On Behavioral Action Hierarchy for Understanding Occupants' Attitudes Driving Indoor Thermal Comfort in Office Buildings

Jessica Romanelli[1] and Anna Laura Pisello[1,2]

[1] CIRIAF – Interuniversity Research Center, University of Perugia, Perugia (Italy)

[2] Department of Engineering, University of Perugia, Perugia (Italy)

Abstract

Occupant behavior is one of the major factors influencing building energy consumption and contributing to uncertainty in building energy use prediction and simulation. Currently, the understanding of occupant behavior is insufficient in building design, operation, and retrofit, leading to incorrect simplifications in modeling and analysis. Recently, the need to integrate social science aspects into energy research has brought more awareness about the role of occupants in buildings and how their actions may be driven. Within this study, we identify a sort of behavioral actions' temporal sequence in a form of timing priority action logic to represent progressive occupants' decisions. This work will contribute to the scientific investigation about the impact of occupants' behavior in building energy assessments by determining a novel behavioral action hierarchy, useful for future advanced algorithm development in dynamic thermal-energy building simulation.

Keywords: Occupants' Behavior, Hierarchy Actions, Buildings' energetic behavior, Continuous monitoring

1. Research Background

The energy-efficiency analysis of buildings today takes into account building energy behavior underestimating the human factor. One of the main objectives of the research is therefore to analyze the behavior of occupants (in terms of their energy need) to understand how this affects the overall energy performance and how much it affects the difference between the expected energy consumption and the actual energy consumption.

Occupational Behavior, for example in offices, include a number of actions that can significantly affect energy consumption, such as adjusting thermostat settings, opening / closing windows, opening / closing curtains or shutters, switching on / off heating / cooling systems and finally moving from one room to another. In addition, behavioral habits, such as changes in clothing, drink consumption and different metabolism, directly affect the individual comfort that influences energy consumption.

The behavior of occupants in buildings is a multidisciplinary research topic that covers social and behavioral sciences, building physics, detection and control technologies, computational science and statistics. One of the greatest difficulties in collecting information is the lack of standardized data as well as privacy issues.

In order to overcome the uncertainty of occupant behavior, (O'Brien and Gunay, 2015) have proposed a design method for modeling actions to make people better adaptive to natural light and shading of a construction of a simulation of energy performance in a building. (Fabi, 2012), on the other hand, investigate the collection of numerous data obtained from experimental campaigns aimed at verifying the predictive precision of the various existing window-opening models in buildings.

Considering also the behavior of occupants on the manual adjustment system according to the presence of shadows, (Yao et al., 2015) have developed a stochastic model for integration with EnergyPlus (dynamic design software). Their results have shown that frequent and inappropriate use of open-cast walls in buildings has resulted in a decrease in internal thermal comfort.

Because of the uncertainty of occupant behavior, the results of dynamic-thermal-energy simulation often greatly vary from the actual energy consumption of the building. (Eguaras-Martínez,et al., 2014) indeed suggested that inclusion or exclusion of occupant behavior in simulations can result in differences up to 30%.

doi:10.18086/swc.2017.15.07 Available at http://proceedings.ises.org

A comparison between the energy consumption simulated at the design stage and the energy measured for the LEED certification (Leadership in Energy and Environmental Design), shows a significant error (mean square error of 18%) in a group of 62 buildings. The forecast error is even greater for low-energy buildings using passive systems, such as natural ventilation; in this case, the behavior of occupants could compromise the final energy consumption. Therefore, the behavior of occupants is one of the main sources of uncertainty in predicting the use of energy.

(Motuziene and Vilutiene, 2013) used four different employment profiles of housing in Lithuania, to show that the heating strategies can lead to savings of up to 31%. In addition, high efficiency can be achieved by optimizing energy consumption during vacation periods. For example, South Korean dorms use up to 31.5% less energy when they are not unoccupied. (Webber et al., 2001) observed, in offices in Washington DC and San Francisco, only 44% of the computers, 32% of monitors and 25% of the printers were turned off at night.

The quantification of energy saving imputable to occupant behavior remains a primary challenge. It was estimated that savings could be made between 10% and 20% for home and between 5% and 30% for commercial buildings (ie private offices) by acting on occupant behavior.

Previous Scientific Research has shown that the role of Occupant Behavior has a major influence on the energy performance of the building. In this work, an office building has been monitored for more than one year in terms of indoor-outdoor microclimate and energy needs. More in details, several rooms were monitored with similar characteristics in terms of their intended use, dimensional characteristics, exposure, constructive features, and presenting devices. By analyzing several key boundary conditions, occupants can be considered as peers (equal) by being related to formation, age, habits and customs and carrying out similar activities.

2. Research Scope

Compared to the state of the art, this study attempts to analyze and identify a sort of timing priority sequence in occupant behavior triggering after perceiving a potential discomfort situation.

