Exploring Occupant Behaviour Potentialities for retrofitting historic buildings

Giorgia Spigliantini

Doctoral dissertation | Politecnico di Torino | Karlsruhe institute of technology

Doctoral Dissertation
Doctoral Program in Architectural and Landscape Heritage (32th Cycle)
Politecnico di Torino

Doctoral program of the Department of Architecture
Karlsruhe Institute of Technology (KIT)

Exploring occupant behaviour potentialities for historic buildings' energy retrofit

by

Giorgia Spigliantini

* * * * * *

Supervisors
Prof. Stefano Paolo Corgnati, Supervisor (Politecnico di Torino)
PD Dr. Marcel Schweiker, Supervisor (Karlsruhe Institute of Technology)
Prof. Chiara Aghemo, Co-Supervisor (Politecnico di Torino)

Doctoral examination committee
Prof. Karel Kabele, Referee (Czech Technical University)
Prof. Giuseppe Riccio, Referee (Università degli studi di Napoli Federico II)
Prof. Dr. Joaquín Medina Warmburg (Karlsruhe Institute of Technology)
Prof. Anna Pellegrino (Politecnico di Torino)
Prof. Andreas Wagner (Karlsruhe Institute of Technology)

Politecnico di Torino

Karlsruhe Institute of Technology

July, 2020

I hereby declare that the contents and organisation of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

…………………………………………......

Giorgia Spigliantini

To my beloved husband and myself

Preface

The present doctoral dissertation is the result of the research activities that I had the chance to realize thanks to the support and collaboration of an international research context. At the beginning of my PhD at Politecnico di Torino, I had the chance to spend one month at the Karlsruhe Institute of Technology (KIT), hosted by the Institute for Building Design and Technology (IEB) and, more specifically, by prof. Andreas Wagner. This period was financially supported by the KIT House of Young Scientists (KHYS). From the very first moment, I received a great welcome both from the university administration and from the IEB-FBTA research group. In particular, during my stay I had the chance to plan my PhD project and prepare the application to obtain a scholarship from the DAAD (Deutscher Akademischer Austauschdienst). In this process, I had the chance to be strongly supported by PD Dr. Marcel Schweiker, who continued to support me also during the whole duration of my PhD, as supervisor. Thanks to these efforts, I obtained the DAAD scholarship "Cotutelle Doctoral Programmes, 2017/2018 – 57299292)", which allowed me to spend at KIT thirteen months between the second and the third year of the PhD. In the meanwhile, thanks to the support of Politecnico di Torino's doctoral school (SCUDO) and the Architecture Faculty at KIT, a cotutelle agreement was established between the two universities, so I was enrolled also as an Architecture doctoral researcher at KIT. For the efforts made in balancing the two universities regulations, I would like to particularly thank my supervisors and the directors of KIT and Polito doctoral schools, prof. A. Wagner and prof. F. Canavero.

The research conducted during this PhD would not have been possible without the fruitful collaboration of four case studies, in which the methodology elaborated from a theoretical point of view, was applied for the first time. A great number of people were involved in this process, from administrators to building operators and occupants. Since it would not be possible to list all of them, I will mention and acknowledge only a few people for each case study, but my gratitude goes to all: M° Zuccarini, Arch. Sartori and Ing. Savasta (Conservatory of Turin), Dr. Nervo, Mr. Ferragina and Ing. Roncisvalle (Restoration Centre La Venaria Reale), Dott. Cristina Scalon, Arch. Gremo and Arch. Amateis (Stupinigi Hunting Lodge), Dott. Giorda and Ing. Maritano (Rivoli Castle). This research experience, for which I am extremely thankful, would not have been possible without the support of my home institution's supervisor (prof. S.P. Corgnati) and co-supervisor (prof. C. Aghemo).

Acknowledgement

During the speech given in the celebration of his Degree honoris causa in Bologna (2013), the famous writer Daniel Pennac said, referring to the years of youth: "*In those very years, it happens that we meet an adult that will be decisive. When he (or she) appears (...), he/she seems not an adult like the others (...). That newcomer opens a window to the future, which is a future of slow acquisition: learning what he/she knows and doing what he/she does (...). It appears that under that guide the future could be exciting! For the first time we feel like a person in the making".*

In recent years, I had the luck to meet a number of "adults" that changed, in different ways, my life and my career. However, I perfectly remember the day when that "adult like no others" appeared and changed my perspective for the first time. It was my second year at the University, in the building physics course. That day, prof. Corgnati explained the "heat balance" of buildings, one of the most difficult topics for the exam. But really, he did something more than just explaining formulas and principles. He told us about the climate crisis and the environmental emergency, the European directives on energy efficiency of buildings, and the role that us, as architects, could have in determining a better world in the coming years. It was 2011 and I was 20. From that day, I started to think that that mission would have been mine. It's been eight years from my first building physics exam; my path on the energy research has been long and progressive, starting with the first essays, through the bachelor and master degree thesis and up to the PhD. In all these years, I would like to thank prof. Corgnati for disclosing, little by little, the magic of the research world, and for letting me follow my passion. I could not be more grateful for letting me free of really shaping my research according to my intuitions and passion, giving me the opportunity to make my choices, supervising my work and guiding me in hard times.

As previously mentioned, in these years a number of "adults" helped me shaping my growing path. In a chronological order, the first person I would like to thank is prof. Becchio, who supervised my master thesis with prof. Corgnati. In all these years, Cristina was (and is) my safe heaven when I have to orientate myself in anything related to my work. How many "*Could I ask you an advice?"* I wrote or told her? Probably too many, but with her support I always feel that I can make the right decision.

The second person I would like to thank is prof. Fabi. At the very beginning of my research path, Valentina was not only my mentor, but when I looked at her, I saw the talented and kind researcher I would like to become in the future. Through her passionate work, she revealed me how “human” our energy research could be, determining all my following research interest and my PhD project. Valentina was also the reason why, today, I can thank another “adult like no others”, the second pillar of my PhD: my supervisor, prof. Schweiker.

During this PhD, Marcel was my continuous reference point. I would really wish all PhD students to have such a precious guide. One of the things I would like to mention (all things for which I am grateful would be too long) is that after all our meetings I always feel extremely enriched, I have thousands of new ideas and things to reflect on. I think that there’s no more precious things you can ask to a supervisor or a research mentor, so thank you so much Marcel.

Last but not least, I would really like to thank prof. Aghemo, my third supervisor, who was always present even when she wasn’t, kindly supporting me in developing my PhD with a continuous attention to the impact of my research on the field of architecture heritage.

Now, I would like to thank my colleagues, without which my days would have been much more boring. Our Polito group changed during the years, and I had the luck to share my journey with a lot of people, so I will try to remember everyone from back in 2016, when I first joined the group. Thank you Mara, Verena, Tiziana, Daniela, Federico, Chiara, Giulia C., Giulia V., Maria Valentina, Carola, Ilaria, Maria Cristina, Maria and Sara. However, this is not over. In fact, my PhD gave me the opportunity to share a part of my path also with some wonderful people at KIT. First, I would like to thank Prof. Wagner for hosting me and providing me with a German “family” research group: I felt extremely welcome from day one, and I believe this is also because of his ability of creating a passionate and heterogeneous group. Among the colleagues, I would like to thank Reza, Sandra, Maryam, Roberto, Carolina, Lukasz and Romina. Moreover, I would like to thank Karin Schakib for her kind help in designing my strategies of interventions for the BIOSFERA methodology. Finally, a special thanks goes to Farah, office mate and beloved friend, thanks to whom I could really understand that friendship does not know any boundaries.

I miei più grandi ringraziamenti vanno infine alla mia famiglia, che durante questo percorso di dottorato è “cambiata”, o per meglio dire “si è allargata”. Il merito di tutto questo è, senza presunzione, mio e di mio marito. Questa tesi è dedicata a noi due, ma forse un po’ di più a te, che hai fatto il gesto d’amore più grande (decidere di vivere tutta la vita insieme) proprio all’inizio di questo dottorato, quando mi hai preso per mano e mi hai portato a realizzare questo grande sogno. Non avrei mai avuto il coraggio di andare in Germania da sola, non ti avrei mai lasciato “qui” in Italia. Ma tu sapevi quanto io ci tenessi, quando il mio lavoro per me DAVVERO fosse la mia più grande passione. E così siamo partiti insieme ed abbiamo vissuto il nostro primo anno insieme “lassù”, coltivando e rafforzando la nostra unione sempre di più. Grazie Artu, perché devo a te la soddisfazione di aver concluso questo percorso così come è stato e la possibilità di continuare a scommettere su questo difficile ma meraviglioso lavoro. Grazie a te per aver fatto sì che le nostre famiglie diventassero una, e che in ogni momento io possa sentirmi a casa. Grazie ai miei genitori, perché fin da piccola hanno supportato i miei sogni (anche quando ancora non sapevo quali fossero) ed hanno reso possibile tutto questo. Ci sono stati tanti momenti in cui avete dovuto fare un “salto nel vuoto” e darmi fiducia: il vostro supporto è sempre stato presente ed incondizionato, ed io non posso che sperare di avervi restituito almeno in parte le felicità che voi avete permesso di vivere a me. Grazie ai miei nonni ed al mio fratellone, che ancora oggi a (quasi) 30 anni mi fanno sentire una “nipotina” ed una “sorellina” anche a centinaia di chilometri. Infine, grazie alla mia “nuova” famiglia: Roberta, Beppe, Lety, Rosi, Giorgio, ma anche tutti i cugini, gli zii ed i pro-zii “acquisiti”. Grazie a voi mi sento a casa dove casa prima non era, ma ora lo è, e non riesco a pensare niente di più bello. Grazie per avermi supportato in questo percorso con l’ascolto, con i consigli o, molto spesso, con un bel pranzo o una bella cena, alleviando la pesantezza di alcuni giorni difficili. Infine, il mio ultimo (ma determinante) ringraziamento va ai miei amici. Lo so, sono sempre stata la vostra amica “maestrina”, “secchiona”, a volte anche “bacchettona” e “pesantona”. Lo so, quindi GRAZIE, perché senza di voi mi sento persa: siete davvero i miei salvavita. Siete troppi amici miei, quindi maschi non offendetevi ma citerò solo le mie amiche del cuore femmine, nell’ordine quelle di “casa 1” e quelle di “casa 2”: Gimpi, Costi, Lau, Betti, Ele, Giuli, Tod, Gaiezza, Jav e Mancio. Vi voglio bene.

Contents

Executive Summary

In recent years, the topic of historic buildings' energy retrofit has been investigated increasingly by the energy research sector, especially in the European area. This phenomenon is related to a number of reasons, among which the increasing awareness about the role that this category of buildings have, to reach the European carbon emissions' reduction targets by 2050. In fact, more than 14% of the European building stock dates from before 1920, but this percentage rises to 50% in several urban centres. Despite the increasing interest on the topic, several studies on historic buildings' energy retrofit seems not aware of cultural heritage protection and conservation legislations and practices. For this reason, nowadays, the objectives of these two sectors seem to be unbalanced. Since the tradition of heritage conservation and protection are rooted in the society's cultural background, there is the necessity of proposing a change of perspective about the role of the energy sector in the restoration field. Primarily, energy retrofit should aim at increasing the liveability and economic sustainability of historic buildings, having their social profitability as a central scope. In terms of solutions, the architectural heritage is characterized by a great variability, so its energy retrofit requires a high level of multidisciplinary knowledge. Moreover, due to the uniqueness of historic buildings, the necessity of individuating replicable solutions for their energy retrofit can be satisfied at a maximum degree by proposing a common procedural approach, to be realized through the elaboration of a methodology. Based on the previous aspects, for the present work a strand of the energy research has been individuated as a potential ground to balance heritage conservation and energy efficiency aims. This strand is occupant behaviour or, more generally, building operation.

This PhD dissertation tackled the previous aspects by proposing the elaboration and test of a methodology called "BIOSFERA" (Building Intelligent Operational Strategies For Energy Retrofit Aims"). Testing the methodology on a pilot study,

which consisted on the experimentation on four case studies, a first answer to the following research question was provided: *What are the potentialities of energy saving and indoor environmental conditions' enhancement by acting only on the way non-residential historic buildings are operated by occupants and operators?*

The **first part** of this work is dedicated to the investigation of the two corpus of knowledge that constituted the basis for the elaboration of the BIOSFERA methodology. After an introductory chapter, the tradition of conservation and protection of cultural heritage was summarized in a chapter dedicated to "Preservation", in which two main questions were answered: *Which buildings are protected and why? How to deal with protected buildings?* The third chapter, dedicated to "Adaptation", contains the energy-related literature that guided the elaboration of the methodology. In particular, the chapter incorporates:

i) A summary on how the topic of energy retrofit has been faced in researches and energy-related legislations and guidelines;
ii) An overview about literature on the management of indoor environmental conditions for artworks conservation;
iii) An outline of a strand of the energy research that has been chosen as a basis to develop the BIOSFERA methodology: building energy–related operation and occupant behaviour.

A fourth chapter is dedicated to summarize the aspects emerged from the previous two ones and introduces how they have been integrated in the theoretical framework of the BIOSFERA methodology.

The **second part** of this dissertation describes the BIOSFERA methodology design and theoretical phases. Chapter 5 is dedicated to an introduction to the methodology design. Chapters 6-8 describe the three theoretical phases (Diagnosis, Intervention and Control) in terms of objectives, materials to be acquired, analyses and results' elaboration. In this part, the objective is to provide a comprehensive overview of a series of instruments and analyses that should be successively chosen based on the application context's specificities and necessities. Based on the previous theoretical framework, chapter 9 proposes conclusions about the methodology potentialities and barriers.

The **third part** describes the application of the BIOSFERA methodology in a pilot study executed in four Italian case studies. In particular, chapter 10 is dedicated to the description of how case studies were selected for the experimentation. Chapter 11 describes how the theoretical phases enunciated in part II can be translated on a real application. This detailed description is provided by reporting the experience on one case study. Chapter shows how the created methodology can be flexible based on the specificities of the buildings to which it is applied. To this aim, the experimentation on the other three case studies is outlined by coupling a synthetic description of the experiment with specific focus topics that were chosen to stress the methodology's flexibility and potentialities. Finally, chapter 13 provides a general "picture" of the impact that the methodology had on the four case studies, providing a first answer to the study's research question.

The **fourth and final part** is articulated in two chapters. Chapter 14 is dedicated to a critical review of the methodology design and theoretical phases in perspective of a possible implementation on a broader scale. The critical review is based on the experience gathered during the pilot study. Chapter 15 contains the conclusive summary, characterized by an outline of the results obtained in the dissertation, as well as the recognized potentialities and barriers in perspective of further researches towards a broader application of the BIOSFERA methodology.

List of Tables

List of Figures

List of abbreviations and symbols

AHU	Air Handling Unit.
BIOSFERA	Building Intelligent Operational Strategies For Energy Retrofit Aims.
BM(s)	Building Manager(s).
BO(s)	Building Occupant(s).
CDD	Cooling Degree Days.
DD	Degree Days [-].
DL	Data Logger.
EE	Electric energy [kWh_e].
E_P	Primary energy [kWh/m^2].
$E_{P, H}$	Primary energy calculated based on thermal energy [kWh/m^2].
$E_{P,TOT}$	Primary energy calculated based on thermal energy and electric energy [kWh/m^2].
HDD	Heating Degree Days.
HLC	High Level of Control (referred to occupants' energy-relevant control potential).
HVAC	Heating, Ventilation and Air Conditioning.
IAQ	Indoor Air Quality.
IEQ	Indoor Environmental Quality.

LLC	Low Level of Control (referred to occupants' energy-relevant control potential).
MLC	Medium Level of Control (referred to occupants' energy-relevant control potential).
N	No
OB	Occupant Behaviour.
PE	Electric power [kW_e].
PI	Performance Index.
PMV	Predicted Mean Vote.
PPD	Predicted Percentage of Dissatisfied.
PT	Thermal power [kW_t].
RH	Relative Humidity [%].
RH_{1h}	Mean hourly Relative Humidity [%].
RH_{1d}	Mean daily Relative Humidity [%].
S	Summer.
T	Temperature (of the air).
T_{1h}	Mean hourly air Temperature [°C].
T_{1d}	Mean daily air Temperature [°C].
T_{sp}	Temperature set-point [°C].
TE	Thermal energy [kWh_t].
TE_N	Normalized thermal energy [kWh_t/DD].
TSV	Thermal Sensation Vote.
VAT	Value-Added Tax (in Italian, IVA).
VS	Versus
W	Winter.
Y	Yes
ΔRH_{1h}	Mean hourly gradient of Relative Humidity [%].
ΔRH_{1d}	Mean daily gradient of Relative Humidity [%].
ΔT_{1h}	Mean hourly gradients of Temperature [°C].

ΔT_{1d}	Mean daily gradients of Temperature [°C].
Ω	Objective.

PART I

Historic buildings' energy retrofit between preservation and adaptation

1

Introduction

In recent years, the interest in **historic buildings' energy efficiency** has increased. In fact, the number of publications on the topic grows every year (Martínez-Molina *et al.*, 2016). One of the reasons why this interest grew, especially in Europe, is that in the last years the existing **building stock replacement rate** has averagely been below 3% (Becchio, 2013; Vieites, Vassileva and Arias, 2015). Therefore, in order to reach the EU Commission's ambitious targets of 80-95% reduction of carbon emissions' by 2050, efforts should be put also in the energy retrofit of existing buildings (Commission, 2012b). In this context, historic buildings play a significant role, since in several European cities they represent a significant percentage of the existing building stock. The definition of "historic building", especially in the context of energy-related studies, has not been agreed, so different authors can refer to this category considering different classifications. However, even considering slightly different periods, which can include e.g. buildings built before 1945 or buildings built before 1920, the percentages referring to this category of the building stock are quite relevant. For example, Troi and Bastian declare that about **14%** of the total European building stock **dates from before 1920**, but in several European cities this percentage could also reach 50% (Troi, Bastian and Al., 2014). In Italy, about 30% of the building stock (about 12.5 million buildings) was constructed before 1945 (Filippi, 2015). In energy terms, buildings could be classified as "historic" also according to the introduction of energy-related standards, which caused important changes of the building technologies (Fabbri, 2013).

Despite the relevance of the percentages above showed, to the best of the author's knowledge, standards in Europe (European commission, 2002; Commission, 2010, 2012a; Mazzarella, 2015) exempted historic buildings from respecting the energy-related performance prescriptions. Unfortunately, this approach caused a general exclusion of the energy-related technological innovations from the practice of restoration, both at professional and academic level

(Franco *et al.*, 2015). As Mazzarella declared, the general approach was to adopt a "derogation regime", so to accept the unrespect of energy-related standards from energy retrofit projects on historic buildings, with a few exceptions at national level (Mazzarella, 2015). For example, in Italy, even if only 1,8% of historic buildings (built before 1945) have specific restrictions according to the Legislative Decree no.42/2004 (Parliament, 2004; Filippi, 2015), interventions on this building category are subjected to significant restrictions, due to the current definition of cultural heritage, which is extremely inclusive and includes "all" historic buildings.

In this context, it is fundamental to understand why historic buildings are usually exempted from respecting the energy-related standards. In particular, it is fundamental to understand why our culture brings us to protect buildings as evidences and, even more importantly, how this protection is translated in our current restoration practices (which include also energy-retrofit interventions) and legislation. In fact, the reason why historic buildings are not usually contemplated in the energy-related standards is that our cultural heritage-related culture, which is also expressed in international agreements and standards, conceive the protection of the evidence (that can be an object as well as a building), as its **"material" conservation**. This requires, theoretically, to leave the object as the history left it for the future generations (Romeo, Morezzi and Rudiero, 2015).

Considering this information, it is possible to individuate the reasons why, nowadays, there is a substantial controversy between the restoration science's and the energy science's objectives. In fact, in the past almost twenty years, from the first European directive on buildings' energy performances (European commission, 2002), the way the problem of reducing the building sector's CO_2 emissions was approached, was by encouraging the enhancement of the building energy performances, focusing on buildings' envelope and HVAC systems. However, this kind of actions (like the insertion of insulation or HVAC systems' infrastructures) require interventions on the building fabric, usually violating the restoration principle of evidences' protection. This does not means that any action on the building fabric can be conducted on historic buildings, but that any restoration intervention (also for energy retrofit aims) usually requires a long process of approval from protection authorities, the use of specific compatible materials and the involvement of a larger number of professionals from multiple expertise areas. Of course, all these characteristics determine, usually, longer periods of realizations and, by consequence, higher costs. These are the main reasons behind the practice of **derogation "regime"** and the common exemption of historic buildings from energy-related standards as mentioned above. Moreover, these were the main reasons why a specific standard for the energy retrofit of historic buildings has been released in the last years (CEN, 2017).

Going back to the first considerations about the relevance of historic buildings for reaching the European's emissions' reduction targets, there is the need to find energy retrofit solutions that respect the principles of conservation and protection that our society expressed in restoration principles and practices. Considering the aspects listed, two main “driving forces” or “needs” to be balanced can be recognized. On the one hand, there is the need to protect historic buildings as evidences of the past, conserving their appearance and materiality as much as possible. This first driving force can be synthesized as a need of “**preservation**”. At the same time, since most historic buildings are still used today and represent a significant percentage of the total building stock, there is the need to “adapt” them, in energy terms (among others), to the present necessities of liveability, health and reduction of energy consumption. In these terms, the second driving force, which should be balanced with the first one, can be synthesized as a need of “**adaptation**”.

Following these categories, this first part of the thesis has been divided in three chapters. The **first chapter** is dedicated to “preservation” and has two main objectives. First, the definition of the object of the protection: cultural heritage, which includes architectural heritage – ***which buildings are protected and why?*** Second, the individuation of the principal values guiding the practice of architectural conservation and restoration, in order to individuate which kind of solutions can be provided to enhance historic buildings’ energy performances without betraying the funding principles of restoration – ***how to deal with protected buildings?*** The **second chapter**, dedicated to “adaptation”, provides an overview of the literature that constituted the energy-related basis of present dissertation. The **third chapter** is dedicated to summarize the principal aspects emerged in the previous two chapters and introduces how they have been integrated in the theoretical framework and the research question of the study.

2

Preservation

2.1 The socio-cultural evolution of the history value and the definition of cultural heritage

The notion of “**cultural heritage**”, as we conceive it today, is quite recent, as it was elaborated in the second half of the 20th Century. However, every civilization, from prehistory, developed a cult for certain objects, places and tangible goods. The “monument”, in its more ancient conception, is “a human creation, which has been constructed with the specific purpose of conserving present and alive single acts or human destinies in the conscience of future generations” (Riegl, 1903). Nevertheless, several buildings that have not been conceived and built as monuments can become symbols of a certain age or historic period, acquiring the same significance. In fact, the history of the development of our species is tied to the attitudes and the rules that in the centuries permitted the survival of certain objects of various nature to the natural fate (Babelon, J.P., Chastel, 1994). Italy is certainly characterized, among all nations, by an unusual quantity and variety of masterpieces on a relatively limited territory. Nonetheless, what distinguishes Italy from several other nations is the capillarity, the density of a territorial heritage, which testify its artistic history (Settis, 2010). This characteristic is not only due to the fact that in the pre-unitary states of Italy many patrons invested on artworks and celebrative architectures, but also to the diffused approach and cult for several objects that were considered “evidences of the cultural identity” of a certain geographical area. In fact, the pre-unitary Italian States started, before anyone else, to establish rules in the area of preservation and conservation. Moreover, another primacy of Italy is that it was the first nation to conceive the cultural heritage protection as contextual to landscape protection, inserting both as funding principles of the Italian Constitution. In the following, a time excursus on the evolution of the cultural heritage concept is provided.

The book *La notion de patrimoine,* by Babelon and Chastel, individuated the Christian civilisation (from the decay of the Roman Empire until the Renaissance) as **the origin** of the idea of cultural heritage (Babelon, J.P., Chastel, 1994). In fact, the Church promoted from the beginning the cult of certain objects (the relics), that should be conserved as much intact as possible and transmitted to the future generations. The perceived "**collective property**" of these objects, transmitted across generations, is absolutely similar to the current legal connotation of "heritage". In these terms, the cult of these objects was transferred also to churches, so buildings that all across history have been considered "inviolable" in their materiality. The **modern concept** of cultural heritage has been defined during the French Revolution (end of XVIII Century) and is related to the first affirmation of the population's collective sovereignty and the idea that all artworks should belong to citizens. Consequently to this conception, the French government promoted the pillage of artworks all over Europe, since all artworks should have belonged to a "free population". This depredation was really suffered by European nations, and a lot of intellectuals condemned this practice. Even if the modern concept of cultural heritage had not been established already, in Italy a high number of laws protecting artworks from displacement had already been established (Emiliani, 2015). The very first example of **artworks' protection law** is the *Museum Florentinum* (1731-63), which was elaborated from the will of a group of Florence's nobles who wanted to protect the Medici's heritage at the end of their era of government. This document served as a law to enshrine the belonging of all these artworks to the city of Florence. Similar laws were established also in Rome, by the popes, and in Naples. In the following years, also the first **goods' protection institutions** were established, again in Italy first. The first was the institution of the commissioner of Antiques in Rome by the pope Paolo III (Settis, 2010). Even after the unification of Italy, the same principles were applied in the first laws for the protection of antiquities and artwork. The first was the law n.364, in 1909, which established the "public interest on the private property on all mobile and immobile goods with historic, archeologic, palaeontology or artistic interest". The next law on the protection of cultural heritage and landscape was established in 1939, in which the authority of the protection institutions (*Soprintendenze*) was increased. Moreover, in the same year also the Superior Institute for Restoration was established. This attachment to cultural heritage was so important for the Italian culture that the development, valorisation and protection of this heritage constitutes one of the first articles of the Italian Republican Constitution.

After the Second World War, the concept of cultural heritage (which technically substituted the previous distinguished landscape and historic and artistic heritage) evolved and acquired a very inclusive meaning. In fact, in these years, the boundaries defining the goods to be "protected" by the law started to be "enlarged" and becoming more and more inclusive. The reason of this "enlargement" are due to the fact that until those years the definition of what was "interesting" and historically worthy of protection was tied to a "judgment of value", which included a judgment of the aesthetics, the representativeness and the historical importance of a certain good. However, during the post War, the entire discipline of history was reformed, adopting a more anthropological approach. For this reason, also the individuation of the goods to be protected started to be tied to their **anthropological representativeness** (Settis, 2010), resulting in a substantial enlargement of the boundaries above mentioned and the general definition of "cultural" heritage. This new way of conceiving all historic evidences (material and intangible) brought, today, to the responsibility of dealing with any historic good with a substantial respect, regardless of the specific restrictions due to its classification. In this context, Emiliani defines a concept of "**global conservation**" as a necessary objective of the conservatory method based on a new concept of culture and cultural heritage, which refuses the realization of sectorial and selective monuments (Emiliani, 1974). However, at the same time, Emiliani recognizes in this debate about the cultural heritage's definition the fracture that was created, during the years of the reconstruction, between the original "authoritarian conservation tradition", which conceived the heritage in relation to a judgement of value, and the liberal dynamic of the society of those years (Emiliani, 1974). According to the author, this fracture is the origin of the constant "qualms" to the **integration of technological progress on the practice of restoration**, which is still recognized, in present days, also by the engineering sector (Franco *et al.*, 2015).

Despite this intellectual debate, the definition of cultural heritage was formalized in Italy only in 2004, as explained in the following. Nevertheless, also at the international level, the definition of a common approach in the definition of cultural heritage as well as the practices of protection and conservation is very complex, since different cultures worldwide have different ways of dealing with historic evidences. However, according to Ferrari, the substantial difficulty in reaching a common definition of cultural heritage (in terms of inclusion and exclusion criteria) has not prevented a common "respectful" practice of conservation (Ferrari, 1998). At the same time, Francois Choay (Choay, 1995) observed that, at the global scale, the current approach to protection, valorisation and restoration promoted by UNESCO (United Nations Educational, Scientific and Cultural Organization) is founded on the "exportation" of the European ideas on the topic. An example of this practice are the regulations related to the World heritage list, established in 1972, which as of today (March 2020) counts 1121 properties world-wide (UNESCO, 2019).

As previously declared, despite the huge debate on the definition of cultural heritage in the decades after the Second World War, the laws pertaining this sector in Italy, as well as its formal definition, remained unvaried until 2004. In this year, the D.Lgs. 22/1/2004, *Codice dei beni culturali e del paesaggio* (Codes of cultural and landscape heritage) was released (Italian Parliament, 2004). This law defines Cultural heritage as "*le cose immobili e mobili che, ai sensi degli artt. 10 e 11, presentano interesse artistico, storico, archeologico, etnoantropologico, archivistico e bibliografico e le altre cose individuate dalla legge o in base alla* *legge quali testimonianze aventi valore di civiltà*"[1]. This definition is quite wide and requires more specifications, provided in art. 10 and 11. In particular, art. 10 defines the categories of protected goods, to which are related other articles defining the practices of protection, conservation and goods' movement that will be described in the next paragraph. About the definition of the categories of goods to be protected and entitled as "cultural heritage", the criteria differ based on three categories: cultural heritage "ex-lege", goods owned by the public administration (or non-profit associations) and goods owned by privates. For these categories, different criteria are applied to define the belonging to "cultural heritage" and by consequence, the subordination to this specific law. The first category is constituted by goods such as museums, galleries, libraries, etc. for which the verification of "cultural interest" has been established and will remain also in case of changes of property or administration. For the second and the third categories the criteria are similar but not identical. For a building to be considered as "cultural heritage" (or "architectural heritage", to be more precise), several options are contemplated (e.g. the building is an historic villa, or a rural building representative of a certain geographical area). However, the most important aspect to be highlighted is that, according to these articles, for any building older than 70 years whose author has died there is a "**presumption of cultural interest**". This means that before any intervention on these buildings a specific verification done by the public authorities should be done to verify if such interventions should respond to the law pertaining cultural heritage.

Keyword: Cultural heritage preservation's history.

[1] "Mobile and immovable goods that, according to art. 10 and 11, present an artistic, historic, archeologic, ethnographic, archival or bibliographic interest or other goods having a value of civilization" (own translation).

2.2 The practices of protection, conservation and restoration.

This paragraph provides, first, an overview on the principles guiding the practices of protection, conservation and restoration according to the Italian law D.Lgs. 42/2004, *Codice dei beni culturali e del paesaggio* (Codes of cultural and landscape heritage). In a second part, the principles guiding the practice of restoration, which are of major interest to develop solutions also for energy retrofit, are provided by presenting the “charters of restoration”. These principles are not only relevant from the Italian point of view, but they have at least a European relevance. Moreover, citing the opinion of some intellectuals like F. Choay, it can be pointed out that the European way of conceiving these principles is usually taken as reference in the work of UNESCO at the global scale.

The D.Lgs 42/2004 provides guidance on protection, conservation and restoration in articles 21 and 29 (Parliament, 2004). The following overview is provided to outline the **restrictions and obligations** in this field according to the law. This way, a latter work can be done to individuate suitable solutions for energy-retrofit actions. The first aspect to be clarified for the aims of this study is the definition of ***restoration***, which according to art.29 (dedicated to conservation), is “a direct intervention on the good through a series of operations finalized to the material integrity and the total recovery of the good for the protection and transmission of its cultural value (…)” (*ibid.*). Together with the definition of restoration it is useful to consider also the definition of ***maintenance***, specified in co.3. “Maintenance is the series of activities and interventions destined to the control of the good’s conditions in terms of integrity, functional efficiency and identity in all its parts” (*ibid.*). These operations are considered as part of the practice of ***prevention***, which is intended as “the appropriate activities to limit situations of risk related to cultural heritage in this context” (*ibid.*) Starting from these definitions, it can be argued that **energy retrofit** operations could be identified either as **maintenance or restoration**, based on the type of retrofit measures. Another important aspect regards the procedures to intervene on these buildings. In fact, about ***protection***, art. 21 establishes that “the execution of works and actions of any kind on cultural heritage is subject to the authorization of the superintendent” and “the authorization is given based on a project or, if sufficient, on a technical report of the intervention (…)” (*ibid.*). These prescriptions are particularly referred to “material” actions on the building or object. Therefore, other **“operational” or “management” actions** are not subject to authorization. These prescriptions of authorization are crucial in terms of energy retrofit actions. In fact, they means that any operation on the building fabric has to be authorized by the public authorities, whose decisions are based on restoration principles (as explained in the following), and cannot be questioned. Article 21 does not list the criteria used in deciding the suitability of actions, so it is very difficult to identify actions that will be authorized “for sure”, a part from “operational” and “management” interventions, for which authorizations are not required. Summarizing, the D.Lgs. 42/2004 defines the object of the protection (cultural heritage), a very few operations that are prohibited (like the destruction, deterioration or attribution of non-compatible function, art.20), very general indications about the definition and the aim of restoration and the procedure for the authorization of activities. However, as previously mentioned, no indications are provided about the theoretical framework and methodological operations to be implemented in the practice of restoration. These aspects are demanded to the Superior Institution for Conservation and Restoration (*Istituto Superiore per la Conservazione ed il Restauro - ISCR*), which is part of the Ministry of cultural heritage and activities. The ISCR was actually born in 1939 to provide the practice of restoration a new "scientific" dimension constituted by **recognizable principles** and rules, to elaborate uniform practices and judgments for all national territory (ISCR, 2019). In the following, relevant ISCR indications will be described and inserted in the framework of the international "restoration charters".

During the 20th Century, the necessity of sharing unique principles about **restoration as a scientific practice** has emerged at European level. The development of common theories and principles took place in international conferences in which professionals and intellectuals from several countries and cultural background elaborated documents (or agreements) defined "**restoration charters**". The very first restoration charter was elaborated in 1931 (the Athene charter) by the International Conference of Architects. The document is composed by 10 points that consist in recommendations for governments aiming at encouraging the protection of architectural heritage and the adoption of a common approach intended to limit the private interests and promote the public interest of restoration. In the following years, Governments elaborated their national restoration charters. In Italy for example, the Ministry of Public Education enacted the first Italian restoration charter (1932). After a few years, the Second World War caused a series of material destructions of cultural heritage all over Europe. In the years immediately after these facts, with an intent of *damnatio memoriae,* the "recovery" practice, which consisted on re-building destroyed buildings as they were before the destruction, conducted to create a series of historical forgeries. These examples all over Europe brought to the necessity of a new discussion of common restoration principles. This debate was concluded with the most important charter of restoration until today: the **Venice charter** (1964). This charter is composed by 16 articles and summarizes the restoration principles (especially in the field of architecture) guiding its practice, theoretically at the international level, until today. Also the following charters declared that the principles of the previous Venice charter remain totally in force. The only big change proposed by the following charters (and in particular by the Cracovia one in 2000) consists on the definition of "cultural heritage", which is distinguished by the previous concept of "monument". As previously described, the main consequence of the introduction of the "cultural heritage" concept was that the principles of restoration had to be applied not only to the single monuments or iconic buildings, but to the entire context hosting them. Moreover, the modern concept of cultural heritage brought to the conception that also non-listed historic buildings should be treated as past evidences and should be maintained as much intact as possible (Council of Europe, 1985; ICOMOS, 2013). Another important step is represented by the Faro Convention, adopted by the European Council in 2005 and entered into forces in 2011, ratified in Italy in October 2019. This convention is very important for the theme of this research, since it introduces the environment as a peer to the cultural heritage for the sustainable development of European society. Art. 8, in particular, is dedicated to "environment, inheritance and quality of living". For the first time, humans and quality of life are considered in the debate about cultural heritage, highlighting the importance of the **social responsibility** for its preservation. Moreover, art. 9 promotes the **sustainable management** and operation of cultural heritage and highlights the importance of maintenance practice (Council, 2011).

Starting from the evidence that the current principles of restoration are still referred to the ones listed in the Venice charter, in the following the most relevant aspects for this research will be summarized. About *conservation*, art. 4 reminds, again, the importance of maintenance. An important point entails the use of "monuments" (the concept of cultural heritage did not exist yet) with **useful functions** for the society; however, it is stressed that the function must not alter the distribution and the aesthetic looking of the building, therefore any change must be conceived in these boundaries (art.5) (ISCR, 1972). Any destruction, new construction or use that could alter the monument ratio between volume and colours cannot be allowed (art.6) (*ibid.*). Moreover, about *restoration*, it is highlighted that the purpose of this activity is to conserve and take care of the formal and historic values of the monument, respecting the ancient entity and the authentic documents. Any addition should not be "in the style" of the monument, but it should be distinguished and recognizable, being an evidence of the present in which it is conceived (art.9) (*ibid.*). Starting from these principles, in Italy a new charter of restoration was released by the government in 1972, summarizing five fundamental principles that any professional or authority in the field of restoration should respect.

1. **Recognition**: every restoration operation should be recognizable, in the sense that the "new" additions should be distinguished from the original parts without creating a disorder in the aesthetic.

2. **Reversibility**: any intervention should theoretically be removable without altering the original parts.

3. **Compatibility**: the materials employed should not create any physical or aesthetical damage.

4. **Minimum intervention**: the operations, changes and any action on the good should be limited to the absolute minimum to respect the historic evidence.

5. **Multidisciplinary**: any restoration intervention should gather several disciplines and knowledges, collaborating and exchanging strategies with the only common purpose of executing a respectful intervention.

Differently from interventions for structural consolidations, which are already contemplated in the charter, interventions related to energy in general, both as insertion of HVAC systems or in general management of indoor environmental conditions are not cited. Also for this reason, it is not easy to individuate suitable specific solutions. The only relevant article to this topic is art. 10, which is dedicated to actions addressed to preserve buildings from damages caused by pollutants or atmospheric variations, for which it is stressed, again, that any operation or action on the building will have to avoid any alteration of the aspect of materials and colours of surfaces. However, if those actions would be considered "unavoidable", they should be totally recognizable (*ibid.*).

Keywords: Restoration, Maintenance, Social responsibility, Sustainable management.

2.3 Final remarks on preservation

Summarizing the contents of the previous paragraphs and putting them into perspective for the purposes of this research, two main questions should be answered and discussed.

1. *Which buildings are protected and why?* Following the inclusive evolution of the concept of cultural heritage in its anthropological terms, all historic buildings (older than 70 years) are conceived as *potential* cultural heritage. For this reason, especially at the strategic level, it is convenient to approach the theme of adaptation (and energy retrofit) by considering all historic buildings as **potential "architectural heritage"**, following the basic principles of national and international conventions and restoration charters.
2. *Which kind of energy retrofit measures are suitable or not-suitable for architectural heritage?* Paragraph 2.2 outlined several prescriptions about the practices of conservation and restoration. In general, restoration is conceived as an "exceptional" operation to be carried out only in cases of possible risks for cultural heritage. In terms of energy efficiency, the question is: is the urgency of enhancing historic buildings' energy performances actually perceived by restoration professionals and authorities? Hypothesizing that this is the case, any restoration operation should follow several indications. For example, they should avoid the alteration of the ratio volumes/colours and any destruction, but they should also be reversible and compatible with the original materials. For these reasons, it is easy to understand why, in several cases, it is so difficult to promote energy-retrofit measures like insulation, substitution of windows or

insertion of HVAC systems. However, it should be noticed that not all historic buildings are declared protected in all parts, so some of these actions can be executed in non-protected parts, even if the authorization from the *superintendent* would still be necessary. Moreover, sometimes energy-related operations are actually considered “urgent”. In fact, most protected buildings are normally provided with HVAC systems and electricity. However, the topic of energy performance’s enhancement is different, since the “approvability” of certain operation is related, as already mentioned, to the perceived risk for cultural heritage. In this context, it should be noticed that **energy-retrofit measures can sometimes be considered as maintenance operation**. Maintenance, differently from restoration, is promoted and encouraged by all conventions and charters. Therefore, these kind of energy-retrofit measures should probably be conducted before any material operation classified as “restoration”.

3

Adaptation

3.1 Adapting historic buildings to the current necessities of energy efficiency

As partly described in the introduction, in the last years energy and thermal comfort in historic buildings became important topics for the scientific community, especially in the European context. There are three main reasons for this trend. First, the **low replacement rate** of existing buildings by new ones (Becchio, 2013; Vieites, Vassileva and Arias, 2015) that highlights the necessity of retrofitting also historic buildings to reach EU CO_2 emissions' reduction goals (Commission, 2012b). The second is the necessity of providing them with liveable and **comfortable indoor environmental conditions** for occupants' wellbeing. The third is that some iconic historic building hosts expositions or museums, so their indoor environmental conditions should be managed in a way that artworks and other apparatus (e.g. decorations) can be protected from damages (see Par. 3.2). As highlighted by Molina et al, the very first publications on the topic of historic buildings' energy efficiency date back to 1970s and 1980s, consequently to the first oil crisis. Then, only two papers were published between 1983 and 1998. The interest on this field returned evidently after the 2007's economic crisis, with a dramatic increase of published articles after 2011 (Martínez-Molina *et al.*, 2016). In this context, Italy has produced the highest number of researches. One of the possible explanations is that Italy is one of the countries with the largest architectural heritage of the world (Fabbri, K., Zuppiroli, M., Ambrogio, 2012; Fabbri, K., Tronchin,. L., Tarabusi, 2014) and, according to Giombini and Pinchi, accounts for around 40% of the European historical heritage (Giombini and Pinchi, 2015). At a global scale, the literature produced in last years tried to identify, from various points of view and adopting different approaches, a critical balance between energy efficiency, mandatory architectural heritage's conservation requirements and users' thermal comfort (Martínez-Molina *et al.*, 2016).

In the following, recent researches, projects and legislation on historic buildings' energy efficiency are presented by differentiating the different contexts.

3.1.1 Projects and initiatives at European level

The necessity of putting research efforts on historic buildings' energy retrofit is confirmed by the several calls from the Joint Programme Initiative (JPI) and the European's Seventh Framework Program and Horizon 2020 (Berg *et al.*, 2017). In this context, several **European projects** and initiatives were addressed to the individuation of suitable technical solutions for historic buildings' energy retrofit.

One of the first examples of European initiatives was the **NEW4OLD** project, which was aimed at retrofitting a XIX Century building located in Brussels. The building hosts the Renewable Energy House, and the project was aimed also at creating a network of renewable energy houses across several EU Member States (European Renewable Energy Council, 2010). The energy retrofit operation was conducted in order to have a showcase of Renewable Energy Sources (RES) integration in historic buildings. In fact, the main goal of the project was to reduce the energy demand for HVAC by 50% and cover it all with RES. Beyond the specificities, this project represents a good basis to perform some reflections. In fact, a large part of the interventions made on the Brussel case study would not have been allowed in other EU member states. For example, the substitution of old windows with new ones or the installation of a PV system (3kWp) in a historic centre would probably have not been allowed in Italy. In fact, even if some studies investigated how to **integrate RES** in historic buildings and in historic urban centres, in countries like Italy their application seems, still today, quite far, due to the approach to protection, which forbids the change of aesthetic appearance of these contexts (Basnet, 2012; Moschella *et al.*, 2013; Troi, 2013; Marchi *et al.*, 2018). The only possibility in such contexts is an adequate integration, which allows a proper balance between energy and conservation needs (Garau and Rosa-Clot, 2017). In this context, the European project **RESSEEPE** was aimed at assessing several types of **compatible retrofit technologies**, from envelope retrofitting solutions to the integration of RES, nanotechnologies and ICT solutions (RESSEEPE Consortium Partners, 2017). In the following years, the **3ENCULT** (Efficient Energy for EU Cultural heritage) project was addressed to individuate suitable active and passive energy efficiency measures for historic buildings, adopting an interdisciplinary approach and challenging the idea that energy efficiency and heritage preservation would be characterized by mutually exclusive purposes (Ragni *et al.*, 2013). More specifically, the project assessed several retrofit measures, taking into account energy and conservation needs at the same time, as well as multiple geographical contexts (Troi, Bastian and Al., 2014). In fact, as previously mentioned, it is fundamental to investigate **climate change risks** connected to historic buildings and, more specifically, damages for historic materials, but at the same time new technologies should be totally compatible and non-intrusive (Bianco *et al.*, 2015; De Fino *et al.*, 2017; Rosina, 2018). Another fundamental aspect highlighted by the report is the strategic importance of historic buildings for the touristic sector, which is particularly relevant for the economy of some European Nations (Invitalia, 2012). In fact, the energy retrofit can be considered as part of the so-called **“valorisation” practices**, being a way of adapting historic buildings to the current **social profitability** needs (Coscia and Fregonara, 2004). The project proposed a methodology that was implemented in eight case studies, consisting in six steps from the definition of the objectives (programme) to the post-assessment phase. Beyond the specificities of each phase, particular emphasis should be given to two moments of the methodology: the **pre-assessment** and the **post-assessment**. In fact, due to the uniqueness of each historic building, the analysis of the current state and the specific building performances becomes crucial. In fact, according to Giuliani, the correct assessment of the operational performance of the building (state of affairs) is key to develop adequate retrofit measures (Giuliani, 2016). The importance of initial diagnostic of the building peculiar energy performances is stressed by standards at European and National levels, but also confirmed by single case studies’ applications (Ragni *et al.*, 2013; Negro *et al.*, 2016; CEN, 2017; Righi *et al.*, 2017). The **RENERPATH** project for example, carried out between 2011 and 2012, was aimed at the development of a methodology for the evaluation of buildings’ energy efficiency through non-invasive diagnostic techniques such as thermography and laser scanning (Junta de Castilla y Leon, 2012). For the same reasons, also the **post-assessment** becomes fundamental, due to the low predictability of the retrofit measures’ consequences. The 3ENCULT project defined also some challenges and topics of interest for the historic building’s research. Among other points, it is interesting to cite the importance of diagnostic and monitoring for in-situ studies and the necessity of defining **replicable solutions** trying to scale-up single case study’s measures, which is a difficult task due to the uniqueness of each historic building and the specificities of historic buildings’ characteristics in terms of geographical context (Genova, Fatta and Vinci, 2017). In addition, the final report highlighted the necessity of integrating the current legislations with indications for historic buildings. In particular, the experts proposed some integrations to the 2010’s EPBD (Commission, 2010), which were partly integrated in the new 2018’s Directive, even if with no particular reference to historic buildings (Union, 2018). Similar researches were conducted also considering the district level. The **EFFESUS** European project developed a decision-making system to support the transition of historic district towards energy efficiency (Eriksson *et al.*, 2014; Eriksson, P., A. Egusquiza, A., Broström, 2016; Lucchi, 2018). This project made a great effort also on the study of compatible materials with the historic fabric, from the concept to the real implementation, considering thermal performance, durability, compatibility and reversibility of the proposed solutions (Becherini *et al.*, 2018).

Keywords: Climate change risks, Social profitability, Replicable solutions.

3.1.2 Historic buildings' energy-related legislations and guidelines

As mentioned in the Introduction, National and International standards and directives on buildings' energy efficiency do not usually entail historic buildings, adopting a **derogation regime** that, as declared by Brito, causes "a shadow of inefficiency and discomfort" (Mazzarella, 2015; Brito, 2016). One of the main reasons of confusion and criticism is that the EPBD directives did not define the real **boundaries** of their application, limiting the exemption to "buildings officially protected as part of a designated environment or because of their special architectural or historical merit, in so far as compliance with certain minimum energy performance requirements would unacceptably alter their character or appearance" (Commission, 2010). However, as previously described, the concept of "officially protected" buildings does not completely comply with the relevant restoration charters and the modern concept of cultural heritage, which implies the protection of every culturally-significant building (Council of Europe, 1985; Jurošević, S., Grytli, 2016). According to De Bouw, historic buildings are usually exempted from the application of standards for four main reasons. First, because, as already explicated in multiple contexts, the objectives of heritage protection and energy savings or comfort optimizations usually seem too difficult to balance. Second, because the application of new technologies or the implementation of new techniques on historic buildings require a high level of expertise from all the professionals involved in the design and realization process. The third is that, even in presence of a great expertise and implementation quality, the long-term consequences of the installation of new materials or technologies on historic fabrics is very hard to predict. The fourth and final reason is that, as explained in the Preservation chapter, it is generally accepted that the conservation of historic buildings' aesthetics and originality should be pursued above any other need, so it is very hard to promote modifications of the building materiality, even if it is for reducing the environmental footprint of these buildings (De Bouw, 2016).

Despite all these complexities, in the past decades the problem of cultural heritage's sustainability has been discussed in several conferences of ministers for heritage preservation at International at European and National level (Litti, G., Audenaert, A., Braet, 2013). However, the main contributions to heritage sustainability in terms of guidelines were provided only in the restoration sector, remaining at a very theoretical level, e.g. the restoration charters presented in Chapter 2. The gap of any kind of coordination or indications on this topic at the **European level** was bridged in 2017 by the European Standard **UNI EN 16883:2017**, elaborated by the technical committee CEN/TC 346 "Conservation of Cultural Heritage" – WG 8 "Energy efficiency of historic buildings" (Co2olBricks, 2013; CEN, 2017). This standard was conceived as a procedural instrument, aimed at providing a **systematic approach** and at facilitating the individuation of the best solutions case by case. In particular, the document provides a **working procedure** to assess and choose between several possible retrofit measures, evaluating necessities, risks and advantages at the same time. However, the procedure does not classify examples of retrofit measures, it only lists a series of technical, economic and cultural aspects that should be considered in the selection process. These aspects are evaluated based on a "risk" scale ranging from "high risk" to "high benefits", following one of the most recent approaches to heritage conservation in general (**risk assessment**), as it will be explained in the following paragraph on Preventive conservation. Accordingly to previous projects and researches both in restoration and energy fields, the standard promotes a **multi-disciplinary approach** and gives a great importance to the pre-assessment phase, namely the diagnosis of the state of affair. The necessity of a multi-disciplinary work-flow consists on the necessity of gather all the stakeholders involved in the energy retrofit process, from building owners to the various professionals (designers, conservators, building managers, constructors etc.). Before this standard, many other studies promoted and adopted this kind of approach for conducting the preliminary analyses of building diagnosis, as well as to individuate appropriate technological solutions for retrofit interventions (Moschella *et al.*, 2013; Troi, Bastian and Al., 2014; Héberlé, E., Burgholzer, 2016; Di Ruocco, Sicignano and Sessa, 2017). Moreover, adopting a multi-disciplinary work-flow, could prevent some rebound-effects' risks due to the evaluation of single elements or phenomena (Agbota, 2014; Pracchi, 2014). An aspect that should be highlighted about the standard, which will be further discussed in the following section, is **the role of "final users"** in the decision making process. In fact, even if the standard explicitly remarks the importance of involving people (generally referred as "users") in the design process due to their weight in determining the building's conservation state, energy performance and costs associated, the selection process do not include them in any stage.

At the **National level**, and particularly in **Italy**, the problem of defining common approaches or solutions for historic buildings' energy retrofit has been faced by constituting an experts' working group (D. Lgs. 20/08/2013) that lead to the drafting of the so-called "Guidelines for the enhancement of cultural heritage's energy efficiency" (transl., *Linee di indirizzo per il miglioramento dell'efficienza energetica nel patrimonio culturale*) (Ragni *et al.*, 2013). The guidelines provide indications on the evaluation and the enhancement of listed buildings' energy efficiency, e.g. presenting a series of viable interventions with reference to the Italian regulations. Due to the uniqueness of every historic buildings, the showed interventions are not intended as a list of possibilities. However, for every case study a rich bibliography and technical properties of the used materials are provided. Similarly to the European standard and other projects or researches, the standard puts a great stress on the importance of the **building specificities' diagnosis** in terms of energy performances and building fabric's characteristics. A first important aspect to highlight is the intended **recipients** of this document, namely professionals and operators of the Ministry of Cultural heritage ad activities. In fact, the document is conceived also as a starting point to establish a technical-scientific debate on the theme of historic buildings' energy efficiency. In these terms, the involvement of a restoration professor in the working group

(Giovanni Carbonara) was a significant choice, as well as the suggestion of designing the energy-retrofit interventions following the five fundamental principles of restoration described in Par. 2.2 (recognition, reversibility etc.). This kind of document (addressed to professionals) should be distinguished from other types of guidelines diffused in other countries. In UK, for instance, a number of guidelines and informative documents are available and directed not only to professionals, but also to private owners and users of historic buildings. Such guidelines are authored and diffused by various organizations and associations at National and Regional level, like the English Heritage, the Historic England etc. (English Heritage, 2010, 2012; Historic England, 2011, 2015; Arnold *et al.*, 2013; STBA, 2015; McCaig, Iain; Pender, Robyn; Pickles, 2018). The text of these guidelines is usually quite informative and for sure they could not substitute other technical publications on the same topics, but it is interesting to notice that this level of communication (or **dissemination**) is provided on these topics, usually relegated only to the professional practice. In fact, these guidelines usually "translate" the contents of regulations for citizens or explain how to operate or conserve historic materials or building components which could be present in historic houses. Another interesting point of the Italian guidelines is that one of the main objectives was to provide the protection authorities (*Soprintendenze*) some criteria to evaluate and authorize energy-retrofit operations on historic buildings. The document was intended also as an instrument to establish energy-saving procedures and intervention for public historic buildings, which represents a huge expenditure voice for the Italian State (Poggi, 2016). In fact, more than 3000 of the overall Italian 5000 architectural heritages (considering museums, palaces and monuments) are managed by the public authorities, with an annual expenditure of about 250 millions of Euros (ENEA, 2017). Moreover, in some museums, the energy costs represent about 70% of the total budget (ENEA, 2017).

Key words: Multi-disciplinary, Systematic approach.

3.1.3 Historic buildings' energy retrofit. Researches on methodologies, energy simulations and financial evaluations

The large majority of energy-related researches conducted on historic buildings are dedicated to the attempt to improve their energy efficiency and thermal comfort in terms of technical improvements (Trust, 2005; Heritage, 2008, 2012; Ascione, F., Rossi, F., Vanoli, 2011; English Heritage, 2012; Martínez-Molina *et al.*, 2016). Historic buildings' energy retrofit implies the involvement of environmental, economic, social and cultural aspects at the same time, so it needs, more than in the common practice for recent buildings, an **interdisciplinary approach** and the involvement of multiple professional expertise (Romeo, Morezzi and Rudiero, 2015). For this reason, several researches are conducted by evaluating energy-retrofit measures' alternatives by taking into account different variables. One of the most investigated aspects is the **financial one**, which is implemented by choosing the energy-retrofit measures also depending on the time for return of the investment or based on more complex analyses' methods (like cost-optimal analyses or life-cycle approach) (Costanzo *et al.*, 2006; Héberlé, E., Burgholzer, 2016; Mauri, 2016; Ascione *et al.*, 2017; Becchio, Corgnati and Spigliantini, 2017; Righi *et al.*, 2017; Bertolin and Loli, 2018; Lucchi, 2018). Another important aspect, which is investigated by a certain amount of researches, is the **"social" relevance**. In fact, since historic buildings are perceived as a collective ownership, their "social dimension" is quite relevant. Moreover, since many "material" interventions are forbidden in such buildings, knowing and intervening on their operation is fundamental. These aspects will be addressed in the following Paragraph (3.1.4). Due to the number of variables to be taken into account in the energy-retrofit process, several studies proposed **energy-retrofit measures' evaluation** and selection methodologies, showing their application on one or a few case studies (Pisello *et al.*, 2014a; Di Ruocco, Sicignano and Sessa, 2017; Lodi *et al.*, 2017; Roberti *et al.*, 2017). This approach is strictly related to the fact that historic buildings are usually unique examples, and retrofit solutions cannot be generalized or advised in all cases. Therefore, a suitable solution is to adopt a homogeneous approach in dealing with different cases, thus proposing a **methodology**. From an energy point of view, the majority of these studies take advantage of **energy models**, used to assess the energy savings obtainable by the different retrofit options and, in some cases, their consequences in terms of thermal comfort enhancement (Pisello *et al.*, 2014b, 2014a; Roberti, Oberegger and Gasparella, 2015; Dalla Mora *et al.*, 2015; Mauri, 2016; Carbonara and Tiberi, 2016; Cornaro, Puggioni and Strollo, 2016; Giuliani, 2016; Mancini *et al.*, 2016; Ascione *et al.*, 2017; Roberti *et al.*, 2017; D'Agostino *et al.*, 2017; Di Ruocco, Sicignano and Sessa, 2017; Lodi *et al.*, 2017; Bruno, De Fino and Fatiguso, 2018; Schibuola, Scarpa and Tambani, 2018). Dealing with historic buildings, several studies also take into account the architectural compatibility or intrusiveness with the historic fabric (Carbonara and Tiberi, 2016; Cornaro, Puggioni and Strollo, 2016; D'Agostino *et al.*, 2017; Lodi *et al.*, 2017). Several of these studies attributes a great importance to the study of the building's specific state of affairs in terms of geometry, materials, technologies and building use (audit or pre-assessment). An accurate knowledge of the building's characteristics can be used, for example, in a first phase, to choose energy retrofit interventions (both operational and physical) (Mancini *et al.*, 2016; Righi *et al.*, 2017; Roberti *et al.*, 2017). Moreover, a proper knowledge of the building configuration and use represents an important instrument to construct a **reliable model** (Pracchi, 2014; Giuliani, 2016; Mancini *et al.*, 2016; Schibuola, Scarpa and Tambani, 2018). Lastly, the **energy audit** can be used to test the reliability of the model, for example by comparing simulated and real energy consumptions (Righi *et al.*, 2017), but also to calibrate the model, as shown in several studies (Cornaro, Puggioni and Strollo, 2016; Giuliani, 2016; Roberti *et al.*, 2017). **Calibrations** and accurate data input are crucial to build a reliable energy model, since adapting the standard analytical tools (like energy simulation software) to the simulation of historic buildings is already quite complicated. In fact, most of these tools were designed to simulate "modern buildings", so they can hardly represent historic materials' thermal behaviour (which is very hard to predict), leading to oversimplified simulations and, by consequence, **estimation errors** (Pracchi, 2014). For these reasons, it becomes particularly important to properly assess (and represent in the model) how the building is handled (operational energy audit), its occupancy and, possibly, some characteristics of its occupants' behaviour (Mancini *et al.*, 2016). In fact, even in modern buildings and even using dynamic simulation tools, unpredicted human behaviour and operational description potentially lead to large predictions' errors (Andersen, R. V., Olesen, B., Toftum, 2007; Mahdavi, 2011; Hong, T., Lin, 2012; Chen, J., Taylor, 2013; Fabi, Andersen and Corgnati, 2013, 2016).

Key words: Methodology, Energy retrofit.

3.2 Managing the indoor environment for preventive conservation

An adequate management of the indoor environment is fundamental for a correct conservation of the building and the objects contained in it, as well as for humans' comfort and wellbeing. Preventive conservation in historic buildings entails several topics, from environmental parameters' monitoring to control techniques practices for the optimization of the indoor environmental quality. Traditionally, this strand of research has been developed to establish standards of indoor environmental conditions with the aim of reducing **heritage conservation risks** (artworks, building decorations etc.), considering single damaging factors (light, temperature, relative humidity etc.), materials (wood, paper etc.), or even considering several parameters together on a potential "entire collection". In the following, an overview of the most important aspects concerning preventive conservation in historic buildings, and especially in museums and expositions, is provided. However, this paragraph will not deepen on restoration and conservation techniques' theoretical framework and philosophies, but it will give an overview of preventive conservation in terms of indoor environmental conditions' control.

The International Council of Museums (ICOM) defines the conservation of tangible heritage as "(…) all measures and actions aimed at safeguarding tangible cultural heritage while ensuring its accessibility to present and future generations" (ICOM, 2008). Moreover, preventive conservation is differentiated from restoration because it is aimed at preventing future possible damages, while restoration is dedicated to "fix" already present damages. More specifically, preventive conservation is a practice that should balance the necessities of **protection** of cultural heritage and **public access** through various solutions of prevention strategies, analyses and actions (National Park Service, 1999). Therefore, preventive conservation is not only aimed at the conservation of artworks and fragile materials, but also at ensuring free access, safety, comfort and energy efficiency of museums (Lucchi, 2018). The first sources on indoor environmental conditions' control for cultural heritage conservation belongs to England and date back to XVI Century. In recent years, Lambert gathered documents containing advices and techniques to optimize light, heat, humidity and other aspects such as insects and dust in historic buildings (Lambert, 2014). These documents, which were addressed mainly to managing staff, are known as "**housekeeping**" practices and advices. Also today, the same practices of "non-intrusive" conservation, pertaining mainly to the English geographical area, are still defined as "housekeeping" techniques, and recent manuals released by the National Trust are taken as reference at the world scale (Trust, 2006). The general approach adopted by the National Trust is to prioritize **"passive" solutions**, in the sense that all conservation measures are addressed to the maximisation of the historic building's potentialities in terms of outdoor conditions' mitigation. In particular, they try to keep the historic building as much "original" as possible, trying to limit the introduction of new systems and technologies. Even if not applicable in every context, this approach is very interesting since it tries to exploit historic building fabrics' intrinsic potentialities and eventually add new technologies in order to integrate them. This is quite different from the approach usually adopted in museums located in historic buildings, at least until a few years ago, in which the design of HVAC systems is usually performed considering the building as an "empty box", not taking into account all its specificities linked to the construction materials and the construction techniques.

After the Second World War, in parallel to the debate that created the concept of cultural heritage, the problem of preventive conservation was faced by many Nations, since a lot of artworks were damaged during the war. In these years, the first laboratories were created in multiple international museums and the first HVAC systems were experimented for active indoor environmental control (Lucchi, 2018). In 1958, Plenderlith explored several **materials' deterioration causes** and demonstrated that an accurate control of environmental parameters such as temperature, relative humidity and light, as well as other pollutants could minimize materials' deterioration (Plenderlith, 1958). In 1967 the Institute for Conservation of Historic and Artistic Works (IIC) dedicated a conference called "museum climatology", deepening on the same field of research. After these years, in which the topic of preventive conservation referred to indoor environmental control arose, different phases characterized this field of research. In 2003, De Guichen classified four different stages on the line of history. After the first phase previously mentioned (1965-75), a second phase of debate lasted about ten years between 1976 and 1985, after which strategies for the environmental control were actually designed (1985-95) (De Guichen, 2003). During the years of debate, the main focus was the definition of "standard conditions" in which artworks, or more generally materials, could be conserved without physical damages. In this context, the International Centre for the Study of Preservation and Restoration of Cultural Property (ICOM, then transformed into ICCROM) played a crucial role in establishing **optimal indoor environmental conditions** for cultural heritage protection (Lucchi, 2018). Another fundamental contribution to the debate came from Thomson, who in 1978 introduced two classes in which museums could be distinguished (Thomson, 1978). The first, called "20/50 standard" (which stands for 20°C/50% relative humidity) and characterized by an active indoor environmental control (HVAC systems), should have been guaranteed by the most important museums independently from their building type (historic or new). The second, dedicated to all those buildings that were not provided with such active indoor conditions' control, had the objective of avoiding major dangers and damages by implementing **low-impact strategies**. Thomson's classes were adopted by several museums institutions worldwide, which were interested in be categorized as "class one" museums. However, since class one's requisites were not very hard to be reached and according to some studies they were not deeply linked to scientific evidences, many examples of "class one" museums in which physical damages happened were registered (Brown, J.P., Rose, 1996). Anyway, despite the problems identified regarding Thomson's classes, his approach, aimed at identifying appropriate "ranges" in which different environmental parameters (light, temperature, humidity ratio etc.) should have been kept in order to reduce damages' risks for different materials, was maintained in next studies and guidelines in various geographical contexts, from Italy (Aghemo, C., Casetta, G.C., Filippi, 1989) to UK (Commission, 1992)(Commission, 1992) and France (Stolow, 1979). The ranges of appropriate conditions remained divided per environmental parameter until Camuffo introduced the concept of "**historic climate**" investigating their cumulative effect in determining the overall conservation conditions (Camuffo, 1998; Fabbri and Pretelli, 2014). This approach was adopted to elaborate Italian standards (UNI, 1999a, 1999b, 2002) and European ones, also several years later (CEN, 2010a, 2010b, 2011). For example, the UNI 10829:1999 established a methodology for field measurements of thermo-hygrometric and lighting parameters. Then, the standard introduced also reference values (ranges) in which the most relevant indoor environmental parameters should have been kept in order to avoid damages. These ranges were based on objects' materials (e.g. painted wood, painting on canvas etc.). For air temperature and relative humidity, not only the ranges of allowed values were determined, but also maximum daily fluctuations. Moreover, the standard provided a method for the elaboration and analysis of data aimed at the evaluation and control of the degradation process. The fundamental statistical indicators provided were maximum daily and hourly fluctuations and maximum, minimum and standard deviations. This standard was integrated, in 2001, by the ministerial decree D.Lgs. 112/98 of May the 10th. This standard established **qualification criteria** for museums, considering the technical and scientific criteria for the preservation of cultural heritage, the documentation to be produced by the institutions for conservative purposes and the environmental parameters to be evaluated within the expositive area (Ministero per i beni e le attività culturali, 2001; Bonvicini *et al.*, 2011). The "European" approach can be distinguished from the Italian one because it was more concentrated on the certification and **classification of the indoor environmental quality** based on the definition of monitoring and measurement methods, not introducing strict requirements or allowed ranges (CEN, 2008).

In the following years, another approach to preventive conservation was introduced: **risk assessment**. This new approach emerged from the experience in museums' management and was addressed not only to the definition of "safeguarding conditions", but also to organizational and managerial practices (Ashley-Smith, 1999; Michalski, 2007). Following this experience, other museums, national and regional administrations published checklists or manuals putting together several aspects (not only environmental ones) contributing to cultural heritage damage risks (Corgnati *et al.*, 2014). In Piedmont (Italy) for example, a tool called Confidential Facility Report (CFR) was developed to analyse museums' quality in terms of different aspects. The report, in fact, was divided in different parts regarding facilities, installation, collections' conservation state and management, safety, security and maintenance (Rota, M., Filippi, 2009). Based on risk-assessment approach, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) published a handbook changing the approach to preventive conservation. In fact, instead of focusing on the ability of the indoor environment in providing correct conservation conditions for single objects or materials (as showed regarding the UNI 10829), the focus was moved to the building potentiality of controlling the indoor space to preserve an entire collection (ASHRAE, 2007). More specifically, in this standard the indoor environment is classified in four possible classes of building-plant systems' "control potential" in relation to conservation risks. The four classes (from AA-no seasonal temperature and relative humidity variation allowed to D- no systems) can be used either to classify existing buildings or designing new exhibition spaces. The criteria used to identify the classes are building construction characteristics, building type, building use, HVAC system's type and practical limits to control the indoor environment.

Regardless of the standard or the approach used to define or label an exposition area, the use of a **monitoring system** is crucial (Corgnati, Fabi and Filippi, 2009). Monitoring campaigns allow the assessment of microclimatic variations over time and are fundamental for diagnostic reasons (to assess the thermo-hygrometric dynamics of the building-plant system), for the definition of the actual microclimatic conditions and for the detection of critical conditions to be fixed. National and International standards clarify techniques, instruments, processing and synthesis procedures in this field (UNI, 1999c, 1999b, 2002; CEN, 2010a, 2010b). Other indicators were elaborated by the scientific community in order to provide a synthetic mean to evaluate the indoor environment performances. A fundamental characteristic of these indicators is that the evaluations of the indoor environment are provided based on medium or long term monitoring campaigns (not punctual or short term ones). This is the case of the so-called **Performance Index** (PI), defined as the percentage of time in which the measured parameter (that could be temperature or relative humidity usually) is within a certain acceptability range (established by the museum curator or taken by the standards) (Corgnati, Fabi and Filippi, 2009; Corgnati and Filippi, 2010; Fabi and Corgnati, 2014). The PI and the Deviation Index (in Italian "*Indice di Scostamento*" - SI), which represents the percentage of time in which the measured parameter is not within the established range, are useful indicators not only to evaluate the indoor environment conservations' potentialities, but also to evaluate the effectiveness of HVAC systems and to assess microclimatic conditions with the aim of evaluating occupants' comfort.

In recent years, the awareness of climate change and the necessity of reducing buildings' energy consumptions as required by the European EPBD Directives (European commission, 2002; Commission, 2010) opened new perspectives of research also in terms of preventive conservation and museums' management. While in the past the main focus was finding a way of controlling the indoor environment in an optimum way for the conservation of artworks, in the present the necessities of conservation have to be balanced with the necessity of **lowering buildings' energy consumption** to reduce their environmental impact. An example of this approach is represented by a study conducted by Erhardt et al., in which potential energy savings were assessed in museums hypothesizing energy management strategies (Erhardt, D., Tumosa, C.S., 2007). In these terms, the element of management is crucial to ensure appropriate conservation practice and an adequate operation of HVAC systems (Cassar, 1995). Another aspect to take into account is that, despite the absence of accurate indoor environmental control systems, most collections and artworks survived until our days (Padfield, 2007). This, because materials are actually capable to acclimatize to the surrounding conditions. This is also due to the usual capability of historic buildings of mitigating outdoor conditions, thanks to their traditional thermal mass which allowed a continuous mitigation of abrupt changes of outdoor conditions. All this considered, a more conscious use of energy and exploitation of "passive" potentialities of building fabrics could allow a notable reduction of energy use in museums (Tombazis, 1998). Again, the role of an accurate and **knowledge-based management** of these buildings appears crucial (De Guichen, 1980), also because several examples of damages due to an improper operation of HVAC systems or consequences of sudden systems' failures have been gathered through the years (Cassar, 1995; AICARR, 2013). These considerations brought, in current years, to a debate trying to re-define the above-mentioned standards with a more flexible and energy-reasonable approach (Cassar, 1995).

Key words: Heritage conservation risks, Knowledge-based management.

3.3 Building operation and occupant behaviour as an opportunity to balance preservation and adaptation

The **social dimension of cultural heritage**, both in terms of definitions and practices, has already been highlighted in several paragraphs and particularly in Chapter 2. However, when it comes to energy-related studies on historic buildings, the so-called "**human factor**" is not often taken into account. However, citing a very famous headline by Janda, "*Buildings don't use energy, people do!*" (Janda, 2011), so this topic deserves a greater attention. In the following, several reflections will give an overview of reasons why building operation (and more generally occupant behaviour) can represent an opportunity of pursuing energy efficiency and conservation purposes at the same time.

Historic buildings' energy retrofit finds its main reason on the preponderant necessity of adapting them to the current lifestyles, which constitutes one of the main reasons why, today, researches are done in order to maintain and valorise them for their **social profitability** (Coscia and Fregonara, 2004). In fact, as declared by De Bouw, while it could be acceptable for these buildings to only partially meet the current energy performance standards, "*users' comfort must be taken into account in order to assure the future use of these buildings*". In fact, "*it is common knowledge that unused buildings decay rapidly and uncomfortable and energy consuming buildings are not likely to be used*" (De Bouw, 2016). As an example, in residential buildings, beyond all conservation necessities, legislative requirements and intellectual positions, final users are mainly interested in configuring the indoor environment in a comfortable way (Humphreys, M., Nicol, F., Roaf, 2011). For instance, a Norwegian research found that the most efficient incentive for retrofitting historic homes was the possibility to improve indoor comfort, more than cutting energy bills (Godbolt, 2014). In these terms, it could be argued that "*the tension between heritage preservation and the need for thermal comfort is probably a bigger challenge than finding retrofit solutions that respect the aesthetic and historic significance of a building*" (Fouseki and Cassar, 2014).

Starting from these considerations, we could identify a common path for energy-related researches and conservation ones. In fact, in a way, historic buildings' energy retrofit could be conceived as an opportunity to reach more comfortable indoor environmental conditions for occupants (possibly enhancing also the energy performances), which supports also the building survival and maintenance. In these terms, we could conceive the "human factor" as the bridging element between these two instances (conservation and energy efficiency) that very often are considered as mutual exclusive purposes. In these terms, in the occupant behaviour research field the definition "human-in-the-loop" is usually used in order to identify an approach that collect and possibly use data on occupancy or occupant behaviour (Wagner and Brien, 2018). Of course, focusing on the **human dimension of energy use** in buildings does not exclude the necessity of technical solutions and a scientific approach to energy efficiency. However, this approach requires a change of perspective, conceiving buildings' energy use as a result of human-building interactions (not only the result of envelope and HVAC systems' performances) and conceiving occupants' comfort as much necessary as energy efficiency. Adopting this perspective, also the role of heritage protection laws, often conceived as barriers, can be re-evaluated. In fact, adopting proportionate and punctual technical measures and **involving occupants in the well maintenance and operation** practices can balance the needs of preservation and energy savings, obtaining considerable positive impacts (Humphreys, M., Nicol, F., Roaf, 2011; Curtis, 2016; Berg *et al.*, 2017).

