THE IMPACT OF USER AND SYSTEM ASSUMPTIONS ON ENERGY SIMULATION RESULTS

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ABSTRACT

Using the example of an existing office building, the present paper explores the influence of different simulation input assumptions such as set point temperatures and ventilation behavior on the heating load of a building. Moreover, heating load simulation results with empirically-based input assumptions are compared with simulation that use standardized input assumptions.

INTRODUCTION

The heating load of a building is influenced by several factors, the building itself (geometry, construction, layout, mechanical equipment), the climate, the location, and the users. It is important to know the influence these assumptions have on the predicted heating load of a building, if a building's thermal performance is to be optimized through a simulation-supported building design process.

In this context, the first objective of this paper is to explore the influence of different simulation input assumptions such as set point temperatures and ventilation behavior on the heating load of a building. The second objective is to compare the extent to which observation-based and code-based simulation assumptions lead to different results in terms of predicted heating load magnitudes.

METHOD

To pursue the above objectives, the following approach was taken:

First, an existing typical office building in Hartberg, Austria was selected as the case in point (Mahdavi 2008). We focused on the thermal performance of six office spaces in this office building (R1 to R6). Figure 1 shows the northeast facing façade with the location of the observed offices. Figure 2 shows a schematic floor plan. The offices were located on the first and second floor of the building. They were either single or double occupancy with two to three manually operated windows, manually operated radiators and four to six luminaries. No ventilation or air conditioning system was installed. The workstations were equipped with desktop computers and in some cases printers.

Subsequently, the indoor conditions in these offices (air temperature and relative humidity, illuminance) were monitored together with user presence and actions (opening and closing of windows, deployment of shades, switching the lights on and off) (Mahdavi 200/). In addition, a weather station was mounted on top of the building collecting information about outdoor temperature and relative humidity, as well as global horizontal irradiance and illuminance. The data was measured and stored every five minutes. Window opening and shading was monitored via time-lapse digital photography: the degree of shade deployment for each office was derived based on regularly taken digital photographs of the façade. The observation period was from mid November 2005 to July 2006.

Figure 1 Façade of the building and location of observed offices

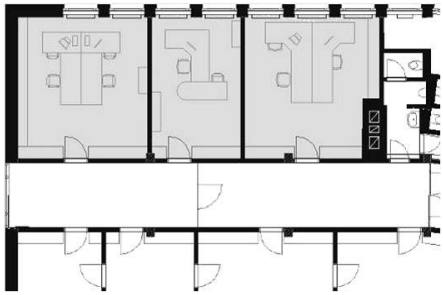

Figure 2 Schematic floor plan of sample offices in Hartberg

To perform parametric simulations, a thermal simulation tool (EDSL 2009) was selected. The simulation model of the six offices was generated based on available data and additional assumptions pertaining to the existing building. An initial model was simulated based on the monitored local weather data as well as observed user presence and control actions. Through the comparison of this model's results (predicted indoor temperatures) with the corresponding measured data, a calibrated version of the initial simulation model could be generated. The process of generating and applying of a calibrated simulation model is illustrated in figure 3. To exemplify the performance of the calibrated model, Figure 4 shows the measured and the simulated indoor air temperature, as well as the outdoor temperature for three days in may 2006. By using this calibrated model, alternative scenarios for the thermal improvement of the building could be assessed and evaluated (Mahdavi 2007).

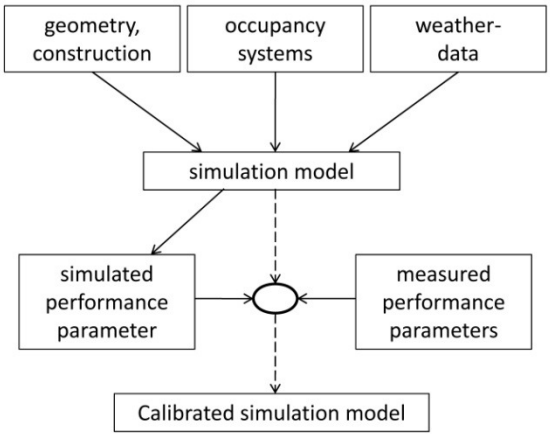

Figure 3 Illustrative depiction of the process of simulation model generation, calibration, and application (Mahdavi 2007)