Determining the sequence of actions that include subjectivity is complex, especially in the analysis of the progressive feeling-to-decision-to-action of occupants. Therefore, this work will contribute to the scientific research envisaged in the Annex 66 program, which aims to identify the state of the art in terms of Occupational Behavior modelling in buildings energy prediction.

The goal is therefore to determine a temporal hierarchy of behavioral actions that is also valid for a predictive and reliable energy evaluation, since the typical reactions may be energy-needy and their time prediction influences building final energy use.

3. Methodology

The methodology implemented in this paper consists of the following main steps:

- *Definition of the research statement,*
- *Selection of the case study,*
- *Continuous experimental monitoring of the main parameters of the internal microclimate and occupancy within each office during a year from April 2016 to March 2017,*
- *Statistical analysis of data and comparison of results.*

The following sections describe the above-mentioned work phases.

3.1. Field Monitoring

In order to study and analyze the different behavior of "peers" and the hierarchy of actions that are carried out within the building, they were considered a group of peers working in some office buildings that houses the University Research Center "CIRIAF" (Perugia, Italy). In particular, five office environments characterized by the same orientation, same architectural layout, size, construction technology, and HVAC system were selected. Consequently, the behaviors of the occupants were continuously monitored by means of special sensors installed in the various offices selected as a case study.

More in detail, the experimental monitoring system was installed in September 2015 and consists of internal microclimate sensors capable of collecting data such as indoor air temperature, workplace illumination, electrical consumption, door / window opening. Therefore, data on the behavior and daily habits of occupants were collected and analyzed in terms of the use of electricity, lights on / off, opening / closing of doors / windows. In particular, the aforementioned monitoring system consists of a set of Wireless Network Sensors (WSNs), consisting of five indoor microclimate monitoring stations, each equipped with several sensors and a collector node (Fig. 1) connected to the cable sensors. The monitoring stations are located each within the five offices. Nodes communicate the data collected via radio to a collection gateway and then they are real-time available within the office web portal managed by the authors.

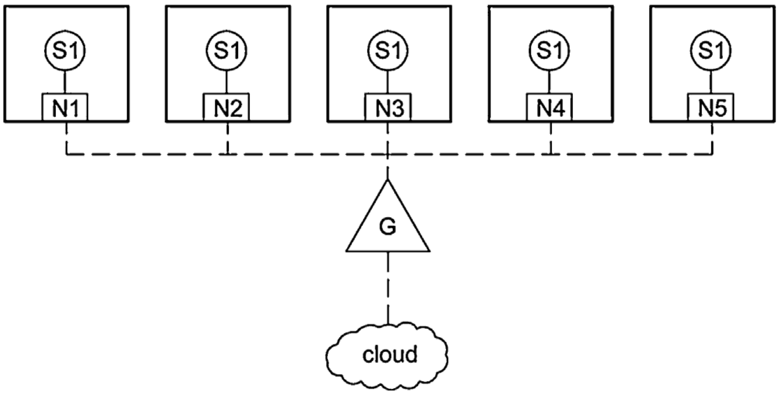


Fig. 1. Functional Diagram of the Wireless Monitoring System (n = nodes, S = sensors, G = Gateway, 1-5 = Monitored Offices (Pisello et al., 2016)

For the purpose of this research work, four types of sensors have been used in order to analyze the following internal parameters (Fig. 2):

- O*pening / closing of doors and windows (magnetic sensors),*
- I*lluminance level above the desk (luxmeter),*
- *Indoor air temperature (air temperature probe),*
- *Use of electricity (amperometer).*

Each sensor can record data every five minutes by sending the signal it to its node and finally to the gateway.

Fig. 2. Sensors installed in each office: (a) opening and closing windows, (b) luxmeter, (c) air temperature probe, (d) ammeter (Pisello et al., 2016).

4. Case Study

The building selected as a case study is represented by a building hosting the Research Center of the Department of Engineering of the University of Perugia, Italy (Latitude: 43 °'0'0'0 '' N; Longitude: 12 ° 21'03 ' 'E) (Fig. 3). It has a two-story rectangular plan, which houses ground floor laboratories, while all the offices of researchers and professors are located at the first floor. The five monitored offices are all located on the first floor and are oriented to the South-West; they have rectangular plan and have the same dimensions (about 4 × 4 × 2.9-h m). Each office has two windows-doors on the South-West façade facing a terrace connecting all the rooms at the same floor. Lighting system is characterized by 4 ceiling lamps manageable from the entrance of each office as 2 groups of 2 lamps. The HVAC system is a centralized heating-cooling air system for the whole building. Each office is provided with a thermostat able to regulate both temperature (+/- 3°C compared to the setpoint centralized temperature) and air volumes (in a graduate scale of 3 steps).

The heating season is officially operating from 10-15 to 04-15, while summer cooling operates from 06-15 to 09-30 by law. Then, every office occupants may regulate their ambient thermostat according to personal needs and occupational perceptions of occupants.

