

7th International Building Physics Conference

# IBPC2018

---

## Proceedings

**SYRACUSE, NY, USA**

September 23 - 26, 2018

---

Healthy, Intelligent and Resilient  
Buildings and Urban Environments

[ibpc2018.org](http://ibpc2018.org) | [#ibpc2018](https://twitter.com/ibpc2018)



## Use of calibrated building simulation to investigate comfort conditions in a healthcare facility

Luca Zaniboni<sup>1,\*</sup>, Giovanni Pernigotto<sup>1</sup>, Matthias Schuß<sup>2</sup>, Kristina Kiesel<sup>2</sup>, Andrea Gasparella<sup>1</sup> and Ardeshir Mahdavi<sup>2</sup>

<sup>1</sup>Free University of Bozen-Bolzano, Italy

<sup>2</sup>TU Wien, Austria

\**Luca.Zaniboni@natec.unibz.it*

### ABSTRACT

Design activity regarding healthcare buildings must not only address the energy efficiency aspects but also account for the indoor thermal comfort conditions. Indeed, the occupants of this category of buildings are affected by different kinds of health issues. Thus, particular efforts are required in order to ensure conditions adequate for therapies and medical treatments. Simulation can be a helpful tool in designing new buildings, particularly in case of complex clinics and hospitals. When analyzing existing facilities, a proper calibration is a necessary step to reduce discrepancies between simulated and measured performance. This improves the reliability of the model itself and allows its use for many purposes, from the assessment of energy performance to the evaluation of indoor thermal comfort, under a broader range of operating conditions and use patterns. In the present contribution, a calibrated model of a healthcare facility in Vienna, Austria, was developed for the assessment of both thermal performance and comfort conditions. The facility, built in the early '90s with later expansions, consists of different rooms and spaces in which several therapeutic activities are performed. Long-term measurements of the air temperature were conducted every 10 minutes for the period between March and June 2015 and used for calibrating the model. During the same period, occupants were interviewed concerning their thermal comfort sensations and detailed short-term measurements were collected to calculate thermal comfort indicators, including Fanger's Predicted Mean Vote and Predicted Percentages of Dissatisfied. The same indices were also calculated through the calibrated simulation model and compared to experimental results and subjective evaluations. The resulting model is finally used to extrapolate the assessment of thermal comfort conditions beyond the measurement period.

### KEYWORDS

Building simulation calibration

Thermal comfort

Healthcare facility

### INTRODUCTION

Ensuring high levels of indoor comfort to all occupants of healthcare facilities can be particularly critical since employees' and patients' comfort perceptions can differ significantly (Hwang *et al.*, 2007; Khodakarami *et al.*, 2012; Skoog *et al.*, 2005; Verheyen *et al.*, 2011). To this extent, building energy simulation, *BES*, can support designers' activity, but when it comes to existing buildings, calibration is required. As reported by Fabrizio and Monetti (2015), among *manual calibration methods based on iterative approach* and *automated techniques based on analytical and mathematical approaches*, also *optimization-based methods* can be

included. For example, Arambula Lara *et al.* (2017) exploited the genetic algorithm implemented in jEPlus+EA to calibrate an EnergyPlus model of an Italian school building. In this work, a portion of a healthcare facility in Vienna was analyzed. After collecting short and long-term measurements, global comfort according to Fanger's model (ASHRAE, 2013; ISO, 2005) was assessed and contrasted with the results by interviews submitted to occupants. An EnergyPlus model was developed and calibrated by means of two steps: first, by comparison with the collected air temperature measurements, and then against the calculated Fanger's indexes - predicted mean votes, *PMV*, and predicted percentages of dissatisfied, *PPD*. After calibration, the developed model was used to predict the comfort in the facility during the whole year, highlighting the extent of the discrepancies between the different occupants' perceptions. Further developments will focus on redesign tasks, based on the analysis of scenarios for long-term thermal comfort optimization, able to manage effectively the discrepancies among the different occupants' perceptions and to minimize overall energy costs.