The opportunity of adopting this new approach for historic buildings is supported by the **difficulty of modelling historic buildings' energy behaviour**, which is highly related to the difficulty of modelling occupant behaviour (1) and historic materials' real thermal properties and dynamics (2) (Pracchi, 2014). Moreover, focusing on user-driven energy efficiency represents one of the few solutions to avoid unintended consequences after an energy retrofit operation. This is the case of the so-called "**rebound effect**", which consists on the non-fulfilment of the prevented building's energy use reduction or even the increase of its energy demand after an energy-retrofit intervention. This phenomenon has been observed in several studies (Bell, M., Lowe, 2000; Dowson, M., Poole, A., Harrison, D., Susman, 2012; Agbota, 2014) and it is recognized as one of the factors responsible of the gap between expected (or simulated) and real energy performances of buildings. One of the possible reasons for the rebound effect is that the majority of studies on historic buildings' energy retrofit are focused on possible building's technical improvements, usually focusing on single elements or single aspects (like energy efficiency or economic convenience), not considering occupant behaviour and not implementing a **"whole-system" approach**. In fact, choosing the most "efficient" or "convenient" measure for a single component could change the whole historic fabric's behaviour, causing more energy expenditure elsewhere (Agbota, 2014). At the same time, changes of the building technologies usually affect also building occupants' expectations and habits (Xing, Y., Hewitt, N., Griffiths, 2011). Only a few studies tried to assess to which extent energy-retrofit measures were able to effectively produce energy savings, considering the possible occupants' behavioural changes that could lead to rebound effects (Agbota, 2014; Ben and Steemers, 2014). In these terms, it seems fundamental not only to adopt a multi-disciplinary approach to efficiently design and implement energy retrofit interventions, but also to put an adequate effort on the assessment of the whole system (building-plants-occupants), considering as much technical and operational aspects as possible (Richards, A., Clarke, A., Hunt, 2016).

Several authors declared that nowadays there is a lack of knowledge about how building occupants perceive and behave in historic buildings (Agbota, 2014; Crockford, 2014; Fouseki and Cassar, 2014; Berg *et al.*, 2017). However, this knowledge is fundamental to apply reliable user-driven energy efficiency strategies, as well as to limit the rebound effects previously mentioned. In this context, there are two aspects to be investigated. First, how historic building's users behave and how this behaviour differs from the studies conducted in other building typologies. In this framework, Adams et al. observed that in UK historic residences occupants' awareness of the building's historic value influenced their evaluation of thermal comfort, probably causing also a different behaviour towards the energy-related controls (Adams *et al.*, 2014). Second, how **occupants can be engaged in a pro-active way** to adequately operate the available energy technologies in historic buildings. This requires some additional attention. In fact, as mentioned by Crockford, "*living a twenty-first-century lifestyle in a period building requires some consideration. One needs to be aware of how the historic building fabric and original layout function*" (Crockford, 2014). This requires that occupants are informed not only about energy-efficiency, but also about historic buildings' specificities. In this direction, some UK's associations elaborated specific guidelines for practitioners and non-practitioners as mentioned Par. 3.1.2 (Heritage, 2008, 2012; Historic England, 2011, 2015). In Scotland, some other initiatives were activated to raise awareness and diffuse relevant knowledge to the different actors involved in the process of energy retrofit (from professionals to contractors and final users) using different channels of communication and providing specific information (Jenkins, no date). A third aspect to be investigated is the **"viability" of user-driven energy efficiency interventions in terms of efficacy**. In fact, once clarified that technical improvements of the building-plant system are not sufficient to obtain energy savings if not coupled to a proper building operation, the "second level" would be to investigate if **occupants' engagement** can be considered as a **"retrofit measure"** itself. Unfortunately, not much research has been done in this direction, but the available evidences are encouraging. For example, a study conducted in the UK by Ben and Steemers found that, in a set of residential buildings, the impact of behavioural change measures brought to higher savings then the ones obtainable with other "physical" improvements (Ben and Steemers, 2014). Focusing more generally on building operation rather than only on occupants' behaviour, since in non-residential buildings these two aspects are connected to different people (building managers and building occupants/users), a research conducted by Schibuola et al. demonstrated that adjusting how the building was operated was a more convenient measure (both in energy and economic terms) than any other "physical" intervention on the building (such as windows' substitution or walls' insulation) (Schibuola, Scarpa and Tambani, 2018).

Key-words: Human factor, User-driven energy efficiency, Rebound effect.

3.3.1 Occupant behaviour

Since user-driven energy efficiency represents a great opportunity for retrofitting historic buildings but not much researches has been conducted in this specific field, in the following an overview of the theoretical framework on energy-relevant occupant behaviour is provided. According to Yoshino et al., buildings' energy consumption is 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) (Yoshino and Al., 2013). Considering this statement, three factors out of six (4, 5 and 6) are related to the way the building is operated by humans in terms of interactions with energy-relevant interfaces of the building. For this reason, factors 4, 5 and 6 can be generally synthesized in a **unique category defined as "occupant behaviour"**, which expresses the "human factor" presented in Par. 3.3. Occupant behaviour was defined by Schweiker in 2010 as "*human being's unconscious and conscious actions to control the physical parameters of the surrounding built environment based on the comparison of the perceived environment to the sum of past experiences"*(Schweiker, 2010). However, as it will be explained in the following, also other types of actions can be identified as energy-related occupant behaviour and have energy impacts, e.g. actions that are not directly intended to change the physical attributes of the indoor environment, such as switching on a TV.

Nowadays, occupant behaviour has been broadly recognized as a crucial aspect, influencing both buildings' energy demand and indoor environmental quality (Rijal *et al.*, 2007; Herkel, Knapp and Pfafferott, 2008; Schweiker and Shukuya, 2009; Mahdavi, 2011; Yan, D., Hong, T., Dong, B., Mahdavi, A., D'oca, S., Gaetani, I., Feng, 2017). In general, this approach requires, as anticipated in Par. 3.3, a change of perspective in order to conceive occupants as **"active players" of the built environment** and not anymore as passive recipients of certain indoor environmental conditions (Langevin, J., Wen, J., Gurian, 2016). In fact, occupants can affect buildings' energy demand in several ways, e.g. opening windows, turning on artificial lights or adjusting thermostats' settings. More specifically, Schweiker et al. categorised two ways by which occupants can affect buildings' energy demand: only being present within a certain space (for their heat production and pollutants like CO_2) and by interacting with building controls (Schweiker *et al.*, 2018).

Of course, different types of "occupants", or more generally "players", can be recognized. In general, two categories can be defined. First, those **people who effectively occupy the building** to perform some activities – building users or occupants (working, living, etc.). Second, **those who "manage" the building-plant system** to obtain certain indoor environmental conditions (e.g. settings HVAC, maintaining the building fabric and technologies)- building operators. These two categories usually coincide in residential buildings, in which typically owners operates, maintain and "use" their home at the same time. In non-residential buildings (such as offices, schools, museums, commercial buildings etc.), these two categories are distinguished, so we could distinguish two groups of people interacting with the building-plants systems: building operators (such as energy or building managers or technicians) and building occupants or users. In these terms, it is fundamental to highlight that, differently from the residential case in which occupants could set the surrounding environment according to their comfort necessities, in this case this is much more challenging and create a crucial potential of dissatisfaction for occupants, which can then cause energy wasting. In fact, building occupants usually tend to configure the indoor environment in a comfortable way, not necessarily considering the energy implications of their behaviour. Energy-related occupant behaviour is highly unpredictable and still not fully understood, but it is necessary to conceive frameworks to interpret it, since it has considerable effects on energy demand, effectiveness of building management strategies and occupants' productivity.

In general, there are two possible approaches to describe the mechanism of energy-related actions by building occupants. The first is founded on the definition of influencing factors, including social and cultural environment, local climate, lifestyle and habits (Peng *et al.*, 2012). In recent years, several researchers elaborated classifications of **contextual factors** of human energy-related behaviour. In this context, different approaches to the problem can be recognized, so in the following a synthetic overview of these classifications is provided in chronological order.

- Schweiker and Shukuya (2009), for example, divided contextual factors in "internal" and "external" ones, defining the first as those related e.g. to occupants' preferences and the second as those factors related e.g. to the building characteristics (Schweiker and Shukuya, 2009).
- Peng et al. (2012) defined three categories of actions depending on three factors: environmental parameters, time and random actions (Peng *et al.*, 2012).
- Fabi et al. (2012) individuated five categories of drivers to describe occupants' interaction with windows. These categories were based on the following factors: physical environmental, context, psychology, physiology and social environment (Fabi *et al.*, 2012).
- Polinder et al. (2013) defined the influencing factors as "internal or external driving forces". The internal ones are due to the interaction between biological, psychological and social aspects. The external ones are related to the building characteristics in terms of fabric and equipment, the physical environment in general and time (Polinder *et al.*, 2013).
- O'Brien and Gunay (2014) grouped contextual factors in four groups: physical environmental (which remain stable over a period of time, such as season); psychological (related to individuals, e.g. current mood); social (e.g. privacy issues) and physiological (e.g. age, sex, weight etc.) (O'Brien and Gunay, 2014).

Another approach to the problem can be to classify actions as "adaptive" or "non-adaptive" (De Dear and Brager, 2002). This classification refers to 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*"(de Dear, Brager and Cooper, 1998). In particular, "adaptive actions" are those by which occupants either adapt the environment to their current needs (e.g. opening windows or regulating thermostats) and/or adapt themselves to the indoor environment (e.g. adding or removing layers of clothes). These actions are usually activated due to adaptive triggers, e.g. a person opens a windows (adaptive action) due to the increasing of CO_2 concentration. "Non-adaptive actions", instead, are not related to the attempt to set the indoor environment in a more comfortable way, but they still cause an energy demand (e.g. the use of plug-in devices such as pc or TV). These actions are activated by so-called non-adaptive triggers, such as daily schedule. More clearly, the first are due to occupants' discomfort or expectations of discomfort, while the second are part of occupants' tasks (Schweiker *et al.*, 2018).

Recently, Schweiker et al. provided a framework to conceive adaptive triggers, non-adaptive triggers and contextual factors all together as all responsible of influencing occupant behaviour. In these terms, contextual factors are conceived as "moderators" of triggers and behaviour (Schweiker *et al.*, 2018).

Occupant behaviour can be investigated by several means. In literature, different approaches can be recognized based especially on the objective of the investigation and the context in which the study takes place. In fact, differently from environmental parameters (that can be measures objectively using sensors), other factors such as psychological or cultural factors cannot be "quantified" directly and objectively (Stazi, Naspi and D'Orazio, 2017). Therefore, researches investigating occupants' behaviour often take advantage of other qualitative investigations such as questionnaires (self-reported information) (Fabi, 2013). However, since these data are qualitative and self-reported, using them requires some considerations about their reliability, as highlighted by several studies (Burak Gunay *et al.*, 2014; Fabbri, 2016; Bennet and O'Brien, 2017).

Keywords: Occupant behaviour, Building occupants, Building operators

3.3.2 Comfort perception and perceived level of control

As already mentioned, occupants' behaviour is strictly related to their perception of comfortable conditions. However, along with objective factors such as indoor environmental conditions, several other factors have been recognized in literature as influencing occupants' satisfaction towards the indoor environment (e.g. perceived privacy and other space attributes). The feeling of control over the environment is one of them and it has been chosen as a relevant one for this research. The reasons are explained in the following.

In recent years, the attempt of limiting buildings' energy demand has encouraged the use of BAS (Building Automation Systems) and, more generally, **automated controls**. This because, theoretically, the implementation of control algorithms allow an "efficient" and **"optimal" management of energy**. In fact, the indoor environment is handled in order to provide certain environmental conditions that are believed to be "comfortable" for building occupants (usually based on international standards such as (ISO, 2006; Ansi/Ashrae, 2017)) and to minimize energy use. However, this approach is usually founded on a definition of thermal comfort based on the resolution of the heat balance equation between the human body and the surrounding represented as a uniform environment (Fanger, 1982). This approach does not consider **contextual factors** that have a huge impact on the occupant evaluation of the indoor environment. In fact, the ASHRAE standard 55:2013 defined it as "*that condition of the mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation"* (Ansi/Ashrae, 2017). Considering thermal comfort as "a **condition of the mind**", also personal characteristics such as psychological attitudes, cultural background and social factors have an important weight. In this framework, occupants' satisfaction towards the building configuration becomes fundamental. This interpretation is supported also by field studies, such as the one conducted by Schweiker et al., which demonstrated the influence of personality traits on energy-relevant behavioural patterns and thermal perception (Schweiker, Hawighorst and Wagner, 2016)

These considerations should be taken into account when designing energy retrofit interventions, since the "complete automation" of the building-plant system is not necessarily a reliable solution to ensure occupants' wellbeing and comfort perception, nor a significant energy saving. According to Hellwig, the provision of sufficient control opportunities to occupants is crucial for their satisfaction towards the indoor space (Hellwig, 2015). Indeed, several researches demonstrated that building occupants feel more comfortable if they have the possibility to adapt themselves and the surrounding built environment in a clear and intuitive way, namely in presence of a **high perceived control** (Wagner *et al.*, 2007). This is particularly relevant in office buildings, in which employees' satisfaction towards their perceived controls appears to reduce also sick building syndrome (SBS) symptoms (Toftum, 2010). At the same time, empowering building occupants with the possibility to interact with building controls and building envelope elements brigs the risk of causing energy wasting due to inconsistency of the performed actions with the design intentions (Deuble and de Dear, 2012).

On the other hand, if the building is characterized by a prevalence of automatic controls, the possibility to get in contact with building operators (energy managers, technicians etc.) becomes fundamental. In these terms, Leaman and Bordass highlighted that perceived control is not only related to the objective availability of control interfaces, but also to "soft factors" related to the possibility of **operating the building indirectly** (e.g. by expressing necessities and uncomfortable situations to building managers) (Leaman and Bordass, 2001). Also in the field of social science, several researches defined control perception as a robust predictor of comfort and wellbeing. These studies are not only related to thermal comfort. For instance, Veitch found that perceived control is a strong predictor of users' satisfaction in terms of lighting quality, having also a notable impact on their productivity (Veitch and Gifford, 1996). Also Boyce confirmed that, in his research, the presence of dimming controls in artificial lighting controls was a strong predictor of occupants' satisfaction and self-assessed productivity (Boyce *et al.*, 2003).

Keywords: Occupant satisfaction.

3.3.3 Occupant engagement

Occupant engagement and **behavioural change** researches investigate techniques to encourage a **pro-active involvement** of building occupants on an optimal use of energy-related interfaces of buildings. One of the most important objectives of these researches is the attempt to increase the awareness of occupants about the implications of their energy-related behaviour. In fact, building occupants are not often fully aware of the positive or negative impacts their behaviour have on buildings' energy demand. The aim of behavioural change studies can be more related to the empowerment of occupants in order to allow them to configure the indoor environment in a proper way for the **optimization of their personal comfort (1)** or, more often, to involve them in the **reduction of the energy waste (2)** due to the misuse of energy-related technologies. However, these two aims can also be balanced and pursued at the same time.

In this direction, several researches investigated the potential of providing **feedbacks** (also real time), in order to "make energy visible", i.e. showing the energy implications of occupant behaviour, and inform users about the "objective" indoor environmental conditions by monitoring some relevant parameters (e.g. temperature) (Karjalainen, 2007, 2009). A feedback can be generally defined as an information about the result of a process or action that can also be used to control or modify another process based on the difference between the desired and the actual results (Darby, 2003, 2006). Literature on feedbacks can be researched in various fields, from psychology to energy technology, demonstrating the multi-disciplinary nature of the problem (Darby, 2000). In recent years, the use of feedback is strictly connected to the use of technological interfaces such as dash-boards, phone or pc apps and, in general, home automation systems. Through these systems, feedbacks are provided in order to show building occupants their energy use, often making comparison with the past or with peers, but they can also be used as "reminders", so instruments to establish a behavioural change and new energy-related habits (Karjalainen, 2011). A relevant aspect to be investigated in this field is the "form" by which feedbacks, engaging or educating information should be delivered to building occupants. This entails both the **medium of communication** (digital, in-home, mobile) and **how data are presented** (in form of graphs, numbers or abstract representations). About the first aspect, it should be considered that a medium could also not be digital, but "physical", i.e. information booklets, paper instructions. This to remark that users' engagement is suitable also in absence of advanced technological infrastructures. Furthermore, the feedback or information could also be directly transferred by a person, i.e. the building manager. However, in the last years, great research efforts can be recognized in the field of "persuasive technology", involving both the fields of computer technology and psychology, which includes devices or communication media aimed at inducing changes in human habits and behaviour, also exploiting social influence mechanisms (e.g. peer competitions, serious gaming etc.) (Fogg, 2003; Chen *et al.*, 2012; Emeakaroha *et al.*, 2014a, 2014b). About the second aspect, the fundamental point to investigate is the comprehensibility and the clarity of data.

Investigating the potential of behavioural change and information techniques, a number of researches and field studies in the last years experimented energy conservation campaigns based on occupants' education and engagement. Most researches of this type were conducted in residential case studies, where behavioural change can be promoted using also an economic incentive. In fact, adopting a more conscious energy behaviour leads to reduce energy consumption and the related energy bills. In these terms, studies conducted in the residential sector brought to save about 15% to 20% of energy averagely (Pothitou *et al.*, 2016). In the tertiary sector, and more specifically in offices, behavioural change is more difficult since employees cannot benefit from the bills' reductions. In this environment, the average savings obtained range between 4% and 10%, even if some researches registered much higher savings (Gulbinas, Jain and Taylor, 2014; Orland *et al.*, 2014). As an example of successful intervention in office environment, a field experiment conducted by Fabi et al. investigated the potential of users' engagement through feedbacks. The study implemented three different strategies in different phases, taking advantage of various types of feedback and communication mediums. Information were provided both in terms of energy consumption and indoor environmental conditions. Technical and energy-related feedback were also coupled with engagement strategies such as peers' serious gaming. During the experimentation, the energy demand decreased by about 31% (Fabi, Barthelmes and Corgnati, 2016). Focusing on persuasive technology, Kastner and Matthies developed a web-based tool for a behavioural change intervention in order to assess feedbacks' potentiality to change some energy-relevant behaviours at work. In this case, the energy saving potentiality was estimated up to 20% (Kastner and Matthies, 2014). Other researches in the field were not addressed to the quantification of energy saving potentialities through behavioural change techniques, but more on the study of the effect of feedbacks on occupant behaviour in general. Meinke et al. for example, investigated the effect of **feedforward information** on occupants' behaviour in terms of choices and awareness. In particular, after having chosen a certain action to restore a thermally comfortable environment, information about its energy implications were provided, giving the possibility to revise the decision. Results showed that about one third of occupants revised their choices, so it could be asserted that increasing energy awareness of occupants can be an efficient way of influencing their behaviour (Meinke *et al.*, 2016).

The experiments showed above were focused on the engagement of building occupants to lower buildings' energy wasting by influencing their actions.

Nevertheless, this approach is suitable only in buildings in which occupants are enabled with a number of energy-relevant controls (e.g. operable windows, operable thermostats etc.). However, as explained before, some energy controls can be automatic or non-directly operable by users. In that case, controls are set by **building operators** such as technicians, or automatically by a control algorithm. The "risk" connected to this type of energy management is that occupants feeling uncomfortable could override the automatic settings or perform actions to restore their comfort possibly causing energy wasting. In these terms, one of the possible solutions is to implement systems to understand occupants' necessities, discomfort causes and preferences and manage the indoor environment accordingly. For instance, Feldmeier and Paradiso adopted an adaptive control architecture through which occupants could indicate the "direction" of their discomfort, allowing the control algorithm to "learn" their preferences and implementing a human-centred and "dynamic" energy management. This study conducted to save about 24% of the total energy demand in respect to the previous "steady" control algorithm (Feldmeier and Paradiso, 2010). This finding is important to assert that establishing comfortable conditions does not imply an increase of the energy demand, so pursuing energy efficiency and occupants' comfort is possible.

This kind of studies, trying to balance energy saving strategies with occupants' necessities and potentialities, can represent not only an opportunity to impact buildings' energy efficiency, but they could represent an opportunity to form theory-driven occupant behaviour profiles to be used to reduce the gap between simulated and real energy consumption of buildings.

Keywords: Occupant engagement, Pro-active involvement.

3.4 Final remarks on adaptation

The previous paragraphs described how the energy field approached the theme of historic buildings' energy efficiency in various contexts, highlighting some barriers and opportunities for further research, which will be investigated also in this thesis. In the following, some remarks will be listed in order to summarize the reasons that brought to the definition of the research questions of the present study.

The first aspect to be highlighted is that, even if the restoration field seems not to perceive (at least based on the current international charters and laws) the urgency of improving historic buildings' energy efficiency, this topic has been faced increasingly, in recent years, by the energy research sector. However, several studies seem not to be aware of the legislation or practices of preservation and restoration, which is the main reason why, nowadays, the objectives of these two sectors seem to be unbalanced. There is, thus, the necessity of changing perspective about the role of the energy sector for the restoration field. First, energy retrofit should be pursued primarily to ensure the liveability and economic sustainability of these buildings, contributing to their survival. In these terms, the energy retrofit can be seen as a valorisation practice, having the social profitability as a primary objective. Energy retrofit of historic buildings requires a high level of multi-disciplinary knowledge and, due to the uniqueness of each building, it is more suited for the elaboration of methodologies, which represent the best level of "replicability" that can be pursued. In fact, the necessity of replicable solution can hardly be pursued by proposing solutions that could be used in every context. Therefore, the replicability of procedures (by methodologies) is the best solution. Starting from the previous aspects, a strand of the energy research (occupant behaviour, or more generally building operation) has been individuated as a potential way of balancing conservation and efficiency aims.

4

Theoretical framework and research question

In this thesis, a methodology called BIOSFERA (Building Intelligent Operational Strategies For Energy Retrofit Aims) was elaborated based on the corpus of knowledge acquired in the field of "preservation" and "adaptation". Fig. 1 gathers all the keywords introduced in the previous chapters in form of a critical

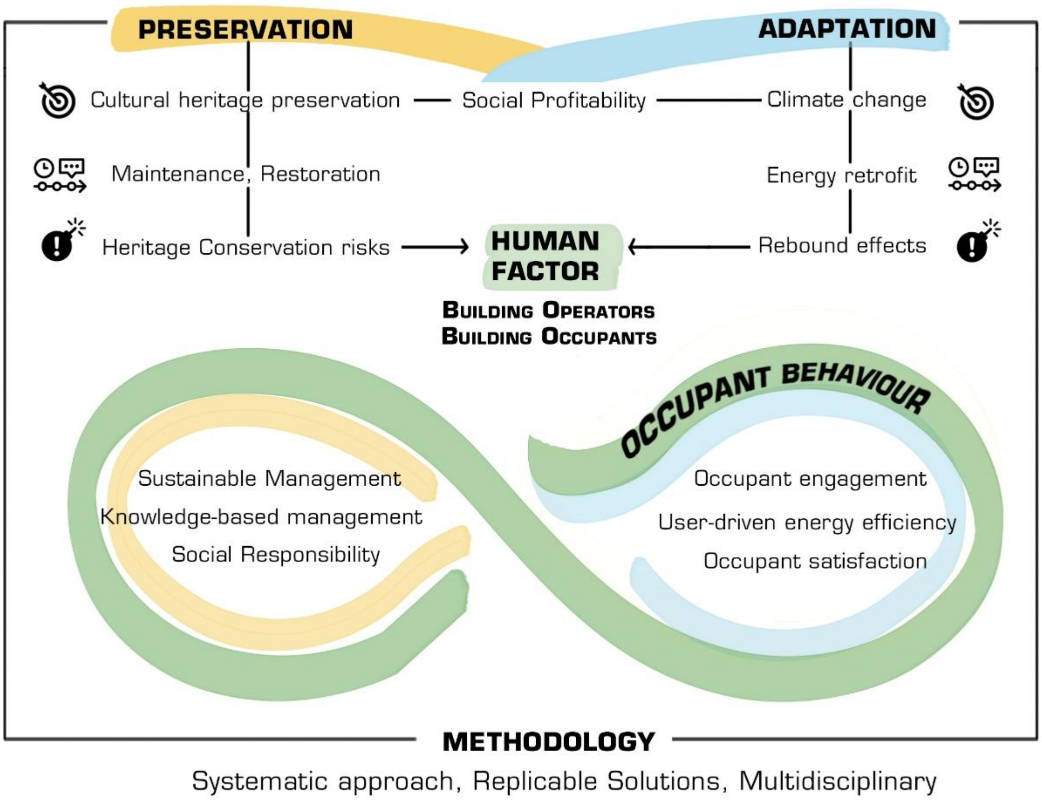


Figure 1.Keywords elaboration to establish a theoretical framework.

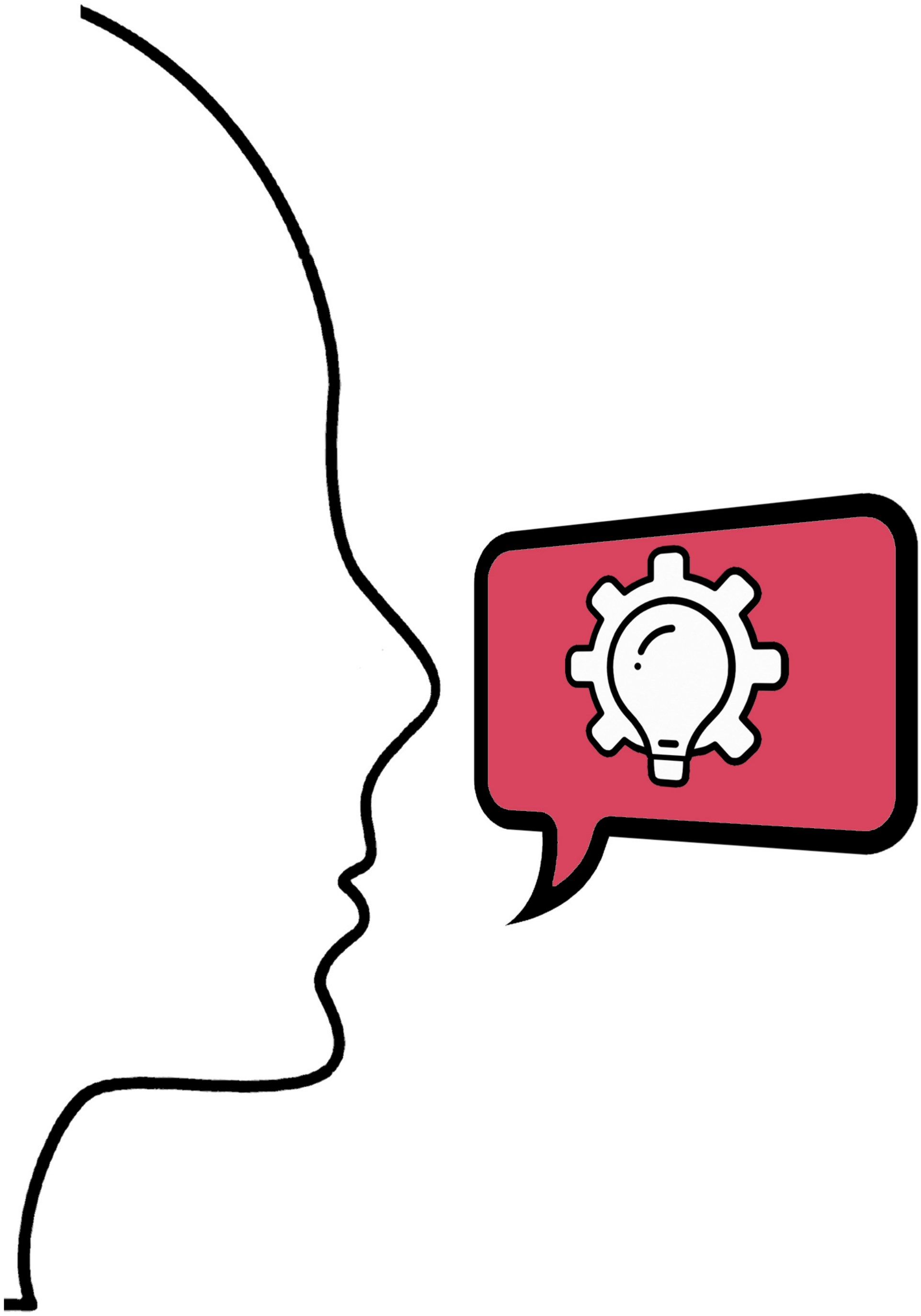
elaboration, in order to establish the theoretical framework that guided the elaboration of the methodology.

The introductory chapters introduced the necessity of elaborating a methodology to address the theme of historic buildings' energy retrofit, due to their uniqueness, which determines the impossibility of identify totally replicable solutions. At the same time, replicability would be desirable. Therefore, a solution is to focus on the elaboration of a methodology, in order to address historic buildings' energy retrofit by replicating the same systematic approach. In these terms, the importance of a multidisciplinary method has been highlighted by several standards and studies. Focusing on preservation and adaptation, for each topic the most important goals have been qualified. If for the first the main goal to address is cultural heritage preservation, for the second is climate change. However, it should be noticed that for both also social profitability (for different reasons) represents a fundamental objective to pursue. Continuing reading the figure from the upper part to the lower one, the instruments or procedures usually adopted to address the previous goals have been individuated. For preservation the practices of maintenance and restoration, while for adaptation the energy retrofit. In the following, the risks related to the previous practices have been highlighted. On the one hand (preservation), the heritage conservation risks (e.g. damages of the building fabric or the contained objects), on the other rebound effects (unintended consequences of energy retrofit interventions). In both cases, one of the main causes of these risks are the people interacting with the building (the so-called "human factor"). Despite the two categories seems to pursue different objectives, often seen also as mutually exclusive, starting from the previous analyses this research choose to investigate the potentialities of occupant behaviour to pursue the adaptation objectives by respecting or even facilitating also preservation goals. The lowest part of the figure shows how occupant behaviour has been conceived as a bridging element between the two categories. In fact, through occupant engagement, it is possible to establish user-driven energy retrofit operations, also having occupants' satisfaction as a goal. At the same time, occupants' engagement can be seen as an instrument to increase the social responsibility towards historic buildings, which coupled with the engagement strategies can result in a more knowledge-based and sustainable management.

Starting from this theoretical framework, the main **research question** of this study was: ***What are the potentialities of energy saving and indoor environmental conditions' enhancement by acting only on the way non-residential historic buildings are operated by occupants and operators?*** This research question was translated in operative objectives and sub-objectives (which will be described in Chapter 5) from which, consequently, a methodology (BIOSFERA) has been elaborated and applied in four case studies located in the area of Turin (North Italy). Since the main output of this work consists on the methodology created, its experimentation in real case studies served as an experience to discuss and improve it towards its applicability on a larger scale.

PART II

The BIOSFERA methodology



5

Introduction to the BIOSFERA methodology

The BIOSFERA (Building Intelligent Operational Strategies For Energy Retrofit Aims) methodology was conceived to be applied in non-residential historic buildings, answering the necessity to enhance their energy efficiency while protecting their historic evidence. The application of the methodology to real historic buildings (presented in Part III) is aimed at trying to answer the principal research question of this study: *What are the potentialities of energy saving and indoor environmental conditions' enhancement by acting only on the way non-residential historic buildings are operated by occupants and operators?*

In order to answer the principal research question and elaborate the methodology, three principal objectives (and a set of sub-objectives) were set by distinguishing three aspects of the problem.

1. **Hypothesize the potential**: How historic buildings are operated by Building Managers (BMs) and Building Occupants (BOs)? Is there the possibility to enhance the operation towards a reduced energy consumption and indoor environmental conditions' enhancement?

In this framework, four sub-objectives were defined: C*haracterize the BMs' energy-related management (1), Quantify the building energy consumptions and energy-related costs for each energy carrier (2), Assess the building's indoor environmental conditions (3) and Appraise energy-relevant information from BOs (4)*.

2. **Elaborate actions to ameliorate building operation by BMs and BOs**: which could be the best operational strategies to be applied by both groups?

This second objective was translated in three sub-objectives to be addressed: *Lower the building's energy consumptions (1), Enhance comfort perception and behaviour of BOs (2) and Ameliorate or solve indoor environmental critical situations related to artworks' conservation (3).*

3. **Define the potential:** based on the application of the previously defined actions, what is the energy saving and indoor environment enhancement potential? Is it possible to guarantee a stable or enhanced comfort for BOs?

The sub-objectives were defined in strict relation to those of the second objective: *Assess the impact of strategies on the building's energy consumption (1), Assess the impact of strategies on BOs comfort perception and behaviour (2) and Assess the impact of strategies on indoor environmental critical situations related to artworks' conservation (3).*

Starting from these objectives and sub-objectives, the BIOSFERA methodology was designed and articulated in three consequential phases: Diagnosis (which corresponds to the first objective), Intervention (which corresponds to the second) and Control (corresponding to the third). Figure 2 shows the outline of the methodology. Each phase is implemented considering simultaneously two groups of people that, as previously mentioned, influence the building's energy consumption: Building Managers (BMs) or technicians and Building Occupants (BOs). These two groups of people are generally different in non-residential buildings, where HVAC systems and other energy-related end-uses are usually operated by different people from the actual building occupants. Following the objectives, the first phase (Diagnosis) is aimed at capturing the building's energy-related state of affair, the second phase (Intervention) has the objective to provide strategies addressed to both BMs and BOs and the third phase (Control) has the objective to analyse the impact of the strategies implemented in phase II.

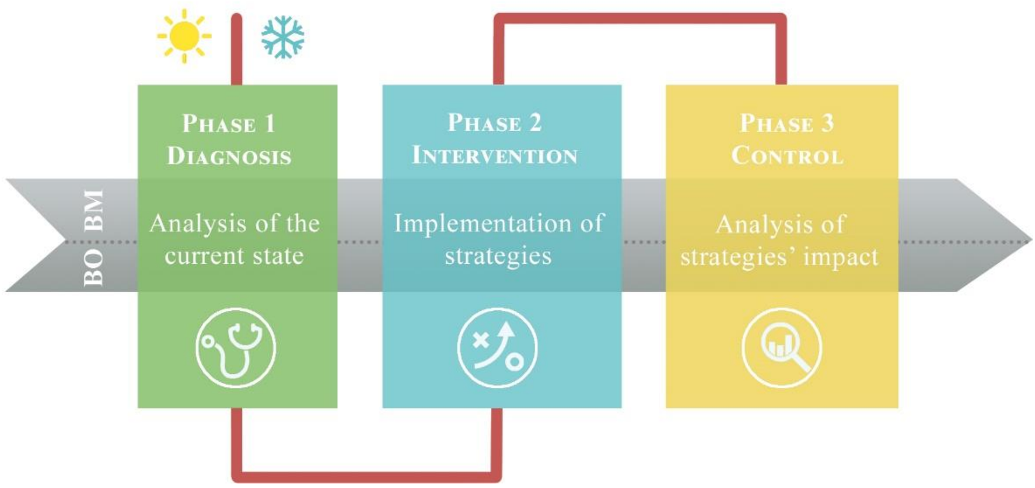


Figure 2.Outline of the BIOSFERA methodology. The three phases are set in relation to the two groups of people determining the building's energy consumption: Building Managers – BM (or technicians) and Building Occupants – BO.

The methodology follows the so-called “waterfall model”(Conrad *et al.*, 2012), in which the project activities are conceived as linear and sequential phases in which the specific actions and analyses of a certain phase depend on the results of the previous one. Also, the methodology follows a pre-test post-test approach, in the sense that certain elements are measured, surveyed or analysed before and after the Intervention phase in order to assess the impact of the implemented strategies. For example, in order to assess the impact of strategies on the building energy consumptions, the energy bills from the Diagnosis phase and Implementation phase are compared during the Control phase. Finally, as symbolized by the sun and the snowflake in Figure 2, the methodology is intended to be applied in the case studies in cooling season and heating season, since humans have different perception of environmental conditions and comfort depending also on weather conditions outside the building (de Dear, Brager and Cooper, 1998). Moreover, their energy-related behaviour tends to be very different when feeling too cold or too warm. The implementation of the methodology in a case study requires at least 18 months, considering the implementation of all three phases in heating and cooling seasons. Figure 3 shows a recommended timeline for the implementation of the methodology in heating and cooling seasons (symbolized by the snowflake and the sun respectively). The “M – number” symbolize the number of months starting from an hypothetic month “0”. However, the specific timeline every case study should be defined in accordance with the administration of the building.

Figure 3. Approximate timeline for the application of the BIOSFERA methodology in a case study, in both heating and cooling season.

In the following, some paragraphs will describe in detail the activities and the instruments elaborated for each phase. Exploiting different means depending on the specific characteristics of the cases studies, each phase has several objectives to reach, directly related to the activities carried on with BMs and BOs.

6

Phase 1 – Diagnosis

6.1 Objectives

The first phase of the BIOSFERA methodology is addressed to understand the energy-related status of the examined building. The general aim is to gather all the relevant information due to elaborate operational strategies to be delivered to BMs and BOs and to analyse some relevant aspect that will be used to assess the impact of the strategies during the Control phase. In the following, all the specific objectives of this first phase are listed (identified by the symbol Ω and the relative number):

Ω 1. *Characterize the BMs' energy-related management.* This objective is addressed to acquire a clear and schematic overview of all the materials and information that can be used to perform the analyses of the first and third phase and the energy-related information that will be used, together with those provided by BOs, to elaborate the Phase II's strategies.

Ω 2. *Quantify the building energy consumptions and energy-related costs for each energy carrier.* The aim of this activity is to be able to compare the state of affairs with the strategies' implementation period; the characterization of the annual or seasonal energy performances of the building are useful but not essential.

Ω 3. *Assess the building's indoor environmental conditions.* In presence of a monitoring system inside the building, this objective is intended to compare the state of affairs' indoor environmental conditions with the strategies' implementation period. This analysis is not mandatory, in the sense that the methodology can be performed also in absence of an objective evaluation of indoor environmental conditions, just considering the information provided by BMs and BOs. However, it is particularly recommended in the case that the analysed building hosts an art exposition or the building itself is characterized by fragile materials (e.g. ancient decorations or frescos). In those cases, the analysis of monitoring data is important to detect dangerous environmental conditions for the fragile materials' conservation and, therefore, to elaborate resolving operational strategies.

Ω 4. *Appraise energy-relevant information from BOs.* Several aspects characterize this objective, since energy-relevant information include, among others, the way BOs subjectively evaluate the indoor environment, their energy-relevant behaviour and the control opportunities they have (or they believe to have). All these aspects are relevant for individualize the correct strategies to be implemented in the second phase in order to correct energy-wasting behaviours but also to educate people to take a proper advantage of their control opportunities, in order to enhance the quality of their experience inside the building.

6.2 Actions and analyses

The objectives listed in the previous paragraphs should be reached by conducting the actions and analyses and by using the instruments that will be described in the following. However, before starting with the proper diagnosis phase, the very first step is to organize a meeting with the building's administration in order to define a chronological program for the implementation of the methodology (as shown in Figure 2) and to obtain the commitment to provide the mandatory materials (e.g. energy-bills) that will be listed in the following paragraphs. Without this commitment, or in case of failure to respect it, the methodology cannot be implemented.

6.2.1. Characterize the BMs' energy-related management.

The aim of the semi-structured interview with the BM is to obtain information about several aspects concerning the energy-management of the investigated building. Reaching Ω1 is mandatory. There are three reasons why BMs are involved in this phase. First, to detect possible mismanagement situations that could constitute potential targets of the strategies proposed for Phase II. Second, to gather information that are relevant for programming and designing the strategies (so questions should be selected accordingly). Third, to collect information and materials that will be necessary to reach the other objectives of phase I. Since in some cases there is not a real BM but energy-related facilities are managed partly by the administration and partly by external technicians, in those cases the interview should involve all the actors dealing with energy-related uses. Having an overview of aspects such as BMs' and BOs' energy-related control opportunities or the building configuration of spaces and activities, prevent to provide general or not applicable energy-related strategies. BOs involvement through questionnaires is also important to acquire insights about several aspects of their experience and behaviour within the building (see 6.2.4), but it cannot substitute BMs' interviews since, for instance, their perception or knowledge of the control interfaces they have could not match the reality. For this reason, BMs should be asked not only about HVAC systems' operation, but also about all energy-related control opportunities and interfaces. Differently from the other analyses, which should be conducted separately for the different seasons, this interview can be conducted only once, acquiring the information about all seasons. Another important aspect is that, if possible, the interview should be followed by an inspection, in which pictures of the relevant control interfaces (e.g. thermostats, blinds or windows) can be taken. Whether the interview is done with a single BM or with a group of people dealing with energy-related facilities, it is important to understand two aspects. First, which are the reference people for different aspects of energy management (e.g. in the case that the technicians of HVAC differs from those of the electric facilities). Second, what kind of relationship they have with BOs (e.g. can they communicate with them directly or indirectly?). Being semi-structured, the interviews should follow a general trace for all buildings. In the following, a guide to conduct it is provided by summarizing the principal information that should be gathered.

~ ***General information.*** This part is dedicated to acquire information about the general configuration of the building, such as the entire conditioned surface and the eventual presence of zones with different destination of use or characterized by different operating logics or systems. In fact, in a multi-functional building, several operational logics and systems can be present at the same time. For example, in a building hosting both a museum and offices, the rules to operate windows could be different in the two areas, or there could be different HVAC systems serving the two zones. If that is the case, the information listed in the following should be acquired distinguishing the different zones.

~ ***Environmental monitoring.*** The first aspect to be clarified is the presence of an environmental monitoring within the building, which is a prerequisite to reach Ω3. In the case that the investigated building hosts an expositive part or is characterized by fragile materials (e.g. decorations), the conservation manager should be involved in this part of the interview (if present). This way, eventual conservation risks or concerns can be expressed about the entire exposition space or about specific objects. Moreover, the conservator could indicate a required tolerance interval in which the monitored parameters should fall in order to avoid conservation problems. If monitoring data are already analysed, it is useful to ask those analyses and evaluate if they can substitute the ones described in par. 6.2.3. In the following, Table 1 lists the principal information to be acquired in the case a monitoring system is present.

Table 1.Principal information to be acquired about the Environmental monitoring.

Sensors position	**-Location of sensors (better if contextualized on a map)**
Monitoring period	-Monitoring period: Spot measures, medium term (week monitoring) or long term (continuous)[1]
Monitored environmental parameters	-Temperature, Relative humidity
Sensors' characteristics	-Principal sensors' specifics (e.g. nominal uncertainty). -Registration time-step[2]

~ ***Energy-related control opportunities.*** Energy-related control opportunities concern all those actions that humans can perform in the building influencing its energy performances. These actions could either cause a "direct" energy use, like switching-on the artificial lighting, or affect the building energy-balance indirectly, like opening a window. This part of the interview is divided in two sections based on the distinction explained above. In particular, the first is dedicated to structural/building envelope interfaces (which do not cause a "direct" energy use) and the second to technological infrastructures. Information regarding the first section are particularly relevant in exhibition areas and museums, in which interfaces like blinds and windows are very relevant for conservative concerns, so they can have fixed and rigid operational schedules. About the second section, it should be noticed that the objective is not to acquire all systems' specifics, but to individuate those characteristics that could influence the choice of strategies (e.g. the system type, terminals and operational logics). In the following, Table 2 and Table 3 summarize the information that should be gathered during the interview.

Table 2. Principal information to be acquired about structural interfaces.

<table>
<tr><th>Structural interface</th><th>Information to acquire</th><th>Who controls it?</th></tr>
<tr><td>Windows</td><td rowspan="5">Relevant characteristics (e.g. blind type)
Standard state of the interface (open/closed)?
Are there fixed rules for their operation (e.g. opening hours or automated devices – if available)?</td><td rowspan="5">BMs or BOs? If BMs acquire information about their characteristics and operation (see next column), if BOs ask to BMs only relevant characteristics.
Operational information should be acquired from</td></tr>
<tr><td>External doors</td></tr>
<tr><td>Internal doors</td></tr>
<tr><td>External blinds</td></tr>
<tr><td>Internal blinds</td></tr>
</table>

---

[1] If spot measures or medium-term, ask if it's possible to organize at least a week campaign during Phase I and Phase III for each considered season. If continuous, agree to acquire data registered during Phase I and Phase III time lapses.

[2] If >60 minutes, ask if it is possible to reduce it, especially for exhibition areas.

	Other relevant information (e.g. why their operation is not done by BOs)	the questionnaire (see par. Ω4).

Table 3. Principal information to be acquired about technological interfaces.

Technological infrastructure	Information to acquire	Who controls it?
HVAC systems	Principal characteristics of the system (relevant for the strategies) Set-points Schedule of operation How the system is controlled (manually, remotely)? Is there a BEMS?	BMs or BOs? If BMs acquire information about their main characteristics and operation. If BOs have the partial or entire control: -what type of interface they have? - How it works? (to be compared with questionnaire's answers)
Artificial lighting	Principal characteristics (e.g. main type of bulbs) Type of control (e.g. manual, sensors, dimmer, remote) Schedule of operation	
Other systems or facilities (e.g. dehumidifier)	Principal characteristics Set-points and schedules (if applicable) Type of control	

~ ***Energy-consumption materials.*** In the case that the building is provided not only with energy counters, but also with other sensors to assess the energy consumption of single end-uses or facilities (e.g. calorimeters) (see par. 3.2.2), the BM should be asked to clarify the type of installed sensors. Then, the interviewer should evaluate if these data can be useful to reach Ω2 and, eventually, agree on the delivery of data registered in Phase I and Phase III time-lapses. Moreover, as agreed in the first meeting with the administration, the BM is asked to provide the energy bills as explained in par. 3.2.2 below.

~ ***Occupant-related information.*** The final part of the interview is dedicated to acquire information related to occupants, with two main aims. First, recognizing homogeneous "groups" to establish what kind of questionnaire should be provided to them (see par. 3.2.4). For example, in a multi-functional building, various "groups" of people experiencing the building in an "energy-related" similar way (e.g. having similar control opportunities and activities) could be recognized (e.g. office workers, museum visitors etc.). Second, the BM should provide approximate number of people belonging to each group, in order to establish the answering rate to the questionnaires that will be done during the different phases of the methodology.

6.2.2. Quantify the building energy consumptions and energy-related costs for each energy carrier.

The analysis of energy consumptions and energy-related costs can be carried out in different ways depending on how the different energy carriers are measured and accounted in the building. Normally, every building that is provided with energy facilities has a counter for every energy carrier, through which the energy provider calculates the energy bills to be paid for the energy use. In Italy, most buildings are heated by natural gas, so they are provided with a natural gas counter. At the same time, buildings are normally provided with electric energy and potable water, each of which have a specific counter. In this research, potable water is not taken into account. In addition to the energy counters, buildings can be provided with other sensors, giving the possibility to deepen the analyses and assess for which end-use energy is used or, for thermal energy, “where” it is delivered. Regarding thermal energy, buildings can be equipped with two kind of sensors that allow detecting how much thermal energy is used in different areas or even by different terminals of the building. If the heating system has horizontal distribution circuits and the building has different units (e.g. different apartments inside an apartment building), heat meters (also called calorimeters) can be installed to quantify the thermal energy delivered to each unit. On the contrary, if the building has vertical distribution circuits, heat cost allocators can be installed in each terminal for the same purpose. Of course, also in horizontal distributed circuits is possible to find heat cost allocators in every terminal, in order to be able to quantify their specific delivered thermal energy, however it is very costly and not very frequent. Regarding electric energy, besides the counter, the building can be equipped with fixed multimeters or smart plugs to monitor the electric energy consumption of specific appliances or end-uses.

Based on the previous considerations, the **required materials** to reach the second objective of the Diagnosis phase (Ω2) are listed in Table 4. The materials are classified as mandatory if their deliverance is a prerequisite for the methodology to be executed.

Table 4. Required materials to perform the Phase 1-Ω2 analyses.

Material	Description	Requirement
Energy bills for each energy carrier	Monthly energy bills for a period of at least two years before the start of the experimentation. Based on the implementation program, the administration can decide to provide only the bills of those months in which it has been decided to carry out the first and second phases of the methodology.	Mandatory
Energy usage data from other sensors	Data from heat counters, heat cost allocators, smart-plugs' or fixed multimeters reports.	Not mandatory

The **energy-related analyses** can be performed using the information contained in the energy bills or deriving from the other sources listed above. Depending on the data type, the analyses can have different levels of detail: they can consider the whole building, single parts or units, single end-uses or even single appliances. In the following, a list summarizes the energy-related performance indicators that will be used in the first phase to characterize the building's energy consumption and in the third phase to assess the impact of strategies. Among these indicators, Electric energy and Thermal energy indicators are mandatory, Normalized Thermal energy is highly advised while Primary energy is an additional and optional one, which can be useful to have one overall energy indicator.

~ ***Building's total energy performance indicator: Primary Energy (E_P).*** Primary energy is a synthetic indicator that allows summing the contribution of energy delivered by different energy carriers in determining the whole energy consumption of the building in a certain period of time. Based on the European standard EN ISO 52000-1:2017 (CEN, 2017), E_P is calculated as follows:

$$E_P = \sum\left(E_{del,i} * f_{P,del,i}\right) - \sum\left(E_{exp,i} * f_{P,exp,i}\right)$$

E_P [kWh/m^2] = Primary Energy, referred to a specific calculation period (typically the month). It can be differentiated for single end-uses (heating, cooling, etc.) or calculated as their sum ($E_{P,tot}$).

$E_{del,i}$ [kWh/m^2] = Energy delivered to the building by the $_{i\text{-th}}$ energy carrier.

$E_{exp,i}$ [kWh/m^2] = Energy exported from the building by the $_{i\text{-th}}$ energy carrier.

f_P [-] = Conversion factors, used to transform the amount of delivered or exported energy deriving from a certain energy vector into "primary" energy. f_P of delivered and exported energy are a result of the equation $f_{Ptot}=f_{p,ren}+f_{P,nren}$, in order to take into account the eventual presence of renewable energy for each energy vector. Italian f_P factors can be found in the DM 26/06/2015 –Table 1 (p. 8) (Italian Ministry of economic development, 2015).

~ ***Electric energy indicator (EE).*** This indicator is referred to the electric energy consumed in a certain period of time and measured by a counter or a meter (if referred to a specific appliance). The indicator is calculated as follows:

$$EE = \sum_{i=0}^{n} PE$$

EE [kWh_e] =Electric energy consumed in a defined period of time (can be daily, weekly, monthly or annually).
PE [kW_e] = Hourly average electric power.
n [h]= number of hours of the considered period of time.

The same indicator can be expressed also as specific electric energy if EE is divided by the net surface or the gross volume of the building or considered space. This way, the indicator will be expressed in [kWh_e/m^2] or [kWh_e/m^3].

~ ***Thermal energy indicator (TE).*** Thermal energy in buildings can be referred to single end-uses, namely heating, cooling, post-heating and domestic hot water, or it can represent the total of all these consumes. The TE indicator is calculated as follows:

$$TE = \sum_{i=0}^{n} PT$$

TE [kWh_t] = Thermal energy consumed in a defined period of time (can be daily, weekly, monthly or annually).
PT [kW_t] = Hourly average thermal power.
n [h]= number of hours of the considered period of time.

The same indicator can be expressed also as specific thermal energy if TE is divided by the net surface or the gross volume of the building or considered space. This way, the indicator will be expressed in [kWh_t/m^2] or [kWh_t/m^3]. Since the natural gas bills usually express the gas consumption in Smc (standard m^3 of natural gas), the consumption value has to be converted in kWh_t to calculate the TE. For the conversion, this research considered the standard value of 38,5 MJ/Smc as natural gas calorific power.

~ ***Normalized Thermal Energy (TE_N)***. Thermal energy used for heating and cooling can be normalized by heating and cooling degree days (HDD and CDD) using the following formula:

$$TE_N = \frac{\sum_{i=0}^{n} PT}{DD} = \frac{TE}{DD}$$

TE_N [kWh_t/DD] = Normalized thermal energy consumed in a defined period of time (can be daily, weekly, monthly or annually).
DD [-] = Degree Days. In winter, Heating Degree Days (HDD) are calculated according to the European standard EN 15927:2008 (UNI EN ISO, 2008):

$$HDD = \sum_{e=1}^{n} (T_0 - T_e)$$

n= Number of days considered as heating period.
T_0 [°C]= Fixed indoor temperature. In Italy, the DPR 412/1993 has established the indoor fixed temperature to 20°C.
T_e [°C]= External daily average temperature (T_e<T_0).

In summer, Cooling Degree Days (CDD) can be calculated as follows:

$$CDD = H_{med} - T_{sp}$$

T_{sp} [°C] = Temperature set-point in summer for indoor environments. According to the standards UNI 10339:1995 and UNI 10349:2016 it can be set to 25°C (UNI, 1995, 2016).
H_{med} = External daily average perceived temperature (Humidex) is calculated as follows:

$$H_{med} = T + \frac{5}{9} * (6{,}11 * \frac{UR}{100} * 10^{\frac{7{,}5\,T}{237{,}7\,T}} \text{-}10)$$

T [°C] = External temperature.
UR [-] = External relative humidity.

The same indicator can be expressed also as specific normalized thermal energy if TE_N is divided by the net surface or the gross volume of the building or considered space. This way, the indicator will be expressed in [kWh_t/DDm^2] or [kWh_t/DDm^3].

Regarding the **energy-related costs**, the most suitable way of characterizing them "ex-post" is to analyse the energy bills, which are usually differentiated by energy vector. All energy bills are characterized by several costs. In Italy, electricity and gas bills are composed by four expenditure items; raw energy (1), transport and management of the counter (2), system charges (3) and taxes (4). In this methodology, since the objective is to assess the impact of operational strategies on the building's energy consumption and related costs, it is important to analyse the energy bills by separating the raw energy costs from the other three expenditure items (that are only partially influenced by the energy consumption). Another item to report in this phase is the tariff of raw energy (for electricity €/kWh and for natural gas €/Smc), since it can be variable between energy delivery contracts and over time. Therefore, when the energy-related costs of the Diagnosis and Intervention phases will be compared, the analysis should be focused on the raw energy expenditure and it should consider also the eventual variation of the energy vector's tariff.

6.2.3. Assess the building's indoor environmental conditions.

The assessment of the building's indoor environmental conditions is referred in this paragraph to the analysis of objective data from an environmental parameters' monitoring system. This type of analysis is not mandatory, in the sense that the methodology can be executed also if the building is not provided with a monitoring system. That is because one of the objectives of this research was to implement the BIOSFERA methodology on a number of case studies by exploiting only the technologies that were already available within the buildings, and this characteristic was not considered as fundamental for the methodology's execution. For the same reason, the available monitoring data could vary a lot depending on the monitored parameters, the monitoring period and the registration time-step. For those cases in which the building is not provided with any monitoring system, when applying the methodology, some consideration about the possibility of installing a low-cost sensors' network should be carried out. In fact, in recent years this new class of sensors emerged, following the necessity of assessing indoor environmental conditions continuously, especially in office environments. Indeed, still today spot measurements represent the dominant practice for indoor environmental conditions' assessment (Parkinson, Parkinson and de Dear, 2019). These devices offer the possibility of building a pervasive monitoring system with reasonable costs. However, concerns remain about their usual testing protocols or in-field performance assessment, which is usually performed in very limited space and time and prevent their pervasive application for professional use (Parkinson, Parkinson and de Dear, 2019). At the same time, their un-assessed accuracy represents a barrier for their application in some historic buildings, such as those hosting artworks or fragile materials.

Since in most monitored buildings the monitored parameters are temperature and relative humidity, the analyses described in the following are aimed at characterizing the thermal or the thermo-hygrometric quality of spaces. In this framework, monitoring data should be analysed for several purposes:

- Assessing the actual thermal conditions in respect of the standards for occupants' comfort and wellbeing;
- Assessing the thermo-hygrometric dynamics of the building plant systems and the microclimatic quality in the case of presence of artefacts or fragile materials;
- Verifying the actual indoor environmental conditions in comparison with the expected ones based on the information provided by BMs during the semi-structured interview;

- Acquiring a better understanding and put into perspective the evaluations made by BOs in the Diagnosis phase's questionnaire.

Finally, the same analyses will be used in Phase III to assess the impact of the HVAC-related strategies implemented in Phase II. Before going into the specification of the analyses to reach Ω3, there is the need to clarify what data should be analysed. First, if the monitoring is carried out in a high number of spots, it is possible to select only representative ones. Second, if the monitoring is continuous, only a period should be selected for the analyses. The selected period could vary based on the type of analysis. However, as a rule, it should concern the time lapse of Phase I. Regarding the monitored parameters, this depends on the building activity. For this research, the EN 15251:2008 was taken into account to evaluate the thermal quality of occupied spaces, referring to the proposed three categories of indoor environment based on indoor temperature (CEN, 2008). Regarding the exposition areas, several approaches are described in the following based on the conservation necessities of the specific case study. In general, these analyses requires the monitoring of both temperature and relative humidity. Based on the previous considerations, the **required materials** to reach the second objective of the Diagnosis phase (Ω3) are listed in Table 5. In this case, the "mandatory" classification is only a requisite to reach Ω3; it does not constitute a barrier to implement the BIOSFERA methodology since the whole Ω3 is not mandatory. About the monitoring, even if the analyses should be carried out taking data from an existing monitoring system, indications reported on the standard EN 15251 should be taken into account. In particular, measurements shall be taken in representative rooms at different zones, orientations and with different loads during representative operation periods (CEN, 2008)

Table 5. Required materials to perform the Phase 1-Ω3 analyses.

Material	Description	Requirement
Temperature monitoring data	Sensors specifics can vary. However, the registration time-step should be less than 60 minutes. The monitoring period could range from one week (minimum) to the entire period of Phase I for all considered seasons.	Mandatory for all buildings
Relative humidity (RH) monitoring data		Mandatory only for buildings containing artefacts (e.g. museums) or fragile materials (e.g. decorations)

The analyses and representations that can be performed in order to reach the objectives above mentioned are listed below:

~ ***Time profiles:*** time profiles graphs can be set up differently based on the type of information that is deemed to be more helpful for the specific case study. First, creating indoor temperature and relative humidity time profiles allows verifying the thermo-hygrometric dynamics of the building plant systems. In these terms, the HVAC settings declared by BMs can be partly verified, e.g. individuating the periods in which the HVAC systems are turned off. This analysis can be useful, e.g., if during the interview the BM report critical situations for BOs comfort (due to previous complains). Moreover, the same graph can show the measured parameter's profiles of several sensors positioned in different areas of the building to detect space-conditioned environmental conditions' differences. This could be particularly interesting, e.g., in buildings in which offices with the same HVAC systems and regulations have different expositions (e.g. some facing West and others facing East). Finally, in non-conditioned spaces, time profile graphs comparing indoor and outdoor temperature or relative humidity show the passive energy performance of the investigated building.

~ ***Frequency distribution and cumulated frequency graphs:*** this type of representation can be useful to evaluate the thermal indoor environment of buildings with mechanical heating and cooling systems. For not mechanically cooled buildings, the same analyses should be performed following the adaptive comfort model, usually represented by scatterplots. Both methods are described in the following.

According to Annex F of EN 15251 standard, it is possible to perform long-term evaluations of the general thermal comfort conditions by analysing parameters based on long (e.g. seasonal) monitoring. For this methodology, Method A of Annex F has been chosen. This method requires the calculation of the number or the percentage of occupied hours in which the PMV (Predicted Mean Vote) or the operative temperature is outside a specific range. This calculation can be represented graphically by a frequency distribution graph with the representation of the cumulated frequency, by which the percentage of values outside the specified threshold can be easily read. About the relevant thresholds to be considered for the evaluation of the indoor environment (long term indicators), for mechanical heated and cooled buildings the EN 15251 establishes that the references are the design values presented in table A.2, which corresponds to Table B.2 of the new standard EN 16798. These values represent minimum operative temperatures for winter season and maximum operative temperature for summer season considering four categories. Standard EN 15251 specified that in most cases the average room air temperature can be used as defining the design temperature instead of operative one (this would not be valid if the space has a big surface with significantly different temperature from the mean air temperature). The four categories correspond to Predicted Percentage of Dissatisfied (PPD) and Predicting Mean Vote (PMV) as shown in Table B.1 of the same standard (UNI EN, 2019), so it is possible to assess the indoor environment according to Annex F – Method A. However, it should be highlighted that, for existing buildings, category III is considered as sufficient for human comfort, while Category I is required only in specific building types such as hospitals.

However, besides these categories, the standard EN 16798 establishes that all national recommended criteria for the thermal environment should be respected. In these terms, for Italy, the DPR n.74, 16/04/2013 establishes different thresholds from those reported above. In fact, for cooling season it establishes a minimum air temperature of 26°C with a tolerance of -2°C (the average air temperature measured on the indoor space should not be below 26°C, with -2°C of tolerance). For the heating season, the threshold is fixed as a maximum average air temperature of 20°C +2°C of tolerance. Exceptions to these thresholds are established for industries and other specific buildings such as hospitals (Italian Parliament, 2013).

Summarizing, the European standard defines for the heating season minimum operative temperatures for different categories, while the Italian legislation defines maximum air temperature. This could seem contradictory, but it should be highlighted that while the European standard is intended to establish minimum requirements for thermal comfort, the Italian DPR is intended to avoid energy wasting. Moreover, looking at the values shown in Table 6 it can be noticed that the two standards can be easily respected at the same time. The only exception is for Category I, which actually is advised for Hospitals, which are not included in the regulations of the Italian DPR.

Table 6.Temperature thresholds for offices during cooling and heating seasons according to EN 16798:2019 and DPR 74/2013.

Type of building or space	**Category**	**EN 16798 Minimum operative temperature for heating °C - Clothing ~1,0 clo**	**DPR 74/2013 Maximum av. Air temperature for heating °C**	**EN 16798 Maximum operative temperature for cooling °C (Clothing ~0,5 clo)**	**DPR 74/2013 Minimum av. Air temperature for heating °C**
Offices and spaces with similar activity. Sedentary activity (~1,2 met)	I	21,0	Not defined	25,5	Not defined
	II	20,0	20 (+2°C tolerance)	26,0	26 (-2°C tolerance)
	III	19,0		27,0	
	IV	18		28	

The same type of graph (frequency distribution with cumulated frequency) could be done also for exhibition areas, substituting the EN 15251 categories with a tolerance interval for air temperature or RH which can be established by the collection curator to preserve the exposed materials. In addition, a Performance Index (PI) can be calculated to represent the percentage of time in which a certain monitored parameter falls into the required interval (Corgnati, S.P.; Filippi, M.; Perino, 2006). The curator could also establish classes of "non-compliance" acceptability. For example, it could be established that a PI<80% is not acceptable due to conservation risks.

~ ***Scatter plots:*** scatter plot graphs are here proposed for two main purposes. First, to assess the indoor environment of non-mechanically cooled spaces, as described in Annex A.2 (EN 15251) or B.2.2 in the more recent EN 16798:2019 (CEN, 2008; UNI EN, 2019) . Second, they are proposed as the most suitable way to assess the thermo-hygrometric quality of exhibition areas, referring to their potentiality to avoid conservation risks for collections. Regarding the first analysis, it is advised for spaces in which occupants control the thermal conditions through windows opening. Moreover, the analysis regards only periods in which the heating system is not in operation. The analysis consists on a graph in which the indoor operative temperature is expressed as a function of the exponentially-weighted running mean of the outdoor temperature. The standard proposes three categories of indoor operative temperature acceptable intervals, which should be related to occupants' satisfaction. If 95% of indoor operative temperature stays within category I, the space should guarantee the "maximum satisfaction". Category II corresponds to a low level of dissatisfaction and Category III to an acceptable bevel of dissatisfied occupants. A similar analysis can be done also following the ASHRAE 55:2017 standard for "naturally conditioned spaces" (Ansi/Ashrae, 2017). This analysis differs from the European standard for the fact that prevailing mean outdoor temperature is used instead of running mean outdoor temperature. Moreover, the ASHRAE standard provides two categories of acceptable daily operative temperature directly related to the predicted percentage of satisfied occupants (90% and 80% respectively). Finally, in case of impossibility to monitor or calculate the operative temperature, it sets some conditions to allow the assimilation of the average air temperature to the operative temperature (Appendix A). The proposed analysis for exhibition areas requires both indoor air temperature and RH monitoring. It can be done in addition to the frequency distribution explained above or it can substitute it, since it considers temperature and relative humidity simultaneously. This evaluation can be performed in two ways, depending on the fact that the exhibition curator has or has not established a required tolerance interval of acceptable temperature and relative humidity for the collection. If that is the case, an area defined by the minim and maximum temperature and relative humidity allowed should be drawn in the scatter plot graph as shown in Figure 6, in order to assess if the monitored parameters respect the tolerance intervals. In scatter plot graphs, since we are evaluating temperature and relative humidity simultaneously, the PI can be expressed as global PI, considering temperature and relative humidity at the same time (Corgnati, Fabi and Filippi, 2009).

If the curator did not established required tolerance intervals for temperature and relative humidity, the exhibition areas can be assessed following the ASHRAE Handbook – HVAC applications – Chapter 23 approach (ASHRAE, 2011). This approach is intended to classify the indoor environmental conditions' control potential of museums, galleries, archives and libraries. This handbook indicates several "classes of control" (from AA to D), specifying them based on the HVAC systems' potential of control in terms of temperature and relative humidity. It should be noticed that the classes we are referring to (summarized in chapter 23 - Table 3 of the Handbook) refers to design parameters, while in this research we are using it to evaluate the buildings' real performances. According to the Handbook, Classes B and C are the best that can be done in most historic buildings. Therefore, the scatter plot graph should individuate the allowed fluctuation for these classes and class D in the same way as Figure 6 shown, but overlapping the different

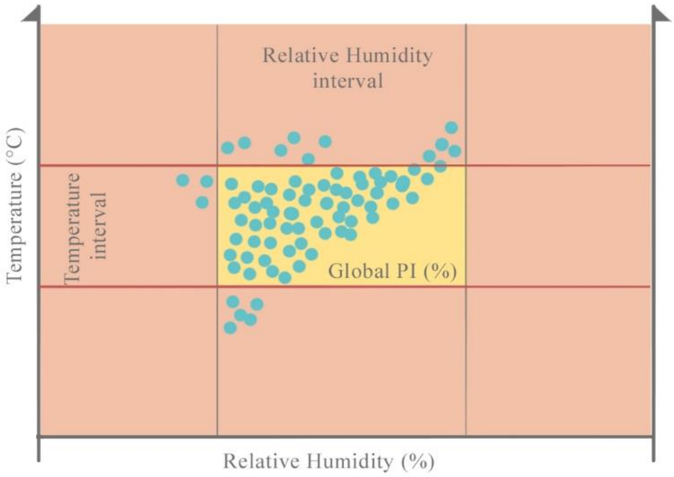


Figure 4. Scatterplot with indication of Global Performance Index.

tolerance areas. In the following, Table 7 specifies B, C and D control classes' characteristics. The related collection risks and benefit can be read in the Handbook. As regards the temperature set-points, the analysis should consider the ones communicated by BMs. Since the monitoring period can vary a lot, the classification at this stage can be done looking only to short-term fluctuations, which have been recognized as the most dangerous aspect in collections' conservation (Aghemo, C., Casetta, G.C., Filippi, 1989). In any case, long-term fluctuation specifications are provided only for Class B.

Table 7. Temperature and Relative Humidity specifications for B, C and D classes of control - ASHRAE Handbook – HVAC applications – Chapter 23.

Type	Set point or annual average	Class of control	Short Fluctuations plus space gradients	Short Fluctuations plus space gradients
General museums, Art galleries, Libraries and Archives	50% RH (or historic annual average for permanent collections) Temperature set between 15°C and 25°C	B	±5% RH, ±2K	RH no change, ±5K
		C	Within 25% to 75% RH year-round. Temperature rarely over 30°C, usually below 25°C.	
		D	Reliably below 75%	

~ ***Statistical values***: the following statistical values can be calculated to verify the compliance of the indoor environmental conditions for the conservation of specific materials according to the UNI 10829:1999 (UNI, 1999). In these terms, the analysis of the measured parameters shifts from the assessment of the whole indoor environment to the focus on a single object's conservation. This analysis is advised only in the case that the collection's curator is particularly concerned about a specific object or a specific material. The statistical values to be verified according to the standard are: mean hourly values (RH_{1h}, T_{1h}), mean daily values (RH_{1d}, T_{1d}), mean hourly gradients (ΔRH_{1h}, ΔT_{1h}) and mean daily gradients (ΔRH_{1d}, ΔT_{1d}). For each of the previous values, standard deviation, minimum and maximum values of the investigated period should be calculated too.

6.2.4. Appraise energy-relevant information from BOs.

As expressed before, acquiring information from BOs is considered indispensable for this methodology to be implemented. Therefore, Ω4's materials are mandatory. In this first phase (Diagnosis), BOs are asked to fill out a questionnaire which entails several aspects that will be listed in the following. The general aim is to gather useful information to choose and design Phase II's strategies and acquire some data that will be acquired also after the strategies' implementation, in order to assess their impact regarding several aspects. For elaborating these questionnaires, several other questionnaires were taken as reference (Wargocki, 1999; Schweiker, 2010; Frontczak, 2011; Schakib-Ekbatan, 2016). Differently from the semi-structured interview with BMs, the questionnaires should be repeated at least for heating and cooling seasons, separately. Since the aim is to acquire the recent indoor environment's evaluations and the recent behaviour, the questionnaire has been designed to be provided to occupants at the end of the season chosen to be the "state of fact" investigated in the Phase I of the methodology. Once distributed, the survey should be open for less than four weeks.

The mean to provide the questionnaire could vary depending on what is considered the best way to reach as much more occupants as possible. For this research, both online questionnaires and paper questionnaires were used, evaluating case by case which was the best option. The online questionnaire was elaborated in LimeSurvey, which is a free and open source on-line statistical survey that enables users publishing surveys, gather responses and export the results to other applications. If using LimeSurvey, it is possible to send the same questionnaire to several case studies and collect responses dividing them case per case, using the Tokens. The participants' privacy is guaranteed also using tokens. The biggest advantage of on-line surveys is that the acquired data are already available on the computer, without having to copy them (which is necessary, of course, in case of paper questionnaires). Another advantage is that, through LimeSurvey, it is possible to send invitations and reminders to all participants. For this research, after the first mail of invitation, reminders were sent once a week for all the duration of the survey. Paper questionnaires represent the best option only in the case that participants do not have direct access to computers (e.g. staff of an expositive area). In the following, Table 8 lists the rate of responses that should be reached to have a satisfactory description of the building sample. The advised rates are taken from the ASHRAE 55:2017 standard (Ansi/Ashrae, 2017). The rates are not mandatory, but they should be seriously considered to evaluate the representativeness of the acquired sample and decide if carrying on the BIOSFERA methodology is possible. Of course, if several groups of occupants can be recognized within the building based on their activity and control opportunities, the rates should be considered for each group.

Table 8. Rate of answers which are requested to have a representative sample of BOs' information according to ASHRAE 55:2017.

