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# Towards high energy performing historical buildings. A methodology focused on operation and users' engagement strategies.

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**Abstract**

"Historical evidence indicates that when man first considered settlements and the order pertaining the rein, he showed concern for the conservation of this order and of monuments" [1].Today, the conservation of historical buildings involves also the necessity to adapt them to the current lifestyles and legislation in order to maintain them, wherever possible, as living evidences of the past. One of the most important challenges of adapting historical buildings to future usages is represented by the enhancement of energy performances of these building, that is crucial both for environmental and economic reasons. The aim of this paper is to outline a methodology to investigate the potential energy savings and the enhancement of historical buildings' livability by acting only on their operation, so that the building fabric could be maintained as much as possible as the original evidence. Furthermore, an example about methodology's application on a real case study will be described in order to translate the theoretic phases into an operative plan.


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*Keywords:* Historical buildings' energy retrofit; Operation strategies for historical buildings; Users' engagement.

## 1. Introduction

Nowadays, there is an increasing consciousness about the importance of energy performances and indoor environmental conditions' enhancement of historical buildings. At the same time, one of the main issues of energy retrofit design of historical buildings is to provide energy-saving solutions trying to preserve as much as possible

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their architectural and historical evidence. In this direction, the following paragraphs will show the potential of strategies addressed to energy efficiency by acting on users' education and adaptation opportunities. The main aim of this methodology is to investigate the potential of energy and economical savings by acting only on the building use, with a special focus on occupant behaviour and awareness. In particular, users' behaviour and preferences in terms of indoor environmental conditions will be investigated and strategies of users' engagement and education will be elaborated and tested. To understand users' necessities and behaviour theories from the field of psychology will be taken into account, e.g. Theory of Planned Behaviour or Social Cognitive theory. In addition, systems' management strategies and feedbacks to and from building managers will be provided and tested. In the following paragraphs, a concise literature survey concerning the main scientific topics involved in the methodology assumptions and development is provided.

## 2. Energy performances of historical buildings

### *2.1. Energy performances of historical buildings*

The relentless gait of history has always dealt with the concept of continuity; the tradition is in continuous development. The appearance and quality of historical buildings is enjoyed by a countless number of people who live them in daily life or who travel around the world in order to experience these memories. Nowadays, the necessity to conserve historical buildings is dictated mostly by the moral commitment to transfer the knowledge of what history left to future generations. In addition, the topic of valorization, sometimes seen controversial, involves the adaptation of these buildings to the current necessities, both in cultural and legislative terms. At present, the increasing sensibility to the architectural heritage has to deal with the current economical crisis that concerns particularly the building sector. In addition, it has to deal with the environmental emergency known under the key word climate change that has attracted the attention of international authorities for many years. For these reasons, the management of any confined environment has to deal with the contemporary necessity to reduce energy consumptions and to search for the maximum optimization of costs. Moreover, historical buildings, as cultural palimpsest, are a source of cultural identity, so they could contribute to a collective education and awareness on energy savings' and sustainability's themselves. Despite that the majority of legislative requirements in terms of energy performances are not addressed to historical buildings, there is an increasing consciousness on the importance of their relevance to reach the European CO2 emissions' reduction goals. In fact, statistical data show that 14% of the European Building stock dates from before 1920 [2]. Moreover, this percentage could dramatically grow in some historical cities; in Bologna (Italy), for example, around 80% of city center buildings were built before 1949 [2]. Currently, heritage preservation and energy efficiency measures are often conceived as mutually exclusive purposes. Often the enhancement of energy performances involves some actions on the building fabric. These interventions, if not well designed, could damage the monumental value and the static stability of historical buildings [3]. Instead, it should be considered also that energy retrofit measures could contribute to historical buildings' preservation by enhancing their liveability and economical sustainability, improving structural protection and enhancing comfort for users. According to the Italian national agency for electrical energy (ENEA), these operations should have a multidisciplinary approach, e.g. by considering microclimatic characteristics of the confined environment in relation with the degradation dynamics of the building fabric [4]. In conclusion, the enhancement of energy performances of historical buildings should be conceived as a reasonable integration of valorization and conservation operations; the aim should be to lower energy consumptions and ameliorate the indoor environmental conditions respecting as much as possible the original architectural evidence of the building.

