7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient
Buildings and Urban Environments

ibpc2018.org | [#ibpc2018](https://twitter.com/ibpc2018)

Occupants' perception of historical buildings' indoor environment. Two case studies.

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ABSTRACT

In Europe, some historical cities have more than 50% of buildings dated from before 1920. Nowadays, these buildings faces challenges when adapted to the current necessities of livability, environmental and economical sustainability. Literature demonstrates that occupants' comfort perception and consequent behavior affect buildings' energy efficiency and are influenced also by the building configuration. Despite a large number of studies in literature investigating occupants' behavior and comfort in different situations, there is a lack of such studies for historical buildings. Therefore, the objective of this paper was to characterize occupants' thermal and comfort perception in two historical buildings during summer season. In these terms, results of objective measures were compared to occupants' evaluations of the indoor environment. Results showed that, for both case studies, despite the good thermal performances of the building fabrics and the fact that almost all of the occupants like to work in a historical building (they would also choose it instead of a modern one), most of them didn't rate the building as comfortable from a thermal point of view.

KEYWORDS

Thermal comfort, Historical buildings, Heritage preservation, Energy retrofit.

INTRODUCTION

These days, a great amount historical heritage buildings are reconverted for activities that differ from the originals, involving a complex processes of building adaptation and energy retrofit (Martínez-Molina, Tort-Ausina, Cho, & Vivancos, 2016). In this field, many studies recognized the positive role played by traditional materials and historic building configurations in mitigating outdoor conditions (Belpoliti *et al.*, 2017). However, two aspects should be considered carefully in the energy retrofit process. First, the implementation of new HVAC systems, because being designed for different technological contexts their installation entail an unavoidable duress on the historic fabric (Filippi, 2015). The second aspect is the so-called "human factor". According to Fouseki and Cassar (2014), the tension between heritage preservation and the need for occupants' thermal comfort is a bigger challenge then finding aesthetic-suitable solutions for historical buildings' energy retrofit. The same authors reported a lack of knowledge regarding occupants' perception of historical buildings and the necessity to do researches on how people feel and behave towards these buildings. Also Agbota (2014) highlights the importance of studying the unintended consequences of energy retrofit interventions for historical buildings' occupants. In this field, Anderson and Robinson's study (2011) showed that despite people appreciation of their home's historical evidence, their main concern was to enhance their thermal comfort in winter. In these terms, Crockford (2014) highlighted the central role of educating occupants in being aware of how the historic building functions and could be exploited in order to host a "twenty-first-century lifestyle".

The objective of this research is to investigate the relationship between occupants' thermal and comfort perception and indoor environmental conditions in two case studies of the same historic period and geographical area. The study was conducted in summer season. .

METHODS

This study is embedded in a larger research investigating different aspects of energy efficiency, indoor environmental quality and occupants' comfort and behavior in historic buildings. This research combined objective field measurements of temperature and subjective data obtained through a questionnaire survey. For this paper data from two case studies were chosen considering the availability of indoor environmental monitoring, historic period of the buildings, occupants' activity and geographical area.

Case studies

The two case studies are both located in the suburban territory of Turin (Italy). The first is the Rivoli castle, which is the product of a reconstruction of XVIII Century and a restoration of XX Century, finished with the opening of the current Contemporary Art Museum in 1984. Today the museum is registering more than 100,000 visitors per year and is listed in the UNESCO World Heritage List. The building, in which the last restoration maintained the original configuration and distribution, has a floor area of about 10,000 m². The surface hosts expositive areas and offices. From a constructive point of view, the Castle is a massive masonry building. During the summer season the building is passively cooled. Two types of occupants performing comparable metabolic activities were taken into account in this building: office workers and security staff of the expositive area. For the analyses, an existing network of eight Data Loggers (DLs) (model testo 175 H1), homogeneously distributed in the first and second floor of the building, was exploited. The second case study, the Centro di Conservazione e Restauro La Venaria Reale (CCR), founded in 2005, is a research, restoration and education center in which conservators, art historians and scientists work within laboratories, offices and classrooms. The CCR is based in the XVIII Century "La Venaria Reale" complex, a royal residence listed in the UNESCO World Heritage list. From a constructive point of view, the building is quite similar to Rivoli Castle; the only big difference is that the internal structure of the building was refurbished to host classrooms, offices and laboratories. For this research only offices were considered. During summer, offices are conditioned with a cooling system with a general set point of 24°C during working hours. However, in each room users are able to regulate indoor temperature with a range of +3°C/-3°C or even turn off fan coils. Regarding windows, only a part of occupants have the possibility to operate them. In both case studies, a monitoring campaign was carried out from June to September 2017. At CCR the monitoring data, consisting on the air temperature of six offices, were extracted from the temperature probes (Sauter EYB250F201) located on offices' walls, near the fan coils.