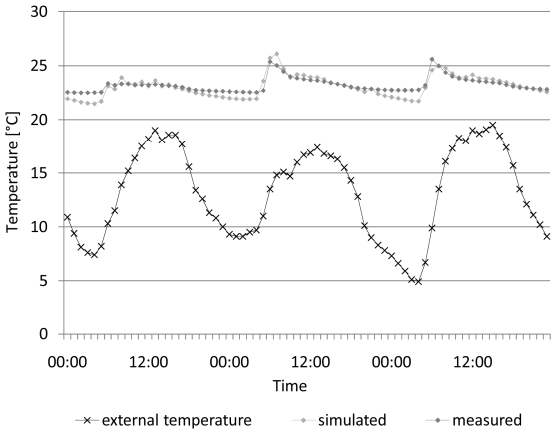

Figure 4 Comparison of the predicted results with corresponding measurements (indoor temperature in an office over the course of 3 days)

Given the calibrated simulation, a base-case (S-1) for the first set of parametric simulation studies was defined as follows: Geometry, materials, and weather conditions as well as the prevailing indoor air temperatures, occupancy, state of windows, shades, and luminaries were all based on observations.

To explore the implications of deviations from this base case, eight additional scenarios (M-1 to M-8) were constructed (see Table 1). The simulation model S-1 and the scenarios M-1 to M-8 are limited to five months (December to April). This period is referred to as observation period. Both a code-based set point temperature of 20°C (M-1, M-2, M-6) and 22.9°C (measured mean indoor temperature in the observation period) were considered for occupied office hours (M-3, M-4). Window operation (duration, position) was defined in scenarios M-5 and M-8 in a manner such that a code-based hourly air change rate (ACH) of approximately 1.22 h^{-1} could be maintained during the occupancy hours. To consider night and holiday temperature setback (unoccupied hours), an indoor air setback temperature of 13°C was selected (M-2, M-4, M-6, M-7, M-8).

Table 1
Scenarios M-1 to M-8

	MODIFICATIONS TO S1
M-1	Set point temperature 20°C
M-2	Set point temperature 20°C ; night and holiday setback to 13°C
M-3	Set point temperature 22.9°C (mean value of the measured indoor temperature during occupied hours)
M-4	Similar to M-3, but with night and holiday setback to 13°C
M-5	Effective prevailing air change rate about 1.2 h^{-1}
M-6	Combined M-2 and M-5
M-7	Night and holiday setback to 13°C
M-8	Combined M-5 und M-7

As mentioned before, simulated heating loads would be different, if, instead of actual observations, code-based simulation assumptions are used. To address this problem, a second set of parametric simulations were run. Thereby, the base case (C-1) represents fully code-based simulation input assumptions as per the relevant Austrian standard (OENorm 2007). Scenarios C-2 to C-8 (Table 2) have been modified in one or the other way to explore the influence of the altered input assumptions on the simulation results. These modifications refer to heating load, calendar, weather data, indoor air temperature, and internal gains (occupancy, lighting, equipment).

The standardized calendar (OENorm 2007) was exchanged with the actual calendar relevant for the observation period (2005/06) (C-2, C-4, C-5, C-8).

Instead of the standardized weather file -generated using Meteonorm (Meteotest 2008) - the actually collected weather data was applied (C-3, C-4, C-5, C-8). Temperature set point was changed to 22.9°C (C-5). The internal gains were also modified. In OENorm B 8110-5 a single value is given for all internal gains. In scenario C-6, C-7 and C-8 the internal gains were separated into light, equipment and occupancy. Toward this end, the hourly lighting loads for a reference day (representing the observation period) was derived based on measured data (see Figure 5 for the lighting load assumptions expressed in percentage of the respective maximal installed lighting power).

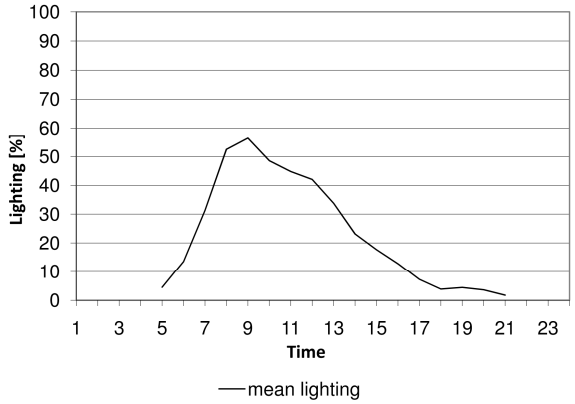

Figure 5 Mean lighting level over the course of a reference day (Mahdavi 2009)

The generic model of occupancy (see Figure 6) represents an average pattern derived from observations in 6 buildings in Austria (Mahdavi 2009) (C-6). The specific occupancy pattern for Hartberg was specifically derived for this building (see Figure 6) (C-7 and C-8).