### *2.2. Energy performances in relation to building use*

According to the Annex fifty-three's project of the International Energy Agency, the energy consumptions of buildings are affected by six factors: climate (1), building envelope (2), building services and energy systems (3), building operation and maintenance (4), occupants' activities and behaviour (5) and indoor environmental quality (6). In particular, the last three factors could be considered as part of the category related to occupant behaviour that can have an influence as great as the first three factors in energy performances [5]. Following the previous considerations about the preservation of historical buildings, this research focuses on the energy and economical savings obtainable acting only on the use of the building, with a particular attention to occupant behaviour.

#### *2.2.1. Occupant behaviour*

Energy efficiency of buildings is strictly related to the presence of occupants and their behaviour. A great extent of energy is used in buildings to maintain adequate and comfortable environmental condition for users. Several studies demonstrated [6,7,8] that occupants' behaviour and preferences have a huge impact on the use of energy. Building users can affect the energy performances of the building in different ways, e.g. setting thermostats, opening windows or using households. Occupant behaviour is influenced by various causes that could be distinguished in "external" to the occupant (e.g. indoor temperature), "individual" (e.g. personal preferences) and building properties [9]. In particular, occupant behaviour related to building control systems is usually connected to indoor and outdoor thermal conditions [9], while in the field of social sciences human behaviour is usually analysed in relation to "individual factors" [10]. The influencing factors for occupant behaviour (both individual and external), are generally described as "drivers" and represent the reasons leading a reaction in the occupant to conduct an action [9]. These drivers are usually categorized as physical environmental factors, psychological factors, physiological factors, social factors and contextual factors. This approach to the occupant behaviour in buildings is represented by the so-called "adaptive theory", according to which "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" [11]. According to this theory, actions made by users could be distinguished in two categories; changes to make it more comfortable (e.g. modify the temperature set in thermostat) and changes that allow the user himself to adapt to the surrounding environment (e.g. change posture of the body). The first category of actions have a direct impact on energy consumption, while the second regards thermal comfort of users, that is generally conceived as driver of many adaptive actions. In general, research has demonstrated that users feel more comfortable if they have the possibility to adapt themselves and their living environment in a clear and intuitive way, i.e. in case their level of perceived control is high [12]. There are several means to study occupant behaviour; data could be collected by technical measurements using sensors or by asking to the occupants information about their comfort perception within the environment and their behaviour (self-reported information) [13]. In general the energy demand of building would be minimum if users would act in a prudent way or maximum if their actions would be highly energy wasting. Therefore, occupants could be divided into "energy saving users" or "energy wasting users" [13].

#### *2.2.2. Perceived comfort and control opportunities*

As already mentioned, many aspects have been recognized in literature as having an impact on the occupants' comfort perception. Today, the necessity to reduce greenhouse gas emissions and control energy consumption of buildings usually encourages an increased use of automated controls within the building. Building automation systems allow reducing energy consumptions. However, providing sufficient control opportunities to occupants is equally important for its positive effect on their satisfaction [14]. Sociologists and psychologists have highlighted that the perception of control is a robust predictor of comfort and wellbeing both physical and psychological. For instance, Veitch found that the perceived control is a fundamental psychological mean for users' satisfaction in respect of lighting quality and having a significant impact on productivity [15]. These considerations about perceived comfort related to control opportunities are very important because they mean that the enhancement of energy performances of buildings could not be possible without a proper engagement of occupants.