Material	**Description**	**Number of occupants**	**Desirable rate of respondents**
Questionnaires for each group of occupants.	Rate of answers which are requested to have a representative sample of BOs' information.	More than 45 people	≥35%
		Between 20 and 45 people	≥15 respondents
		Less than 20 people	≥80%

About the different groups of BOs, they should be recognized during the semi-structured interview with the BM, as described in paragraph Ω1. The questionnaire consists in a list of closed questions (plus the possibility of adding a comment in a number of relevant cases), which are organized in five sections. Of course, the questions of each section vary depending on the occupant "group". Since this methodology was elaborated to be applied in non-residential buildings, three types of questionnaires were elaborated addressing three types of possible occupants' groups. The three groups are differentiated essentially by how occupants interact with the building, in terms of time spent within the indoor space and energy-related control potential. The control potential is intended as the possibility that occupants have to directly interact with structural interfaces and technological interfaces. The proposed occupant groups are High Level of Control HLC (1), Medium Level of Control MLC (2) and Low Level of Control LLC (3). The general characteristics of these groups are listed in Table 9. As an example, in a real case study of a multi-functional building which hosts some offices and a museum, HLC questionnaires could be provided to office workers, MLC to the staff of the exposition area and LLC to the visitors.

Table 9. Characteristics of HLC, MLC and LLC occupants' groups.

Occupants' Group	Description
High Level of Control (HLC)	They are stable occupants of the building, in the sense that they are not occasional visitors (probably they work there). They spend most of the time in a specific space, in which they have several control opportunities (structural and technological) and they can directly affect the energy use (e.g. they use facilities). E.g. office workers.
Medium Level of Control (MLC)	They are stable occupants of the building (probably they work there). They do not necessarily spend most of the time in a specific space of the building. They have some potential of control, but the eventual use of the control should not be addressed only to the personal interest/comfort, because other people experience the same space or because they have to follow specific rules. E.g. staff of an expositive area.
Low Level of Control (LLC)	They are occasional visitors of the building. They only have personal adjustments to control their experience of the indoor space. E.g. visitors of a museum.

Before the beginning of the questionnaire, a page containing general information should be provided. In particular, participants should be informed about the average time requested to fill out the whole questionnaire, information about the people in charge of the research, the aim of the questionnaire and information about how the data will be used. Important aspects are also the voluntariness declaration and the authorization to the treatment of the provided data according to the national law. In these terms, for this study it was chosen to guarantee the anonymity of responses, in order to encourage occupants to answer sincerely.

The five sections of the questionnaire are General information (1), Cultural background, habits and changing attitudes (2), Comfort conditions and preferences (3), Occupants' behaviour (4) and Control opportunities and preferences. The **first section** (**General information**) contains those information that could be used in a second step to analyse the provided data by dividing the building sample in homogeneous groups, e.g. by gender, level of education or office type. The **second section** (**Cultural background, habits and changing attitudes**) is dedicated to assess some cultural aspect (e.g. ecological habits or energy-related education), which could have an influence on some of the evaluation that will be done in the third section or on their behaviour. An important aspect of this section is to understand the attitude occupants have towards the historic building in which they work and the attitude towards historic buildings in general. These evaluations are done in order to evaluate the hypothesis that the indoor environment evaluations or occupants' behaviour could be influenced by the context in which they are. For example, the fact that they work in an historic building could have some influences on their evaluation of comfort, because their expectations could be different from those that they would have in a "modern" and "very technological" building. Another issue addressed in this section is the "sensibility" of occupants towards the conservation of the historic evidence of the building. Even if for the European restoration culture the best way to deal with historic buildings is to preserve their material evidence as much intact as possible, it is not said that non-experts would have the same opinion. For example, how many of them would renounce to an elevator not only to save energy but to preserve the material evidence of the building? The last aspect addressed in this section is the willingness to accept or profit of energy-related education. The **third section** of the questionnaire is entitled "**Comfort conditions and preferences**". This section regards the evaluation of all indoor environmental parameters from different perspectives. The first question is a very general assessment of the personal perceived importance of two environmental parameters (natural light and room temperature) and two aspects that are not apparently related to them (architectural aesthetic of the room and the view out of the windows). The second part of the section is dedicated to the perception of singular environmental parameters (temperature, air quality, light, humidity and noise), which is done using a scale that differs for every parameters but is a 7 point scale (except for air quality, which has 4 points). The scales are listed in the following for each environmental parameter:

- *Indoor air temperature*: cold, cool, slightly cool, neutral, slightly warm, warm and hot.
- *Indoor air quality*: clearly not acceptable, just not acceptable, just acceptable and clearly acceptable.
- *Natural light level*: dark, very low, slightly low, neutral, slightly high, very high and dazzling.

- *Humidity level*: very dry, moderately dry, slightly dry, neutral, slightly humid, moderately humid and very humid.
- *Noise level*: silent, very low, slightly low, neutral, slightly high, very high and deafening.

The third aspect analysed in the third section is the comfort perception related to each of the above listed environmental parameters. For each of them, a question asking to assess the perceived comfort related to each parameter is provided. For the comfort evaluation, a 5 point scale has been chosen (very uncomfortable, moderately uncomfortable, neutral, moderately comfortable and very comfortable). Another aspect investigated in this section is the local discomfort, by identifying singular sources of discomfort that could not directly be related to the parameters evaluated before (e.g. air draft from windows). Finally, the last investigated aspect of this section is related to the self-perceived productivity in relation to thermal comfort. The **fourth section** of the questionnaire is dedicated to **Occupants' behaviour**. The first investigated aspect of this section is the clothing level, for which three clothing "levels" were proposed for summer and winter (heavy, medium and light winter and summer clothing). Specific dress codes can also be specified. Then, the second investigated aspect is if occupants ever tried to solve some energy-related problems and how they searched information for this aim. After, a series of questions are dedicated to the actions that occupants usually perform to fix a problem of discomfort related to a certain environmental parameter. For this reason, for each of the environmental parameters previously assessed, a list of possible actions is provided. Following section three's evaluations, the questions are asked regarding those actions that can be performed in case of thermal discomfort, too low natural light level, too high natural light level, poor indoor air quality and not proper humidity level. For each of the proposed actions, the participant has to select how often he/she performs it choosing between the following options: two or more times per day, once per day, once every two-four days, once per week, less than four times per month and never. The "never" option is also advised to be selected in the case that the participant don't have the possibility to perform a certain action, e.g. because it requires a control interface that is not available for him. After, a series of more direct questions are asked in order to assess the participant's behaviour in relation to artificial lights and windows' opening. Finally, the last assessed aspect are the habits related to those actions that the participant may perform when living the indoor space (e.g. turning off lights). The **fifth** and final **section** is dedicated to **Control opportunities and preferences**. This section is mainly dedicated to assess the perceived controls of occupants. The first investigated aspect regards the HVAC systems that the participant think are present in the investigated space. Then, a series of questions are asked regarding several controls (both technological and structural). The first aspect assessed in these terms is whether the participant think to have a certain control opportunity and, at the same time, if he is interested in having it. Moreover, if he doesn't have a certain control, he is asked to express if this don't bother him or if he would be interested in having it. The second aspect, which is complementary to the first, is to understand which is the perception of the automated controls. Therefore, given a list of controls, the participant has to evaluate if they are automated and if he is ok with each automation or if he would prefer it to be manual. The last aspect investigated in this section is the relationship that the participant has with the building manager (or other people in charge) and a general evaluation of his/their work in terms of velocity and efficacy.

In the following, Table 10 lists the questions for each section of the questionnaire. Moreover, for each question there is the indication of which group of occupants it should be asked. The listed questions, as an example, are related to a heating season's questionnaire. The appendix to this thesis contains the questionnaire for HLC workers- summer season as an example, while on the Annex CD attached to this thesis all questionnaires for both seasons are provided. The cooling season's questionnaire does not differ on the type of questions, but only on the period to which the questions are referred. Moreover, it changes in some answers' options, according to the specificity of the season. Of course, the questionnaire should fit the investigated building as much as possible, so for the implementation of the methodology in real buildings the questionnaires can be modified according to the specific characteristics of BOs groups (that can differs from the HLC, MLC and LLC described above).

Table 10. List of questions and targeted occupants' groups.

Section	Question	Occupants' group
General information	1. Which of these age groups do you belong? (Age)	HLC, MLC, LLC
	2. Which of these groups do you belong? (Gender)	HLC, MLC, LLC
	3. What is your educational qualification?	HLC, MLC, LLC
	4. Which period of the day is it now?	HLC, MLC, LLC
	5a. Which period of the day do you usually spend at work?	HLC, MLC
	6a. How much time do you usually spend in the building per day (not considering breaks, meetings etc.)?	HLC, MLC
	7a. How are distributed the following working activities during your usual working day?	HLC
	8a. What of these groups the space you work in belongs?	HLC
	5b.In which state and city do you live now?	LLC
	6b.Indicate the date of today.	LLC
	7b.Which are the weather conditions today?	LLC
	8b.How long was the visit of this building?	LLC
	9.How often did you visited this building in your life?	LLC
Cultural background habits and changing attitudes	1. Are you currently living in a different city than your city of origin?	HLC, MLC
	2. Please mark which of the following action you normally do (ecological habits)	HLC, MLC
	3. What of these effects do you think have the following actions for your thermal comfort in your work environment in winter season.	HLC, MLC
	4. Do you like the historic building in which you work?	HLC, MLC
	5. If you like, specify the reasons of your last answer (open question)	HLC, MLC
	6. Suppose that you can choose the building you can work in. Which of the following option would you prefer? (Historic or modern building)	HLC, MLC
	7. If you like, specify the reasons of your last answer (open question)	HLC, MLC
	8. Let us suppose that the building you work could acquire the following facilities. Generally, these facilities make your comfort higher. However, their installation would cause damages to the historic building. Below you have to choose if you would	HLC, MLC

	renounce to these appliances to preserve the historical building, even if maybe your "comfort" would not be the same as modern buildings.	
	9. Do you think that historical buildings are more or less energy-costly than more recent ones?	HLC, MLC
	10. Do you think you would profit from being given advice about your behaviour in relation to ventilating, cooling and heating at workplace?	HLC, MLC
Comfort conditions and preferences	1. In your opinion, how important the following points are to feel comfortable at workplace?	HLC, MLC
	2. Please tick the circle that best represents how you feel at workplace during this winter.	HLC, MLC, LLC*[3]
	3. Basing on the previous thermal sensation, please tick the circle below that best describes your comfort perception at workplace during this winter.	HLC, MLC, LLC*
	4. Please tick the circle below that best represents the quality of the air (regarding smell, presence of dust etc.) at workplace during this winter.	HLC, MLC, LLC*
	5. Please tick the circle below that best represents the natural light level you perceive during the day at workplace during this winter.	HLC, MLC, LLC*
	6. Please tick the circle below that best represents the natural light level you perceive during the day at workplace during this winter.	HLC, MLC, LLC*
	7. Basing on the previous lighting level evaluation, please tick circle below that best describes your comfort perception (related to lighting level) during this winter.	HLC, MLC, LLC*
	8. Please tick the circle below that best represents the humidity level you perceive at workplace during this winter.	HLC, MLC, LLC*
	9. Basing on the previous humidity level evaluation, please tick the circle below that best describes your comfort perception (related to humidity level) during this winter.	HLC, MLC, LLC*
	10. Please tick the circle below that best represents the noise level of your office.	HLC, MLC, LLC
	11. Basing on the previous noise level evaluation, please tick the circle below that best describe your comfort perception (relate to noise level).	HLC, MLC, LLC*
	12. Do you recognize any of these sources of discomfort? You can choose more than one option.	HLC, MLC, LLC*
	13a. Some people think that they work best when they are not in a state of thermal comfort (e.g. they feel slightly cold), others think that when feeling cold or	HLC, MLC

[3] LLC* means that the period to which the evaluation is referred is the time spent in the building during the visit.

	warm they cannot work. When you think you are in a state of thermal comfort, does this condition enhance the quality of your work (+3), it has no effect (0) or it worsen the quality of your job (-3)?	
	13b.Do you remember some specific areas in which you felt too cold or too warm? Which ones? (open question)	LLC*
Occupant behaviour	1. In which of these categories do you recognize your usual clothing for the current season?	HLC, MLC, LLC*
	2a. Do you have a specific dress code to go to work?	HLC, MLC
	2b. Do you think that the administration of the museum should advise to carry some clothes for the coldest parts of the building?	LLC
	3. Have you tried to find information about how to solve the indoor environmental problems (related to temperature, air quality, lighting etc.) you may have?	HLC, MLC
	4. How often do you usually perform these actions when feeling thermally uncomfortable in winter season? If an action is not available (e.g. opening the window, click "Never")	HLC
	5. How often do you usually perform these actions when the natural lighting level is too low in the winter season?	HLC
	6. How often do you usually perform these actions when the natural lighting level is too high in winter season?	HLC
	7. How often do you usually perform these actions when feeling that the indoor air quality is low in winter season?	HLC
	8. How often do you usually perform these actions when feeling that the humidity is not proper in winter season?	HLC
	9. When do you usually turn on the lights in winter?	HLC
	10. When do you usually open the windows in winter?	HLC
	11. After you opened the window, for how long it usually remains open?	HLC
	12. When the window is open, do you turn off the following systems?	HLC
	13. When you leave the workplace what of these actions do you perform in winter season?	HLC
Control opportunities and preferences	1. Which of these systems do you have at workplace to control indoor environmental conditions in winter?	HLC
	2a. Do you personally manage the heating system in winter season?	HLC
	2b. When you detect a problem related to temperature, humidity or light, do you usually call someone who can fix the situation?	MLC

	3. If you cannot control the system personally, do you know the person in charge of this duty?	HLC, MLC
	4. In the following some actions are listed. Select one cell considering two aspect. 1) if you can perform the action and 2) if the possibility of performing this action is important to you or not.	HLC, MLC
	5. If during winter the temperature is too low and you don't have a heating system (or it doesn't work properly), are you allowed to bring/or have your personal heater?	HLC, MLC
	6. Which of these operations are automatic (or you wish to be automatic) through your working environment?	HLC, MLC
	7. Have you ever made requests to the building manager (or person in charge) for changes to the heating, cooling, lighting or ventilation systems?	HLC, MLC
	8. If yes, how satisfied in general were you with the speed of response?	HLC, MLC
	9. If yes, how satisfied in general were you with effectiveness of response?	HLC, MLC

Since the questionnaire is quite long (53 questions for HLC), it is useful to individuate which are the main objectives or topics by grouping the questions. In a way, Table 11 analyses the questionnaire with a different perspective, highlighting some questions that directly respond to specific topics of interest for Ω4. Moreover, these topics could represent the basis for interesting comparisons between several investigated buildings, in order to put into perspective the results of a certain building in respect to the others. In addition or in alternative to the following topics, the comparisons could be done within the same building or across more buildings considering different occupant groups (based on Section I questions 1, 2, 3, 7) or different activities (Section I questions 6-8).

Table 11. Analysis of the questionnaire in relation to specific objectives/topics for the comparison between different cases.

Objective/topic	Specific aspects	Related questions
How different HVAC systems or the presence of building automation could influence occupants' behaviour?	Characterise the HVAC systems present within the analysed space.	Section V questions 1,4,5,6
	Characterisation of occupants' behaviour in relation to the HVAC systems.	Section IV questions 4, 5, 6, 7, 8, 12, 13.
	Characterisation of preferences regarding HVAC systems and control	Section V questions 4 and 6

	opportunities (how people would change their environment).	
Relation between occupants and building managers (or people in charge of similar duties)	Presence of BMs and interaction with occupants.	Section V questions 2,3,7,8 and 9.
Occupants' perception of the indoor environment	Indoor environmental parameters' evaluation.	Section III questions 2-11.
How people behave in case of discomfort (not considering systems)	Questions related to different discomfort situations.	Section IV questions 4-11.
Characterization of cultural background and ecological habits	Questions related to cultural background and habits	Section II questions 1, 2. Section IV questions 1-3.
	Questions related to environmental consciousness	Section II questions 3,10. Section III question 3 in comparaison to question 2.
	Questions related to changing attitudes	Section II question 10.
Characterization of the relationship with historic buildings	Relationship with historic buildings	Section II questions 4-7.
	Willingness to lower comfort requirements to preserve the building	Section II question 8.

Once gathered all the data from the questionnaire, their analysis vary depending on the type of question and the evaluation that the person who is implementing the methodology wants to have. From a methodological point of view, descriptive analyses such as graphs can be chosen based on the type of question and the type of information that it is useful to visualize. For this research, data were analysed using the software SPSS, which is a software package used for interactive, or batched, statistical analysis.

6.3 Outputs of Phase I. The reports.

All the analyses listed in the previous paragraphs are used by the person who implement the methodology to individuate opportunities of operational strategies addressed to BMs and BOs. Beside this "professional" use, it could be useful to report some of the analyses to the buildings' administration and to the occupants for more "informative" and "negotiating" aims. Therefore, once finished all Phase I analyses and having detected a number of possible strategies, the elaboration of a report should be evaluated (it is not mandatory). Chronologically, the report should be collocated between Phase I and Phase II. In fact, Phase II corresponds to the period chosen to implement the strategies. However, the choice of strategies takes place before, and it should include a negotiation with the administration of the building. The report could be a useful tool to show to the administration relevant outputs of the analyses using a document that they can read before or during the meeting. It is also a way of demonstrating that all the provided materials (energy bills, questionnaires etc.) were analysed and "used" to elaborate the strategies. Since Phase I is conducted separately for heating and cooling periods, also the reports should be divided for the two periods. Therefore, chronologically, Phase I takes place in a certain season, then before the beginning of the same season the year after, a meeting should take place to decide together with the administration what strategies to implement. The same report can also be shared with the occupants that participated to the survey, in order to inform them about the building's energy performance, the "objective" indoor environmental conditions (from the monitoring system) and how the other occupants responded the questionnaires.

Before entering the description of the advised report structure, it is important to highlight that, since the objective of this document is to constitute a negotiation and informative document, not all the performed analyses should be shown, but only a short and meaningful selection of them. Moreover, the writing should consider that not all readers will be experts, so the chosen graphs should be understandable or, if difficult, carefully explained. In the following, Table 12 lists the principal information that should be provided in each section of the report. In general, the report should contain a selection of relevant information regarding the following aspects: Building energy management (1), Indoor environmental conditions (2), Energy consumption and costs (3), Occupants' evaluations and behaviour (4) and Possible Strategies (5). Example of the report can be found in the attached CD Annex.

Table 12. Indicative structure of a Phase I's report.

Section	List of contents
SUMMARY	Indoor Environmental conditions: principal outputs of the monitoring data analysis. Indication of critical situations. Energy consumption and costs: synthetic information about the period of analysis and indicators like total energy consumption (preferably referred to the period of phase I) and energy cost for each energy carrier. Occupants' evaluations: two graphs summarising two essential aspects. First, if people like to work in that historic building. Second, the comfort vote associated to each of the evaluated parameters (temperature, natural light etc.).
BUILDING ENERGY MANAGEMENT	Report who is responsible of the energy management and how he operates in general (e.g. he uses a BEMS). How the following interfaces and services are managed (very synthetically): Ventilation (natural or mechanical , temperature set point and schedule in case of mechanical),

	Cooling or heating system (depends on the season) (type of system and terminals/controls, set-points, schedules), Humidification/de-humidification (present/not present, set-points and schedules), Windows (fixed opening rules) Internal and external doors (fixed opening rules), Internal and external blinds (fixed opening rules)
INDOOR ENVIRONMENTAL CONDITIONS	Characteristics of the monitoring system (number of sensors, monitored parameters, duration of the monitoring etc.) Analyses. Only a few graphs, as much understandable as possible (probably time profiles would be one of the easiest). Synthetic description of each graph and individuation of critical situations that could constitute reasons to adopt certain strategies.
ENERGY CONSUMPTION AND COSTS	Short description of the materials that were used and the performed analysis (e.g. seasonal or yearly) Selection of energy information that can be easy understood (e.g. total or specific energy consumption) Graphs that can be used for detecting critical situations (e.g. energy consumption divided for time period, depending on the energy tariff) Graphs that highlight the entity of costs (energy versus taxes and other costs)
OCCUPANTS' EVALUATIONS AND BEHAVIOUR	Division of results by occupants' group. Specification of survey period, survey type (on-line or paper) and number of answers (and rate). Graphs of selected relevant information. Probably one of the easiest graphs to interpret is the cake graph. However, it should be accompanied by percentages. For the non-obvious questions an explication of the question itself (why is it asked) and the graph (the result obtained and its implication) should be provided.
POSSIBLE STRATEGIES	The strategies should be listed in this section following all the critical situations and improvement opportunities listed in the reports. The strategies should be sorted by: Technological interfaces' strategies – to be implemented by BMs Structural interfaces strategies – to be implemented by BMs Proposal for educating strategies addressed to BOs. All the proposed strategies should be negotiated.

7

Phase 2 – Intervention

7.1 Objectives

Chronologically, the second Phase of the methodology should correspond to the same period in which Phase 1 took place, but one year later. The first aspect to clarify is that, according to the methodology, Phase 2 corresponds to the implementation of the strategies. However, in this paragraph, the majority of space will be dedicated to the work that precedes Phase 2, in which the strategies have to be chosen and prepared for their implementation. The strategies proposed for the Intervention should have several objectives that are listed in the following, identified by the symbol "Ω".

Ω 1. *Lower the building's energy consumptions.* This objective can be reached only by engaging BMs and BOs at the same time, considering their specific control opportunities.

Ω 2. *Enhance comfort perception and behaviour of BOs.* This objective should be reached considering the trends emerging from the survey conducted during Phase 1. It involves both BMs and BOs. In particular, BOs are protagonists since they should be educated to take a proper advantage of their control opportunities, in order to contribute to reduce the energy wasting and ameliorate the indoor environment.

Ω 3. *Ameliorate or solve indoor environmental critical situations related to artworks' conservation.* In case of critical situations emerged from the analysis of indoor environmental conditions during Phase 1, strategies addressed to HVAC systems and structural interfaces of the building should be elaborated in collaboration with the conservation responsible of the expositive area. This objective is mainly related to the activity of BMs.

Differently from the first phase, the objectives of the second should not be addressed with separate actions or analyses. Choosing the strategies, all the listed objectives should be addressed at the same time. This approach will require a continuous balancing effort, and sometimes it will require choosing which objective to prioritize to the detriment of another. Establishing a fixed priority is not an easy task, so in the case of having to choose one objective over another, the advised approach is to consider both options and discuss the two scenarios with the administration of the building. Beside the listed objectives, another "collateral" one, which is important for the Phase 2 to succeed, is to encourage the exchange of information between BMs and BOs, especially having considered the former approach assessed during Phase 1. Another general aspect to take into account, especially during the "designing" phase of strategies, is the necessity to provide clear and understandable operative information in the case that the BMs are not professionals, but maybe inexpert. In the following, Phase 2 will be described dividing two sections. The first will describe some of the possible "operational strategies", dividing them by the group to which the strategy can be addressed (BMs and BOs). The second section will describe how to communicate, engage and encourage the two groups to implement the strategies. Again, the communication means will be divided for BMs and BOs groups.

7.2 Selecting the strategies

Chronologically, the first action to perform is to decide what strategies to propose for both BMs and BOs groups. Of course, the choices should be strictly related to the findings of Phase 1's analyses and satisfy the objectives listed in the previous paragraph. However, the strategies' choice for the two groups should differ both on the "reasons" to adopt a certain strategy and the way that the strategy is implemented during Phase II. For BMs, the main objective should be solving "critical" situations related to energy consumptions (1), artworks conservation (2) or uncomfortable indoor environment (3), and the strategies' implementation will consist in a different "way" of managing the targeted energy-related interface for the whole Phase II. For BOs, the strategies' choice will mainly be aimed at providing them with the necessary education to take a proper advantage of the control opportunities they have (both personal adjustments and control interfaces). In operative terms, this means that the strategies' implementation will not consist on the establishment of new energy-related "rules" to be followed for the whole Phase II period, but on providing them with possible solutions for various "uncomfortable" situations, explaining also what are their actions' impact on their comfort (and the others), and the building's energy use.

Table 14 lists possible operational strategies that can be proposed to BMs dividing them by interfaces. Note that his list is not exhaustive, for specific cases, other strategies could be individuated based on the investigated building's peculiarities. At the same time, the probable impact of each strategy is evaluated considering the objectives listed in the previous paragraph. Table 13 is a legend to interpret the colours describing the impact of the strategies for each objective. Of course, these impacts should be considered as general trends, so they should be always questioned considering the investigated building's specificities. In some cases, as anticipated before, the colours of the "energy efficiency" column and the "BOs comfort" column could be different for the same strategy. Those are the cases in which the priorities should be discussed also with the administration, to choose what objective should be privileged and, therefore, if that strategy should be chosen or not. In some cases, instead, the colours of the two columns will be the same. For example, if both columns are coloured in red, than probably the strategy is not advisable for that particular season, with the exception of particular cases (e.g. necessities of artworks conservation). In fact, the same action in winter and summer could have opposite outcomes, both in energy and comfort terms. Regarding the strategies for BOs, it should be noticed that in the cases of controversial outputs (opposite colours for energy and BOs comfort), the final decision lies with the BOs. In those cases, the only role of the administration could be to decide if providing or not the education for that specific strategy. Of course, Table 14 shows a general list of strategies; the choice of a certain strategy has to take into account the control opportunities and the technologies that BMs have. At the same time, it could also be decided that, even if until Phase 2 BMs did not had certain duties or controls over the indoor environment, they could be given new ones. For example, even if in the past they never had to manage the windows' opening in the early morning, it could be evaluated that this strategy would be beneficial for a certain building (e.g. free cooling in summer). In that case, they would "acquire" a new duty. In this sense, strategies could also consist in changing the control opportunities (of course taking into account the technological feasibility).

Table 13. Legend to interpret the impact of strategies listed in Table 12.

Impact on energy consumptions, BOs comfort and artworks conservation	Colour
No impact	(grey)
Positive impact	(green)
Could be positive or negative, depends on the cases	(yellow)
Negative impact	(red)
Not implementable in expositive areas	(white)

Table 14. List of possible strategies for BMs. H=heating season; C=cooling season.

Interface type or control	**Strategy description**	**Energy Efficiency**	**BOs Comfort**	**Artworks conservation**	**Possible reasons to adopt the strategy (examples) or comments**
HVAC systems	Change systems' schedule –reduction of operation hours				The systems are operating also in unoccupied hours (e.g. night).
	Change systems' schedule –increase of operation hours				In summer, BOs claim that the space is too warm when they arrive in the morning. In an exposition, temperature increase too much during not cooled hours (summer).
	Give BOs the possibility to change temperature set-points				Users desire to control indoor temperature because they are not satisfied with the current conditions.
	Limit BOs possibility to change temperature set-point – e.g. limit the range of temperature they can set in the thermostats				BOs control thermostats but energy consumption is too high.
	Program thermostats in a way that after a period the set-point return to a prefixed value				The space is used by several BOs in different times of the day. BOs have the access to thermostats but there is the necessity to reset the conditions after a while.
	Increase the temperature set-point (where thermostats are not operable by users)	W S	W S		In summer, the energy used is too high. If BOs claimed that they felt cold the output is green! In

					winter, if BOs claimed that they felt too cold.
	Lower the temperature set-point (where thermostats are not operable by users)	W S	W S		In winter, the energy used is too high. Or BOs claimed that the indoor environment was too warm. In summer, because BOs claimed that they felt too warm.
	Mechanical ventilation –change operation schedule				Mechanical ventilation is used also during un-occupied times.
	Mechanical ventilation – increase the ventilation rate				BOs claim that the air quality is too poor.
	Mechanical ventilation – lower the ventilation rate				BOs claim that there is too much air movement.
Lights*	In case of remotely controlled artificial lights – reduce schedule of operation				Lights are switched-on also during un-occupied hours
	If lights are dimmerable – lower the luminosity during unoccupied hours				To be considered when some lights cannot be switched off for security reasons.
	Switch on the lights earlier or increase the luminosity (if dimmerable)				In service spaces, if BOs claimed that the light level was too low to work or for security reasons
Windows*	Night or early-morning fixed openings	W S	W S	[4]	In summer it can be done to cool the space. In every season it could be done because BOs claimed poor air quality (for naturally ventilated buildings).

[4] Temperature and RH short-time fluctuation should be carefully assessed.

External blinds	Leave external shutters closed during daytime*	W S	W S		In summer, to avoid glare or overheating.
	Leave external shutters open during daytime*	W S	W S		In winter, to profit of natural light and free heat gains from the sun.
	Leave external shutters closed during night time	W S			In winter, to decrease heat losses from the envelope.
Internal blinds*	Leave internal blinds (e.g. curtains) closed during daytime	W S	W S		In summer, because of glare and to lower the cooling load.
	Leave internal blinds open during daytime	W S	W S		In winter, to delay the switching on of artificial lights and maximise external heat gains.
Doors * (service or external)	Leave the doors closed, if normally open	W S[5]	W S		In winter, for reducing draft and heat losses. In summer, advisable if outdoor temperature is higher than indoors.
	Leave the doors open, if normally closed	W S[3]	W S		In winter, viable only in case of very poor air quality. In summer, for free cooling if outdoor air temperature is lower than indoors and to increase air velocity (if windows are also opened and the building is not mechanically cooled).

*only in the case that they are not operable by BOs, or in accordance with them.

[5] Depends on outdoor temperature. If daytime, then green (outdoor temperature is probably higher than indoor). If night-time or early morning, could be red (possible free cooling due to lower outdoor temperature).

Table 15 lists a number of operational strategies that can be proposed to BOs, with a similar approach to the one adopted in the previous table. In this table, there are three aspects to be highlighted. First, besides the previous control interfaces, the "personal adjustment" category has been added, including a series of actions that the person can perform to adapt "himself" to the indoor space. Second, the impact on artworks conservation is not present in this table, because BOs should not be able to influence the indoor environmental conditions of expositive areas. Third, the "generic energy-related education" strategy has been added. Even if it is not addressed to a specific interface or control opportunity, this "strategy" should be considered in all buildings to "reinforce" and put into perspective the other strategies that are specifically addressed to an interface or to solve a specific problem. Of course, the listed strategies for BOs will be communicated adopting different means that will be described in the following. While for BMs' strategies it could be sufficient to negotiate and establish some measures that will be tested "for sure" during the period of phase II, with BOs it is not possible to establish new protocols of behaviour or fixed rules. Therefore, the key point is to educate BOs to adopt the proper strategy at the proper time, also establishing a hierarchy of the possible actions, privileging those that do not entail an energy use or those that can reduce energy wasting. In these terms, if the education is efficient people will choose case by case which is the better action to do, with more flexibility than the "fixed" strategies that can be negotiated with the BMs. Of course, giving BOs the freedom to control a large number of interfaces (structural and technological) it is more difficult to predict the real impact of strategies on energy consumption, because everything will depend on their free will. Looking at the table, it should be noticed that in this case most of the BOs column is green. This is because most of the proposed strategies are aimed at ameliorating their comfort. At the same time, it should be noticed that in several cases both energy and comfort columns are contemporarily green. This is because in choosing the BOs strategies, the ones that allow BOs comfort enhancement and reduction of the energy waste has been privileged.

Table 15. List of possible strategies for BOs.

Interface type or control	Strategy description	Energy Efficiency	BOs Comfort	Possible reasons to adopt the strategy (examples) or comments
Personal adjustment	Advise BOs to drink cold beverages			Since they are personal adjustments, so they can be adopted in (almost) every case and their adoption do not imply an energy use, educating BOs about these strategies should be done in all buildings.
	Advise BOs to drink hot beverages			
	Advise BOs to add a layer of clothes			
	Advise BOs to remove a layer of clothes			
	Advise to have flowers or plants in the room especially in summer, to cool the air through the evaporation of water and, if positioned near to the windows, to have some shadowing			
	Advice to change position of the desk or the chair in the case that the air-flow from the mechanical ventilation or from other terminals is too direct on the body			
	Advise to have a short walk to avoid the pain due to the air conditioning (e.g. muscles' rigidity)			
	Advise to use a blanket when feeling too cold			
HVAC systems	Teach how to use thermostats or temperature controls in terminals (e.g. fan-coils)	[6]		Advised if BOs have thermostats available in the space but there are not instructions on how to use them.

[6] Teaching how to use thermostats could not necessarily lead to energy savings. However, if the education is effective, it should lead to a more comfortable indoor environment.

	Teach how to re-enter the standard set-point when they exit the room			To avoid uncomfortable conditions for other users (in case of MLC) and avoid energy wasting in spaces in which BOs have thermostats available in the room.
	Engage BOs in verifying if the mechanical ventilation is actually working			Encourage people to pay attention to indoor environmental conditions. For example, if the air is not flowing they could communicate it to the BM.
Windows	Teach how to use windows to guarantee a good IAQ			Only for buildings with operable windows, especially if naturally ventilated buildings.
	Teach how to use windows for free cooling and to avoid overheating			Especially for buildings without mechanical cooling.
External and internal blinds	Teach users when it's better to open or close external and internal blinds in different situations (e.g. glare, low natural light level) and seasons (necessity of heat gains in winter versus necessity to limit the cooling load in summer)			Especially for buildings with big windows and risk of glare.
Doors	Teach users to use doors for changing air			In cases in which the mechanical ventilation does not work properly or as an alternative for window opening when the outside temperature is too hot or too cold, so their opening would be
Lights	Teach BOs how important is to turn on lights just when the natural light is not sufficient			Good strategy for all cases in which Lights are operable by BOs

	Teach BOs how to use light dimmering			Only in cases in which lights are dimmerable
	Teach occupants how important is to turning off lights when leaving the room			Good strategy for all cases in which Lights are operable by BOs
Generic energy-related education	Provide BOs generic knowledge about energy and comfort in buildings			Good strategy, potentially for all buildings.

7.3 Implementing the strategies

As previously expressed, having chosen the strategies for BMs and for each BOs group, the second step is to discuss with the administration which of the proposed strategies will be implemented and how. Since the strategies addressed to BMs are represented by some measures that should be implemented during all the duration of Phase II, it is necessary to negotiate them and establish their implementation before the beginning of the phase II's period. Therefore, as described in paragraph 2.3, it is advised to organize a meeting with the BM and (possibly) the administration, in which the strategies to be adopted should be discussed based on the analyses and the proposals contained in the Report of phase I. Once the strategies have been established, for BMs there are not other means to design, since it is all decided and agreed during the meeting. The only other action to be considered is the establishment of periodic meetings or contacts (e-mail, phone calls) with the BMs, to acquire updates about the strategies' implementation (e.g. BOs complaints) and evaluate eventual adjustments.

Regarding the BOs, together with the choice of the strategies also the communication means used to "transfer" the information should be chosen. The communication means should be decided together with the administration. For this research, three types of communication means have been considered; newsletters, workshops and signs. These means are not alternative to each other; they can be overlapped. Moreover, the same strategy can be communicated by several means. Also, the choice of the communication mean should depend on the characteristics of the BOs group's characteristics. For example, not all types of BOs could be easily reached by newsletter or participate to a workshop. An important aspect is that for this study the only "digital" communication mean is the newsletter. This is because one of the assumptions made at the beginning of the study was to propose a methodology that can be applied in historic buildings by only exploiting the current technological infrastructure of the building. For this reason, the use of communications and feedbacks via app or dashboards (the so-called digital interfaces) was not considered, because it is very rare that historic buildings are provided with these technologies. Of course, the different communication means have different characteristics and are more appropriate to deliver certain information. In the following paragraphs, the three selected means will be described by highlighting their characteristics, their "pros and cons" and which are the strategies that are more suitable to be communicated by that mean.

7.3.1. The workshops

Workshops are characterized, among the other communication means, by the fact that the person who is implementing the methodology (the presenter or facilitator) interacts directly with BOs or BOs' groups (Staddon *et al.*, 2016; Endrejat and Kauffeld, 2017; Endrejat, Baumgarten and Kauffeld, 2017; Axon *et al.*, 2018). Workshops can be organized involving all BOs together or separating the different groups that are contemporarily within the building, to which different questionnaires were provided (e.g. HLC group, MLC group). As intended in this research, the workshops should be addressed to "stable" occupants of the building (HLC and MLC). However, if the building in which the methodology is a public building, seminars could be organized, in accordance with the administration, using a structure that is similar to the workshops. The main difference would be that the focus would not be necessarily the building in which the methodology is implemented, but general education about the use of energy in buildings. Of course, this activity is not strictly related to the BIOSFERA methodology, since carrying it is not expected to affect the objectives listed in the first paragraph of this chapter. In the following, Table 16 summarizes the parts that should characterize the workshop. Of course, the structure can be modified to take into account particular requests of the building administration. The proposed structure is characterized by three parts: "Results of last year's survey" (1), "Advices to deal with the building and the systems in the coming season" (2) and "Presentation of the BIOSFERA materials" (3). The workshop should be organized before the beginning of Phase II, since it provides education to deal with the building's interfaces in the coming season and it presents the other communication means that will be established during Phase II. The duration of the workshop could range. However, each part's presentation should not exceed 10 minutes. While for the first part the Questions&Answers (Q&A) could be done immediately after the presentation (but should be limited to 10 minutes) in order to allow BOs to immediately comment the presented results, for the second and third part the Q&A should be done at the end of the third part. Of course, during the Q&A discussion topics could emerge. For this reason, it is best if the BM and someone from the administration could participate to the workshop, in order to allow a direct verbal confrontation between the actors. In this phase, the presented content should have a "facilitating" role and should include a note that some aspects could be used to "adapt" the strategies that will be implemented in the Phase II. For this reason, a short meeting with the BM and the administration at the end of the workshop is advised, in order to discuss eventual changes in the proposed strategies for BOs. Finally, some thoughts about the "pros" and "cons" of the workshops. The main "pro" is that this is the only communication mean that allow a direct consultation of BOs, which could be fruitful for the other strategies' implementation and to individuate problems that did not emerge from the survey. Another "pro" is that, if the BM and someone from the administration participate, it would be one of the very few occasions of having a direct discussion between all "actors" affecting the building's energy use. The main “cons” of workshops are that it is very hard to involve a large number of participants and finding a timeslot that fits several group’s working schedules.

Table 16. Workshop parts.

Part	Duration	Description
Results of last year’s survey	~ 10 min. presentation + ~10 min Q&A.	Presentation of some results from the survey conducted during Phase I (regarding the season for which phase II is about to start). The selected results should be regard data that are interesting to BOs or represent topics that could be clarified by them (e.g. results that identified a specific problem) or discussed between the administration or the BM and the BOs.
Advices to deal with the building and the systems in the coming season	~ 10 min. presentation	This part should be characterized by general advices and information regarding how to deal with the upcoming season from an energy-perspective. The information contained in the presentation should not be “instructions” to singular problems (e.g. instructions to use the thermostats). On the contrary, they should constitute a “background” to the “ready-to use” solutions that will be provided by other means like signs. Moreover, the delivered education should be mainly focused on those strategies that can implemented by not using energy or saving it (e.g. personal adjustments and structural interfaces). Another aspect that should be addressed is the false belief that “more comfortable” means “more energy use”.
Presentation of the BIOSFERA materials	~ 5 min. presentation + final Q&A	The last part should present all the materials that will be provided during Phase II, namely the signs that will be positioned within the space (e.g. thermostat instructions, comfort advices) and the newsletters. In this part, particular emphasis should be given on what is the objective of each material (for what it should be used). Moreover, BOs should be consulted in order to ask them what would be the most appropriate position of each sign type.

7.3.2. The newsletters

The newsletters are characterized by the fact that during all the duration of the Phase II they can be sent several time and each time they can deliver a different information (Kastner and Matthies, 2014; Staddon *et al.*, 2016; Axon *et al.*, 2018). Differently from the workshop, the newsletters should be sent during the Phase II period, reminding BOs of the ongoing experimentation of strategies. The major "cons" of this communication mean is that it requires the will from the BO to open and read it. For this methodology, two "types" of newsletters can be used. The first should be privileged especially in those cases in which the workshop was not done. It consists of newsletters that deliver "education" regarding the theme of energy and comfort in buildings, similarly to the second part of the workshop. The second option is to send "nuggets of wisdom", namely information related to a problem that was detected during the Phase I analyses or in the workshop. In both cases the newsletter should have two main characteristics. First, they should be very illustrative. Second, they should contain small texts, privileging bullet lists or other synthetic means. Moreover, the best option is to insert the information to be delivered directly in the body of the e-mail. In fact, inserting the information in attachment would require another "action" by the users, reducing the probability of being read. Another aspect to be considered is by whom the e-mail is sent. Probably, the best option is to ask to someone known of the administration to forward the email prepared by the person who cure all the methodology implementation. This way, the e-mail would have a known consignor, which increase the probability for the e-mail to be opened. In the following, Figure 6 shows an example of a possible newsletter of the second type (wisdom nugget), which could be addressed to a naturally-ventilated building in which the survey highlighted that BOs do not open windows often enough. Then, Figure 7 shows an example of a possible newsletter of the first type, in which some education about how our body interacts with the indoor space is provided.

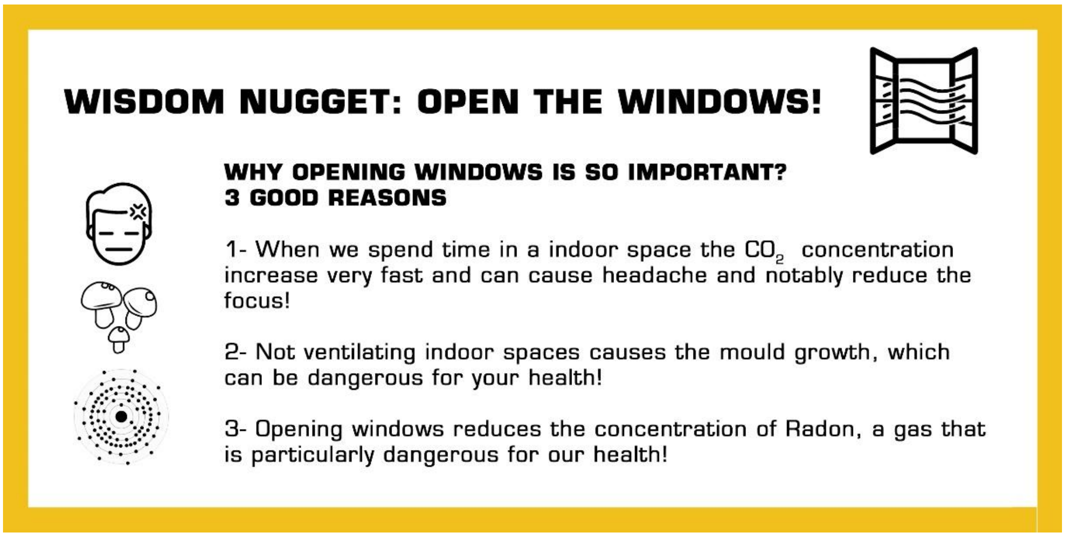


Figure 5. Example of a wisdom nugget newsletter.

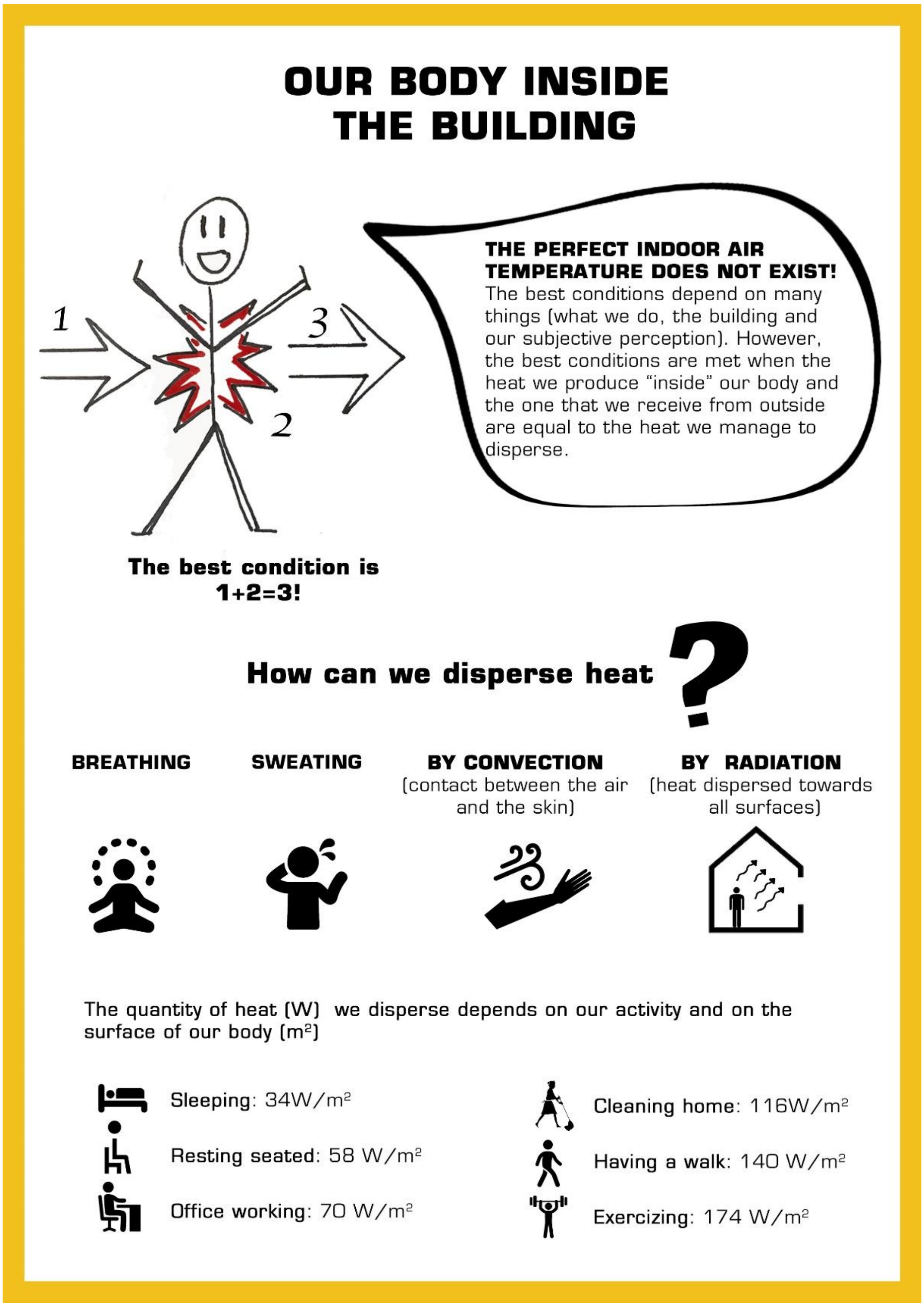


Figure 6. Example of an educational newsletter.

7.3.3. The signs

The signs are characterized by the fact that they are positioned within the indoor space, so they should be kept in the same position for all the duration of Phase II. Signs can be used for several purposes, but usually they are positioned as "reminders" or "instructions" (Kastner and Matthies, 2014; Staddon *et al.*, 2016; Zhang *et al.*, 2018). For this research, three types of signs were designed. However, as for all other communication means, other types of signs could be designed based on the investigated building's necessities and specificities.

The first type of sign is called "Comfort advices for the summer season". It consists on a sign to be attached on the wall in a position that should be very visible, e.g. near the windows. This sign consists on a series of advices to solve different situations of discomfort that could occur in the indoor space. The advices consist in actions that are ordered from the ones that permits to save energy to the ones that require an increase of energy use, passing by those actions that would not affect the energy consumptions. The impact on energy is expressed by different bubbles coloured in green (actions that permit an energy saving), blue (actions that would not impact the energy consumptions) and red (actions that require an increase of energy usage). Of course, the advised actions should respect the control opportunities that BOs have within that specific space, even if it is not always easy to do this (sometimes, even within the same part of a building, different rooms have different control opportunities). Therefore, a disclaim should be written in the sign, advising to switch to the next option if one is not available. Figure 8 shows an example of "Comfort advices for summer season".

The second type of sign is a reminder to be positioned near to the door, with the title "Before leaving the room… please remember". The information contained in this sign, expressed as a "to do list", depend on the type of control that BOs have available within the space and "how" (which state) the BM decided that the control should be leaved by BOs. For example, if the room is equipped with operable thermostats, the sign could ask to set a certain temperature (that is considered to be advisable) before leaving the room. Figure 9 shows an example of this kind of sign.

The third type of sign is an "instruction" one. The title in this case depend on the type of interface the instructions are aimed. It could be addressed to explain how the thermostat can be used by BOs to change the temperature set-point, or how to deal with the controls present in a fan-coil. The instructions should not be generic, but specific for the interface to which it is addressed. Moreover, it should contained a photo or an illustration of the device and the explanation of the various buttons. Figure 10 shows an example of this sign.

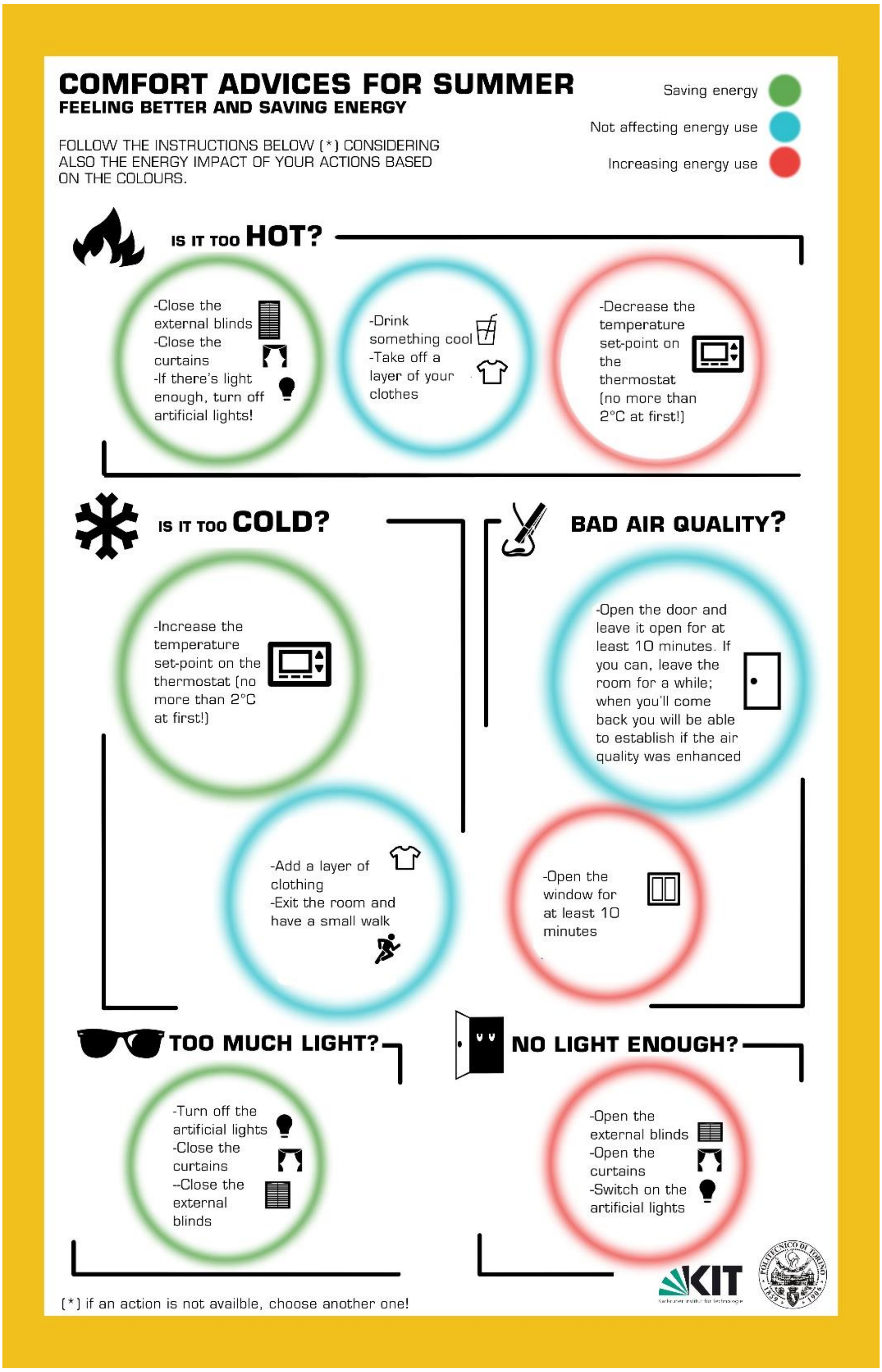


Figure 7. Example of "comfort advices" sign for the summer season.

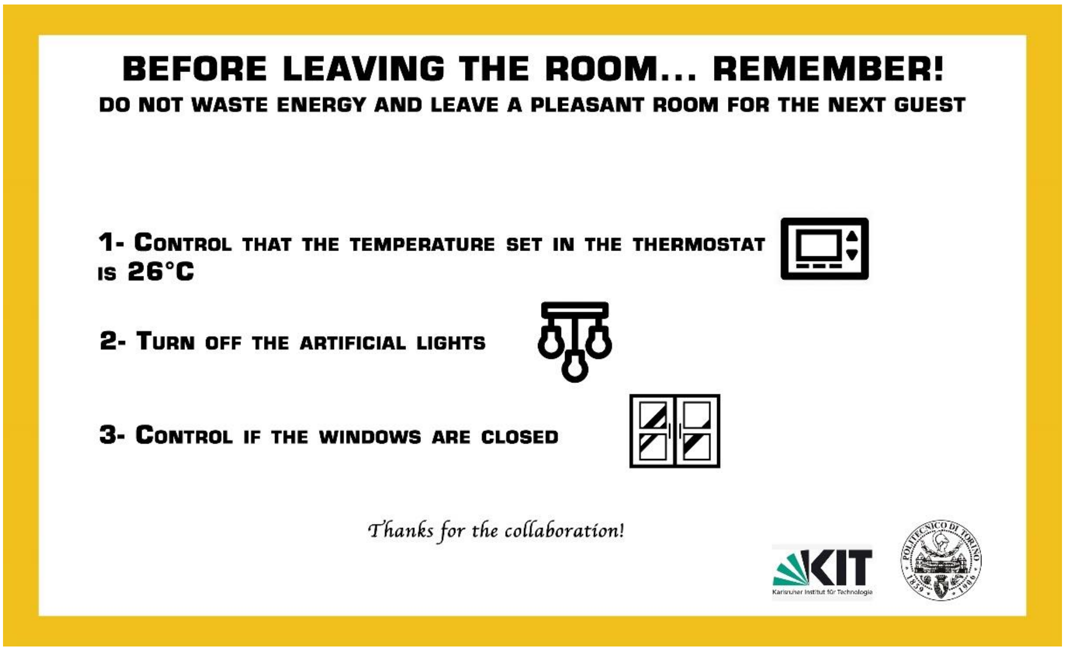


Figure 9. Example of "Before leaving the room" sign for the summer season.

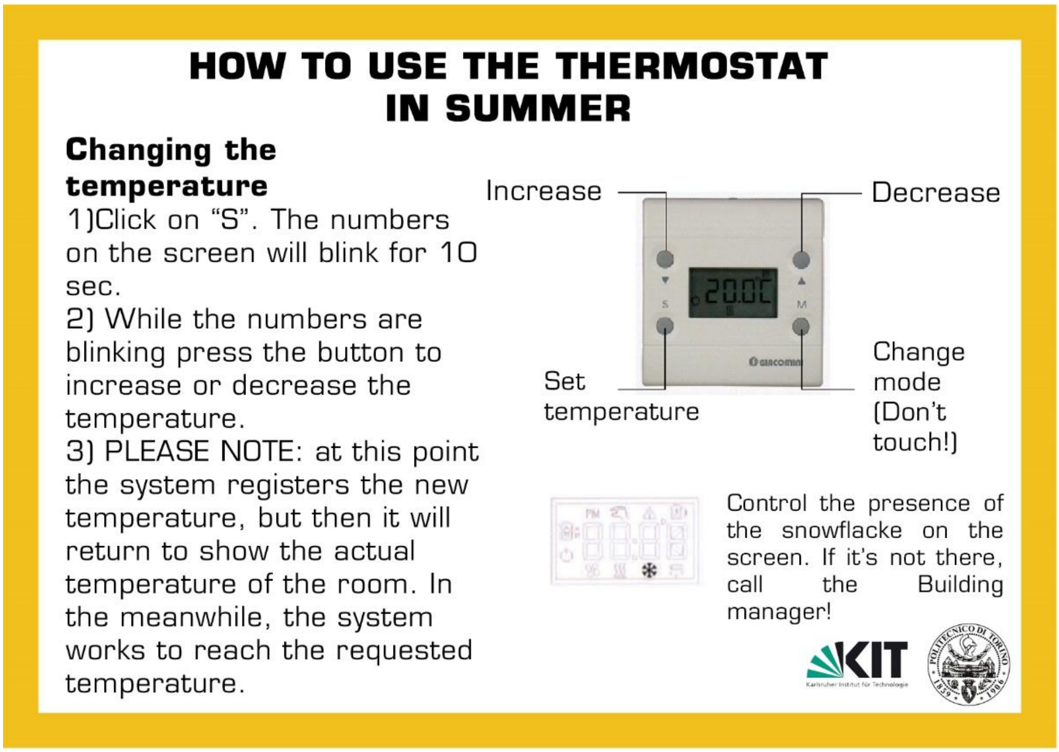


Figure 8. Example of "How to use the thermostat" sign for the summer season.

8

Phase 3 – Control

8.1 Objectives

The objective of the third Phase, called “Control”, is to assess the impact of the strategies implemented during Phase II in respect of the three objectives that were set at the beginning of chapter 6, namely the objectives that guided the strategies' choice. The three objectives were: lowering the building's energy consumption (1), enhancing comfort perception and behaviour of BOs (2) and ameliorating or solve indoor environmental critical situations related to artworks' conservation (3). This phase represents also the so-called “post-test”, which consists on repeating some analyses previously done during Phase I (the “pre-test”). Comparing the results of the “pre-test” and the “post-test”, the impact of the strategies (test) can be identified (Conrad *et al.*, 2012; Endrejat and Kauffeld, 2017). Chronologically, the Control phase should be positioned right after Phase II is concluded. However, somehow it is superimposed, in the sense that during Phase II some of the elements that will be necessary for Phase III's analyses have to be gathered. For example, if a monitoring system was present during Phase I, the registrations should be carried on also during Phase II. Then, the analyses will be executed during Phase III. Due to this necessity of “superimposition”, the analyses of Phase III should be planned before the beginning of Phase II, in order to establish the materials that should be gathered during the strategies' implementation. Describing the third Phase, two different perspectives should be considered. The first addresses what are the analyses that should be performed in order to quantify the “results” of the methodology's implementation – more specifically, the quantification of the strategies' impact in respect of the three objectives listed above. The second perspective regards what information should be acquired from each group (BOs and BMs). In the following, three sections will be dedicated to the analyses that should be performed in order to assess the strategies' impact in respect of the three objectives identified at the beginning of Chapter 6.

8.2 Assess the impact of strategies on the building's energy consumption

This section is dedicated to the analyses that should be performed in order to quantify the impact of Phase II's strategies on the buildings' energy consumption and the relative energy-related costs. The materials to be used depend on the ones used to perform the analyses of Phase I. Therefore, if the energy bills were used in the first phase, also in the third they should be used with the same approach. Then, if other sensors are present within the building, their data can be used also regarding the period of Phase II in order to compare their registrations before and during the strategies' implementation. Of course, even if in Phase I some analyses were done to assess the energy performance of the building during the whole year or considering the whole season, the comparison at this stage should entail primarily the months that correspond to the ones chosen for Phase II. This is important because sometimes, even if Phase I and II time lapses should be decided before the methodology's start, during the implementation there could be some delays or problems, so at the end Phase I and II could not be entirely overlapped. For example, even if in the first phase the energy-related analyses were done considering a "whole" cooling season, from June to September, if (for unexpected situations) the strategies were implemented only in July and August, then the comparisons should be done, first, considering only these months. Then, the analyses can shift to the comparison of all the season, but before the analyses should be as more detailed as possible. Since in most cases the detail is related to the data of energy bills, which account for the monthly consumptions, the analyses should start from the single months, then they can also move up, in order, to the whole Phase II time lapse, the season and the year.

Regarding the **energy consumption** indicators to be calculated, theoretically all the ones that were calculated for Phase I should be re-calculated in this phase. However, particular relevance should be given to the normalized thermal energy, since the normalization is aimed at "eliminating" the influence of the outdoor climatic conditions, which for sure differ in two consecutive years.

Regarding the quantification of the impact on the **energy-related costs**, as anticipated in Chapter 6, the comparison should be done between the raw energy expenditures. Moreover, since the raw energy tariff changes over time, the analysis should take into account these changes and report them. Finally, the comparison should be done between the raw energy expenditures "normalized" by the energy vector's tariff of Phase I and II time lapses.

Alongside these analyses, there are two activities that can be helpful in interpreting the results. The first is to analyse the monitoring data, in order to verify if the proposed strategies (e.g. changes of the temperature set-points or HVAC operation schedules) were effectively implemented. This verification should be done by time profiles graphs. The second activity is to have another interview with the Building Manger, in order to ask if the strategies were implemented and how, if any problem or complains by the BOs occurred during the implementation and other elements that can be useful to interpret the results of the previous analyses.

8.3 Assess the impact of strategies on BOs comfort perception and behaviour

The impact of strategies on BOs comfort and behaviour should be analysed by two means. The first is based on the monitoring system, so it is a more "objective" analysis. The second is based on a self-report done by occupants – a new questionnaire. The first analysis is the assessment of the thermal conditions according to the EN 15251:2008 and EN 16798:2019 standards (CEN, 2008; UNI EN, 2019). The analysis should be performed as already described in Chapter 6. The aim, in this case, is to verify the eventual impact of the strategies on the classification of the indoor environmental thermal quality for BOs comfort.

The second activity is directly related to BOs (self-reported assessment). Similarly to what was described for the first Phase, the questionnaire can be provided by an internet survey or as a paper questionnaire, depending on which type is considered to be more convenient in terms of probable answers. Of course, the desirable answering rates would be the same as Phase I. However, whereas a low rate of answers in the first phase would have involved the questioning of continuing or not the methodology's implementation, in this phase it would only be a matter of representativeness of the survey for evaluating the strategies' impact. The questionnaire of the third Phase should be kept as short as possible, since it would be the third or fourth (depending on the season) questionnaire that the BOs have to answer. For this reason, for this research a very short questionnaire was elaborated for Phase III. In this questionnaire, some questions ask directly for information (e.g. changes of the period of the strategies' implementation in respect to Phase I); others are aimed at assessing the changes in an indirect way. In practice, some questions are the same that were asked during the Phase I questionnaire. The comparison between the two phases in this case will be indirect because the changes in the answers will be a meaning to detect the changes due to the strategies' implementation. About the questionnaire itself, of course it should be different for different BOs groups, following the same approach described in Chapter 6. For the LLC group, which is constituted by occasional visitors of the building, of course only the "direct" question can be asked (since it is not said that they experienced the building before at all).

In general, the questionnaire should be divided in three sections. The first is dedicated to **Thermal comfort** (1) and should be composed by:

~ Questions asking directly if changes occurred (and how) in the thermal sensation and the related comfort. Similarly to the previous questionnaire, the answers should be expressed using a scale. For the first question, asking if during the strategies' implementation period changes in the thermal perception were detected in respect to the previous phase, the scale should have a "minimum" which represents the maximum decrease of temperature, a mean point representing "no change" and a maximum point representing the maximum increase of the temperature. These labels should be explicit. Regarding the second question, asking for the changes in thermal comfort referred to the same period, the labels would be "maximum worsening" for the lower point, "no change" for the middle one and "maximum enhancement" for the higher one.

~ Questions asking about the thermal perception during the period of the strategies' implementation and the related comfort, using the same scales used in the Questionnaire of phase I. The answers to these questions will be directly compared to the ones gathered in the first Phase.

The second section of the questionnaire (**Awareness**) should be dedicated to the evaluation of the communication means used to educate BOs (workshops, newsletters and signs). Of course, every BOs group will be asked to express their opinion only about the means that directly involved them (Endrejat and Kauffeld, 2017). The aspects that should be asked for each communication mean are:

~ If the communication mean was noticed by the participant. The answering options should be: never saw, saw but not read, saw and read once, saw and read several times. Moreover, for each a free comment should be allowed.

~ Evaluation of the usefulness of the communication mean and the provided information. The answer should be given using a 5 point scale, in which the minimum correspond to "minimum usefulness" and the maximum to "maximum usefulness". Also in this case, a comment should be allowed for each answer.

The third section is dedicated to **Behaviour**. Similarly to the first section, a part of the questions here should ask directly about the changes (in this case behavioural changes) and a part should be a re-proposition of the questions asked in the first phase's questionnaire.

~ The first type of questions should ask if, during the strategies' implementation, the participant changed his behaviour towards a list of interfaces (e.g. thermostats, artificial lights etc.). The answer options here should be "yes" and "no". Of course, the listed interfaces should be those addressed by the educational strategies. Moreover, for each interphase a comment to specify how the participant changed behaviour should be allowed.

~ The second type of questions should repeat some of those asked in Phase I's questionnaire, based on what type of behaviour BOs were expected to change. For example, if some education was provided in order to encourage BOs to turn on artificial lights only if natural one is not sufficient, the question asking "How often do you usually turn on lights" should be provided in Phase III questionnaire also.

Finally, a space for a **comment** should be leaved at the end of the questionnaire in order to allow the participant to signal eventual problems occurred during Phase II or to advise other ways to enhance the indoor environment in his perspective.

In the following, Table 15 summarizes the questions contained in a HLC questionnaire of Phase III. Similarly to what has been done in Table 10 for each question the occupants' groups are listed. The "periods" written in brackets should be substituted in the questionnaire by the corresponding period (e.g. this July and August).

Table 17. List of questions of Phase III questionnaire and targeted occupants' groups.

Section	**Question**	**Occupants' group**
Comfort	1. During (the period of Phase II), did you perceived a change in the temperature in respect of (the period of Phase I)?	HLC, MLC
	2. In the same period, did the thermal comfort conditions changed?	HLC, MLC
	3. Please tick the circle that best represents how you felt at workplace during (Phase II).	HLC, MLC, LLC*
	4. Basing on the previous thermal sensation, please tick the circle below that best describes your comfort perception at workplace during (Phase II).	HLC, MLC, LLC*
Awareness	Did you noticed that you received some newsletters containing advices to enhance your comfort and reduce the energy wasting?	HLC, MLC
	Did you noticed the following signs positioned across the building? (list of the signs)	HLC, MLC
	Can you evaluate the usefulness of the following communication means used during (phase II) to help you enhancing your comfort and reducing the energy consumption?	HLC, MLC
Behaviour	Did you changed your behaviour towards the following interfaces during (phase II)?	HLC, MLC
	When do you usually open the windows in (season of Phase II)?	HLC
	When do you usually turn on the lights in (season of Phase II)?	HLC
	How often do you usually perform these actions when feeling thermally uncomfortable (season of Phase II)? If an action is not available (e.g. opening the window, click "Never")	LLC

[1] For LLC* means that the period to which the evaluation is referred is the time spent in the building during the visit.

8.4 Assess the impact of strategies on indoor environmental critical situations related to artworks' conservation

Analyses of the impact of strategies on indoor environmental conditions related to the conservation of artworks and fragile materials should be carried out if Phase I highlighted critical situation that brought to specific actions during Phase II. Since the aim was to solve critical situations, the best analyses to be done would be the same that detected the critical situations in Phase I. Of course, the monitoring period to be taken into account is Phase II time lapse, in which the changes in HVAC systems' operation and other eventual strategies were implemented. Particularly relevant will be the calculation of synthetic indexes like the PI. If the curator did not established tolerance intervals instead, but the will of strategies was to enhance the level of control calculated according to the ASHRAE Handbook, the same analysis should be repeated in this phase. Finally, if particular problems were detected regarding specific materials according to the UNI 10892:1999, the statistical values calculated in the first Phase should be re-calculated to appreciate the eventual changes.

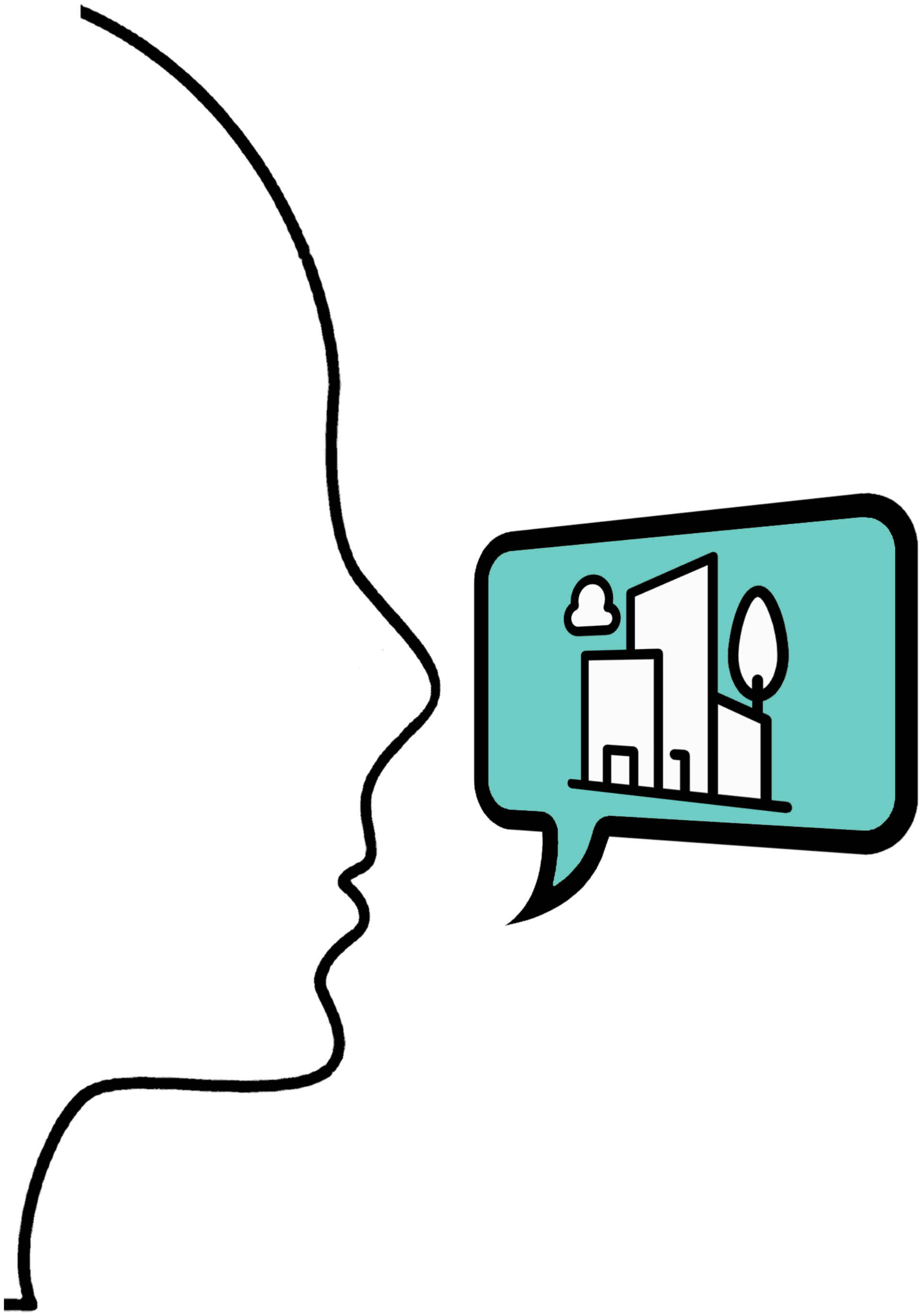
9

Conclusions about the BIOSFERA methodology's theoretical framework

This part of the thesis described the BIOSFERA methodology from a theoretical point of view. One of the most important aspects to be remarked are the reasons why this methodology was conceived for historic buildings, even if it could also be implemented in non-historic ones. The main reasons are the necessity to preserve their architectural fabric, which has to be balanced with the necessity to enhance their energy performances to reduce the energy-related operational costs and the necessity to enhance indoor environmental conditions for BOs' activities and artworks' conservation. All these objectives are addressed by zero (or nearly-zero) costly interventions, focusing only on the building operation by BOs and BMs. Another prerogative of the methodology, at least in its intentions, is the "flexibility" of the analyses that can be performed and the vast possibility to choose different solutions. In fact, only a few materials are mandatory, and the choice of the analyses to evaluate the different aspects leading to the choice of strategies is left very open based on the building's specificities and the implementer's knowledge. However, the biggest weakness of the methodology resides on the fact that the whole efficacy of strategies depends on BOs and BMs willingness to implement them. Therefore, besides the "numbers", the impact of strategies will always require a critical analysis of how they have been received and implemented. This would be particularly crucial to understand the real "occupant behaviour potentialities" for retrofitting historic buildings. In the next chapters, the implementation of the BIOSFERA methodology on real case studies will be described (Part III). Then, based on the considerations of the previous discussion paragraphs and the experience gathered by the implementation of the methodology on real case studies, the methodology will be partly revised (Part IV).

