Proceedings of the 2nd ICAUD International Conference in Architecture and Urban Design
Epoka University, Tirana, Albania, 08-10 May 2014
Paper No. 198

The Impact of Window Operation Assumptions on the Thermal Simulation Results of an Office Building

Sara Torabi Moghadam, Federica Soncini, Stefano P. Corgnati, Valentina Fabi
TEBE Research Group, Department of Energetics
Polytechnic University of Turin, Turin, Italy
sara.torabimoghadam@studenti.polito.it; federica.soncini@studenti.polito.it;
stefano.corgnati@polito.it; valentina.fabi@polito.it

Farhang Tahmasebi, Ardeshir Mahdavi
Department of Building Physics and building Ecology
Vienna University of Technology, Vienna, Austria
farhang.tahmasebi@tuwien.ac.at; bpi@tuwien.ac.at

ABSTRACT

Buildings' actual energy performance frequently does not meet the expectations at the design phase. One of the potential reasons for the discrepancy between expected and actual energy performance may be the uncertainties associated with building occupants' presence and behavior (e.g., operation of windows, blinds, luminaires). In this paper, we investigate the implications of different occupancy-related assumptions (pertaining to presence and window operation) on the predicted heating and cooling loads of a sample office building in Turin, Italy. Specifically, we deploy a dynamic numeric simulation application to compare standard occupancy models with probabilistic models in view of the computationally predicted heating and cooling demand of the building.

KEYWORDS: Thermal performance simulation, occupants' behavior, stochastic models

1 INTRODUCTION

Buildings account for 40% of the total energy consumption in EU member states (EC, 2004). Consequently, reduction of energy use in the built environment is an important contributor to a sustainable environment. In recent years, attention has focused increasingly towards the realization of sustainable buildings with the aim of reducing the global energy consumption and environmental impacts of the construction sector. Given this background, building performance simulation tools have been used to help designers to achieve their goals in designing energy-efficient buildings. However, buildings' actual energy performance frequently does not meet the expectations at the design phase. One of the potential reasons for the discrepancy between expected and actual energy performance may be the uncertainties associated with building occupants' presence and behavior (IEA-ECBCS Annex 53).

Occupant behavior in buildings influences buildings' energy demand for heating, cooling, and ventilation (Mahdavi, 2011). Accordingly, several approaches have been adopted in building performance simulation tools to represent the occupants' presence and their interactions with building systems. Simulation tools users typically deploy libraries of diversity factors and schedules to introduce occupants' presence and behavior. In a number of studies, these diversity factors are called "deterministic" as they have a non-probabilistic nature. More recently, efforts have been made in the scientific and professional communities to develop probabilistic models that would capture the randomness of occupants' presence and behavior. Fritsch et al. (1990) propounded a Markov chain model for actions on windows, with the outside temperature as driving variable. Mahdavi et al. (2008) inquired the possibilities of identifying general patterns of user control behavior as a function of indoor and outdoor environmental parameters such as illuminance and irradiance. Moreover, the effect of indoor and outdoor temperature on the window opening behavior in offices was investigated by means of logistic regression [Rijal et al. (2007), Herkel et al. (2008), Yun and Steemers (2008)].

Given this background, the present paper investigates the implications of different assumptions with regard to window operation in a mechanically ventilated office building for the energy use. Toward this end, a dynamic numeric simulation application was deployed to simulate the building thermal performance. To define ventilation scenarios for simulation, both fix schedule and stochastic window operation assumptions were considered.

2 METHODOLOGY

2.1 The office building

The case study involves an office building design generated within the framework of the DARC program (Developing Architectural Education in Response to Climate Change) of the Polytechnic University of Turin, with a focus on expertise in materials, building-plant system and technological innovation. The design includes in each floor (see Figure 1) 15 individual office cells connected to a corridor characterized by two ventilation chimneys.

2.2 Basic modelling assumptions

The office building is simulated as a multi zone model of the west side of a single floor (specified in Figure 1). Each individual office of the building is modeled as a separate zone. The simulations were performed for the humid subtropical climate of Turin, Italy. The modelling assumptions for the building use are listed in Table 1. Simulations were carried out for 3 different distinct assumptions (or categories I, II, III) pertaining to the heating and cooling set points of the building's control systems as relevant to the office spaces. These categories are defined in Standard EN 15251:2006 and included in Table 1.

