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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

Anna Laura Pisello [a,b,*], Veronica Lucia Castaldo [a], Cristina Piselli [a], Claudia Fabiani [a], Franco Cotana [a,b]

[a] CIRIAF—Interuniversity Research Center, University of Perugia, Via G. Duranti 67, 06125 Perugia, Italy
[b] Department of Engineering, —University of Perugia, Via G. Duranti 93, 06125 Perugia, Italy

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ABSTRACT

Occupants' behavior can significantly affect building performance, in particular in massive institutional buildings occupied by a wide variety of users. This work aims at highlighting the importance of peers' personal attitudes in determining building thermal-energy, lighting performance, and openings' schedule. A university building located in central Italy was selected. Different rooms with equivalent end-use, geometry, exposure, construction characteristics, occupancy, and appliances were considered. Occupants could be considered as peers, since they carry out the same job and schedule and have the same education and age. Nevertheless, they presented different attitudes and thermal perception, therefore producing different energy need. In order to assess peers' behavior, office rooms were continuously monitored in terms of indoor visual-thermal comfort parameters, electricity consumption, and door/window opening rate in spring, summer, and winter conditions. Occupants' attitudes were compared by considering also the outdoor climate conditions. Results demonstrated that occupants' individual behavior represented a key variable affecting building management of large buildings even if the occupants can be theoretically assumed to be "peers". Significant discrepancies were found between the monitored rooms, demonstrating that typical peers do not behave the same at all, but require differential energy needs that should be considered while predicting thermal-energy and lighting behavior of massive institutional buildings.

1. Introduction

In recent years, the global world energy use has rapidly increased, taking building energy consumption to the levels of transport and industry and even more [1]. The main reasons for this deep change lives in the broad population growth, the increase of building services and comfort levels, and obviously, the rise of time spent indoor. In particular, commercial and institutional buildings, which include a wide variety of energy appliances and uses, have expanded their energy consumption from 11% to 18% from the 1950s in the USA, while the European average, accounted for around 11% of all final energy use in 2004 [1]. Therefore, the environmental effects of the building stock could be significantly improved by increasing the energy efficiency of functional buildings, i.e. using less energy for heating, cooling, lighting, and other appliances, without affecting human health and comfort conditions [2]. The spread of building energy efficiency truly is a key issue in the European strategy for smart and sustainable growth [3], in fact, the European Directive 2010/31/EU (EPBD) requires the energy refurbishment of existing building stock and the construction of all new buildings to be Nearly Zero Energy by 2020 [4]. When public buildings are considered, the above-mentioned deadline is moved up to the end of 2018, confirming the strategic role played by these buildings in the European energy context. Institutional buildings are asked to be a model of good practice in the context of sustainable building development. Moreover, in educational and research buildings occupants spend the most of their daytime doing sedentary intellectual activities that require specific indoor comfort conditions [5]. Given these considerations, a large amount of literature faces the improvement of the energy efficiency of commercial and institutional buildings, and usually focuses on technical approaches. Lin and Hong [6], for example, investigated the impact of factors such as indoor temperature set

* Corresponding author at: Department of Engineering, University of Perugia, Via G. Duranti 93, 06125 Perugia, Italy.
E-mail address: anna.pisello@unipg.it (A.L. Pisello).

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Fig. 1. (a) Picture and (b) plan view of the monitored institutional building in Perugia, Italy.

Fig. 2. Typical indoors of a monitored office room.

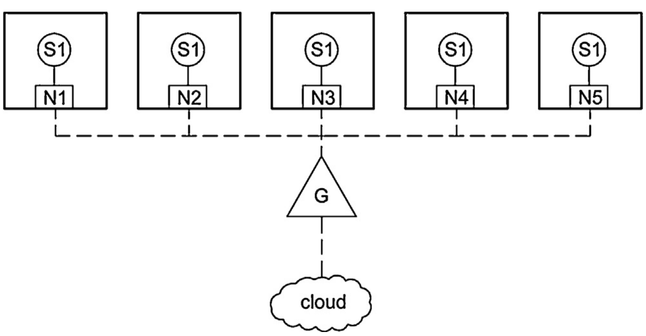

Fig. 3. Scheme of the positioning of the Wireless Sensor Network inside the 5 monitored offices (N = nodes, S = sensors, G = gateway, 1–5 = monitored rooms).

point, air infiltration, building type, and climate on the variation of space-heating energy use in office buildings. Furthermore, a large number of researches develop active and passive methods for reducing the energy demand of HVAC systems. Passive methods generally concern heat loss reductions through improved insulation of the building envelope [7,8]. Active methods tend to improve or upgrade the building components, e.g. by means of energy and emission analysis of institutional building chillers [9,10].

A thermal-energy efficient and sustainable design of institutional buildings, however, can only be obtained by factoring several parameters, such as the interaction between indoor and outdoor environment and building end-use and operational processes. Among the parameters to be taken into account, occupants' behavior is a key factor influencing its thermal-energy performance. In fact, human attitudes and habits in interacting with system controls and building envelope are widely recognized parameters affecting building indoor microclimate and energy needs [11–14]. They can also significantly alter the effectiveness of well-acknowledged energy efficient retrofit solutions [15,16]. Therefore, both technical and human based parameters have to be taken into account in the achievement of building energy efficiency. In this view, Chen et al. [17] carried out a statistical survey and a one-year monitoring in residential buildings in order to define three-levels of systematic definitions of occupant behaviors. Similarly, Hong et al. elaborated a framework of Drivers, Needs, Actions, and Systems (DNAS) to standardize energy-related occupant behaviors in buildings [18] and developed a schema to be used for the implementation of such DNAS framework into building simulation tools [19].

Accordingly, predictive tools for studying thermal-energy performance of buildings should take into account even the personal variation of behavioral attitudes, together with classic occupancy schedules [20,21]. In order to overcome occupant behavior modeling uncertainty, O'Brien and Gunay [22] proposed a robust design method to model people's adaptive actions on daylighting and solar shading in building performance simulation. Fabi et al. [23], instead, collected numerous data from an experimental campaign to verify the predictive accuracy of different existing models of window opening in buildings. Still considering occupants' manual control of solar shades, Yao et al. [24] elaborated a stochastic model to be coupled with EnergyPlus dynamic simulation software for co-simulation purpose. The obtained results showed that infrequent and unappropriated use of solar shadings in office buildings was found to contribute to the decrease in indoor thermal comfort.

On the other hand, aware and green occupants' attitudes can be considered as possible energy retrofits, especially in those buildings where other invasive and expensive energy retrofits are unachievable [25,26]. Therefore, people should be educated to sustainable behavior in order to achieve overall energy efficient buildings. To this aim, eco-feedback is a widely diffuse practice based on providing to individuals or groups of users' feedbacks on their energy behaviors and possible negative consequences aiming at increasing their environmental impact awareness [27]. A novel eco-feedback system was investigated by Gulbinas and Taylor [28] who showed the influence of organizational network dynamics in energy conservation among commercial office building occupants. Moreover, they demonstrated the diverse impact of eco-feedback in office buildings compared to residential buildings. Assessing various feedback types, Kamilaris et al. [29] analyzed the response of different office employees in a university building to individual feedback on energy use at the work-desk finding aware use of appliances and energy reduction until 13 weeks after the feedback removal. Nevertheless, simply informing people on their consump-

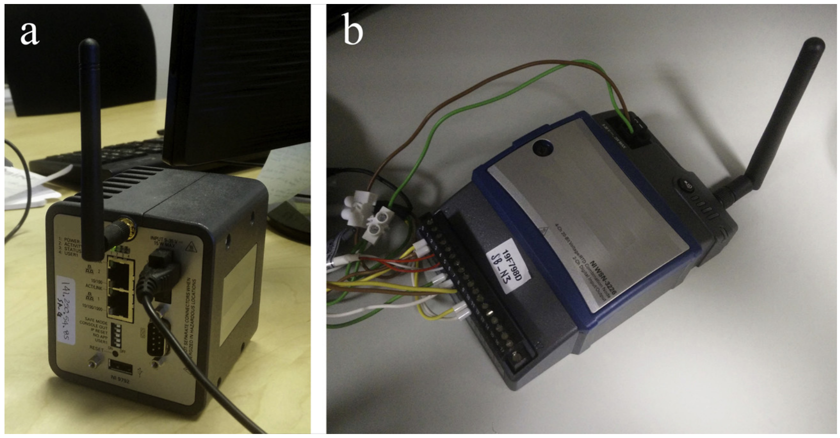

Fig. 4. Picture of the (a) gateway and (b) node installed in each of the monitored office room.