#### *2.2.3. Users' engagement through feedbacks and persuasive technology*

Engaging occupants to make them aware of their energy-related behaviour and the condition of their living environment has great potentialities to reduce the gap between predicted and actual energy consumption in buildings. In this direction, there is a growing interest on the potential of real time feedbacks that could be used, for example, to inform occupants about their energy usage and environmental conditions [16,17]. Leaman and Bordass

[18] found out also that the possibility to have a fast connection with building operators affects the perceived comfort. In particular, feedbacks related to the effectiveness of occupants' control on building systems appear to have a great impact [19]. A feedback is usually conceived as an information regarding the result of a process or action that can be used both to control or modify another process, especially by noting the difference between the desired and the actual results [20,21]. A lot of researches on feedbacks have already been conducted in various fields, from psychology to energy technology [22]. Typically feedbacks inform occupants about their energy usage, often making comparison with the past; their utility stands mostly on the possibility to be periodical reminders, because in general users are not very aware of their energy usage and tend to forget indications if they don't become actual habits. Another relevant aspect regarding feedbacks is how information should be communicated. In particular, two aspects should be considered; first, the instrument that acquire and transfer the information, second how the information is expressed in order to be understandable and usable by users. Moreover, it should be considered that feedbacks could be information that are send to users by the building automation system or by the building manager, but also information about preferences and necessities given by users to the building manager or the automation system. Focusing on the utilities of feedbacks, it could be recognized a double role they can have; on one side the possibility to inform users about their conditions and energy usage, on the other the possibility to induce them in changing some energy-wasting habits. In these terms, Persuasive Technology is a recent proposal to induce changes in human habits and behaviour through technology and social influence [23,24,25]. The discipline entails both computer technology (internet, computer games) and psychological persuasion.

### *2.2.4. Researches on the potential to enhance the energy performance of buildings*

A number of researches related to the potential of energy conservation by acting on building usage and focusing on occupant behaviour exists, but there are no experiences with historical buildings. The following research results are described in order to list potentials and methodologies that have been used in the past. A field experiment conducted by Fabi et al. [26] has investigated the potential of users' engagement through feedbacks in an office environment. The experiment was conducted in three phases in which different types of feedbacks were used to inform users about their environmental condition, their energy usage, and comparing the energy usage of the participants. In this experiment, the objectives were to investigate the potential in terms of energy savings through feedbacks and also to evaluate the effectiveness of the different feedbacks that were used. The energy usage considering the whole period of experimentation decreased in average by 31% percent, with a peak of 44% in one of the three phases. Other research with occupant behaviour and satisfaction had different objectives. Meinke et al. [27] for example, studied the effect of feedforward information on building occupants. In particular, participants were given four possible actions to respond to a situation of thermal discomfort and, after their first decision, were informed about the energy and comfort consequences of their action. After the information, they had to confirm or revise their decision. About one third revised their choice and most of them declared an influence by the received information. According to this result, information could be considered a useful tool to increase users' energy-aware behaviour and thermal acceptance. Another possible approach to occupant behaviour is presented by Schweiker et al. [28] that in its study made an analysis on the influence of personality traits on four types of behavioural patterns and two dimensions of thermal perception. Through experiments done in a semi-controlled climate chamber with 65 subjects, they showed that personality traits lead to significant differences between behavioural patterns. The potential of this kind of studies could be to form theory-driven occupant behavioural profiles usable for building performance simulation and reduce the gap that exists between the predicted and the actual energy consumption of buildings.

## 3. Methodology

### *3.1. Outline of the methodology and objectives*

In the outline of the methodology below (Figure 1) the main research question ("What are the potentialities of energy and economical savings by acting only on building use?") is set in relation with three main objectives (system management and operation, providing adequate indoor environmental conditions and occupants' engagement and education). In particular, the research is structured in three steps. The first, developed in parallel through the Stages (S) 1 and 2, addresses the understanding of each case study in terms of building characteristics related to building operation (S1) and specific necessities of indoor environmental (IE) conditions and occupant behaviour (S2). Factors that have been taken into account are listed in the graph below. In the second step, consisting of S3 and S4, the framework of strategies have been settled up for each case study, based on the analysis of S1 and S2. Thereby, S3 is related to the strategies for the operation of the building and S4 to the strategies of engagement and education of users. The third step is represented by S5, in which the frameworks of solutions provided by S3 and S4 are tested in order to answer to the first research question.