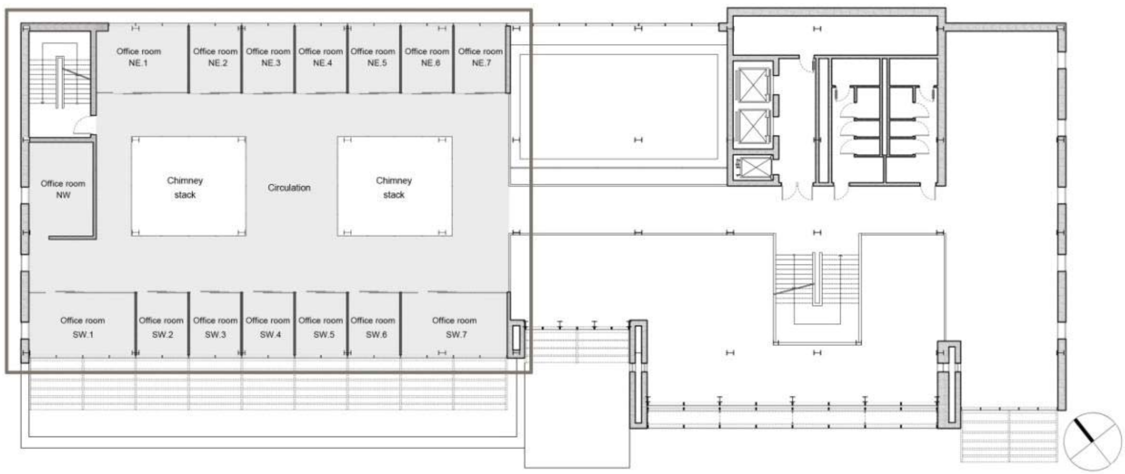

Figure 1: Building standard floor plan

Table 1: Modelling assumptions for building use

<table>
<tr><th>Modelling assumptions</th><th>Offices</th><th>Circulation area</th></tr>
<tr><td>Installed lighting power</td><td colspan="2">10 W/m^2 (1)</td></tr>
<tr><td>Occupancy</td><td>8:00–18:00 (2)</td><td>-</td></tr>
<tr><td>Air change rate (3)</td><td>1 h^{-1}</td><td>0.5 h^{-1}</td></tr>
<tr><td>Equipment (occupied period)</td><td>15 W/m^2</td><td>-</td></tr>
<tr><td>Equipment (unoccupied period)</td><td>5% of total emitted heat</td><td>-</td></tr>
<tr><td rowspan="3">Heating and cooling set point (4)</td><td>21-25.5°C (Cat I)</td><td rowspan="3">20-26°C (Cat II)</td></tr>
<tr><td>20-26°C (Cat II)</td></tr>
<tr><td>19-27°C (Cat III)</td></tr>
</table>

(1) 100% of the lights are assumed to be switched on during working hours.
(2) With lunch break from 12:00 to 14:00 (The occupancy assumption was non-probabilistic and identical in both scenarios).
(3) Ventilation starts at 7:00 and ends at 18:00.
(4) Standard EN 15251:2006. Recommended temperature ranges for the internal temperatures in office buildings energy calculations.

2.3 Window operation scenarios

In order to investigate the impact of different window operation scenarios on building's thermal performance, it was assumed that the building is equipped with a mechanical ventilation system, which provides an air change rate of 1 h^{-1}. Two window operation scenarios were considered for simulations:

Scenario I – Windows are assumed to be closed at all times. Hence, fresh air is only provided via the mechanical ventilation system.
Scenario II – Windows are operated in accordance with a stochastic model (Haldi and Robinson 2009) implemented in IDA ICE, i.e., the simulation applications used in the present study (IDA ICE, 2013).

Given the stochastic nature of deployed window operation model, we conducted a 30-run Monte Carlo simulation for the second scenario to obtain a probabilistic distribution of the results. Simulation results included annual and monthly heating and cooling loads.

3 RESULTS

Table 2 provides a summary of simulated annual heating and cooling loads for the above mentioned 2 scenarios and 3 categories. Note that the results shown for Scenario II represent average values of the 30-run Monte Carlo simulations.

As it can be seen from this Table, load implications of the two scenarios are significant. As compared to Scenario I, Scenario II results in a 44.5% higher heating load and 21.0% lower cooling. Figures 2 and 3 illustrate the monthly heating and cooling loads for the same scenarios and categories.