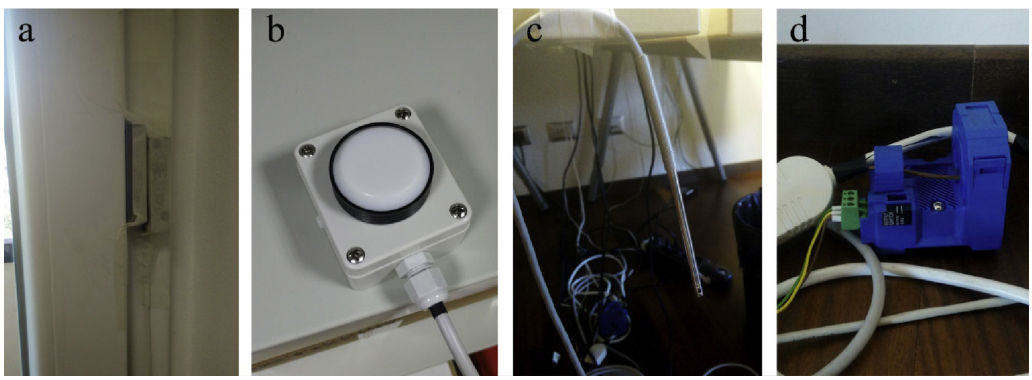

Fig. 5. Picture of the sensors installed in each office: (a) opening-closing of windows, (b) lux meter, (c) air temperature probe, (d) ammeter.

Table 1
Summary of the differences in the monitoring of the five office rooms selected.

Room number	Occupancy level [people per room]	Monitored appliances
1	3	3 computers
2	2	2 computers
3	2	2 computers
4	3	3 computers
5	2	2 computers

tion behaviors does not ensure their behavior change. It is necessary to understand personal motivations that lead to sustainable behavior in order to influence eco-practices [30]. Therefore, Barreto et al. [31] studied such motivations in the context of residential buildings showing that they are driven by both individuals' environmental care and self-perceived responsibility, need for a sense of security, and expense management.

Additionally, several research studies aimed at evaluating the behavior of occupants' peer networks. In existing literature peers are usually considered to act similarly in terms of energy saving and behavioral attitudes [32,33]. For instance, Jones and Lomas [34] performed a clustering of electrical energy demand in UK buildings based on the socio-economic and dwelling parameters affecting electricity consumption. Chen and Taylor [35], instead, developed a multi-layer network model, that considers a peer network and a geospatial building network as a single layered network, to model the diffusion of energy saving behaviors. All these research contributions generally assume that occupants acting as peers tend to behave the same when interacting with similar indoor and outdoor microclimate conditions. However, people's attitudes are also affected by their social and educational private background. Therefore, the so considered peers can be found to behave differently when acting in similar contexts in terms of environmental boundary conditions. In this view, this experimental research has the aim of demonstrating that peer occupants can act differently depending on personal background, attitudes, and habits, thus affecting building thermal-energy performance.

2. Purpose of the work

Starting from previous occupants' studies, which consider peers' identical response to similar environmental conditions and investigate their role in determining building thermal-energy performance, this research stresses how different peer occupants' personal attitudes and habits can affect the indoor environmental behavior of buildings, given their intrinsic variability. In fact, despite most of the occupants of the selected case study, which is a university research building used as office building, can be identified as "peers" in terms of age, educational background, and time schedule, their cultural background, energy need, indoor thermal perceptions, microclimate thermal taste and controls are significantly different from one to another. This leads to significant differences in the thermal-energy performance of different areas situated in the same building. Therefore, peers' personal attitudes represent a key variable to be considered while predicting the overall building thermal-energy behavior of institutional buildings such as university buildings with investigators' offices. Nevertheless, peers' personal habits and thermal perceptions imputable to very subjective attitudes and preferences are usually neglected in peer network analyses. The purpose of the present work is to (i) identify the different attitudes and energy behaviors of occupants typically considered as peers, (ii) correlate occupants' habits with outdoor

Table 2
Main technical features of the sensors installed in each office.

Sensor	Type	Dimensions [mm]	Measurement range	Working Temperature [°C]	Cable length [m]	Accuracy
Lux meter	Photodiode	58 × 65 × 52	20 ÷ 2000 lx	−20 ÷ 60	10	<5%
Temperature probe	PT1000 class A Cable: Teflon + silicon rubber	6 × 100	−40 ÷ 200 °C	−20 ÷ 60	3	<0.15 °C @ 0 °C
AC current transucer	APR B10	50 × 40, 18 (Ø)	30 ÷ 6000 Hz	−20 ÷ 60	–	<±1%
Open/close sensor	Magnetic	30 × 10 × 10	on/off	−25 ÷ 70	3	–

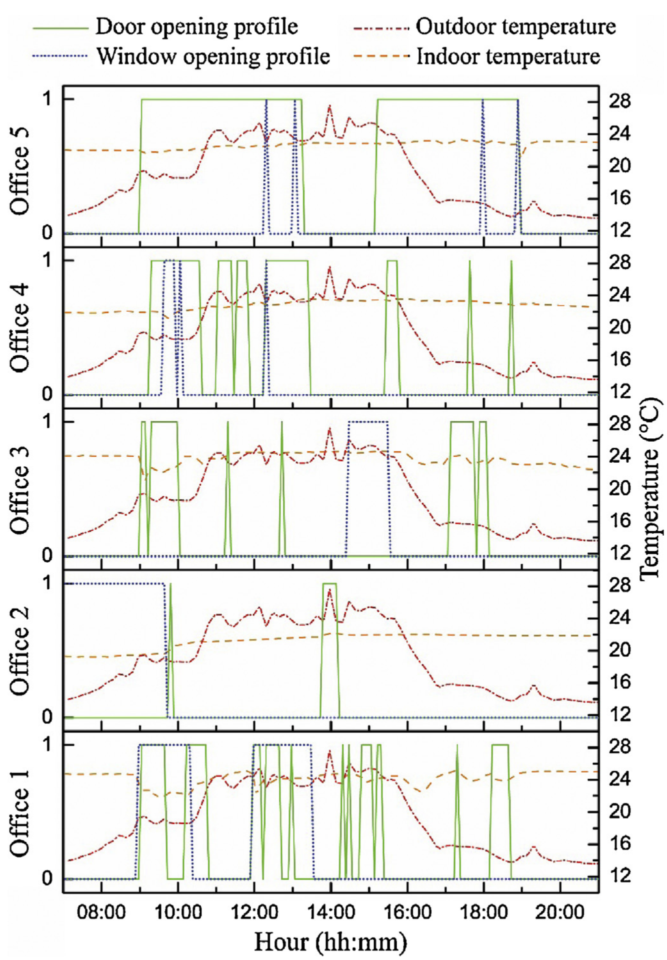

Fig. 6. Indoor and outdoor temperature and door/window opening profile of the investigated office rooms in a selected day, i.e. May 26th, representative of spring environmental conditions (1 = open door/window, 0 = closed door/window).

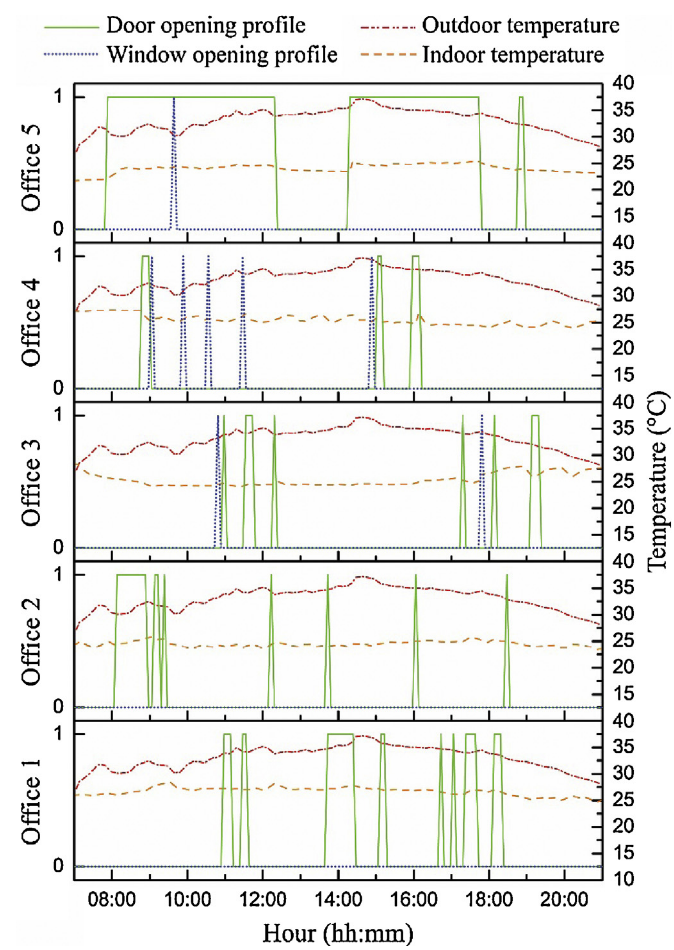

Fig. 7. Indoor and outdoor temperature and door/window opening profile of the investigated office rooms in a selected day, *i.e.* July 8th, representative of summer environmental conditions (1 = open door/window, 0 = closed door/window).

climate conditions, and (iii) define how such divergent habits can influence the thermal-energy performance of the indoor building environment.