## METHODS

**Case study and measurements** The study was conducted on the Physikalisches Institut Leopoldau, a private physiotherapy center located at the ground floor of a 20-year old building in Vienna. The analysed area, about 103 m<sup>2</sup>, includes 22 therapy rooms, where therapies are performed from 7:00 am until 8:00 pm, from Monday to Friday. Further details of the case-study, as well as the collected measurements and outcome of the survey on thermal comfort, are reported in a previous research (Zaniboni *et al.*, 2017), in which a new approach for calibration of TRNSYS energy model and cross-validation against calculated and measured Fanger's indexes was proposed.

**Simulation model definition** Since the technical details of the heating system (primary air system integrated with radiators) are largely unknown, it was decided to adopt a simplified model of an ideal air system active only during the occupancy time, with a simple control of air flow rate and temperature, the latter ranging from 22 °C to a 40 °C. EnergyPlus was chosen as simulation code, while the calibration was made partially manually and by means of jEPlus brute-force approach. The analysis included only one thermal zone and the 3D model was prepared using Rhinoceros and the Grasshopper plugin Honeybee. The same initial values and weather data, provided by ZAMG (Zentralstalt für Meteorologie und Geodynamik), used in Zaniboni *et al.* (2017), were set. The average daily occupational profile was calculated from the occupancy data, known from July 2<sup>nd</sup> 2014 to January 20<sup>th</sup> 2015. Shading devices, covering only part of the windows' areas, were simulated as a shading factor equal to 0.6. The EnergyPlus default specific infiltration rate for square meter of façade, equal to 0.0006 m<sup>3</sup>/(s m<sup>2</sup>) and representative of leaky buildings, was selected. Since it was observed that windows were quite often opened in the facility, a dynamic control for natural ventilation was modelled.

**Simulation model calibration** 14 variables were identified for calibration. The initial simulated air temperature profile resulted quite far from the measured one, therefore a first attempt manual calibration was made, considering a different interval of variation for each variable. A sensitivity analysis on *RMSD* (Figure 1) was performed to reduce the number of variables to calibrate in a second step, based on both manual and automatic brute-force calibration with jEPlus.

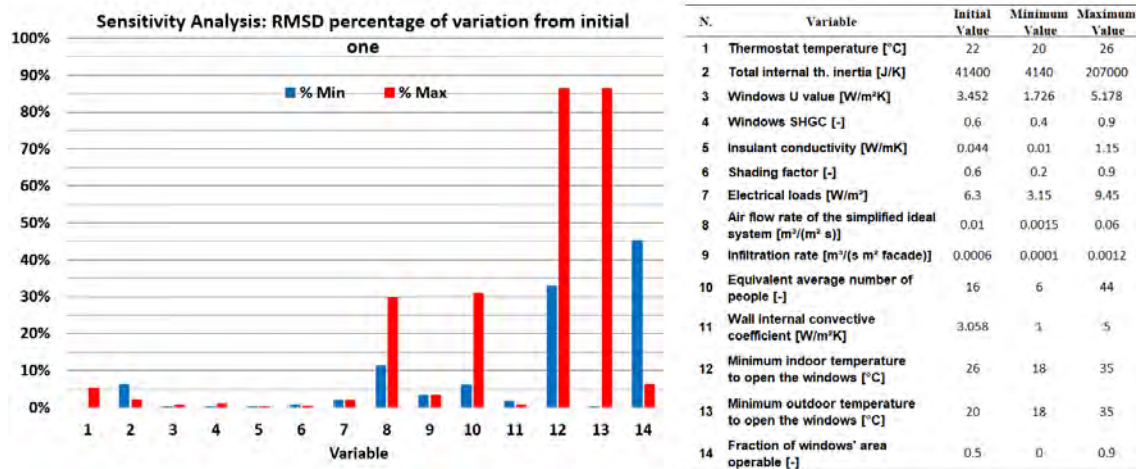


Figure 1. The sensitivity analysis results: percentages of variation of the *RMSD* in comparison with the initial value, using the maximum and the minimum limit values for each parameter reported on the right.