Table 1: Simulated annual heating and cooling loads for ventilation Scenarios I and II and heating/cooling set point categories, I, II, and III

	Heating load [kWh.m^{-2}]			**Cooling load** [kWh.m^{-2}]		
	Scenario I	Scenario II	Relative Deviation	Scenario I	Scenario II	Relative Deviation
Cat I	43.5	62.8	44.4%	16.1	14.4	-10.7%
Cat II	41.9	59.8	42.7%	15.6	13.3	-14.3%
Cat III	40.6	58.7	44.5%	14.6	11.5	-21.0%

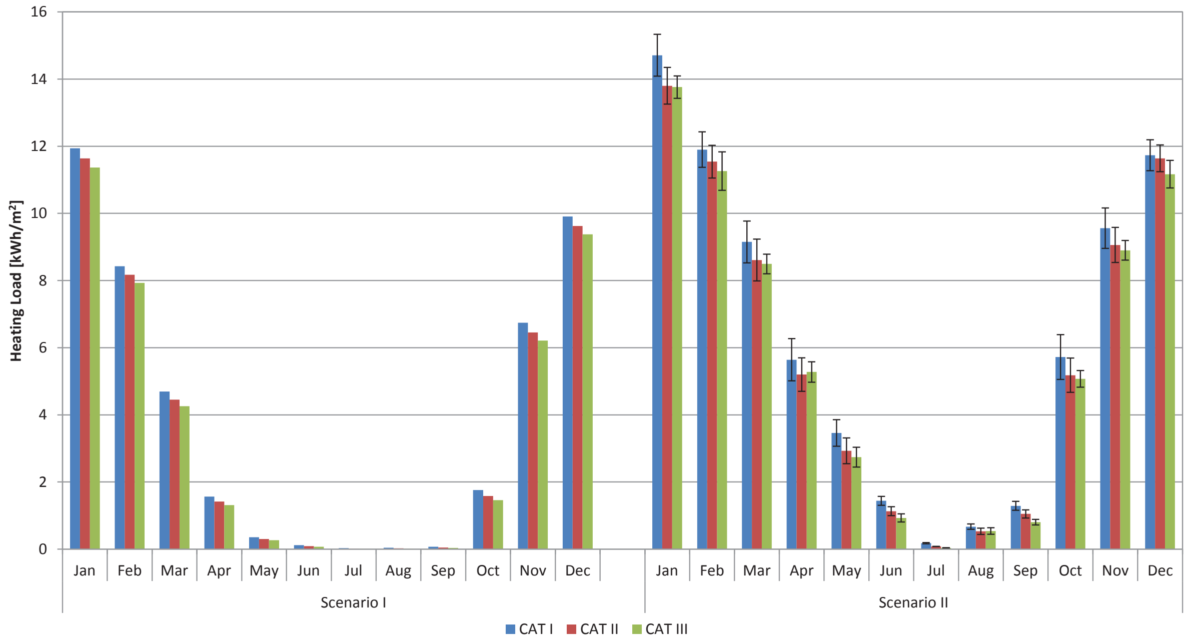

Figure 2: Simulated monthly heating loads for Scenarios I and II (mean values and standard deviations)