PART III

The BIOSFERA methodology applied to real historic buildings



10

The selection of case studies

The methodology presented in Part II was elaborated to be implemented on a real context. The objective of Part III of this thesis is to describe how the theoretical phases can be translated in a real context and answer to the principal research question of the study (*What are the potentialities of energy saving and indoor environmental conditions' enhancement by acting only on the way non-residential historic buildings are operated by occupants and operators?).* Case studies were chosen at the beginning among existing connections that the Politecnico di Torino's TEBE research group[1] had with suitable historic buildings' administrators. The only strict criterion in selecting the cases (in addition to the historicity of the building) was to exclude residential buildings. The phase of contacting buildings' administrators lasted a few months. At the end, eight case studies accepted to participate to the experimentation. Most of the cases (six out of eight) are located in the city of Turin and the surrounding area, i.e. in the North-West of Italy. The other two cases are located in Umbria, which is a region in the centre of Italy. From a climatic point of view, all cases are located on the Italian climatic region "E", characterized by 2101-3000 Degree Days (DD). DD are calculated as the yearly sum of the daily positive difference between the indoor temperature (fixed conventionally to 20°C) and the mean outdoor temperature (Italian Parliament, 1993). From a regulatory point of view, this classification determines the period of the year in which heating systems can be activated, as well as the daily maximum hours of operation. For climatic region "E", the heating period is from the 15th of October to the 15th of April, with a maximum operation of fourteen hours per day. About the historic period in which these buildings were constructed, there is a great variety of ages. However, since this study is addressed at investigating energy-related characteristics, it is important to highlight that all these buildings are

[1] *www.tebe.polito.it*

massive-masonry buildings. Therefore, their "passive" thermal behaviour should be comparable. Another element the selected cases have in common is the ownership, since all of them are, with a variety of specifications, hold or ruled by public administrations' entities. Looking at the analysed building functions (and therefore to the types of building occupants) the first element to notice is that all of them are multi-functional buildings, even if it was not possible for all to take into account more than one building function (and by consequence occupants' "groups"). Four out of eight cases have the same building function (museum exposition area and offices, both analysed). Also, it should be noticed that offices are present in all cases. Moreover, also considering the other building functions, similarities can be found between the way building occupant "groups" can manage and control the indoor environment. For instance, the restorers working in restoration laboratories and the museums' staff have similar energy-related control opportunities within the building (they can be defined as Medium Level of Control - MLC, according to Part II's definition). Table 18 summarizes the principal characteristics of the selected case studies (Name, Location, Historic period, Owner and Building functions) and the phases of the BIOSFERA method to which they participated. In fact, only four case studies were selected to continue with the implementation of the methodology after Phase I. The chosen case studies were: the Turin Conservatory of music, the Restoration Centre "La Venaria Reale", the Rivoli Castle and the Stupinigi Hunting Lodge. Two main reasons determined the exclusion of the other cases from continuing with the experimentation:

- **Lack of relevant data**: the Valentino Castle was not chosen to continue with the experimentation after Phase I because the energy consumptions' data (energy bills) referred to all the Valentino Castle's campus, which includes also non-historic buildings. For this reason, it was not possible to distinguish the energy consumption of the "Castle" (historic part) from the others, so it would have been very hard to assess the impact of Phase II's strategies only on the part in which they were applied. This element emerged during an interview with one of the energy managers. In fact, even if it was not possible to separate the historic building's energy consumption from the rest of the campus, it was still possible to identify the offices located only on the Castle. The participation to Phase III was decided to acquire a "control case" sample and compare answers from occupants that received the various Phase II's strategies from other occupants (the Valentino Castle ones) who did not received any energy engagement strategy.
- **Non-participation to Phase I's surveys**: the Metropolitan urban centre, the Priori Palace and the Gubbio Ducal Palace were excluded because very small percentage of occupants participated to the questionnaires, so some of the mandatory materials were not delivered.

Table 18. Case studies' summary.

Name	Location	Historic period	Owner	Building functions	Methodology implementation (phases)
Valentino castle – Architecture faculty offices	Turin	XVII Cent.	Polytechnic of Turin	Multifunctional: offices and classrooms	**I, III**
Turin Conservatory of music G. Verdi	Turin	Beginning of XX Cent. (finished in 1928)	Turin Municipality	Multifunctional: offices, auditorium and classrooms	**I, II, III**
Rivoli castle – Museum of contemporary art	Rivoli (TO)	IX Cent.	Rivoli Municipality	Multifunctional: museum exposition area and offices	**I, II, III**
La Venaria Reale restoration centre	Venaria Reale (TO)	XVII Cent.	Italian State	Multifunctional: restoration laboratories and offices	**I, II, III**
Stupinigi hunting lodge	Stupinigi (TO)	XVIII Cent.	Ordine Mauriziano	Multifunctional: museum exposition area and offices	**I, II, III**
San Bonaventura block's building – Metropolitan urban centre	Turin	XVII Cent.	Turin Municipality	Multifunctional: conference rooms and offices	**I**
Priori Palace- Umbria national gallery	Perugia	XIII Cent.	Perugia Municipality	Multifunctional: museum exposition area and offices	**I**
Gubbio ducal palace	Gubbio (PG)	XV Cent.	Cultural Heritage Ministry	Multifunctional: museum exposition area and offices	**I**

In the following, three chapters will be dedicated to the implementation of the BIOSFERA methodology in the four case studies that were chosen for the complete experimentation. The first chapter (Chapter 11) will be dedicated to a detailed description of how the theoretical phases described in phase II can be translated in a real implementation. The chosen case study was the Conservatory of Turin. The second Chapter (12) is dedicated to the description of the methodology's implementation in the other three case studies. However, in this chapter, besides a synthetic description of the implementation, the aim is to highlight a few "focus topics" that were identified for each case, in order to show how the methodology was adapted to different contexts and necessities. The third and final chapter (13) is dedicated to acquire a general "picture" of the impact that the methodology had on the four case studies, comparing and discussing energy and BOs – related results.

11

Implementing the BIOSFERA methodology in a real context

This chapter is dedicated to the description of how the BIOSFERA methodology can be implemented in a real case study. Since the methodology was conceived to be applied differently in different contexts, this chapter is aimed at offering a detailed description of the procedural approach. The aim is to highlight how data can be gathered, analysed, interpreted and translated. The chosen case study, for several reasons, is the Conservatory of Turin. First, this case had two BOs typologies (HLC and MLC). Second, because the building undergone a major energy retrofit intervention which caused an unexpected increase of the energy consumption. This phenomenon offered the possibility to highlight how the methodology can be used as a multi-dimensional diagnostic instrument, as well as an opportunity to enhance building's performances. Third, the two BOs groups had very different energy control opportunities and occupied two different parts of the building; one quite "antiquated" (the non-retrofitted part) and one very "technological" (the one just retrofitted). In this context, it was interesting to analyse to what extend the two BOs groups related and acted in these two spaces inside the same building, and how a more "comfort oriented" technological infrastructure do not always performs as expected if not managed properly. Lastly, in this case study the methodology had, in general, great results, and when it did not the causes were identified.

11.1 The Giuseppe Verdi Conservatory of music

The Turin Conservatory of music is located in the city centre (Piazza Bodoni, 6). The building was designed by Giovanni Ricci and inaugurated on the 8th of May 1928. In 1984, a fire damaged the concert hall that was closed and restored in 1986. In 2015, the building undergone an important energy retrofit and architectural re-arrangement of the ground floor. The principal architectural interventions were the

Figure 11. Timeline of the experimentation decided for the Conservatory of Music.

positioning of an elevator and the adjunction of a mezzanine, which allowed the insertion of six new classrooms. The energy retrofit was carried out only in the classrooms' area. The administration of the Conservatory agreed to take part on the experimentation of the BIOSFERA methodology also to have insights about the possible reasons why, after the interventions of 2015, the energy consumptions (especially electric energy) increased considerably- the so-called rebound effect (Agbota, 2014).

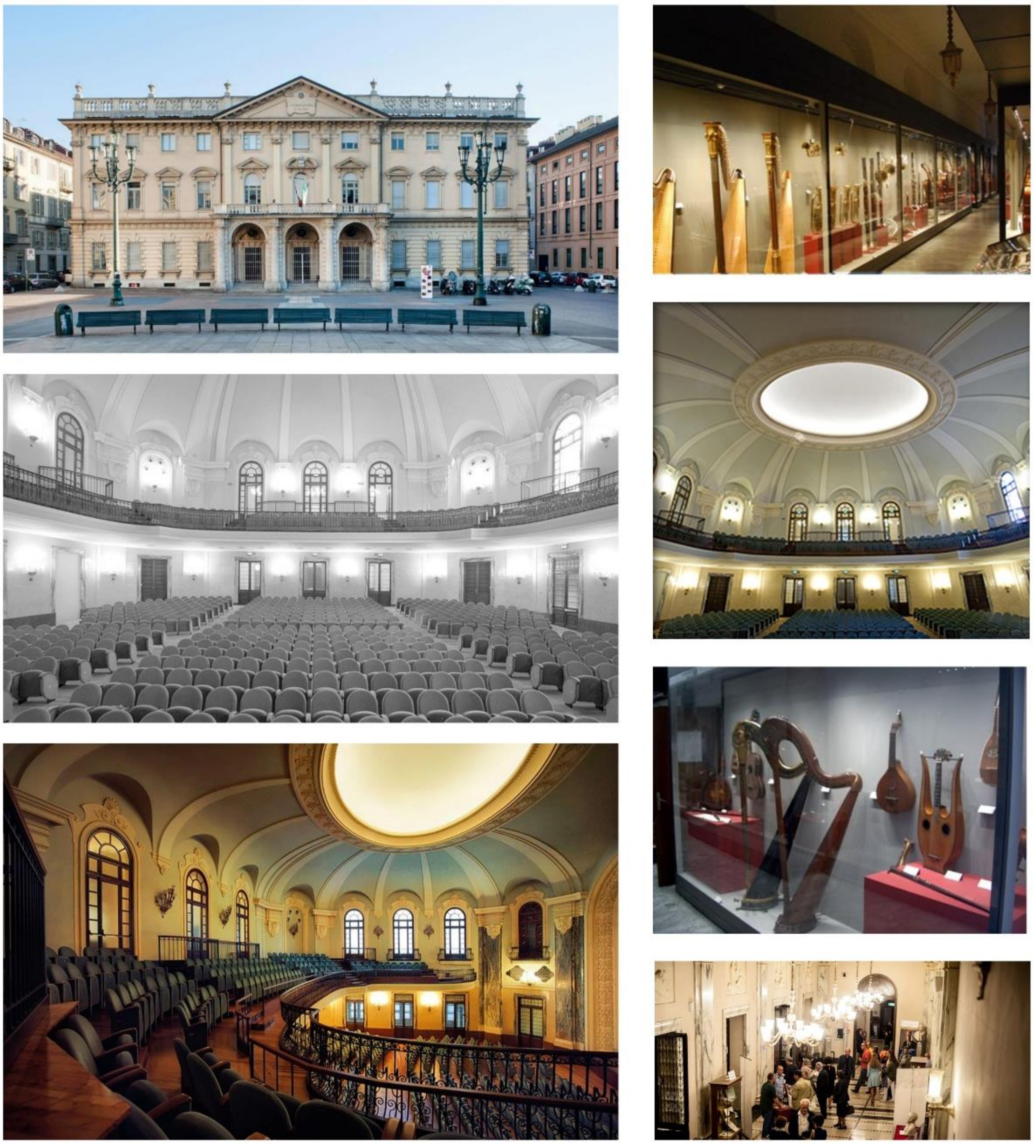


Figure 12. Views of the Conservatory of music: the building façade, the ancient instruments' gallery, the auditorium and the hall.

In fact, even if part of the energy intervention was the substitution of classrooms' HVAC systems and the insertion of the cooling system and the mechanical ventilation (which were not present before), the size of the energy-use increase was not justified and required better insights. Two persons from the administration and two technicians were actively involved in the experimentation. In particular, from the administration the Director of the Conservatory participated in the first meeting and was always very participative in every stage, while a

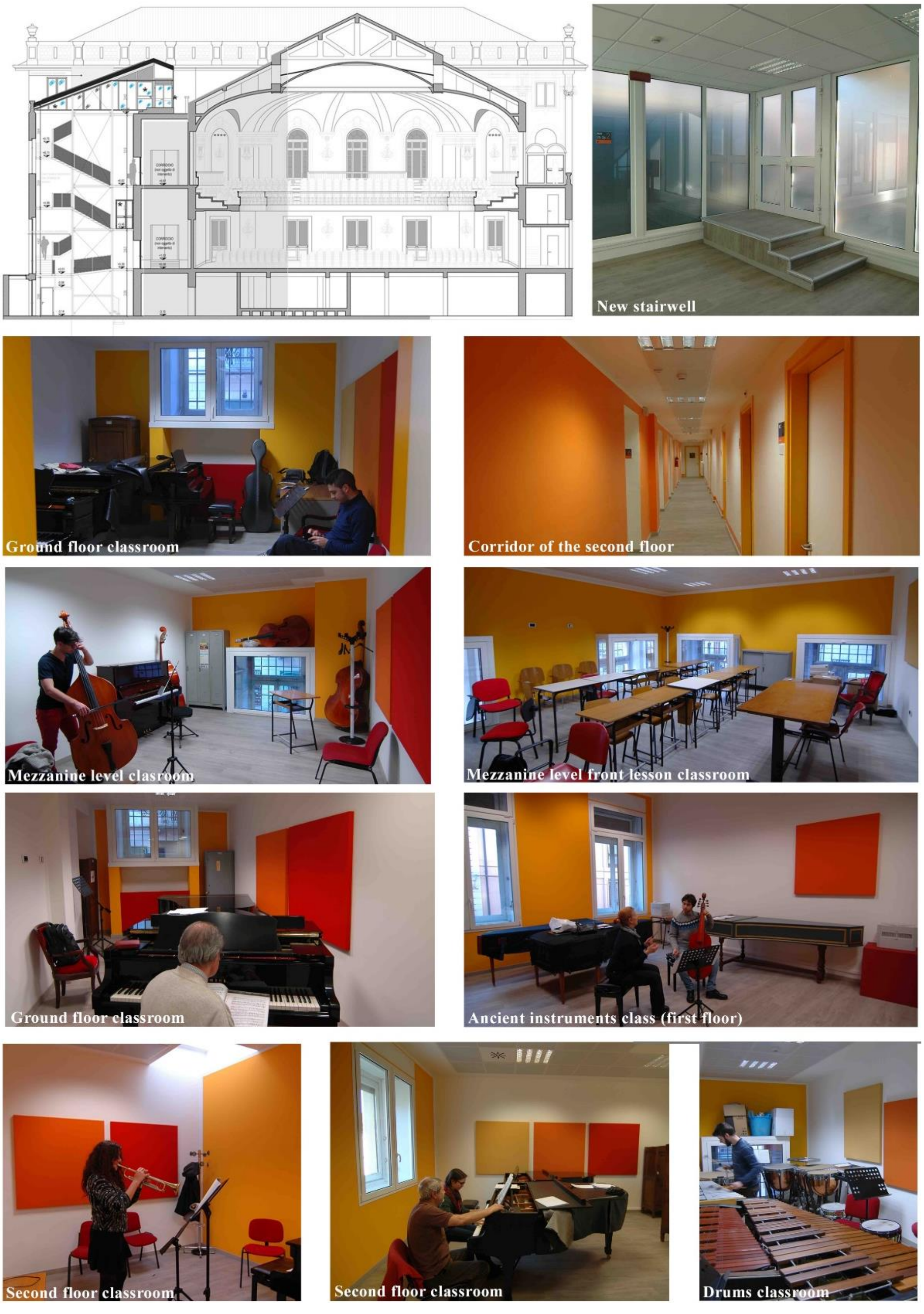


Figure 13. Photos of the interventions made in 2015 in the classroom part of the conservatory.

permanent employed (a maintenance manager), was the reference person to which information and clarification could be asked. Regarding the BMs category, the Conservatory is not provided with an energy manager: two technicians from two external firms are responsible of HVAC systems' operation and electric appliances' management. However, for singular problematic situations, an external consultant is usually involved. For the methodology implementation, he was involved in the environmental monitoring and participated to the meeting for deciding the strategies to be applied in Phase II. During the first meeting, to which only the two participants of the administration took part, an approximate timeline for the implementation of the methodology (shown in Figure 11) was established. Figure 12 shows photos of the Conservatory. Figure 13 shows pictures of 2015's interventions. In the section drawing, the new stairwell (with the insertion of the elevator) is shown (on the left), as well as the new mezzanine level that was introduced by dividing the height of the ground floor. The photos show different areas that were changed during 2015's interventions. An important point to be highlighted is how the windows of the ground floor have been "divided" between the ground floor and the mezzanine level. Since the historic windows were protected by specific restrictions (and could not be substituted), in all retrofitted classrooms (ground-floor, mezzanine level, first and second floor) a new PVC window was positioned inside, on the windowsill. Another element to be highlighted is that on the second floor classrooms have different orientations. More precisely, those that correspond to the main façade face west, while the others, facing East, do not have windows, but only small skylights.

11.2 Phase I

Phase I of the experimentation was implemented during Summer season 2017 and Winter season between 2017 and 2018. In the following, the gathered materials and the performed analyses will be listed following the approach described in Part II of this thesis.

11.2.1 BMs' energy-related management

At the Conservatory there is not a unique building manager dealing with all aspects related to the energy management of the building. Therefore, three people were interviewed to gather all the required materials and information. In the following, all the information acquired in the semi-structured interviews will be listed and the people that were involved for each point will be made explicit, in order to show how this kind of studies can be stratified and complicated in a real context.

~ ***General information.***

This information were mainly provided by the maintenance manager. The building is characterized by three activities, which correspond to three main areas of the building. First, the didactic activities, mainly performed in the classroom area. Second, the office work, which is performed in the office area. Third, the music performance (concerts and rehearsals), which is done mainly in the auditorium. These three activities are located, as previously mentioned, in three different areas of the building and are characterized also by different occupation schedules and different type of energy-relevant interactions that people can have with the building. Of course, all these areas are linked by a common area and served by the same distribution elements (like the main hall, the corridor and the stairs). The conservatory hosts also a small exposition of historic instruments in the corridor of the first floor. The total conditioned floor area is 3800 m^2.

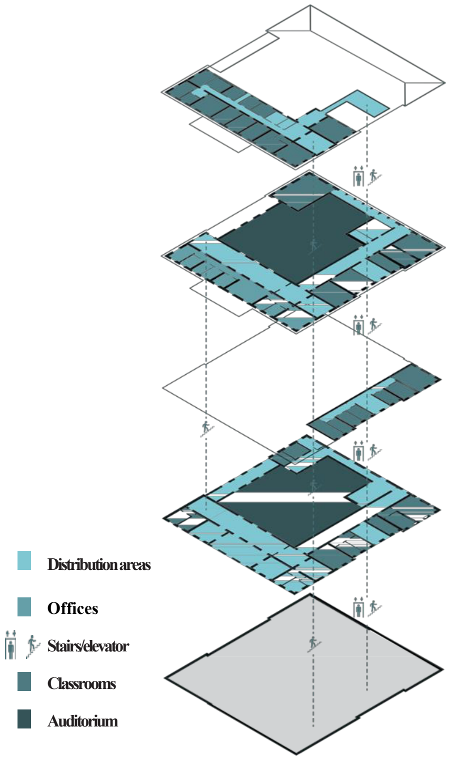


Figure 14. Axonometric projection of the Conservatory and division in functional areas.

~ ***Environmental monitoring.*** The conservatory is not provided with a continuous environmental monitoring system. Nevertheless, an external consultant was hired by the administration to conduct a monitoring campaign at the end of Summer 2017 (September) and in November 2017 in order to have an idea of measured indoor environmental conditions inside classrooms, due to a series of complains that occupants made about indoor air quality, especially in the mezzanine level. Regarding the small expositive part (the gallery of historic instruments), the indoor environmental conditions are not monitored, but all instruments are conserved in proper glass expositive cases. The data monitored by the consulting engineer were provided afterwards to perform the analyses. Table 19 lists the characteristics of the monitoring campaign that was performed in September and November 2017. Of course, the best would have been to have the "winter" monitoring during the planned period of Phase I. However, the consultant was hired separately from the experimentation, so he performed it autonomously from the methodology's implementation.

Table 19. Conservatory of Turin. Principal information about the indoor environment monitoring.

Sensors' number and location	Three sensors were positioned in three classrooms (6A, 14 and 18). The location was chosen based on occupants' complains. In fact, most complains came from the mezzanine level (especially classroom 6A) and from the second floor (in which 14 and 18 classrooms are located). The position was about 1,20 m from the floor, on the wall, having previously verified that the point was not affected by AHU air flow or other sources that could influence the registration.
Monitoring period	The monitoring periods were: -From 12/11/2017 to 18/11/2017 for winter -From 15/09/2017 to 19/09/2017 for summer
Monitored environmental parameters	Temperature and relative humidity.
Sensors' characteristics	Registration time-step: 5 minutes Sensor characteristics: KIMO KH50 model. Nominal uncertainty ±0.1°C, ±0.1% RH. Registration range (Temperature: -40°C >70°C).

~ ***Energy-related control opportunities.*** This information were provided partly by the maintenance manager and partly by the two external technicians, which were responsible of HVAC and electric systems' operation respectively. Based on the three main activities and related areas of the conservatory, Tables 20-26 list all relevant characteristics related to structural and technological interfaces. However, it should be highlighted that classrooms' tables will distinguish further between classrooms of the different floors, which are characterized by partially different control opportunities, both in terms of structural and technological interfaces, since also HVAC systems partially differ in these areas. For each area, a few comments provided by the interviewed people could be included to highlight problems or specifications. External doors are not listed in the different areas since they are part of the common spaces. There are two external doors. The main entrance is usually closed unless there is an event in the auditorium, while the secondary entrance is always open during the horary in which the Conservatory is open. These doors are managed by the coadjutor staff.

Table 20 shows the structural interfaces available in classrooms. As additional information to those provided in the table, the maintenance manager reported that BOs (especially in the mezzanine level) usually complain about the impossibility to open windows and operate external blinds. In particular, on the ground floor and the mezzanine, BOs complain about poor air quality. Not having the possibility to open doors (since too much noise would be caused in corridors and other classes due to instruments), the window remains the only way to solve air quality problems. Nevertheless BOs are not allowed to operate windows. Moreover, opening the new windows on the ground and mezzanine floors would provoke too much noise in the classroom immediately above or below, since they are only separated by the new windows (they share the original external window, as partially visible in Figure 15). At the same time, the mechanical ventilation should work. Nonetheless, its operation is very reduced due to a problem that took place during the design phase. In fact, according to the HVAC design, classrooms' doors should have been equipped with aeration grids, which were necessary for the air flow to be inlet in the room by the mechanical ventilation and expelled by the grid (due to the pressure difference). During the realization phase, sound-insulating doors were installed, which were not provided with aeration grids. Another problem, which entails the mezzanine classrooms, is that in the design phase the mechanical ventilation (and particularly the air-flow) was dimensioned considering an occupancy of two people per room; however, very often these classrooms are used by more than two people, so the concentration of pollutants cannot be totally disposed by the mechanical ventilation system.

Figure 15. The new PVC window (on the front) and the original window (behind). Photo took on the ground-floor (the external window is shared with the mezzanine level). The sign asks to occupants to avoid operating the window due to the presence of mechanical ventilation.

Complaints were often registered also about the impossibility of operating the external blinds, especially from BOs who study or teach on second floor's classrooms and especially in those facing west. In fact, not having contextual shadowing from trees or other buildings nor external or internal blinds, the overheating and glare of those classrooms (in the afternoon) was very frequent.

Table 20. Structural interfaces characteristics - CLASSROOMS.

Structural interface	Who controls it?	Information to acquire
Windows	Not operable	During the 2015 renovation works, a new PVC window was installed, to double each old (and original) one, since the external "appearance" of the Conservatory was protected by a specific restriction that forbids the substitution of windows. Windows are theoretically operable in all floors except of the mezzanine, in which they are locked for security reasons. However, classrooms' BOs are not allowed to open neither the old nor the new windows due to the presence of the Mechanical Ventilation (a sign in each classroom forbids it), and on the ground and mezzanine floors also for acoustic reasons.
Internal doors	BOs	Doors of classrooms are PVC sound-insulating doors in order to avoid too much noise outside classrooms. For the same reasons, doors remain usually closed, especially during classes.
External blinds	Not operable	The building is provided with roller blinds. Nevertheless, they are quite old and they do not work well. For security reasons, the administration forbids BOs to operate them. Moreover, the controller of the roller is positioned between the new and the old window. Since the new window should not be opened, external blinds cannot be operated.
Internal blinds	Not present	Internal blinds of whatever type are not present, except in two classrooms on the first floor.

As shown in Table 21, classrooms at different levels are provided with different terminals for heating and cooling. Nevertheless, the general temperature set-points are always set remotely by the external technicians. Therefore, when complains happen, the administration has to reach the technicians and ask for changes. While the fan-coils of ground floor classrooms have a range of control for the temperature set-point, the control range possible for the other classrooms is very wide, which empower the occupants with a great degree of freedom in setting their preferred indoor conditions, but could be very dangerous in terms of energy efficiency. Moreover, the temperature set-points of the mechanical ventilation result quite high in winter and extremely low in summer. In order to justify it, technicians explained that the summer set-point was "cool" in order to ameliorate the perception of the air quality, especially in the mezzanine level, while the winter set-point was "warm" because occupants complained about the cold air flow on their backs.

Table 21. Technological interfaces characteristics – HVAC CLASSROOMS.

Classroom Floor	HVAC system	Terminals	Who operates and controls it?	Set-points and operation schedule
Ground Floor (GF)	Heating and cooling	Fan-coils	BM: only general set-points and operation schedules (controlled remotely) BOs: Controls on the terminal: on/off, air flow (1-3), cooling or heating (dummy), temperature (±2°C in respect to the general set-point)	Summer Tset-point=24°C, Operation= 7:00-19:00 Winter Tset-point=20°C, Operation= 7:00-19:00
	Mechanical ventilation	Air vents	BM: AHU set-point and operation schedules controlled remotely. No control to BOs	Summer T= 20°C, RH= 50% Operation= 7:00 -19:00 Winter T=23°C RH=50% Operation=7:00-19:00
Mezzanine First and Second floor	Heating and cooling	Radiant ceilings	BM: only general set-points and operation schedules (controlled remotely) BOs: Controls on thermostats in each room: temperature. No range of T control, but the system reset and set the general set-point (see next column)	Summer T set-point= 24°C (reset if T set >30°C or <20°C), Operation= 7:00-19:00 Winter T set-point =20°C (reset if T set >26°C or <17°C), Operation= 7:00-19:00

Table 22. Technological interfaces characteristics – Artificial Lighting and other systems- CLASSROOMS.

Technological infrastructure	Information to acquire	Who controls it?
Artificial lighting	Mainly fluorescent lights. Manual control (no sensors nor dimmers).	BOs, completely freely.
Dehumidifier	Two dehumidifiers positioned only on the ancient instruments' room, controlled by the harpsichord professor based on instruments' intonation (no monitoring).	Harpsichord professor.

Offices, which are located on the first floor, are naturally ventilated and did not undergo 2015's interventions. Regarding the cooling system, the maintenance manager reported that, since there is one appliance for each office, BOs have to deal with their colleagues' preferences, which represents an element of contention.

Table 23. Structural interfaces characteristics - OFFICES.

Structural interface	Who controls it?	Information to acquire
Windows	BOs	The offices did not undergone the interventions of 2015. Therefore, BOs still operate the original windows, which are single-glasses + wood frame windows. The operation is free (no fixed rules of opening).
Internal doors	BOs	Doors are wood + glass. Users can operate them without any restriction or rule.
External blinds	BOs	Offices are provided with the original roller blinds. However, differently from classrooms, occupants are allowed to operate them, even if most of them do not do it because several ones are broken or unsafe (the maintenance manager reported it).
Internal blinds	BOs	Offices are provided with internal blinds (several types), all operable by BOs.

Table 24. Technological interfaces characteristics – OFFICES.

Technological infrastructure	Information to acquire	Who controls it?
Heating system	Ambient terminals: Cast iron radiators (no thermo-valves). Temperature set-point= 22°C. Operation: 7:00-19:00.	Settings of the heating system are handled by the technician.
Cooling system	Multi-splits controlled manually directly by office occupants. No restriction (or advices) for temperature settings nor operation schedule.	Only BOs.
Artificial lighting	Mainly fluorescent lights. Manual control (no sensors nor dimmers).	BOs, completely freely.

The auditorium is differentiated by the other spaces because it is used also for concerts during the evening, so it is opened (and conditioned) for a longer time. However, at the moment of the interview, the AHU operation schedule was not programmed based on concerts (which are not all evenings).

Table 25. Structural interfaces characteristics - AUDITORIUM.

Structural interface	Who controls it?	Information to acquire
Windows	Not operable	Windows are original (single glass + wooden frame) and not operable.
Internal doors	BOs	Doors are wood + glass doors. They can be operated by BOs but they are usually closed (standard position), in order to avoid disturbing the activities inside (both during concerts and classes or rehearsals).
External blinds	Not present	
Internal blinds	Not present	

Table 26. Principal information about technological interfaces – AUDITORIUM.

Technological infrastructure	Information to acquire	Who controls it?
Air Handling Unit (AHU)	The system is an air-conditioning. Set-points and operation: Summer T set-point= 24°C UR=50%, Operation= 7:00-24:00 Winter T set-point=22°C, UR=50% Operation= 7:00-24:00	The system is totally operated by the technician. The control is remote.
Artificial lighting	Mainly fluorescent lights. Manual control but not for single appliances, for groups (no sensors nor dimmers).	Coadjutor staff

~ ***Energy-consumption materials.*** The building is not provided with energy consumption's specific monitoring systems, so the only available materials were energy bills (electric energy and natural gas). Energy consumption and costs data from bills were available and provided. The available data were from 2013 to present. However, until June 2016 the actual energy bills were not available. Therefore, from 2013 to June 2016 the only available data were monthly (total) electric energy consumption (or gas) and the total cost. Therefore, for example, it was not possible to distinguish the evolution of raw energy tariffs.

~ ***Occupant-related information***. Following the information provided in the first part of the interview, two main groups of BOs were identified. First, all classrooms users (professors and students). Second, office workers. In respect to the explanations in Chapter 6, the first were classified as MLC, while the second were classified as HLC. The sample size quantification for the total number of classroom occupants is challenged by the flexible frequentation of the Conservatory by both professors and students. In fact, depending on the instrument, the course, the age and other aspects, they could spend from 1 hour to 20 hours per week at the conservatory. Moreover, the number of students was not provided. The total number of professors was around 100. It should be noticed that, differently from the other universities, at the conservatory professors do not have their office, so they go to the building only for classes. About the offices (administration, secretary etc.), the employees are 10 people.

11.2.2 Energy consumption assessment

As previously mentioned, the energy-related analyses were based on electric energy and natural gas bills. Data from bills were available from 2013, even if the actual bills were available only starting from June 2016. Before entering the analyses as described in Chapter 6, in the following, a number of graphs show the energy consumption trend for both energy carriers. This analysis was important to assess the evolution of the building's energy consumption before and after the energy-retrofit operation of 2015. In fact, as anticipated in the first paragraph of this chapter, the main reason why the administration decided to take part to the BIOSFERA methodology's experimentation was that the energy consumptions and related costs after the renovation were too high.

Figure 16 shows the trend of electric energy consumption before and after the renovation. In particular, it shows the total energy consumption of a year, as a specific value, and the relative cost, expressed in Euros. In 2016, the electric energy consumption increased by 27% in respect of the average of the consumptions between 2013 and 2015. In 2017, the electric energy consumption increased by 44% in respect to the same years. In terms of electric energy costs, extracted from bills, in 2016 the electric energy costs increased by 16%, while in 2017 they increased by 37%, always in respect to the average of the years before the interventions. Possible causes of these trends after the renovation works were the insertion of the cooling system and the mechanical ventilation, which require more electric energy. However, an increase of about 40% in the second year could not be justified by the new end-uses, especially because the total floor area supplied by these new services is less than half of the total floor area of the building. For this reason, it was important to assess how HVAC systems were operated by the technicians and the occupants (e.g. thermostats' operation, temperature set-point and schedules).

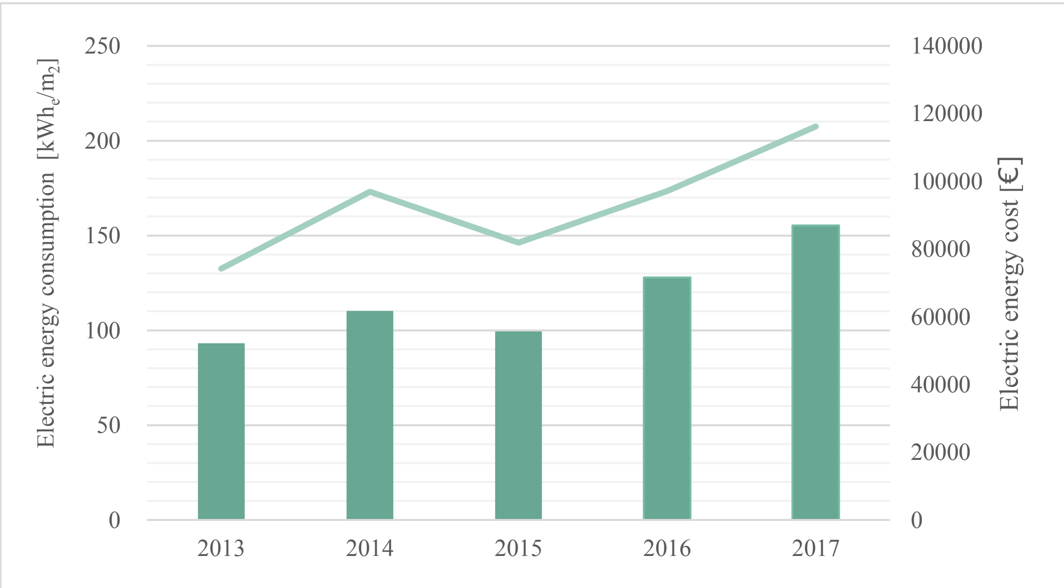


Figure 16. Conservatory of music. Yearly electric energy consumption (specific) and cost. Renovation works were conducted between October 2015 and January 2016.

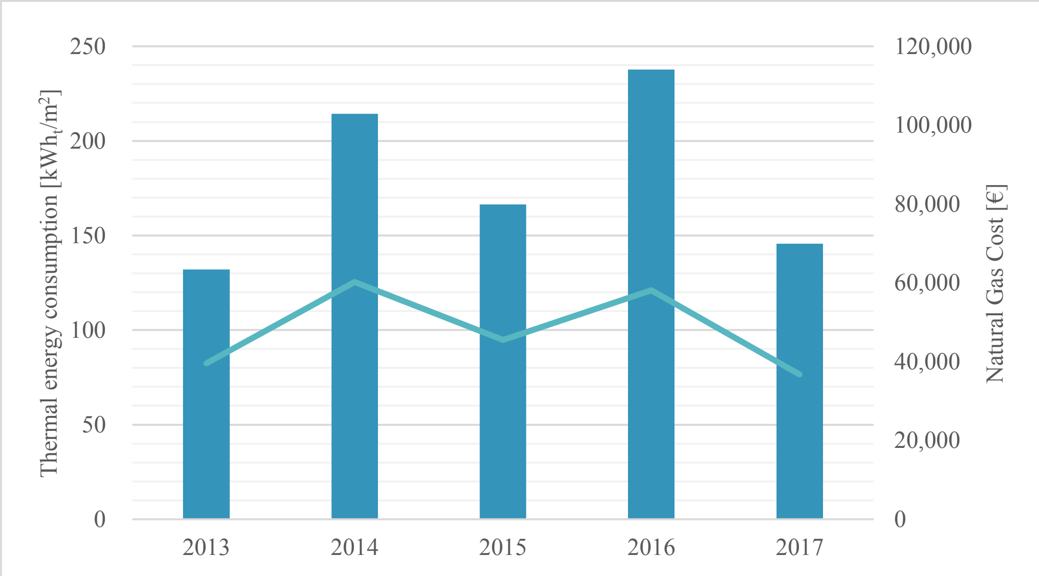


Figure 17. Conservatory of music. Yearly thermal energy consumption (specific) and cost.

Figure 17 shows the trends of thermal energy consumption (natural gas) and related costs before and after the renovation works. Also thermal energy consumptions increased immediately after the end of the renovation works. In fact, in 2016, natural gas consumption increased by 33% (related costs increased by 20%) in respect to the average of the previous three years. In 2017, instead, the natural gas consumption decreased by 15% (related costs decreased by 24%). The increase of natural gas consumption in 2016 is particularly not expected, since the former heating system in the classroom part was substituted by a new and more efficient one. Moreover, an insulation layer was inserted in the internal side of classroom walls and the new PVC windows were inserted in order to enhance the building's "passive" performances. The technicians justified the natural gas increase of use in 2016 by the fact that in the very first months after the renovation the system had to be started and optimized, which normally cause a phase of energy wasting. At the same time, it should be noticed that 2017's consumptions were not particularly different from 2013's and 2015's one, so based on the interventions that were done, there could probably be room for more savings. As previously mentioned, several reasons can be hypothesized to explain the general increase of both energy consumptions and costs. However, the fact that energy consumptions increased also in 2017 in respect to the previous year (about 20%) allows thinking that most of the reasons for the energy use increased should be searched in the building operation. In order to support this hypothesis, Figure 18 below shows the mean monthly temperature of the years that were object of analyses (all outdoor data of the present work were gathered from the regional agency for environmental protection- ARPA[2]). As shown, 2016 and 2017 did not differ much in outdoor climatic conditions in respect to the previous years. In particular, the outdoor

[2] *http://www.arpa.piemonte.it/*

temperatures did not constitute an objective reason for the electric energy use increase in 2017 in respect to 2016.

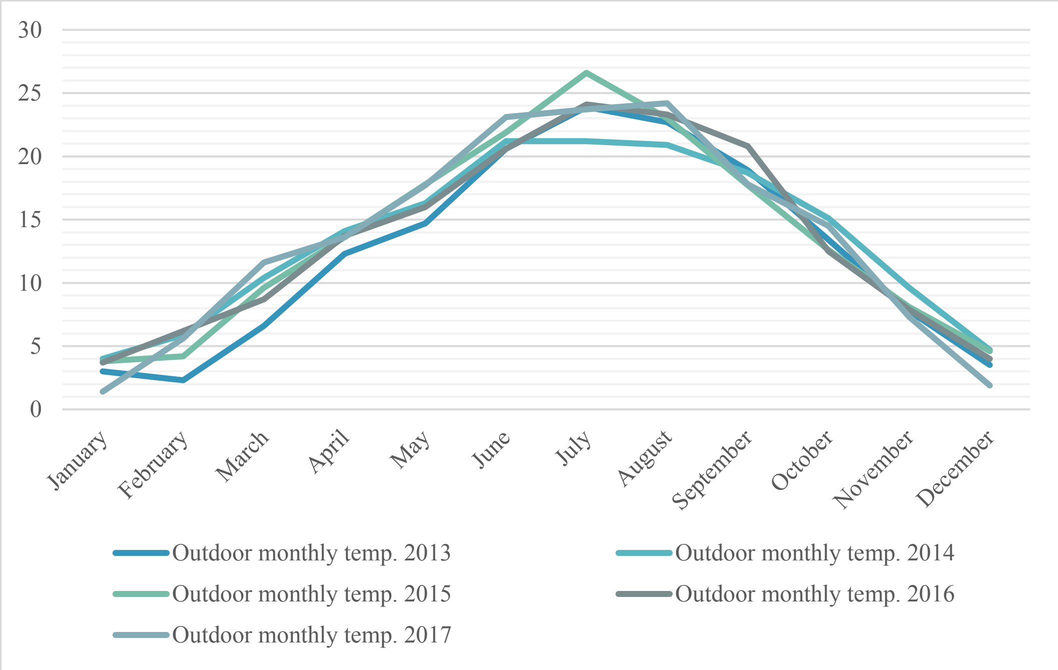


Figure 18. Comparison between monthly average outdoor temperatures.

Table 10 lists relevant indicators about the yearly energy performance of the conservatory. EP tot represents the primary energy calculated considering both the electric energy and the natural gas energy consumptions. Electric energy was not normalized by degree days because even if the cooling system usage depends on outdoor conditions, the electric energy used for this end use could not be divided from other non-climatic-dependent end uses such as artificial lighting. Table 27 lists relevant data about yearly energy-related expenditures referred to the same years. About the raw energy tariffs, they are not available until June 2016, not having the energy bills, but only cumulative data on a excel sheet. However, the most important data is the raw-energy tariff of 2017 and beginning of 2018, which refer to the periods of summer and winter of Phase I of the methodology, since they will be used to compare energy consumptions registered in Phase I with the ones registered in Phase II. In 2017 and beginning of 2018, the raw-energy tariff for electricity was 0.08 €/kWh, while for natural gas the raw-energy tariff was 0.23€/smc.

Table 27. Energy performance indicators across several years before and after the renovation (including Phase I of the methodology).

	EPH [kWh/m²]	EPTOT [kWh/m²]	EE [kWh$_e$]	EE [kWh$_e$/m²]	TE [kWh$_t$]	TE [kWh$_t$/m²]	TE$_N$ [kWh$_t$/DD]
2013	139	364	354272	93	501516	132	178
2014	225	492	419040	110	814296	214	348
2015	175	415	377956	99	632555	166	251
2016	249	559	485852	128	902718	238	350
2017	153	529	590156	155	553127	146	216

Table 28. Energy-related costs gathered from bills across several years before and after the renovation (including Phase I of the methodology).

	Electric energy expenditure	Natural gas expenditure	Total energy expenditure	Total energy expenditure
2013	74,216 €	39,546 €	113,762 €	29.94 €/m²
2014	96,974 €	60,191 €	157,165 €	41.36 €/m²
2015	81,845 €	45,527 €	127,373 €	33.52 €/m²
2016	97,161 €	58,090 €	155,252 €	40.86 €/m²
2017	115,676 €	36,737 €	152,413 €	40.11 €/m²

In the following, analyses will be dedicated to **Phase I** - summer and winter seasons, which will be used in Phase III to compare the energy consumptions in the pre-test and test (phase II) periods.

Summer energy consumption's analyses

Phase I of the methodology in summer season took place between June and September 2017. In the following, graphs describe the energy consumptions for each energy carrier considering the period of June-September 2017. Before entering the analyses dedicated to summer 2017, Figure 19 shows the **electric energy consumption** of this period from 2013 to 2017. This graph is particularly relevant to hypothesize the reasons of the yearly energy consumption's increase after 2015's renovation. In fact, in 2016 the electric energy consumption in summer months is not much different from 2013 and 2014. This means that probably the insertion of the cooling system in the classroom area did not affect much the electric energy consumption per se. In addition, the fact that in summer 2017 the electric energy consumption increased by 19% in respect to 2016 support the cause previously hypothesized, namely an improper systems' operation.

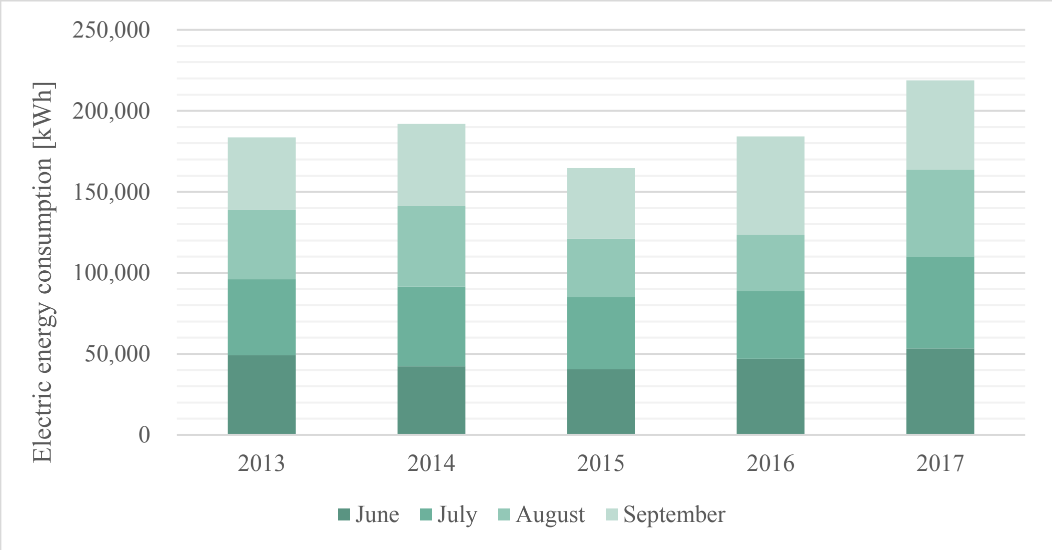


Figure 20. Conservatory of music. Electric energy consumption during summer months, from 2013 to 2017.

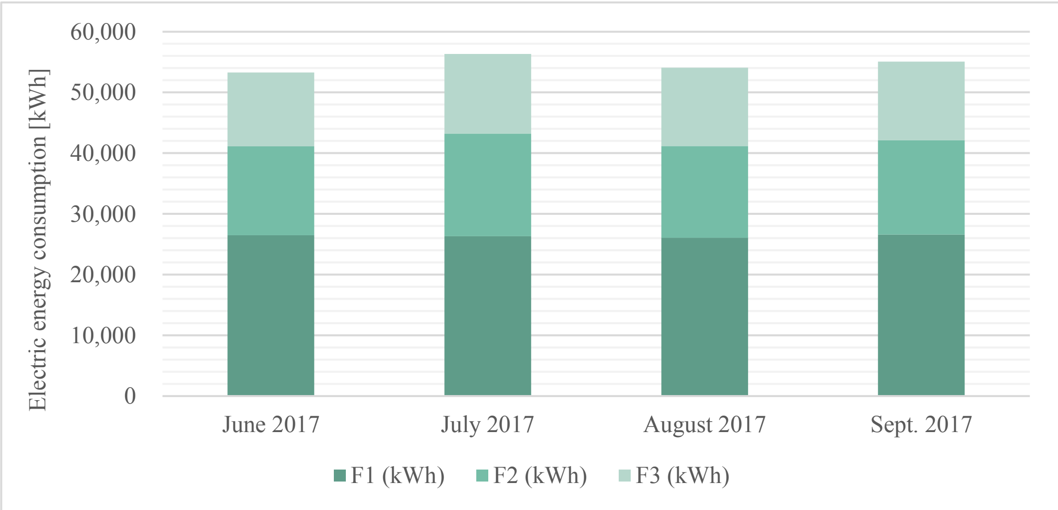


Figure 19. Conservatory of music. Electric energy consumption during summer time Phase I, divided by F1, F2 and F3.

Focusing on phase I of the methodology, Figure 20 shows the electric energy consumption in three different time slots, which correspond to different raw energy tariffs. F1 corresponds to the consumption during daytime, F2 to early night time and F3 to night. The graph shows that the consumptions in F2 and F3 (which correspond about to 19:00 to 7:00 in the morning), if summed, are about the same of F1 consumption, which is quite surprising considering that the conservatory is open only between 8:30 and 19:00, except for the soirée at the auditorium for concerts. One of the possible causes of this consumption during night time are the external lights of the conservatory that illuminate the whole building. A possible strategy here would be to reduce the amount of light appliances switched on after a certain horary in the night (e.g. after 1:00). However, this is not always possible depending on the configuration of the electrical system, which could not allow to switch off only a part of bulbs. In fact, according to the technicians, this strategy would require a major intervention on the system, which is not contemplated in the BIOSFERA methodology itself, since it would require not only an “operational” strategy, but a proper intervention on the electrical system.

Figure 21 shows the electric energy costs during Phase I (summer 2017). The graph shows that the incidence of raw-energy costs is generally less than 50% of the total amount. The “other costs” correspond to the expenditures described in Chapter 6. The major fact to be highlighted in this graph (as well as the previous one) is that the electric energy consumption and the related costs remained almost unaltered during August, which is the “holiday” month. In fact, in August the conservatory is closed for two to three weeks (or opened only occasionally for single soirées or concerts). This means that also in this period no electric devices were switched off also during unoccupied times.

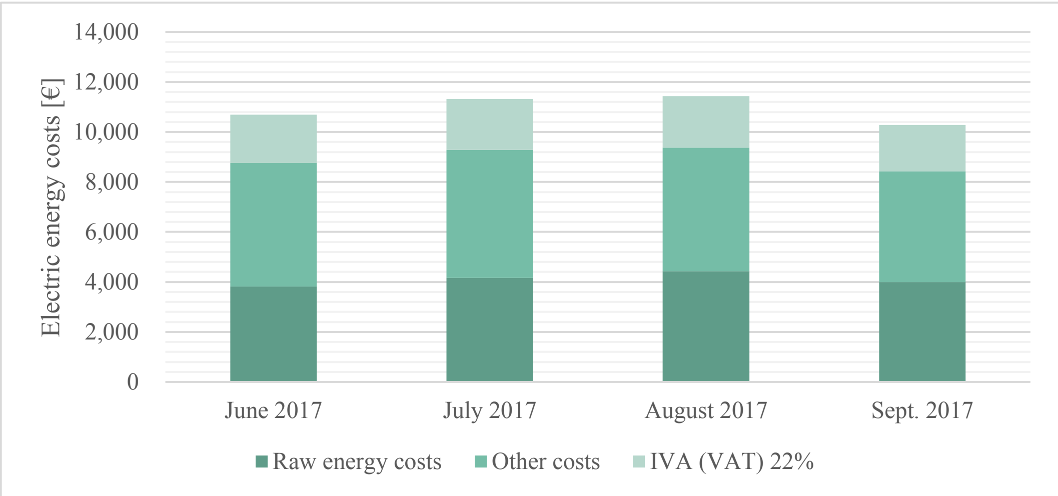


Figure 21. Conservatory of music. Electric energy costs (divided per type) in Phase I - summer.

In the following, the same analyses will be repeated also for **natural gas** consumption. Unfortunately, it was not possible to perform the same analyses shown for electric energy consumption, comparing monthly consumptions across several years (from 2013 to 2017). In fact, monthly bills were not available between 2013 and 2015 (only an excel sheet with total amount of consumption and costs), and looking at the values it seems that in most cases the value of consumption is not referred to the current (or just passed) month, but it corresponds to an adjustment of previous months. In fact, several times the spring months registered “zero” consumption, then in June or July a relatively high consumption was charged. 2016’s natural gas bills were available. However, similarly to the previous years, it seems that the consumptions do not correspond to the “exact” month. In fact, as shown in Figure 22, only September registered an energy consumption

consumption, which is not realistic. Similarly, for September 2017 no natural gas consumption was registered.

About costs, similar considerations can be done. From the analyses shown in Figure 23, it seems that the account of natural gas consumption and related costs

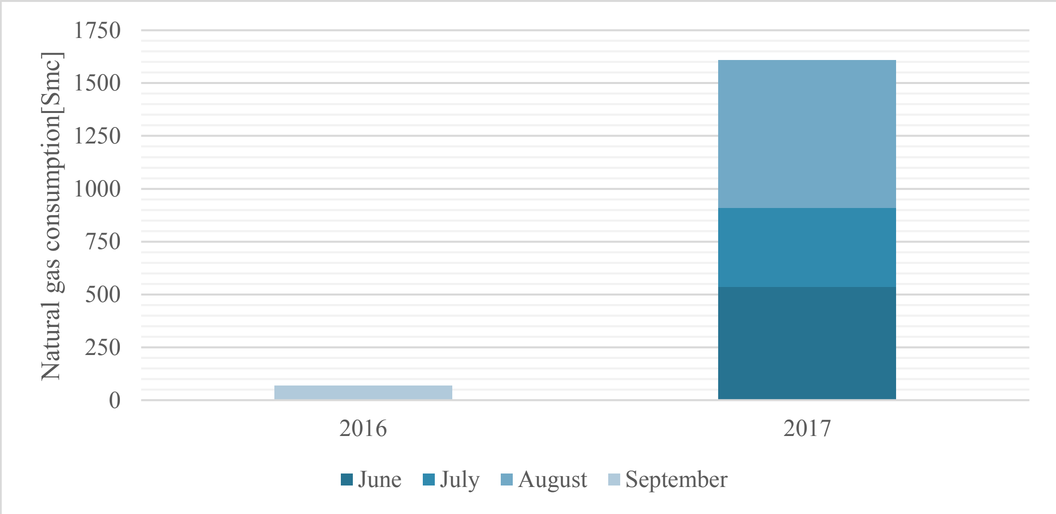


Figure 22. Conservatory of music. Summer natural gas consumption after renovation.

are not month wise. Anyway, it should be noticed that even if no raw energy costs were accounted, taxes and VAT were charged.

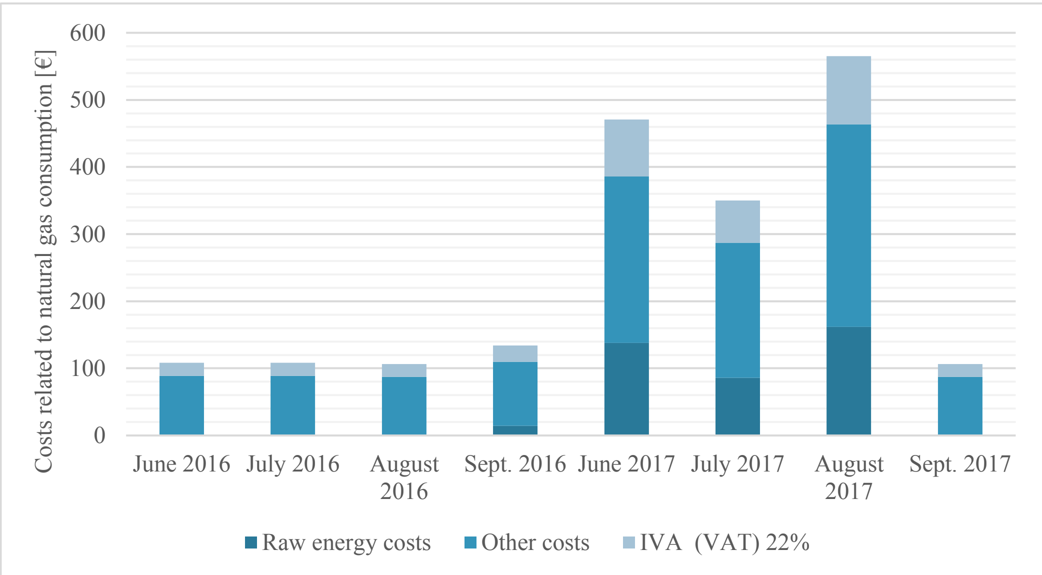


Figure 23. Conservatory of Turin. Natural gas related costs. Phase I- summer.

Winter energy consumption's analyses

Figure 24 shows the electric energy consumption of winter seasons from 2013 to 2018. The graph confirms the same trends already shown for the annual consumptions. In fact, in the winter season 2016-2017, which was the fist after the renovation works, the electric energy use increased by 66%, while in the following season (which corresponds to Phase I implementation of the BIOSFERA methodology) the increase was 85% in respect to the winter seasons between 2013 and 2015. This trend was probably due to mechanical ventilation.

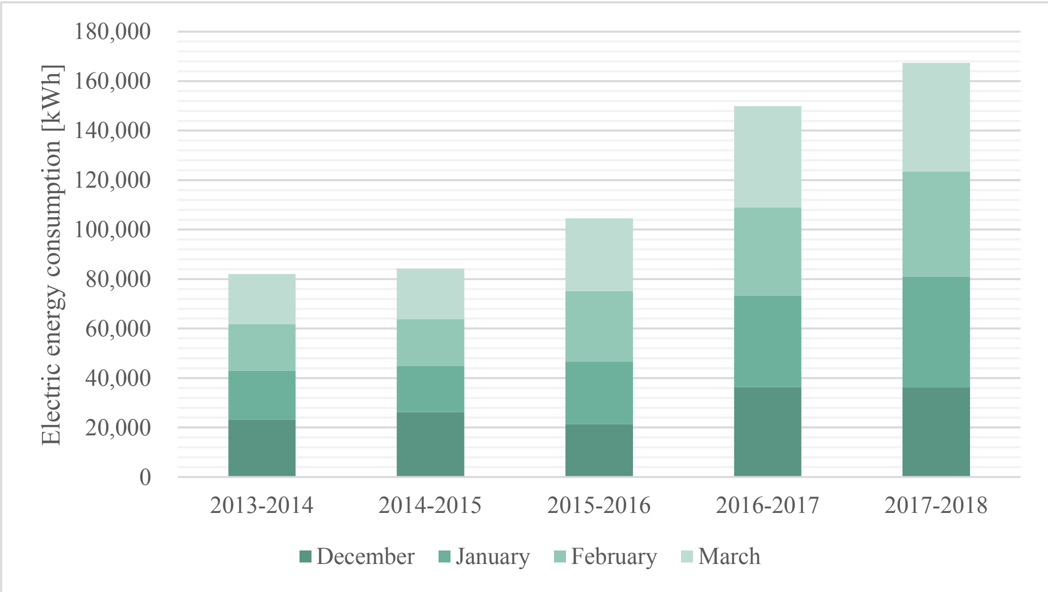


Figure 24. Conservatory of Turin. Electric energy consumption in winter seasons 2013-2018.

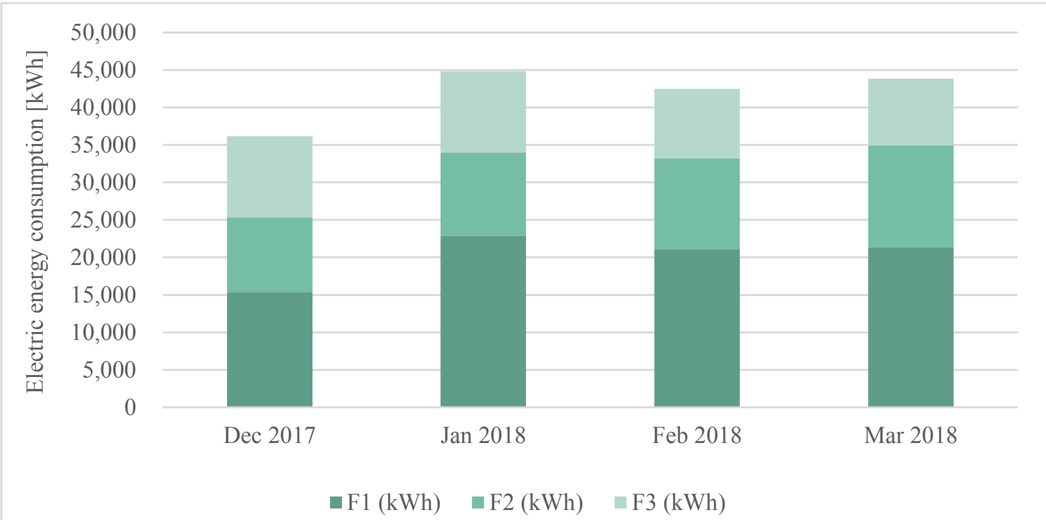


Figure 25. Conservatory of Turin. Electric energy consumption of Phase I- winter divided per F1, F2 and F3 time slots.

Figure 25 shows the electric energy consumption of Phase I's months divided by time slots (F1, F2 and F3). The trend of the electric energy use during the day is similar to the one shown for summer season. In fact, summing the consumption of

F2 and F3 consumptions, they are about the same as F1. Moreover, since F2 and F3 are about the same amount, it could mean that the contribution of internal artificial lights was very small compared to the external artificial lights, or that they were not turned off overnight. Finally, Figure 26 shows the electric energy related costs of Phase I. Similarly to summer season, the weight of raw energy costs is about the same of other costs, not considering VAT.

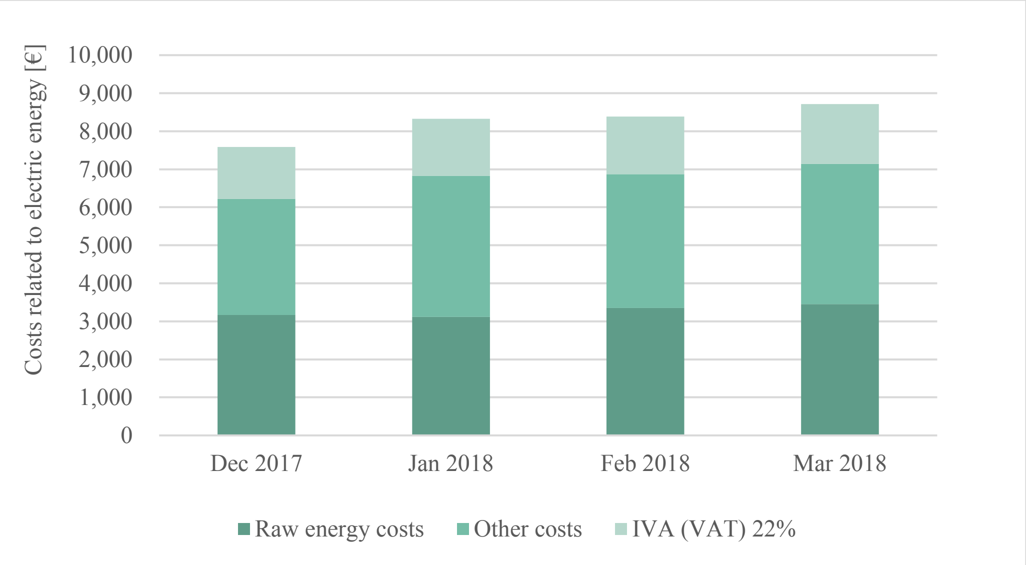


Figure 26. Conservatory of Turin. Costs related to electric energy consumption. Phase I-Winter.

About natural gas consumption, Figure 27 shows the trend of Phase I (winter season 2017/2018) in respect to the previous seasons from 2013 to 2015. Just after the end of 2015 interventions, the natural gas consumption was extremely high, even if no consumptions were registering during the month of December, since the building was still not occupied due to the renovation. While in the season 2016-2017 the natural gas consumption were about the same of the ones before the interventions, in 2017-2018 there has been a reduction. However, the reduction was mainly due to the consumptions in January, which were not ordinary. According to

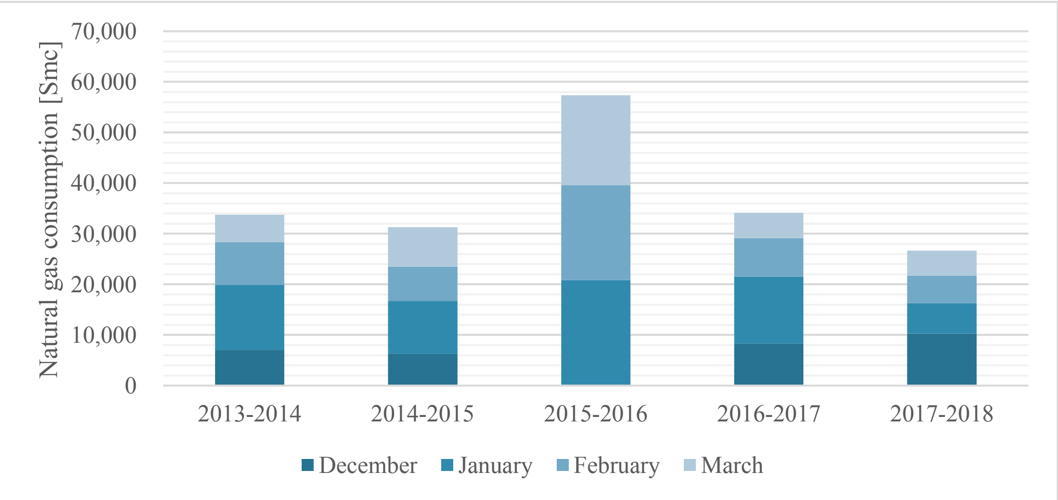


Figure 27. Conservatory of Turin. Natural Gas consumption during winter months between 2013 and 2018.

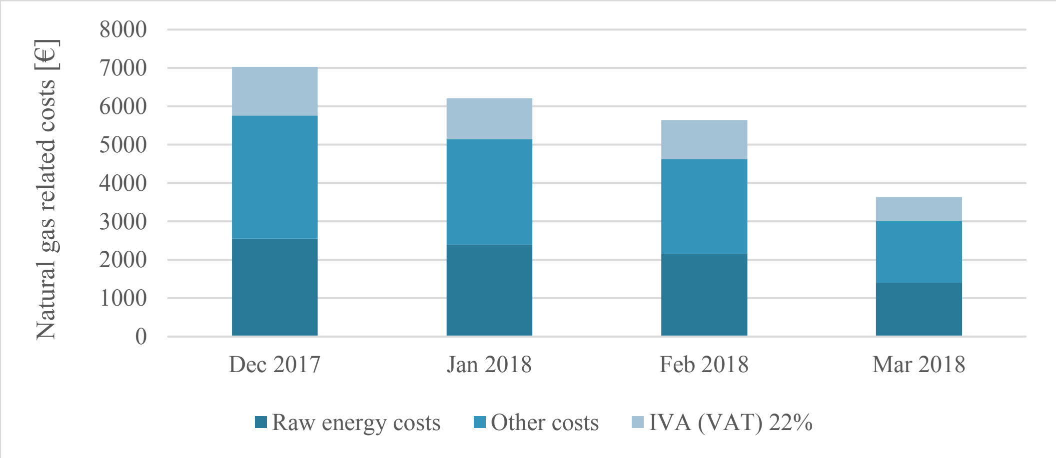


Figure 28. Conservatory of Turin. Natural gas-related costs during Phase I - winter.

the operators, there has been problems with the heating system during that month that lead to the switching-off of the heating system for several days. The conclusion that was reached at the end of these analyses was that, probably, good operational strategies could lead to reduce the consumptions of natural gas more. In fact, most of the interventions of 2015 should have improved the "passive" performances of the building (addition of the PVC window from the inside and internal insulation of walls) but also reduced the heating load due to the introduction of the mechanical ventilation and the prohibition to open windows. Figure 28 shows the costs related to natural gas consumption. In this case, the cost of raw energy is notably lower than the other costs.

11.2.3 Indoor environment assessment

The indoor environment assessment for Phase I was based on two monitoring campaigns that were carried out independently from the BIOSFERA methodology (see par. 11.2.1). However, the periods were evaluated as suitable to represent the indoor environment during Phase I both for summer and winter seasons.

Summer indoor environment assessment

The summer monitoring campaign was carried out between the 15th and the 20th of September 2017 in three classes that were considered as representative by the external consulting engineer (mainly based on the objective of the monitoring which was to investigate reasons of BOs complains), which was in charge of this campaign. In the following, Figure 29 shows the time profiles of the temperatures registered in the three classrooms, which were in the mezzanine floor (6A) and the second floor (14 and 18), and outdoor temperature. As it can be seen, the granularity of indoor and outdoor data are different. In fact, indoor data were registered with a time step of one minute, while outdoors are hourly average values. The graph shows that the indoor air temperatures were very similar throughout the whole period of monitoring, even if class 18 seems to have a different dynamics from the other two. The first data to be highlighted is that indoor temperature does not seems to be influenced by outdoor conditions, which is quite unsurprising in this building, due to the presence of mechanical ventilation and the prohibition to open windows. Only in the two final days of monitoring some influence of outdoor conditions can be noticed. Another aspect to consider is that during the weekend (16th and 17th of September) the temperature remains quite stable, even if the system should have

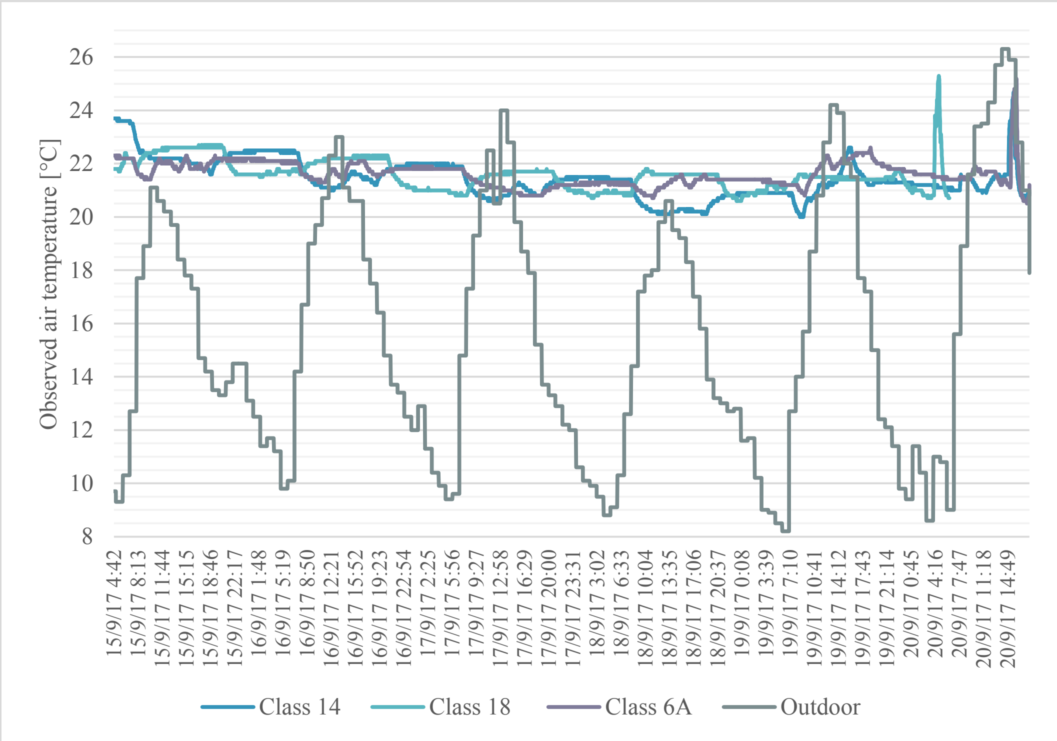


Figure 29. Conservatory of Turin. Time profiles or indoor air temperature of three representative classrooms of the conservatory during Phase I - summer.

been turned off.

Another consideration to be done is that probably this monitoring campaign was not very representative of summer season, since outdoor temperatures cannot really be considered as “summer” period average temperatures. For this reason, it cannot be presumed that the indoor air temperature (which is partially set in classrooms by BOs operating thermostats) was representative of summer season. According to BMs, during those days HVAC systems were functioning and the indoor “general” set-point was still 24°C – cooling season set-point (which could have been changed in each classroom by BOs), and 20°C for the AHU. Looking at the temperature profiles, the most probable scenario is that the cooling system was actually not working (being the air temperature lower than 24°C, it was not activated), so only the AHU was actually on. Nevertheless, this condition could implicate two opposite scenarios. First, BOs could have felt cold. In that case, they would not have any mean to adapt the environment to their needs (being still in “cooling mode”, even setting higher temperature set-point the system would not heat, it would simply not work). Second, BOs could have felt fine, which is plausible since, due to outdoor conditions, they could had already changed their clothing towards the “autumn” ones.

