VERIFICATION OF THE IMPACT OF OCCUPANCY-RELATED ASSUMPTIONS ON THE ENERGY PERFORMANCE OF AN OFFICE BUILDING IN DIFFERENT CLIMATES

V.Fabi[1], V. Camisassi[1], and SP. Corgnati[1]

[1]TEBE Research Group, Department of Energetics, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

ABSTRACT

Building energy simulation is a commonly used method for predicting the energy performances of buildings. Simulation is adopted for its possibility to reproduce the physical behaviour of a building. Nowadays, many simulation tools are available, but there are some drawbacks to their usage, i.e. there are no applications of building simulation which involve the usage of the building by its occupants. These tools rely on assumptions with regard to human behaviour, for example in the case of thermal load calculations. In building physics, behaviour research is mainly focused on control-oriented user behaviour, as the interaction between the occupants of a building and its controls, like windows, lights and heating systems. This study focuses on the simulation of human activity behaviour in office buildings; aiming at verifying the impact of window opening assumptions on building energy performances in different climates.

INTRODUCTION

Increasing computer power, better algorithms and better calibrated models let designers and engineers able to simulate physical processes at a more detailed building level in shorter periods of time (Hensen, 2004). By simulation, a designer can find out what are the consequences of his design decisions on the performance of the building. In this way, building energy simulation can make the design process more efficient (de Wilde, 2004), which leads to more optimal, cost effective designs. Therefore it is not surprising that building simulation is now an integral part of the building process. Many simulation tools are available, but further space for research and development still remains, for example there are no applications of building simulation tools involving the building usage related to its occupants. Building simulation tools rely on assumptions referring to human behaviour, for example in the case of thermal load calculations (Nicol, 2001). In building physics, behavioural research is mainly focused on control-oriented user behaviour, i.e. the interaction between the occupants of a building and its controls, like windows, lights and heating systems (Hunt, 1978; Fritsch et al., 1990; Zimmermann, 2006; Mahdavi et al., 2008). To extend the knowledge about user control behaviour, with as final goal to incorporate this knowledge in building information systems, Nicol (2001) suggests the usage of stochastic models of occupant behaviour as starting point for developing building control systems.

Window-opening behaviour can have a significant influence on variation in energy consumption and indoor environment. Therefore, it is important to contemplate the uncertainty related to manula windows operation, when designing and realizing the energy efficiency buildings. Currently, computational simulation is one of the most widespread and potential analysis tools of a building's energy performance. Its complexity is connected to miscellaneous disciplines in the scientific area and concerning human behavior. Therefore, it is not easy to combine these aspects and ensure that the building performance simulation maximizes its potential. Commonly, the occupant behaviour is simplified through the implementation of standardized schedules. Furthermore, the creation of a dynamic behaviour of occupants can not only be used to analyse existing situations, but also to simulate new building designs taking the digital design as input. This is also relevant for architects to evaluate the performance of a building design in the early phase of the project.

The main goal of this study is to analyze the discrepancy between predicted and simulated energy performance through the analysis of the assumption related to the occupant window opening. The present paper investigates how different occupant-related models assuming a probabilistic pattern of window-opening could affect the energy use in an office building in different climates. A dynamic numeric simulation application was deployed to compare a model based on fixed schedule along with a probabilistic model.

SIMULATION OF WINDOW OPENING BEHAVIOUR

The first aim of the research was to compare window control system (see table 1) by probabilistic models in two different climates, in order to highlight differences in window behaviour influence on energy consumption dicsrepancies.