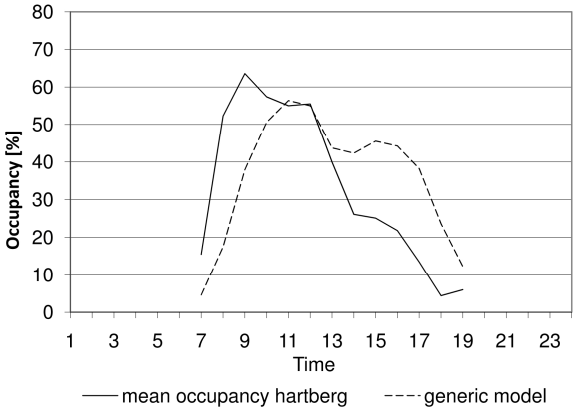

Figure 6 Mean occupancy Hartberg and generic model of occupancy over the course of a reference day

The input assumption for equipment has been linked to occupancy, assuming that the office equipment was used, whenever the office was occupied. This assumption was used in connection with the generic model of occupancy or mean occupancy HB.

Table 2
Scenarios C-2 to C-8

	MODIFICATIONS TO C1
C-2	Calendar 2005/06
C-3	Local (measured) weather information
C-4	Combination C-2 and C-3
C-5	C-4; set point temperature 22.9°C
C-6	Observation-based lighting load; generic occupancy model
C-7	Observation-based lighting load; building-specific mean occupancy
C-8	Combination of C-4 and C-7

RESULTS

Figure 7 shows the simulated heating load results for S-1 for each room over the observation period. The corresponding results for scenarios M-1 to M-8 over the observation period are shown in Figure 8. Heating load results for scenarios C-1 to C-8 are shown in Figure 9 (whole year) and figure 10 (observation period).

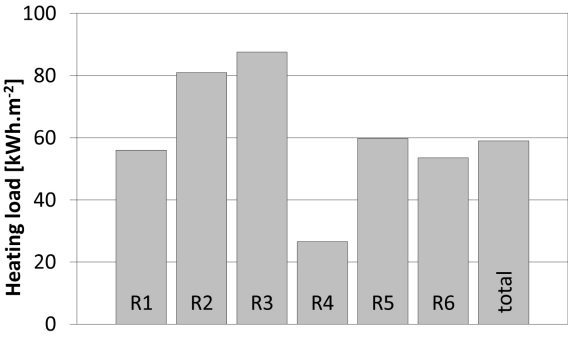

Figure 7 Simulated heating loads for S-1 (for rooms R1 to R6 as well as the total) over the observation period

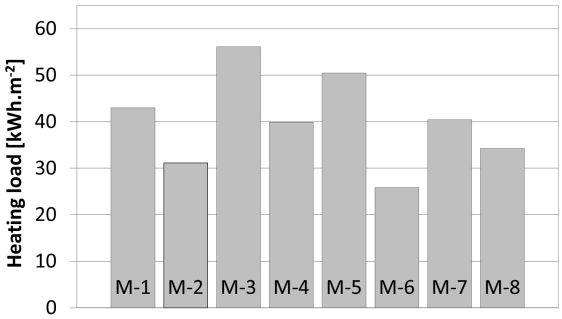

Figure 8 Simulated heating loads for scenarios M-1 to M-8 over the observation period

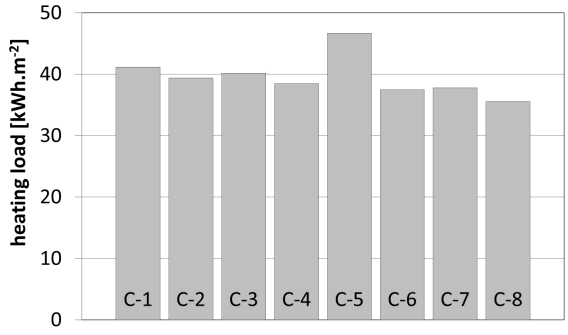

Figure 9 Simulated heating loads for scenarios C-1 to C-8 over the observation period