To this aim, a group of peers working in different rooms of a university research building characterized by the same end-use, i.e. researchers' office rooms, were considered. In particular, five office rooms characterized by the same orientation, architectural layout, size, construction technology, and HVAC system were selected for the continuous monitoring of occupants' attitudes. The occupants are represented by peers having the same job, similar age (i.e. from 25 to 30 years old) and educational level, and theoretically the same working schedule.

The continuous monitoring of the main indoor microclimate indicator, i.e. indoor air temperature and illuminance over the work plane, is therefore carried out, and data about occupants' daily attitudes in terms of electricity use, switching on/off of lights, and opening/closing of doors/windows were collected and analyzed. Additionally, a survey among the occupants was carried out to support the experimental collected data in identifying the different habits of the peers representing the main users of the selected case study institutional building. In this perspective, the study wants to demonstrate how peers behave differently in their offices located in large institutional buildings, despite their clear theoretical similarities. Therefore, in order to perform reliable studies and predictions of these typically massive constructions, random behaviors should be considered, also because peers' attitudes showed to be very weakly driven by outdoor environmental parameters usually selected as predictor parameters for energy need.

3. Methodology

The methodology implemented in the present work consisted of the following main steps:

- Selection of (i) the case study building, (ii) the peer occupants, with comparable age, educational background, and working schedule, and (iii) rooms with same characteristics in terms of

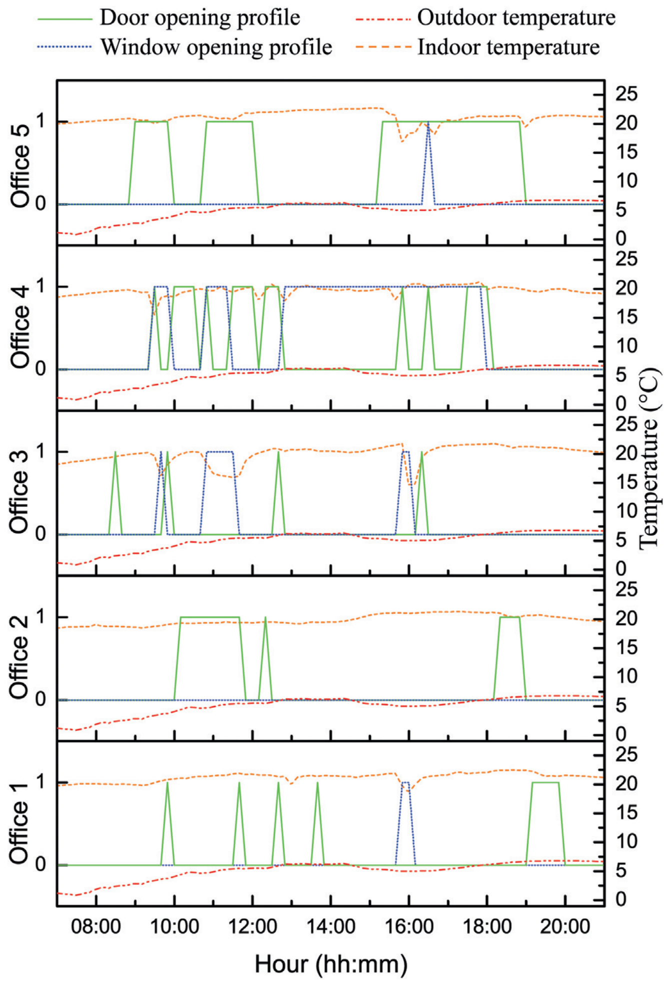

Fig. 8. Indoor and outdoor temperature and door/window opening profile of the investigated office rooms in a selected day, *i.e.* January 14th, representative of winter environmental conditions (1 = open door/window, 0 = closed door/window).

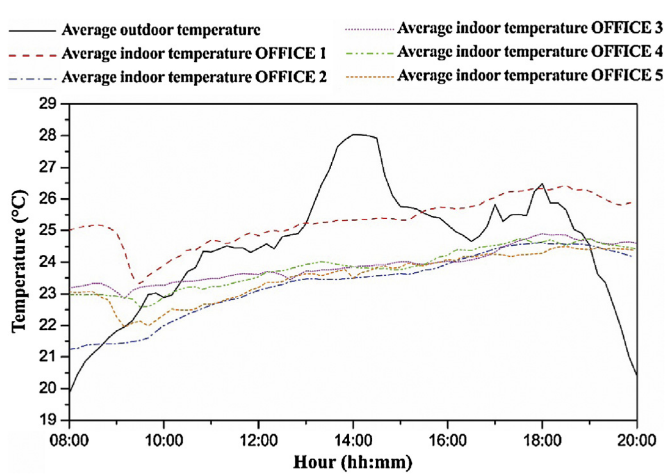

Fig. 9. Average outdoor and indoor temperature distribution of the investigated office rooms during spring.

orientation, geometry, HVAC systems, and construction technologies to be monitored.

- Continuous monitoring of the main indoor parameters related to (i) indoor microclimate and (ii) occupants' activity inside each one of the selected office rooms by means of dedicated microclimate monitoring stations during spring/summer/winter 2015.

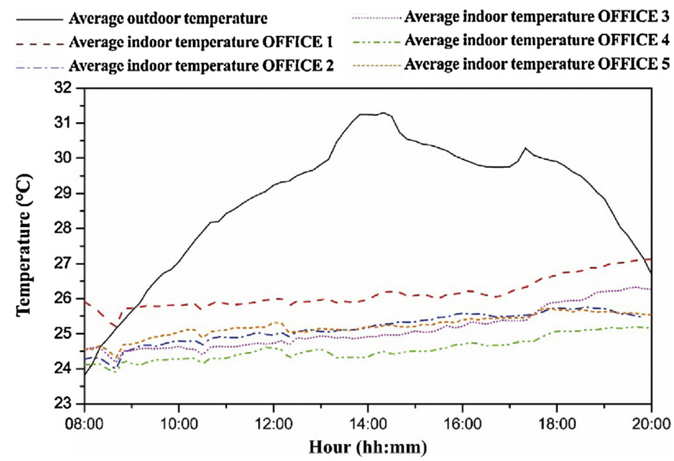

Fig. 10. Average outdoor and indoor temperature distribution of the investigated office rooms during summer.

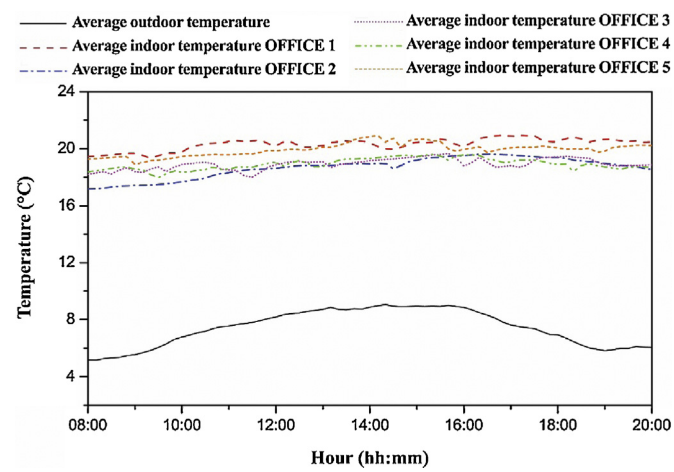

Fig. 11. Average outdoor and indoor temperature distribution of the investigated office rooms during winter.