Regarding the analysis of the indoor environmental conditions, since the conservatory is provided with mechanical ventilation and mechanical cooling system (with ceiling radiant panels as terminals), the most appropriate analysis is the one described in Chapter 6 - Frequency distribution and cumulated frequency graphs, which is proposed based on standards EN 15251:2008 and EN 16798:2019 (CEN, 2008; UNI EN, 2019). Figure 30 shows frequency and cumulated frequency of temperature registered during occupied hours. Since the three analysed rooms are classrooms, occupied hours should be from 08:30 to 19:30, which is the opening horary of the classroom area. Assuming that the monitored temperature were representative of a "summer" situation, it could be asserted that the conservatory did not respect DPR 74/1993's prescription, which establishes a minimum cooling set-point of 26°C (with 2°C tolerance) (Italian Parliament, 1993). At the same time, it would be in Class I based on EN 16798:2019 (UNI EN, 2019). However, it should be remembered that this class is not indicative of "better quality" for human comfort; it is a classification of the HVAC "potential" of providing certain conditions, which in this case would not even be necessary (not being a Hospital). Moreover, it is surprising that this graph is much more similar to a "winter" situation. These analyses would capture a situation of HVAC mismanagement in summer conditions, but also a probably situation of occupants' discomfort. Nevertheless, as already mentioned, based on outdoor conditions, this monitoring campaign is probably not much representative of summer conditions, and due to the already cool outdoor conditions, occupants could have already changed their clothes towards an autumn condition and be satisfied with indoor conditions.

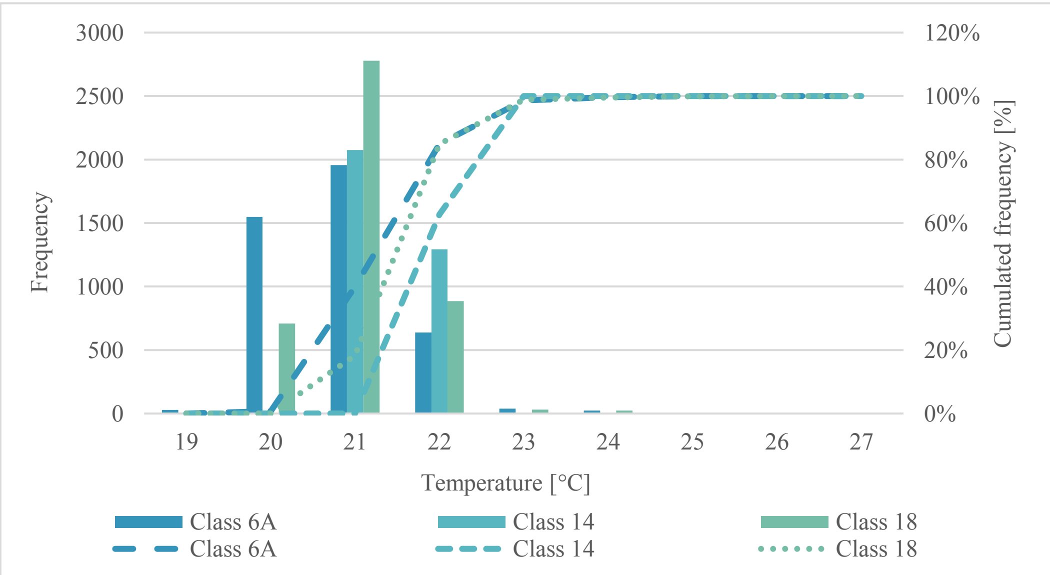


Figure 30. Conservatory of Turin. Indoor air temperature monitored during occupied hours. Cooling season.

Winter indoor environment assessment

The winter monitoring campaign was carried out between the 12th to the 18th of November. This period was not part of the months selected for Phase I- winter. Nonetheless, it was useful to have a hint of what the indoor air temperature was with “cold" outdoor environmental conditions. Also in this case, the registration interval differs for indoor and outdoor data (the first is 5 minutes, the second 1 hour). In this case, the graph shows clearly the temperature fluctuation at night when the heating system was turned off. The general trend seems coherent with the set-points declared by BMs (Heating system T=20°C, AHU T=23°C). Unfortunately, it is not possible to evaluate a whole weekend, since the monitoring started on Sunday at 19:00. However, it seems that until 19:00 the temperature was around 23, then there is a lower peak in the night until the switching-on on Monday

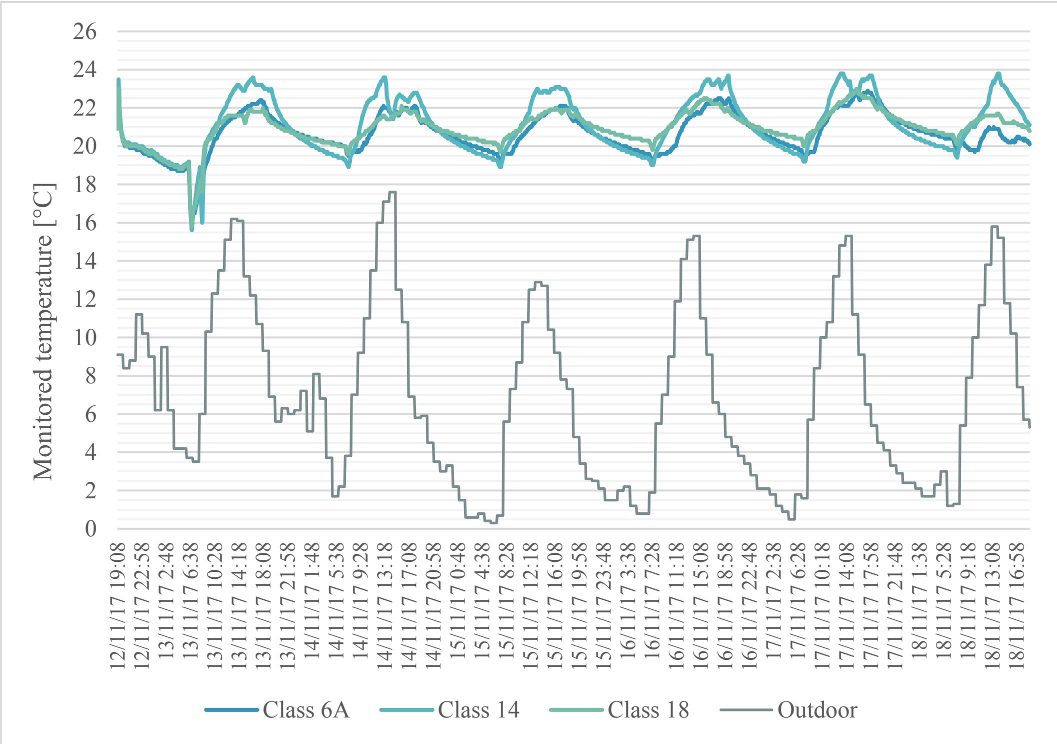


Figure 31. Conservatory of Turin. Time profiles or indoor air temperature of three representative classrooms in heating season.

morning.

Similarly to what was done in the previous section for summer data, Figure 32 shows frequency and cumulated frequency of indoor air temperature values registered during occupied hours (8:30-19:30). Considering the EN 16798:2019 categories, it can be asserted that all classrooms have a minimum heating set-point of 20°C (UNI EN, 2019). Only class 6A had about 20% of values below (19°C). Anyway, as previously mentioned (chapter 6), Category III is supposed to be sufficient to ensure human comfort. Focusing on the Italian regulation (DPR n.74/1993), class 6A and class 18 do not respect the limit of 20°C during heating season, anyway they are within the tolerance interval (+2°C). Class 14, instead, has about 30% of registered values greater than 22°C, so it did not complain with the restrictions (Italian Parliament, 1993). In general, for all analysed classrooms, a

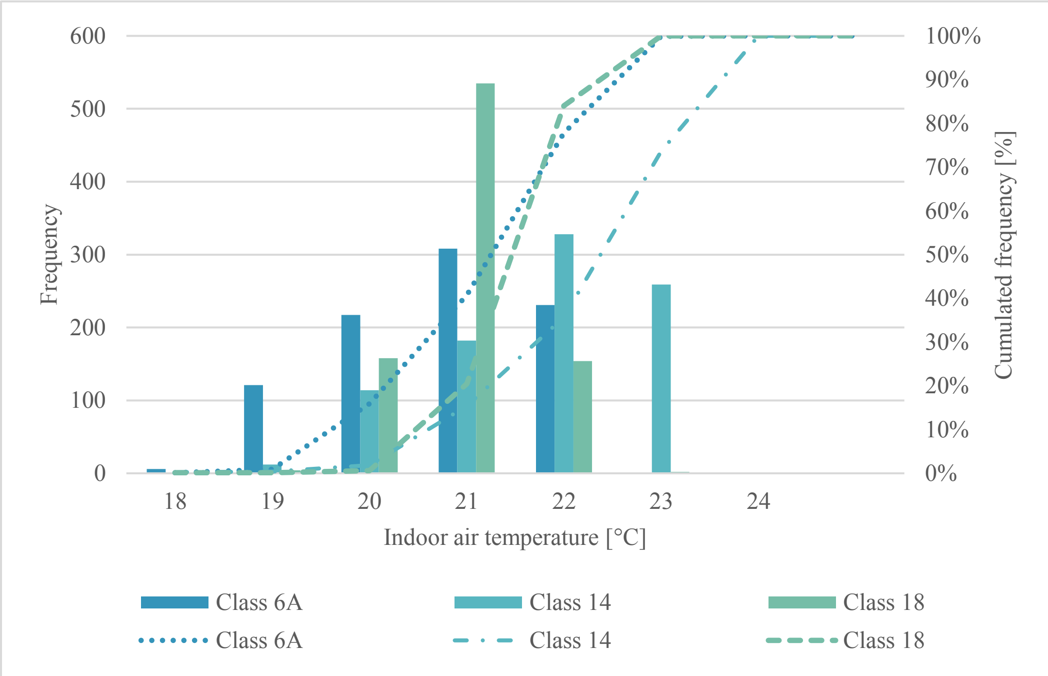


Figure 32. Conservatory of Turin. Indoor air temperature monitored in occupied hours. Heating season.

decrease of indoor air temperature would be desirable to privilege energy efficiency.

11.2.4 Energy-relevant information from BOs

Energy relevant information from BOs were extrapolated from the results of the surveys done at the end of Phase I's summer and winter seasons. In the following, only information that were relevant in order to choose the strategies implemented in Phase II will be shown. Results are presented by dividing BOs types. In fact, as anticipated in paragraph 8.2.1, two groups has been established, which corresponds to MLC and HLC categories (classroom occupants and office workers). The two groups are kept separate, in a first analysis, because strategies has been decided based on the two groups' evaluations, control opportunities and systems' type separately.

Office workers (HLC)

Office workers participated to the questionnaire campaign online, by filling out a questionnaire prepared on Limesurvey. The invitation to fill out the questionnaire was sent by e-mail. A first invitation contained all relevant information about the questionnaire (average duration, aim, information about the author of the questionnaire, the aim of the BIOSFERA methodology, privacy issues etc.). Every week, a reminder was sent by the system. Summer season's questionnaire campaign lasted four weeks, from the 15th of September to the 15th of October 2017. 9 people out of 10 answered the questionnaire, so the percentage totally satisfied the desirable rate of answers described in Chapter 6. Winter season's questionnaire campaign lasted four weeks, from the 1st of March to the 1st of April 2018. 6 people out of 10 answered the questionnaire, so the percentage satisfies the desirable rate of answers described in Chapter 6. In the following, only a part of the elaborated results will be listed based on the information that were relevant to choose the strategies to be implemented during Phase II – summer and winter.

The most relevant results of the **questionnaire's first part** (General information) for summer and winter seasons are shown in Table 29. In particular, the selected aspects were question 5a (which period of the day do you usually spend at work?), I-6a (how much time do you usually spend in the building per day?), I-7a (how are distributed the following working activities during your usual working day?), I-8a (what of these groups the space you work in belongs?). As shown in the Table, approximately the same people answered to the two questionnaires and provided the same answers in the two seasons. All occupants spent at least six hours per day at the office between morning and afternoon, and about 80% of the time was spent at their desk. Moreover, about 80% of occupants worked in small offices. These considerations should be integrated in elaborating the strategies, e.g. in elaborating the "nuggets of wisdom", considering for example that most energy-related choices (e.g. windows opening) will be shared between at least two colleagues.

Table 29. Conservatory of Turin. Office workers. Answers to relevant Part I questions - summer and winter.

Question	Options	Summer	Winter
I-5a. **Which period of the day do you usually spend at work?**	*Only morning*	-	-
	Only afternoon	-	-
	Sometimes morning/sometimes afternoon	-	-
	Morning and afternoon	100%	100%
I-6a. **How much time do you usually spend in the building per day?**	*Less than two hours*	-	-
	From 2 to 4 hours	-	-
	From 4 to 6 hours	-	-
	From 6 to 8 hours	100%	100%
I-7a. **How are distributed the following working activities during your usual working day?**	*Desk work*	81%	81%
	Meetings	10%	10%
	Work outside office (but inside the building)	7%	7%
	Other activities	2%	2%
I-8a. **What of these groups the space you work in belongs?**	*Big office (more than 3 people)*	-	-
	Small office (2—3 people)	78%	83%
	Single office	22%	17%

From the **second part of the questionnaire** (cultural background, habits and changing attitudes), the most relevant information were the appreciation of the historic building in which BOs work (question II-4) and the choice they would make between working in a modern building or a historic one (question II-6). Another aspect to consider was occupants' evaluation of possible information campaigns related to indoor environment's management (II-10). Results are shown in Table 30. Differently from the answers of the first part, which were more "objective", these information were related to personal opinions of respondents, which apparently changed overtime. In fact, a significant percentage of occupants changed their mind about the choice they would make if they could decide in which building they would (historic or modern building). Also the answers about the perceived usefulness of advices to change their energy-related behaviour changed; however, summing the answers beginning with "yes", which identify people who perceive a certain usefulness of this initiative, the overall percentage was between 60% and 70%. Moreover, the others di not judge this initiative as useless, but they did not have an opinion ("no idea").

Table 30. Conservatory of Turin. Office workers. Answers to relevant Part II questions - summer and winter.

Question	Options	Summer	Winter
***II-4.* Do you like the historic building in which you work?**	*Yes*	75%	50%
	No	-	-
	Don't care	25%	50%
***II-6.* Suppose that you can choose the building you can work in. Which of the following option would you prefer?**	*Historic building*	63%	17%
	Modern building	37%	83%
***II-10.* Do you think you would profit from being given advice about your behaviour in relation to ventilating, cooling and heating at workplace?**	*Yes, I would profit a lot*	25%	33%
	Yes, I would profit a bit	50%	33%
	No, I would not profit a lot	-	17%
	No, I would not profit at all	-	-
	No idea	25%	17%

The **third part of the questionnaire** was crucial to decide most BMs' related strategies (e.g. changes of HVAC set-points and operation). This part, dedicated to comfort conditions and preferences, contains occupants' evaluation of indoor environmental parameters and the related comfort assessment. Figure 33 shows the evaluation of thermal sensation (Thermal Sensation Vote, TSV). In summer, the most relevant information was that more than 50% of occupants felt slightly cool or cool, which could be related to an improper use of HVAC systems. Since offices were provided with multi-splits, which are directly operated by occupants, the improper use is probably due to occupants. This has been considered to choose Phase II strategies. Also in winter, more than a half of occupants felt slightly cool

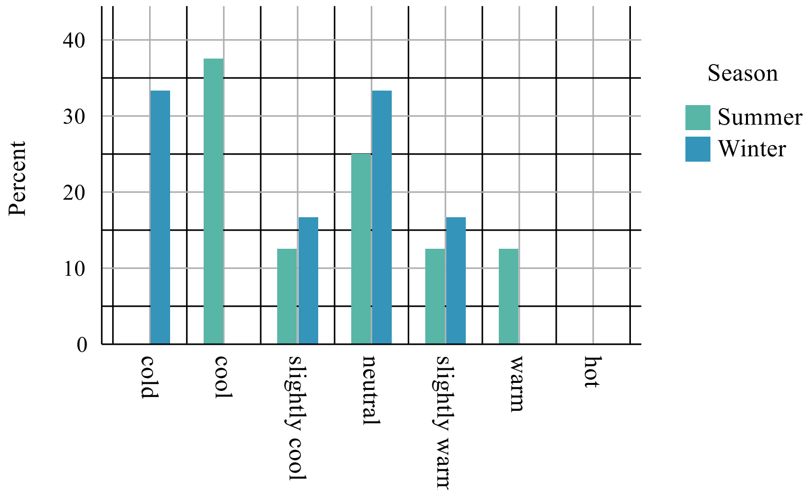


Figure 33. Conservatory of Turin. Phase I Thermal Sensation Vote (TSV) in offices.

or cold. Due to the presence of original windows with single glasses and wooden frame, the data was not much surprising. However, this should be taken into account to provide some alternative strategy (e.g. change position in the room if too close to the window). About thermal comfort, Figure 34 puts in relation thermal comfort votes and thermal sensation ones. About summer, the most relevant data is that about 25% of occupants that voted “cool” as TSV actually felt moderately uncomfortable, so their education to a proper use of multi-splits would possibly allow both energy savings and thermal comfort enhancement. Nevertheless, another possible explanation could be related to disagreements with colleagues: in fact, all those votes came from small offices. Another interesting aspect was that none of occupants voting “neutral” as a thermal sensation considered it as an uncomfortable condition; in winter, all of them considered it as moderately comfortable. Moreover, in only about 15% of cases the “neutral” TSV corresponded to a “neutral” thermal comfort (in summer).

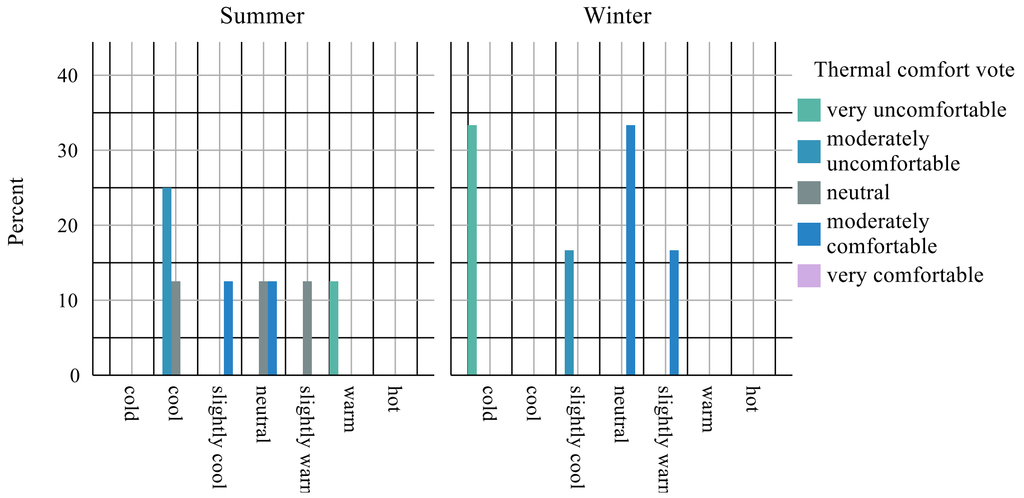


Figure 34. Conservatory of Turin. Thermal comfort vote vs TSV in offices, Phase I.

Regarding the natural light level evaluation shown in Figure 35, it was interesting to compare the natural light perception and the related visual comfort judgement (Figure 36). In fact, the summer “dark” vote about natural light level resulted on a “very comfortable” vote. At the same time, the “neutral” perception

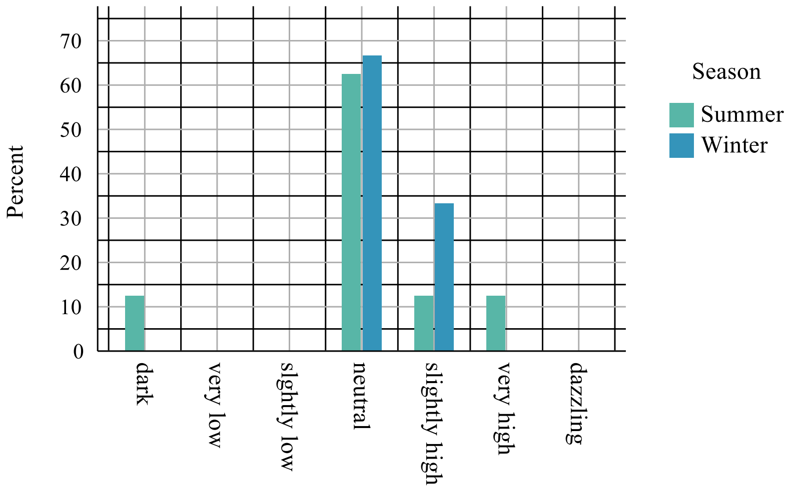


Figure 35. Conservatory of Turin. Natural light perception in offices, Phase I.

vote resulted, in both summer and winter, on around 20% moderately uncomfortable votes.

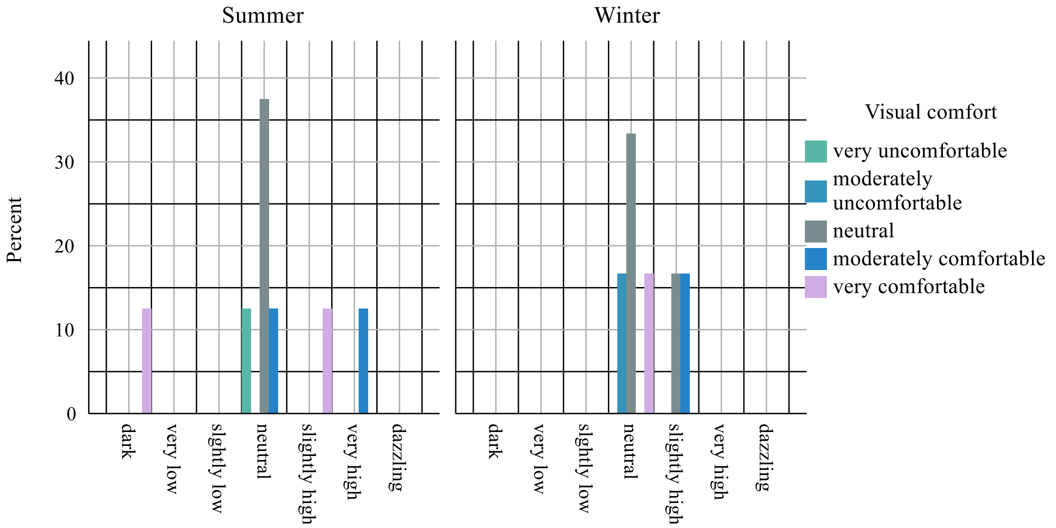


Figure 36. Conservatory of Turin. Natural light vs visual comfort in offices, Phase I.

About air quality (Figure 37), summer season seems not problematic, while in winter more than 50% of occupants thought that air quality was not acceptable. The office area is not provided with mechanical ventilation, so this data should be compared with the behaviour in terms of windows' operation presented in the following (part IV of the questionnaire), also in order to educate occupants to efficiently manage windows and natural ventilation.

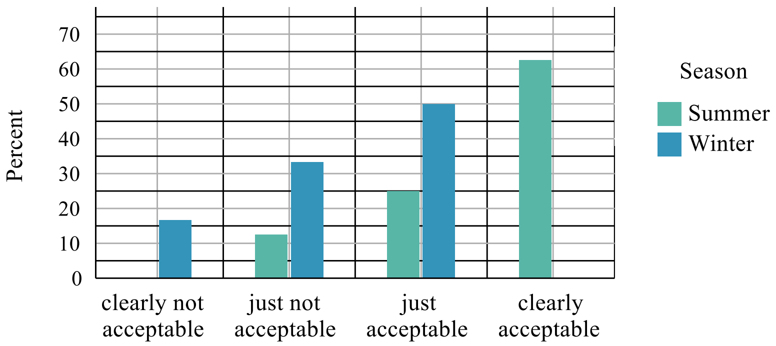


Figure 37. Conservatory of Turin. Phase I evaluation of indoor air quality in offices.

About humidity level, it is again very interesting to compare answers related to the perception of this parameter (Figure 37) with the related comfort judgment (Figure 38). In fact, Figure 37 shows that while in the summer the indoor environment was perceived as slightly humid (about 37% of votes), in winter half of occupants perceived it as slightly or moderately dry. While about 50% of occupants evaluated the comfort related to humidity level as neutral, it is interesting to notice that those perceiving humid or dry conditions usually judges this sensation as uncomfortable. This condition was more relevant in winter season apparently, in which about 30% of occupants was uncomfortable due to dry perceived air. At the same time, since in summer more than 35% of occupants perceived the indoor environment as slightly humid (and about two third of them judge this feeling as uncomfortable), education about how to use the multi-split seemed beneficial and could easily change this situation.

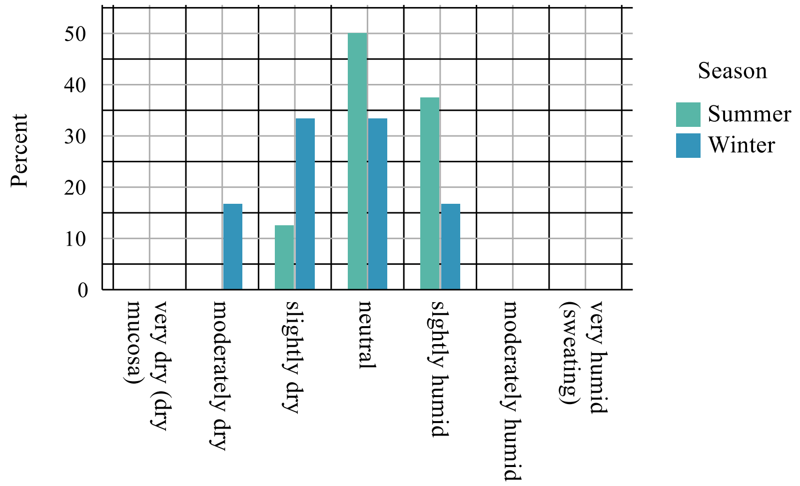


Figure 39. Conservatory of music. Humidity level evaluation in offices,

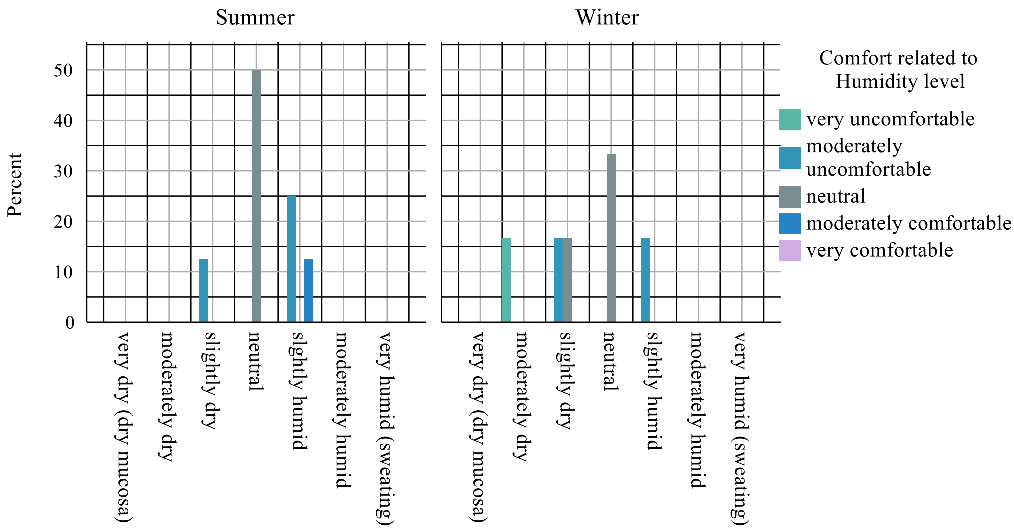


Figure 38. Conservatory of music. Humidity level vs comfort evaluation in offices, Phase I.

The last investigated environmental parameter was noise. Figure 40 and 41 show noise level and related comfort evaluation. As shown, the noise level changed across seasons. In particular, during summer it seems that it was slightly higher, possibly due the increment of windows opening, which causes noise from outside. Focusing on the comfort evaluation, in general occupants seems satisfied in winter, in which only about 16% of occupants are moderately uncomfortable, while in summer this percentage is slightly higher (about 25%). In general, the evaluation of this parameter was interesting in this building since the instruments' playing generates a certain noise level in all rooms (also offices). However, it seems that this do not cause problems to office workers.

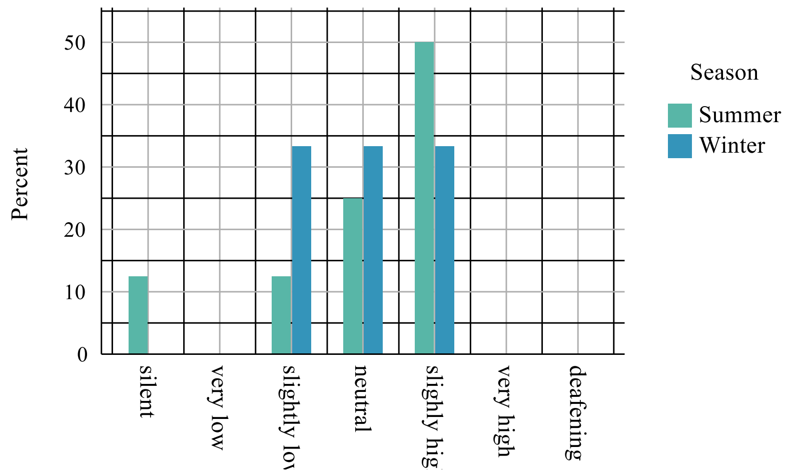


Figure 41. Conservatory of Turin. Noise level perception in offices, Phase I.

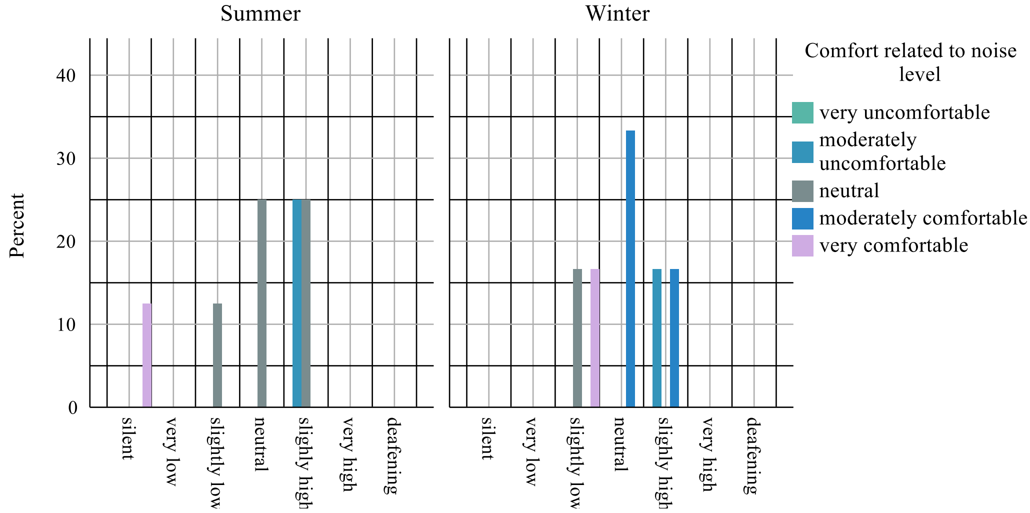


Figure 40. Conservatory of Turin. Noise level vs comfort evaluation in offices, Phase I.

The last relevant aspect of questionnaire's part III was the evaluation of local discomfort causes in winter and summer seasons. The first aspect to highlight is that some discomfort causes, such as glare, did not emerged from the previous evaluations of the environmental parameters. In fact, no occupant choose "dazzling" as summer perception vote. Actually, this can be explained. In fact, the "perception" question asks for the "average" seasonal evaluation, which cannot excludes some point-in-time discomfort sources such as glare. This discomfort source is recognized by 22% occupants, so it constitutes a point to be integrated in the strategies in terms of education to internal and external blinds, which are operable in offices. Ambient surfaces (too hot or too cold) were recognized as cause of discomfort in both season. Probably windows were responsible of these votes. Air draft was also recognized as a problem, especially in winter, which is not surprising based on windows' characteristics. At the same time, also air movement seems to represent a problem, especially in summer. This cause of discomfort is usually linked to the evaluation of indoor air quality, which can be reported as a lack of air movement in the room. The fact that this cause is recognized also in summer supports the idea of providing education on how to use multi-splits.

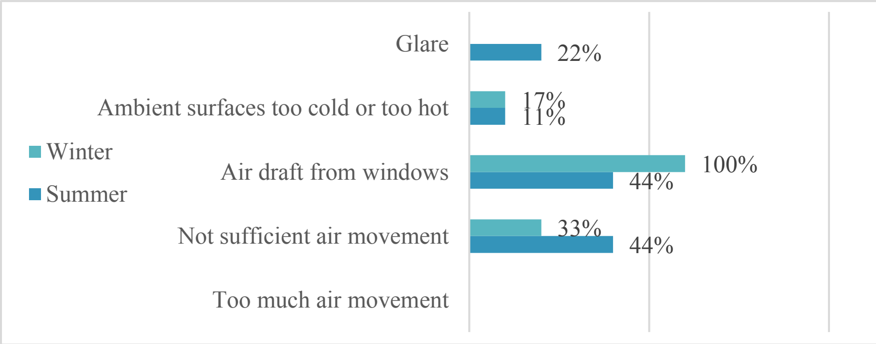


Figure 42. Conservatory of Turin. Local discomfort causes in offices, Phase I.

The first relevant aspect considered from the **fourth part of the questionnaire** (Occupant behaviour) was the clothing level. Table 31 shows the answers to this questions in summer and winter seasons. In summer, the large majority of occupants declared a medium clothing level, which means that they could be encouraged to wear lighter clothes in order to reduce the use of the cooling system. Similar considerations can be done also for winter season. In fact, only 17% of occupants wear heavy clothes, while half of them wear light winter clothes. Clothes regulation can be advised as adaptive opportunity to avoid discomfort in case the HVAC system cannot be operated by occupants (which was the case of offices in winter season).

Table 31. Conservatory of Turin. Clothing level in offices, Phase I.

Question	Options	Votes
***IV-1.* In which of these categories do you recognize your usual clothing for the current season (summer)?**	*Light: t-shirt, light skirt or short pants and sandals*	-
	Medium: light pants/skirt, short-sleeved shirt, light socks and shoes	87%
	Heavy: cotton shirt (long-sleeved) work pants, wool socks and shoes	13%
***IV-1.* In which of these categories do you recognize your usual clothing for the current season (winter)?**	*Light: Trousers, long-sleeved shirt (cotton), cotton pullover, cotton socks and office shoes*	50%
	Medium: Trousers, long-sleeved shirt, suit jacket, wool socks and office shoes	33%
	Heavy: Trousers, wool shirt, wool pullover, wool socks and boots or winter shoes.	17%

In relation to the environmental parameters evaluated in the previous section, this part of the questionnaire was addressed also to understand occupants' actions when one of those parameters creates an uncomfortable condition. The first investigated actions, related to thermal discomfort, are shown in Figure 43. The figure shows relevant information. For example, the fact that in summer season occupants are less likely to adjust their clothing level than in winter (more than a half perform this kind of action less than once a day), or that in both seasons they use very rarely internal and external blinds to mitigate thermal discomfort (e.g. overheating in summer). At the same time, it seems they operate windows more likely to intervene on thermal discomfort situation.

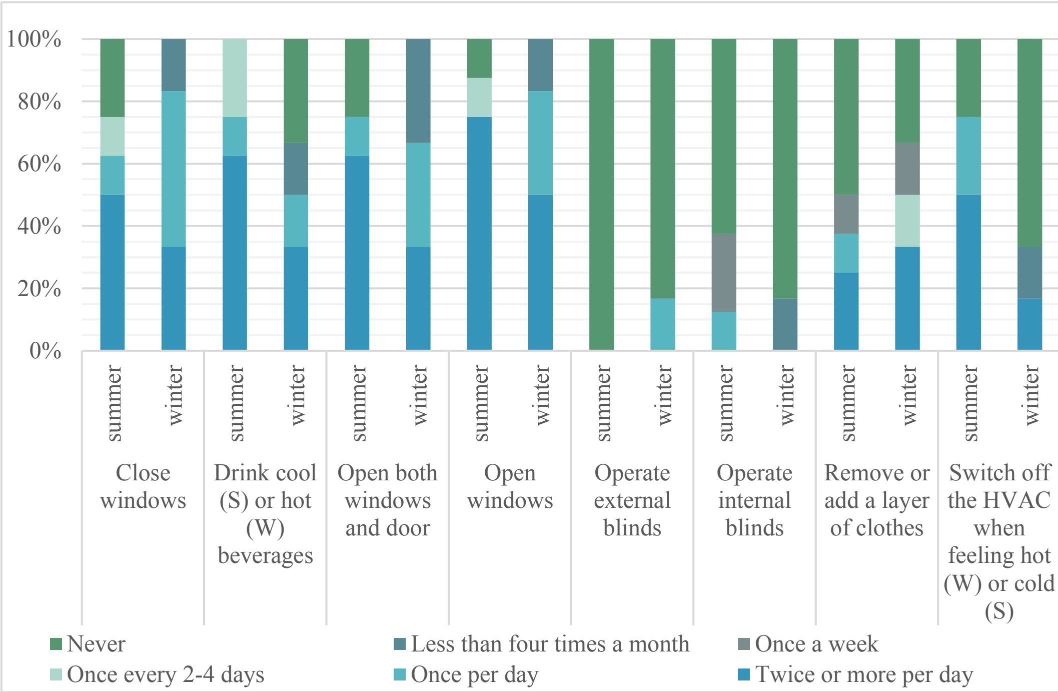


Figure 43. Conservatory of Turin. Actions in case of Thermal discomfort. Offices, Phase I.

Figure 44 shows occupants' actions in case of a too low natural light level. Among the several information, the figure shows that both in summer and in winter only a small percentage of occupants operated internal and external blinds. In both seasons, in case of low natural light level, the large majority of occupants switched on the general lights of the office. Moreover, the fact that the action was performed only once per day probably means that once switched on, it was not switched off until the occupant leaved the office. This aspect will be deepen in the following by a specific question. If the problem is the opposite, namely a too high natural light level, the actions performed are shown in Figure 45. The figure shows quite coherent information in respect to the previous one. In fact, also in case of too high natural light, occupants seems not to have the habit to use internal and external blinds to avoid glare. Since Figure 42 showed that 22% occupants declared discomfort due to glare, they are probably not aware of the possibility to control it by operating blinds, and this should be considered for Phase II strategies.

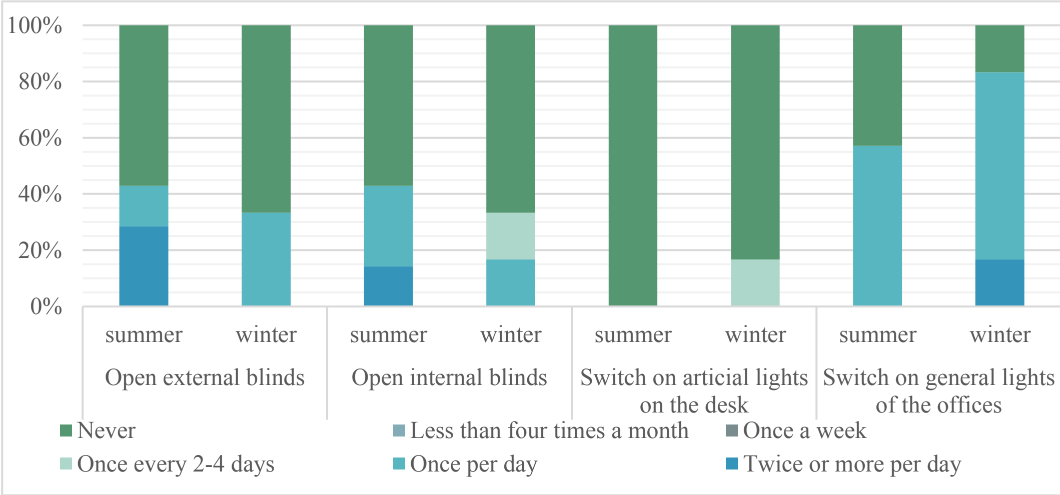


Figure 44. Conservatory of Turin. Occupants' actions when the natural light level is too low.

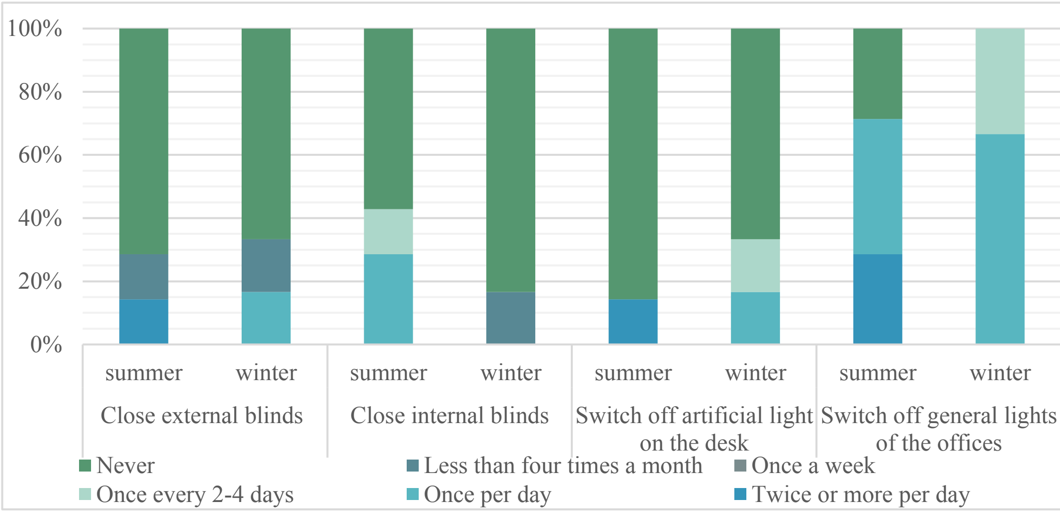


Figure 45. Conservatory of Turin. Occupants' actions when the natural light level is too high.

Figure 46 shows the actions performed by occupants in case of poor indoor air quality, which emerged as a probable cause of discomfort in the previous questionnaire's section. As partially emerged in Figure 43 for thermal discomfort, the majority of occupants operated windows twice or more per day, especially in summer. This is coherent with the fact that offices are not provided with mechanical ventilation, so windows' opening is the only mean to ventilate rooms. In winter, the door opening is preferred as a mean to ventilate the room. Nonetheless, it should be noticed that slightly less than 20% of occupants never open windows. Moreover, based on these answers the IAQ-related evaluations previously shown are not much explained; probably, windows' opening is not sufficient or frequent enough to create good air quality conditions.

As shown in Figure 47, windows' opening was used also as a mean to fix uncomfortable situations due to humidity in summer season. However, multi-splits were used as de-humidifier too by the majority of occupants. In winter, instead, despite the dry air emerged as a problem in the questionnaires' III part, occupants seems to take no actions. For example, none of them placed the humidifier on the radiator.

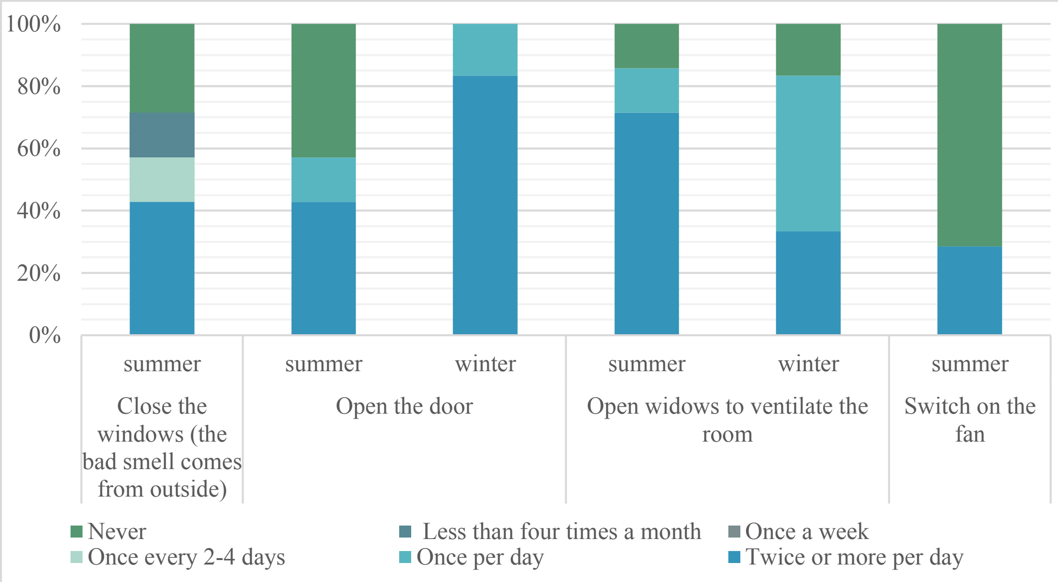


Figure 47. Conservatory of Turin. Occupants' actions in case of poor air quality. Offices, Phase I.

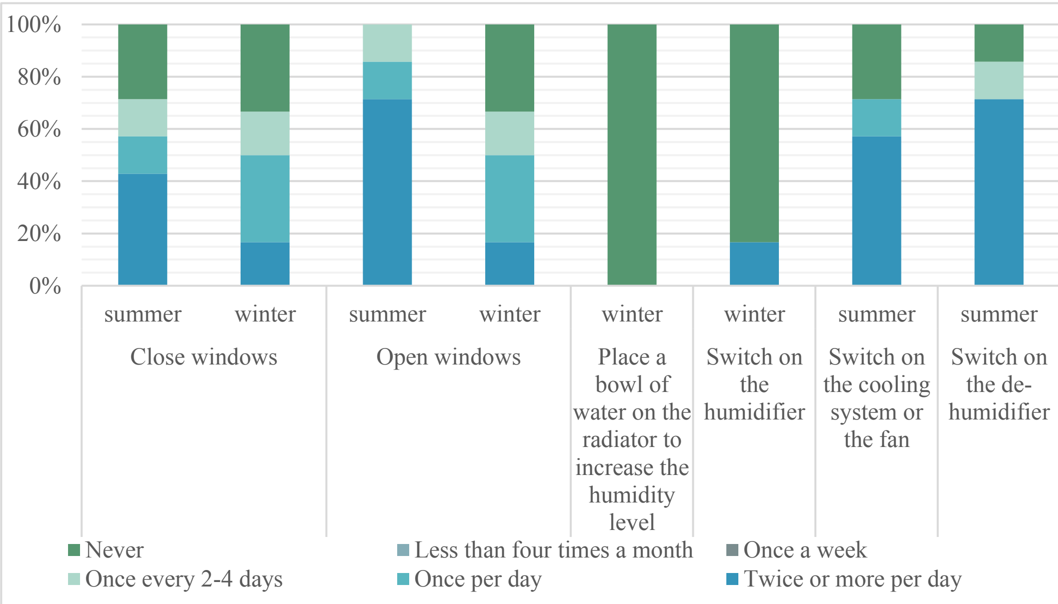


Figure 46. Conservatory of music. Occupants' actions in case of uncomfortable situations due to humidity. Offices, Phase I.

As previously mentioned, windows-related behaviour has been investigated also by specific questions. Figure 47 and 48 are dedicated to understand to which aim, in general, windows are opened by occupants (48) and for how long they remain open (49). These questions were very useful to identify energy-wasting habits. For example, in summer a notable percentage of occupants open windows to mitigate the cold sensation due to the use of multi-splits. Of course, this is not desirable, so it should be considered for Phase II's strategies. A similar behaviour is declared also in winter as a mean to mitigate the overheating. About natural ventilation, the percentage of occupants opening windows when the air quality is not proper is quite low in winter. About the period for which windows remain open, the large majority of occupants declare that windows remain open only for the time due to re-establish the proper conditions.

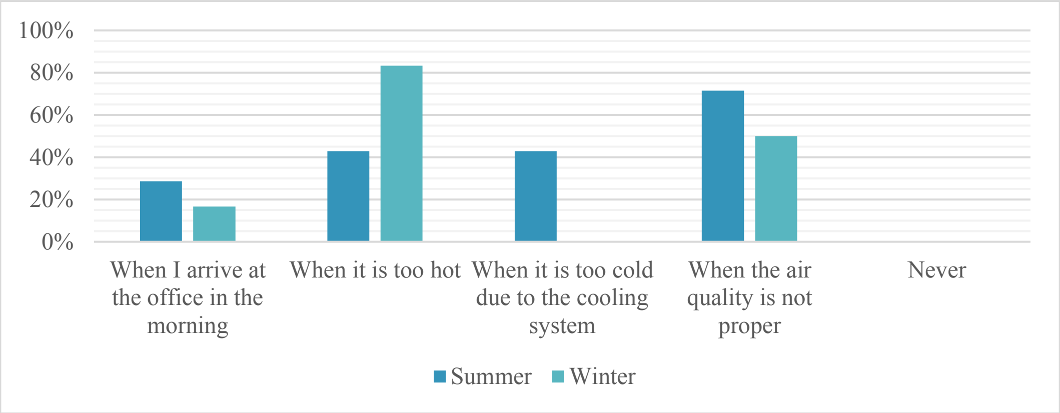


Figure 48. Conservatory of Turin. Office workers seasonal habits in terms of windows' opening. Phase I.

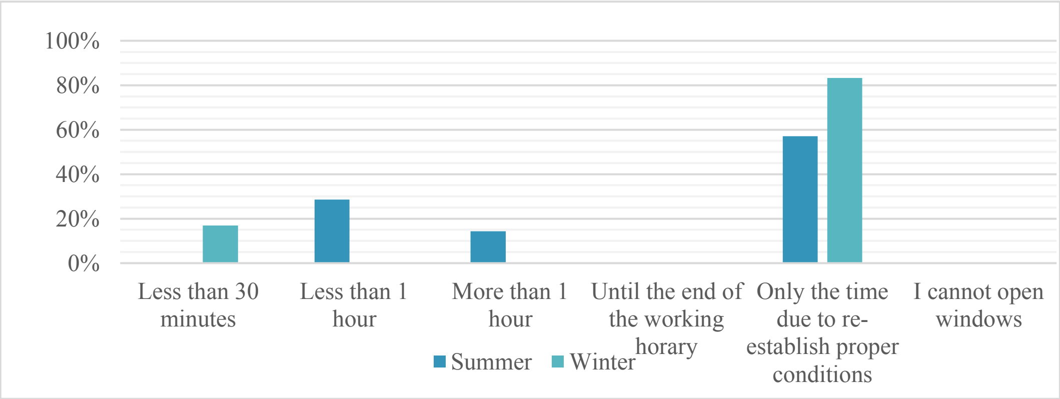


Figure 49. Conservatory of Turin. How long windows remain open in offices, Phase I.

Another energy-related behaviour for which a specific question was inserted in the questionnaire is artificial lights' usage. In fact, also for this technological interface, certain specific energy-wasting behaviour could not emerge from previous questions. Figure 50 shows the answers to a question asking when occupants usually turn on artificial lights. Despite the large majority of respondents declared that they only turned on them when the natural light was not sufficient, there was still about 20% of occupants who did it when they arrived at the office in the morning.

The last aspect investigated about occupants' behaviour in offices was the energy-related habits "before leaving the room". In particular, the question to which occupants answered was "When you leave the workplace, what of these actions do you perform (during the current season)?" Also from this question, some energy-wasting behaviour emerged. For example, more than a half occupants declared that in summer if artificial lights were switched on they switched them off only at the end of the working day, which is quite surprising since natural light usually is present during the working hours. In general, since the respondents in summer and winter seasons were approximately the same, it is surprising that certain "non-seasonal" dependent actions seems to change overtime. A possible explanation is that probably these habits are not much stable, which could be useful to establish new "less energy-wasting" ones.

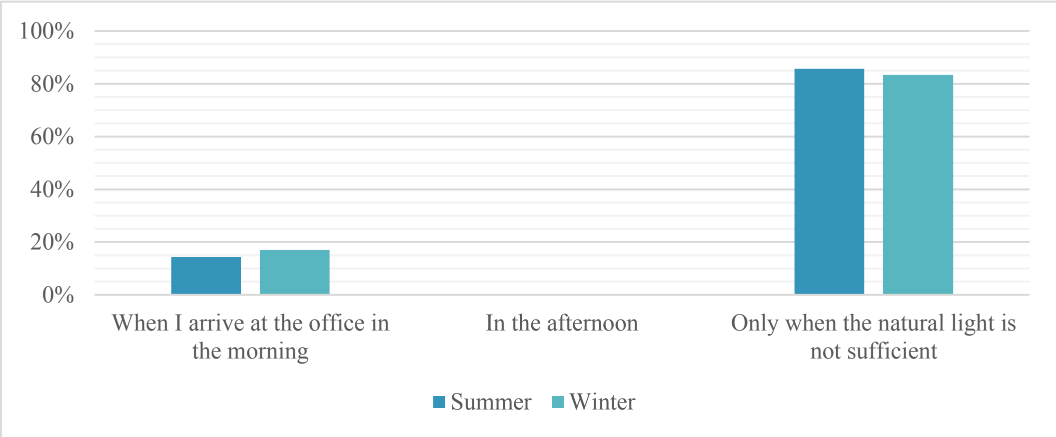


Figure 51.Conservatory of Turin. Office workers' habits in terms of artificial lighting use. Phase

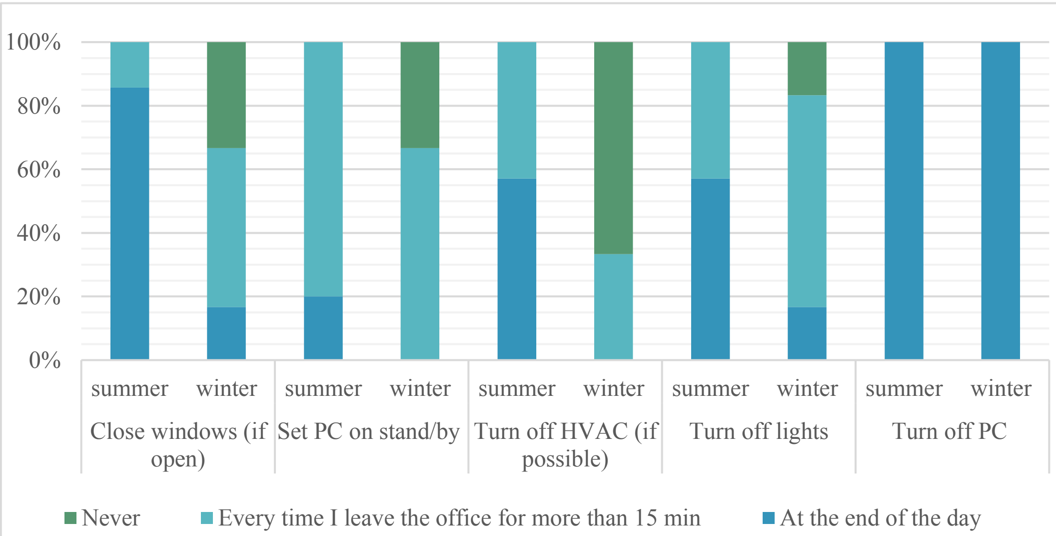


Figure 50. Conservatory of Turin. Office occupants' energy-related habits "before leaving the room". Phase I.

From the fifth and last part of the questionnaire, the most relevant aspect for the elaboration of Phase II's strategies was the perceived control and the evaluation of its compliance with the real control possibilities. Figures 52 and 53 show this aspect. They both represent answers to the same question. The first aspect to highlight is that there is no compliance between summer and winter answers regarding internal and external blinds' operability. In fact, all offices are provided with these elements, which are theoretically controlled by occupants. In effect, looking at the previous figures, it is quite clear that a certain percentage of occupants suffer from natural light-related problems that could be mitigated by operating blinds, but they were not. Considering Figure 52, it seems that either occupants were not aware of this possibility (i) or they declared that they cannot operate blinds due to disagreements with colleagues (ii). Another curious aspect was that all occupants answered that they can regulate artificial lights (dimmering). Anyhow, offices' lights are not dimmerable. Probably the description of this answer was not very clear. However, this shows the importance of "double-checking" perceived control with real control opportunities within the indoor environment. About systems, occupants were quite aware of their control possibilities (only a small percentage believes to be able to switch on the heating system). Nevertheless, it should be noticed that the large majority of them would like to be able to have the control of the heating system (both switching on and regulation). This aspect has been signalled to the administration of the building, which could consider it for a future intervention of thermo-valves installation. Anyway, this intervention cannot be part of the BIOSFERA methodology, which is aimed to exploit the already-present technologies.

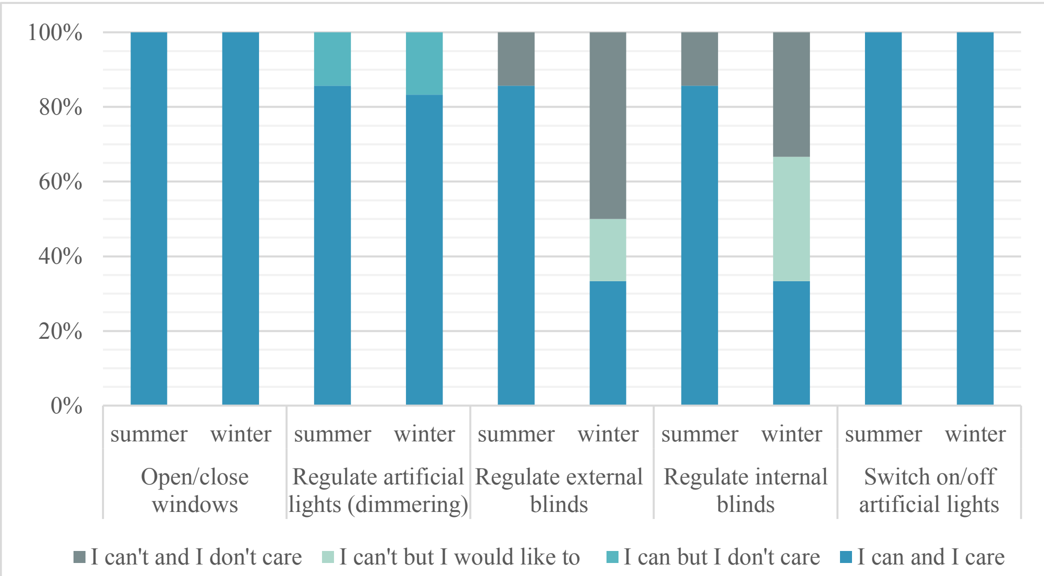


Figure 53.Conservatory of music Office workers' perceived control opportunities, Phase I (1).

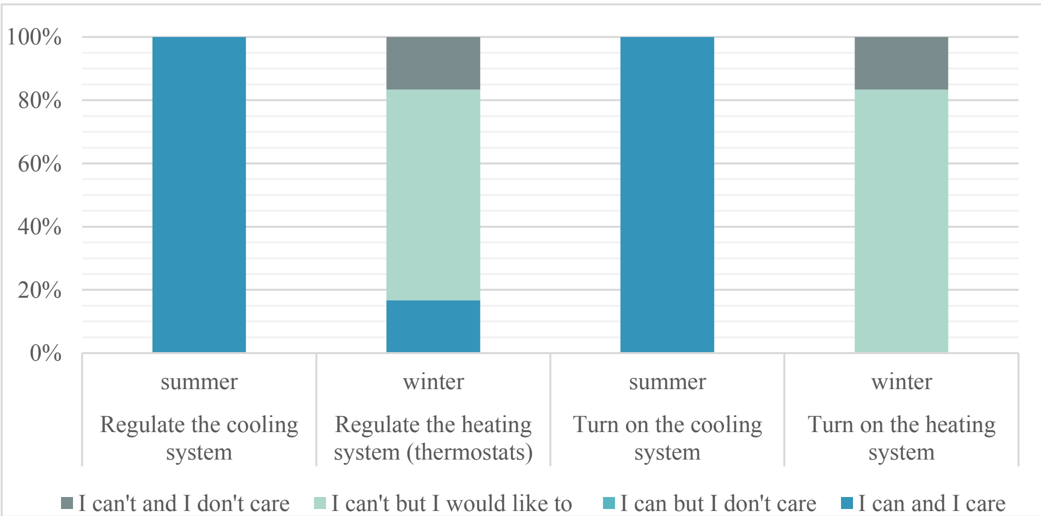


Figure 52. Conservatory of music Office workers' perceived control opportunities, Phase I (2).

Classroom users (MLC)

Classroom occupants answered to the questionnaire in paper, because the administration decided that this was the probably most efficient way of reaching professors and students at the same time. Questionnaires were distributed partly by the secretary (mostly to professors) and partly by myself, directly in classrooms. The first questionnaire, which was distributed and collected within four weeks from the 15th of September 2017 to the 15th of October 2017, had 52 answers. The winter survey, which took place from the 15th of March to the 15th of April, received only 17 answers, despite the mean of distribution was identical. The only difference, which probably is not negligible, was that for the first survey professors' questionnaires were collected directly by the Conservatory's director during a meeting, which probably influenced their willingness to participate. The response rates are not easy to be assessed, since classrooms are occupied by a very flexible number of students. The total number of professors, who actually do not all teach in the main building (which is the object of the evaluation), is approximately one hundred. Nonetheless, these data are not sufficient to calculate a proper respondents' rate. In the following, only a part of the elaborted results will be listed based on the information that were relevant to choose the strategies to be implemented during Phase II. Due to the flexibility of spaces' usage, this questionnaire applied to this specific case study has some fragilities. In fact, classrooms of different floors have different peculiarities. However, dividing questionnaires per area was not considered a good option from the administration, since BOs continuously change room (for different courses etc.).

From the **first part of the questionnaire**, the most relevant information were how much time participants spend in classrooms (averagely) and which period of the day they usually spend at the conservatory. These data are presented in Table 32. Also looking at these answers the flexible use of the spaces (in terms of occupation) is confirmed. Anyway, it can be seen that about half of the participants spend in the building from 4 to 6 hours averagely.

Table 32. Conservatory of Turin. Classroom occupants. Answers to relevant Part I questions - summer and winter.

Question	Options	Summer	Winter
***I-5a.* Which period of the day do you usually spend at work?**	*Only morning*	-	6%
	Only afternoon	2%	12%
	Sometimes morning/sometimes afternoon	33%	47%
	Morning and afternoon	65%	35%
***I-6a.* How much time do you usually spend in the building per day?**	*Less than two hours*	10%	6%
	From 2 to 4 hours	18%	18%
	From 4 to 6 hours	56%	58%
	From 6 to 8 hours	16%	18%

From the **second part of the questionnaire**, the most relevant information were the appreciation of the historic building in which BOs work or study and the choice they would made if they could between a modern and an historic building. Moreover, the other aspect to be accounted is the evaluation of the usefulness of energy-related education for their appreciation and management of the indoor environment.

Table 33. Conservatory of Turin. Classroom occupants. Answers to relevant Part II questions - summer and winter.

Question	Options	Summer	Winter
***II-4.* Do you like the historic building in which you work?**	*Yes*	98%	88%
	No	2%	12%
	Don't care	-	-
***II-6.* Suppose that you can choose the building you can work in. Which of the following option would you prefer?**	*Historic building*	85%	94%
	Modern building	15%	6%
***II-10.* Do you think you would profit from being given advice about your behaviour in relation to ventilating, cooling and heating at workplace?**	*Yes, I would profit a lot*	33%	47%
	Yes, I would profit a bit	25%	23%
	No, I would not profit a lot	17%	6%
	No, I would not profit at all	15%	12%
	No idea	10%	12%

From the **third part of the questionnaire**, the most relevant information were those related to the evaluation of indoor environmental parameters and the related comfort assessment.

Figure 54 shows Thermal Sensation Votes (TSV) of classrooms' occupants. About summer season, the most relevant aspect is that TSVs were distributed approximately in all scale. This is not much surprising, since each classroom was handled separately by occupants. Only 20% of people felt neutral; the other part of the sample was divided quite equally between those who felt cold and those who felt warm. Another notable data is represented in Figure 55 (thermal comfort vote), which shows that more than 40% of occupants felt not comfortable. This is quite surprising; in fact, giving occupants the possibility of handling each room autonomously, the administration's expectation was to provide more comfortable and satisfying indoor environmental conditions. Moreover, the fact that a notable percentage of those expressing a "slightly cool" or "cool" TSV expressed a discomfort vote is significant. These data are very relevant also in respect to the energy consumptions analysed before. In fact, considering these two aspects together, they highlights that the energy demand increase was not useful in providing occupants with comfortable conditions. About winter season, the TSV evaluation shows that a half of occupants felt warm, while about 24% of participants felt cool. Looking at the comfort vote, about 24% felt uncomfortable. This is interesting if compared with the monitoring data. In fact, looking at them, the impression that the administration had was that the energy demand increase was addressed, as for summer, at providing more comfortable conditions to occupants. However, occupants' evaluations seem not to confirm it. The fact that about a half of occupants felt slightly warm or even warm encourage to try to keep indoor air temperature lower. At the same time, giving occupants' the possibility to handle thermostats autonomously, this objective should be pursued by engaging them on a proper indoor environment configuration.

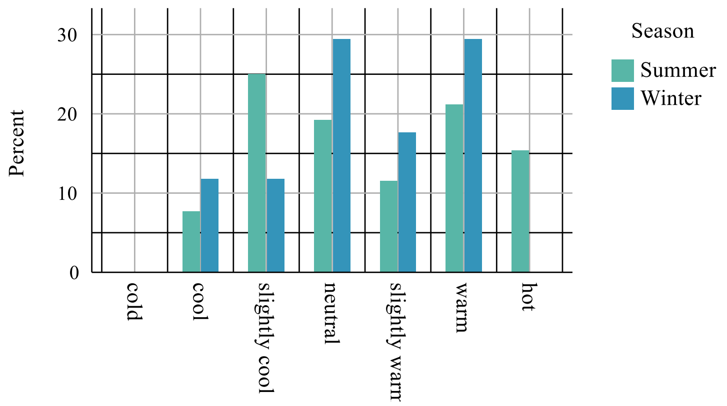


Figure 55.Conservatory of Turin. Thermal comfort vote in classrooms, Phase I.

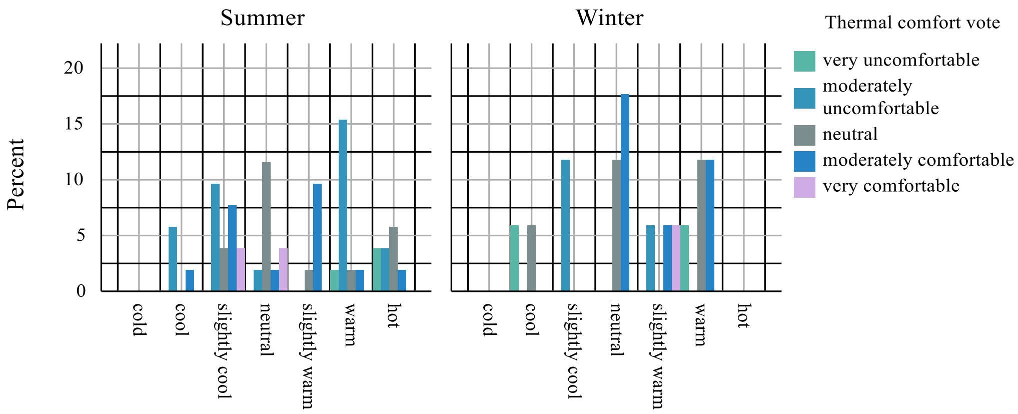


Figure 54. Conservatory of Turin. Thermal comfort vote in classrooms, Phase I.

Figure 56 shows the evaluation of indoor air quality, which was presumed as a possible problem due to the inconveniences happened during the realization of the mechanical ventilation system previously mentioned. Quite surprisingly, most occupants did not perceive poor air quality in classrooms. Only about 20% of them, both in summer and in winter, perceived poor air quality. This could be symptomatic of the use of natural ventilation, so the disregard of the request of not opening windows. In fact, windows are locked only on the mezzanine; on the other floors there's a sign in which it is written that windows should not be opened due to the presence of mechanical ventilation, but they're not locked. Unfortunately, MLC questionnaire is not provided with windows-related behaviour questions, so the only question that could be used to investigate their usage is the one about control perception (V4), which will be presented in the following.

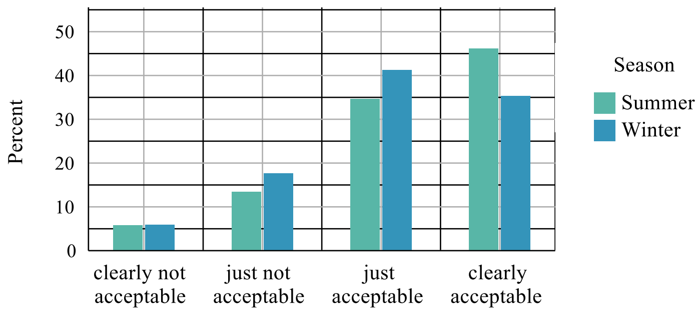


Figure 56. Conservatory of Turin. Classroom occupants' evaluation of air quality. Phase I.

Figure 57 and 58 show the evaluation of natural light level and visual comfort, respectively. In both seasons, the majority of occupants perceived, averagely, a neutral natural light level. However, in should be noticed that in summer about 30% perceived a low light level. The problem persists also in winter, in which it causes a higher percentage of discomfort (about 25% in total). In general, it is interesting to notice that the general trend is opposite to what was evaluated by office occupants. The variability of natural light's evaluations is quite normal since classrooms have different orientations.

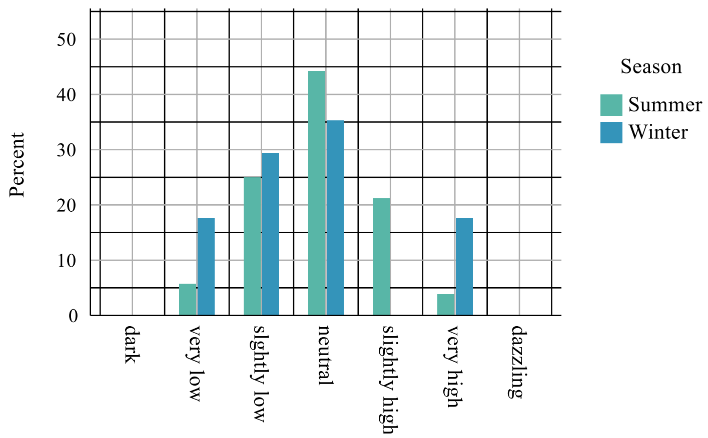


Figure 58. Conservatory of Turin. Classroom occupants' evaluation of natural light level. Phase I.

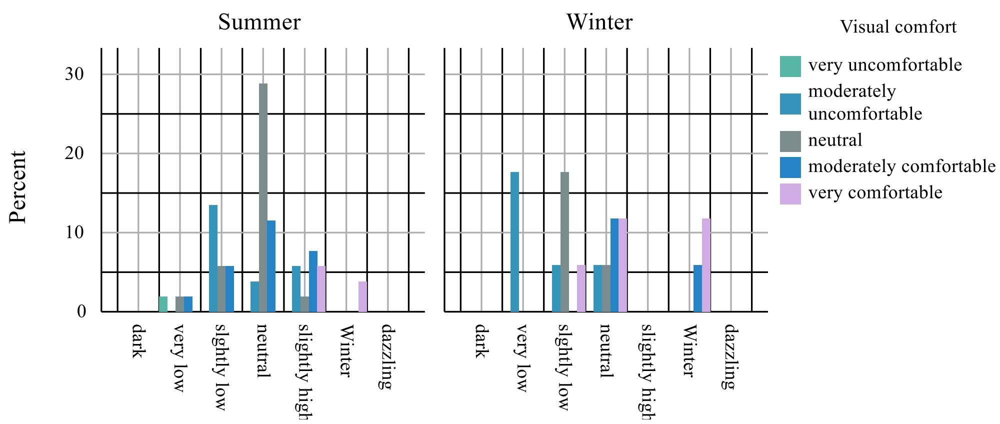


Figure 57. Conservatory of Turin. Classroom occupants' evaluation of visual comfort.

