Can we assume that peers behave the same? Results from a continuous monitoring campaign in an office building

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Abstract

It is well established that building energy performances can significantly be affected by occupants’ interaction with both building envelope and control systems. For this reason, a large number of scientific studies in the literature aims at modeling the effect of human behavior on a building, generally considering the assumption that peers occupants tend to behave similarly when exposed to identical environmental conditions. In this work, the importance of peers’ personal attitudes is investigated, by considering both their real door and window opening schedule and their effect on the building thermal-energy and lighting performance. To this aim, five different rooms of an institutional case study building located in central Italy were selected and continuously monitored in terms of door/window opening rate and indoor visual-thermal comfort during summer 2015. The considered rooms are characterised by identical geometry, construction characteristics, exposure and end-use, and their occupants are assumed to be peers, since they all have the same education, age and job. Dedicated surveys were also performed in order to extend the results of the study to a larger sample of peers. Results showed substantial differences among the monitored office rooms in terms of all the investigated parameters, highlighting that occupants’ personal attitudes and thermo-visual preferences do vary from one peer to another, despite identical boundary conditions. This result clearly demonstrates that building thermal-energy and lighting performances of peers, should be more carefully evaluated by considering differential energy needs, especially in massive institutional buildings.

Keywords: Peer’s energy consumption; Indoor thermal and visual comfort; Indoor and outdoor continuous monitoring; Personal attitudes.

1. Introduction

A growing body of research has recently shown how the building sector energy consumption is rapidly increasing all around the world, mostly because of the enhancement of its service, technology and expected comfort levels. In particular, the average energy consumption in commercial and institutional EU buildings, which
generally include a wide variety of energy appliances and uses, accounted for around 11% of the whole final energy use [1]. Therefore, it is clear how huge could be the effect of improving the energy efficiency of buildings, and why the European strategy for smart and sustainable growth heavily relies on the Nearly Zero Energy campaign [2]. The improvement of the buildings energy efficiency, and in particular that of commercial and institutional buildings, generally focuses on technical approaches. Passive methods involving the reduction of heat losses through the building envelope are widely investigated [3, 4], together with active methods aiming at improving the efficiency of HVAC systems and their regulation, e.g. Lin and Hong [5] with their work about the impact of indoor temperature set point, air infiltration, building type and climate, and other parameters on the variation of space-heating energy use in office buildings.

Nevertheless, implementing a thermal-energy efficient and sustainable design of the building only considering technical features can be misleading and produce non reliable data. Human attitudes and habits, in fact, have been proven to highly affect the building indoor microclimate and the related energy needs [6-9]. In fact, human attitudes and habits are widely acknowledged to be parameters able to influence buildings’ indoor microclimate and energy need by interacting with system controls and building envelopes [10-13]. For this reason, they are also able to significantly modify the performance of traditional and usually effective energy efficient retrofit solutions [14-15]. Therefore, both technical and human-based parameters have to be taken into account for achieving building energy efficiency. To this aim, robust design methods, predictive tools, and experimental monitoring campaign were performed in order to be able to take into account the intrinsic variability of personal attitudes in addition to the classic occupancy schedule while assessing building’s thermal-energy performance [16-18]. In this same scenario, significant research effort was spent in order to educate buildings’ occupants to a green and sustainable personal behavior, since a more energy-responsible attitude of buildings’ users could also represent a cost-effective and non-invasive energy retrofit strategy [19]. In particular, eco-feedback systems able to provide building occupants with information about their energy consumptions were developed in order to increase their environmental impact awareness [20-21].

Additionally, multi-layer models were proposed in order to analyze the behavior of occupants’ peer networks, which are constituted by people with similar energy and behavioral attitudes [22-23]. While such research efforts are usually based on the assumption that peers’ occupants behave the same when interacting with equivalent indoor and outdoor microclimate condition, the present study takes into account the fact that people’s attitudes are also affected by their social and educational private background. Therefore, such peers can behave differently when acting within similar environmental boundary conditions.

The present research is therefore aimed at experimentally demonstrating that peers act differently depending on personal background, and habits, thus affecting building thermal-energy performance by a non-negligible way. In detail, the purpose is to (i) identify different attitudes and behaviors of peer occupants, (ii) correlate occupants’
habits with outdoor environmental boundary conditions, and (iii) define how such divergent habits influence indoor thermal-energy performance.

2. Methodology

Starting from previous studies, which consider peers’ identical response to similar environmental conditions, this research wanted to highlight the role of different peer occupants’ attitudes in affecting the indoor environmental conditions in buildings. To this aim, 5 office rooms with the same geometry, construction technologies, HVAC systems, and orientation were selected inside a university office building (Figure 1). Additionally, the occupants of such office rooms were selected as representative of peers’ sharing the same age, educational background, and work-schedule, but characterized by different energy need and indoor thermal perceptions that generate non-negligible differences in the thermal-energy performance of different areas situated in the same building.

![Figure 1. View (a) and plan (b) of the selected case study university building with highlighted the monitored office rooms (pink).](image)

The methodology of the work consisted first of the continuous monitoring during summer 2015 of the main indoor microclimate indicators, i.e. indoor air temperature and illuminance over the work plane, and occupants’ daily attitudes i.e. switching on/off of lights and opening/closing of doors/windows (Figure 2-Table 1).