All the variables affecting the *RMSD* of more than the 5 % were considered. A manual calibration was made on these ones, i.e., thermostat setpoint temperature, the minimum outdoor temperature to open the window and the fraction of windows' area operable. At this point, a brute force calibration using jEPlus was applied to the internal thermal inertia, the air flow rate of the simplified ideal system and the equivalent average number of people present in the structure, the latter used to represent the thermal load by the occupants considering a load of 104 W per person, corresponding to the average between patients' and employees' metabolic rate. For each variable, new ranges were defined with a discrete number of levels from 5 to 7, and a total number of 175 simulations.

Comfort indexes *PMV* and *PPD* were derived from both measured and simulated data during occupancy time in order to validate the calibrated model. Considering the indexes determined from simulations, EnergyPlus air and mean radiant temperature outputs were used in calculations, together with average humidity and air speed by measurements. Finally, in both cases, the *PMV* evaluated at the same time in which votes were collected, were compared for both patients and employees.

**Prediction of the thermal comfort during the whole year** The calibrated model was used to calculate the indexes at each hour during the measurement period of three month, and also during the whole year. To do this last step, the Vienna typical year downloaded from the EnergyPlus Website (2018) was used.

## RESULTS

**Calibration** The first attempt of manual calibration halved the *RMSD* from 2.67 to 1.28 °C. The second attempt of manual and automated calibration made it furtherly decrease to 0.21 °C. The values of the variables after the first attempt manual calibration and at the end of the process are reported in Table 1.

The profile of the measured and simulated air temperature inside the thermal zone are reported in Figure 2, during the whole period and for the last month as an example. As it can be observed, the two profiles get along very well.

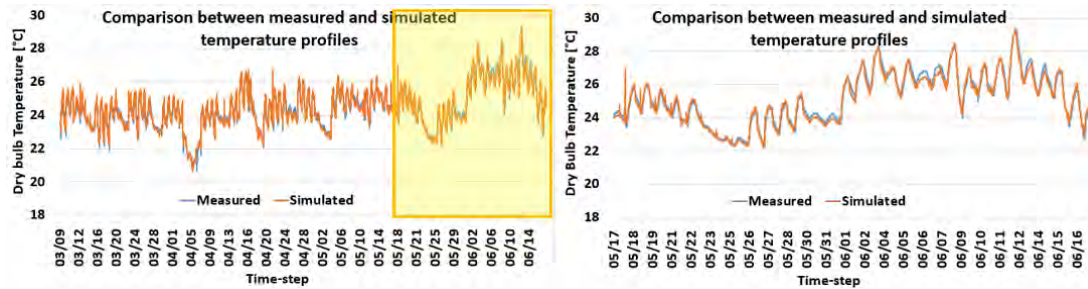


Figure 2. The comparison between the air temperature profiles (measured and simulated) during the whole period and for the last 20 days of March 2015.

Table 1. List of the variables varied in the second attempt manual and automated calibration

| Variable  | Initial | Final |
|---|---------|-------|
| Thermostat Setpoint Temperature [°C]  | 22      | 22    |
| Internal Thermal Inertia [J/K]  | 20700   | 41400 |
| Air flow rate of the simplified ideal system [m <sup>3</sup> /(m <sup>2</sup> s)] | 0.0022  | 0.04  |
| Equivalent average number of people [-]   | 22      | 13    |
| Minimum Indoor Temperature to open the window [°C]                                | 26      | 18    |
| Minimum Outdoor Temperature to open the window [°C]                               | 24      | 20    |
| Fraction of window operable area [-]  | 0.5     | 0.5   |

**PMV and PPD indexes** The comparison between the *PMV* indexes at the time in which questionnaires were filled out by the occupants and the corresponding votes is reported in box and whiskers charts in Figure 3. Considering the patients, there is a good agreement between the average values of comfort indexes evaluated from measurements and votes collected by questionnaires and indexes calculated from the simulated model. On the contrary, the average *PMV* calculated from measurements and simulations overestimate the real employees' votes and dissatisfied percentage, which show also larger interquartile ranges. The wider dispersion of comfort sensation of employees can be explained by the large range of clothes and activities made. Figure 4 reports a comparison between average hourly *PMV* and *PPD* indexes calculated by measured and simulated data. The values are the hourly averages during the three months at which the measurements were taken, during the occupational time. In this case, the indexes do not refer to the time in which questionnaires were compiled by employees and patients but to the whole occupancy time. Also in this case, the two groups of indexes are similar, even if a slight underestimation of *PMV* and *PPD* calculated by simulation data can be registered.