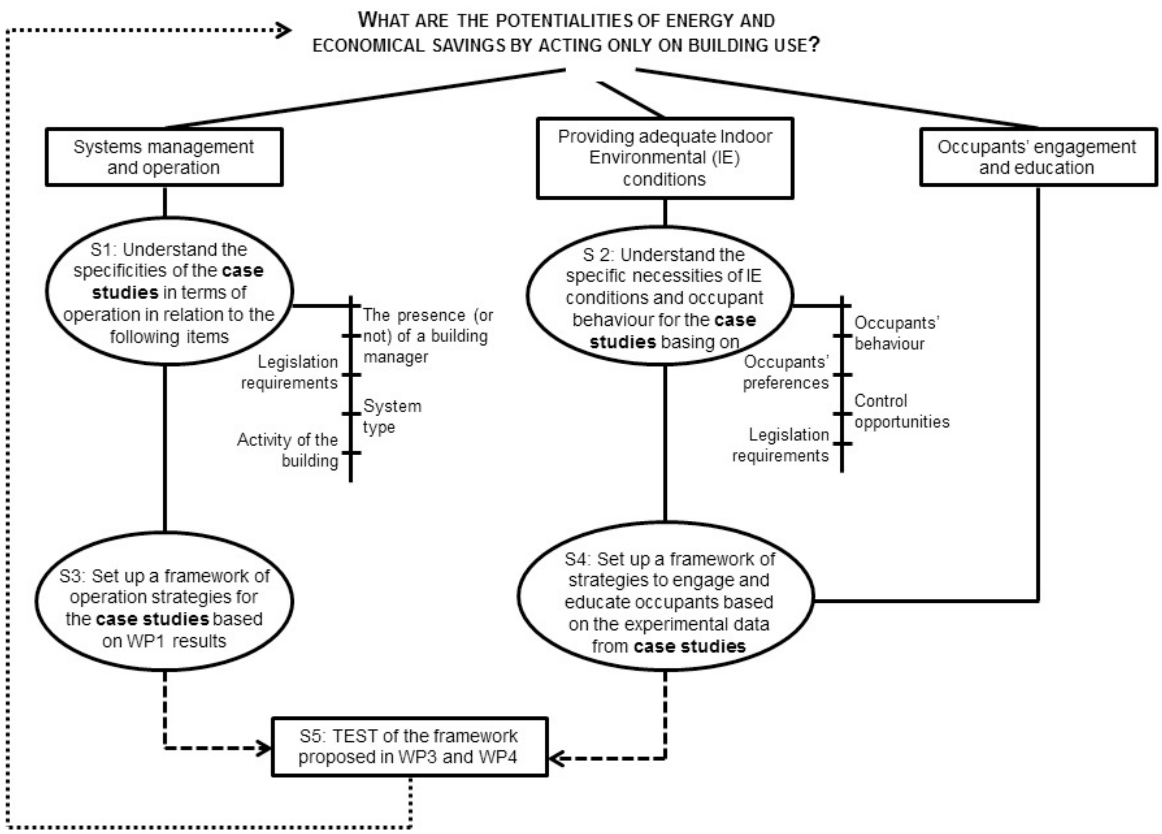


Figure 1. Outline of the project.

### 3.2. Insights on methodology phases

In this section, strategies and methods for each Stage are described. The main structure of the methodology follows a pre-test/post-test design. The pre-test phase consists of the first round of surveys (S1 and S2) that has the purpose to understand the characteristics of the case study that have be considered to set-up the strategies (S3 and S4). The post-test phase consist of the second round of surveys (S5) conducted after applying the strategies elaborated in S3 and S4. The surveys have to be conducted in two different moments of the year: the cooling season and the heating season. This choice depends on the fact that people have different perception of comfort depending also on climatic conditions outside the building and react very differently when feeling too warm or too cold. The methodology is thought to be applied in real case studies, at least five Italian historical buildings (from different geographical areas) with at least 10 participants for each. Each case study have his own surveys and strategies.