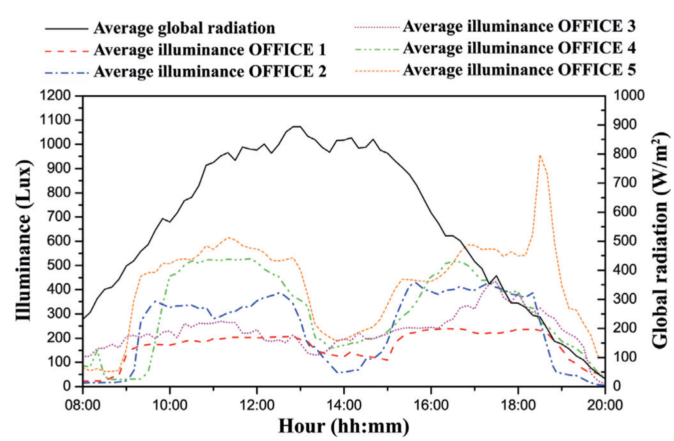

Fig. 12. Average global radiation and illuminance conditions of the investigated office rooms during spring.

- Survey campaign among the monitored peer network in order to support the experimental data provided by the indoor microclimate station to better identify each occupant's behavior.
- Post-processing of the data, statistical analysis, and comparison of the results.

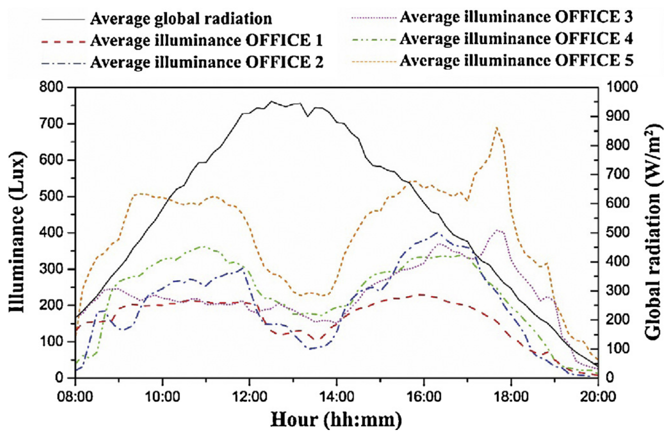

Fig. 13. Average global radiation and illuminance conditions of the investigated office rooms during summer.

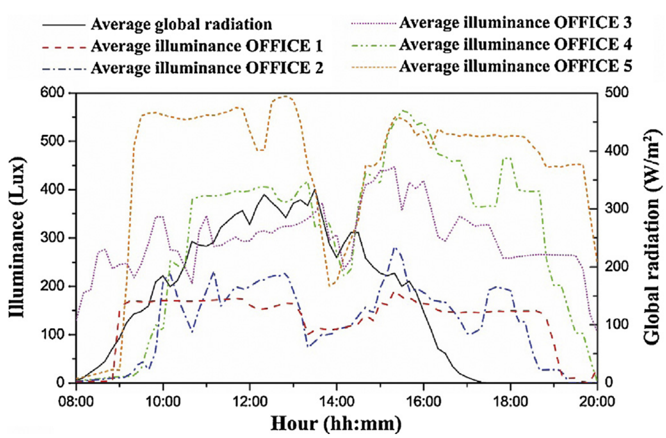

Fig. 14. Average global radiation and illuminance conditions of the investigated office rooms during winter.

3.1. Description of the case study

The case study building is represented by a research office building situated inside the campus of University of Perugia, Italy (Latitude: 43°07′04″N; Longitude: 12°21′03″E) which houses the Department of Engineering (Fig. 1). It is a rectangular-shaped two-story building, with gallery along the first floor, hosting mainly laboratories in the ground floor and professors and researchers' offices in the first floor. The structural system consists of reinforced concrete columns and beams. The opaque envelope consists of traditional external brickwork (0.10 m), rock wool insulation panel (0.10 m), air gap (0.10 m), and internal gypsum plasterboard (0.020 m), with a global thermal transmittance of 0.34 W/m^{2}K. The partitions are composed of two layers of gypsum plasterboard (0.03 m) with interposed hollow bricks (0.10 m). The roof is made of an internal layer of plasterboard (0.013 m), air gap (0.20 m), glass wool insulation (0.14 m), asphalt (0.010 m), and white tiles paving (0.005 m). The windows are composed by double clear glass panes (4 mm–10 mm with 6 mm air) with aluminum frame and internal venetian blinds.

The five monitored offices are all located on the first floor and are on the same South-West oriented side of the building. They are all almost rectangular shaped and have the same dimensions (about 4 × 4 × 2.9(h) m). They are all provided with two big windows on the South-West side and are equipped with the same HVAC system and lighting system. Heating and cooling systems operate between October, 15th–April, 15th and June, 1st–September, 30th, respectively. Additionally, each office is equipped with a dedicated thermostat, which is set up by the occupants according to their personal needs and thermal perceptions.

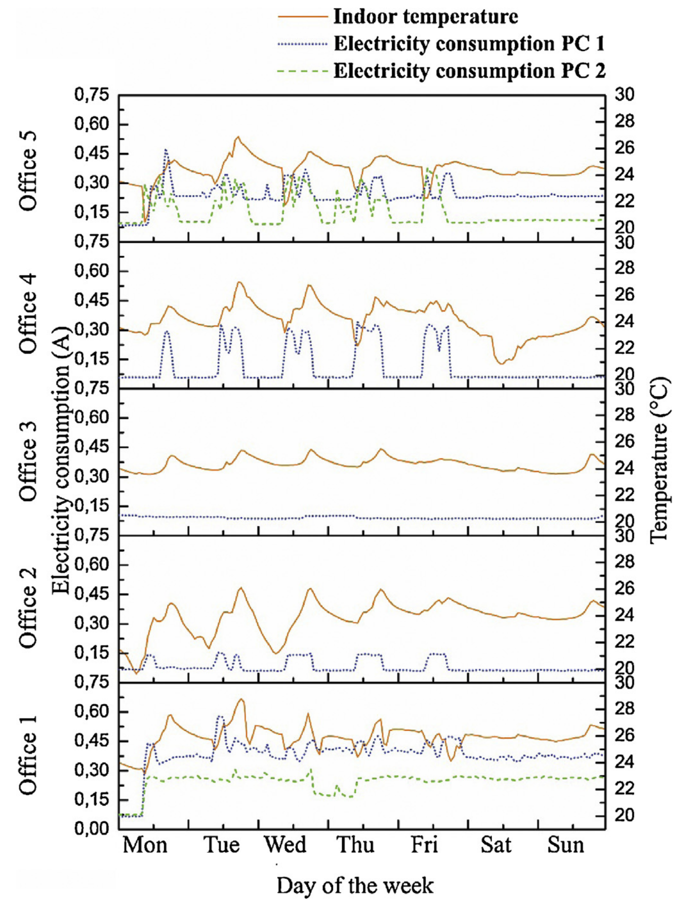

Fig. 15. Electricity consumption profile and indoor temperature distribution of the investigated office rooms in a reference spring week (from May 11th to May 17th).

Each office room is also equipped with two or three computers and hosts two or three people. A typical office room is showed in Fig. 2. Table 1 summarizes the main characteristics of each monitored office room in terms of occupancy level and appliances.

3.2. Continuous monitoring setup

The continuous monitoring setup is represented by a Wireless Sensors Network (WSN) system. The system is composed of five dedicated indoor microclimate monitoring stations, each one consisting of different sensors and a collector node (Fig. 4) connected to sensors by cable. Monitoring stations are positioned inside each one of the five office rooms. Then, nodes communicate the collected data via wireless to a gathering gateway (Fig. 4), as showed in Fig. 3.

More in detail, four types of sensors are used to collect the following indoor parameters (Fig. 5):

- Opening/closing of doors and windows (magnetic sensors);
- Illuminance level (lux meter);
- Indoor air temperature (air temperature probe);
- Electricity usage (ammeter).

Each sensor is able to register data every five minutes and send them to the relative node and, finally, to the gateway. The main technical features of the monitoring equipment are summarized in Table 2.