The annual simulation results in Figure 6 show very low *PMV* for the patients. The image reports also a second solution, with a higher temperature thermostat setting. The too low *PMV* and *PPD* during the annual simulation are due to the fact that the period of measurements at which the model was calibrated, was a particular year, hotter than usually. This could be solved by the regulation of the thermostat. The lowest peaks are due to the fact that the plant is switched on at 7:00. A solution can clearly be to anticipate it, but at 7:00 not many patients are present in the structure.

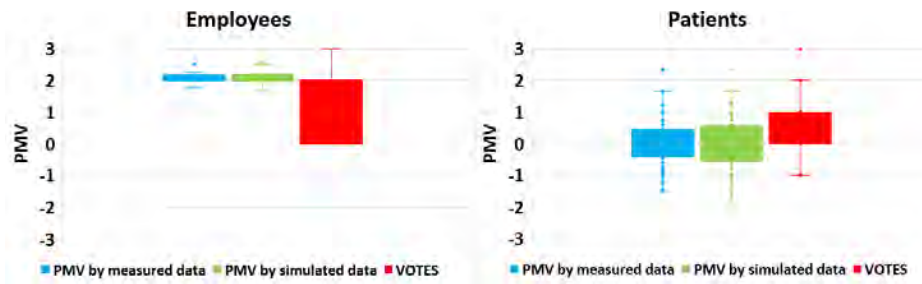


Figure 3. Comparison among PMV indexes obtained by measured and simulated internal temperatures and real votes – box and whiskers chart.

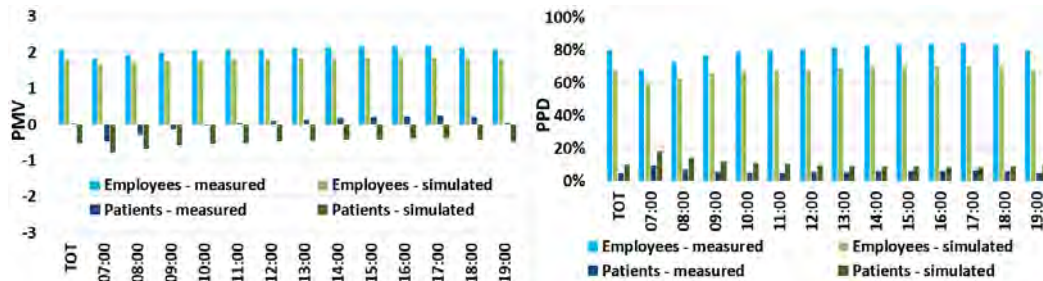


Figure 4. Hourly and daily comparison between PMV and PPD indexes obtained by measured and simulated internal temperatures.

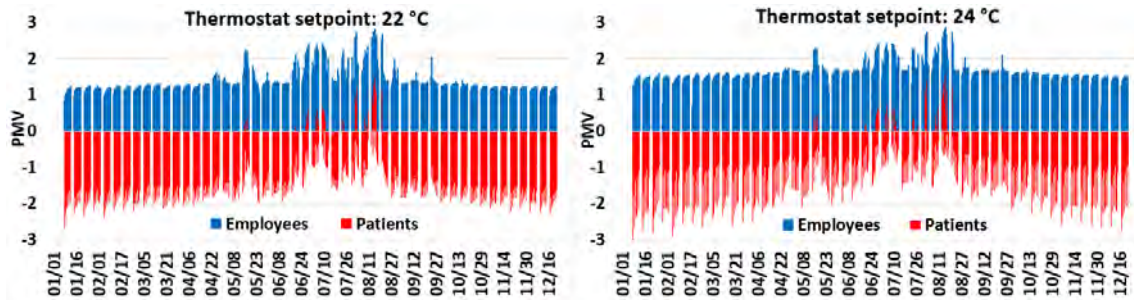


Figure 5. PMV calculated during the whole year, hour by hour, regulating the thermostat with 22 °C and 24 °C.