#### 3.2.1. S1. Understanding the specificities of the case studies in terms of operation of the building phases

Stage 1 is dedicated to understand the operation of the building in terms of systems' and building automation's management for each case study. Principally, the target group of this stage will be the building managers or people in charge of similar duties. Depending on the possibility to have the technological instruments, a survey about energy consumptions of the building during this phase (pre-test) should be done. S1 consists on one task described below to deepen the methodology that are used to answer the related research questions.

- Interviews. Interviews have to be conducted with the building manager (if present) or person in charge in order to understand the current management of systems and building automation in the case studies. The semi-structured interviews lasts for at least 30 minutes and leads to qualitative data helping to clarify how the operation of the building is currently managed, but also to receive more general information about the case study (type of systems, energy bills, general information about control opportunities within the building etc). If the building manager is not present, the interview questions have to be adjusted to the building owner or another person that deals with the systems of the building but is not a qualified building manager. In addition to these interviews addressed to the case studies, other interviews have to be done with building managers of other buildings in order to verify the results of the survey in case studies with a sample. The topics of these second interviews are the type of systems available, their operation strategies and the interaction between building manager and occupants.

#### 3.2.2. S2. Understanding occupant behaviour characteristics and specific necessities of IE conditions for the case studies

Stage 2 is dedicated to understand occupants' behaviour and preferences in the chosen case studies. The objective is to understand how occupants' behaviour and preferences change e.g. by building configuration and other boundary conditions.

- Surveys. The surveys consists of quantitative questionnaires (closed questions) to building users. These questionnaires are addressed to understand different kind of information: some questions are done to users in order to understand how different kind of systems or the presence of building automation could influence occupants' behaviour and preferences. Questions are dedicated also to understand the relationship between the activity of the building and occupants' behaviour and preferences. Users should be asked also to give information about their relation with the building manager (if present) or, more generally, the person in charge of operational competences. Other questions have the objective to understand how people perceive their environment, how they would change it, what actions they usually perform when they feel uncomfortable, what control opportunities they have and wish to have in their environment, what automatic controls they wish to have in their environment (or don't mind if are present) and what are the principle variables they recognize as drivers to perform some actions (e.g. open the windows).
- Data Analysis through statistics. Once made the surveys in all the case studies (S1 and S2 pre-test), a database is created and analyzed through statistical methods. Statistical instruments vary depending on what kind of

information is needed. For instance, T-Tests are used for group comparisons. This test could be used e.g. to understand the differences between occupant behaviour in historical buildings and more recent ones. This analysis could be done for my research taking into account 5 historical buildings and 5 more recent ones that will be considered comparable (similar activity, similar number of workers and similar geographical area). Other statistical instruments and methods could be used for other type of analysis based on the information acquired through the survey and the research questions previously presented. In addition, the question is addressed whether occupant's preferences in historical buildings are different from new buildings. In addition to the analysis of the survey data, this question is answered by comparing databases from historical buildings and non-historical buildings that are similar for several other characteristics (activity of the building occupants etc.). The results from the statistical analysis is used to set up a synthesis about occupants' behaviour and preferences in the specific case studies. This synthesis is used both for S3's operational strategies and for the framework of users' engagement and education of S4.

### *3.2.3. S3. Elaboration of the framework for operation strategies*

Stage 3 framework of strategies are addressed to building operation and have the objectives listed below.