In each office there are two or three computers and two or three people. (Fig. 3-4)

Fig. 3. Planimetry of Monitoring Offices (Pisello et al., 2016).

Fig. 4. Typical Offices (Pisello et al., 2016).

4.1 Data analysis scheme in the building

This analysis, which considers peers as occupants having similar characteristics (in terms of age, occupation, activity, and timetable) under the same environmental conditions, highlights how the attitudes and personal habits of different occupants differently affect the overall building behavior given their intrinsic variability. The table below describes (Tab. 1) the main features of each monitored office.

Tab. 1. Main features for each monitored Office.

Room	People in the office (n°)	Doors/Windows	PCs
1	3	1 D, 1 W	3 pc
2	2	1 D, 1 W	2 pc
3	2	1 D, 1 W	2 pc
4	3	1 D, 1 W	3 pc

Considering all the possible actions that can be taken, such as resulting in energy consumption or a different behavior of the building, the analysis was carried out by identifying macro categories and focusing on the opening and closing of the door and the window. The aim was to identify, where possible, a temporal correlation between the thermal discomfort and the occupation action.

First, the processing of collected data was carried out with reference to the continuously monitored weather data provided by the weather station positioned on the roof of the building that houses the offices.

Specifically, the correlation level analysis between the monitored internal parameters and the external microclimate was performed considering the outside air temperature, the total solar radiation on horizontal plane, the maximum internal temperature and the opening / closing of the doors / windows. The analysis of how internal parameters are influenced by external environmental conditions shows that there is always a time shift between the maximum incident solar radiation and the maximum internal temperature, as expected. From the monitored data analysis, the maximum incident solar radiation occurs between 11:00 am and 1:00 pm on average, while the maximum internal temperature is recorded between 3:00 pm and 6:00 pm. Of course, there are exceptional cases due to the use of technological installations and / or the change of external atmospheric conditions to vary this trend. additionally, the analysis of collected data has been made by considering the behavior of occupants in order to assess how personal attitudes and specific peer peaks can affect internal environmental parameters equal conditions.

In this regard, 12-month monitoring data, specifically from April 2016 to March 2017, were analyzed and the Global Maximum Incident Solar Radiation and the External Temperature were identified as the two key variables for each day. At the same time, the maximum internal temperature and external temperature and global radiation were selected as indoor feedback every day. For each day, based on these data, the opening of the door and the window timing was assessed and correlated to radiation and temperature profiles and peaks, by also investigating the time span of the action and the possible consequential relation.

5. Results and Discussion

5.1. Analysis of occupants' behavior

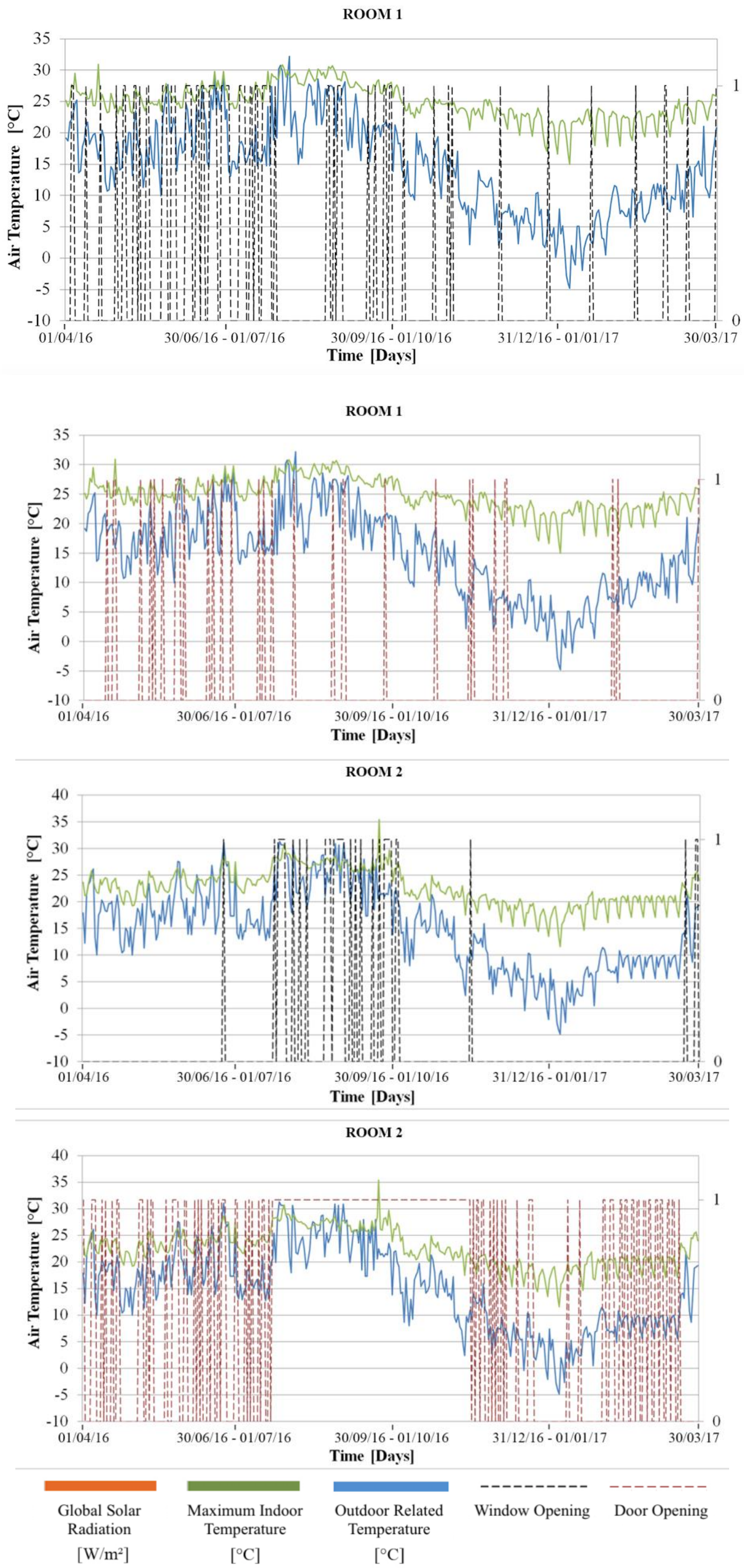
As mentioned, the present study aims to demonstrate that peers, i.e. persons of the same age, origin, activity and working hours, have different behavior from the thermo-energy point of view despite their theoretical similarities and the common work environment and how they react to environmental stimuli by implementing a temporal series of actions.