Figure 59 and 60 show the evaluation of the humidity level and the connected comfort perception respectively. Classrooms seems not to present particular problems related to humidity, except about 30% of occupants perceiving air as dry both in summer and winter. However, looking at Figure 60, this do not causes an uncomfortable condition for the majority of them.

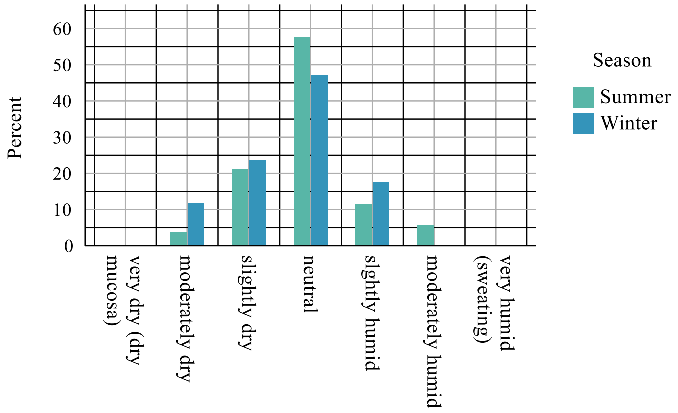


Figure 60. Conservatory of Turin. Classroom occupants' evaluation of humidity level. Phase I.

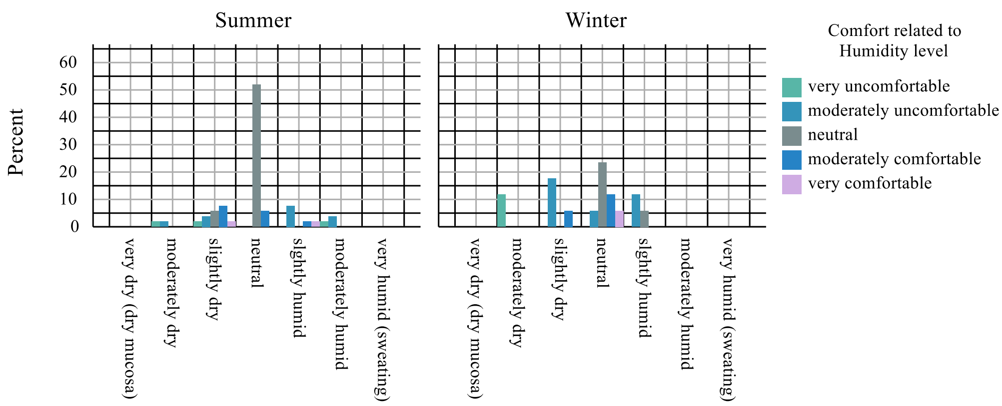


Figure 59. Conservatory of Turin. Classroom occupants' evaluation of comfort related to humidity. Phase I.

The last environmental parameter assessed by occupants is noise level. Figure 61 and 62 show the evaluation of noise level and the relative comfort condition

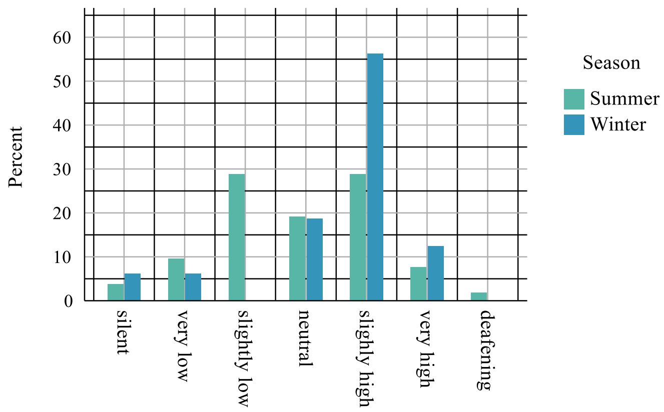


Figure 61. Conservatory of Turin. Classroom occupants' evaluation of noise level. Phase I.

respectively. As shown in the Figures, there is a great variability of noise perception in classrooms. Nevertheless, the most relevant data is that a very low percentage of classrooms are judged as "neutral", in terms of both noise level and comfort. In general, those voting in the upper part of the scale are uncomfortable. This data are very useful for the administration, in order to evaluate the interventions done in 2015, since many efforts were made in order to try to enhance classrooms acoustics (e.g. doors, sound absorbing panels in each room etc.).

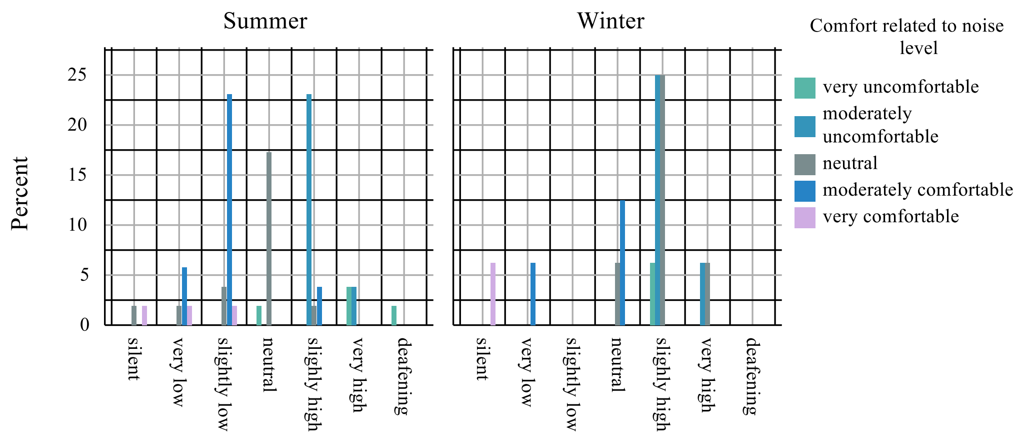


Figure 62. Conservatory of Turin. Classroom occupants' evaluation of acoustic comfort.

The last investigated aspect of this part of the questionnaire was local discomfort, as shown in Figure 63. The most relevant aspect emerging from the figure is the high percentage of occupants declaring a problem of "not sufficient air movement", which is normally linked to air quality problems. This seems not coherent with what previously shown about air quality evaluations. However, it could represent the cause why occupants disrespect the prohibition of operating windows, if that is the case.

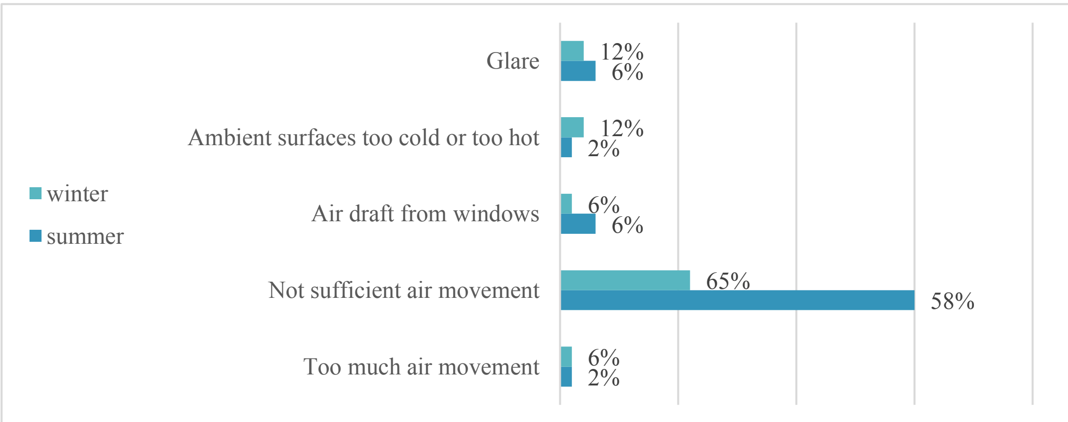


Figure 63. Conservatory of music. Classroom occupants' evaluation of local discomfort. Phase I.

The fourth part of the questionnaire for MLC occupants is very reduced. The only aspect relevant for evaluating phase II's strategies is clothing level, which is shown in Table 34. Similarly to offices, the large majority of occupants wear a medium level of clothes for both summer and winter season. Of course, also in this case this aspect can be considered to encourage occupants to adjust layers of clothes in order to adapt to the indoor environment.

Table 34. Conservatory of Turin. Classroom occupants' clothing level. Phase I.

Question	Options	Votes
IV-1. **In which of these categories do you recognize your usual clothing for the current season (summer)?**	*Light: t-shirt, light skirt or short pants and sandals*	14%
	Medium: light pants/skirt, short-sleeved shirt, light socks and shoes	80%
	Heavy: cotton shirt (long-sleeved) work pants, wool socks and shoes	6%
IV-1. **In which of these categories do you recognize your usual clothing for the current season (winter)?**	*Light: Trousers, long-sleeved shirt (cotton), cotton pullover, cotton socks and office shoes*	23%
	Medium: Trousers, long-sleeved shirt, suit jacket, wool socks and office shoes	65%
	Heavy: Trousers, wool shirt, wool pullover, wool socks and boots or winter shoes.	12%

From the fifth part of the questionnaire, the most relevant aspect to elaborate strategies was the assessment of occupants' control perception and compliance with their real availability. Figures 64 and 65 show these aspects. In figure 64, the most

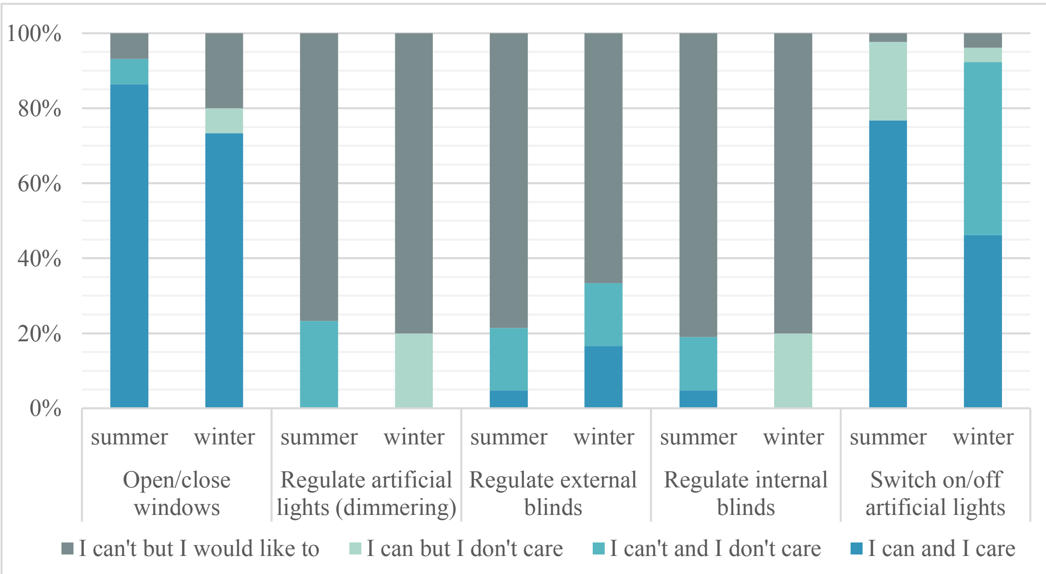


Figure 64.Conservatory of music Classroom occupants' perceived control opportunities, Phase I (1).

relevant data is the perceived control about windows opening. In fact, the large majority of occupants (around 80%) think that they can operate them. This means that the sign positioned in each classroom, forbidding the use of windows, was not seen by occupants (even if it is positioned near or on the window) or occupants did not take it as a "real" prohibition. Another interesting information is that most occupants were aware of the fact that they cannot use external blinds (and that they don't have internal ones), but 80% of them would like to have them.

In figure 65, it can be seen that a notable percentage of occupants were not aware of the fact that they're allowed to operate thermostats. Anyway, while in summer the large majority of them would like to have these controls, in winter the percentage of occupants who would like to directly operate systems is lower.

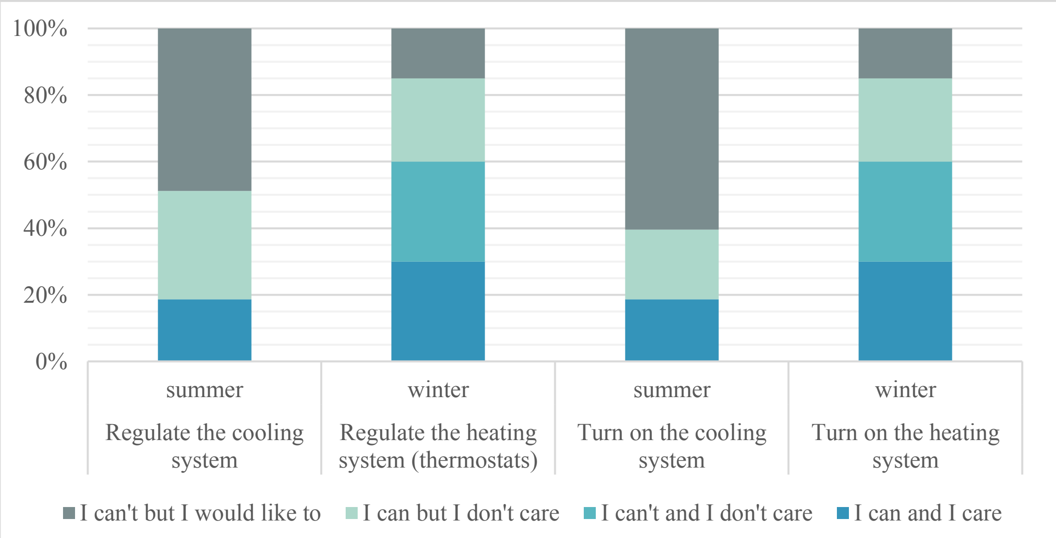


Figure 65. Conservatory of music Classroom occupants' perceived control opportunities, Phase I (2).

11.3 Phase II

Phase II strategies should pursue three objectives, as mentioned in Part II of this work; lower the building's energy consumptions (1), enhance comfort perception and behaviour of occupants (2) and ameliorate or solve indoor environmental critical situations related to artworks' conservation (3). Of course, for this case study the main objectives to be pursued will be the first two. As mentioned in Part II, before deciding the strategies to be applied, a seasonal report of Phase I analyses was shared and discussed with the administration in a specific meeting (the report can be visualized in the CD rom with annexes). In the following, the strategies' proposals and implementation are described for cooling and heating seasons.

11.3.1 Summer season strategies' proposals and implementation

In the following, the strategies will be described and justified based on what emerged from Phase I's analyses. Phase II – summer took place from the 20th of July until the end of September, so slightly after what was planned at the beginning of the experimentation.

Offices

For the office part, no strategies were proposed for **BMs**' group. In fact, the cooling system is handled autonomously by BOs and no other BMs-related necessities emerged in Phase I. For **BOs** instead, several potential education themes emerged from the analyses. The mean for communicating and engaging them was chosen together with the administration, who decided to use **newsletters** as a unique mean to communicate and diffuse information. In the following, Table 35 summarizes the themes that were chosen to be addressed as BOs strategies for summer season. As mentioned, the chosen communication mean was the newsletter, which could be a "longer" explanation or a "wisdom nugget". The choice of providing a certain information in a longer or shorter form depended on the possibility of grouping different information in only one communication or leaving only a few information in a shorter and more specific one. For example, the newsletter encouraging a more frequent and aware use of windows was delivered as a wisdom nugget, while several personal adjustment advices were grouped into a unique newsletter. Four newsletters were sent during Phase II in summer (the first on July's last week and the others on September, since most office workers are on vacation on August). From a graphical point of view, newsletters and wisdom nuggets were similar to those shown in Chapter 7.

Table 35. Conservatory of Turin. Office BOs strategies for summer season.

Interface type or control	Strategy	Reasons to adopt the strategy (identified in Phase I)
Personal adjustment	Drink cold beverages	Avoid overheating (TSV=slightly warm or warm >20% of votes)
	Adjust layers of clothes	BOs are not much active in using clothes adjustments to adapt to the indoor environment
	Movement to avoid the pain due to the air conditioning (e.g. muscles' rigidity)	TSV=slightly cool or cool ~25% of votes
HVAC systems	Teach how to use multi-splits and set a proper temperature, as well as de-humidification mode	~25% of TSV<0. Moreover, ~37% of BOs perceive a humid environment but t
Windows	Teach how to use windows to guarantee a good IAQ	About 20% of BOs never open windows
External and internal blinds	Teach users when it's better to open or close external and internal blinds in different situations (e.g. glare, low natural light level)	22% BOs signalled glare as a local discomfort problem, but they do not operate internal and external blind to mitigate the problem.
Lights	Teach BOs how important is to turn on lights just when the natural light is not sufficient	~20% BOs turn on lights when they arrive at the office in the morning.
	Teach occupants how important is to turning off lights when leaving the room	About 60% BOs switch off artificial lights only when they leave the office at the end of the day.
Generic energy-related education	Insights about internal and external heat sources in summer	To mitigate overheating

Classrooms and auditorium

In the following, the **<u>strategies proposed to the BMs</u>** are shown on Table 36, which synthesizes the strategies' description, cause of adoption and implementation, since some interventions were proposed but not accepted by the administration.

Table 36. Conservatory of Turin. Phase II strategies for classrooms. BMs - summer season.

Interface type or control	Strategy description	Cause of adoption	Implemented (Yes/No)
HVAC systems	Change systems' schedule –reduction of operation hours	Cooling system was switched on during unoccupied hours.	Y
	Limit BOs possibility to change temperature set-point – e.g. limit the range of temperature they can set in the thermostats	Classrooms' thermostats had very wide ranges for the temperature set-point (in summer the allowed range is T=20°C-30°C).	N
	Program thermostats in a way that after a period the set-point return to a prefixed value (general set-point)	Avoid energy wasting or uncomfortable conditions for the following occupants.	N
	Increase the temperature set-point (general)	Temperature general set-point T=24°C below the law prescriptions (more than 30% of BOs' TSV was slightly cool or cool, which caused ~40% uncomfortable votes).	Y
	Mechanical ventilation –change operation schedule	Mechanical ventilation was used also during un-occupied times.	Y
	Mechanical ventilation –change temperature set-point	The temperature set-point in summer was T=20°C	Y
Windows*	Night or early-morning fixed openings	Reduce the cooling demand and naturally ventilate classrooms.	N
External blinds	Remove the prohibition of operating windows in order to let BOs operate external blinds	Glare and overheating especially in some classrooms facing west (several complains with the maintenance manager).	N

Doors	Establish a schedule for internal door opening in order to activate the mechanical ventilation	Poor air quality especially on the mezzanine level (~60% BOs voted "not enough air movement as local discomfort cause).	N

Table 36 was elaborated in order to show how strategies could be classified in each building in which the methodology is applied. Moreover, the table shows that strategies can also not being accepted by administrations. However, from a methodological point of view, it is important to report them together with the reasons why the experimenter proposed them. In the following, both accepted and refused strategies are described and motivated more in detail.

Cooling system – During Phase I, the declared temperature set-point in classrooms and auditorium was 24°C. Nevertheless, in classrooms, about 30% of occupants felt slightly cool or cool. Moreover, this set-point was lower than the national limit expressed by the DPR n.412/93, which is 26°C (Italian Parliament, 1993). At the same time, some zones had overheating problems directly reported to the BMs. During Phase I, the temperature was completely manageable by users using the thermostats in each room or the control panels on the fan-coils. Nonetheless, the large majority of them seemed not aware of this control option. Anyway, the proposed strategy was to change the general set-point (as shown in Table 37) and insert a daily reset of the temperature set by users in the thermostats, in a way that every morning every room would be set according to the general set-point. Moreover, a limitation of the temperature set-point range was proposed, with a ±3°C limit. About the schedule of operation, during phase I the system was functioning from 7:00 to 19:00 every day (including Sundays). Moreover, in the auditorium the system operation was extended until midnight, independently from concerts. For this reason, the proposal was to shorten the operation schedule as shown in Table 37.

Mechanical ventilation – During Phase I, the declared temperature set-point for the air outlet in classrooms was 20°C. This set-point is very low for being in summer period. Even if technicians justified it claiming that a "fresh" air flow could enhance the perception of air quality, this could also have caused the sensation of cold voted by more than 20% of occupants. Moreover, since about 60% of occupants claimed "not sufficient air movement" as a cause of local discomfort, this strategy was not very efficient. For this reason, the temperature set-point was changed (Table 37). About the operation schedule, during Phase I the mechanical ventilation had the same schedule as the cooling system. This means that it was functioning also during un-occupied hours, so a schedule change was implemented (Table 37). Unfortunately, the not sufficient air movement claimed by users had an objective cause. In fact, probably the mechanical ventilation worked less than expected due to a system's realization problem, as explained before.

Having discussed these aspects in a meeting with technicians, the maintenance manager and the consulting engineer, the strategies listed in Table 35 were agreed for Phase II-summer season for classrooms and the auditorium. The strategies were slightly different for July, August and September to different necessities of use of the conservatory. The automatic reset of thermostats and the limitation of the temperature range were not accepted by technicians due to technical limitations of the thermostats. In fact, the technicians could not do it remotely and the thermostats could not be set to do it automatically. The strategies were implemented only starting from the 20th of July, due to technicians' delays. At the end of August, the administration asked to have a Temperature set-point of 26°C instead of 27° in September (in classrooms), because they were afraid of receiving complains for a too high air temperature.

Table 37. Conservatory of music. HVAC strategies for summer season - Phase II.

	Cooling system – Classrooms	**Mechanical ventilation– Classrooms**	**AHU auditorium**
July 2018 (from the 20th) and August 2018	Temperature set-point: 27°C Operation schedule: 9:00-18:00 + switched off on weekends	Temperature air outlet: 25°C Operation schedule: 9:00 – 18:00 + switched off on weekends	Temperature set-point: 27°C HR set-point:50% Operation schedule: 10:00-22:00 only in case of concerts, otherwise 10:00-18:00. Switched off in weekends except in case of events.
September 2018	Temperature set-point: 26°C		Temperature set-point: 26°C

During the strategies' implementation, a monitoring campaign was conducted in collaboration with the consulting engineer. The campaign took place between the 25th of July and the 3rd of August. The monitored classrooms were 6A, 5A, 18 and the auditorium. The administration asked to monitor the auditorium especially to verify the HR fluctuations due to the switching-off of the AHU during weekends. In fact, the ancient instrument professor was worried about the fluctuations' repercussions on the wooden organ.

Windows management. For windows, two possible strategies' proposals were discussed with the technicians and the administration. First, the proposal of removing the prohibition due to the problems of operation of the mechanical ventilation (highlighted also by the BOs questionnaires). In fact, if the mechanical ventilation does not work, BOs should be allowed to open windows, at least in the classrooms in which the external window is operable. Moreover, most occupants probably operate them anyway, as it emerged from the questionnaires. This causes a problem for mezzanine level's classrooms, in which the "external" window is shared with the ground floor classrooms. For this reason, the proposal was to establish a scheduled horary in which the windows could be opened in the mezzanine level and the ground level at the same time to ventilate both rooms. Nevertheless, this proposal was refused by the administration. The second proposal was the opening of windows in early morning for around 30 minutes (when the coadjutor staff arrives, around 7:00), in order to have free cooling and natural ventilation and the same time. However, also this strategy was refused, since the administration refused to ask to the coadjutor staff to perform this operation every day.

Internal doors. Following the same approach of the first strategy proposed for windows, it was proposed to ask BOs to open internal doors in order to activate the mechanical ventilation. In particular, alternative to the strategy previously described for windows, it was proposed to establish "schedules" of door opening, in order to encourage BOs to do it and allow the mechanical ventilation to work and re-establish a good air quality in the classrooms. This proposal was only partly rejected. In fact, it was agreed to provide the advice of opening doors in case of bad air quality (in the comfort advices' sign), but it was refused to establish "opening schedule" to be shared by every class.

Internal and external blinds. Internal and external blinds are fundamental in summer season in order to save energy and reduce the cooling load. Unfortunately, at the Conservatory there are not internal blinds in the classrooms and the external blinds cannot be operated due to the prohibition of operating windows. The proposal was to remove the prohibition of operating windows in order to let occupants operate external blinds, especially on the second floor. In fact, in the classrooms of the second floor facing west, there are glare problems and overheating, especially in summer afternoons. Since there are not internal blinds, and the external blinds can be operated using the wire positioned between the "old" and the "new" window, the only way to operate them is to open new PVC windows. This proposal was not accepted because the external blinds were considered too old and "dangerous" for BOs.

As regards of **BOs strategies**, in Part II of the thesis three means were described; workshops, newsletters and signs. For classroom occupants, a workshop and several types of signs were proposed as Phase II's strategies. Nonetheless, the administration rejected the workshops due to organizational problems (finding a proper space and a horary that could fit the schedules of most professors and office workers). Moreover, the workshop should have been organized during the exams period (July or September), which was not possible due to the scarcity of available spaces.

About the signs, all the three types described in Chapter 7 were adopted; "Comfort advices", "Before leaving the room… please remember" and the instruction for using the thermostats (Classrooms of mezzanine, first and second floor) and the fan-coils' controls (Ground-floor) . The signs were studied based on occupants' control possibilities and were similar to those presented in Chapter 7. Following the characteristics of the classrooms of ground floor (which are provided with fan coils) and those of the mezzanine, first and second floors (which are provided with radiant panels), the instructions on signs were different, as well as the comfort advices and the "before leaving the room…". Therefore, for each sign typology two versions were prepared; one for ground- floor classrooms and one for the others. The used signs can be visualized in the Annexes CD attached to the thesis.

11.3.2 Winter season strategies' proposals and implementation

Differently from what happened for the summer strategies, for winter ones the meeting was done only with the conservatory administration, due to unavailability of the technicians. However, the changes proposed for HVAC systems operation should have been implemented from around the 15^{th} of December.

Offices

In the office part, no strategies were addressed to **BMs** in terms of changes of HVAC settings. In fact, the heating set-point was T=22°C (which is higher than the limit established by the DPR n.412/1993 (Italian Parliament, 1993) but within the 2°C tolerance), but more than 50% of occupants declared that they felt slightly cool or even cool. Since rising the set-point was not advisable, the best option was to provide BOs with alternative strategies to reduce thermal discomfort. For **BOs**, newsletter were proposed as a mean to communicate information and education similarly to summer season. In fact, during the Phase II-winter period four newsletters in form of longer communications or wisdom nuggets (as shown in Chapter 7) were sent to the office workers. Regarding the topics, in addition to those shown in Table 35, those shown in Table 38 has been added, since they were more specific for winter season.

Table 38. Conservatory of Turin. Office BOs strategies for winter season, Phase II.

Interface type or control	**Strategy description**	**Reason to adopt the strategies**
Personal adjustment	Advise BOs to drink hot beverages	In order to adapt to the indoor environment without increasing the
	Advise BOs to add adjust layers of clothes as adaptive action	

	Advise to use a blanket when feeling too cold	energy demand (more than 50% of BOs expressed a "slightly cool" or "cool" TSV
	Position a bowl of water to humidify the indoor environment in case of dry air	About 30% of BOs are not comfortable due to dry air.

Classrooms and auditorium

In winter, the proposed strategies for **BMs** were not much different from those proposed for Phase II in summer season. In fact, many problems that were already discussed for summer were signalled also for winter (e.g. the poor air quality in the mezzanine level). Table 39 summarizes the proposed changes of the temperature set-points and operation schedules.

Table 39. Conservatory of music. HVAC strategies for phase II - winter.

	Heating system – Classrooms	**Mechanical ventilation – Classrooms**	**AHU auditorium**
From December 15th 2018 to the end of March 2019	Temperature set-point: 21°C Operation schedule: 7:00-18:00 + switched off on weekends	Temperature air outlet: 21°C Operation schedule: 9:00 – 18:00 + switched off on weekends	Temperature set-point: 21°C RH set-point:50% Operation schedule: 8:30-22:00 only in case of concerts, otherwise 10:00-19:00. Switched off in weekends except in case of events.

About the other strategies, the proposals were similar to the ones of summer (except the windows' opening for free cooling). The difference was that in this case the administration agreed to establish a schedule for windows opening on the mezzanine and ground floor levels. In fact, in the months before Phase II, they received more and more complains about the poor air quality in this area, so they decided to try this approach.

Therefore, they agreed to establish a schedule according to which **BOs** could open windows on the mezzanine level and on the ground floor at the same time, based on a panel that has been positioned in the classrooms (described in the next paragraph). Of course, beyond opening the new "pvc" window, ground floor occupants should open the "original" window to naturally ventilate the two rooms. The proposed schedule was a windows' opening every 2 hours for 10 minutes starting from 11:00-11:10 and finishing at 17:0-17:10. The other signs positioned in classrooms were completely re-designed in order to be used both in summer and winter. In fact, for example, Figure 8 shown in Chapter 7 was a "comfort advices" sign for summer season. Since the winter phase II was the last one, the idea was to re-design all signs in a way that they could have been left there also after the experimentation. The signs can be visualized in the CD annexes.

11.4 Phase III

The following paragraphs are dedicated to describe the impact of the strategies explained in par 11.3. The impacts are assessed in respect of the objectives of the strategies, which were the reduction of the building's energy consumptions (1) and the enhancement of comfort perception and behaviour of occupants (2).

11.4.1 Assessment of the impact of strategies on the building's energy consumption

Summer season

In the following, Table 40 shows the comparison of the monthly **thermal energy** consumptions of the months corresponding to Phase II (July-September 2018) in respect to the corresponding months of Phase I (July-September 2017). Of course, in summer the thermal energy consumption is much reduced in respect to winter. However, major relevance should be given to the monthly and seasonal difference normalized based on the cooling degree days (CDD), which shows a "seasonal" (July to September) thermal energy reduction of 37%.

Table 40. Conservatory of Turin. Thermal energy consumption phase I vs phase II- summer.

	Cooling degree days CDD	**Natural gas cons. [kWh$_t$]**	**Natural gas [kWh$_t$/CDD]**	**Monthly difference**	**Seasonal difference**	**Monthly difference (CDD)**	**Seasonal difference (CDD)**
Jul-17	13	3978	306				
Aug-17	36	7486	208				
Sept-17	1	0	0				
Jul-18	28	8331	298	109 %	**-20%**	-3%	**-37%**
Aug-18	30	823	27	-89%		-87%	
Sept-18	0	0	0	0%		0%	

Electric energy consumption is particularly relevant in summer, since one of the main expected reasons why the energy consumption increased after the operations of 2015 was the insertion of the cooling system. As mentioned in Phase I, even if the insertion of the cooling system (and the mechanical ventilation) should have caused an increase in the electric energy consumption, the trends shown in the first phase were not due solely to this insertion, but more to how the new cooling system and mechanical ventilation were handled. In fact, the implementation of new temperature set-points and operational schedule (as described in par. 11.3) brought notable results, as shown in Table 41. In fact, 38% of electric energy was saved in the months of Phase II in respect to those of Phase I. Moreover, it should be noticed that in July the reduction is limited only because the systems' operation changes took place starting from the 20th of July.

Table 41. Conservatory of Turin. Electric energy consumption in phase I vs phase II - summer.

	EE [kWh$_e$]	**Monthly difference**	**Seasonal difference**
Jul-17	56363		
Aug-17	54100		
Sept-17	55019		
Jul-18	44707	-21%	
Aug-18	30126	-44%	**-38%**
Sept-18	28497	-48%	

A very interesting analysis is, at this point, the comparison between the electric energy consumption before the works of 2015 and after, in order to see if the "operational strategies" could reduce the "negative" impact that the insertion of the cooling system and the mechanical ventilation had on the overall EE consumption. In the following, Table 42 shows the comparison between the energy consumption of summer 2014 (before renovation works) and summer 2018 (phase II). It seems very surprising that, overall, there has been a reduction of electric energy consumption, since in that summer there was any cooling system or mechanical ventilation in the classrooms.

Table 42. Conservatory of Turin. Electric energy consumption before renovation works and phase II - summer.

	EE [kWh$_e$]	**Monthly difference**	**Seasonal difference**
Jul-14	49326		
Aug-14	49765		
Sept-14	50603		
Jul-18	44707	-9%	
Aug-18	30126	-39%	**-31%**
Sept-18	28497	-44%	

However, Table 43 can explain the reason. In fact, at the conservatory there are two electric energy counters. More or less, one corresponds to the consumption of the auditorium and the other one to the rest of the building. Looking at Table 43, which shows the EE consumption of the whole building excluded the auditorium part, it can be seen that the electric energy consumption increased a lot in this part. Nevertheless, overall, there has been a reduction, since the auditorium has a great weight in the total electric energy consumption of the building and in 2014 it was handled similarly to phase I. Therefore, applying new temperature set-points and operational schedules reduced the energy demand notably, with a great weight also on the overall energy consumption of the building.

Table 43. Conservatory of Turin. Electric energy consumption (without auditorium) in summer season 2014 vs 2018 (phase II).

	EE [kWh_e]	Monthly difference	Seasonal difference
Jul-14	4041		
Aug-14	2108		
Sept-14	4561		
Jul-18	6090	51%	
Aug-18	5036	139%	**67%**
Sept-18	6720	47%	

Looking at costs of raw energy shown in Table 44, the trends shown for the energy consumption is confirmed with about the same extent of percentage reductions for both thermal energy and electric energy.

Table 44. Conservatory of Turin. Raw energy costs comparing phase I and II - summer.

	Natural gas costs (total bill)	Monthly difference	Seasonal difference	EE costs	Monthly difference	Seasonal difference
Jul-17	85.96 €			3,645.75 €		
Aug-17	161.76 €			3,888.00 €		
Sept-17	0 €			3,823.60 €		
Jul-18	187.05 €	118%		2,806.07 €	-23%	
Aug-18	18.54 €	-89%	-17%	1,826.97 €	-53%	-44%
Sept-18	0 €	0%		1,745.51 €	-54%	

As advised in Chapter 8, at the end of Phase II the technicians were asked about the effective implementation of the proposed strategies, and they declared that they applied what was agreed during the meeting.

Winter season

In the following, Table 45 lists the analyses regarding **thermal energy**. Differently from the previous section, in this case the comparison was made not only between Phase II and Phase I, but also with previous years and "before" the works of 2015. This choice was due to the fact that between the Phase II and the Phase I an increase of natural gas consumption was detected. Moreover, in Phase I, as mentioned before, the heating system had problems and did not work for several days, in fact the natural gas consumed in January was notably lower than the other years (which can be seen since the monthly difference between January 2018 and January 2019 was +81%). For this reason, further analyses comparing the consumptions also with the previous years were necessary. Considering the mean of natural gas consumption of the three seasons shown in Table 45 previous to phase II, the result would have been **+4%** (+6% if considering the normalized results). This was the seasonal difference of winter 2018/19 versus the mean of the previous years. In fact, the proposed strategies did not change much the temperature set-point, but they did asked a reduction of the operation schedule (e.g. the switch-off during Sundays), so a change would have been expected. Anyway, an explanation of this trend has been found. In fact, at the end of February, several complains were done to the administration due to a too high air temperature in the classrooms. What happened was that, since the outside temperature was relatively high for the period, users operated the thermostats trying to switch-off the heating system. When the experimenter (the author of the thesis) went to classrooms to try to understand what happened, she found a number classes with thermostats showing the current temperature of 24°C. However, looking at the set-point set, it was 16°C. What happened was that users, feeling too hot, tried to switch off the thermostats by setting a very low temperature. Anyway, below a certain temperature (allowed range), the thermostat reset and set the "general" set-point, that should have been set by the technicians according to the indications shown in Table 39. Anyhow, the technicians did not applied the winter set-points, so the general set-point remained 24°C for almost all winter season. Therefore, in those classrooms in which users did not use the thermostats properly or tried to switch-off the heating system setting a temperature outside the allowed range, they actually heated the classes more. Of course, this resulted in higher thermal energy consumption, especially in February.

Table 45. Conservatory of Turin. Thermal energy consumption's comparison between phase II and previous years. Winter season.

	HDD	**Natural gas [kWh$_t$]**	**ETN [kWh$_t$/CDD]**	**Monthly difference**	**Seasonal difference**	**Monthly difference (HDD)**	**Seasonal difference (HDD)**
Dec-17	562	109597	18.23				
Jan-18	456	64509	13.23				
Feb-18	478	97458	19.06				
Mar-18	406	53397	12.30				
Dec -18	522	104421	18.70	-5%	**12%**	3%	**24%**
Jan -19	538	116794	20.30	81%		53%	
Feb -19	384	86561	21.08	-11%		11%	
mar-19	290	55782	17.99	4%		46%	
Dec -16	497	88978	16.74				
Jan -17	579	141113	22.79				
Feb -17	402	81791	19.02				
Mar -17	260	52895	19.02				
Dec -18	522	104421	18.70	17%	**0%**	12%	**1%**
Jan -19	538	116795	20.30	-17%		-11%	
Feb -19	384	86561	21.08	6%		11%	
Mar -19	290	55782	17.99	5%		-5%	
Dec -14	510	75631	13.87				
Jan -15	496	137231	25.87				
Feb -15	396	90015	21.26				
Mar -15	299	58424	18.27				
Dec -18	522	104421	18.70	38%	**1%**	35%	**-2%**
Jan -19	538	116794	20.30	-15%		-22%	

Feb -19	384	86561	21.08	-4%		-1%	
Mar -19	290	55782	17.99	-5%		-2%	

About **electric energy**, Table 46 shows the comparison between the months of Phase I and Phase II - winter. As shown, the trends for electric energy are very similar to those shown for summer season, with a 39% seasonal decrease of EE consumption.

Table 46. Conservatory of music. Electric energy consumption phase I vs phase II - winter.

	Ee [kWh$_e$]	**Monthly Difference**	**Seasonal Difference**
Dec-17	36177		
Jan-18	44824		
Feb-18	42482		
Mar-18	34841		
Dec -18	21560	-40%	**-39%**
Jan -19	25428	-43%	
Feb -19	26084	-39%	
Mar-19	23430	-33%	

About costs, Table 47 shows the impact of strategies on the raw energy-related costs at the conservatory in winter season. However, differently from summer season, in which the energy tariffs remained approximately the same between phase I and II, in winter they slightly change, especially for electric energy. In fact, the natural gas energy tariff passed from 0.23€/smc approx. (phase I) to 0.24€/smc (phase II), while the EE raw energy tariff passed from 0.08€/kWh to 0.06€/kWh (phase II), which causes an overestimation of the seasonal average difference of energy-related costs. In fact, a normalized calculation would result in a reduction of electric energy related costs by 48% instead of 61%.

Table 47. Conservatory of Turin. Energy costs comparison of phase I and II - winter.

	Natural gas costs (total bill)	**Monthly difference**	**Seasonal difference**	**EE costs**	**Monthly difference**	**Seasonal difference**
Dec-17	2,389 €			2,087.36 €		
Jan-18	2,389 €			2,259.79 €		
Feb-18	2,562 €			2,400.64 €		
Mar-18	1,404 €			2,728.23 €		
Dec -18	2,360 €	-1%	**-6%**	885.95 €	-58%	**-61%**
Jan -19	2,632 €	10%		893.17 €	-60%	
Feb -19	1,956 €	-24%		914.36 €	-62%	
Mar-19	1,261 €	-10%		1,018.42 €	-63%	

11.4.2 Assessment of the impact of strategies on BOs' comfort perception and behaviour

Summer season

In the following, the results of the post-assessment questionnaire will be described by dividing the results of offices occupants and the ones from the classrooms' occupants, since the applied strategies were differentiated for these two BOs groups.

Offices occupants

Office occupants participated to phase III questionnaire in paper, differently from phase I, by request of the Conservatory director. The questionnaires were distributed to all office occupants on September 15th and gathered on October 15th 2018. All occupants (10 out of 10) participated. Figure 67 shows the evaluation of the temperature changes (+ 3 meant maximum increase while -3 maximum decrease), that occupants perceived in respect to Phase I (the previous summer). In offices, no strategies were implemented regarding temperature set-points since multi-splits are handled directly by BOs, so the results should be attributed only to their behavioural change. A similar comment can be done also for Figure 67, which shows the evaluation of thermal comfort during Phase II in respect to Phase I (the scale goes from -3, which means a maximum worsening, to +3, maximum enhancement, with "0" meaning "no change").

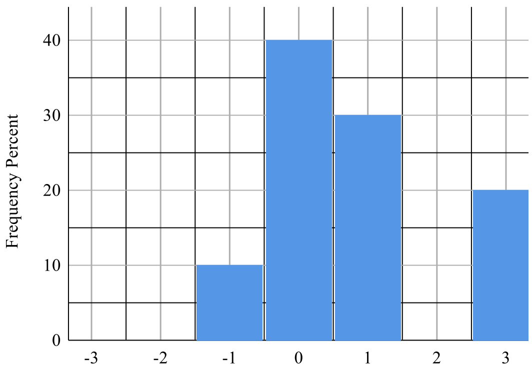


Figure 67. Conservatory of Turin. Office workers evaluation of indoor air temperature change during phase II - summer.

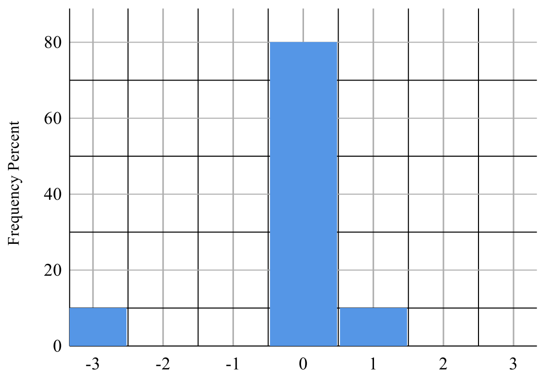


Figure 66. Conservatory of Turin. Office workers evaluation of thermal comfort change during phase II - summer.

Figure 68 shows the difference between the votes expressed during Phase I and during Phase II regarding the thermal sensation vote. Even if the operation of the multi-split was totally handled by BOs, these graphs show a positive trend regarding the behavioural change. In fact, it is possible that the educational means addressed to reduce the energy wasting in summer "worked". In fact, the thermal sensation vote shifted from the "cool" part of the scale to the "warm" part, which probably was caused by a reduced use of the cooling system. The figure confirms and explains the answers shown in Figure 67; it is not said that this trend is positive for BOs comfort, but it sure is regarding energy efficiency.

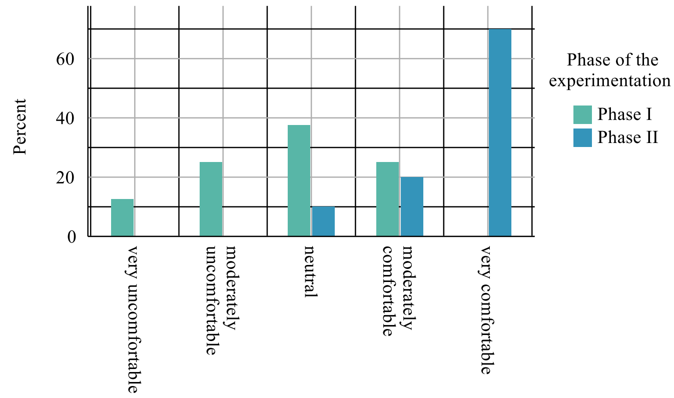


Figure 68. Conservatory of Turin. Office workers' thermal sensation vote phase I vs phase II - summer.

Looking at the thermal comfort votes shown in Figure 69, the positive trend highlighted for the thermal sensation vote is confirmed. In fact, the total percentage of people feeling thermally uncomfortable remained almost unchanged, while about half of the people that answered "neutral" before probably answered "moderately comfortable" in the second phase. This is a very good result, because it means that saving energy corresponded to an enhancement of comfort in this case.

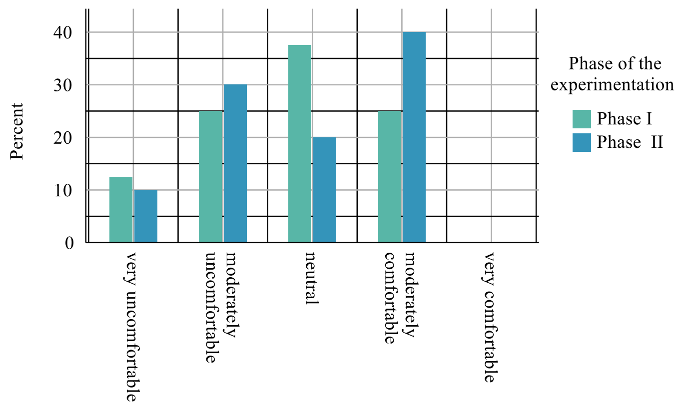


Figure 69. Conservatory of Turin. Office workers thermal comfort vote phase I vs phase II - summer.

Since in the offices the only "communication mean" used were newsletters, they also were the only mean that BOs were asked to evaluate in the post-assessment questionnaire. In particular, the majority of occupants saw the e-mail and also read it (80%) at least once (56%), while the other 20% never saw the newsletters. In the following, Figure 70 shows the answers to the question "did you change your behaviour towards the following control interfaces"? This question represents the behavioural change direct assessment. As shown, only a very small percentage occupants believed to have changed their behaviour. The only relevant percentage is the one referred to windows opening, which is about 20%.

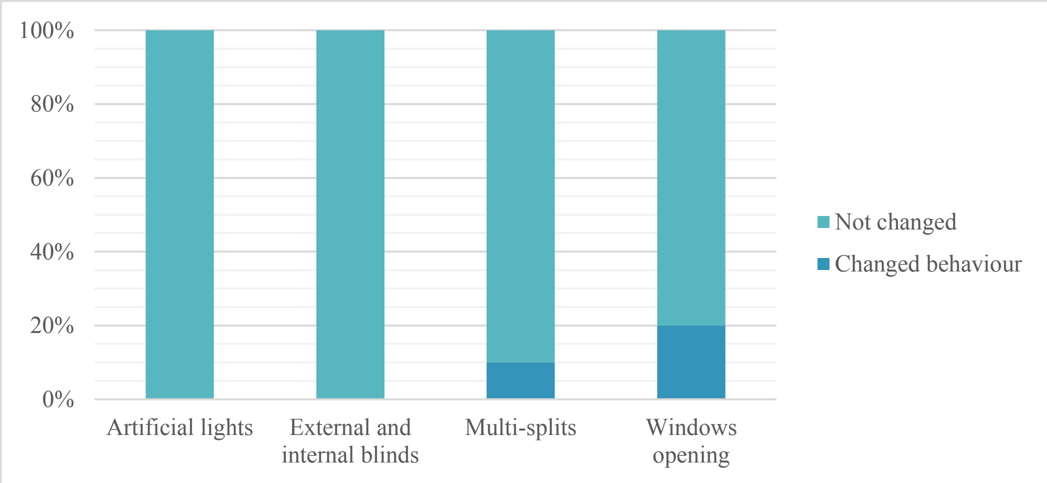


Figure 70. Conservatory of Turin. Office workers behavioural change towards some interfaces - summer season.

However, in Figure 70 behavioural changes can be recognized. Figure 70 represents the answers to a question (How often do you perform these actions due to thermal discomfort in summer season) that was repeated exactly in the same way for Phase I and II in order to assess the behavioural change indirectly. In phase I questionnaire, for example, only half of the occupants had the habit to adjust clothing when feeling thermally uncomfortable. In phase II, this percentage was reduced to 13%. Moreover, while during Phase I 25% of occupants did not turned off the cooling system when feeling cold, during phase II this percentage was reduced to 0. Moreover, occupants seems much more active with internal and external blinds and windows, differently from the self-report shown above.

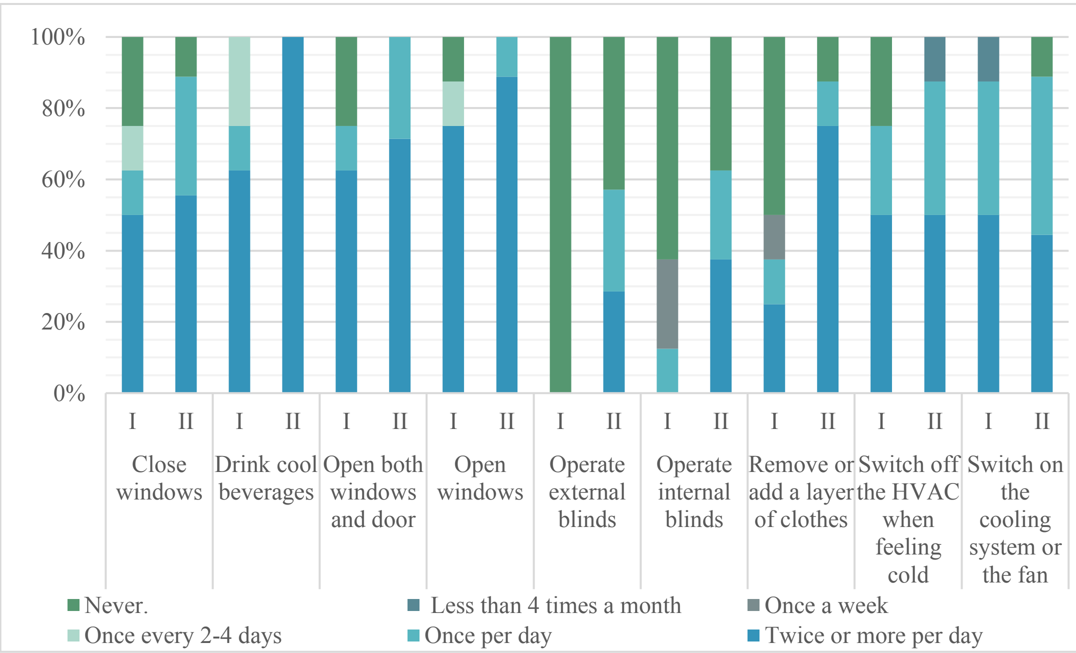


Figure 71. Conservatory of Turin. Office workers actions in case of thermal discomfort. Phase I vs Phase II - summer.

About artificial lights, Figure 72 shows another indirect assessment of behavioural change. While in the first Phase 14% of occupants switched-on lights when they arrived in the office in the morning, in Phase II they all declared that they switch on lights only in case of a not sufficient natural light level inside the room.

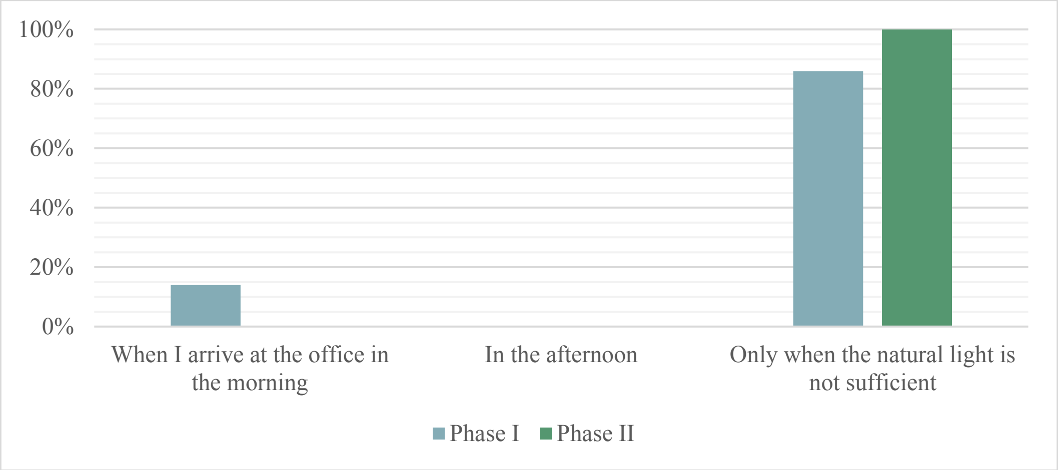


Figure 72. Conservatory of Turin. Office workers habits of switching on lights. Phase I vs phase II - summer.

Finally, the same indirect assessment was made also regarding the behaviour in terms of windows opening, which is shown in Figure 73. Also in this case, BOs behaviour seems to change quite a lot, differently from what declared and shown in Figure 71. The first positive aspect is that people, in Phase II, do not open windows due to the cold sensation related to the cooling system. Also the percentage of those opening windows when feeling too hot is halved. The importance of ventilating the indoor spaces has also been probably understood by a part of occupants, who did not ventilate the indoor space when arriving at the office in the morning.

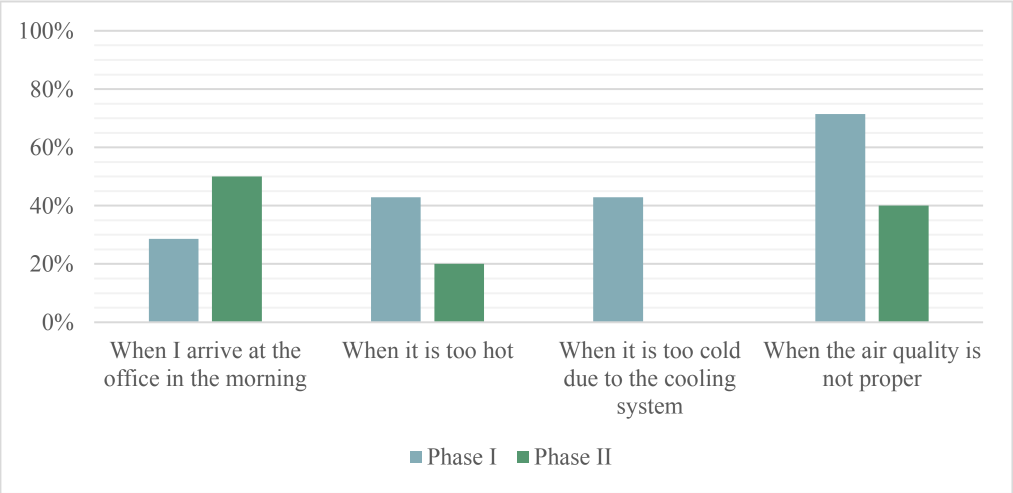


Figure 73. Conservatory of Turin. Office workers habits of windows opening. Phase I vs phase II - summer.

Classroom occupants

Classrooms' occupants participated to the questionnaire in paper, similarly to phase I. The method of distribution of questionnaires was similar to the Phase I, as well as the duration (15th of September-15th of October 2018). Unfortunately, differently from office workers, it is not said that the participants to this questionnaire campaign were the same of phase I. Moreover, only 14 occupants participated (in respect to 52 participants to the first phase summer questionnaire). Figure 74 shows the evaluation of the air temperature change (maximum increase +3 to maximum decrease -3) that occupants perceived in respect to Phase I (the previous summer). The majority of occupants voted that they perceived a slight decrease of temperature. In Figure 75, it is possible to see that this sensation brought to an enhancement of the thermal comfort perception (-3 meant maximum worsening of thermal comfort while +3 meant a maximum enhancement). The results shown in these figure are unexpected, since the general set-point was increased by 3°C. However, BOs were encouraged to use thermostats accordingly to their comfort necessities, so maybe those answering the questionnaire actually set the temperature in a way that they could feel cooler than the previous summer. Anyway, the objective of enabling occupants to set thermostats adequately for their comfort seems reached, at least for the respondents. The energy results shown in the previous paragraph showed that enabling BOs with this opportunity did not resulted in much energy wasting, since a notable energy saving was actually reached. Nevertheless, the previous statement should be compared with the "indirect evaluation" of thermal perception and comfort, since as shown for office occupants, sometimes the direct assessment is not entirely reliable.

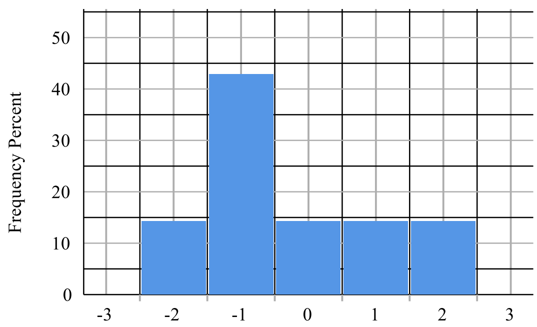


Figure 75. Conservatory of Turin. Classroom occupants' evaluation of air temperature change in phase II in respect to phase I - summer.

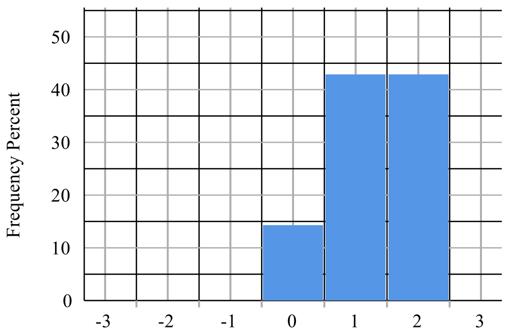


Figure 74. Conservatory of Turin. Classroom occupants' evaluation of thermal comfort in phase II in respect to phase I - summer.

These evaluations should be compared to the analyses shown in Figure 76 and 77. In fact, while in Phase I almost all thermal sensations were present among the votes, during Phase II the range of votes was more limited around the neutral zone, which should be good also from a thermal comfort point of view. In particular, the percentage of occupants feeling warm or hot is reduced to zero.

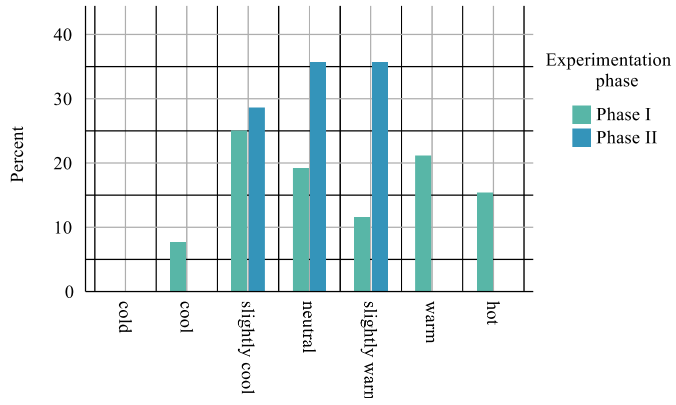


Figure 76. Conservatory of Turin. Classroom occupants' thermal sensation vote. Phase I vs phase II - summer.

Figure 77 shows thermal comfort votes. As mentioned for the previous figure, the graph confirms the positive trend of the previous one, since the around 45% of users feeling thermally uncomfortable in phase I was reduced to 7% in phase II.

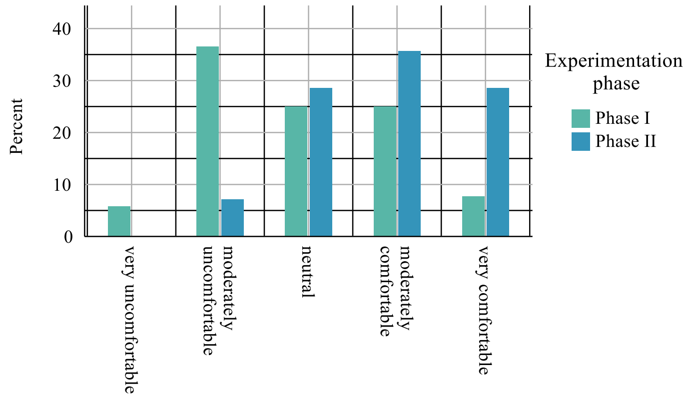


Figure 77. Conservatory of Turin. Classroom occupants' thermal comfort vote. Phase I vs phase II- summer.

About the second part of the questionnaire, which is dedicated to the evaluation of the communication means by BOs, Figure 78 shows that the signs positioned in the classrooms were noticed by all occupants. Moreover, the larger part of BOs read the signs at least once. The comfort advices panel was the most read (about half of the participants read it more than once). At the same time, the opinion about the useful of these signs shown in Figure 79 is various, even if the large majority of occupants evaluated the signs between 3 and 5 in a scale of five points for all types.

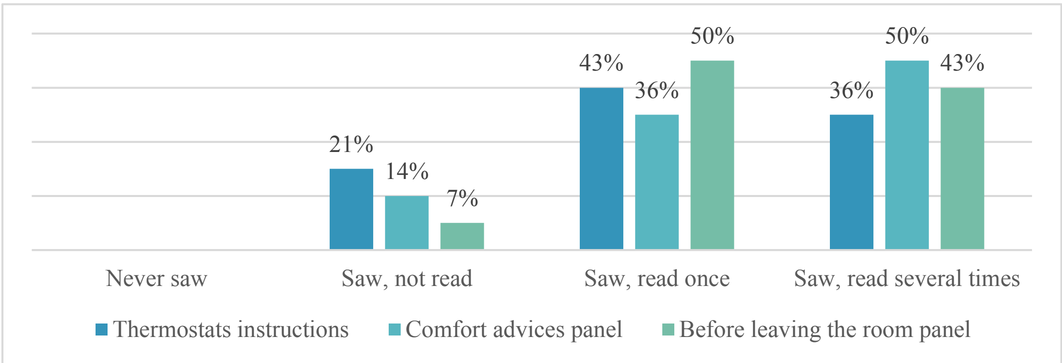


Figure 78. Conservatory of Turin. Classroom occupants' evaluation of signs - summer.

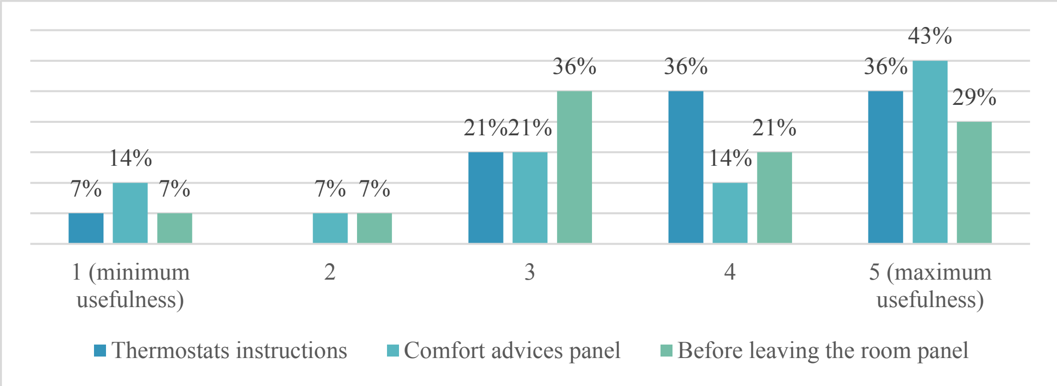


Figure 80. Classroom occupants' evaluation of signs' usefulness. Summer.

Finally, since most of the behavioural-related questions of first phase questionnaire were not asked to MLC BOs, there is not the possibility to perform the behavioural change indirect assessment as shown for office BOs. However, Figure 80 shows the results of the answers to the question: Did you change your behaviour towards the following elements? As shown, results are more promising than in offices, probably due to the presence of signs, which are continuous reminders of certain call to actions such as "switching off lights" before exiting the room. In fact, almost a half of occupants declared to have changed their behaviour towards windows and artificial lights.

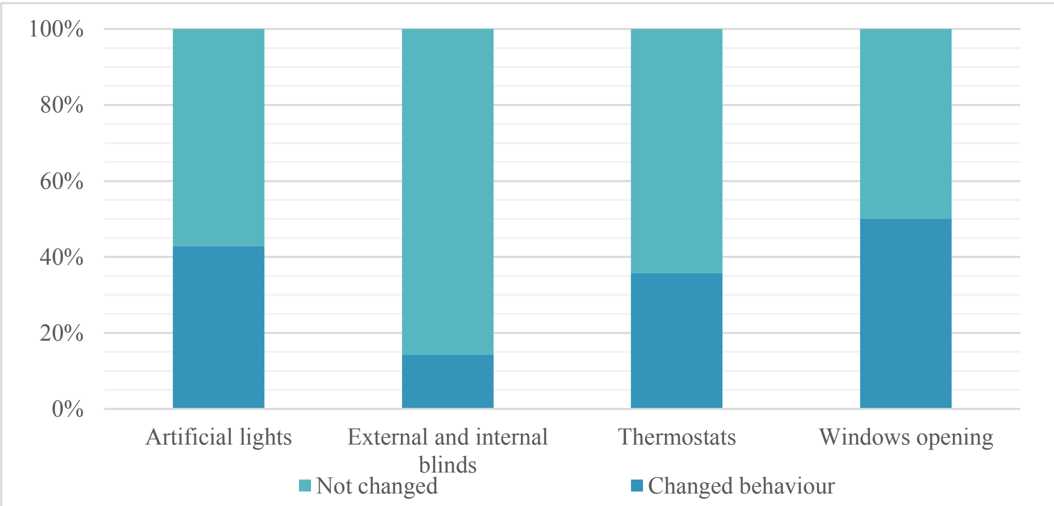


Figure 79. Conservatory of Turin. Classroom occupants' behavioural change direct assessment. Summer.

Winter season

Offices occupants

In offices, participants filled paper questionnaires, similarly to phase I. The questionnaire campaign took place from the 15th of March to the 15th of April 2019. 9 out of 10 occupants answered to the questionnaire. In the following, Figure 81 shows that the large majority of occupants did not noticed any changes in the temperature, which is correct, since the temperature set-point was not changed. Changes in this figure should be due to behavioural changes and adaptive actions. The same considerations can be done about the thermal comfort evaluations shown in Figure 82.

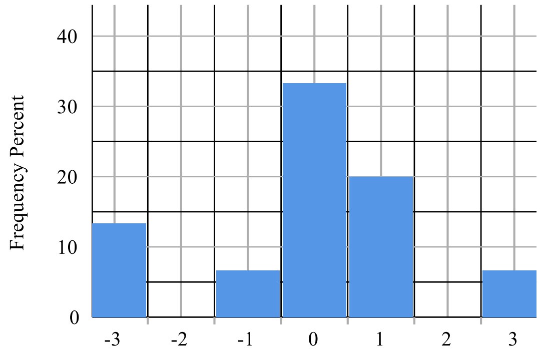


Figure 81. Conservatory of Turin. Office workers' evaluation of air temperature of phase II vs phase I - winter.

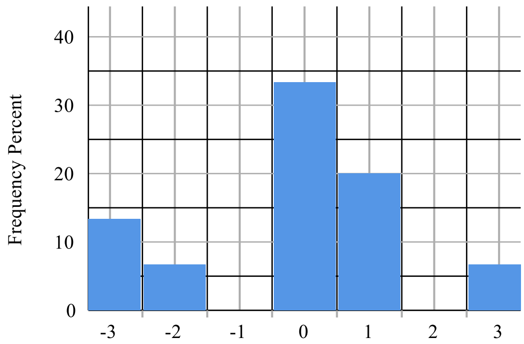


Figure 82. Conservatory of Turin. Office workers' evaluation of thermal comfort of phase II vs phase I - winter.

In the following, Figure 83 shows the thermal sensation votes and Figure 84 shows the thermal comfort votes in Phase I and Phase II. As it can be seen, even if the temperature set-point did not change, the thermal sensation seems to shift to the warmer part of the scale. In fact, there are no more "cold" votes. About the thermal comfort, the total percentage of occupants feeling comfortable did not changed. However, also in this case there was a little enhancement, since the percentage of occupants voting "very uncomfortable" was reduced. A possible cause of this trend are the personal adjustment strategies to deal with thermal discomfort.

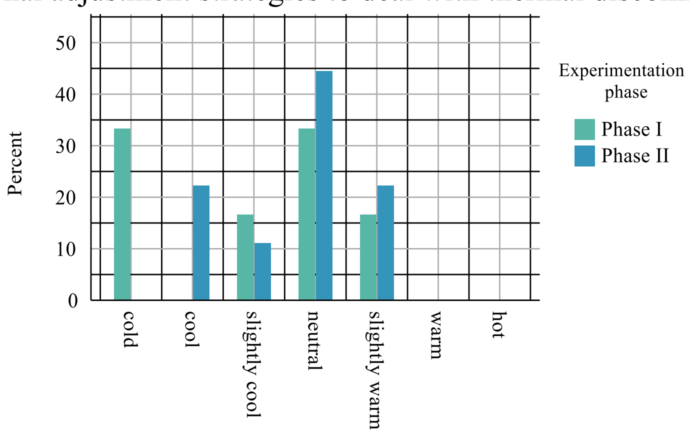


Figure 83. Conservatory of Turin. Office workers Thermal sensation vote in phase II vs phase I - winter.

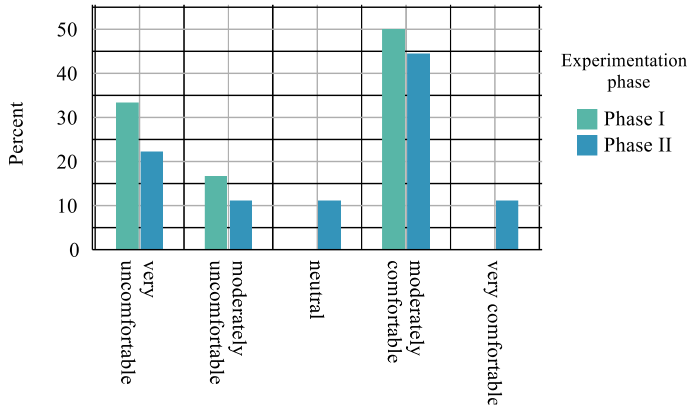


Figure 84. Conservatory of Turin. Office workers thermal comfort evaluation, phase II vs phase I- winter.

Since office BOs were provided only with newsletters, only this mean was evaluated. Analysing the data, it emerged that 11% of BOs never saw them, 33% of them saw and read them once, while 56% saw and read them several times. Figure 85 shows the self-evaluation made by offices' BOs about their change of behaviour towards some energy-related control interfaces. In respect of summer results, it seems that winter's newsletter were slightly more efficient, at least in terms of perceived behavioural change.

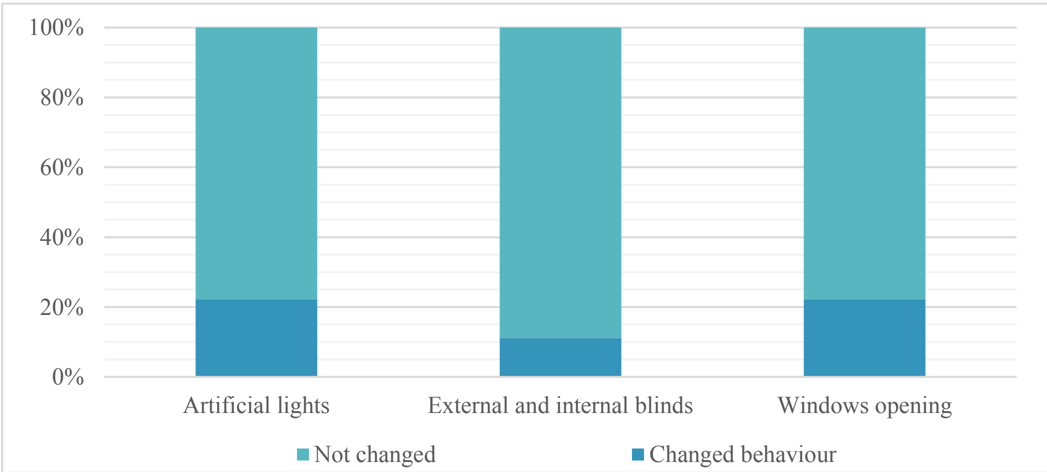


Figure 85. Conservatory of Turin. Office workers direct assessment of behavioural change - winter.

Figure 86 shows the indirect evaluation of behavioural changes towards several interfaces. The shown actions are related to the actions performed in case of thermal discomfort. As shown, it seems that during phase II occupants were more active in terms of personal adjustment, e.g. hot beverages' drinking or clothing adjustment, which is positive since they do not have thermostats available. At the same time, it is curious that certain BOs declare to switch on and off HVAC when necessary due to thermal discomfort, which can only be related to personal heaters, since they do not have control over the HVAC.