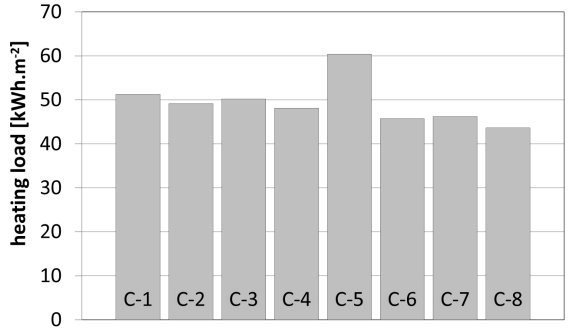

Figure 10 Simulated heating loads for scenarios C-1 to C-8 over the entire year

DISCUSSION

Variance of heating loads in different rooms

Figure 7 suggests a significant difference in the simulated heating loads of the selected offices. To obtain a better understanding of the contributing factors, a more detailed analysis was performed (see Figure 11). Thereby, simulated heating loads for the observation period are shown for the individual rooms together with empirically-based input assumptions concerning window opening (ratio of open window area to the room's floor area), indoor air temperature (mean value of the occupied office hours), and internal gains (mean value). Note that in Figure 11 the input information is not given in absolute terms. For internal gains and window areas, they were expressed as the percentage of the highest value in each category. For indoor temperature, 100% denotes the highest observed mean temperature (24.3 °C) and 0% a reference mean temperature of 20 °C.

As Figure 11 implies, higher indoor air temperatures generally translate into higher heating loads. Room 6 seems to contradict this conclusion. However, the internal gains are, in this case, the lowest of all rooms, thus contributing to higher heating loads. As to the window opening, higher values generally correlate with higher heating loads. The exception in this case, namely R3, has the highest indoor air temperature. Apparently, the associated heating requirement was not compensated either with the high internal gains or the lower window opening level.

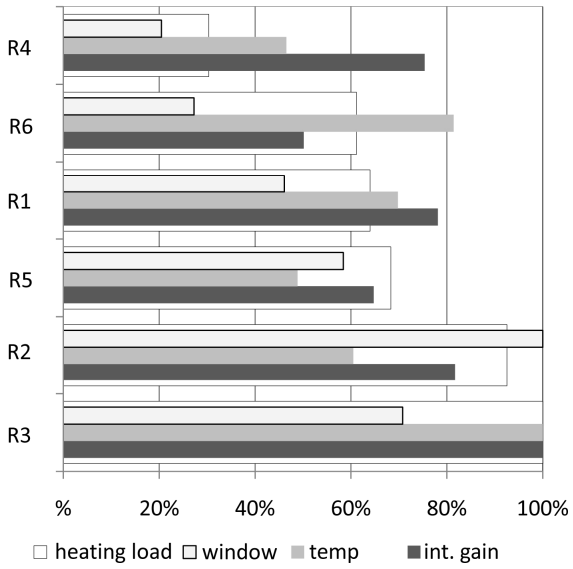

Figure 11 Simulated heating load (heat), as well as observed values of mean window opening area (window), mean indoor air temperature (temp), and internal gains (int.gain) expressed in percentage of the highest (reference) value for each item.

Impact of input assumptions (scenarios M-1 to M-8)

Figure 12 shows simulated heating load reduction to scenario M-1 to M-8 compared to S-1. None of the scenarios increased the heating load. The scenario with the lowest heating load is M-6. (56.9% lower than S1). This implies that a combination of several measures is necessary to achieve the largest effect. If we consider single measures (single changes to S1), scenarios M-1, M-3, M-5, and M-7 would be relevant. The most effective scenario (31.4% load reduction) with only one modification to S1 is M-7 (temperature setback for the non-occupied hours). Moreover, lowering the temperature set point for heating (M-1) also reduced heating load significantly (27.1%). Realizing an equivalent air change rate of 1.2 h^{-1} would also lead to heating load reduction (14.5%; scenario M-5).

It can thus be concluded, that in the present case lowering the average indoor temperature (e.g. through setback schedule for non-occupied hours) is the most important factor toward heating load reduction. Priority should of course be first given to heating schedules that involve temperature setbacks in the non-occupied hours, as these do not affect users' freedom in setting their preferred room temperatures.