Table 1:
Window control system

NAME	DESCRIPTION
Fixed	Windows are assumed to be closed at all times. Hence, fresh air is only provided via the mechanical ventilation system
Manual	Windows are operated in accordance with a stochastic model (Haldi and Robinson, 2009)

Human interaction with building control systems is governed by a stochastic process, e.g. the influence of human behavior on windows operation and shading devices (Mahdavi, 2011). Since, the behaviour varies from person to person, accordingly, the threshold at which the probability of action is carried out is different for every individual (Nicol, 2001). For this reason, recent developments in this area inclues some detailed aspects of occupancy. Regarding the definition of Reinhart (2004), through the delineation of representative active and passive users, the individual variability, which characterizes human behavior, should be incorporated in building simulations. Specifically, Reinhart determines occupants as active or passive users in relation to the daylight, defining active people who pursuits to use natural light as much as possible, while a passive user tends to refer only to artificial light. Moreover, the same definition is applied to window blind users: active is someone who operates the blind in order to maximize daylight availability or avoiding discomfort due to glare, whereas a passive manages blind with the intention of eliminate daylight. According to the above-mentioned study of Reinhart, the current research examines the implications of different type of window users with the purpose to understand how the distinction between active and passive users can influence on the predicted energy loads, in an office building. Towards this end, the model defined by Haldi and Robinson (2009) is considered as a reference stochastic window model.

Model description: the office reference building

In this study, an attempt is made to define building design variable for a medium-sized office building with cellular office space. The floor plan of the basic building model (Figure 1) is based on the framework of the Developing Architectural Education in Response to Climate Change Program (DARC Program, POLITO). Figure 1 shows the model geometry. The floor-to-floor height is 3.5 m and the floor area is 570 m^2.

The simulations are performed in two different climate locations (Continental and mediterranean).

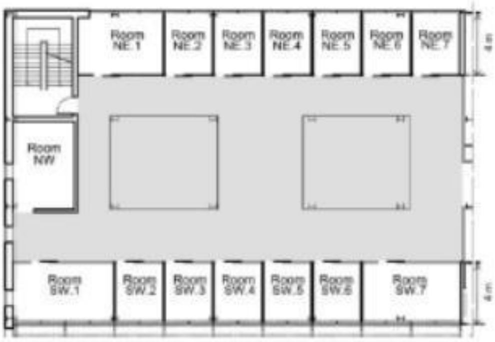

Figure 1: Reference building standard floor plan

METHODOLOGY

To assess the office building energy consumption in different climates, the office reference building has been simulated in a Continental climate, using Turin weather data, and in a Mediterranean one, taking Athens TRY.
For each thermal zone, in every selected climate - Turin and Athens - the algorithm describing users' interactions with window, developed by Haldi and Robinson (2009), is implemented in the dynamic simulation tool IDA ICE (version 4.21).

Simulations were run 30 times for each 3 category settings all fixed inputs and one occupant, to understand the impact of window's behaviour on the three main performance indicators: heating load, cooling load and ACH. IDA Indoor Climate and Energy (IDA Ice) was selected as building simulation software because of its capability to manage occupant behavioural patterns, by implementing statistical equation. Moreover, the mathematical models are described in terms of equations in a formal language, NMF, so at the advanced level, all variables, equations and parameters can be modified to study different models of behaviour.

Since buildings that are based exclusively on window operation to get hygienic ventilation are decreasing over time, many office buildings are equipped with a hybrid ventilation system in which mechanical ventilation is provided in cooperation with operable windows. As a result, every office room of the current study was equipped with a similar type of ventilation system in which both fixed and manual opening of windows were allowed.
The window behavioral model developed by Haldi and Robinson (2009) was selected to be implemented in the simulation software because it is based on seven years of measurement and it has been verified by Schweiker et al. (2012). Specifically, they analysed the influence of occupancy patterns, indoor temperature and outdoor climate parameters

(temperature, wind speed and direction, relative humidity and rainfall) on window opening and closing behaviour in 14 south-facing cellular offices in Switzerland. Following the approach, in the current research, occupants' interaction with windows was modelled as a discrete-time Markov process and was implemented in IDA ICE.

Since most window openings can be associated with the arrival of an occupant in the office, the probabilities of opening and closing windows were separately estimated in three different sub-models representing the situations of occupants' arrival, departure and during their presence (Herkel et al., 2008).