Analyses

The data were analyzed with the following procedure. First, for both cases analyses were made in order to assess DLs' measurements differences and calculate the daily fluctuation of temperature as an average of those in the same range. Second, mean daily temperatures were calculated for the whole summer season and compared with mean daily outdoor temperature of the nearest meteorological station, for both cases located in Turin. Third, the thermal indoor environmental quality was evaluated according to ASHRAE 55 (2004) and EN 15251 (2008) standards. For ASHRAE 55, analyses were done according to the prescriptions for "Naturally conditioned spaces". While for Rivoli Castle this would have been the only choice, being a passively conditioned building, for CCR the choice was partly due to the necessity of comparing it with the other building and partly due to the absence of data regarding humidity ratio, mean radiant temperature and air speed. For these analyses, indoor operative temperature was assimilated to average air temperature because all the conditions of

ASHRAE 55 Appendix A-Case 1 were met. Regarding EN 15251 standard, evaluations of indoor environmental conditions were made following Annex A “Recommended criteria for the thermal environment” indications. While for Rivoli Castle the evaluations were made only according to the second section, dedicated to buildings without mechanical cooling systems, CCR was evaluated according to both first section (dedicated to mechanical heated and cooled buildings) and second section. Fourth, subjective perception of indoor environment was evaluated basing on data from a questionnaire. In particular, authors took into account one part of the third section (Comfort conditions and preferences) and the second section (Cultural background, habits and changing attitude). The two aspects taken into account from the third section were:

- Thermal sensation vote (TSV), according to ASHRAE 55’s seven point scale (-3=cold, -2=cool, -1=slightly cool, 0=neutral, 1=slightly warm, 2=warm, 3=hot);
- Comfort evaluation according to a 5 point scale (-2=very uncomfortable, -1=moderately uncomfortable, 0=neutral, 1=moderately comfortable and 2=comfortable).

The questionnaire took place only once at the end of the season, so the evaluations were referred to the whole just-ended summer. The two considered questions of the second section were:

- If occupants like working in a historical building (yes, no, I don’t care);
- If occupants would choose to work in a modern or in a historical building.

For both case studies, the response rate was sufficient to consider occupants’ sample as representative of the building according to ASHRAE 55 “Survey of Occupant responses to Environment” section (22 respondents out of 35 for Rivoli Castle and 16 out of 19 for CCR).

RESULTS

Figure 1 shows mean indoor daily temperature and maximum indoor daily temperature of both case studies compared with the outdoor mean daily temperature data of the nearest meteorological station. Indoor mean daily temperatures of the case studies were not very different despite the presence of a cooling system in CCR (which actually had, in general, higher indoor temperature). The only noticeable difference is in the shape of profiles, which is more jagged for CCR, probably due to a fluctuating use of the cooling system. The maximum and average indoor temperature profiles show that there is not much fluctuation between day and night, because of the high thermal mass of both buildings. For both cases, indoor temperature profiles follow outdoor conditions, confirming a typical high-massive behaviour of the building envelope.

Regarding the indoor environment evaluation, Figure 2 and Figure 3 present the results of the application of ASHRAE 55 and EN 15251 standards for not mechanically cooled buildings. The graphs show the monitored average daily operative temperature compared to the prevailing mean outdoor temperature. Based on the results shown in Figure 1, at CCR there could be a high amount of users turning off their fan coils or regulating it with the highest temperature available (27°C). As a general comment, both buildings seem to behave quite well from a thermal point of view. In fact, considering ASHRAE 55 standard, in both cases almost all daily average temperature fall in the 80% acceptability interval. Regarding the 90% acceptability interval, which is not a normative requirement, 92% of values registered at Rivoli castle fall in this interval, while the equivalent percentage of CCR is 71%. Regarding the EN15251 standard, Figure 3 shows that both cases would be classified in Category I. Of course it should be noticed that for CCR these results would be relevant to the standard only assuming that the cooling system is not used.