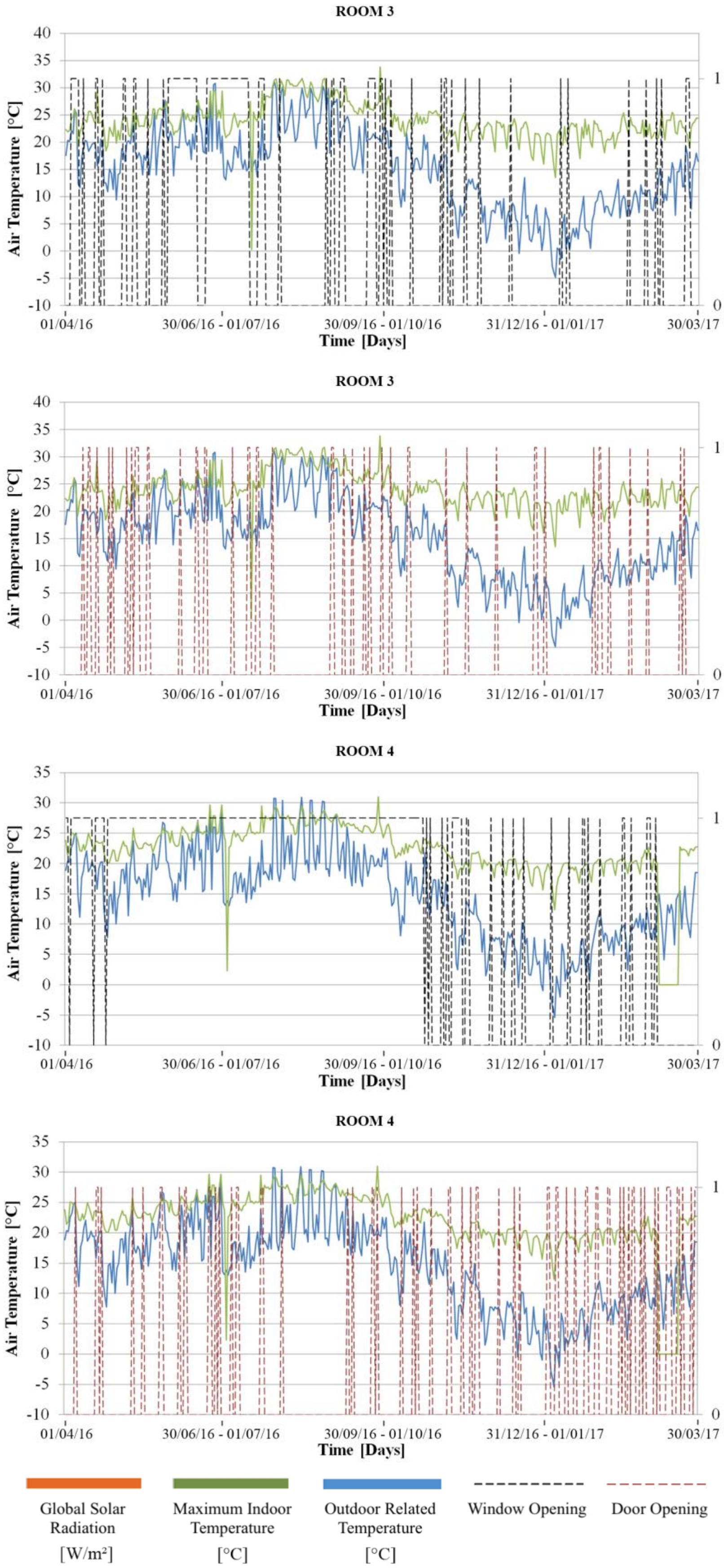
Room 1 and Room 3 office occupants often use window and door opening to adjust the temperature (openings normally coincide with indoor maximum indoor temperatures). Room 2 Office users do not use the window opening (there is only one opening in June at the peak of the measured temperature, about 30 ° C, and during September), but they act on the door opening to respond to the condition of overheating discomfort and adjust the internal temperature.