![Figure 2. picture of the sensors installed in each office room: (a) opening-closing of windows, b) lux meter, (c) air temperature probe.](image)
Secondly, a survey was performed among the occupants of both the monitored office rooms and additional non-monitored offices in the same university campus in order to extend the analysis and the experimental results to a larger sample of peers. Afterwards, the statistical analysis and comparison of the collected data was carried out. In this perspective, the study wanted to demonstrate how peers behave differently in their offices, despite their clear similarities. Therefore, in order to perform reliable studies and predictions of these large institutional buildings, randomly variant peers’ behaviors should be considered, also because peers’ attitudes are showed to be very weakly driven by outdoor environmental parameters usually selected as predictor parameters for energy need.

3. Results

First, the results in terms of average indoor temperature trend of each office during the working hours were analyzed (Fig. 3). In particular, a very weak influence of the outdoor thermal conditions on the indoor thermal environment of the different thermal zones i.e. office rooms was detected, mainly due to a low-frequent opening of both doors and windows. In fact, the gap between the summer outdoor and the indoor thermal conditions is sensible, reaching up to average values of about 7°C (i.e. office 2-1 pm). Secondly, the effect of occupant’s behavior was investigated in terms of illuminance level over the horizontal work plane (desk) in each office. Fig. 4 shows the average illuminance values for the five monitored rooms and the relative global incident solar radiation. In this case, the influence of the different and personal occupant’s behavior was found to be more evident compared to the temperature trends, since equal external boundary conditions correspond to very different illuminance levels for each office. In fact, all the illuminance data showed a similar profile characterized by a quasi-constant illuminance level during the day, reaching specific values for every room, and a minimum value during lunchtime. In particular, two offices also showed a peak in the final part of the day, i.e. office 5 and 3. The maximum illuminance level is associated to office 5, i.e. ~1000 Lux, and the minimum to office 1, i.e. ~200 Lux.

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Dimensions [mm]</th>
<th>Measurement range</th>
<th>Working Temperature [°C]</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luximeter</td>
<td>Photodiode 58x65x52</td>
<td>20-2000 lux</td>
<td>-20 ÷+60</td>
<td>&lt; 5%</td>
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<tr>
<td>Temperature probe</td>
<td>PT100 class A, Cable: Teflon+silicon rubber 6x100</td>
<td>-40-200 °C</td>
<td>-20 ÷+60</td>
<td>&lt; 0.15°C @ 0°C</td>
</tr>
<tr>
<td>AC current transducer</td>
<td>APR B10 50x40x40 mm</td>
<td>30-6000 Hz</td>
<td>-20 ÷+60</td>
<td>&lt; ±1%</td>
</tr>
<tr>
<td>Open/close sensor</td>
<td>Magnetic 30x10x10 mm</td>
<td>on/off</td>
<td>-25 ÷+70</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. Main technical features of the sensors installed in each office.
The same independence previously found between peers’ indoor thermal and lighting control and the outdoor temperature and global radiation, respectively, was also found out for the door/windows’ opening profile, as showed in Fig. 5.

Therefore, door opening seemed to be clearly motivated by personal habits of the specific monitored peer. Moreover, the window opening profile was detected to be fully detached from the variation of outdoor environmental conditions. This might be motivated by the fact that the high summer medium outdoor temperatures lead the
occupant to keep the windows closed for longer periods, especially during the hottest hours of the day.

A correlation analysis was therefore performed in order to overcome the complexity of the relationships driving peers’ behavior and to better evaluate the relative effect of the monitored parameters. Fig. 7 summarizes the analysis’ results in a $4 \times 4$ matrix in terms of (i) dispersion graphs and (ii) correlation factors associated to each couple of parameters resulting from the combination of outdoor temperature, relative humidity, global radiation, wind velocity. The Pearson’s correlation factor between the previous parameters and the indoor temperature and illuminance of each office are shown in Table 2.
Interesting correlation factors were detected between outdoor temperature, relative humidity, and global radiation, i.e. values above 0.6, while all the other couples of parameters were found to be not correlated at all. In particular, the interaction between the indoor parameters, 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 office. Furthermore, these correlation factors are quite different from one office to another, and switch from positive to negative values.

Finally, a direct survey was performed in order to extend the results of the experimental analysis previously carried out to a wider sample of peers. To this aim, more office rooms situated in the same university campus were included in the survey in addition to the five monitored offices. Therefore, all the buildings’ peer users occupying both the monitored and the additional non-monitored office rooms were asked to answer some questions about their attitudes and habits while at work, i.e. use of lights, opening of doors/windows, use of regulation systems during the winter and summer season. The results in Figure 8 showed to be consistent with the experimental analysis since, even by enlarging the sample of peers sharing the same age, working schedule, and cultural education, very different habits and environmental behaviors were detected also despite the identical condition in terms of building features and climate boundary. In fact, the percentages of interviewed peer occupants were well distributed in each different considered typology of behavior (Fig.8).