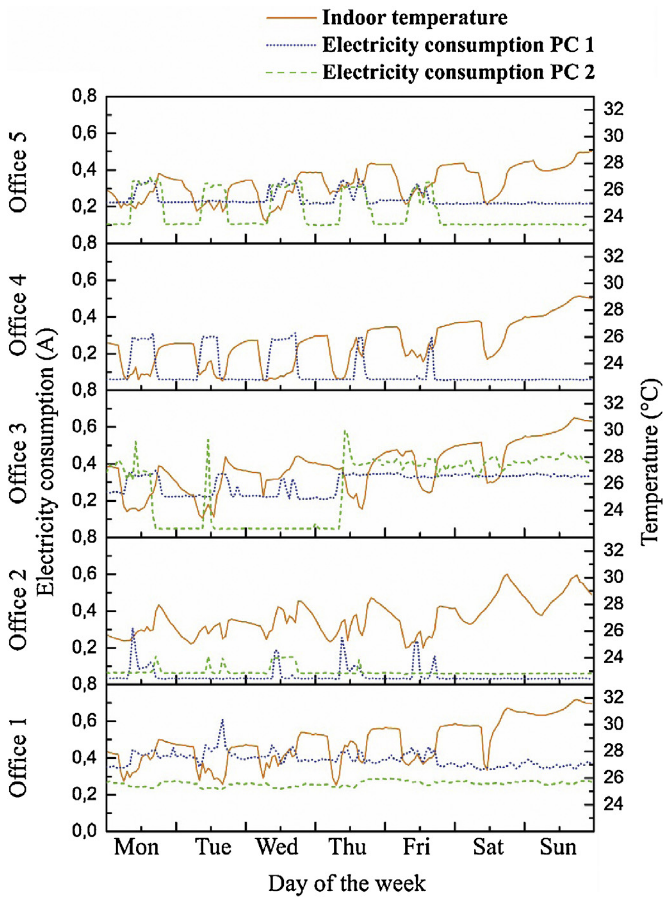

Fig. 16. Electricity consumption profile and indoor temperature distribution of the investigated office rooms in a reference summer week (from June 29th to July 5th).

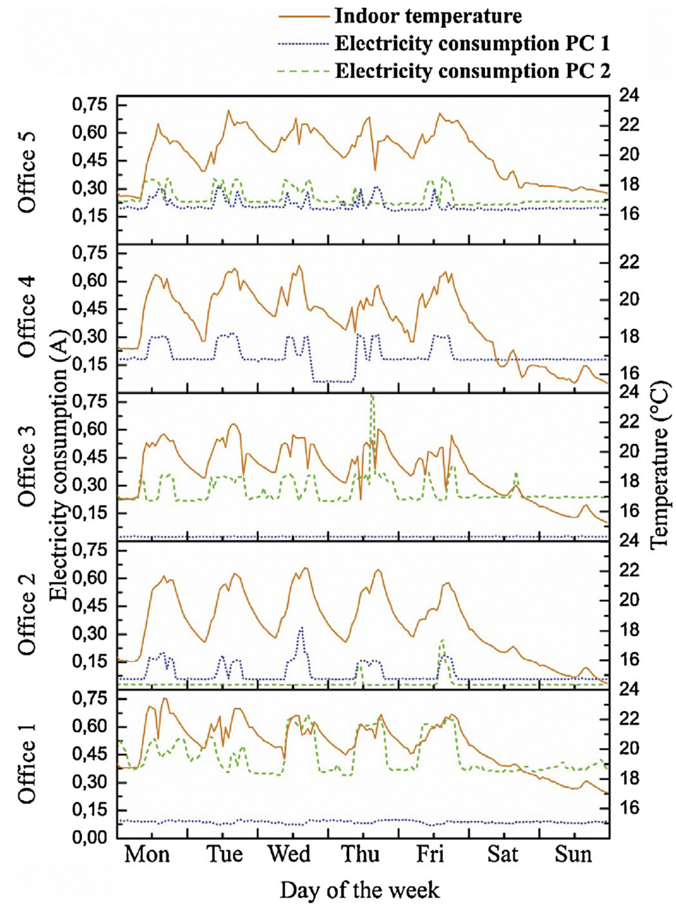

Fig. 17. Electricity consumption profile and indoor temperature distribution of the investigated office rooms in a reference winter week (from January 11th to January 17th).

3.3. Data analysis

First, the post-processing of the collected data is performed with reference to the outdoor continuously monitored weather data provided by a dedicated weather station positioned on the roof of the office building.

In particular, the analysis of the correlation level between the monitored indoor parameters and outdoor microclimate parameters is performed, by considering the outdoor air temperature, the relative humidity, the global incoming solar radiation, and the wind velocity as most representative of the outdoor weather boundary conditions. The main goal is to determine how the indoor measured parameters are affected by time-varying external environmental boundary conditions.

To this aim, the variation between the illuminance level, the indoor air temperature, and the closing and opening attitudes for doors and windows with varying outdoor weather boundary conditions is evaluated.

Additionally, the average variation of the indoor measured parameters when considering a typical week working day is analyzed in order to better identify the role of occupants' personal attitudes in determining indoor environmental conditions of equivalent rooms.

Secondly, the analysis of the collected data is performed by considering occupants' behavior in order to assess how personal attitudes and specific thermal perceptions of peers can affect the indoor environmental parameters with equal conditions in terms of room geometry, exposition, and construction and HVAC technology. More in details, the percentage of hours in the day during which the doors and windows are open is calculated, in order to detect the different occupants' behaviors and to estimate how this would affect the indoor thermal comfort inside each room. Therefore, the variation of the monitored indoor parameters with reference to the opening/closing of both doors and windows is also assessed. Lastly, the specific hourly consumption of appliances during one representative spring, summer, and winter week is evaluated and a specific electricity use profile is defined for each office room.

4. Results

4.1. Peers' occupancy profiles

During the post-processing of the continuous monitoring campaign, two occupancy profiles of each of the investigated office rooms are outlined by considering the window opening and the door opening patterns, respectively. The so built profiles are then compared with the outdoor and the indoor monitored environmental conditions, in order to investigate a possible correlations between them. In particular, the outdoor and the indoor temperature contours of each office room are outlined and superimposed to the previously mentioned door and window opening profiles. The obtained results show a large variation between the five peers' opening profiles, in spring, summer, and winter period. Spring profiles are partially correlated with the outdoor environmental conditions, and have a non-negligible effect on the indoor thermal contour of the office rooms. Still, as displayed in Fig. 6, which shows the aforementioned profiles for a representative spring day, i.e. May 26th, all the office rooms seem to react differently to identical envi-

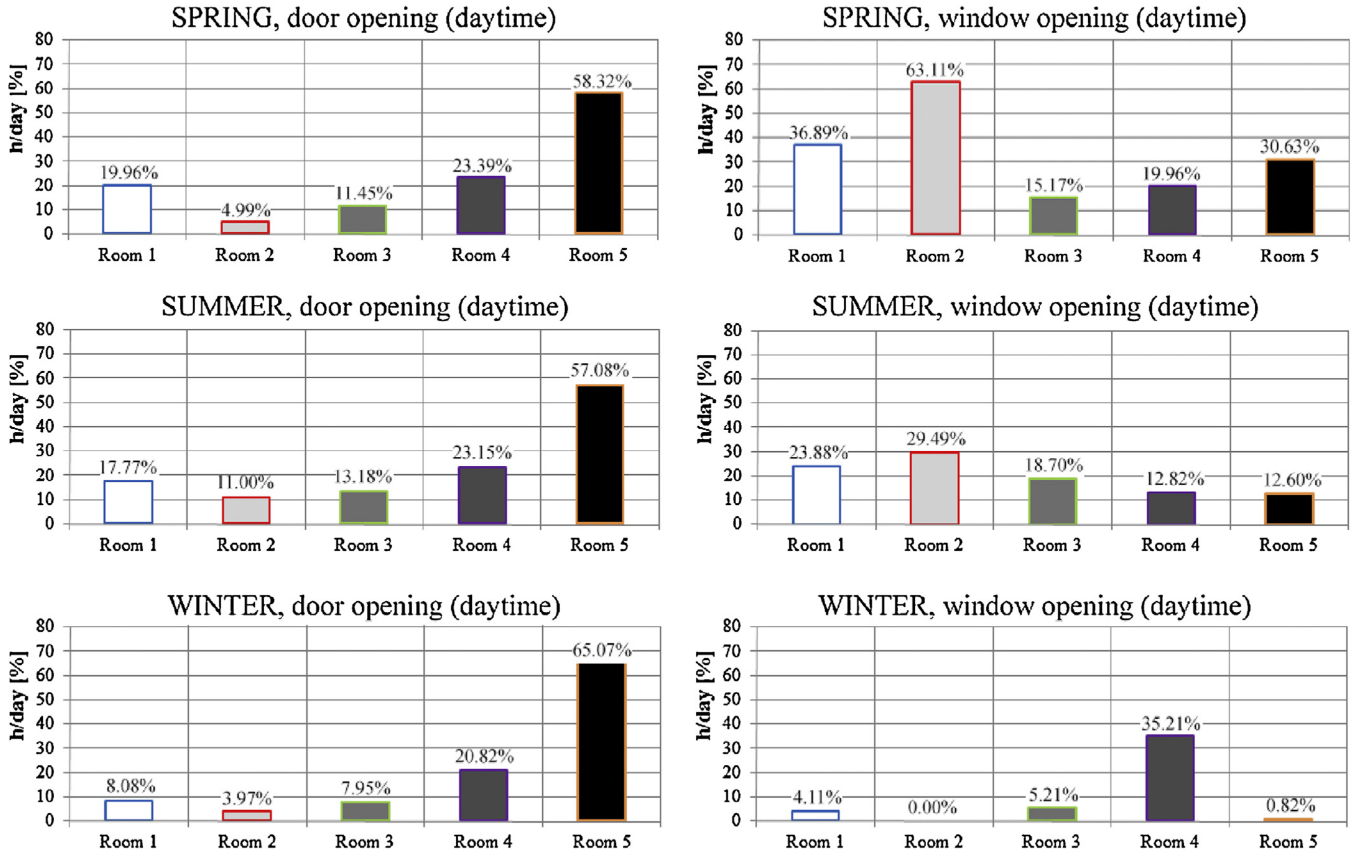

Fig. 18. Door/window opening percentage in spring, summer, and winter daytime.