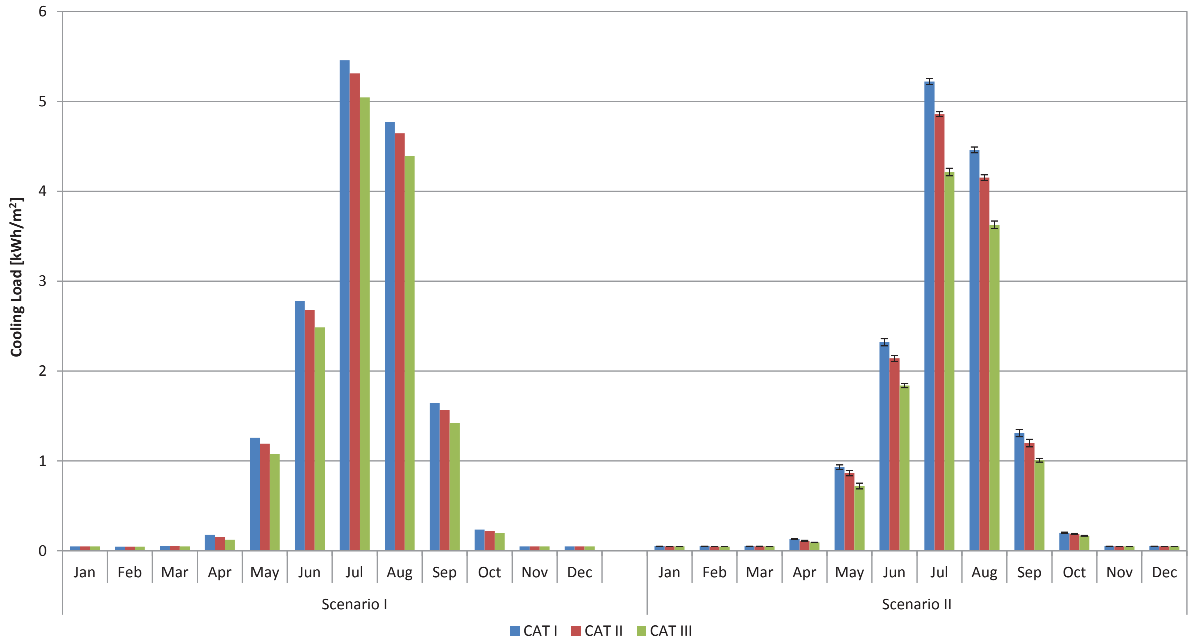

Figure 3: Simulated monthly cooling loads for Scenarios I and II (mean values and standard deviations)

A relevant question with regard to the Scenario II concerns the fluctuations of the Monte Carlo simulation results. To address these fluctuations numerically, the statistical indicator CV (Coefficient of Variance) is applied. This indicator represents the ratio of the standard deviation to the mean value of a sample and can be used as a measure of the sensitivity of simulation results to simulation input variation (in this case different state of windows resulting from the probabilities of window operation). Applied to simulated annual loads, CV was found to be about 4% for heating load and less that 1% for cooling load. Figures 4 and Figure 5 show CV values for monthly heating and cooling loads respectively. These results suggest that for the present case study, stochastic variations pertaining to window operation (as represented in the respective model in the simulation application) are of little significance while simulating annual heating and cooling loads. Likewise, with regard to the monthly loads, CV values are rather small in case of cooling (Figure 5). The somewhat higher CV values in case of the monthly heating loads (April to October) suggest the higher influence of window operation assumptions when load magnitudes – and the associated mean values – are smaller (see Figures 2 and 4).

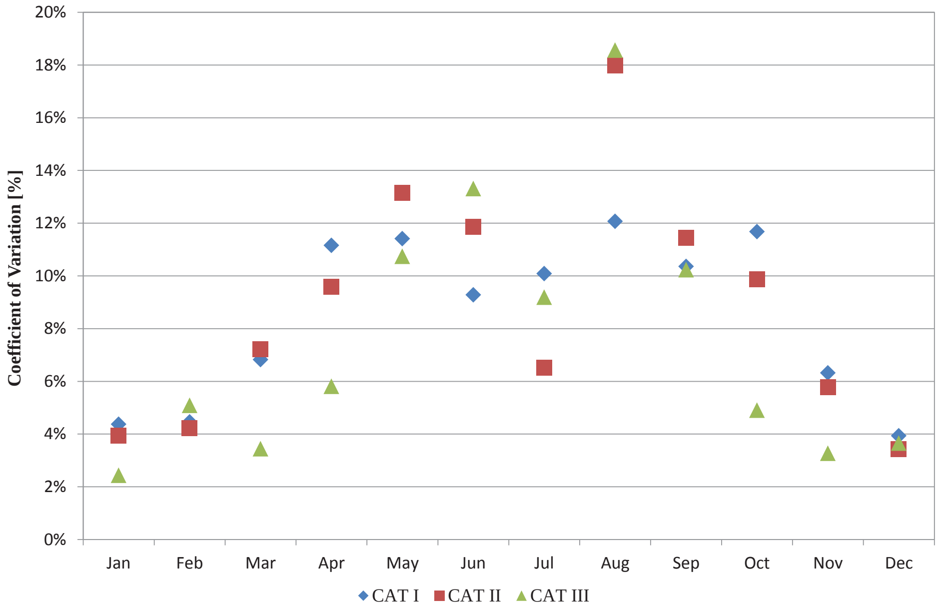

Figure 4: CV values for monthly heating loads (Scenario II)