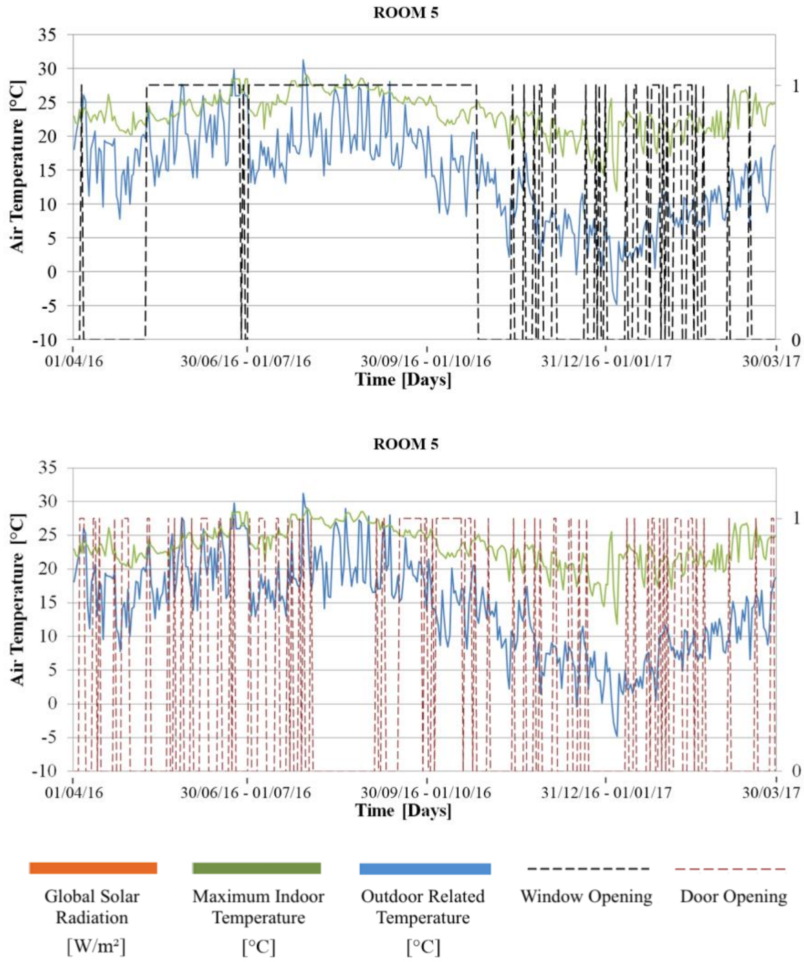
In "Room 4" office, the sensor data show that except for a few times, the window remained open throughout the day, even at night. In this case, the measurement was considered as not significant as this result may be due to a malfunction of the sensor or, if not, the action of opening the window is not a result of temperature variation.

However, occupants of the "Room 4" office used door opening as a solution to counteract environmental discomfort caused by rising temperature in the room. The Room 5 office is a synthesis of the previous ones; the opening of the window is recorded for long periods (especially during Spring and Summer), while the door opening does not always happen at the temperature peaks.

Another highlighted information to note is the behavior of the occupants of the office "Room 3", which, between May and June, with a temperature around 25°C, have constantly used the opening of the window while always closing the door. However, the internal temperature was on average around 25°C. It is likely that the opening of the window was not due to the air conditioning of the room, but to the need for occupants to breathe fresh outside air due to the pleasant temperature. As said many times, despite the fact that the "occupants" are potentially "peers", it emerges that the action is subjective or linked to its momentary and personal perception, privacy, etc. The following charts show the results of how each office occupants (Room1-2-3-4-5) react to the conditions just described.