For instance, around 60% of the peers prefer to work with the window open, while around 20% and 22% are used to keep the window closed and to open it just sometime, respectively. Additionally, while 41% of the peers keep the door of the office closed, the 37% usually keeps it always open, and only the 22% tends to keep it open just sometime. Moreover, the majority of the interviewed peers (i.e. 47%) uses the thermal regulation and keeps the lights on while working during the day.

The last part of the study concerned the comparison between the attitudes of the peers occupying (i) the monitored and (ii) the non-monitored office rooms (Fig. 9). Consistently with the previous analyses, no-consistent trends between the behaviors of the interviewed people were detected but, on the contrary, very different attitudes were reported despite the fact that the occupants are peers, due to their personal taste and habits, as previously motivated. In general, by comparing the behaviors of the peers

<table>
<thead>
<tr>
<th>Office</th>
<th>T_out</th>
<th>RH_out</th>
<th>Rad</th>
<th>W_vel</th>
<th>T_in</th>
<th>T_out</th>
<th>RH_out</th>
<th>Rad</th>
<th>W_vel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>0.414</td>
<td>0.320</td>
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<td>0.312</td>
<td>0.031</td>
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<td>0.088</td>
<td>0.062</td>
</tr>
<tr>
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<td>-0.250</td>
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<td>0.270</td>
<td>-0.112</td>
<td>0.138</td>
<td>0.031</td>
<td>0.088</td>
<td>-0.082</td>
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<tr>
<td>4</td>
<td>0.309</td>
<td>-0.292</td>
<td>0.423</td>
<td>0.253</td>
<td>-0.088</td>
<td>0.097</td>
<td>-0.041</td>
<td>-0.125</td>
<td>-0.023</td>
</tr>
<tr>
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<td>-0.368</td>
<td>0.542</td>
<td>0.345</td>
<td>-0.148</td>
<td>0.142</td>
<td>-0.070</td>
<td>-0.065</td>
<td>-0.007</td>
</tr>
</tbody>
</table>

Table 1. Pearson’s correlation factors for the different offices 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)
working in the monitored offices with the ones of those working in the other non-monitored rooms, very randomly dispersed behaviors were registered due to the peculiar habits of the peers, especially with reference to the lights control and window opening regime. Additionally, it was detected how most of the monitored people tend to use the thermal regulation systems (i.e. 67%) compared to the other people who are not used to do it (i.e. 55%).

Figure 8. Results of the surveys in terms of different attitudes of the peer occupants concerning (a) the use of light, (b) the window opening, (c) the thermal regulation use, and (d) the door opening.

Figure 9. Results of the surveys in terms of different attitudes of the peer occupants concerning (a) the use of light, (b) the window opening, (c) the thermal regulation use, and (d) the door opening.
4. Conclusions and Discussion

The present study investigated how peers’ personal attitudes associated to five office rooms equal for architectural design, dimension, construction technology, HVAC system, and orientation change in terms of indoor thermal control, lighting control and opening/closing of doors and windows. In fact, despite these similarities, the results obtained from (i) continuous monitoring and (ii) dedicated surveys performed over summer 2015 showed significant discrepancies between the considered offices, which lead to huge differences in the thermal-energy performance of each equivalent office room, and of the whole building itself. These differences can be imputed only to peers’ cultural background, individual energy need, indoor thermal perception, microclimate taste, and subjective attitudes in terms of thermal control, since all the other parameters i.e. boundary environmental conditions, offices’ construction characteristics, and occupants’ socio-demographic profile or working schedule were the same. In detail, the collected data in terms of indoor thermal control of the offices showed different preferences and perceptions of the peers. Office 1, in fact, always showed higher indoor temperatures, i.e. average value of 27.2 °C. On the other hand, occupants in office 4 kept lower indoor temperature, i.e. 25.4°C on the average.

The capability of peers’ personal habits to influence the indoor thermal-energy performance of thermal zones with equal characteristics was also evident in terms indoor illuminance, which was highly different from one office to another, even though the monitored peers performed the same job, worked in the comparable rooms, and had equivalent working schedules. For instance, different average illuminance values of 159.6 and 391.7 Lux were found for office 5 and 1, respectively. Also peers’ door/window opening profiles showed significant differences from case to case. In fact, the door opening profiles changed depending on different habits of the peers, while window opening profile had a similar trend irrespective of the variation of outdoor environmental conditions, due to the high summer outdoor temperatures that induce the occupants to keep the windows closed for longer periods.

Finally, consistent results were detected by performing dedicated surveys among a larger sample of peer occupying the same university buildings, in order to extend the results of the experimental analysis. In fact, very different and randomly variant behaviors attributable only to personal habits and individual thermal taste and perceptions were detected among all the interviewed occupants despite the fact that they were peers. In conclusion, it is here demonstrated how of course occupants’ behavior is a key point to define while investigating building indoor thermal-energy performance but, additionally, occupants’ behavior could not be simplified into peers’ categories, since individual attitudes were mainly driven by very subjective preferences, and just a very weak correlation was found to be imputable to outdoor weather forcing. In fact, the investigated variables in this study were found to vary the building thermal-energy and lighting performance up to 300%.

References