ronmental stimuli. All the peers, in fact, tend to open doors and windows during their staying inside the office, but some of them are more inclined to frequently change the door/window opening status than others. Furthermore, the considered offices clearly show a different use of doors and windows during the day, e.g. office 5 is associated to a large open door attitude (long lasting mode) and a few, short window opening events, while office 1 shows two large window opening periods and an irregular use of the door.

Summer profiles, on the contrary, generally seem to be decoupled from the outdoor and indoor temperature outlines. Fig. 7, which represents the door/window opening profiles of a representative summer day, i.e. July 8th, shows that all the office rooms seem to react differently to identical environmental stimuli. Some of the peers, in fact, only act on doors, leaving the windows closed for the whole day, while others tend to keep the doors shut for longer periods and open for short times the windows.

Lastly, winter door/window opening profiles, shown in Fig. 8, confirm that all the considered office rooms tend to exercise a different control on both door and windows. Indeed, even if the indoor temperature of the offices is taken and kept at a pseudo-constant level in each room, some of the offices occupants prefer to keep the window shut along the entire day, and act mostly on door status, i.e. in office 1 and 2. On the other hand, office 5 likes better to maintain the door open during the working hours, and only open for short times the window.

4.2. Peers' indoor thermal control

Figs. 6–8, reveal interesting details about the indoor temperature trend of each office room during the hours of work, which can be generalized to the entire spring, summer, and winter period, respectively. During spring, in fact, the opening of doors and windows clearly plays a significant role in the thermal regulation of the room indoor temperature. Generally, the indoor thermal profile varies consistently with the door/window opening events. In summer, on the other hand, the influence of the outdoor thermal conditions on those of the specific thermal zone is significantly reduced. This summer decoupling is associated to a less frequent doors and windows opening, and is even more perceivable when the seasonal average temperature values, reported in Figs. 9–11, are considered. In summer, in fact, the gap between the outdoor and the indoor thermal conditions is way more sensible than in spring, reaching average values of about 7 °C, i.e. office 2 around lunchtime. This huge difference is even bigger for winter indoor and outdoor thermal profiles. Fig. 11, in fact, shows a significant spin-off between these contours, and differences reaching even 16 °C almost during the entire day. Looking more carefully at Figs. 9–11, it is possible to observe that the indoor thermal profiles of the investigated office rooms, even for average values, do not converge on a single contour, but end up identifying a sort of “thermal band”. This band is thicker in spring, were differences of about 4 °C can be reached between the considered rooms, and more narrow in summer and winter, were the offices thermal profiles seem more comparable in both shape and values.

Anyhow, the influence of occupants' behavior on the indoor thermal profile of the offices is unequivocally shown in Figs. 15–17, where the considered thermal profiles are outlined for a selected week, together with the electricity consumption of the specific peer. In all the cases, the considered graphs let appreciate the more stable free-floating condition that characterizes the weekend, especially during spring, and the huge impact of the occupant's behavior during the working days. Furthermore, the aforementioned peers' control effect is widely different from one office room to another, in terms of both temperature peak value reached, and

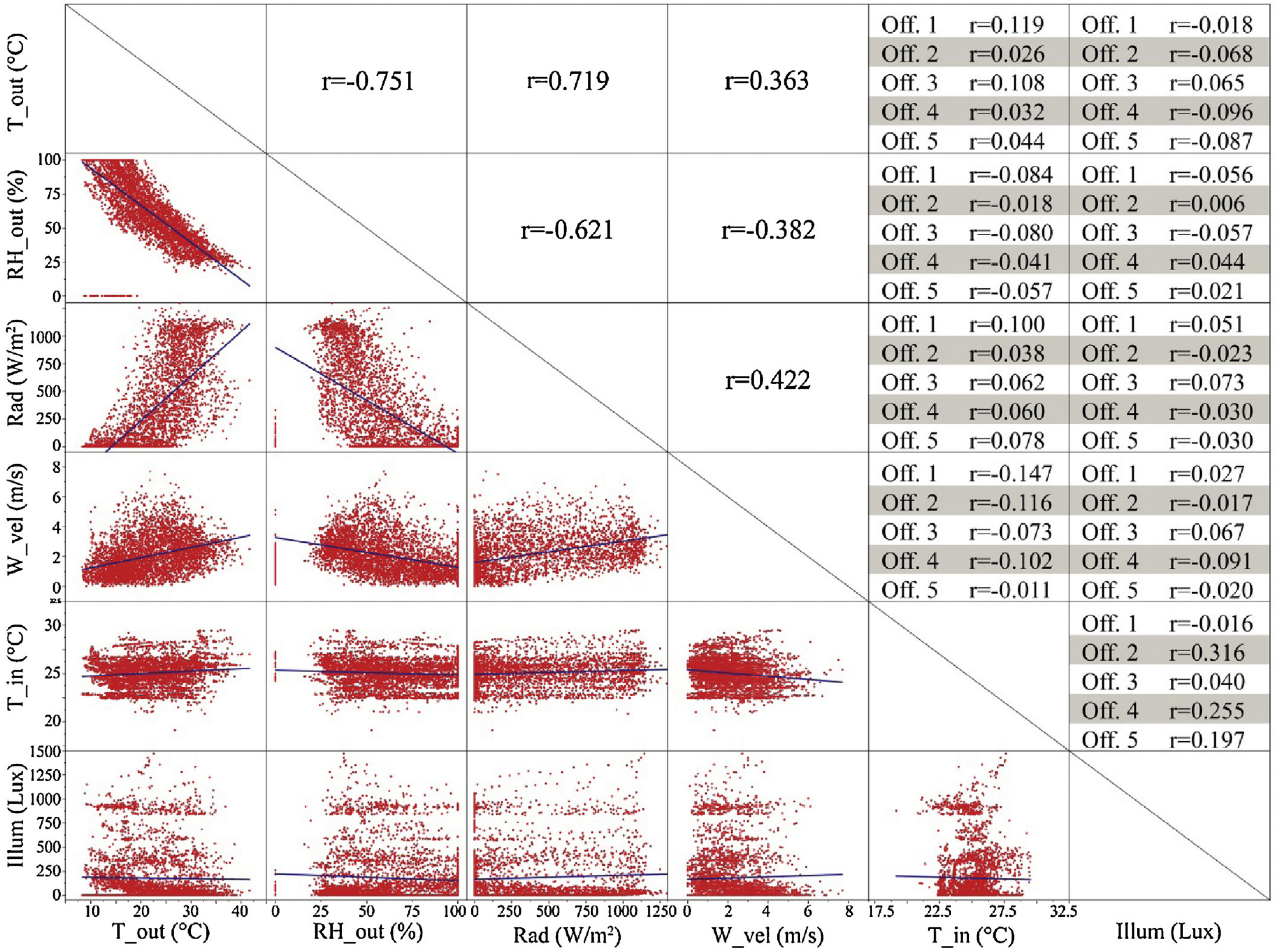

Fig. 19. Pearson's correlation factor between outdoor temperature (T_out), outdoor relative humidity (RH_out), global incoming solar radiation (Rad), wind velocity (W_vel), indoor temperature (T_in) and illuminance (Illum), in spring conditions.

outlined trend. Lastly, it is noteworthy that Fig. 15–17 seem to denote a correlation between the electricity consumption of the computer appliances inside the offices, and their indoor temperature. This correlation though, does not constitutes a seasonal invariant law, since it is direct in spring and winter conditions, while it is indirect in summer.