This dynamic method can account for the real adaptive processes of occupants by performing for each of those sub-models a logistic regression which takes into account the most relevant environmental parameters. The logistic regression describes the window opening behaviour as an equation which calculates the probability of a window being opened or closed in a given situation, by means of random numbers (between 0 and 1) which converted into a deterministic signal the probability of action, enabling the implementation in the simulation tool. Finally, with the purpose of assuring more accuracy at the approach, all models have been simulated 30 times to get a probabilistic distribution of the results which, instead of single value, is considered more representative of actual users' impact on energy consumption.

Simulation strategy

Since the user behaves in order to maintain or improve the comfort level (Fabi et al. 2011), and comfort categories are related to the users' expectations (EN 15251, 2008) (table 2), it is evident that they have a strong impact on energy consumptions. In this work, a first phase of investigation will analyze the dependency between ICQ comfort categories and heating energy demands through the deterministic approach of simulation tools. Afterwards a probabilistic approach in building energy modelling is presented, with the purpose of defining user type patterns to be implemented in simulation tools.

Table 2:
Modelling assumption for building use

		OPERATIVE TEMPERATURE [°C]		
BUILDING TYPE	**CATEGORY**	**MINIMUM FOR HEATING**	**MAXIMUM FOR COOLING**	**ACH [H^{-1}]**
Office room	I	21	25.5	1
	II	20	26	
	III	19	27	

The simulation approach has been developed into two subsequent scenarios which were based the two window's controls defined in table 1.

Firstly, the study has treated the office energy performance as automatically performed in the design stage of energy dynamic simulation software; secondly, the model assumed a probabilistic interaction between users and window opening and closing has been built. For each climate location, weather data have been organized in Excel and loaded into IDA Ice as two different external file sources: external climate file and rainfall file, for both Turin and Athens by sorting it into three comfort categories.

In the following sections the results of this experimental approach will be described.

RESULTS

The following graphs (Figures 2, 3 and 4) provide a summary of simulated annual heating loads, cooling loads and air change rate for the above mentioned two scenarios and three categories of EN 15251. Especially, each performance indicator is presented comparing Turin and Athens' climates:

- to verify the impact of different climates on energy consumption and window opening behaviour;
- to investigate the influence of climate on the alteration in results between the standard and probabilistic approach to the building energy simulation;
- to investigate that for each control, as well as each simulation set, how would be the influence of climate on the fluctuation of the result, due to the changes in behavior of the window.

As may be gathered from Figure 2, by analyzing variations in heating energy consumption, passing from a deterministic to a probabilistic approach to windows' opening, in a hybrid ventilated building, increases the energy use because of more frequent occupants-windows interactions.

The average values coming from the simulations' sets are higher than the hygienic mechanical zones (Figure 4). The explanation has to be found in the users' interaction with windows: using a deterministic approach, occupants are always supposed to open the window according to the fixed schedule, while the stochastic model calculates the probability of a window being opened or closed without been driven by physical thresholds.

Figure 4 shows that even if with the same trend, the air change rate in Turin and Athens entails wide variations in results. The warmer climate presents a higher frequency of window's opening compared to the colder climate. In Turin the probabilistic model provides air change rate's predictions closer to the ones coming from the standard model (i.e. maximum ACH for Cateogory III in Turin = 3.3 h^{-1}), while in Athens the gap between results is more significant (i.e. maximum ACH for Category II in Athens = 5.4 h^{-1} instead of 1 h^{-1} of the hygienic mechanical ventilation). Furthermore, in models using a probabilistic algorithm for the windows' opening, the higher energy use for heating is in Turin (Figure 2) while the higher energy use for cooling is in Athens (Figure 3), as it happened in the deterministic model.

It is then possible to affirm that the climate has some influence on this probabilistic model. The effect of climate on mean values of heating and cooling energy consumption and air change rate could be summarized as follows:

- models in Athens always show the maximum cooling energy use and air change rate and the lowest heating energy consumption;
- models in Turin have the highest energy use for heating in all scenarios and the lowest air change rate and cooling energy consumption.