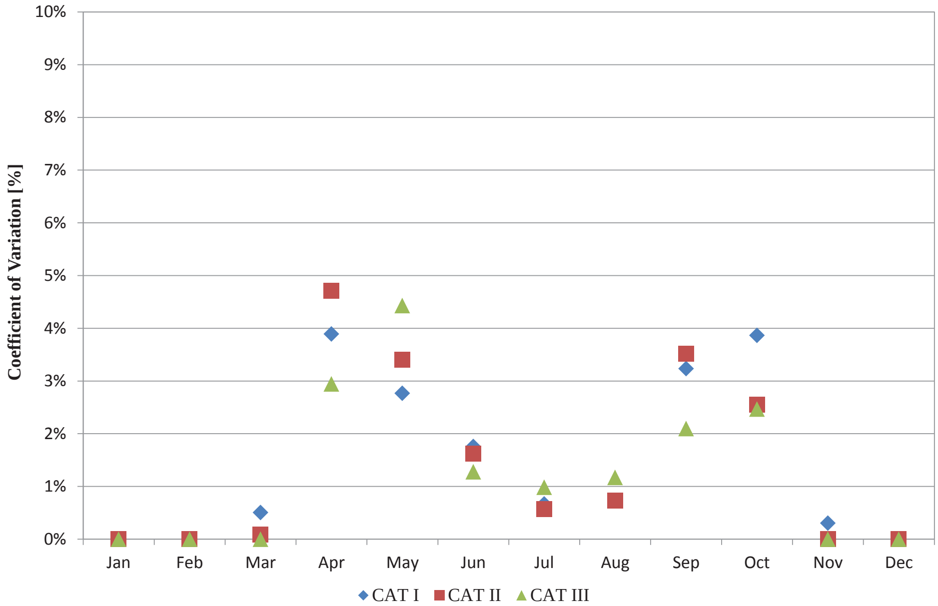

Figure 5: CV values for monthly cooling loads (Scenario II)

As noted earlier, air change rate was assumed to be constant (1 h^{-1}) in case of Scenario I, whereas Scenario II included, in addition, natural ventilation. The effectively maintained monthly air change rates for the latter scenario are shown in Figure 6. The corresponding CV values can be seen in Figure 7.

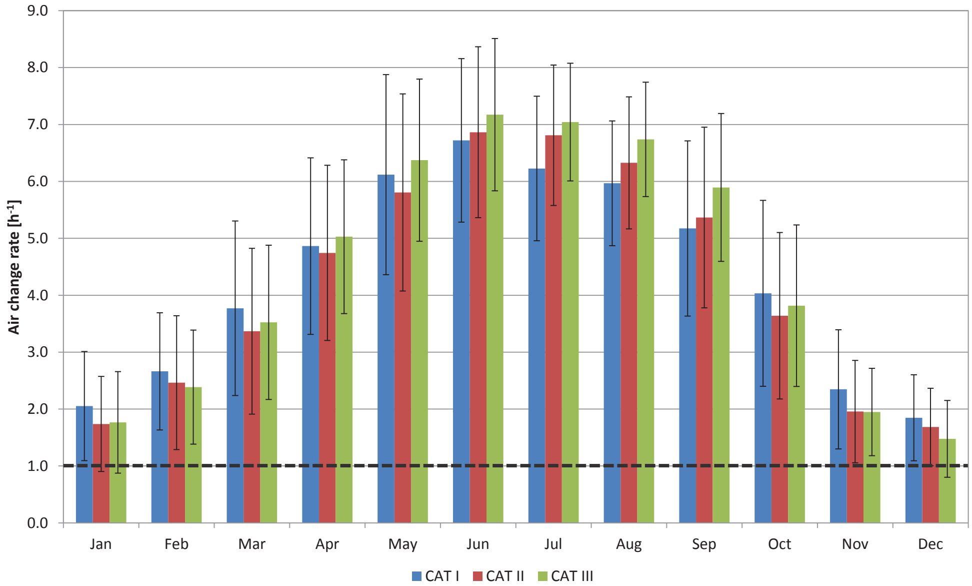

Figure 6: Mean values and standard deviation of air change rates (Scenario II)