4.3. Peers' lighting control

The effect of occupant's behavior is also investigated in terms of illuminance on the horizontal work plane in each of the considered office rooms, which, it should be remembered, are characterized by the same orientation. Figs. 12–14 show the average illuminance values for the five investigated offices and the relative outdoor main forcing parameter, i.e. the global incident solar radiation, in spring, summer, and winter conditions, respectively. In this case, the influence of the occupant's behavior is even more evident than for the temperature profiles, since the same external boundary conditions are associated to highly different illuminance contours for each of the considered office rooms, in each one of the monitored seasonal conditions. All the illuminance profiles share a common trend characterized by a pseudo-constant illuminance level during the day, reaching specific values for every office room, and a minimum value during lunchtime. Two offices also show an additional peak in the final part of the day, i.e. office 1 and 3, which is particularly evident in the summer period. It is noteworthy that the maximum illuminance level is associated to office 5, with a peak value of almost 1000 lx, and the minimum to office 1, associated to a top value around 200 lx, regardless of the specific seasonal period. More generally, the two graphs seem to suggest a seasonal invariance of the illuminance level for the different office rooms.

4.4. Peers' electricity consumption

The continuous monitoring campaign carried out in the case study building also includes the analysis of the electricity consumption associated to the computer appliances of each room. The obtained data were post-processed in order to define the specific hourly consumption of every considered appliances during one representative spring and summer week, i.e. May 11th–May 17th (Fig. 15), and June 29th–July 5th (Fig. 16), respectively, and one selected week of winter conditions, i.e. January 11th–January 17th (Fig. 17). The electricity consumption profiles are largely different from one office room to another, in spring, summer, and winter conditions. During the reference spring week, for example, the only computer operating in office 3 maintains a quasi-constant consumption of about 0.1 A, while the one in office 4 shows five local consumption enhancements reaching about 0.3 A, corresponding to the day time hours of the working days, and a baseline consumption of about 0.07 A. The same day time hours enhancement of the electricity consumption can also be noticed in all the offices, and in office 4 and 5 during the representative winter and summer

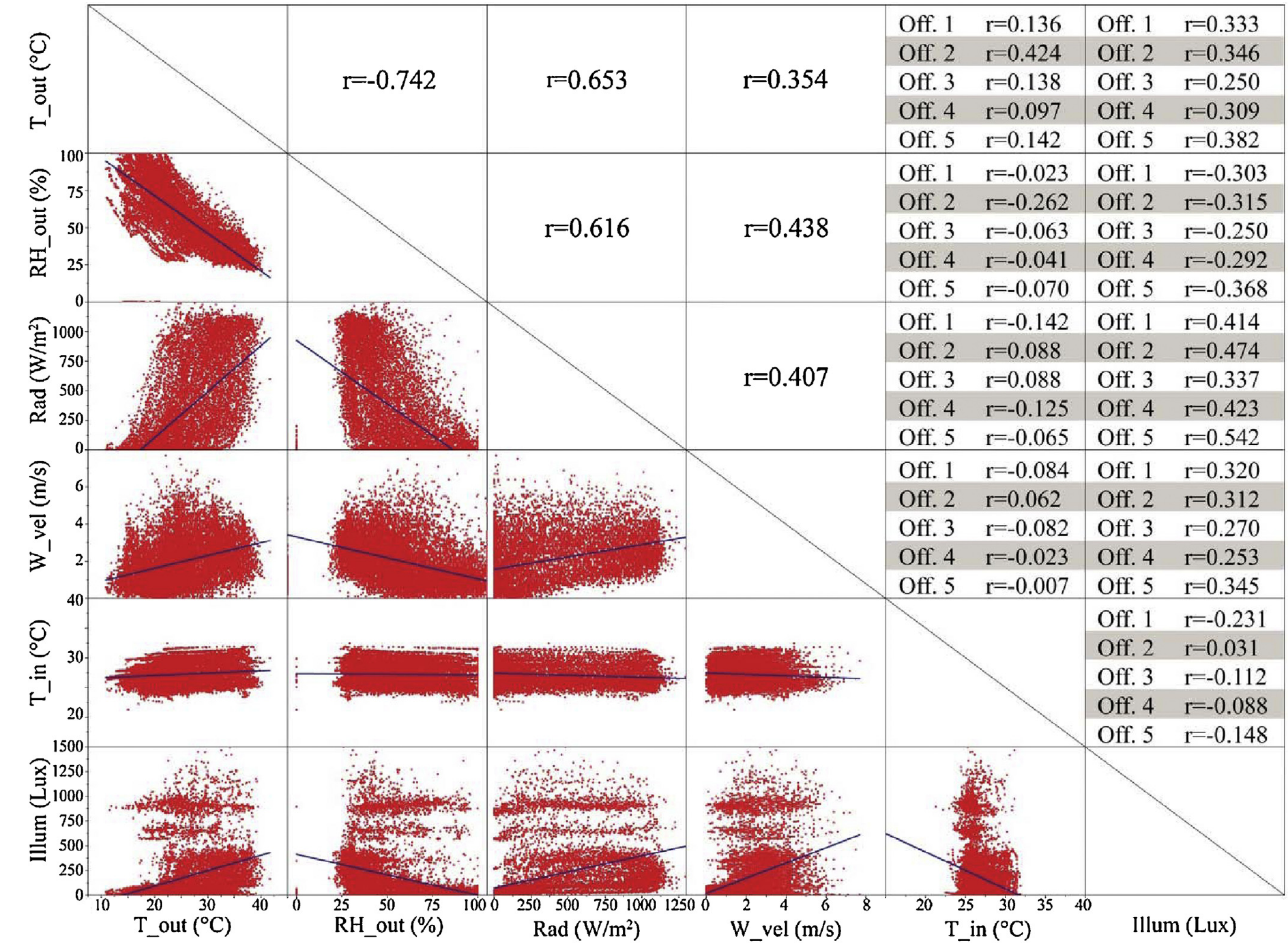

Fig. 20. Pearson's correlation factor between outdoor temperature (T_out), outdoor relative humidity (RH_out), global incoming solar radiation (Rad), wind velocity (W_vel), indoor temperature (T_in) and illuminance (Illum), in summer conditions.

week, respectively. On the other hand, offices 1, 2, and 3 seem to be associated to less predictable energy consumption profiles during the selected summer week, and tend to keep switched on their computers during the night.

Additionally, this representation allows to notice a general high difference between the electricity consumption during the working days and the week-end days, when in most cases, the electric profiles tend to decrease and flatten over a base-consumption value, which varies from case to case. The only exception to this, is represented by office room 3 in the selected summer week, which, on the contrary, shows higher electricity consumptions from Thursday to Sunday, with an average value of about 0.4 A for the two computer appliances in the office.

4.5. Peers' attitudes with varying seasonal weather conditions

In the previous sections, peers' attitudes in terms of door and window opening profile, indoor temperature regulation, and indoor lighting control have been evaluated in spring, summer, and winter conditions for each of the selected office rooms. The obtained results generally show a differential response to the environmental conditions variation. As showed in Sections 4.1 and 4.2, in fact, peers' indoor thermal and lighting control seems to be independent from the outdoor temperature and global radiation, respectively. The same independence seems to be associated to the door opening profile, which, as showed in Fig. 18, accounts for similar percentages in winter, summer, and spring conditions. Therefore, door opening is motivated by personal habits of the specific monitored peer. On the other hand, the window opening profile seems to be partly correlated with the variation of outdoor environmental conditions in spring period. Moreover, it is fully detached from it in summer, when the higher medium outdoor temperatures induce the occupant to maintain the windows closed for longer periods, especially during the hottest hours of the day. In winter conditions, instead, most of the monitored office rooms tend to keep the windows closed, while office 4 seems to open them with higher frequency than in summer and spring.

Considering the complexity of the relationships that drive the occupant's behavior, a fully developed correlation analysis is also performed, in order to better understand the actual reciprocal effect of the monitored parameters. The obtained results are resumed in Figs. 19–21, for spring, summer, and winter conditions, respectively. In this figures, the dispersion graphs and the specific correlation factors associated to each couple of parameters resulting from the combination of outdoor temperature, relative humidity, global radiation, wind velocity, indoor temperature, and illuminance, are given in a 6×6 matrix.