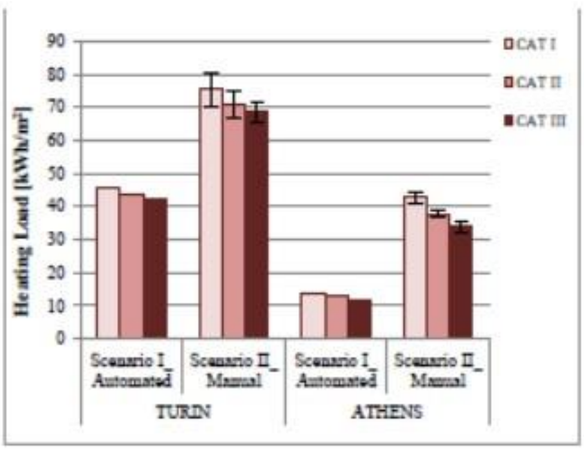

Figure 2: Simulated annual heating loads in the office reference building located in Turin and Athens

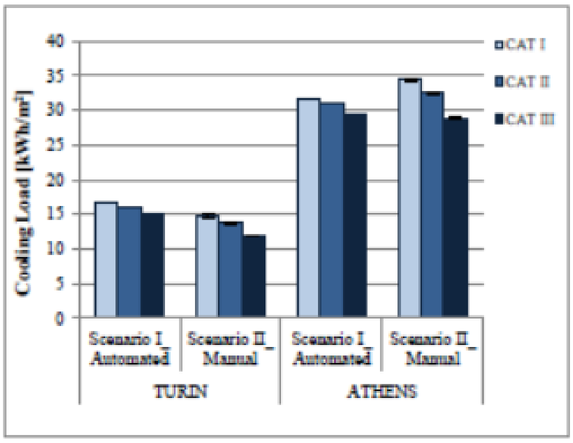

Figure 3: Simulated annual cooling loads in the office reference building located in Turin and Athens

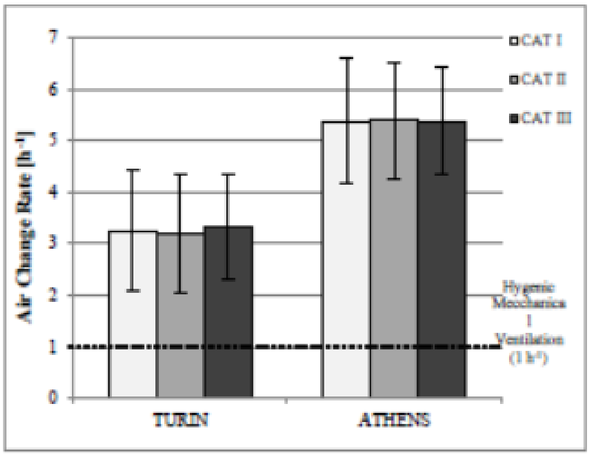

Figure 4: Mean values and standard deviation of air change rates in the office building located in Turin and Athens

Once the influence of manual control on energy demand is evaluated, the results' fluctuation within the same set of simulation is analysed for the entire building using the Coefficient of Variation (CV) in Figure 5. the Coefficient of Variation (CV) represents the ratio of the standard deviation and the mean: it can be defined as the measure of the sensitivity of the performance indicator respect to changes in simulations.

With regard to the annual loads, CV values are rather small in case of cooling. The slightly higher Coefficient of Variation values in the case of the heating loads suggests the higher influence of window operation assumptions when load magnitudes – and the associated mean values – are smaller (Figures 2 and 3). However, it can be seen that the two climate zones have similar values of CV, with the only exception of the air change rate in which Turin is about 40%, while Athens amounts to 25%.

