visible how the Tabula best result presents a downshift that the automatic procedure was not able to balance. Moreover, Figure 3 shows how with deeper inspection (e.g. by fixing shadings installed in the rooms) and additional calibration steps based on human observation, it is possible to reach an optimal result on a single floor, comparable to the full model one, but with a reduction in the calculation time of one order of magnitude – see Table 1 and [15].

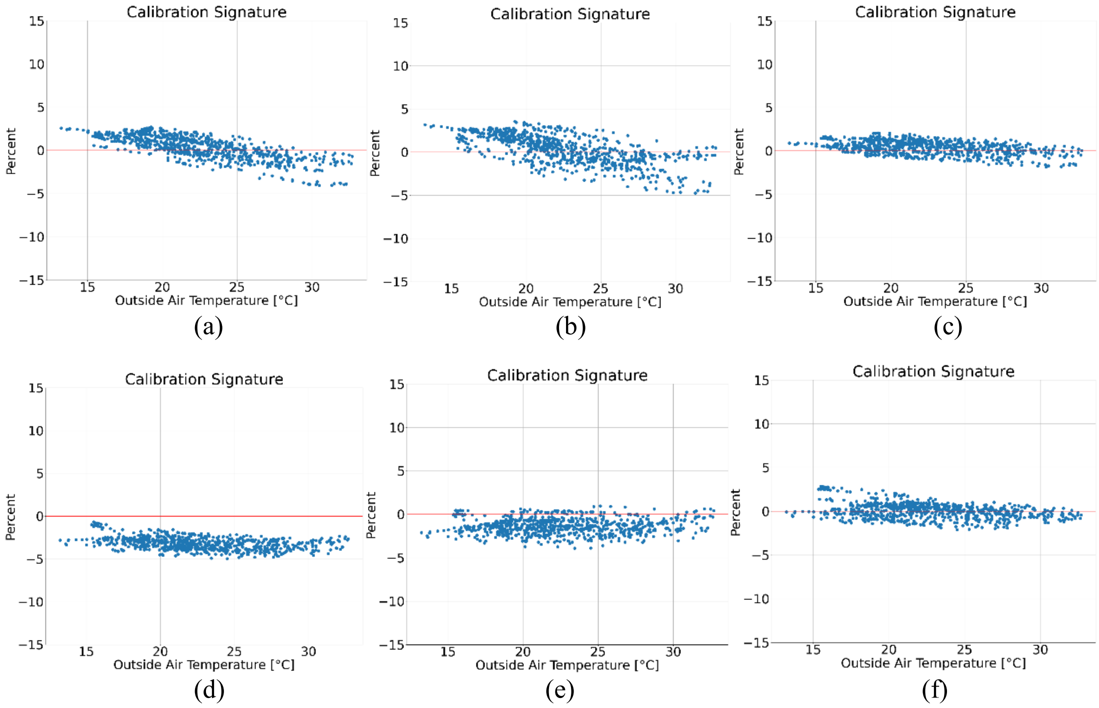


**Figure 3**. Calibration signatures: (a) full model, (b) N-S and (c) floor aggregations, (d) ground floor with Tabula inputs and (e) realistic inputs, (f) more detailed ground floor calibration [15].

**Table 2**. Final calibration errors achieved with the different models.

| Model setting | MBE | RMSE | $Error_{TOT}$ |
|---|---|---|---|
| Full model I | -0.082 | 0.404 | 0.413 |
| Full model II | -0.081 | 0.500 | 0.506 |
| Full model III | -0.101 | 0.248 | 0.268 |
| Single floor – realistic | 0.394 | 0.472 | 0.615 |
| Single floor – Tabula | 0.976 | 0.922 | 1.322 |

Results on a single floor show that it is possible to adopt lighter models, usable through a REST service, which can otherwise present timing issues. This possibility may support automatic and eventually real-time performance gap feedback to end users, and it is under test inside the E-DYCE project. Moreover, the optimal average results on the different full model versions are obtained at the expense of imprecisions in room detail. Figure 4 shows that some rooms perfectly align with the simulated floor average, while others, which can be considered critical for several reasons (e.g. rooms under the roof), are badly aligned and compensated in the average. The adoption of a lighter model would allow to address these criticalities better, achieving a better fitting in each room.