ROOM 1
Air Temperature [°C]
35
30
25
20
15
10
5
0
-5
-10
1
0
01/04/16
30/06/16 - 01/07/16
30/09/16 - 01/10/16
31/12/16 - 01/01/17
30/03/17
Time [Days]
ROOM 1
Air Temperature [°C]
Time [Days]
ROOM 2
Air Temperature [°C]
40
Time [Days]
ROOM 2
Air Temperature [°C]
Time [Days]
Global Solar Radiation [W/m²]
Maximum Indoor Temperature [°C]
Outdoor Related Temperature [°C]
Window Opening
Door Opening


ROOM 3
Air Temperature [°C]
Time [Days]
01/04/16
30/06/16 - 01/07/16
30/09/16 - 01/10/16
31/12/16 - 01/01/17
30/03/17
ROOM 3
ROOM 4
ROOM 4
Global Solar Radiation [W/m²]
Maximum Indoor Temperature [°C]
Outdoor Related Temperature [°C]
Window Opening
Door Opening



A further point to note is that the analysis of the opening of doors and windows at the maximum internal temperature is not significant during the winter season where the maximum indoor temperatures are consistently higher than the external ones and the user's action is not directly proportional to the discomfort.

The occupants are also able to use the thermostat (user autonomy ± 3 ° C) to raise the temperature during working hours as a measure of the minimum internal temperature. However, a sensor has not been installed yet, that monitors user action on the thermostat itself.

Analyzing the results, there is a clear difference in actions at the Maximum Solar Radiation (W / m²) that normally does not correspond to a condition of internal discomfort and therefore a noticeable non-action (Fig. 5). The Maximum Solar Radiation is recorded around 12:00pm-1:00pm daily, the time when the indoor temperature is normally lower. The Maximum Indoor Temperature, however, occurs almost always in the afternoon. This constancy is justified by the specific orientation of the offices being analyzed and the internal gains progressively heating the room.

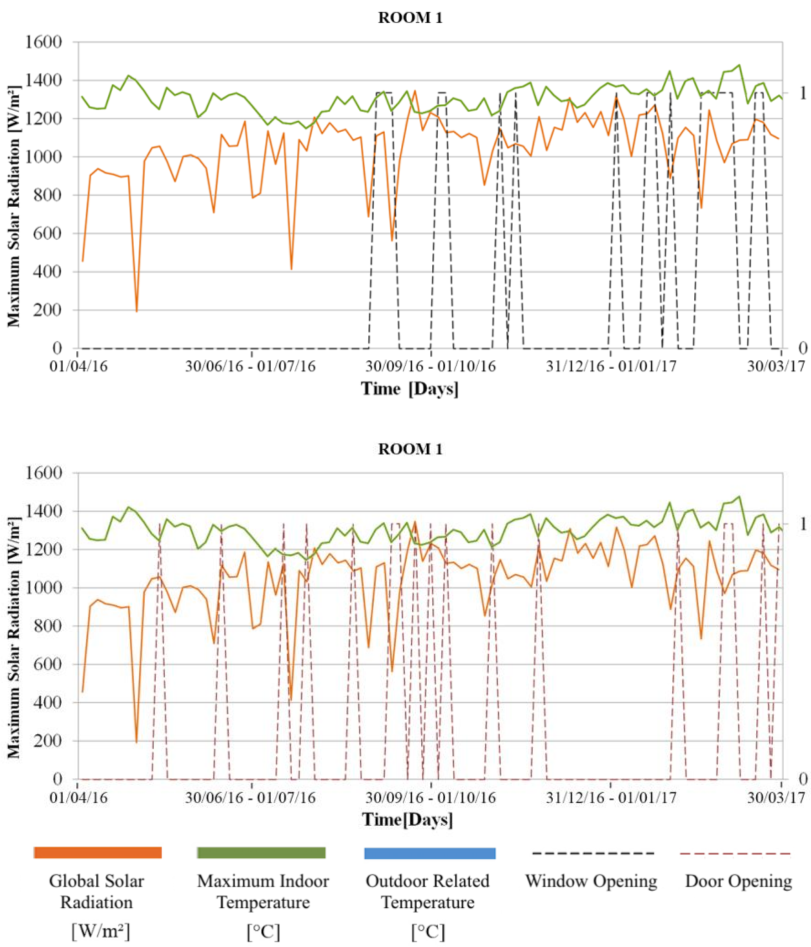


Fig. 5. Door and Window's Opening related to the Maximum Solar Radiation and Indoor Temperature.

In the following table, a synthesis of one year actions collected data for each office is described (Tab. 2).

Tab. 2. Results for each office of the analysis considering 365 days including 16 holidays.

Rooms	External Global Solar Radiation (W/m²)			Maximum Interior Temperature (°C)		
	Door	**Window**	**Door + Window**	**Door**	**Window**	**Door + Window**
1	37	52	12	32	74	21
2	148	28	28	137	34	34
3	47	99	15	48	94	17
4	74	237	42	69	233	32
5	103	188	94	106	203	89

5.2. Temporal Hierarchy Actions

Analyzing the results of occupancy actions, attention was focused on registered actions and time correspondence with recorded discomfort.