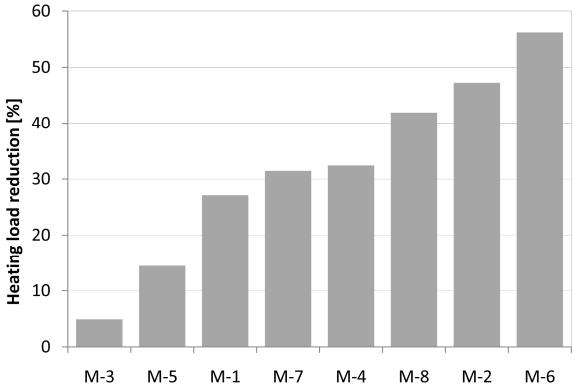

Figure 12 Heating load reduction [%] for scenarios M-1 to M-8 compared to S-1

Most efficient measure (M-1 to M-8)

Obviously, the choice between multiple alternative measures toward energy conservation must consider "practical" issues, such as the ease and cost of implementation. We define here this "cost" or "expenditure" factor in terms of three variables: financial investment require to realize the measure, effort (required behavioral change), and frequency (of required actions on the user side). To address this issue in a simplified (and qualitative) way, we rate these expenditure criteria in terms of the attributes: low (1), medium (2), and high (3). The corresponding values are simply added up to provide an aggregated indicator value. Figure 13 shows, for three measures: heating schedule for non-occupied hours, global fixed set point temperature, directed user-based window operation). These measures correspond to scenarios M-7, M-1, and M-5 respectively (see Table 1).

The financial cost of directed user-based ventilation is obviously low (M-5), but the effort required from the users and the frequency are considerably high. The installation of thermostats for temperature control (M-1) requires some financial investment but little in terms of effort and intervention frequency. Reducing the heating at night and on weekends (M-7) can be done automatically or manually. In the present discussion, we make the assumption that it is done automatically and therefore the respective financial expenditure is medium. The required effort is low, as no work needs to be done and the frequency is medium, as the system has to be maintained and adjusted regularly.

Interestingly, those measures that can be done easily, also have a high impact on heating loads. Proper adjustment of user-based ventilation is rather difficult to achieve. Moreover, in the present instance, it does not display a significant impact on heating load. Adjusting the set point temperatures and scheduled temperature setbacks (during the night hours), on the other hand, do have a high impact and are easy to implement (see Figure 13).

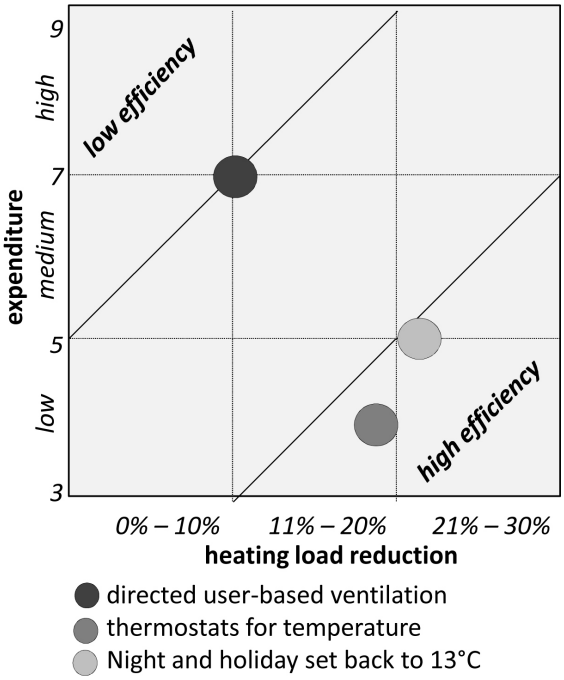

Figure 13 A simplified comparison of the thermal effectiveness (heating load reduction) of three measures (see text) in terms of the expected expenditures

Comparison of simulation results obtained by observation-based input data (S-1) with those obtained by code based input data (C-1)

Computed heating demand as per the code based scenario C-1 is 30% lower than the respective results of the S-1 simulation model. To account for possible reasons for this difference, Figure 14 shows S-1 and C-1 results along a number of "intermediate" scenarios.

Looking at the input assumptions in both models, the following can be noted:

Contrary to the code based scenario there was no temperature setback for the non-occupied hours and no set point temperature in the actual building. And the observed ventilation behavior differs from the one assumed by the code. Figure 14 shows the deviation in heating load [kWh.m^{-2}] between observation based simulation model S-1 and code based simulation model C-1 and the impact of the different input assumptions on the heating load.