- Provide strategies to lower energy consumptions of the building having considered innovative approaches (see S1-Task 1), historical building peculiarities and existing systems potentialities.
- Provide strategies in order to enhance the comfort perception of users by acting on systems and building automation. Strategies are elaborated according to the results S2 surveys.
- According to the interviews conducted in S1 and the surveys of S2 indications are provided about how information and feedbacks have to be exchanged between building manager and users. In particular, the building manager should be able to inform users about their energy usage and users should be able to communicate their preferences in terms of indoor environmental condition and specific cases of discomfort to the building manager.
- If the building manager is not present, the framework of strategies are elaborated in a way that the person that receives it is able to understand the information and to actuate the suggested strategies on the systems of the building.

### *3.2.4. S4. Set up a framework of strategies to engage and educate occupants based on the experimental data from case studies*

Stage 4 framework of strategies aims at engaging and educate building users. Strategies are elaborated basing on occupants' characteristics synthesized in S2 and communication techniques selected through a specific literature review. Communication means depend on the possibilities of each case study (e.g. mail, internal network of the company, app for smart-phones etc.). Different indications regarding the behaviour should be given to users basing on their control opportunities through the environment. Some controls could be made automatically by the building automation (if present), while others could be made only by the users.

### *3.2.5. S5. Test of the strategies provided by S3 and S4*

- Post-test. This last phase of the experimentation is dedicated to the so-called "post-test" phase in which the strategies proposed in S3 and S4 for each case study are applied. After applying the strategies, the "post-test" phase consists of surveys in the same period of the year in which the "pre-tests" (S1 and S2) were made in order to verify the actual changes in similar conditions.

- Analysis of results. Data from the "pre-test" and "post-test" phase are analyzed in three main ways. First, a comparative analysis between the energy consumptions in "pre-test" phase and "post-test" phase are done for each case study in order to quantify the enhancement of energy performances by acting only on the building use. If specific technological instruments were available in the case study to measure energy use during the two phases the comparison would be more accurate, otherwise energy bills are used. Second, a financial analysis is based on the calculation of financial savings for energy costs in "post-test" phase (if the energy consumptions have actually decreased). Another interesting financial analysis is the quantification of the economical effort to implement strategies (S3, S4) and the payback period of the investment considering the economical savings related to energy-costs. The third analysis focuses on occupants' changes in behaviour and satisfaction. The comparison between "pre-test" and "post-test" questionnaire are used to understand if occupants perceived a modification in their indoor environment, if after the intervention their preferences changed, if their behaviour changed (and how) and how the relationship with the building manager changed.

## 4. Case study. National Gallery of Umbria

In this paragraph, the application of the methodology to a real case study will be described. The National Gallery of Umbria is located in Perugia, Italy. The Gallery has his origins around the middle of XVI Century, but is located in the Priori Palace, one of the most relevant examples of residential Gothic architecture, from 1878. Nowadays, the Gallery hosts one of the more complete and eloquent Italian collection of paintings on wood planks. Here the methodology phases are declined to take into account the building peculiarities and specific goals. The entire experimentation lasts for around 18 months, in order to actuate the pre-test and post-test phases in the same period of the year. In the following, Figure 2 shows the experimentation timeline.

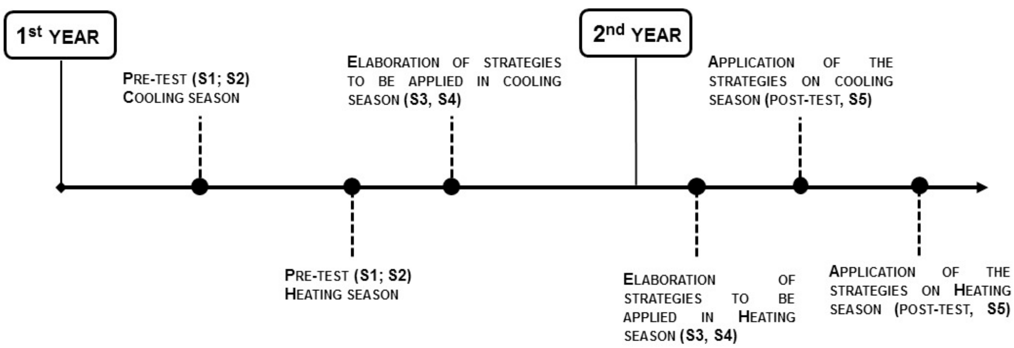


Figure 2. Experimentation Timeline.