Figure 2. Indoor environment analysis - ASHRAE 55 standard. a) Rivoli Castle b) CCR.

Figure 3. Indoor environment analysis - EN 15251. a) Rivoli Castle b) CCR.

Figure 4. Indoor environment analysis (buildings with mechanical cooling) – EN 15251. CCR

Figure 4 presents CCR's indoor temperature profile evaluation with respect to the guidelines for mechanically cooled buildings according to EN 15251 standard. The figure shows that until the beginning of September the building does not comply even with Category III.

Figure 5 shows occupants' TSV and comfort evaluation. For Rivoli Castle the graph shows the combination of the two types of occupants considered. Referring to Figure 5.a, less than 70% of Rivoli Castle occupants voted between -1 (slightly cool) and +1 (slightly hot), with a quite homogeneous distribution of votes in the "warm" sensation part of the scale. About CCR occupants' TSV, percentages show a quite homogeneous distribution across all the scale, but only 57% of occupants voted between -1 and +1. Referring to Figure 5.b, two approaches could be used to describe results. The first is that only 19% of Rivoli castle and 14% of CCR occupants are comfortable (voted 1 or 2), the second is that 62% of Rivoli castle and 28% of CCR occupants are not uncomfortable (voted between 0 and 2). In the following, Table 1 describes Rivoli Castle's votes dividing office and exhibition part workers.

Figure 5. a) Thermal sensation vote and b) Comfort perception vote in the two case studies.

Table 1. Rivoli TSV and comfort votes (Comf) among office (Off.) and exhibition staff at Rivoli Castle.

Off.	Exb.	Off.	Exb.	Off.	Exb.
-1<TSV<+1	-1<TSV<+1	Comf>=0	Comf>=0	Comf>=1	Comf>=1
88%	46%	75%	54%	13%	23%

The answers related to the general attitudes towards historical buildings mentioned in method section showed that 95% of Rivoli Castle's and 93% of CCR's occupants like to work in a historical building. Moreover, 95% of Rivoli Castle's and 86% of CCR's occupants would choose to work in a historical building instead of a modern one.

DISCUSSIONS

The case studies investigated for this research offered the opportunity to have an idea of occupants' thermal comfort perception within the historical building in which they work. In general, occupants' evaluations were different from what it was expected looking at the indoor environment analyses performed according to the standards. Considering the CCR for example, referring to the analysis represented in Figure 4, it was expected that a large majority of people would have expressed a TSV between 1 and 3, but instead the percentage is about 56%, with also 30% of people feeling slightly cool. In this frame it is also curious that with a temperature set-point of 24°C the temperature profiles is quite stable around 27°C. A possibility could be that people felt too cold so they decided either to increase the set-point to 27°C or turn off the fan coils. Having this large opportunity of configuring their environment, a good comfort rate would be expected. Instead, only 28% of CCR occupants feel not uncomfortable (which is surprising in comparison to 62% of Rivoli Castle, which is passively

cooled). Two reasons could be identified: either people turn off fan coils because of punctual discomfort (e.g. disturbing position of the cool air flow) or they don't know how to properly use their control opportunities. It should be also noticed that a certain amount of occupants at CCR don't have access to windows. Further analyses should be done to see if this group of occupants have a specific pattern. Regarding Rivoli Castle, the two analyses represented in Figure 2 and 3 did not predicted very well occupants' evaluation of thermal perception and comfort. For these analyses two groups of occupants were considered. Among the groups, it should be noticed that in general workers of the exposition part were less satisfied with their environment. A possible explanation is that they are not allowed to personally open windows (they have to ask to a person in charge) so their control opportunities are lower.

CONCLUSIONS

This paper investigated the relation between human thermal comfort and indoor environment in two historical buildings in Italy during summer season. Results showed quite different results of occupants' evaluations from what it would have been expected in modern buildings with similar indoor conditions. Most occupants don't feel thermally comfortable in the two case studies. However, their thermal comfort seems not influencing their pleasure of working in a historical building. In conclusion, even if strategies to ameliorate indoor environmental conditions are necessary, it seems fundamental to educate users to adequately manage their working environment, especially when a cooling system is present.

ACKNOWLEDGEMENTS

Authors would like to thank the two institutions presented as case studies for sharing their data, actively participating to the research and being partner of the project.

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