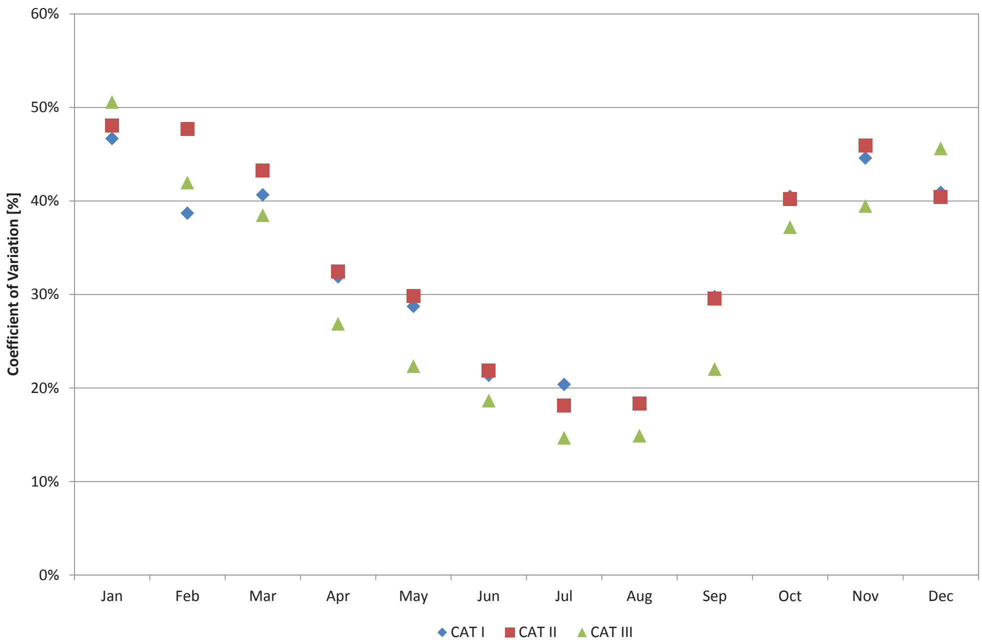

Figure 7: CV values for monthly air change rates (Scenario II)

As Figure 6 suggests, the window operation model in Scenario II results in significantly higher effective air change rates (far beyond the minimum necessary rate). This explains the building's higher heating load (Figure 2) and it could also explain its lower cooling load (Figure 3) if the implied window operation facilitated the exploitation of free cooling potential of the outdoor air. However, there is no evidence that the deployed window operation model captures real occupant behavior. Note that CV values for effective ventilation rates are much higher in the colder months of the year not so much because of higher standard deviations, but mainly because of lower effective ventilation rates in these months.

4 CONCLUSION

The main goal of this paper was to investigate the impact of window operation assumptions (and the resulting air change rates) on heating and cooling load calculations for an office building. As compared to a fix ventilation rate assumption (Scenario I), the probabilistic window operation mode embedded in the simulation application (deployed for Scenario II) resulted in higher heating and lower cooling loads. The results further suggest that, in this case, the variance arising from the probabilistic window operation assumption is of low significance with regard to annual and monthly load simulations.

REFERENCES

EC, European Union Energy and Transport in Figures, 2006 ed. Part 2, Energy, Directorate General for Energy and Transport, European Commission, Brussels, 2004.

Fritsch, R., Kohler, A., Nygård-Ferguson, M., Scartezzini, JL. 1990. A Stochastic Model of User Behavior Regarding Ventilation in “Building and Environment 25”, pp. 173-81.

Haldi, F., Robinson, D. 2009. Interactions with Window Openings by Office Occupants in “Building and Environment 44”, pp. 2378-2395.

Herkel, S., Knapp, U., Pfafferott, J. 2008. Toward a Model of User Behavior Regarding the Manual Control of Windows in Office Buildings in “Building and Environment 43”, pp. 588-600.

Humphreys, MA., Nicol, JF. 1998. Understanding the Adaptive Approach to Thermal Comfort in “ASHRAE Transactions”, 104, pp. 991–1004.

IDA ICE, 2013. http://www.equa-solutions.co.uk/en/software/idaice.

Mahdavi, A., Mohammadi, A., Kabir, E., Lambeva, L. 2008. Occupants’ Operation of Lighting and Shading Systems in Office Buildings in “Journal of Building Performance Simulation 1”, pp. 57-65.

Mahdavi A. 2011. People in building performance simulation. In: Hensen J, Lamberts R, editors. Building Performance Simulation for Design and Operation. New York: Taylor & Francis; pp. 56-83.

Page, J., Robinson, D., Morel, N., Scartezzini, J.L. 2008, A Generalized Stochastic Model For The Simulation Of Occupant Presence in “Energy and Building 40”, pp.83-98.

Reinhart, C.F. 2004. Lightswitch-2002: A Model for Manual and Automated Control of Electric Lighting and Blinds in “Solar Energy 77”, pp. 15-28.

Rijal, H.B., Tuohy, P., Humphreys, M.A., Nicol, J.F., Samuel, A., Clarke, J. 2007. Using Results from Field Surveys to Predict the Effect of Opening Windows on Thermal Comfort and Energy Use in Buildings in "Energy and Buildings 39", pp. 823-836.

Yun, G.Y, Steemers, K. 2008. Time-Dependent Occupant Behaviour Models of Window Control in Summer in "Building and Environment 43", pp. 1471-1482.