Starting from the specific action, it was analyzed whether the specific action occurred at the maximum internal temperature or if there was a time shift when the action was coming.

Results in Figs. 6-7 show how, starting from a situation of discomfort, subjective actions of the occupants are implemented. The subjectivity consists of the type of action, e.g. the fact that some occupants facing high internal temperature were opening the door while others, for privacy reasons, only managed the window. A further result is represented by the fact that not all the occupants reacted at the same moment of maximum internal temperature, but that within a given temporal order (5-10-15 minutes) the action was usually widely implemented. However, the goal is to extend the time interval, up to about 2h, in order to understand and identify a possible recurring attitudes in the actions. The work in progress consists of the elaboration of an algorithm to quickly locate this correlation.

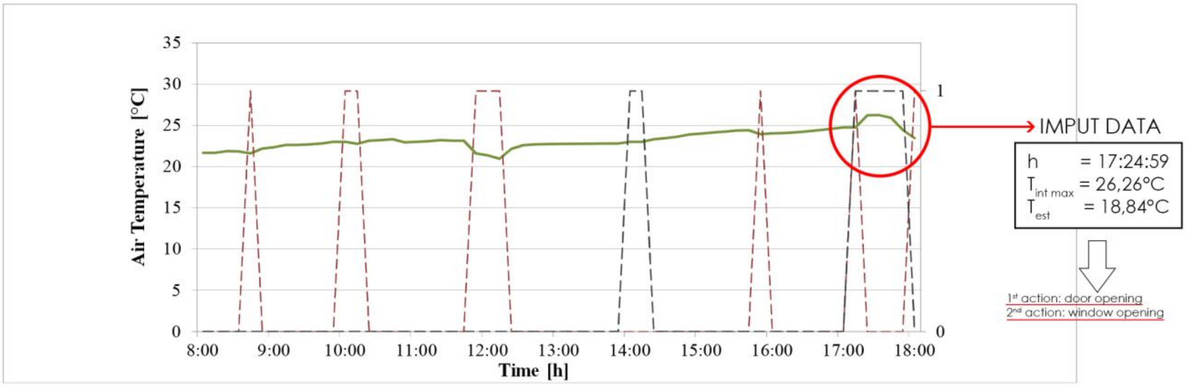


Fig.6: Daily Hourly table where are indicated Occupants' actions when the indoor temperature is maximum.

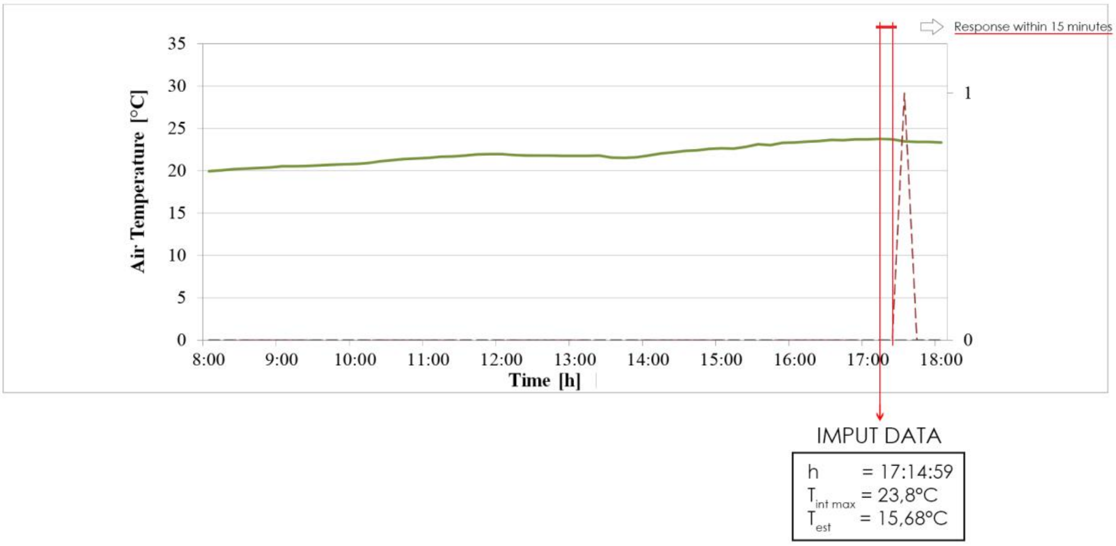
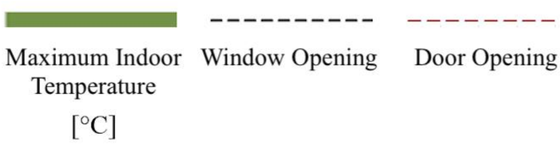


Fig. 7: Daily Hourly table where are indicated Occupants' actions with 15 minutes' time reaction range after the maximum indoor temperature.