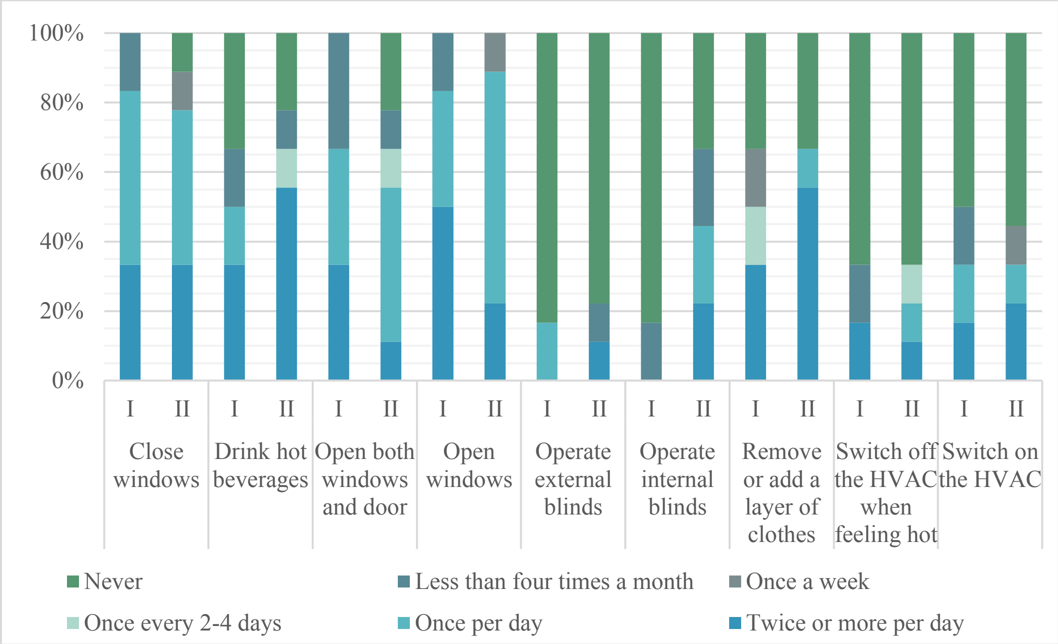


Figure 86. Conservatory of Turin. Office workers behavioural change indirect assessment - behaviour in case of thermal discomfort, phase I vs phase II - winter.

In Figure 87, an example of worsen behaviour occurs. In fact, in Phase II less occupants seems to open windows only when the natural light is not sufficient (BOs could choose more than one option).

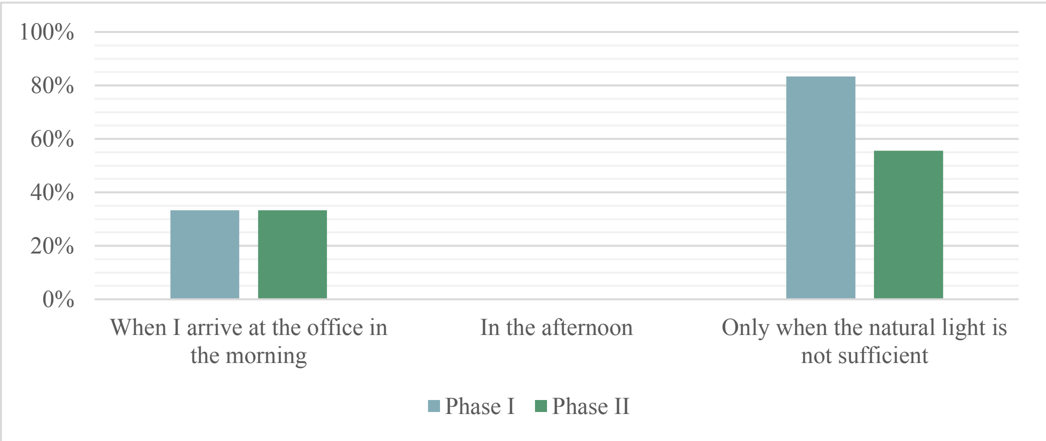


Figure 87. Conservatory of Turin. Office workers switching on artificial lights, phase II vs phase I - winter.

Differently from the previous graph, it seems that the windows behaviour did change positively in Phase II, as shown in Figure 88, since all occupants declare to open windows when the air quality is not proper and the percentage of those opening when it is too hot due to the heating system is reduced. It seems also quite normal that in winter season the percentage of people opening windows in the morning for natural ventilation was quite low, even if the reduction in respect to the previous phase is not positive.

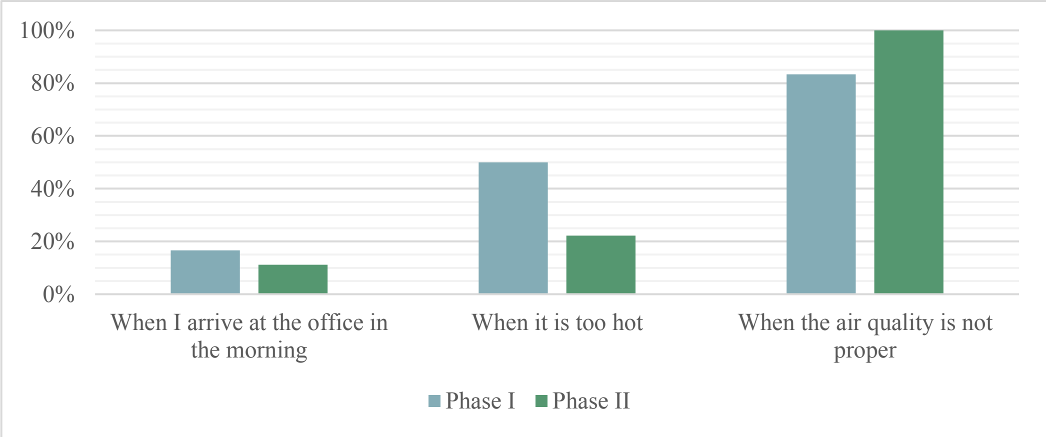


Figure 88. Conservatory of Turin. Office workers habits in terms of windows opening, phase I vs phase II - winter.

Classrooms occupants

In classrooms, the participants filled paper questionnaires, similarly to summer season. The questionnaire campaign took place from the 15th of March to the 15th of April 2019. 20 people participated to the questionnaire. As it can be seen in Figure 89, the majority of occupants did not noticed particular changes in the air temperature. Those who noticed it, declared an increase. About the comfort instead (Figure 89), the majority of occupants noticed slight enhancement.

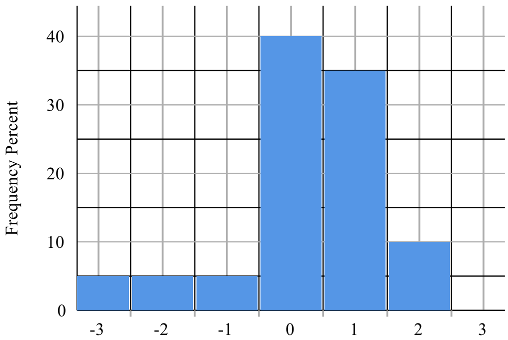


Figure 89. Conservatory of Turin. Classroom occupants evaluation of air temperature change, phase II vs phase I -

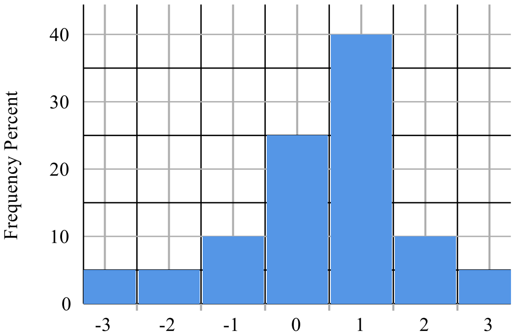


Figure 90. Conservatory of Turin. Classroom occupants evaluation of thermal comfort change, phase II vs phase I - winter.

Also looking at Figure 91, it seems that the thermal perception of occupants in the classrooms did not changed much. This could be realistic, since the temperature set-points, that should have been decreased by technicians in respect to those of the previous year, were not changed. They actually remained the same of summer season, but hopefully they were entered only in February, when some BOs tried to switch off the heating system as explained in par. 11.4.1. Actually, the results could also mean that occupants did not operated the thermostats much differently from phase I. The situation seems not to have changed much also in terms of thermal comfort, as shown in Figure 92, even if the percentage of BOs voting "very comfortable" increased notably, while those none reported a "very uncomfortable" condition.

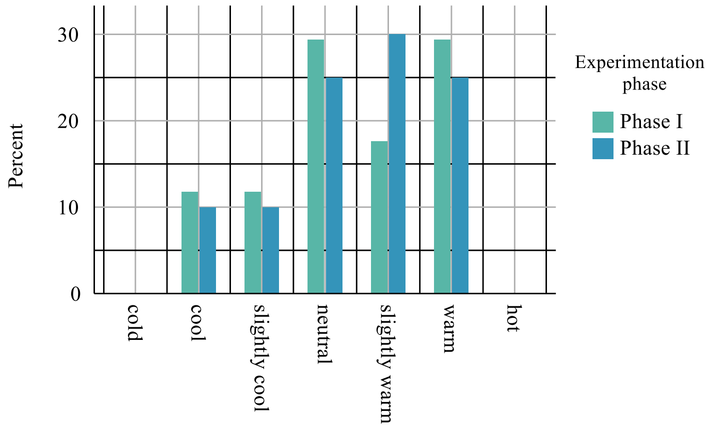


Figure 92. Conservatory of Turin. Classroom occupants' thermal sensation vote phase II vs phase I - winter.

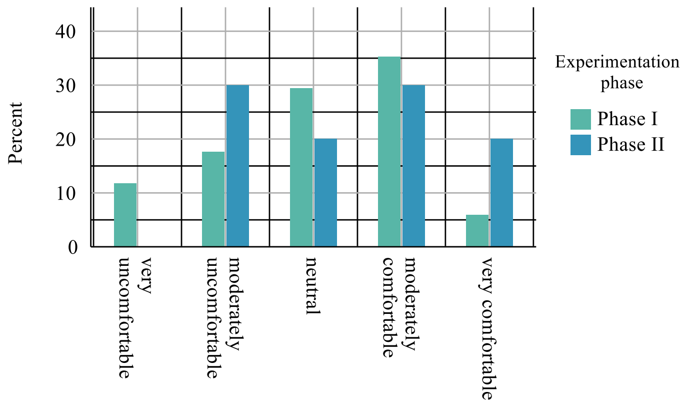


Figure 91. Conservatory of Turin. Classroom occupants' thermal comfort evaluation, phase II vs phase I - winter.

About the evaluation of the communication means, as it can be seen in Figure 93, the large majority of occupants saw and read the signs at least once (about a half). However, the evaluation of their usefulness, shown in Figure 94, is very

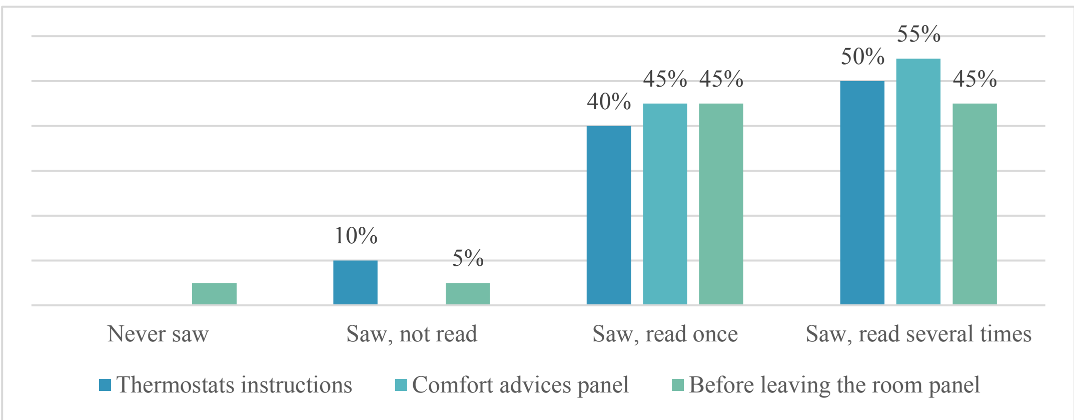


Figure 93. Conservatory of Turin. Classroom occupants' evaluation of communication means - winter.

various across all the scale, with a prevalence of votes between 3 and 5 (maximum usefulness).

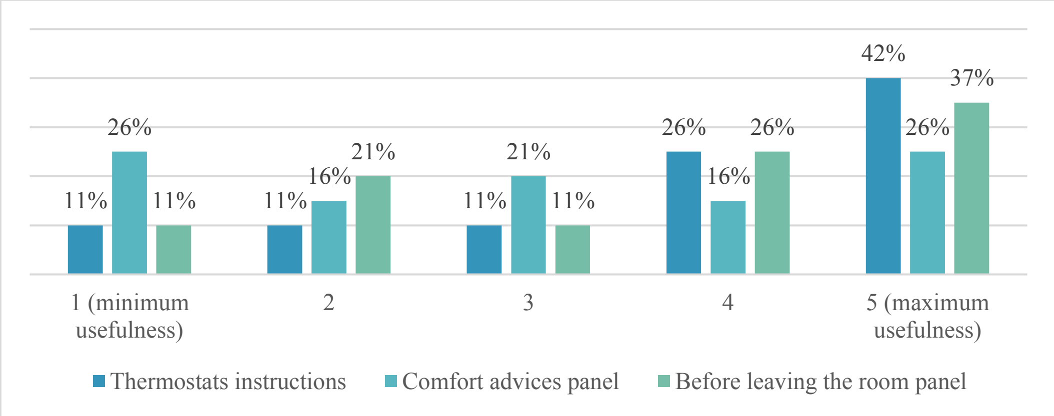


Figure 94. Conservatory of Turin. Classroom occupants' evaluation of signs' usefulness- winter.

Finally, about behavioural change shown in Figure 95, the percentage of people declaring a behavioural change is relevant, especially about thermostats, even if the "result" of this change is not quite visible from the evaluation of thermal sensation and thermal comfort votes. As expected, the behaviour in respect to internal and external blinds did not changed much, since these are not operable (external ones) or present in the classrooms (internal ones).

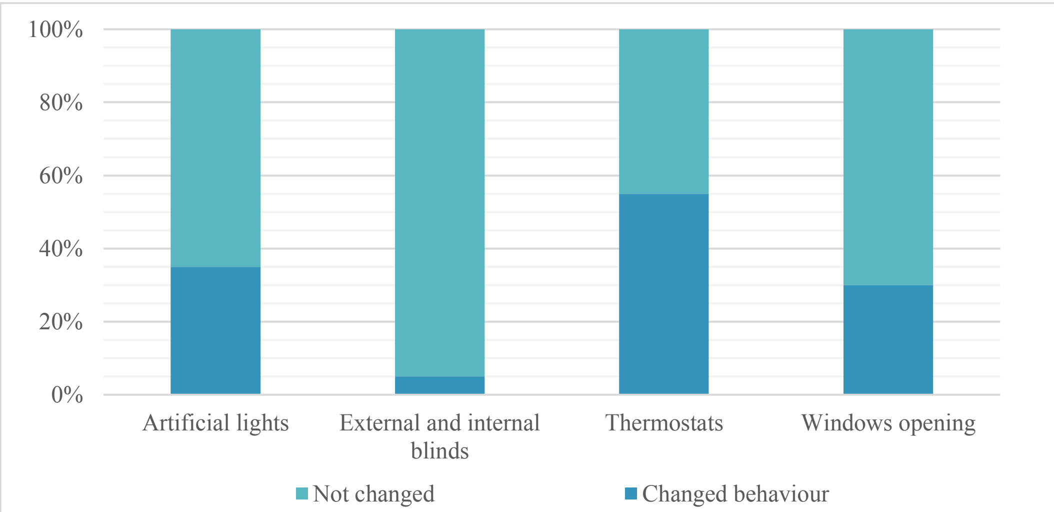


Figure 95. Conservatory of Turin. Classroom occupants' behavioural change direct assessment - winter.

12

Challenging the methodology's flexibility

The present chapter describes how the BIOSFERA methodology has been implemented in other case studies. In fact, even if the phases described in Chapter 11 have been implemented in a similar way in the three other case studies in which the methodology has been applied completely, peculiarities can be recognized in each implementation. Since one of the main objective of the methodology was to be an open and flexible instrument, in the following the description of the methodology's implementation on the other three case studies will be very synthetic and focused on the description of how the case studies' peculiarities has been faced implementing the methodology.

12.1 The restoration centre La Venaria Reale

The restoration centre La Venaria Reale (CCR) is located in Venaria Reale (TO), in Turin suburbs. The restoration centre was founded in 2005 and hosts a university of restoration, as well as several restoration laboratories and research areas. The centre is a work and education space, in which different professionals, from historians to scientists, work in labs, offices and classrooms. The restoration centre takes its name from the big complex in which it is located, which is the XVIII Century royal residence "Venaria Reale", part of the UNESCO World Heritage List. The building is a massive masonry structure. However, except from the external walls, it has been completely renovated in its internal structure in order to hosts the various spaces necessary for the new function established in 2005 (Figure 96). For this research, only offices and restoration labs were considered. The restoration labs were chosen in order to experiment the methodology on a space in which Indoor Environmental Conditions (IEC) are primarily managed for artworks' conservation, so occupants' comfort is not the primary objective and personal adjustment is fundamental to adapt to the indoor environment.

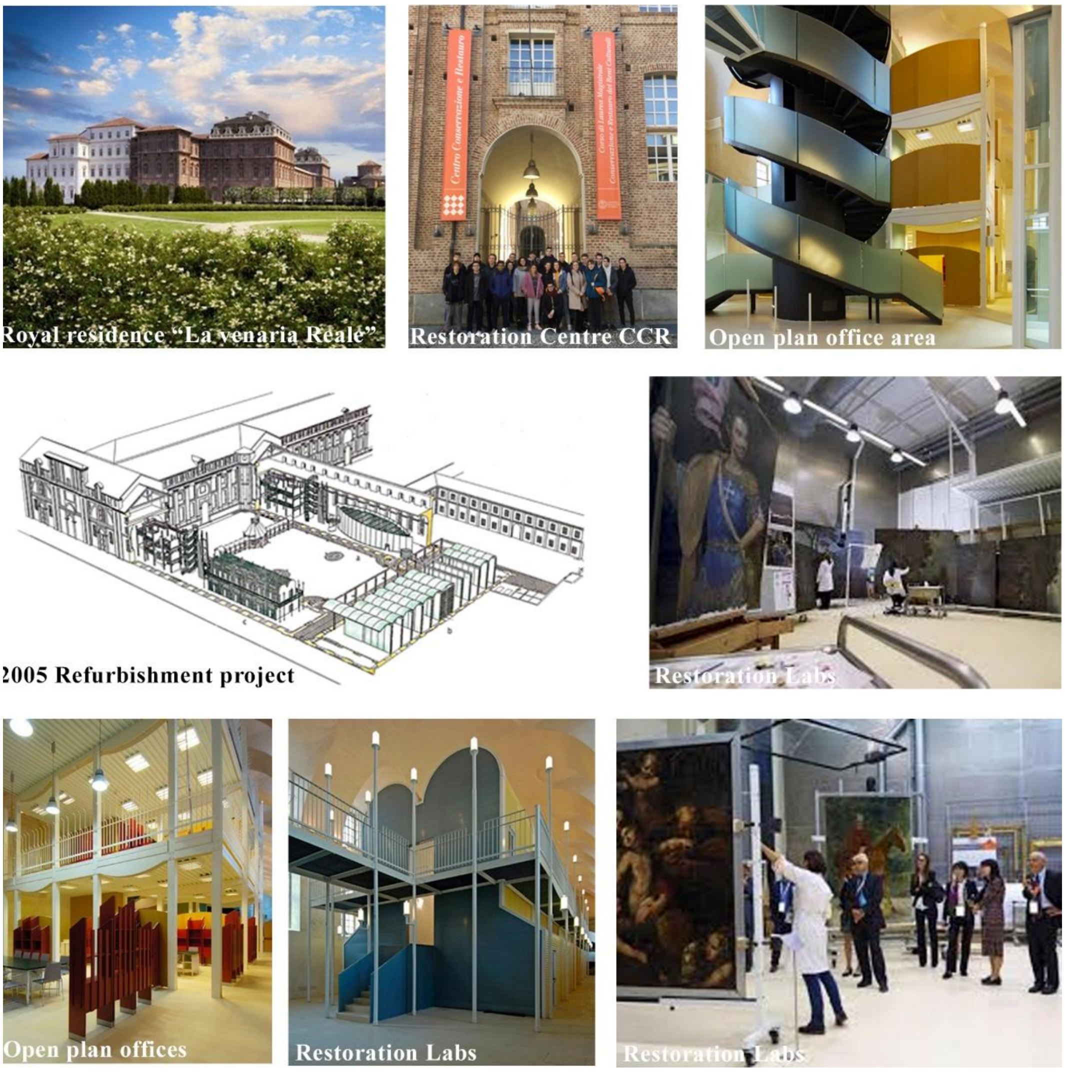


Figure 96. CCR. Photos of the refurbishment intervention (2005).

Following the purpose of this chapter, **two main topics** have been chosen as "key" aspects to be described about this case study, which differentiate the implementation of the methodology in this building from the others. Therefore, the synthetic description of the methodology's implementation will try to provide a general overview, but also insights on the "focus topics". The first focus topic regards **laboratories' BOs**. In fact, as mentioned, they were a particular BOs group to study and to provide strategies. For this reason, one of the focuses will be about their comfort (especially thermal comfort) and the efficacy of strategies in providing solutions to adapt to lab's peculiar indoor environmental conditions. The second focus topic regards small **offices' BOs**, and particularly their thermal comfort conditions in summer season. In fact, this case offers the possibility of showing the importance of contemporarily analyse indoor environmental conditions (monitoring data) and subjective evaluations (questionnaires).

The implementation of the BIOSFERA methodology took place in the same period shown for the Conservatory of Turin in Figure 11. Therefore, Phase I took place in summer season 2017 (June-September) and in winter season 2017-2018 (December-March). Phase II in summer season took place only in August and September 2018, while in winter season it took place from December 2018 to March 2019.

12.1.1 Phase I

In the following, information about Phase I in term of data, gathered materials and analyses will be provided synthetically in order to give an overview of the work, while emphasizing the three focused topics previously mentioned.

BMs' energy-related management. For this case study, three BMs were interviewed and collaborated during all the experimentation. One is a researcher and expert of indoor environmental monitoring, who was also the main "reference" contact of this case study, the second is the facility manager of the building and the third is an external consulting engineer, who takes care of HVAC systems' maintenance. As already mentioned, the building hosting the CCR is actually a part of a big complex of a royal residence. More than half of its conditioned floor area hosts restoration laboratories, but the building is provided also with offices, classrooms and a small auditorium. The total conditioned floor area is 8,000 m^2. This research took into consideration offices and restoration labs. Two types of offices can be recognized in this building: open plan offices and small/single offices. The two office types are located in two different areas of the building and are characterized by different control opportunities for occupants. For example, in open plan offices windows and internal blinds are not operable, while in small offices they are. For this reason, office workers related data were analysed based on office type. Normally, only restoration laboratories are provided with a continuous **environmental monitoring,** which is also provided with an alarm system, since in this part of the building temperature and relative humidity should always be kept in a specific range required for artworks' conservation. Environmental monitoring data of this part of the building were not available for this research. For this reason, it was agreed to monitor some rooms of the small offices' area, in order to perform analyses and have insights to interpret BOs answers to questionnaires. In total, six rooms were continuously monitored during the whole Phase I in summer and winter season. Table 48 summarizes the principal information about offices' environmental monitoring.

Table 48. CCR. Principal information about indoor environment monitoring - phase I.

Sensors' number and location	Six offices monitored in two different floors (3+3) in the small offices' area. The sensors were located in fan-coils, about 0.9m from the floor.
Monitoring period	The monitoring periods were: -From 21/16/2017 to 21/09/2017 for summer -From 21/12/2017 to 21/03/2018 for winter
Monitored environmental parameters	Air temperature.
Sensors' characteristics	Registration time-step: 30 minutes Temperature probes (Sauter EYB250F201) located on offices' fan coils. Nominal uncertainty ±0.1°C. Registration range (Temperature: 0°C >40°C).

About **energy-related control opportunities**, as mentioned the focus were offices and restoration labs. Moreover, offices were distinguished in open-plan and single/small offices since they are located in two different areas of the building and characterized by different control opportunities. In small and single offices, windows are operable, as well as doors and internal blinds. The building is not provided with external blinds. About technological interfaces, these offices are provided with operable thermostats (allowing temperature set-point adjustment with a range of ±3°C) and artificial lighting. Each office is provided with fan-coils for heating and cooling, but they are naturally ventilated. Seasonal set-points and operation schedules are summarized in Table 49. The open plan offices instead, are located on a big volume in which a metal structure was positioned to create open spaces, as shown in Figure 96. For this reason, windows and blinds are not operable, while internal doors are not present. These offices are cooled by floor radiant panels (heating and cooling), while for ventilation there is not a proper mechanical ventilation, but only a de-stratification system, usually not used because they create notable acoustic discomfort (the fans are very noisy). These offices are provided with thermostats, theoretically identical to small ones, however these are dummy, so if BOs have thermal comfort issues they contact the facility manager to ask for a set-point change. Seasonal set-points and operation schedules are summarized in Table 49. Restoration labs are characterized by stable indoor environmental conditions during all the year, as shown in Table 49. These spaces are air conditioned. In this area, occupants are allowed to modulate the temperature set-point in the allowed range, while for problems related to the air flows they have to contact the facility manager. Thermostats do not show the temperature, so operating them BOs are not aware of the set-point they are setting. In terms of structural interfaces, windows are not operable, as well as internal blinds, while external blinds are not present. Doors can be operated to enter the spaces, but in order to maintain stable indoor environmental conditions they have to be closed immediately. In fact, for conservative reasons, regardless of seasons and outdoor conditions, temperature is kept in a range between T=19-24°C, while RH is kept between 40-60% or 45-65% (depends on laboratories).

Table 49. CCR. HVAC settings, phase I.

Space type	HVAC system	Terminal	Information to acquire	BOs controls
Single/ Small offices	Heating and cooling	Fan-coil	**Summer** T set-point= 24°C. Operation: 8:00-18:00 **Winter** T set-point= 22°C. Operation: 8:00-18:00	Operable thermostats (range ±3°C)
Open plan offices	Heating and cooling	Floor radiant panels		Dummy thermostats
Restoration labs	Air conditioning	Air vents	**Summer and Winter** T set-point= 19-24°C RH=40-60%; 45-65% (depends on labs) Operation: 0:00-24:00	Operable thermostats (range 19-24°C)

Energy consumption information were available, both in terms of electric energy and in terms of thermal energy. Nevertheless, only for electric energy monthly bills were available. In fact, thermal energy is payed by the CCR to a consortium handling the production of cold and hot fluids for all the royal residence complex. This payment is done, yearly, based on the relative floor area of the centre in respect to other parts of the complex, so it is not possible to quantify monthly nor seasonal energy consumption data. Moreover, also on a yearly basis, it is not possible to assess the "real" contribution of CCR in respect to the other parts, since the "count" of the energy to be paid is not based on real consumptions, but on the relative floor area, as already mentioned. For this reason, thermal energy consumption was not considered in this implementation of the methodology. Therefore, all energy-related analyses of Phase I and the following were addressed only at electric energy. As regards of electric energy, monthly bills were provided from 2016 (one year before phase I).

Occupant-related information have been already partly mentioned. The methodology was implemented in offices and restoration laboratories. For offices, BOs were considered, similarly to the other similar cases, HLC, even if open plan office workers have not much energy-related controls available. For this reason, the analyses of questionnaires answers were distinguished for single/small offices and open plan ones. In restoration labs, for the reasons already explained, BOs were considered as MLC. At CCR various types of restoration labs can be distinguished, based on the type of material, analyses and restoration works. However, the largest area is occupied by large laboratories in which indoor environmental conditions are kept as described in the energy control part. For this reason, even if some labs are outside the strict controlled area, labs' BOs has been kept as a unique category. This, also because usually restoration professionals occupy different laboratories based on the type of work or analysis they have to perform. Of course, in the questionnaire it was explicitly asked to evaluate the "strict controlled" restoration labs.

Energy consumption assessment. As mentioned, only electric energy consumption was analysed for the application of the methodology. In fact, for thermal energy only the total cost for each year was available: 106,135€ (7€/m^2) in 2016 and 100,412€ (6.70€/m^2) in 2017. In Table 50, yearly total and specific electric energy consumption are shown. The same values has been analysed monthly to assess seasonal (phase I in summer and winter) indicators and analyses as shown for the Conservatory of Turin. Seasonal analyses will be directly shown in phase III to assess the energy efficacy of strategies.

Table 50. CCR. Principal energy consumption indicators, phase I.

	EPH [kWh/m^2]	EPTOT [kWh/m^2]	EE [kWh$_e$]	EE [kWh$_e$/m^2]	TE [kWh$_t$]	TE [kWh$_t$/m^2]	TE$_N$ [kWh$_t$/DD]
2016	NA	NA	895425	112	NA	NA	NA
2017	NA	NA	979456	122	NA	NA	NA

Indoor environment assessment. In order to assess the indoor environment, analyses were conducted, similarly to the previous case study. However, it is interesting to show a number of analyses conducted for phase I – summer, which were informative of a certain situation that has been then addressed in phase II with specific strategies. These analyses are shown in order to demonstrate how diagnosis can be done thanks to the comparison of information and data from different sources. Figure 97 shows the mean daily indoor air temperature from the six offices monitored in CCR during the whole phase I summer season (21th of June-21th of September 2017). The graph shows that the six offices are handled approximately in the same way. Moreover, it seems that the indoor air temperature is quite influenced by outdoor conditions, with a certain delay due to the massive structure of the building. The temperature profiles seem to be more similar to what expected in a passively cooled building. For this reason, more focused analyses has been done in the various offices. An example is the one shown in Figure 98, which shows the monitored air temperature within one approximately representative summer week. As shown, the temperature trend is similar for the first days of the week (17th of July was a Monday), while it slightly changes between on Saturday and Sunday

(22[th] and 23[th]). From the graph, it seems that the cooling system is switched on every early morning, then switched off, also because during the weekend, when the system is switched off by "general settings" the indoor air temperature is not much different from the other days. Then, the weekly reset of the temperature set-point can easily be seen, since in both Mondays the temperature in the early morning is similar, but probably then the fan coils are switched off. In any case, the declared cooling set-point is not shown in this graph, as well as in the other offices. For this reason, when analysing the data, the experimenter asked for clarifications to the facility manager, who is responsible of all HVAC settings. He declared that, actually, small offices' BOs usually complain about fan-coils because of the cold air flow, which is just behind the back for at least one worker in each office. For this reason, users normally switch off the fan-coils when they arrive at the office in the morning, when actually the system has already worked for about 1.5 hour. This was very explanatory. However, more insights were searched in phase I –summer questionnaires. Moreover, in terms of indoor environment analysis, since occupants normally switched off fan-coils and these offices were naturally ventilated, it meant that windows were used as a primary mean to regulate the air temperature. For this reason, it was decided to perform an analysis also adopting the adaptive comfort model, also in order to compare the subjective evaluation of occupants in terms of TSV and thermal comfort with was would be predicted by this model.

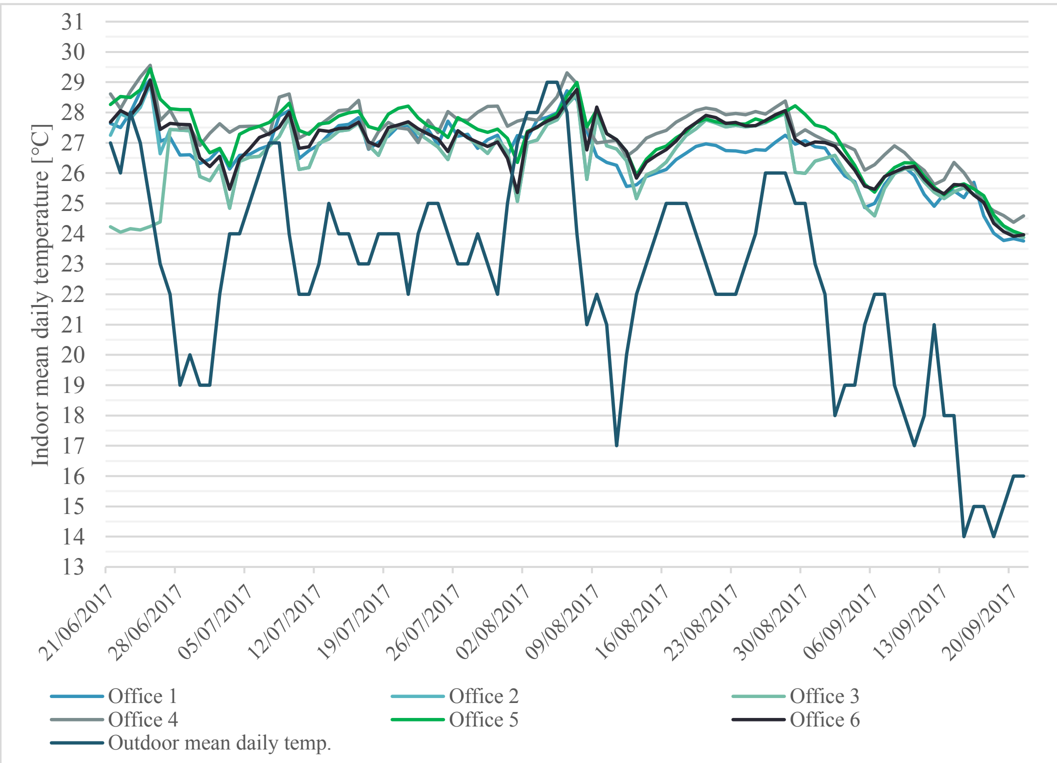


Figure 97.CCR. Offices indoor air temperature - phase I- summer.

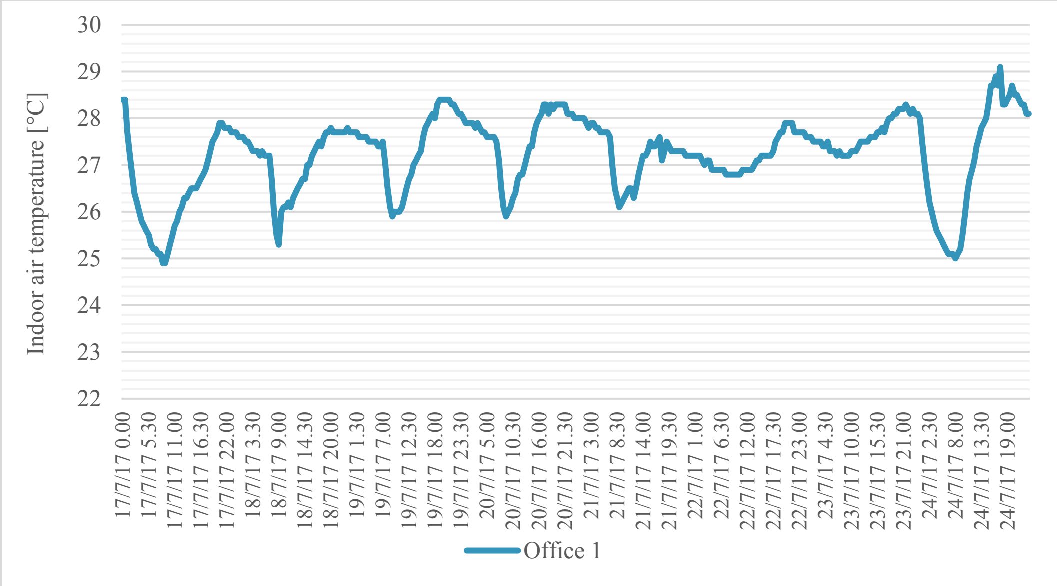


Figure 99. CCR. Offices indoor air temperature in one office during one week. Phase I- summer.

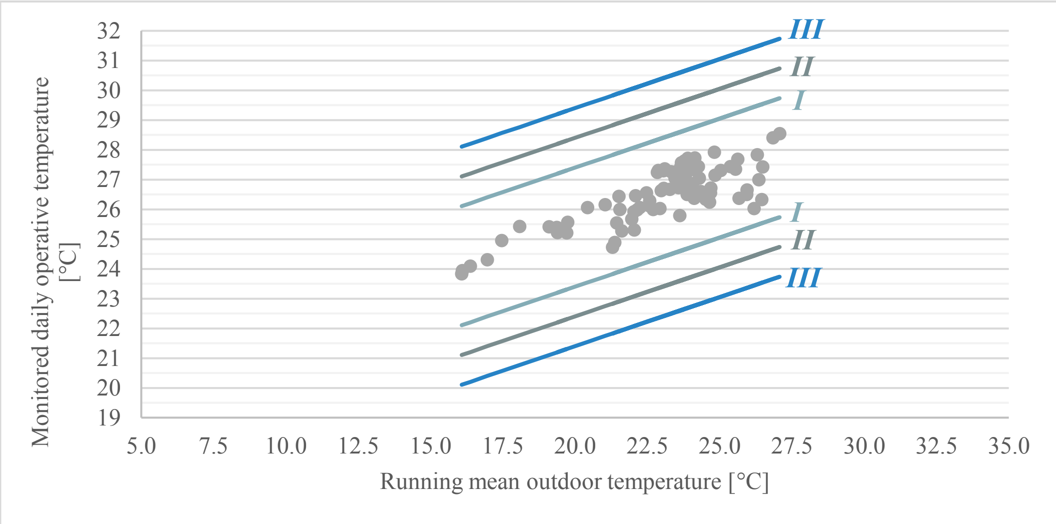


Figure 98. Adaptive comfort model applied to monitored air temperature in offices, phase I - summer.

Energy-relevant information from BOs. The questionnaire campaign of phase I was conducted in summer from the 15th of September until the 15th of October 2017, while in winter from the 15th of March to the 15th of April 2018. **Office workers** answered to the questionnaire online, similarly to what was described for the Conservatory of Turin. The surveys had 16 out of 20 respondents for summer season and 13 out of 20 respondents for winter season. Considering the ASHRAE 55:2017 standard, these numbers are representative for summer season but not for winter, since it would suggest to have at least 15 respondents for a sample of 20-45 occupants. **Laboratory BOs** answered to the questionnaires in paper, because they are professors, short-term collaborators and students. For this reason, reaching every one (and only the right ones) by email would have been difficult. Moreover, in most laboratories workers do not use their PC, so they would have been obliged to fill the questionnaires outside working hours, reducing the probability of answers. A reference person for the distribution and collection of questionnaire was identified and asked to have about 20 blank questionnaire. This does not mean that this is the correct number of labs' BOs, which is not easy to be fixed. However, since is the only data available, it was the reference to establish response rates. In summer, the respondents were 15 out of 20, while in winter they were 12 out of 20. For this reason, in terms of representativeness, the same consideration of offices can be done. The analyses of questionnaires were conducted similarly to what has been shown for the Conservatory of Turin. Nevertheless, following the purpose of this chapter, here only a small part of the elaborated results will be displayed in order to show relevant information.

For example, in respect to what was shown for offices' indoor environment assessment in summer, the first investigated topic for **offices BOs** was TSV and thermal comfort. As shown in Figure 100, in small offices more than half of occupants felt slightly cool or cool, while in the large open-plan offices they all felt warm or hot. As regards of thermal comfort, the important implication of the previous analysis is that more than a half of occupants felt thermally uncomfortable in small offices. Both information are quite surprising if compared to what emerged by the environmental monitoring, in which it seems that the temperature registered in offices is much higher than the cooling set-point. Insights on this point were provided by the question dedicated to local discomfort, in which a space for comments was provided in the questionnaire. In that comment, four people wrote

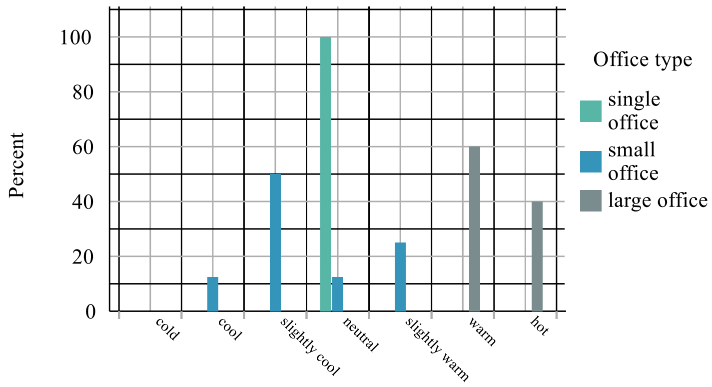


Figure 100. CCR. Office BOs TSV. Phase I- summer.

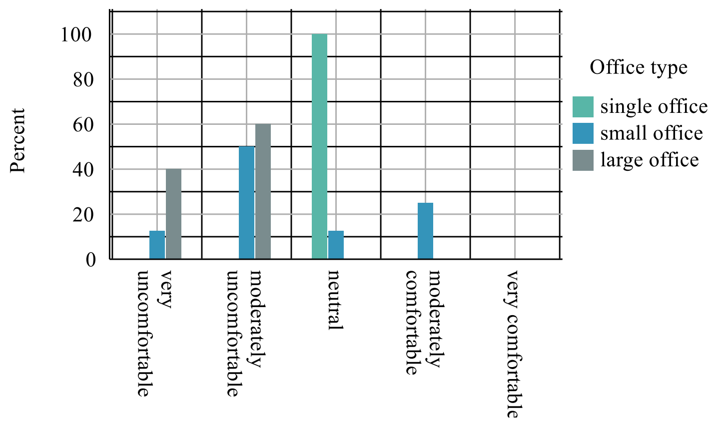


Figure 101. CCR. Office BOs Thermal comfort vote. Phase I - summer.

that the thermal discomfort was due to the cold air flow coming from fan coils directly on their back. This information was exactly the one provided by the facility manager, so the correlation of different data and information were essential to understand a situation that otherwise would have been interpreted differently. Based on these data, there was also the need to understand occupants' windows usage to

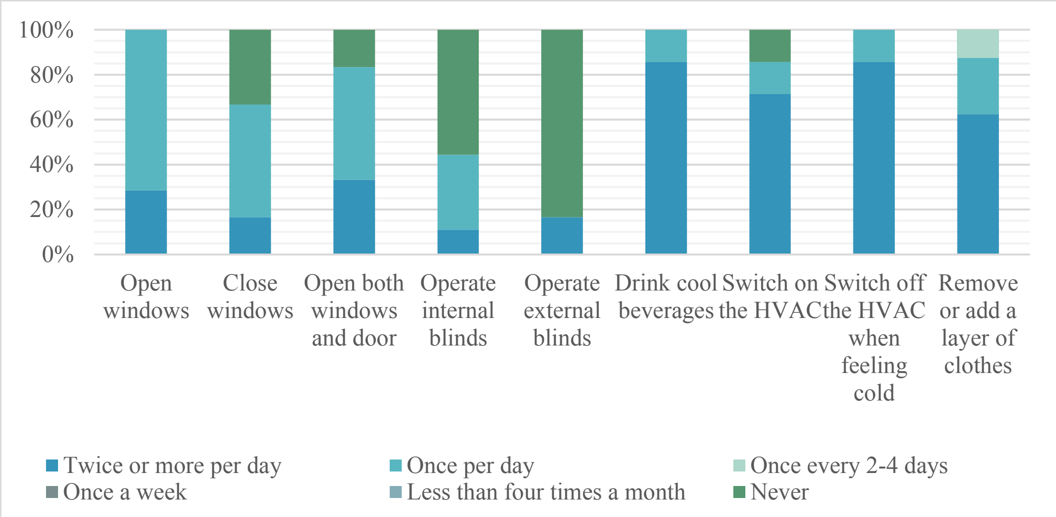


Figure 102. CCR. Small offices' workers actions in case of thermal discomfort. Phase I - summer.

understand how much this adaptive opportunity was used to mitigate indoor environmental conditions. As shown in Figure 102, about all small offices' BOs use windows at least once a day to manage thermal-related issues, so the use of the adaptive comfort as an analysis method is justified. However, according to that analysis, about 95% of occupants should have felt comfortable. Instead, more than a half were not. Again, the local discomfort information was fundamental in order to interpret the data, which would not have been explained otherwise. Another element that was essential was the air quality in open plan offices, which was evaluated since windows are not operable in that area and the de-stratification system is never used. Anyway, both in summer and in winter BOs evaluate it as acceptable.

For **laboratories BOs**, the first relevant aspect was the evaluation of TSV and thermal comfort. In fact, based on the temperature range allowed for all the year (19-24°C), the expectation was that the majority of occupant would have had thermal comfort issues in summer, since the maximum allowed temperature is relatively "low". This expectation was confirmed, as shown in Figure 103 and 104. In fact, in summer more than 50% of occupants feel slightly cool or cool, and those expressing this vote feel, in the majority of cases, moderately uncomfortable or very uncomfortable. In winter instead, 50% BOs feel neutral and for the majority of them there is not a thermal discomfort problem. However, 40% of them feel slightly warm-hot and some of them evaluate this situation as an uncomfortable one. From an air quality point of view, there are not particular problems in terms of acceptability, but in summer 40% of BOs signal "too much air movement" as a local discomfort cause, while in winter 33% of them signal "too low air movement".

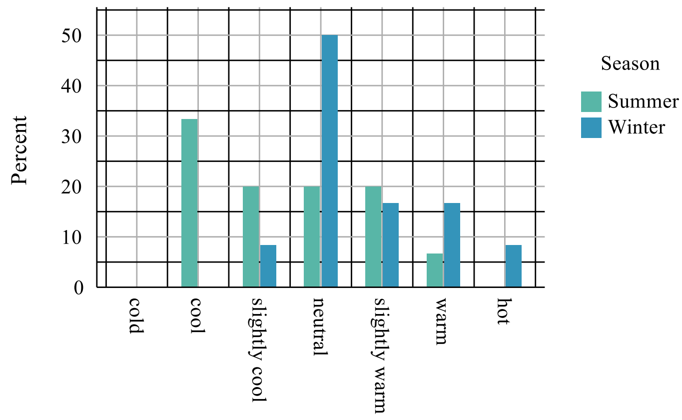


Figure 103. CCR. Lab BOs TSV - phase I.

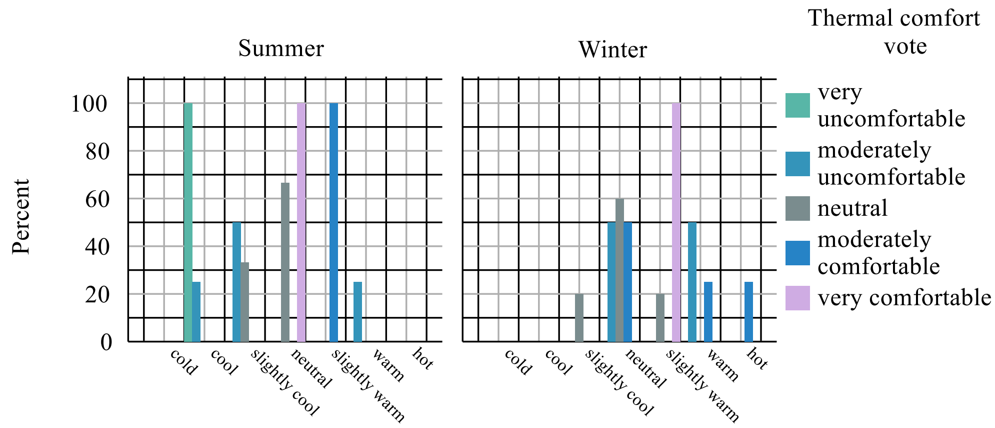


Figure 104. CCR. Lab BOs thermal comfort vote - phase I.

The first hypothesis, considering the previous information, is that probably BOs are not much aware of their possibility of adjusting the temperature in the allowed 19-24°C range. This hypothesis is supported by a further question (Part V), to which in summer over 60% BOs and 100% BOs in winter answered that when they experience discomfort problem they directly contact the facility manager. Another aspect that was investigated was the clothing level, since other behaviour related questions were not present in MLC questionnaire. In summer, 7% BOs declared to usually wear "light summer clothes", 53% "medium summer clothes" and 40% heavy summer clothes. Moreover, as figure 105 shows, those reporting an

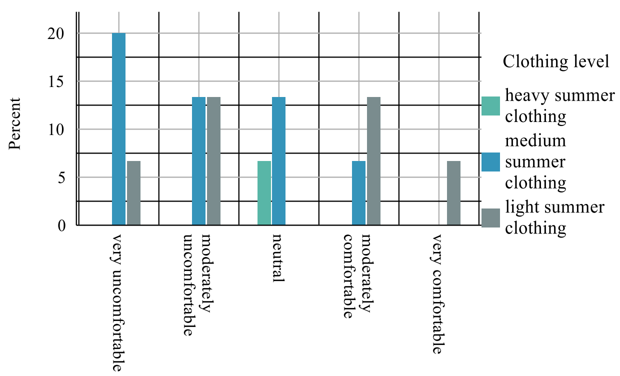


Figure 105. CCR. Lab BOs thermal comfort votes versus clothing level. Phase I – summer.

uncomfortable condition in summer usually wear medium or light summer clothes, so they could add layers of clothing as a personal adjustment measure. Both aspects (thermostats and clothing adjustment were considered to elaborate phase II's strategies).

12.1.2 Phase II

In the following, the strategies proposed for the case studies in phase II – summer and winter will be summarized for each season.

Summer season. Analysing the questionnaires gathered at the end of Phase I - summer, several aspects to be addressed by phase II strategies were identified with a similar approach of the one shown for the Conservatory of Turin.

In terms of **BOs** engagement, different objectives and necessities were identified for single/small offices, open plan offices and restoration laboratories. Particular relevance was given to the use of windows as adaptive opportunities, since from the questionnaire it emerged that windows were already used as "alternative" to the cooling system or even to mitigate the cooling system (when feeling too cold). Another relevant topic (mainly addressed by comfort advices signs and newsletters) were personal adjustment strategies to enhance personal comfort. In terms of communication means, Table 51 summarizes the means, the areas and the topics. Signs can be visualized in the Annex CD attached to the thesis.

Table 51. CCR. BOs strategies for phase II – summer season.

Communication mean	Building area	Delivered information
Comfort advices sign	Single/small offices	What to do in case of thermal discomfort (too hot or too cold), poor air quality, too high or low light. Advices are distinguished in each area depending on control possibilities, including personal adjustment.
	Open plan offices	
	Restoration laboratories	
How to use the thermostat sign	Single/small offices	Thermostats or fan-coils instructions, specific for each area.
	Open plan offices	
	Restoration laboratories	
Before leaving the room sign	Single/small offices	Specific remind based on available controls (e.g. artificial lights, pc etc.).
	Open plan offices	
Newsletter	Single/small offices	The main topics were windows opening and personal adjustment.
	Open plan offices	
	Restoration laboratories	

In terms of **BMs** related strategies, the first indication was to re-arrange, where possible, the position of desks in small offices, in order to avoid the collocation of fan-coils behind chairs. This was not possible in all offices, but in some cases yes. About HVAC, in the single and small offices' area, the set-point was increased to 27°C (the previous set-point was 24°C). This way, BOs can modulate the set-point until 24°C (lower limit) or 30°C (upper limit), reducing the problem of local discomfort previously mentioned. In open plan offices instead, since a notable percentage of occupants felt warm, the set-point was set to 26°C, which is the minimum allowed by the DPR n.412/1993 (Italian Parliament, 1993). In the laboratories, since the only "set-point" is the allowed temperature range 19-24°C, no strategies were proposed to the BM; the only effort was to educate BOs to use thermostats properly, since a notable percentage of them declared that when having thermal discomfort issues they directly involved the BM, not exploiting the thermostat available. Another measure was to turn off the systems (only in the office part) on weekends.

Winter season. Winter season analyses were not much shown in the previous paragraphs, since the summer situation was considered more interesting to show the methodology's potential. In winter, the IEC monitoring showed that in the **office area** (both small offices and open plan) the mean daily temperature during occupied hours is around 23°C, with a maximum of 25°C. This phenomenon was mainly attributed to the fact that the set-point was 22°C, but BOs had still the possibility to range the temperature by ±3°C. For this reason, the temperature set-point was decreased to 20°C. In terms of BOs strategies, the ones shown for summer season were repeated also in winter. Of course, the signs were "rephrased", similarly to what was shown for the Conservatory of Turin, in a way that the signs could be leaved on walls in both cooling and heating season. In winter, small offices' occupants seemed much less active in terms of windows opening (80% of them opened windows less than once a week). Therefore, specific newsletters were sent in order to encourage windows opening to ventilate rooms. **In the laboratories**, 42% of BOs felt warm; however, 83% of them is not uncomfortable. Nevertheless, it was proposed to limit the upper limit of the temperature range to 22°C (instead of 24°C), only for winter season. The BM agreed to this measure, since it privileges energy efficiency but should not interfere with artworks' conservation.

12.1.3 Phase III

In the following, the results of Phase II strategies will be synthetically summarized, especially focusing on the two focus topics identified for this case study. The first results regards the impact of phase II strategies on energy consumption and related costs. In these terms, it is important to highlight that the CCR had a different **energy saving potential** in respect, for example, to the Conservatory of Turin. In Part II (chapters of the theoretical framework of the methodology), the variability of energy-related results due to buildings' peculiarities was already mentioned. This is one of those cases in which the potential was not very high, especially because more than half of the restoration centre's floor area is occupied by the restoration laboratories, which have to be kept in specific indoor environmental conditions for all the year. Moreover, these conditions are energy-demanding in summer, since the maximum temperature allowed is 24°c, which is 2°C below the minimum temperature allowed by the Italian regulation. For these reason, the facility manager declared that his objective was to find a way to save about 10% of electric energy, which would have been a great result in his opinion. This objective was approximately reached, as shown in Table 52. In terms of costs, it seems surprising that the raw energy costs did not change. However, the EE raw energy tariff changed between august 2017 and 2018; in fact, it passed from 0.05€/kWh (2017) to 0.06€/kWh (2018). Normalizing the raw energy costs by the energy tariffs we would obtain, actually, a cost reduction of -17%.

Table 52. CCR. Energy related results of phase II strategies - summer season.

	EE [kWh_e]	**Monthly difference**	**Seasonal difference**	**EE costs**	**Monthly difference**	**Seasonal difference**
Aug-17	55791			3,443.57 €		
Sept-17	68422			4,264.99 €		
Aug-18	52690	-6%	**-9%**	3,580.54 €	+4%	**0%**
Sept-18	60106	-12%		4,119.85 €	-3%	

In winter, the expectations were higher because the temperature range was reduced in laboratories (from 19-24°C to 19-22°C), while in offices the set-point passed from 22°C to 20°C, with the possibility for BOs of ranging it by ±3°C. As expected, the results are slightly higher than summer in terms of energy savings, as shown in Table 53. In terms of energy costs, similarly to summer season the analysis of energy tariffs revealed that in December 2017 the EE raw energy tariff was 0.06 €/kWh, while in December 2018 it was 0.08. Re-calculating the seasonal difference with normalized raw energy costs the result would be a reduction of costs, coherently with the energy results (-15%).

Table 53. CCR. Energy related results of phase II strategies – winter season.

	EE [kWh_e]	**Monthly difference**	**Seasonal difference**	**EE costs**	**Monthly difference**	**Seasonal difference**
Dec-17	118924			6,642.11 €		
Jan-18	109555			7,611.18 €		
Feb-18	107368			7,468.46 €		
Dic-18	96331	-19%		6,658.09 €	0%	
Jan-19	110507	1%	**-11%**	9,855.69 €	29%	**14%**
Feb-19	91726	-15%		8,197.40 €	10%	

In terms of BOs, both in laboratories and in offices a paper questionnaire was distributed in September 15th and gathered in October 15th 2018 for summer season, while for winter the period was 15th of March-15th of April 2019. Laboratories BOs did not filled the questionnaire of summer season Phase III. In fact, only two answers were gathered, so it was impossible to perform any analysis. Offices BOs instead, filled 12 out of 20 answers. In winter season, BOs laboratories participated with 11 out of 20 filled questionnaires, while for offices' BOs 16 out of 20 answers were gathered.

In the following, Figure 106 shows **lab BOs**' thermal comfort vote in phase I and phase II, which is interesting since the upper limit of temperature was decreased by 2°C (22°C). In phase I, BOs felt generally warm, but the majority of them declared a comfortable condition, so the challenge was to obtain an energy saving (which occurred as previously described) by lowering the temperature set-point without harming BOs thermal comfort. This result was reached.

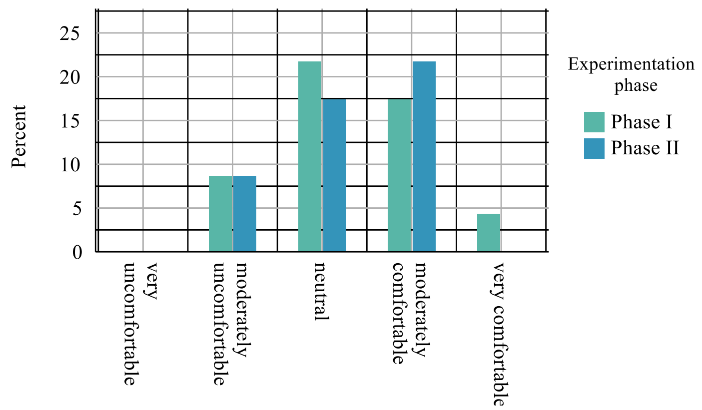


Figure 106. CCR. Lab BOs thermal comfort vote, phase I vs phase II - winter season.

For **offices BOs**, results are shown in the following focusing on single and small offices, which were one of the focus topics for this case study. In summer, the temperature set-point was increased by 3°C (from 24°C to 27°C), but efforts were made also to educate BOs to a proper use of thermostats. In winter, the set-point was decreased (from 22°C to 20°C), after having verified from the air temperature monitoring data that the mean temperature during occupied hours was 23°C. The objective in summer, was to lower the energy consumption but also eliminating or reducing thermal discomfort due to the cold air-flow from fan-coils. In terms of TSV, as shown in Figure 107, the range of votes was reduced mainly to -1 (slightly cool) / +1 (slightly warm), while in terms of thermal comfort (Figure 108), the percentage of occupants feeling uncomfortable was notably reduced (from 55% to 25%). In winter, quite surprisingly, despite the temperature set-point lowering, TSV were shifted to the warm part of the scale, except a bout 15% of BOs feeling slightly cool or even cool, which also expressed an uncomfortable vote after. For the rest of occupants, thermal comfort increased.

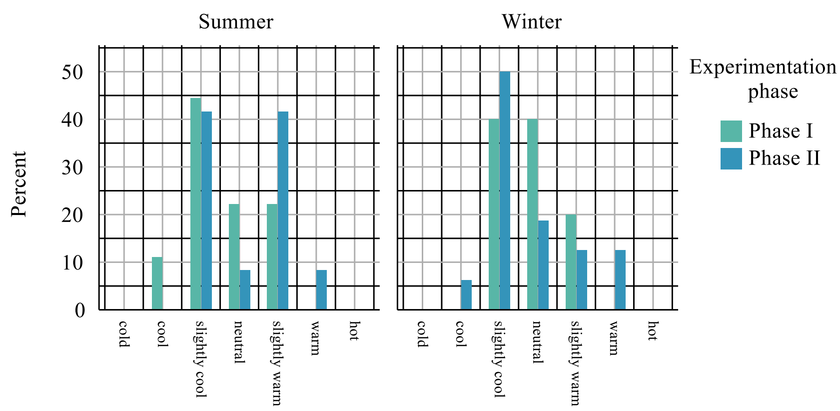


Figure 108. CCR. Single/small offices BOs TSV, phase I vs phase II.

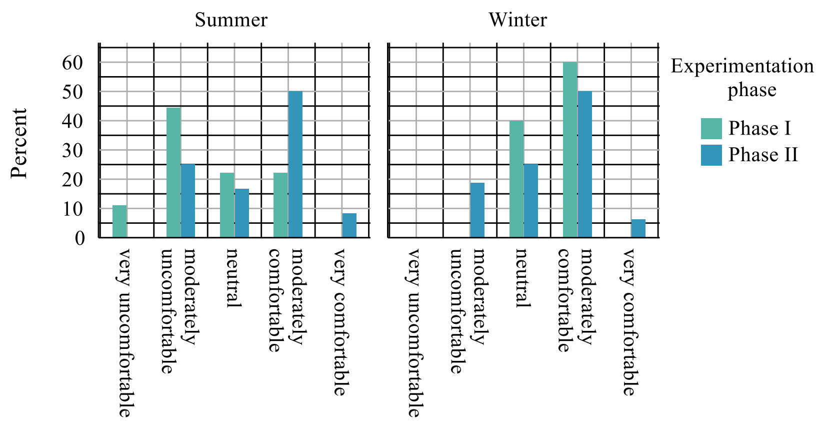


Figure 107. CCR. Single/small offices BOs thermal comfort, phase I vs phase II.

12.2 The Rivoli Castle

The Rivoli castle is located in Rivoli (TO), in Turin suburbs. The castle, inscribed in the UNESCO world heritage list, was reconstructed after a destruction in XVIII Century and restored in the eighteens, with an intervention finished in 1984. Today, the castle hosts a Contemporary Art Museum. The complex, which hosts about 10,000 visitors each year, has a floor area of about 16,000 m^2, considering the two buildings composing it, namely the “Castle” and the so-called “Manica Lunga” (Long sleeve). The castle hosts the “education department”, the offices and the expositive part. The Manica Lunga, for which the restoration works ended in 2000, hosts the ticket shop, the bar, stock areas, some offices (with a small library) and expositive areas (for permanent and non-permanent expositions). In the same complex, there is also a restaurant. For the implementation of the BIOSFERA methodology, the restaurant was not considered; however, the energy consumption of this part, as well as those of the bar, are included in those of the castle. From a constructive point of view, the building is very similar to the CCR, namely a massive masonry building.

Also for this case study, **three main focus topics** were identified and will be privileged in the description of the methodology's implementation. The first aspect to highlight is that this is the only case in which no strategies were provided in terms of **HVAC settings'** changes, since the energy management was already managed by a professional company. For this reason, the results assessed in phase III should be attributed only to BOs and BMs behavioural change (during phase II no HVAC settings' changes were made in terms of schedules nor set-points). The second aspect to highlight is that this case study which is partly passively cooled. In fact, the whole castle is **not provided with mechanical cooling system.** For this reason, it was interesting to analyse the monitoring data and compare them with BOs evaluation both in the expositive part (in which BOs are considered a MLC group) and in offices (in which BOs are considered as HLC). The third and final aspect that will be highlighted is that this was the only case with an **expositive part** for which the indoor environmental monitoring could be evaluated in terms of museum's artworks conservation potential according to what described in part II of the thesis.

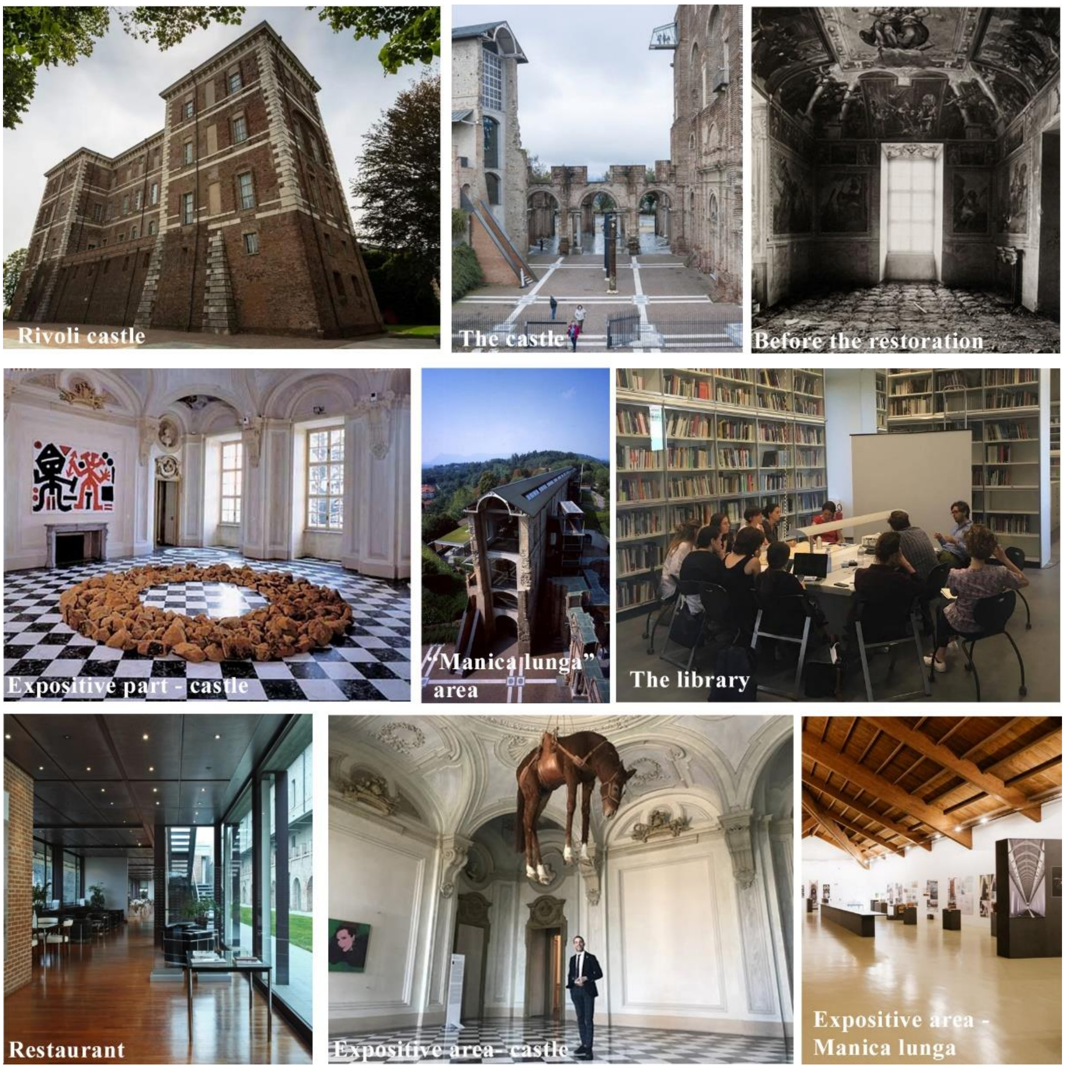


Figure 109. Rivoli Castle photos.

In this case study, the BIOSFERA methodology was applied approximately in the same period shown for the previous two cases. Phase I took place in summer season 2017 (June to September), while in winter season from December 2017 to March 2018. Phase II instead, was applied during summer 2018, starting from the beginning of June to the end of September. In winter season, instead, the methodology was applied from the beginning of January to the end of March 2019.

12.2.1 Phase I

In the following, the implementation of Phase I's analyses and data gathering will be explained synthetically, highlighting only the parts related to the three main focus topics previously mentioned.

BMs' energy-related management. For this case study, three main BMs were interviewed and collaborated in various way to the methodology's implementation. The first is a contact person who was contacted for the various phases, who distributed and gathered paper questionnaires and diffused the communication materials. The second is a facility manager working permanently at the Castle, who is responsible, e.g., of the envelope elements' operation in the expositive area, the artificial lighting etc. The third was an external consultant engineer, who was in charge of all HVAC settings and management, as well as energy consumption materials. As already mentioned, the Rivoli Castle is actually a complex composed by two buildings. The castle is 10,413 m^2, while the "Manica Lunga" is 4,640 m^2. In terms of **environmental monitoring**, data from eight dataloggers positioned in the castle (first and second floor) were provided by the CCR, who positioned the dataloggers in the castle due to a continuous environmental campaign in accordance with the administration. The data from these dataloggers can be considered as representative also for the castle offices, since they are positioned in proximity of the expositive area. Dataloggers were positioned by CCR professionals after an accurate spot measuring campaign, so the chosen spots should be representative of the whole studied floor area. A map of the spots is provided in Figure 110. In the rooms, dataloggers were positioned in an appropriate position, but possibly hidden from visitors' view (e.g. in fireplaces).

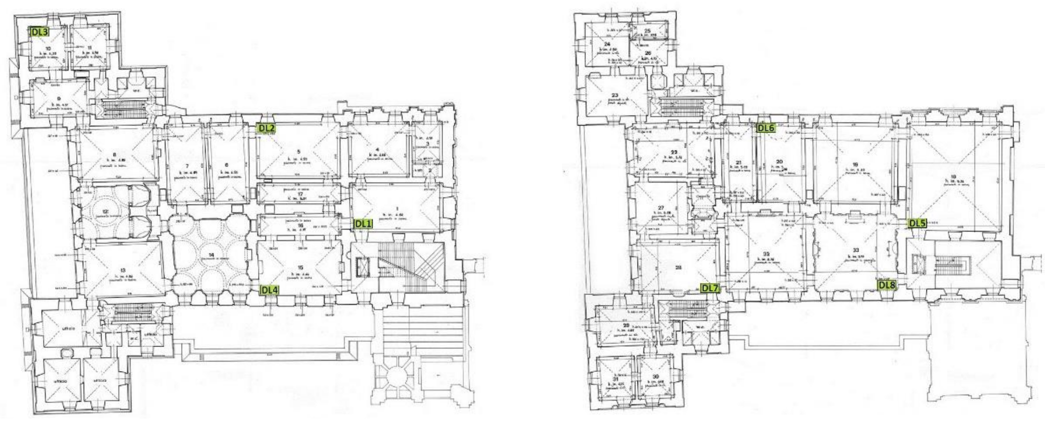


Figure 110. Rivoli. Datalogger position in the castle floor 1st (left) and 2nd (right).

In terms of technical features, Table 54 summarizes all relevant information about the monitoring system.

Table 54. Rivoli. Principal information about indoor environment monitoring.

Sensors' number and location	Eight dataloggers positioned in two floors of the castle (expositive area). The sensors were located in a way that they could not be seen by visitors.
Monitoring period	The monitoring periods were: -From 21/16/2017 to 21/09/2017 for summer -From 21/12/2017 to 21/03/2018 for winter
Monitored environmental parameters	Air temperature and Relative Humidity (RH).
Sensors' characteristics	Registration time-step: 15 minutes Dataloggers (Testo 175-H1). Nominal uncertainty ±0.4 °C, 0,1%RH. Registration range: Temperature: -20°C-55°C, RH 0-100%

In terms of **energy-related control opportunities**, the Rivoli castle complex presents various situations based on the building. In fact, the buildings are provided with different HVAC systems and terminals. HVAC settings are shown in Table 55.