This matrix only shows interesting correlation factors between outdoor temperature, relative humidity, and global radiation, i.e. values above 0.6, in both spring and summer conditions, while all the other couples of parameters cannot be considered as correlated at all. In particular, the interaction between the indoor parameters,

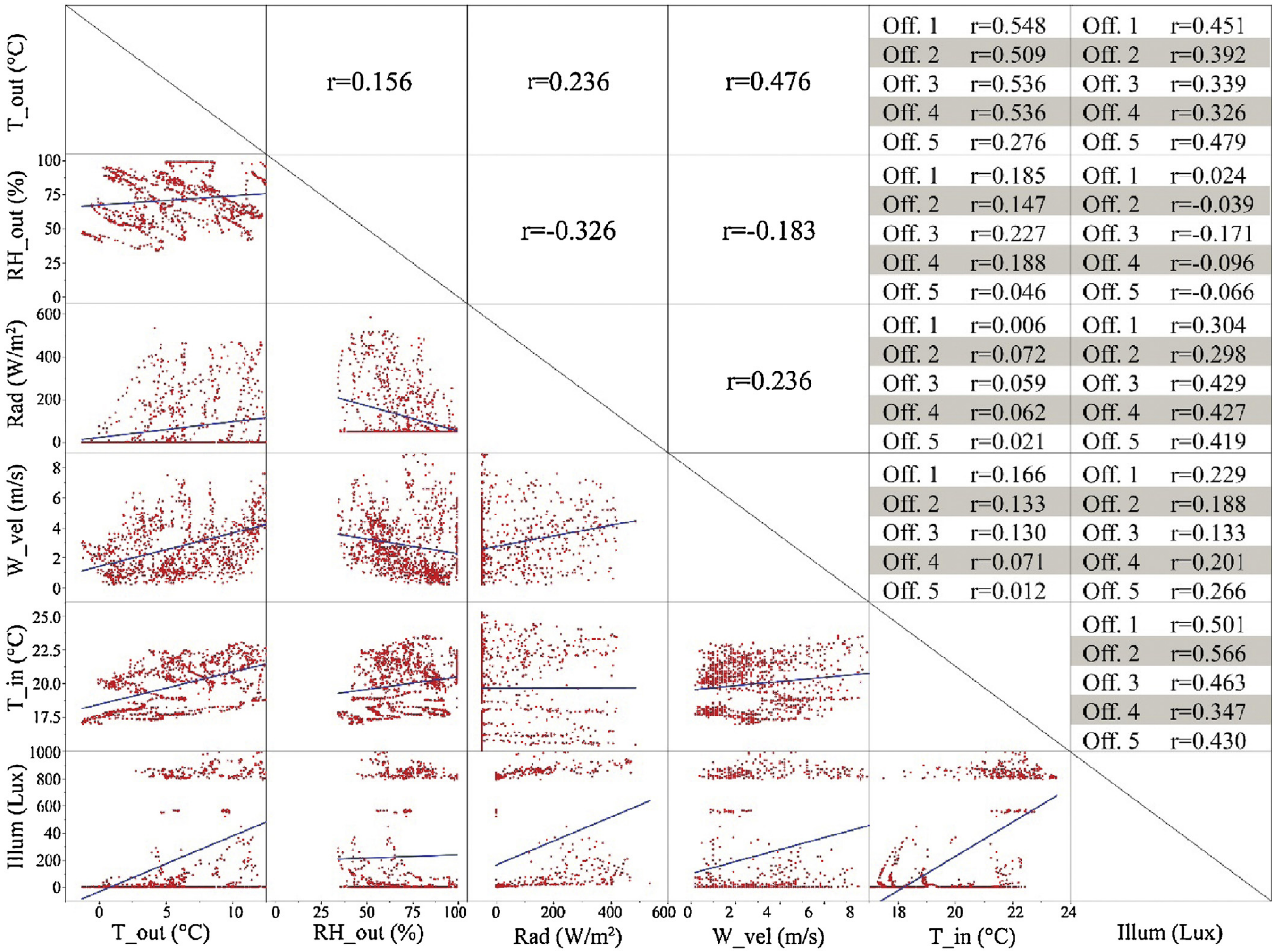

Fig. 21. Pearson's correlation factor between outdoor temperature (T_out), outdoor relative humidity (RH_out), global incoming solar radiation (Rad), wind velocity (W_vel), indoor temperature (T_in) and illuminance (Illum), in winter conditions.

i.e. indoor temperature and illuminance, and between these parameters and the outdoor environmental ones, is always associated to very small r values for each of the considered offices. Furthermore, these correlation factors can be quite different from one office to another, and even switch from positive to negative values. When winter conditions are considered, i.e. Fig. 21, no significant correlation can be established between any of the outdoor parameters. Furthermore, when the other couples of parameters are considered, it can be seen that they all possess a Pearson's correlation factor lower than 0.6, even though the indoor temperature and illuminance level seem to present higher r values when matched with the external parameters than in the previous cases.

Nevertheless, it is clear that there is no correlation between the indoor temperature and the illuminance level of the office rooms, and the main outdoor environmental parameters, demonstrating peers' attitude to control their indoor environmental condition without paying attention to daylighting and outdoor thermal fluctuation.

5. Discussion and conclusion

The analyses so far presented investigate the main outdoor and indoor microclimate indicators and the occupants' daily attitudes associated to five selected office rooms, in terms of electricity use, switching on and off of lights, and opening/closing of doors and windows. The five office rooms are characterized by the same shape, dimension, construction technology, HVAC system and orientation, and their occupants are of comparable age, education level, job, and very similar working schedules. Despite all of these equivalencies, the results obtained from the presented continuous monitoring campaign generally show significant discrepancies between the management of the considered office rooms, which lead to huge differences in terms of their thermal-energy performance of the case study institutional building. These discrepancy cannot be imputed to the variation of the boundary environmental conditions, the construction characteristics of the offices, or the occupants' socio-demographic profile or working schedule, since they were basically fixed by the applied methodology implemented in this work. These intrinsic discrepancies must then be a consequence of other factors such as the peers' cultural background, personal energy need, indoor thermal perception and microclimate taste, and personal attitudes in terms of thermal control and, therefore, of their different individual management. When the indoor thermal control of the office rooms is considered, different preferences of the peers in terms of occupants' thermal control are clearly shown. Office 1, in fact, is always associated to higher indoor temperatures in spring, summer and winter conditions, i.e. an average value of about 25.4, 27.2 and 20.6 °C, respectively. On the other hand, office 4 occupants clearly prefer lower indoor temperature during summer and winter period, i.e. about 25.4 and 18.3 °C, respectively, and this can probably be associated to peers' thermal preference and they personal perception. Personal habits and perception is also the key factor influencing the indoor illuminance of the investigated office rooms, which is highly different from case to case, even though the monitored peers do the same job, work in the comparable office rooms, with very similar working schedules. In fact, when office 5 and 1 are compared, differences of over 500 and 700 lx can be noticed in their average illuminance profiles in specific hours, i.e. 5:30 p.m. and 6:30 p.m. in the average spring and summer, and winter day, respectively. Furthermore, when the average profiles are associated to a medium day value, illuminances of about 167.4 and 420.8 lx are found in spring, 159.6 and 391.7 lx in summer, and 58 and 143.4 lx in winter conditions, for office 1 and 5, respectively. Continuing the comparative discussion, the presented figures perfectly represent the diverse electricity use of the peers in different offices, and allow appreciating various appliances management habits. Some of the peers, in fact, clearly are used to shut down their computer during the night, e.g. office 2 associated to an average night consumption of about 0.07 A, while others prefer to keep it going, e.g. office 1 with an average night consumption of about 0.22 A. Furthermore, significant differences can also be noticed during the weekend days, where most of the peers tends to shut down computers, but office 3 keeps it going, resulting in a high week-end energy consumption. Lastly, the peers' door/window opening profiles also show significant differences from one office to another. Anyhow, it is noteworthy that door opening profiles seem to keep similar base values in each room, with varying the seasonal conditions, while window opening profile, as expected, completely change their trend, even for single offices, turning from spring to summer and finally to winter conditions. Starting from these experimental considerations, it is clear that peers' personal habits and thermal perceptions, which are imputable to very subjective attitudes and preferences, play a significant role (i.e. variability up to 300%) in the building thermal-energy and lighting performance. In institutional buildings, in fact, occupants are usually assumed to behave the same as peers, since they perform the same job every day and they are intended to belong to the same social-behavioral cluster. Nevertheless, despite the people category clustering carried out in this work, they showed to behave very differently, highlighting the necessity to consider more detailed occupancy models for predicting thermal-energy and lighting behavior and different opening schedules in buildings. All these components should be more carefully evaluated, especially for elaborating reliable prediction models or post-occupancy assessment in huge constructions such as institutional buildings.

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