Adding temperature setback for the non-occupied hours to the S-1 scenario (a step that would bring this model closer to the code based assumptions) translates into a heating load reduction of 18.6 kWh.m^{-2} (M-7). Implementing a code based fixed set point temperature (M-8) would further reduce heating load another 6.2 kWh.m^{-2}. If ventilation behavior is changed, such that it would correspond to the code based minimum air change rates (M-6), a further

decrease in heating demand would result (8.4 kWh.m^{-2}).

On the other hand, input assumptions for C-1 could also be modified so as to better relate to observed information as the basis for simulation model input. C-2 users the actual calendar of the applicable year, which has fewer working days than the standardized calendar (applied in C-1). This is due to the fewer working days in the actual year. Likewise, C-4 uses the actually monitored weather data instead of the reference year weather file used for C-1. Moreover, C-8 uses observation-based internal gains assumptions as opposed to code based assumptions.

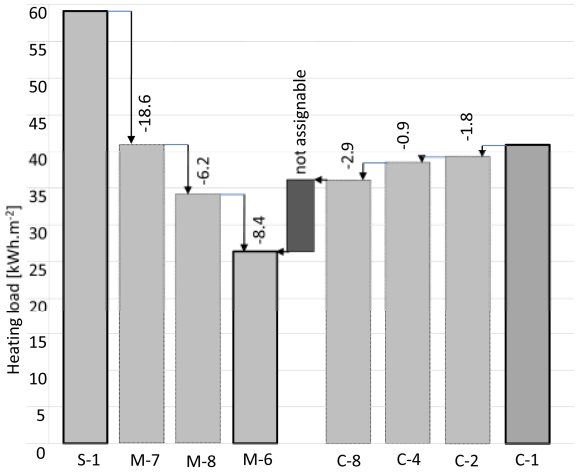

Figure 14

Exploring the contributing factors to the difference between observation-based and code-based simulation results (heating load in kWh.m^{-2})

CONCLUSION

Importance of human behavior

Next to the necessity of effective central control of buildings environmental systems (e.g. night-time temperature setback) the study points to the critical importance of human behavior. The prevailing temperatures in the observed offices were mostly too high. Very high set point temperatures for indoor air combined with excessive ventilation lead to unjustifiably high heating demands (see, for example R2 in Figure 11). On the hand, appropriate set points for indoor temperature together with proper ventilation behavior lead to relatively reasonable heating requirements (see R1 and R5 in Figure 11). Of course the human factor is hard to predict, and therefore difficult to calculate. But the impact the user behavior has on the heating load is significant. By informing the users about the influence of their behavior on buildings' energy use, a change in behavior may result, leading to a better building performance.

Benefits and limitations of standards

Standards typically use highly simplified calculation methods (OENorm …). Specifically, models of human behavior are rather crude. Reliable approximations of actual energy performance cannot be expected from code-based procedures, unless much more realistic (empirically-based) input information (concerning internal gains, occupancy, ventilation behavior) become available.

Effectiveness and efficiency of measures

An attempt was made to put the energy conservation objective in a broader context including the human dimension and the expenditures for realization of improvement measures. The initial results of this effort indicate that the most effective measures to reduce heating loads do not have to be either expensive or difficult to implement.

REFERENCES

EDSL 2010. A-TAS Version 9.1.4. Environmental Design Solutions Limited. www.edsl.net

Mahdavi, A. 2007. People, Systems, Environment: Exploring the patterns and impact of control-oriented occupant actions in buildings. (Keynote) PLEA 2007. Wittkopf, S. & B. Tan, B. (Editors)

Mahdavi A., Orehounig K., Mikats N., Lambeva L., El Habashi A. 2007. Analyzing Traditional Buildings Via Empirically Calibrated Building Performance Models, Proceedings of the 10th International Building Performance Simulation Association Conference and Exhibition, Beijing, China.

Mahdavi A., Mohammadi A., Kabir E., Lambeva L. 2008. Occupants' operation of lighting and shading systems in office buildings. Journal of Building Performance Simulation, 1 (1), p. 57-65.

Mahdavi A., Pröglhöf C. 2009. Towards empirically based models of people`s presence and actions in buildings, Proceedings of the 11th IBPSA Conference, Building Simulation 2009, Glasgow, Scotland, pp. 537 - 544

Meteotest 2008, Meteonorm Version 6.1, www.meteonorm.com

OENorm 2007, B 8110-5: Thermal insulation in building construction - Part 5: Model of climate and user profiles, Austrian Standards Institute, Vienna