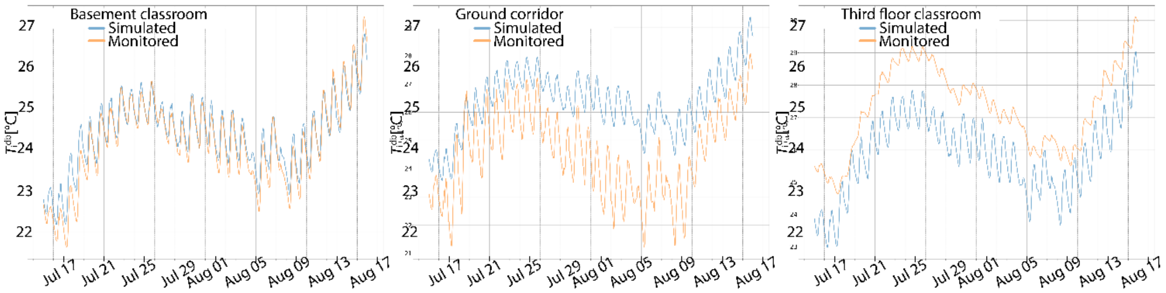


**Figure 4**. Time-series results with sample room details considering the floor aggregated model.

### *3.2. Performance gap results in the occupied free-running period*

The resilience of the calibrated models on occupied free-running periods has been tested in spring and autumn 2021 and 2022. Schedules and net values for occupancy, lighting, equipment and natural ventilation are set according to two different approaches: the former is derived from European EPBD ones, in line with EN16798-1, and the latter is built after detailed inspection of classroom usual habits (e.g. entrance-exit hours, number of children). Both standard and adapted conditions are simulated, and results compared with the same indicators computed from monitored data, exploiting an automatic performance gap analysis scenario developed inside the PREDYCE tool [8]. As main indicators, the operative temperature and the Adaptive Comfort Model (ACM) are considered: ACM POR (Percentage Outside the Range) is defined as the percentage of hours in thermal discomfort, adopting Cat. II boundaries calculated in line with EN 16798-1. To compute both indicators on monitored data, the measured dry bulb temperature is used and compared with the simulated operative.

Table 3 shows average results on the ground floor classrooms during the four testing periods considering three of the tested simplification approaches. Results on the single floor models are significantly better than those obtained on the full model with floor aggregation. With the floor aggregation standard and adapted conditions give similar results and, in some cases – see Figure 5 – standard ones better follow the monitored trend as if compensating modelling limitations. Looking instead at the single floor models, adapted conditions allow to reach the overall best performance than with standard ones, and the model fed with realistic building parameters is more resilient in the long term than those fed with Tabula inputs.

**Table 3**. Performance gap results in different model settings considering the classroom average.

| | ACM – POR [%] | | ACM cat I [n.h.] | | ACM cat II [n.h.] | | Operative Temp. [ºC] | |
|---|---|---|---|---|---|---|---|---|
| Model | STD | ADP | STD | ADP | STD | ADP | STD | ADP |
| Floor agg. | 9.18 | 11.04 | -443 | -658 | -48 | 139 | -2.33 | -1.19 |
| Single floor – realistic | -1.86 | -0.95 | 253 | 17 | -50 | 10 | 0.32 | 0.27 |
| Single floor – Tabula | -2.33 | -1.19 | 323 | -58 | 130 | 161 | -0.33 | 0.03 |

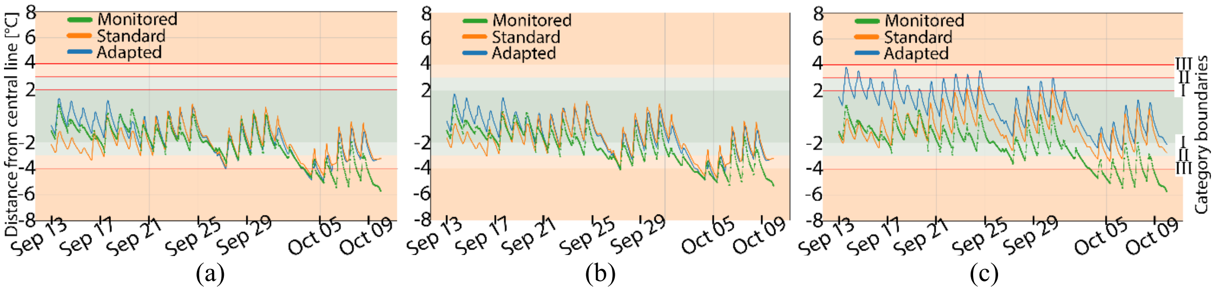


**Figure 5**. Timeseries ACM results on autumn 2021: (a) ground floor – realistic, (b) ground floor – Tabula, (c) full model with floor aggregation.

## 4. Conclusions

This study shows that different model simplification approaches, both structural and zoning, have a relatively small impact on indoor temperature and thermal comfort estimation, especially after calibration. Particularly, cut models (at the floor or the apartment level) can reach optimal results, comparable to a fully detailed model but allowing different kinds of applications, thanks to their lightness, including real-time web services. It should be underlined that various simplification solutions may work differently for other building typologies, especially considering their orientation.

Moreover, the obtained calibration results demonstrate the importance of a detailed inspection plan to define realistic variation ranges and the usability of an automatic procedure to support commonly manual operations, specifically of the PREDYCE tool, such as real-time performance gap detection.

**Acknowledgement**

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