## DISCUSSION AND CONCLUSIONS

In this work, an EnergyPlus model of a thermal zone of a healthcare building in Vienna, Austria, was calibrated for the assessment of both thermal behavior and comfort conditions. Many properties of the building envelope and system were unknown and initial values were assumed from direct inspections and documentation on technical standards. Air temperature measurements taken from March to June 2015 were used for calibrating the model. During the same period, occupants were interviewed about their thermal comfort sensations and detailed short-term measurements were collected to calculate Fanger's Predicted Mean Votes and Predicted Percentages of Dissatisfies. Simulated air and mean radiant temperature profiles from the calibrated model were used to evaluate the same indexes, which were compared to the ones calculated from the short term measured data and people's votes for cross-validation purposes. With the calibrated and cross validated model, an annual simulation was made using the typical year. Thanks to these analyses, we observed that:

- Even starting with a limited number of monitored variables, it is possible to calibrate a simplified model able to simulate, with sufficient accuracy, the comfort indexes for the considered thermal zone.

- With a good synergy of manual and automated calibration, the calibration time can be significantly reduced. This is particularly true when, as in this case, the sensitivity analysis shows a strong dependence of the model on some variables, and also gives some clear indications on how to change these variables in order to minimize the objective function.
- The validated and calibrated model permits to extend the comfort analysis in the structure to time periods which are different from the one in which the measurements were taken for building management purposes. In this case, this allowed to observe that, using a typical year instead of 2015 data as weather file, a different building management is required to ensure proper thermal comfort to patients.

Possible further developments on this case study will be based on the calibrated model and deal with optimization techniques and solutions of model predictive controls. As a final consideration, the proposed method is expected to be applicable also to similar buildings, with the aim to assess the building management in order to optimize thermal comfort for occupants in various seasons and years.

#### ACKNOWLEDGEMENT

This study has been funded by the project “Klimahouse and Energy Production” in the framework of the programmatic–financial agreement with the Autonomous Province of Bozen-Bolzano of Research Capacity Building. The authors kindly thank the Zentralanstalt für Meteorologie und Geodynamik (ZAMG) for providing the meteorological data.

#### REFERENCES

- Arambula Lara R., Naboni E., Pernigotto G., Cappelletti F., Zhang Y., Barzon F., Gasparella A., and Romagnoni P. 2017. Optimization Tools for Building Energy Model Calibration. In: *Energy Procedia* 111:1060-1069.
- ASHRAE. 2013. *ASHRAE Standard 55*, Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.
- CEN. 2005. *EN ISO 7730:2005*. Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Brussels, Belgium: CEN.
- Energy Plus. 2018. Accessed March 2018. <https://energyplus.net/>
- Fabrizio E., Monetti V. 2015. Methodologies and advancements in the calibration of building energy models. In: *Energies*, vol. 8, no. 4, pp. 2548–2574.
- Hwang R. L., Lin T. P., Cheng M. J., Chien J. H. 2007. Patient thermal comfort requirement for hospital environments in Taiwan. In: *Building and Environment* 42: 2980–2987.
- ISO. 2001. *ISO 10551*. Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgement scales. Geneva, Switzerland: ISO.
- Khodakarami J., and Nasrollahi N. 2012. Thermal comfort in hospitals – A literature review. In: *Renewable and Sustainable Energy Reviews* 16: 4071– 4077.
- Skoog J., Fransson N., Jagemar L. 2005. Thermal environment in Swedish hospitals: summer and winter measurements. In: *Energy and Buildings* 37: 872-877.
- Verheyen J., Theys N., Allonsius L., Descamps F. 2011. Thermal comfort of patients: Objective and subjective measurements in patient rooms of a Belgian healthcare facility. In: *Building and Environment* 46: 1195-1204.
- Zaniboni L., Kiesel K., Schuß M., Pernigotto G., Gasparella A., Mahdavi A. 2016. Calibrated simulation models for indoor comfort assessment: the case of a healthcare facility in Vienna. In: 3<sup>rd</sup> Building Simulation Applications Conference BSA 2017 at Bolzano, Italy February 8-10.