6. Conclusion and Future Development

The present study analyzed the possibility of establishing a sequence in the actions of occupants of an office building in order to assess the impact of subjectivity and time-hierarchy of user actions responsible for the variability of indoor air temperature in close proximity to each working station.

The results show how, in discomfortable situations, the subjective actions of the occupants find a common matrix of doing a subjective action. Subjectivity was found in the type of action, i.e. in the fact that for example some occupants reacted to high internal temperature with opening the door, while others, for privacy, the window.

Another result is that not all occupants reacted at the same time, but within a given time order (5-10 to 15 minutes) the action was completed. It is also important to note the difference in the actions at the maximum solar radiation (W/m²) that normally does not match an internal discomfort and therefore a noticeable non-action.

Being the subject of deep interest and study, the understanding of occupant behavior represents a new opportunity to shape the future evolution of building energy prediction models and technology, to improve the energy efficiency and comfort of occupants of buildings,.

7. Acknowledgements

This work was supported by the CIRIAF Interuniversity Research Center of the University of Perugia, Department of Engineering, on the PhD. The authors would like to thank Luigi Metelli S.p.A for supporting their research entitled COOL CRETE. This work has been carried out also within the framework of IEA-EBC Annex 66 “Definition and Simulation of Occupant Behavior in Buildings”.

8. References

Eguaras-Martínez, M., Vidaurre-Arbizu, M., Martín-Gómez, C., 2014. Simulation and evaluation of building information modeling in a real pilot site. Appl Energy, 114,475–484.

Fabi, V., Andersen, R.V., Corgnati, S., Olesen, B.W., 2012. Occupants’ window opening behavior: a literature review of factors influencing occupant behavior and models. Build. Environ. 58, 188–198.

Heck, S., Tai, H., 2014, Sizing the Potential of Behavioral Energy-Efficiency Initiative in the US Residential Market Report, McKinsey Company.

Hong, T. Lin, H.W., 2013. Occupant Behavior: Impact on Energy Use of Private Offices. Ernest Orlando Lawrence Berkeley National Laboratory ReportLBNL-6128E.

Hong, T., Sarah, C., Lange, T., D’Oca, S., Yan, D., Corgnati, S.P., 2015. Advances in research and applications of energy-related occupant behavior in buildings. Energy Build, 116, 694-702.

Martinaitis, V., Zavadskas, E.K., Motuzien˙e, V., Vilutien˙e, T., 2015. Importance of occupancy information when simulating energy demand of energy efficient house: a case study. Energy Build. 101, 64–75.

Motuziene, V.,Vilutiene, T., 2013. Modelling the effect of the domestic occupancyprofiles on predicted energy demand of the energy efficient house.Procedia Eng, 57:798–807.

O’Brien, W., Gunay, H.B., 2015. Mitigating office performance uncertainty of occupant use of window blinds and lighting using robust design. Build. Simul, 8-6, 621–636.

Pisello, A.L., Castaldo, V.L., Piselli, C., Fabiani, C., Cotana, F., 2016. How peers’ personal attitudes affect indoor microclimate and energy need in an institutional building: Results from a continuous monitoring campaign in summer and winter conditions, Energy Build., 126, 485-497.

Pothitou, M., Kolios, A.J., Varga, L., Gu, S., 2014. A framework for targeting house hold energy savings through habitual behavioral change, Int. J. Sustainable Energy, 686-700, h HYPERLINK "http://dx.doi.org/10.1080/14786451.2014.936867" HYPERLINK "http://dx.doi.org/10.1080/14786451.2014.936867"ttp://dx.doi.org/10.1080/14786451.2014.936867.

Schakib-Ekbatan, K., Fatma Zehra, C.¸ Schweiker, M., Wagner A., 2015. Does the occupant behavior match the energy concept of the building? Analysis of a German naturally ventilated office building. Build Environ, 84:142–150.

Turner, C., Frankel, M., U.G.B Council 2008, Energy Performance of LEED for New Construction Buildings, New Buildings Institute, Vancouver, WA.

Webber, C.A., Roberson, J.A., Brown, R.E., Payne, C.T., Nordman, B., Koomey, J.G., 2001. Field surveys of office equipment operating patterns, in: Lawrence Berkeley National Laboratory Report, LBNL-46930.

Yan, D., O’Brien, W., Hong, T., Feng, X., Burak Gunay, H., Tahmasebi, F., Mahdavi, A., 2015. Occupant behavior modeling for building performance simulation: current state and future challenges, Energy Build. 107, 264–278, http://dx.doi.org/10.1016/j.enbuild.2015.08.032.

Yao, D.H.C. Chow, R.Y. Zheng, C.W. Yan, Occupants impact on indoor thermal comfort: a co-simulation study on stochastic control of solar shades, J. Build. Perform. Simul. 2015