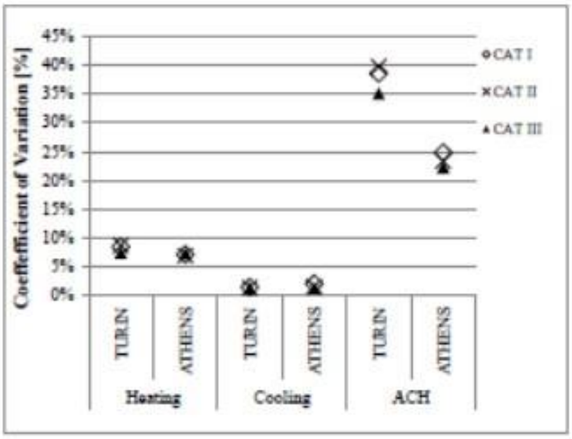

Figure 5: CV values for annual heating, cooling and air change rates

CONCLUSIONS

The ultimate goal of this study was to identify the impression of simulated window's behaviour on the predicted heating and cooling demands in an office building in different climates, through the implementation of a behavioural model taken from the literature, in a dynamic simulation tool. If this probabilistic model can be considered representative of the actual occupant behaviour, the conclusions drawn from the analyses could be as follows. Our study suggested that in summer the performance of this model might be preferable to a fully automatic (fixed building, whereas in winter energetically it might not be as efficient as automatic, for both climate zones. In other words, using a stochastic model, the use of the window in not predictable with certainty, but it is linked to the behaviour of the user. Consequently, in winter the heating system has to compensate the higher heat loss due to a more frequent interaction with windows. Conversely, in summer, the probabilistic model seems to have a lesser but positive influence, but only in Continental climate of Turin; since operations on windows seem to support the system to cool down the building reducing the expected cooling consumption. The same notion was not valid for Athens, probably because of the high temperatures of the Mediterranean weather. As a matter of fact, in warmer climate naturally ventilated building tend to get overheated during summer periods and consequently users tend to open windows more frequently. This interaction necessarily leads to an increase of ventilation losses and hence cooling delivered energy. Based on that there is a difference in heating and cooling loads of fixed control versus manual, it is necessary to clarify this discrepancy by further studies in more detail. The comparison shows that there are energetically different outcomes between different control systems, regardless that the model is representative in reality or not.

REFERENCES

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

Clarke, J.A. 2001. Energy Simulation in Building Design, Second Edition, Butterworth-Heinemann, Oxford.

Fabi, V. 2013. Influence of Occupant‘s Behavior on Indoor Environmental Quality and energy Consumption, doctoral dissertation.

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. 2008. On the Behaviour and Adaptation of Office Occupants in “Building and Environment 43”, pp. 2163-2177.

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.

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.

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.

Raja, I.A., Nicol, J.F., McCartney, K.J., Humphreys, M.A. 2001. Thermal Comfort: Use of Controls in Naturally Ventilated Buildings in “Energy and Buildings 33”, pp. 235-244.

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

823-836.

Schweiker, M., Haldi, F., Shukuya, M., Robinson, D. 2012. Verification of Stochastic Models of Window Opening Behaviour for Residential Buildings in “Journal of Building Performance Simulation 5”, pp.55-74.

Wagner, A., Gossauer, E., Moosmann, C., Gropp, Th., Leonhart, R. 2007. Thermal Comfort at Workplace Occupant Satisfaction – Results of Field Studies in German Low Energy Office Buildings in “Energy and Buildings 39”, pp. 758- 769.

Wang, W., Zmeureanu, R., Rivard, H. 2005. Applying Multi-Objective Genetic Algorithms in Green Building Design Optimization in “Building and Environment 40”, pp. 1512–25.

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

Yun, G.Y., Steemers, K., Baker, N. 2008. Natural Ventilation in Practice: Linking Façade Design, Thermal Performance, Occupant Perception and Control in “Building Research & Information 36”, pp. 608–624.

IDA ICE 4.0, Manual version 4.0 EQUA simulation AB (September 2009).