As previously anticipated, the methodology phases previously described have been declined in order to be applied to this real case study. The first phase (S1), dedicated to the study of building's energy performances and the interviews with the building manager, is managed acting in two main directions. Since the Priori Palace is particularly complex, the characterization of its energy performances requires an accurate energy audit to be conducted starting from the energy bills analysis to the creation of an energy model in a dynamic simulation tool. An important part of this work is dedicated also to the characterization of the expositive part's indoor environmental conditions in order to verify their adequacy to artworks' conservation. This study is conducted through a monitoring campaign. In particular, fifteen significant points of the expositive part are monitored through temperature and humidity ratio sensors. The monitoring campaign analysis has a crucial role for the elaboration of operation strategies (S3) that will have to search for the ideal balance between conservation and visitors' comfort necessities. The second direction of S1 is addressed to obtain information about systems' operation and maintenance. This building is not provided with a building manager; interviews are conducted with two operators having similar duties. The second phase of the methodology (S2) is characterized by a survey addressed to building occupants in order to understand their behaviour and comfort conditions. In this case study, three types of occupants were recognized; office workers, visitors and workers of the expositive part (security operators etc.). Starting from occupants' categories different questionnaires are elaborated, basing on the type of experience they have through the indoor environment. For instance, visitors questionnaires are synthetic surveys to understand the quality of their experience only in terms of thermal comfort, while office workers are asked to give more detailed information about their relationship with systems controls, their thermal comfort during different phases of the day and so on. Workers of the expositive part have different questionnaires from office workers for two main reasons; first, because typically they don't have access to systems' controls, second because their work routine is different from the office one (they usually don't have to be sit during working hours, they could change rooms during the day etc.). Currently, the experimentation is still ongoing.

Once the results from S1 and S2 will be available, they will be analyzed with two different aims. First, they will be used to be compared with surveys from similar case studies. Second, they will be used to elaborate different operation strategies (S3) for the expositive area and offices. Strategies for the expositive area will search for the optimization of conservation needs, visitors' comfort and energy saving possibilities, while the aim of S3 for offices will be to ameliorate comfort conditions of occupants while adopting energy saving measures. The fourth phase of the experimentation (S4) is principally addressed to offices' occupants, but some indications could be elaborated also in form of suggestions for visitors and workers of the expositive area in order to enhance their thermal comfort and explain, eventually, particular situations (e.g., if a room has to be maintained in specific conditions for conservative reasons visitors could be informed). The analysis previously explained for S5 are all conducted for this case study, possibly differentiating results for the expositive part and offices.

**Conclusions**

This paper dealt with the important theme of enhancing energy performances of historical buildings, taking into account the necessity to preserve as much as possible the architectural evidence of these buildings. Energy and economical saving potential was investigated focusing only on building use and operation possibilities, with a special regard to occupant awareness and education. The exposed methodology was conceived with a pre-test and post-test design approach in order to quantify, for every case study, the efficacy of proposed strategies, addressed to building operation and occupants' engagement. It should be noticed that this is the first study investigating the effect of occupant behaviour on historical buildings. Moreover, the goal to lower energy consumption and reducing economical effort related to historical buildings' operation would be a great answer to the necessity of adapting them to the current necessities of livability, conserving them with a reasonable economical effort (especially with respect to other energy retrofit measures) and maintaining the architectural evidence almost intact. Focusing on the methodology itself, the description of its application to a real case study demonstrated that the procedure is very flexible and inclusive; indeed, for the particular case of museum, it was partially adapted to take into account artwork conservation necessities for the expositive part without compromising results' comparability to other case studies. Future perspective of development for this study are represented, e.g., by its application to case studies from different geographical areas and cultures, in order to investigate their difference in terms of occupants' behaviour, relationship with historical buildings and efficacy of engagement strategies.

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