In the Castle building, the expositive part is provided with floor radiant panels (only for heating), while offices and service areas (such as toilets) are provided with high temperature radiators. The castle hosts also a small auditorium, which is autonomously managed (with an AHU) and was not part of the analyses. As previously mentioned, the castle is not provided with a cooling system. In terms of BOs control opportunities, despite several thermostats are positioned in various spots of the building, they are not operable by BOs, but only by BMs, mainly remotely. In fact, the whole complex HVAC system is managed by a BEMS by an external consulting agency. This building is naturally ventilated. However, while in offices BOs are allowed to manage windows according to their necessities, in the expositive part the windows can only be opened by a unique responsible person (the facility manager) for responsibility reasons. Usually, windows remain closed if not explicitly asked by expositive part's workers. Anyway, even when asked, if all windows can be opened in the third floors, since they are provided with protections against poultries, these protections are installed only in 4 rooms in the first and second floor. For this reason, when required, only windows of these rooms can be opened. The facility manager reported that in summer they usually keep these windows open from 9:00 to 17:00 (museum opening hours), while in winter they are always closed (unless if specific requests due to air quality reasons occurs). This seems inadequate and will be further investigated in the following, anyway it should be mentioned that the castle is provided with one-glass wooden frame windows, so actually a certain amount of natural ventilation occurs by infiltration. Internal doors of offices are operated directly by BOs, while in the expositive part they represent a big source of energy wasting. In fact, the stairwell is not conditioned and separated from the outside by a glass sliding door. At each floor, the expositive area is not closed, so in winter the rooms near to the stairwell are very cold. Nevertheless, according to the facility manager, it is not possible to close these doors because they are fire-proof very heavy doors, which could not be easily open by visitors. In terms of artificial lights, rooms are equipped with various bulbs types: a small percentage of rooms have LED lights, but others have still incandescent ones. While some areas (like toilets) are already provided with presence sensors, in the expositive part artificial lights are manually switched on by the staff of the expositive part based on their perception. Only one room is provided with light dimmering because it had conservation problems (the whole room is covered with ancient Chinese paper which requires an extremely low illumination to avoid colours' and materials' damages). In offices, artificial lights are managed autonomously. In terms of natural light management, the castle is not provided with external blinds. About internal blinds, they are autonomously managed in offices. In the expositive area, they are managed differently based on the season. In fact, in summer the majority of them are closed for artworks' conservation reasons (so artificial lights are switched on), while in winter there is not a particular indication, so they are managed by the conservation responsible and the museum's director based on the exposition necessities.

Table 55. Rivoli. HVAC settings.

Space type	HVAC system	Terminal	Set-point an	BOs controls
Expositive part and offices of the castle	Heating	Floor radiant panels	**Winter** T set-point= 20°C. Operation: 5:00-16:30	No controls
Library offices and expositive of the "Manica Lunga"	Heating and cooling	Fan-coil	**Summer** T set-point= 24°C. Operation: 0:00-24:00 **Winter** T set-point= 20°C. Operation: 0:00-24:00	Fan-coils regulation

The Manica Lunga, differently from the castle, is provided also with a mechanical cooling system. The terminals in this buildings are fan-coils, which provides also indoor air replacement with outdoors by a plenum. This building, differently from the castle, has a continuous operation of the hot and cool fluids generators because it has to guarantee specific indoor environmental conditions in a special artworks' deposit. In this building, the stairwell and the ticket shop are air-conditioned. The bar is autonomously air-conditioned. In terms of energy-related controls of envelope elements in the exposition and offices area, the management logics is the same described for the castle building. The only difference is that in the offices, which corresponds to the library, the fan-coil controls are manageable by BOs. Fan coils are not operable in the expositive part.

Energy consumption materials were available, both in terms of electric energy and in terms of natural gas energy bills. The data were available starting from 2015, so two years before the beginning of the BIOSFERA experimentation.

Occupant related information emerged from the interview with BMs. Essentially two groups were identified in this case study. The first is office workers, which were categorized, as usual, as HLC. The second group is the one of the workers of the expositive part (staff of the museum), which is classified as MLC. These people have almost no control opportunities except the possibility to switch on artificial lights when they perceive that it is necessary, so their only mean to manage their environmental related comfort is personal adjustment. For this case study, it was proposed also to distribute questionnaires to the museum's visitors (which would have been LLC). This distribution should have been done during all the year (all seasons). However, it was not successful, because at the end of the experimentation only 10 filled questionnaires were delivered. For this reason, this group was not analysed.

Energy consumption assessment. As previously mentioned, electric energy and natural gas energy bills were provided from 2015 until the end of the experimentation. Therefore, in phase I it was possible to perform the various analyses that were shown in the detailed implementation of the methodology (Chapter 11). Here, for synthesis reasons, only yearly indicators are shown, in order to present general information about the Rivoli castle's energy performances.

Table 56. Rivoli. Principal energy consumption indicators, phase I.

	EP_H [kWh/m^2]	**EP_{TOT}** [kWh/m^2]	**EE** [kWh_e]	**EE** [kWh_e/m^2]	**TE** [kWh_t]	**TE** [kWh_t/m^2]	**TE_N** [kWh_t/DD]
2015	78	193	718762	48	1112297	74	442
2016	82	194	695338	46	1175212	78	455
2017	85	203	738691	49	1211926	81	473

Indoor environment assessment. This part of the methodology implementation gathers two of the focus topics identified in the beginning of the paragraph dedicated to the Rivoli castle. The first is more focused on BOs comfort conditions, especially in summer season and only in the Castle building, where the dataloggers were positioned. Figure 111 shows the adaptive model graph elaborated following the instruction of the standard EN 15251. As shown, all monitored indoor air

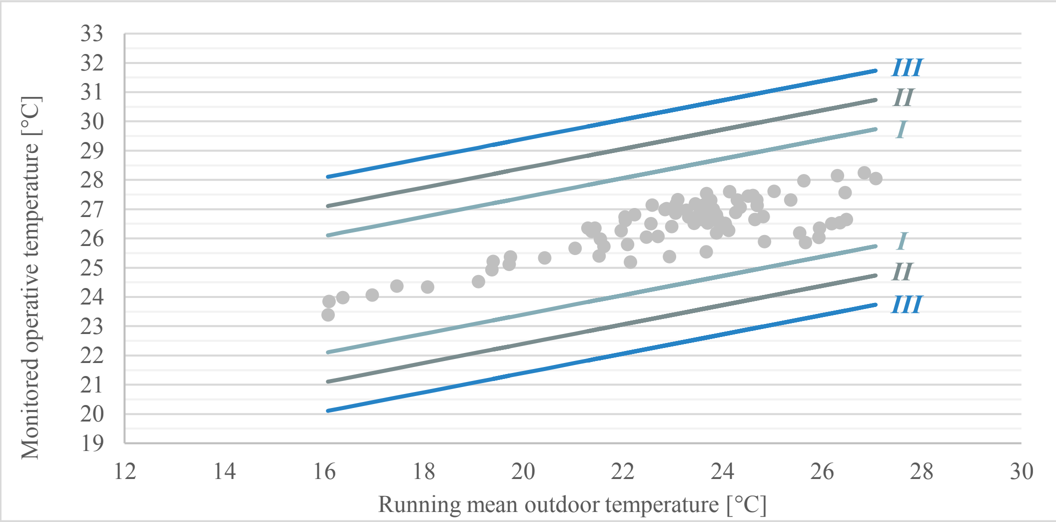


Figure 111. Rivoli. Adaptive comfort model - summer season phase I.

temperature fell in Category I. This data should be then compared with TSV and thermal comfort evaluation of occupants, in order to understand how much this analysis capture occupants' effective evaluation of the indoor environment. In general, about the building, it should be highlighted that the massive masonry structure results in notable passive energy performances. The second analysis that was chosen to be presented in this paragraph regards the "class" of "control potential" for artworks' conservation, shown in Figure 112. The classes were evaluated according to the ASHRAE handbook - HVAC application, chapter 23 (ASHRAE, 2011). The graph shows the scatterplots of all monitored indoor air

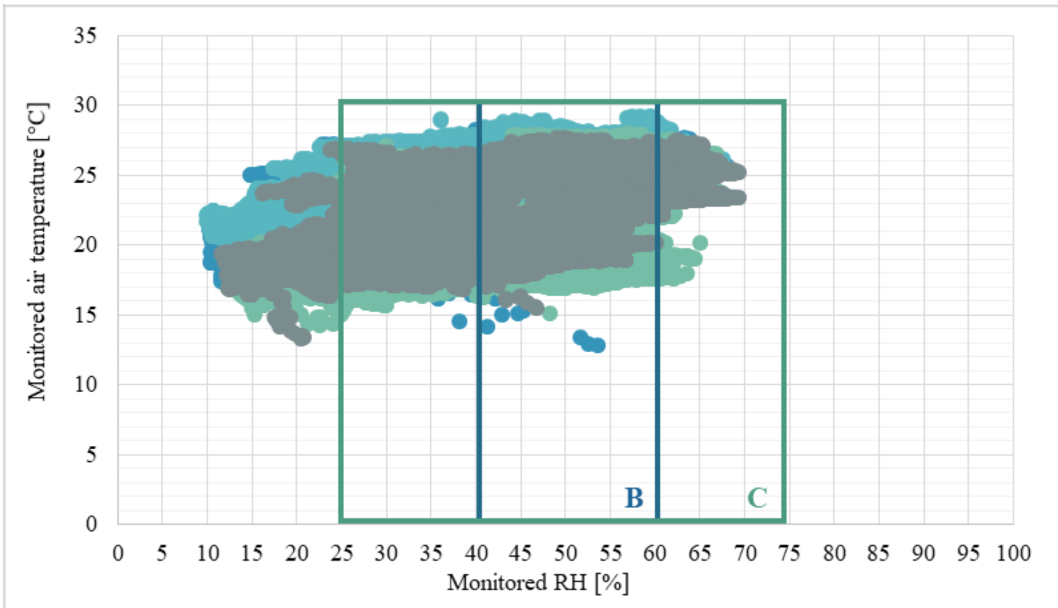


Figure 112. Rivoli. Control classes for artworks conservation according to Ashrae Ch. 23 HVAC applications.

temperature of one year, since the "long-term" fluctuations should be assessed before deepening in short term ones. The two monitored floors of the castle were analysed separately. Figure 112 shows the analysis of the first floor (dataloggers 1-4) (second floor analyses were very similar). As shown, the attributed control class cannot be B nor C (which are considered as the most suitable classes for historic buildings). In fact, 18% of the total relative humidity values are below 25%, which is the lower limit of class C. This means that the building should be considered as "class D", since it still guarantees that, all year long, relative humidity is below 75%. The information that should be transferred to the museum's curator is that, due to these environmental conditions, Ashrae handbook declares a "*high risk of sudden or cumulative mechanical damage on most artefacts and paintings because of low-humidity fracture*". However, damages due to high humidity (such as mould and deformations in paper and paintings) should be avoided. Fortunately, the Rivoli museum of contemporary art do not conserve many fragile artworks. Nevertheless, these information are fundamental for the conservation of the building apparatus and decoration (e.g. woodworks).

Energy relevant information from BOs. Office workers (HLC) participated to phase I questionnaire online, similarly to what already described for the previous cases. In summer, 8 out of 16 occupants filled the questionnaires, while in winter only 5 out of 16 occupants participated. About the workers of the expositive area (MLC BOs) they filled out paper questionnaires. In this case, the total number of BOs was not provided as an "exact" number, because only a part of people working in the exposition is hired by the museum; a quote of them is part of an external agency. For this reason, the approximate number chosen was 15 BOs, which is the number of blank questionnaires that were asked by the administration. In summer, 14 out of 15 MLC BOs filled the questionnaires, while in winter the answers were 11 out of 15.

The following analyses are focused on the castle occupants, excluding the "manica lunga" ones. Moreover, the MLC (workers of the exposition) were asked to refer to the castle when answering the questionnaires, since also for the administration, the acquisition of data on BOs' comfort conditions was more relevant in this area. This choice did not exclude any MLC BOs, since they all

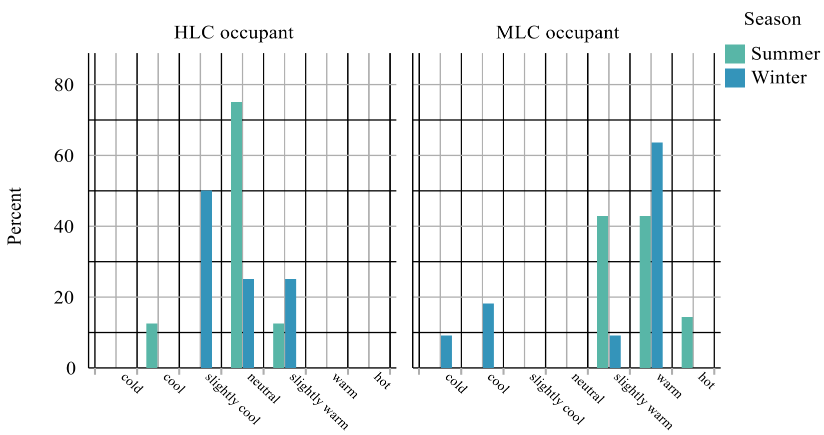


Figure 113. Rivoli. Castle BOs Tsv - phase I.

“rotate” in the museum exposition area. One of the most interesting aspects to investigate about the castle, was thermal comfort and TSV of the two BOs categories. In fact, offices are located nearby the expositive part and managed (in terms of HVAC) in the same way. However, BOs have different control opportunities (e.g. possibility to open windows and operate curtains or open/close doors), which could influence their perception, as well as the “local” indoor environmental parameters (e.g. air temperature, air velocity, natural light level etc.). In effect, looking at Figure 113 and 114, showing TSV and thermal comfort respectively, show quite different results for the two occupants’ categories. The adaptive model graph previously shown overestimated the percentage of comfortable BOs, since also in offices (HLC), about 25% BOs felt slightly uncomfortable in summer (season to which the graph was referred). Nevertheless, the adaptive comfort model seems not predictive for MLC thermal comfort, since about 50% of them was not comfortable. This is actually not much surprising, since the adaptive model should be valid “only” if occupants had access to windows as a mean of thermal adjustment – which is not exactly the case for MLC BOs in this case study, since if they wanted to open windows they had to ask to a specific responsible person to perform the action. Therefore, it is probably not much surprising that the percentage of uncomfortable people was higher than predicted. Anyhow, again, the importance of considering information and data from several sources and point of views is again remarked by this case, in which the reasons why the adaptive model was not quite predictive for MLC BOs could be hypothesized thanks to the information gathered by BMs.

Tsv and thermal comfort graphs show that MLC BOs felt, in the majority of cases, warm both in summer and in winter seasons. This condition results, with approximately the same percentages, on a large variability of thermal comfort states. However, the percentage of BOs feeling comfortable is quite low (less than 30% in both seasons). Thinking back to the adaptive model previously mentioned and also to thermal-related comfort expectation, it would have been reasonable to hypothesize that historic buildings’ BOs, especially in a “particular” context such as a castle, would have had lower comfort expectations. Therefore, these results

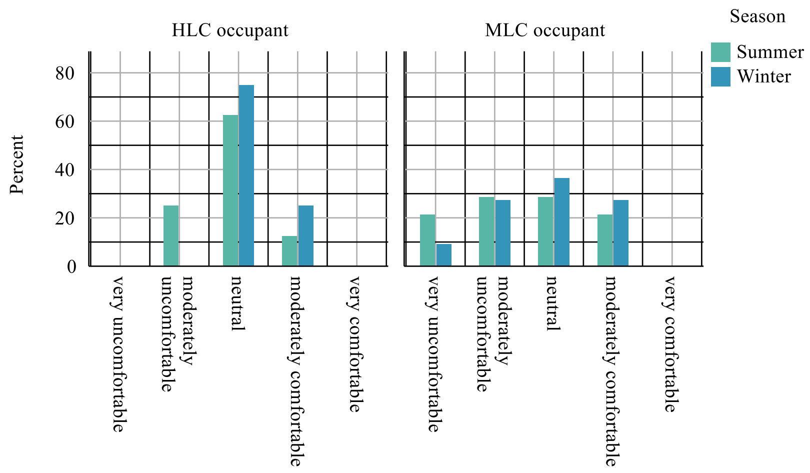


Figure 114. Rivoli. Castle BOs thermal comfort - phase I.

were quite surprising, especially if compared with the adaptive model analysis. However, this offers new insights of the probable weight that perceived control has on thermal-related evaluation, especially if comparing HLC and MLC BOs' evaluations.

Another aspect that was accurately evaluated was perceived indoor air quality, especially in winter season, since BMs declared that in Winter windows are never

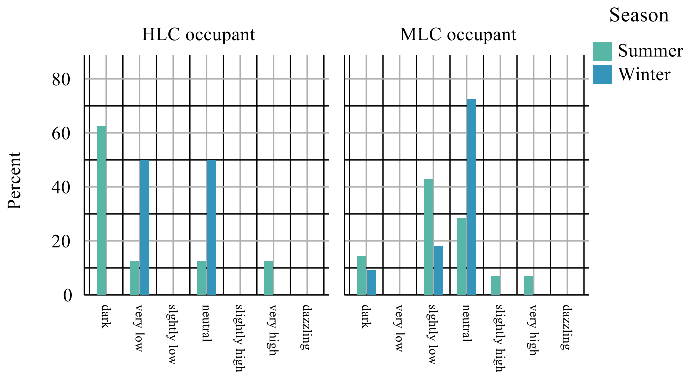


Figure 115. Rivoli. BOs evaluation of natural light level. Phase I.

open. Therefore, the only ventilation of the building was by infiltration and by the stairwell, which is connected to the outside with a glass sliding door. Quite unexpectedly, MLC BOs did not perceive a bad air quality, especially in Winter. In fact, while in summer the air quality was judged as "not acceptable" by about 30% of BOs, in winter this was declared by less than 20% of BOs. Also in terms of local discomfort, while 67% BOs complained about "too hot or too cold surfaces" in summer and 50% complained about draught in winter, no complains about bad air quality were registered. Nevertheless, another environmental parameter resulted critical, especially in offices. In fact, as shown in Figure 115, the natural light level was generally judged as quite low (dark, by 60% BOs in summer season). This is quite surprising, since office BOs have free access and operation to curtains. However, they do not have the habit of operating them much in order to adjust the natural level, preferring to operate artificial lights (evidences will be shown in the following to assess the effectiveness of behavioural change measures).

12.2.2 Phase II

In the following, the strategies proposed for the case studies in phase II – summer and winter will be summarized for each season. The main difference of phase II strategies for the Rivoli castle in respect to the other cases was that no strategies were proposed in terms of HVAC settings' changes, since the consulting agency who delivered the energy bills was hired to handle systems' operation already, so it would not have been possible to overlap their professional management with the methodology. Nonetheless, the agency declared that during the Phase II (summer and winter) no changes to the HVAC settings (in terms of set-points and schedules) were made in respect to Phase I, so the eventual changes that will be addressed in phase III will be a result of BM (facility manager) and BOs behavioural change. Analysing the BMs interviews and the questionnaires gathered at the end of Phase I, several aspects to be addressed by phase II strategies were identified with a similar approach of the one shown for the previous case studies.

Summer season.

In terms of strategies proposed to **BMs**, proposals were made for the management of the expositive part, in which BOs do not have much controls over the principal elements. The possibility of providing BOs with the possibility of opening windows or curtains was not accepted, for responsibility reasons. For this reason, the facility manager (who personally open windows) was discouraged to keep the expositive part operable windows (those with fly screens) open from 9:00 to 17:00 in summer season, because outdoor temperature is higher than inside, so they actually worsen the indoor climatic condition, which is already judged generally warm to hot by BOs. The advice was to open windows in early morning (from 8:00 to 9:00) to naturally ventilate and profit of free cooling. Then, during the day, a number of openings should be guaranteed to ventilate the space, but for a limited period of time. Another aspect emerged from phase I analyses and was proposed as a strategy for Phase II, but could not be addressed. In fact, from Phase I electric energy bills analyses, an anomalous EE consumption emerged in F3, so night horary. That consumption was due to the night illumination of the castle. The administration was not aware, before this analysis, of the fact that the electric energy used to illuminate the castle was payed by the museum. Unfortunately, they could not immediately change the lights' operation (e.g. switching off a part of the lights a certain late hour in the night), because the system did not allowed that. However, they decided to plan an intervention to the external lights in order to address this strong cause of energy demand.

In terms of **BOs** engagement, different objectives and necessities were identified from the questionnaires and the complains signalled by BMs. The most important difference in respect to the other cases is that this was the only case in which a workshop was organized, involving both MLC and HLC BOs. The workshop was structured according to what described in part II of the thesis. The only difference was that the presentation was also printed to be distributed to BOs and delivered to those who cannot attend it. Particular relevance was given, for office BOs, to the use of windows and curtains in offices, since the questionnaire analysis highlighted their mismanagement. Another relevant topic of the workshop was personal adjustment strategies (from the questionnaire it emerged that only 50% BOs adjusted clothes when feeling thermally uncomfortable). Another topic of intervention (through newsletters and signs) was artificial light behaviour, since from the questionnaire it emerged that in Phase I 75% BOs switched them on when arriving at the office in the morning. This was linked also to the use of curtains, which were operated by only 50% of office BOs. In terms of communication means, Table 57 summarizes the means, the areas and the topics. Signs (and the workshop presentation) can be visualized in the Annex CD attached to the thesis.

Winter season. In winter, the most **BM**-related relevant aspect that emerged was the low relative humidity, which could damage both building's materials and BOs (even if only 25% BOs evaluated the air "dry"). However, in terms of building management, the only advice that could be provided was to equip some rooms (the most dry ones) with humidifiers, even if this kind of strategy was not in line with the BIOSFERA methodology, since it would imply the purchase of humidifiers. The other topic related to BMs was the expositive part windows' opening for natural ventilation. In fact, even if BOs seems not to perceive a bad air quality, opening windows is fundamental in a naturally ventilated buildings.

In terms of **BOs** strategies, the chosen communication means are shown in Table 57. In winter, the workshop was not repeated due to administration impossibility of finding a suitable date. In terms of relevant topics, the most relevant behavioural aspect were those already emerged in summer season (e.g. artificial lighting switching). The only main difference was related to the management of dry air, which could be addressed in offices also with a zero-costly measure. In fact, since in offices the terminals are cast iron high temperature radiators, the simple use of a bowl full of water on the radiator could slightly humidify air. This was advised in a specific newsletter.

Table 57. Rivoli. BOs strategies for phase II – summer season.

Communication mean	**Building area**	**Delivered information**
Comfort advices sign	Castle offices	What to do in case of thermal discomfort (too hot or too cold), poor air quality, too high or low light. Advices are distinguished in each area depending on control possibilities, including personal adjustment.
	Manica lunga offices	
How to use the fan-coils sign	Manica lunga offices	Fan-coils instructions.
Before leaving the room sign	Castle offices	Specific remind based on available controls (e.g. artificial lights, pc etc.).
	Manica lunga offices	
Newsletter	Office workers (all)	The main topics were artificial lights and curtains operation.
Workshop	All BOs	Major relevance given to personal adjustment.

12.2.3 Phase III

Phase III analyses will be synthetically shown in the following, addressing energy-related results and occupants' related results, especially in respect to what was shown in the previous paragraphs.

Table 58 summarizes electric energy demand and costs (raw energy), comparing data of phase I and phase II for both summer and winter season. As shown, in both seasons the overall EE saving was around 10%, which is a quite remarkable result if considering that no HVAC settings were changed, so the result should be attributed only to BOs behavioural change. Moreover, it should be noticed that, especially in summer, right after the distribution of materials (like signs) and the workshop, the result was remarkable, while in the following months the engagement probably decreased. In terms of energy costs, it should be noticed that while in summer 2017 the average tariff was around 0.06 €/kWh, for the following seasons it was around 0.09 €/kWh. This information was provided by the external energy consulting agency, who did not sent the electric energy bills starting from 2018, but a summarizing calculation sheet containing only energy consumption, and a general indication of the energy tariff. Anyway, a normalized calculation of EE costs savings for summer season would not result on a +14%, but on -4%.

Table 58. Rivoli. Electric energy demand, phase I vs phase II - summer and winter.

	EE [kWh$_e$]	Monthly difference	Seasonal difference	EE costs	Monthly difference	Seasonal difference
Jun-17	76039			5,524.79 €		
Jul-17	85086			6,119.70 €		
Aug-17	61201			4,452.15 €		
Sept-17	50978			3,657.24 €		
Jun-18	46476	-39%	**-8%**	4,182.84 €	-24%	**14%**
Jul-18	73673	-13%		6,630.57 €	8%	
Aug-18	66733	9%		6,005.97 €	35%	
Sept-18	64219	26%		5,779.71 €	58%	
Jan-18	56834			4,829.49 €		
Feb-18	54833			4,787.01 €		
Mar-18	56660			5,099.40 €		
Jan-19	50934	-10%	**-9%**	4,584.06 €	-5%	**-6%**
Feb-19	50407	-8%		4,536.63 €	-5%	
Mar-19	52081	-8%		4,687.29 €	-8%	

In terms of Natural gas consumption (smc), which was translated in thermal energy (kWh$_t$), results are shown in Table 59. As it can be seen, the best results were reached in summer season. However, in this season natural gas consumption is very reduced anyway, so winter ones are more relevant. In these terms, the normalized seasonal difference is not much relevant (-3%). Anyway, it should be noticed that in the castle BOs did not have any access to thermostats. In the Manica lunga instead, the BM had access to fan-coils (as well as office BOs in the library), therefore their behavioural change could have had a slight impact. About costs, the seasonal difference in summer was -3% between phase I and phase II, while in winter it was -6% (considering only raw energy costs). About thermal energy.

Table 59. Rivoli. Natural Gas consumption, phase I vs phase II - summer and winter season.

	DD	Thermal energy [kWh_t]	ETN [kWh_t/DD]	Monthly difference	Seasonal difference	Monthly difference (HDD)
Jun-17	1	2684	2684			
Jul-17	13	2973	229			
Aug-17	36	267	7			
Sept-17	1	2705	2705			
Jun-18	0	2331	2331	-13%	**-21%**	**-31%**
Jul-18	28	2555	91	-14%		
Aug-18	30	491	16	84%		
Sept-18	0	1465	1465	-46%		
Jan-18	456	249105	546			
Feb-18	478	269275	563			
Mar-18	406	232155	572			
Jan-19	538	284611	529	14%	**-12%**	**-3%**
Feb-19	384	214519	559	-20%		
Mar-19	290	159828	551	-31%		

Building occupants were asked to fill paper questionnaires, which were distributed and gathered in the same period shown for the previous case studies. In

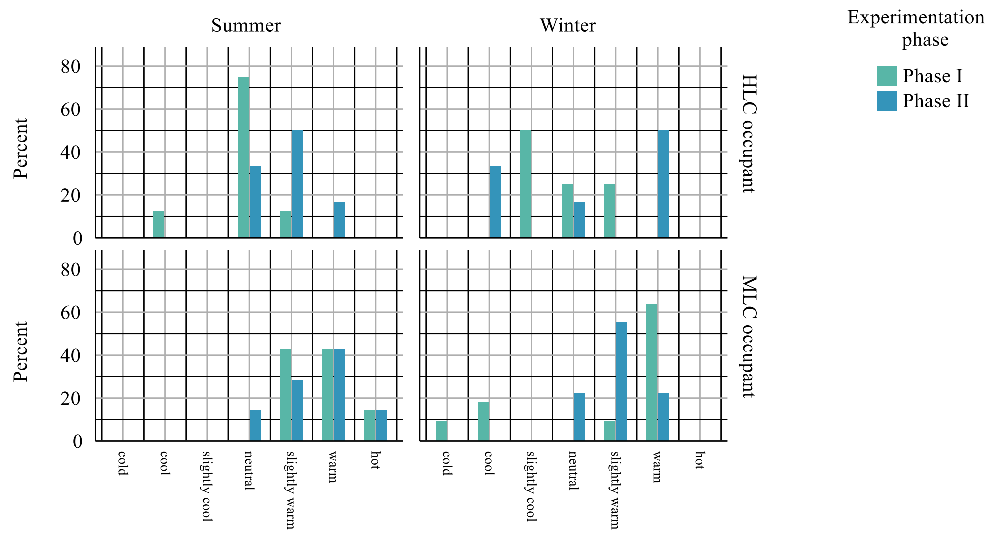


Figure 116. Rivoli. HLC and MLC TSV, phase I vs Phase II - summer and winter season.

summer, 6 out of 16 HLC BOs and 7 out of 15 MLC BOs answered the questionnaire, while in winter participants were 6 out of 16 HLC BOs and 9 out of 15 MLC BOs. Unfortunately, it cannot be established if participants of the first phase were the same of the third one, since questionnaires were anonymous. In terms of the evaluations made by BOs, Figure 116 and 117 show TSV and thermal comfort comparing phase I and II, in summer and winter season. As it can be seen, no particular problems were registered in terms of thermal comfort by office workers also in the first phase. Anyway, thermal comfort seems to increase during phase II. MLC BOs' thermal comfort evaluation was quite various across the scale, while TSV was quite concentrated in the "warmer" part of the scale (except about 30% BOs feeling cool in winter). In general, in phase II the percentage of occupants voting "neutral" as thermal comfort vote was quite reduced. However, while in winter the general trend shows an increase of comfortable votes (in percentage), in summer the overall percentage of comfortable and uncomfortable was almost unchanged. In terms of behavioural change, in phase I an inappropriate use of artificial lights by office workers was detected. Figure 118 shows how the answers to the same question asking when BOs usually operated artificial lights, changed between phase I and II.

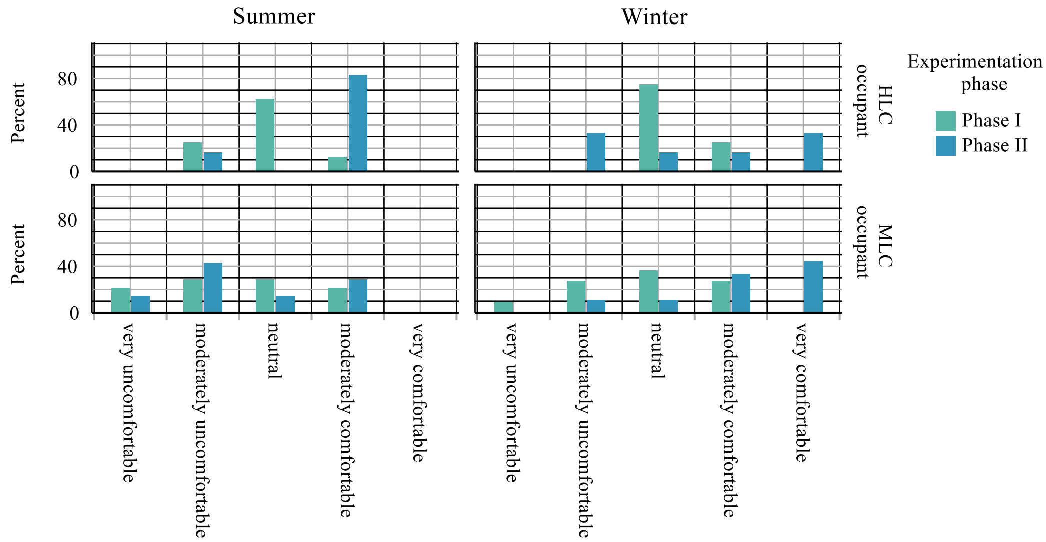


Figure 117. Rivoli. HLC and MLC thermal comfort, phase I vs Phase II - summer and winter season.

As it can be seen, in general the percentage of people switching on lights only in case of too low natural light increased notably, especially in summer season (it reached 100%). In winter, a notable percentage of people switching on lights when arriving at the office in the morning remained (60%), while in summer it was eliminated.

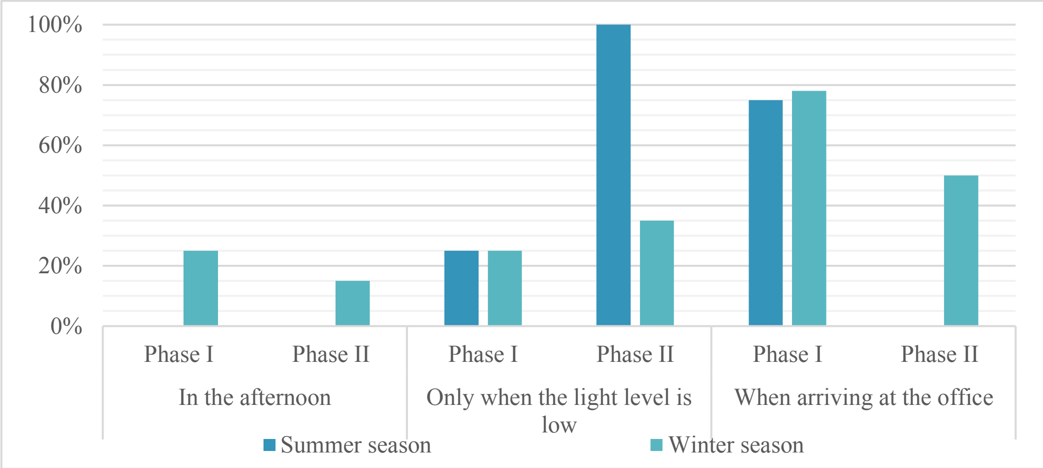


Figure 118. Rivoli. Office workers habits in terms of artificial lights' use. Phase I vs phase II - summer and winter season.

Another relevant aspect identified in phase I was windows' opening. In fact, especially in winter season, about a half of occupants never opened windows to ventilate the room. As shown in Figure 119, despite a specific newsletter was sent to encourage windows' opening, the only aspect in which it seems that it had an efficacy was the importance of summer free cooling in early morning (the percentage of workers opening windows when arriving at the office in the morning passed from less than 15% to 67%). Other information, like the inefficacy of opening windows to cool rooms when feeling too hot in summer, were not integrated (or accepted). In winter, the percentage of occupants never opening windows was reduced by about 15%.

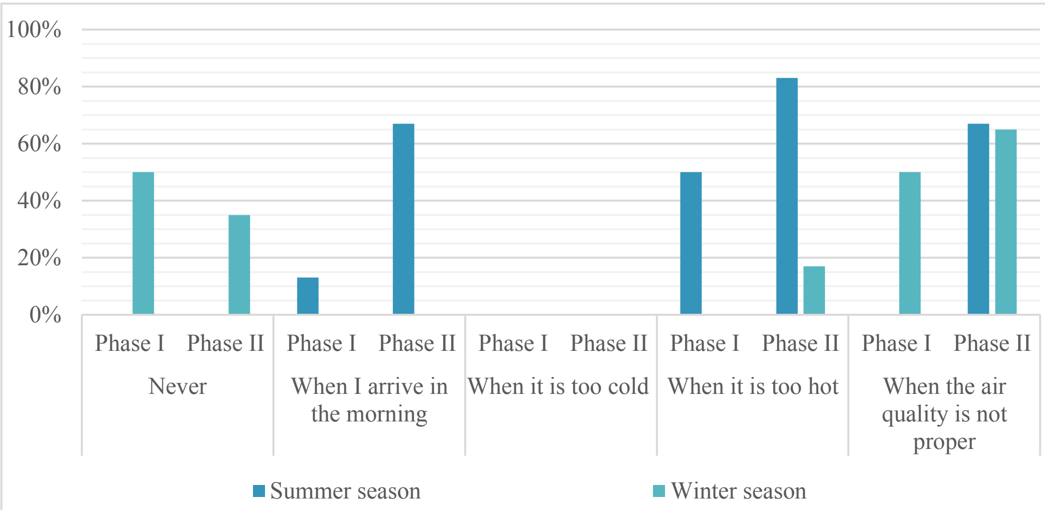


Figure 119. Rivoli. Office workers habits in terms of windows opening. Phase I vs phase II- winter and summer season.

12.3 The Stupinigi hunting lodge

The Stupinigi hunting lodge was built at the beginning of the Eighteenth Century, near to the city of Turin, approximately 10 km from the Ducal Palace of the city. The architect who designed the palace, Filippo Juvarra, worked also in the other royal residences presented before (the Rivoli castle and the Venaria Reale). The hunting lodge is listed in the UNESCO World Heritage List. From a constructive point of view, the building has a massive masonry structure, but differently from the previous cases, it is characterized by big openings, according to the international rococo style. The building was restored (1995-2002) and today is partly opened as a "museum of itself", namely as a royal residence, complete with its original furniture and decorations. As shown in Figure 120, the original structure was divided in new functional areas. However, the museum is still not entirely opened, since the "West apartment" and the carriage gallery are still under restoration. The offices are located in the east barn.

Figure 120. Stupinigi. Photos of the hunting lodge and the restoration project.

This case study was characterized by a series of events which caused limitations to the implementation of the BIOSFERA methodology, partly accidental and partly not. For this reason, the following description of the case study will be particularly focused on the elements that contributed to the difficulty of implementing the methodology and caused the impossibility of implementing the strategies and/or analysing their impact in terms of energy efficiency, BOs' comfort and behavioural change.

The methodology's implementation took place approximately in the same period previously shown for the other case studies, so phase I took place in summer 2017 (June-September) and winter 2017/2018 (December-March), while phase II took place in the same months of summer 2018 and winter 2018/2019.

12.3.1 Phase I

BMs energy-related management. The first aspect to be highlighted as a difference in respect to the other case studies, is that in this case the reference contact was a person working for the foundation owning the hunting lodge, who actually was not a "building manager" as intended in this methodology. However, it was the contact that was reached and agreed to participate to the methodology's implementation. An element that became fundamental, was that this person did not usually worked in the hunting lodge. For this reason, in a second time, two other people working at the hunting lodge and a technician were involved. Nevertheless, there was never a meeting of all parties together, which complicated the communication. For example, in case of necessity, it was not very clear which of the responsible people should be involved or contacted. The information about the building and its usage were provided in different times and by different people. The building, as shown in Figure 120, has been divided in several functional areas. The offices are located in the east barn and are all small offices. The whole HVAC system is handled by a BEMS (Desigo – Siemens). The total conditioned floor area, according to the BEMS system, is 1623.5m^2. The total floor area of the building was not provided. The expositive area was provided with an **environmental monitoring system**, very similar to the one shown for the Rivoli Castle, since the monitoring was curated by the CCR, who installed the dataloggers and periodically evaluated the environmental parameters in order to evaluate conservation risks for the museum collection. Therefore, the specifics presented in Table 54 for the Rivoli castle are valid also for this case study. Dataloggers were positioned based on a spot measures campaign conducted by the CCR. Similarly to the Rivoli castle, they are located in different points of the rooms in order to not being visible by visitors. Differently from the Rivoli Castle, the environmental conditions monitored cannot be considered as representative also for the offices area, which is handled separately and is located quite far from the expositive part. For these reasons, the analysis for human comfort could be conducted only for visitors or members of the staff and should be carefully evaluated, since the temperature set-point (shown in Table 60) is not set for human comfort, but for conservation reason (in order to avoid major conservation damages).

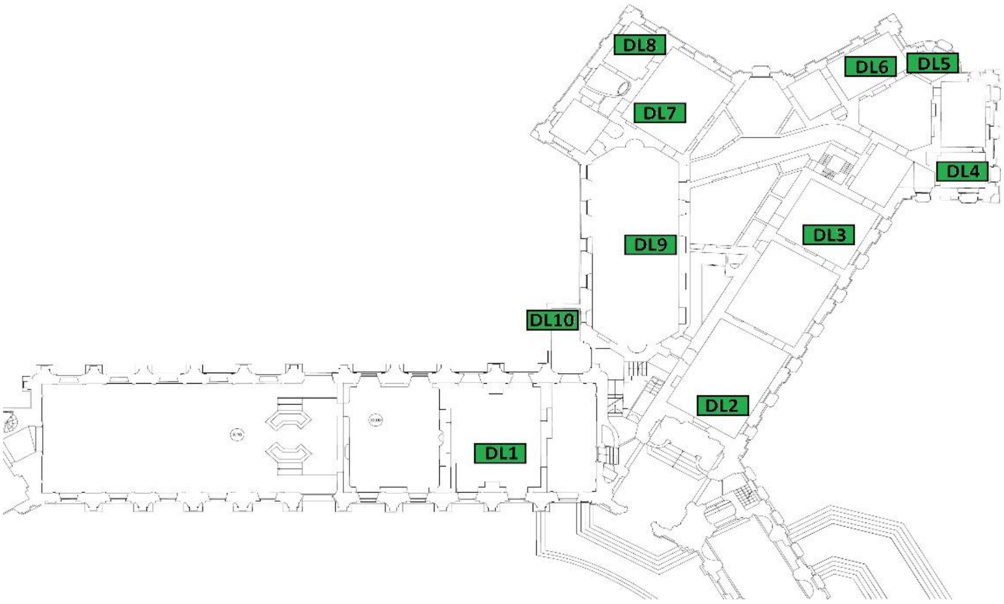


Figure 121.Stupinigi. Collocation of dataloggers.

In terms of **energy-related control opportunities**, different information were gathered for the expositive part and the offices part. In the expositive part, only the conservation curator can open windows, curtains, external blinds, doors and switch on artificial lights. In terms of HVAC settings, the museum is only heated in winter; in summer the building is passively cooled thorough windows' opening. The ticket shop is handled separately from the museum; it is equipped with fan coils that can be regulated by BOs. This area was not considered because it has only 2 BOs and it is just one room. In offices, BOs can open windows, curtains, artificial lights and external blinds (were present). In terms of HVAC settings, they are provided with heating and cooling system. The heating system is controlled by the technician only in terms of temperature of hot fluids entering the high temperature iron radiators. At the room level, radiators are provided with a thermos-valve, which do not change the temperature set-point, but only the quantity of hot fluids arriving to the terminal. In summer, offices are provided with water sourced heat pump units, which are controlled by BOs in each office. A major reason of complain reported by the BMs is that the stairwell is not conditioned, so every time a worker has to exit the office he experiences a very uncomfortable space, very cold in winter and hot in summer. HVAC settings are shown in Table 60.

Table 60. Stupinigi. HVAC settings, phase I.

Space type	HVAC system	Terminal	Set-point an	BOs controls
Expositive part	Heating	Floor radiant panels	**Winter** T set-point= 14°C. Operation: 5:30-16:30	No controls
Offices	Heating and cooling	Fan-coil	**Summer** Water source heat pumps autonomously set by BOs **Winter** T hot water inlet = 60-75°C based on outdoor climatic conditions. Operation: 8:30-17:30	Winter: thermo-valves Summer: heat pump operation

The delivery of **energy consumption materials** was one of the main problems for the implementation of the BIOSFERA methodology in this case study. In fact, at the beginning of the experimentation a small number of energy bills were provided. However, after, only a few energy bills were provided (only a few months), so for none of the periods corresponding to phase I and II, both in summer and winter season, it was possible to perform energy-related analyses. Based on what explained in Part II of this thesis, once seen that at the end of phase I energy bills were not delivered, the experimentation should have been stopped. Anyway, the BMs declared that the energy bills would have been searched and found in the archives and collected for the future, so there was no problem to continue with the experimentation. In reality, also at the very end of the experimentation, bills were not provided. This impeded the possibility of conducting the energy-related analyses performed for the other case studies.

In terms of **occupant-related information**, as anticipated, at the beginning three groups were identified. Office workers (HLC), workers of the expositive part (MLC) and the museum's visitors (LLC). Nonetheless, starting from phase I questionnaires, MLC and LLC samples were excluded, since only 2 MLC questionnaires and 0 LLC questionnaires were delivered at the end of phase I. Therefore, only office workers' sample (HLC) was evaluated in all methodology's phases.

Energy consumption assessment. As previously mentioned, no sufficient materials were provided by BMs to be able to assess energy consumptions of phase I in summer or winter season. The only “complete” data were those of 2016’s energy bills (which was the year before the application of the methodology). For this reason, the only possible analysis was the one shown in Table 61. As shown, the absolute values are not much different for the previous two case studies, while the specific ones are remarkably high. In terms of EE, the calculation of the specific value considering only the conditioned area (which is much smaller than the total one) would not have been the best choice if the total building floor area was available.

Table 61. Stupinigi. Principal energy consumption indicators (2016).

	EP_H **[kWh/m^2]**	**EP_{TOT}** **[kWh/m^2]**	**EE** **[kWh_e]**	**EE** **[kWh_e/m^2]**	**TE** **[kWh_t]**	**TE** **[kWh_t/m^2]**	**TE_N** **[kWh_t/DD]**
2016	749	1328	388751	239	1157780	713	449

Indoor environment assessment. As previously mentioned, the expositive part of the Stupinigi hunting lodge was provided with a monitoring system, as shown in Figure 121. Since no questionnaires were filled by MLC and LLC BOs, the analysis of monitored data for human comfort could not be compared with building

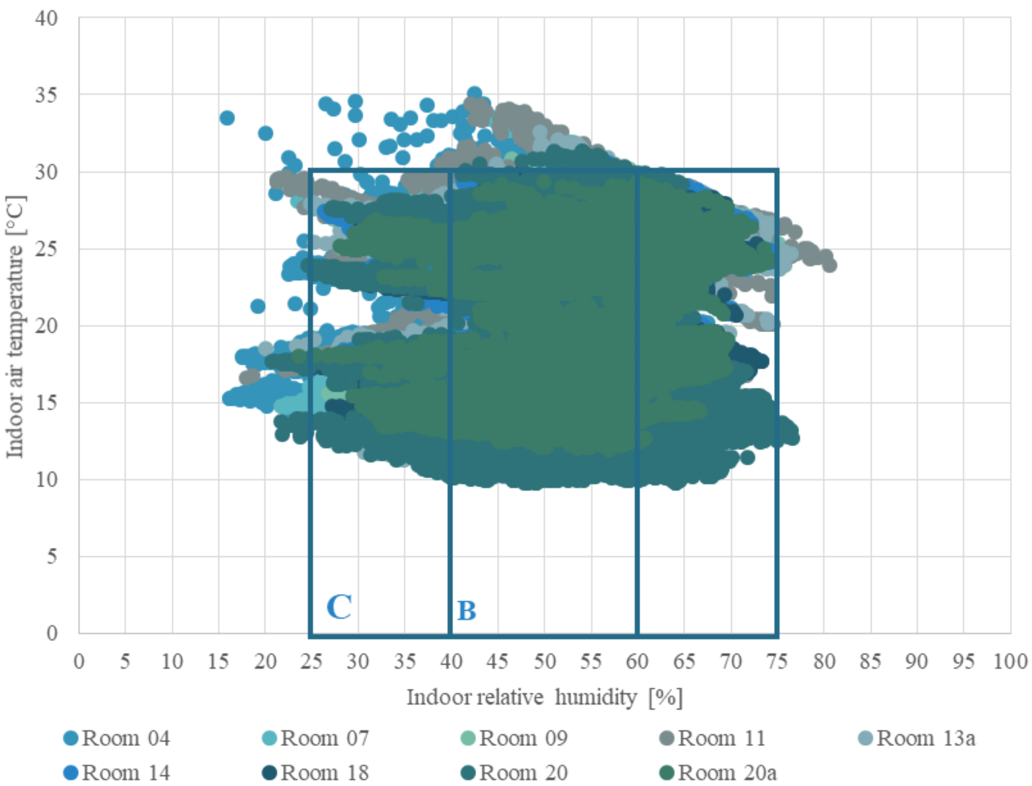


Figure 122. Stupinigi. Analysis of control potentialities for artworks conservation according to ASHRAE Handbook.

occupants' evaluation, so it will not be presented. However, an important analysis for the conservator of the museum was the one presented in Figure 122. The graph presents the same analysis already presented in Figure 112 for the Rivoli Castle. The difference is that, in this case, the Stupinigi hunting lodge can be classified as a Class "C" museum, since, RH is usually between 25% and 75% (values are outside the range are less than 1%) and the temperature is usually below 25°C (70% of time averagely) and rarely above 30°C (less than 1%) (ASHRAE, 2011). This control class is defined as "high risk" only for very fragile artefacts, while it ensures moderate risk for most paintings and other decoration. However, in terms of strategies, the enhancement of indoor environmental conditions to pass to a "B" class would require a relative humidity control, which would require the installation of new specific HVAC (changing the present system's settings would not remarkably enhance relative humidity conditions).

Energy-relevant information from BOs. The questionnaire campaigns took place in the same period that was presented for the other cases (summer: 15th of Septermber-15th of October 2017, winter 15th of March-15th of April 2018). As previously mentioned, questionnaires for the workers of the expositive part and museum's visitors were delivered to the BMs, who decided to distribute them instead of the experimenter in order to explain to all of them the whole project on a meeting (in which the experimenter was not involved). However, at the end of the questionnaire campaign, only 2 questionnaires were filled (summer season), while in winter no questionnaires were filled. About visitors (LLC) questionnaires, they should have been distributed and promoted by MLC BOs, who were the only ones in direct contact with them. Nevertheless, no filled questionnaire were delivered back at the end of both seasons. For this reason, the only "valid" sample was the HLC BOs, namely office workers. This part of BOs actively participated to the questionnaires of Phase I, with 10 out of 10 participants at for summer season and 8 out of 10 participants for winter season. From these questionnaires, one of the most interesting aspects was the evaluation of thermal sensation votes and thermal comfort. In fact, in summer a notable percentage of BOs voted "slightly warm" to "hot". In total, 60% BOs felt uncomfortable (all occupants expressing an uncomfortable vote felt warm or hot). This was quite surprising, considering that in each office (which are all small ones) BOs had the complete freedom to manage heat pumps. In winter, in which BOs have less control over the environment (only

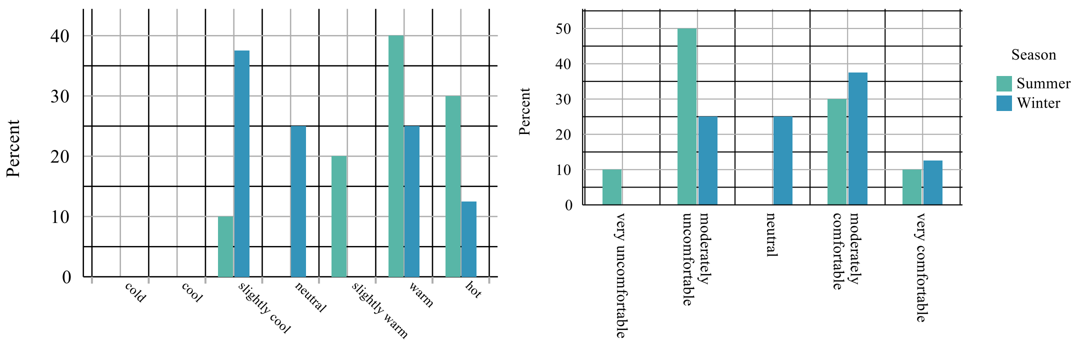


Figure 123. Stupinigi. Office workers' TSV and thermal comfort in summer and winter - phase I.

thermos-valves on the radiators), the uncomfortable votes are reduced to 25%. However, the uncomfortable condition is expressed principally by those who voted “slightly cool” for TSV, while occupants feeling “warm” or “hot” expressed a comfortable vote. In both seasons, education about the use of thermos-valves and heat pumps seems fundamental. In winter, for example, 88% of occupants do not operate thermos-valves when feeling too hot. Other relevant aspects were related mainly to the use of windows (40% BOs never open windows) and internal and external blinds, which are not operated by averagely 80% of BOs (considering both seasons).

12.3.2 Phase II

Summer season. In terms of strategies proposed to **BMs**, no possibilities for HVAC settings optimizations were identified with the technicians, since offices’ heat pumps were completely handled by occupants, while the museum was not mechanically cooled. In terms of envelope elements, the conservator completely handled windows, blinds and lights based on conservation necessities, so it was not possible to provide more indications.

In terms of strategies proposed to **BOs**, all strategies previously mentioned for the other case studies were prosed and focused on the necessities emerged from phase I questionnaire. However, when the moment of distributing signs arrived (middle of June), there was an “accident” which damaged the possibility of implementing the methodology in the following two months. In fact, the electric generator broke, so a temporary generator was used for the entire summer, waiting for the substitution of the permanent one. In this period, heat pumps’ use was forbidden, since the temporary generator could only support essential demands from pc, printers etc. For this reason, the administration decided to avoid the distribution of signs, comfort advices and “before exit the room” signs, in order to avoid more stress for workers, who were already in an uncomfortable condition. For these reasons, only newsletters were kept as communication means. Due to the present conditions of that period, the newsletters were mainly concentrated on passive means for handling the indoor environment (use of internal and external blinds and windows).

Winter season. In winter, no HVAC settings changes were implemented by the **BM**, since in the expositive part the temperature was already set very low (14°C) and only to avoid damages on the collection and artefacts. In the offices part, instead, the system was already set to the more reasonable and efficient settings based on the potential of the present system, since the temperature of hot water in circuits was already set based on outdoor climate regulation. Therefore, efficiency and comfort could only managed by BOs by handling thermos-valves.

For this reason, the main effort to enhance indoor thermal comfort were addressed to the education of **BOs** to a proper use of thermos-valves. Moreover, all the signs already prepared (and not used) for summer season, were adapted for season and winter and distributed and explained for phase II – winter. Moreover, the "how to use heat pumps" signs were distributed for the following season, since the methodology implementation was finished. The communication means are listed in Table 57.

Table 62. Stupinigi. BOs strategies for phase II – winter season.

Communication mean	**Building area**	**Delivered information**
Comfort advices sign	Offices	What to do in case of thermal discomfort (too hot or too cold), poor air quality, too high or low light, considering
How to use the thermos-valves sign (winter) and heat pumps (summer)	Offices	Thermo-valves and heat pumps instructions for a proper and efficient use.
Before leaving the room sign	Offices	Specific remind based on available controls (e.g. artificial lights, pc etc.).
Newsletter	Offices	Main topics based on what emerged in phase I questionnaires for each season. The main topics were windows opening and blinds operation.

12.3.3 Phase III

As previously mentioned, energy-related results cannot be shown for this case study, since energy bills were not provided in a sufficient number to perform analyses and compare months of the first and second phase.

In terms of **BOs**, office workers participated to phase III questionnaires in the same period shown for the other case studies cases (summer: 15th of Septermber-15th of October 2017, winter 15th of March-15th of April 2018). In summer, 7 out of 10 BOs filled the paper questionnaire, while in winter 10 out of 10 filled it. As previously mentioned, since in summer (phase II) heat pumps were not functioning (differently from phase I) an increase of the perceived air temperature would have been expected. This was confirmed, as shown in Figure 124. In winter, instead, the thermos-valves instructions seemed to have not changed or slightly increased indoor air temperature.

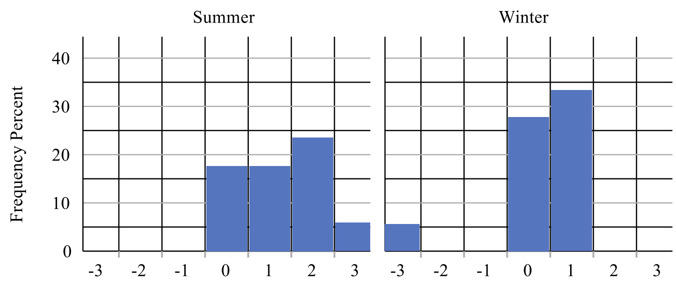


Figure 124. Stupinigi. Office workers' perceived temperature in phase II (vs phase I).

However, it seems surprising that thermal comfort seems not changed even in absence of heat pumps, or even enhanced. A possible explanation, since those expressing an “uncomfortable vote” in the previous phase were those feeling warm or hot, was that possibly BOs were not satisfied with the heat pump performances. This was partly confirmed by a comment on the questionnaire, in which a worker wrote that they would profit of a cooling system that actually cool down the air temperature. Once this comment was reported to the technician (BM), he told that, actually, offices’ heat pumps are not much efficient, because they work with groundwater, which is not cool enough to lower the temperature as expected. In

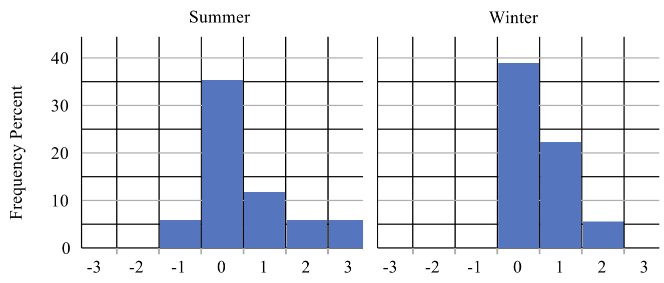


Figure 126. Stupinigi. Office workers' perceived thermal comfort in phase II (vs phase I).

winter, the perceived air temperature did not change or slightly increased, which resulted on unchanged or increased thermal comfort. This is coherent with the fact that in phase I the “uncomfortable” votes were expressed mainly by occupants feeling cold. The high percentage of occupants who did not perceive a change in temperature suggests that they probably not changed their behaviour towards the thermo-valves, despite the signs. This is quite confirmed by Figure 126, which shows that only 10% of occupants changed behaviour towards HVAC controls. In the same picture, it seems curious that 15% BOs declare to have changed behaviour towards HVAC controls in summer (since heat pumps were not functioning). However, the behaviour change is probably due to the fact that they could not operate them. Nevertheless, in general, the implemented strategies seem not to have influenced BOs behaviour, due to the low percentages shown in Figure 126.

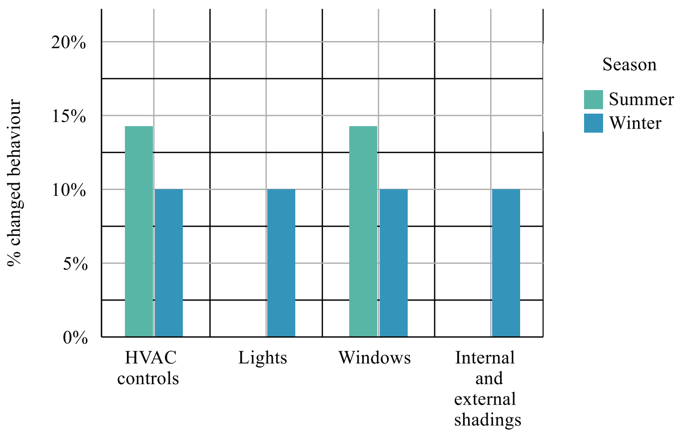


Figure 125. Perceived behavioural change towards energy-relevant building interfaces in phase II.

13

The big picture

The present chapter has the objective of comparing the results obtained in the four case studies for which the implementation of the methodology has been completed. The comparison is useful to identify similarities and hypothesize the reasons of observed tendencies, in order to discuss the methodology and suggest changes that will be proposed in Part IV. In fact, this first application of the methodology was intended as a "pilot study", in which results are more intended to acquire "lessons from the field" that could be integrated for a broader implementation on a larger scale. After summarizing the strategies implemented in the four case studies, results will be analysed following the scheme of the objectives that, according to the methodology described in Part II of this work, should have guided the choice of phase II strategies. Since no strategies were expressively addressed at solving artworks' conservation problems (for impossibility or not necessities), this objective will not be addressed in the following.

13.1 Implemented strategies

Table 63 summarizes the strategies applied in the four case studies in which the methodology was implemented from phase I to phase III. The colours of the table identify if a certain strategy was implemented (green) or not (red). Stupinigi's museum's row is grey because BOs of that part did not participated to the experimentation. Looking at the distribution of colours across the table, the following considerations can be made. First, in general, BMs related strategies were much less implemented than those of BOs. Another consideration, which is not generalizable for all case studies, is that office workers (HLC BOs) received more communication strategies than MLC. This is expected, since more control potential results in more saving potential (more possibility for behavioural change strategies). In a way, elaborating a similar type of table could be an indication of these potentials also at the beginning of the experimentation, just after the interview with BMs, since the relevant information is control potential of the various BOs groups.

Table 63. Summary of the strategies implemented in the case studies. Red cells identify a strategy that was not implemented, green ones a strategy that was implemented.

Case study	Analysed function	BMs strategies				BOs groups	BOs strategies									
		Building elements		*HVAC settings*			*Signs*						*Newsletters*		*Workshop*	
							HVAC instructions		*Comfort advices*		*Before leaving*					
		Sum	*Win*	*Sum*	*Win*		*Sum*	*Win*	*Sum*	*Win*	*Sum*	*Win*	*Sum*	*Win*	*Sum*	*Win*
Conservatory of Turin	Offices	Red	Red	Red	Red	HLC	Red	Red	Red	Red	Red	Red	Green	Green	Red	Red
	Classrooms and auditorium	Red	Red	Green	Green	MLC	Green	Green	Green	Green	Green	Green	Red	Red	Red	Red
Restoration Centre CCR	Offices	Green	Red	Green	Green	HLC	Green	Green	Green	Green	Green	Green	Green	Green	Red	Red
	Restoration laboratories	Red	Red	Red	Green	MLC	Green	Green	Green	Green	Red	Red	Green	Green	Red	Red
Rivoli castle	Offices	Red	Red	Red	Red	HLC	Green	Green	Green	Green	Green	Green	Green	Green	Green	Red
	Museum	Green	Green	Red	Red	MLC	Red	Red	Red	Red	Red	Red	Red	Red	Green	Red
Stupinigi Hunting Lodge	Offices	Red	Red	Red	Red	HLC	Red	Green	Red	Green	Red	Green	Green	Green	Red	Red
	Museum	Red	Red	Red	Red											

13.2 Energy-related results

Before comparing the results reached in phase III, Table 64 shows the comparison of the energy-related indicators for each case study, except the Stupinigi Hunting lodge, for which data referred to 2017 (which corresponds approximately to the first year of the experimentation) were not provided. For this case study, the following comparison of energy-related results would not be possible, since they did not provided the required energy materials. As shown in Table 64, the Conservatory of Turin was probably the most energy consuming case study (uncertainty exists since thermal energy data for the restoration centre are not available).

Table 64. All case studies. Comparison of energy indicators. Data referred to 2017.

	EPH [kWh/m^2]	**EPTOT** [kWh/m^2]	**EE** [kWh$_e$/m^2]	**TE** [kWh$_t$/m^2]
Conservatory of Turin	153	529	155	216
Restoration Centre Venaria	NA	NA	122	NA
Rivoli Castle	85	203	49	81

Table 65. All case studies. Comparison of the effect of BIOSFERA methodology on EE and TE.

Case Study	**Effect on Electric energy Consumption (%)**		**Effect on Thermal energy Consumption (%)** [3]	
	Summer	*Winter*	*Summer*	*Winter*
Turin Conservatory of music	-39%	-43%	-20%	+4%
Rivoli Castle	-8%	-9%	-21%	-12%
Venaria Restoration Center (CCR)	-9%	-11%	Not available	

Table 65 summarizes the energy-related results of the application of the methodology in the three case studies for which the analyses were possible. The results are in general calculated comparing phase I and phase II. The only exception is the winter thermal energy calculation of the Conservatory, which was calculated comparing the consumption of phase II with the mean of the thermal energy consumption of the previous three years (see par. 11.4.1). As shown in Table 65, in general the implementation of the methodology brought to save energy. As previously explained, thermal energy calculations were not possible for CCR (see

[3] Normalized values were: -31% summer -3% winter (Rivoli castle) and -37% +7% winter (Conservatory of Turin).

par. 12.1 for insights). Another level of calculation is shown in Table 66, in which the previous savings (divided in electric energy and thermal energy) were considered together in order to calculate an unique result synthesizing the full impact of the BIOSFERA methodology implementation (total savings). Of course, for the CCR the indicators are the same as the previous table, since no data about thermal energy was available.

Table 66. All case studies. Total savings obtained by the BIOSFERA methodology (EE+TE).

Case Study	Total savings in *summer*	Total savings in *winter*	Total savings *(sum+win)*
Turin Conservatory of music	-36%	-10%	-16%
Rivoli Castle	-12%	-10%	-11%
Venaria Restoration Center (CCR)	-11%	-9%	-10%

Looking at the results in detail, at the **Conservatory of music** the savings were remarkably higher than in the other cases, except for the natural gas consumption in winter season. This is relevant since it was one of the cases in which both BMs and BOs strategy were applied at the same time (in the classroom and auditorium area, which are more than 90% of the total building floor area). As shown in Table 64, the building was very energy demanding, also in respect to the other case studies. As explained in par. 11.4.1, the +4% of thermal energy consumption in winter was calculated considering as a comparison the TE of the previous three years, due to an anomalous natural gas consumption in January 2018. This result was investigated, being the only case of energy consumption increase. As explained in Chapter 11, one of the main reasons of this result was that the technicians did not implement the new temperature set-points required for winter's Phase II. This is actually a risk of this methodology: there is no guarantee that the advices/strategies will be actually implemented. A possible solution to the problem would be a more frequent analysis of environmental monitoring data, if a monitoring system is present. Results at the **Rivoli castle and CCR** were very similar and "in line" with similar researches in literature, which registered a mean of 4-10% savings (see par.3.3.3 for insights. These results, even if less than those at the Conservatory, should be evaluated considering the saving potential already mentioned and the "accountability of results". In fact, at CCR the HVAC settings changes' benefits were probably not captured by analysing only EE. Moreover, in this case study the majority of the conditioned area was occupied by restoration labs, in which only small changes were allowed. In terms of EE results, it is interesting to report that a 10% saving was the "desired" result expressed by BM. At the Rivoli Castle, the results should be evaluated considering that they were reached by not implementing HVAC settings' changes, so only by BMs and BOs behavioural change.

13.3 Building Occupants-related results

In the following, results of phase III questionnaires will be summarized and compared for the four case studies in which the methodology was applied completely. The objective is to evaluate the impact (positive or negative) of the strategies in terms of thermal comfort enhancement (1), to assess how the BOs communication means were evaluated by the recipients (2) and to assess the efficacy of strategies in changing BOs behaviour (3).

Table 67 shows a summary of the BOs sample, divided per case study, season and phase. The complete sample counts 332 respondents. As shown, the Conservatory of Turin provided the majority of answers, which is due to the presence of students. In terms of offices, the samples are very similar (10 to 20 BOs averagely). Another relevant information is that phase I had 195 respondents, while phase II had 137. Moreover, summer had more respondents than winter (179 versus 153).

Table 67. All case studies. Respondents to questionnaires for each case study, season and phase.

		Restoration Centre CCR		Conservatory of Turin		Rivoli castle		Stupinigi Hunting Lodge
		HLC	*MLC*	*HLC*	*MLC*	*HLC*	*MLC*	*HLC*
Winter	*Phase I*	13	12	6	17	5	11	8
	Phase III	16	11	9	20	6	9	10
Summer	*Phase I*	15	15	9	52	8	14	10
	Phase III	12	0	10	14	6	7	7
Total		94		137		66		35

Focusing on the themes previously mentioned, the following graphs evaluate if strategies enhanced BOs thermal comfort conditions. Figure 127, shows answers to the question "*during (period of phase II), did you perceive a change in the*

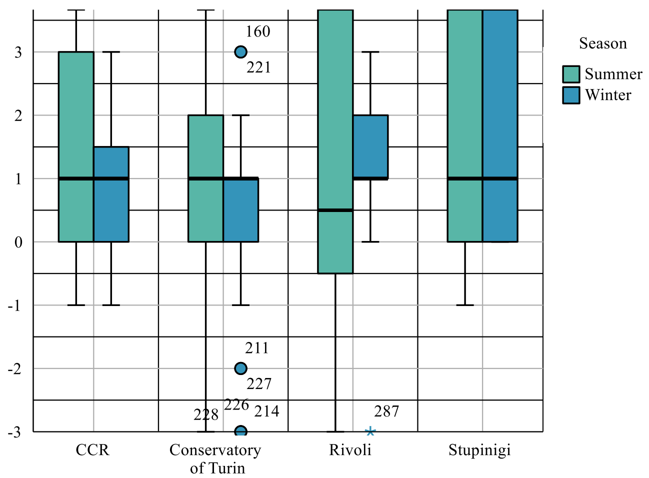


Figure 127. All case studies. Answer to the question: during (period of phase II), did you perceive a change in the temperature in respect of (the same period in phase I)? Answers are in scale +3 (max enhancement) -3 (max worsening).

temperature in respect of (the same period in phase I)?" which describes the perceived change of thermal comfort during the implementation of strategies in winter and summer season. The HLC and MLC samples were coupled for this analysis. As shown, in all cases, averagely, there was an enhancement of thermal comfort. The mean vote is very similar in all cases. The "summer" result at Stupinigi is surprising, since in phase II the cooling system was not available, so a worsening was expected, but this was already discussed in Chapter 12. However, besides the "direct" assessment just shown, which corresponds to a perceived

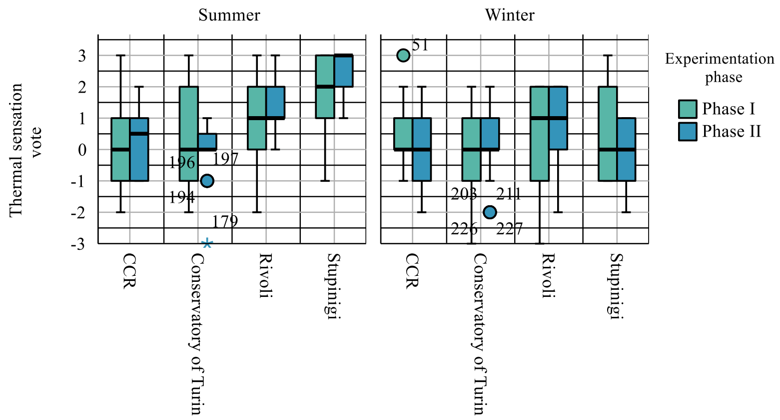


Figure 128. All case studies. TSV phase I vs phase II in winter and summer season.

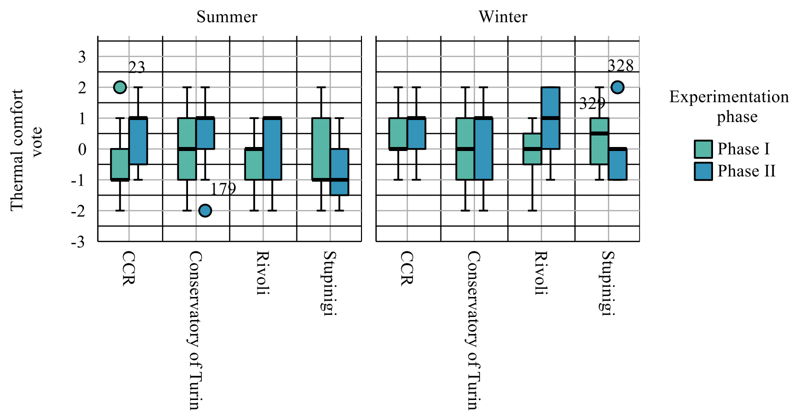


Figure 129. All case studies. Thermal comfort phase I vs phase II in winter and summer season.

change, the indirect assessment was also conducted, by repeating TSV and thermal comfort questions also in phase III. In these terms, Figure 128 and 129 show thermal sensation votes and thermal comfort votes in phase I and II, in winter and summer season. The first aspect to highlight is that, as expected, Stupinigi's TSV actually increased in summer season - which is coherent with the not functioning cooling system, which corresponded, according to this indirect assessment, to an actual worsening of thermal comfort. In fact, even if the mean vote is identical, the boxplot is translated towards the "uncomfortable" part of the scale. As for the other cases, in terms of TSV it is important to notice that (except one case), the range of votes was unaltered or decreased. Moreover, votes are generally between slightly cool (-1) and slightly warm (+1). This resulted, in terms of thermal comfort votes, on a general enhancement. The only exception to this trend was the Stupinigi hunting lodge, for which the decrease of comfort in summer was explained, while in winter it is unexpected. In fact, the only change in terms of HVAC settings was to provide BOs with thermo-valves instructions, in order to help them to configure the indoor environment according to the their necessities. In order to test the statistical significance of the results shown in Figure 128 and 129, independent t-test were performed. A first test compared all case studies together considered as one sample, comparing TSV and thermal comfort votes in phase I vs phase II (dividing the analyses for winter and summer seasons). TSV did not significantly differ between the two phases and also the effect size was small ($p=0.631$, $r=0.04$ in summer and $p=0.974$, $r=0.03$ in winter). As previously mentioned, this could be considered a positive result, but it has also to be evaluated together with thermal comfort votes. Thermal comfort votes, considering all case studies as a unique sample, changed significantly in summer season, with small effect size ($p=0.001$, $r=0.26$), but not in winter season ($p=0.108$, $r=0.14$). Further analyses highlighted that, in all case studies except the Stupinigi hunting lodge, thermal comfort changed significantly during phase II at least in one season. In particular, it significantly changed in summer at the Conservatory of Turin ($p=0.035$, $r=0.23$) and CCR ($p=0.009$, $r=0.40$), with a small and medium effect size respectively. At the Rivoli castle, thermal comfort changed significantly in winter, with a medium effect size ($p=0.02$, $r=0.42$).

The second investigated aspect was BOs' evaluation of the communication means. As shown in Figure 130, all means were evaluated approximately in the same way, with a mean of answers of 3/5. The less appreciated mean was the sign containing comfort advices.

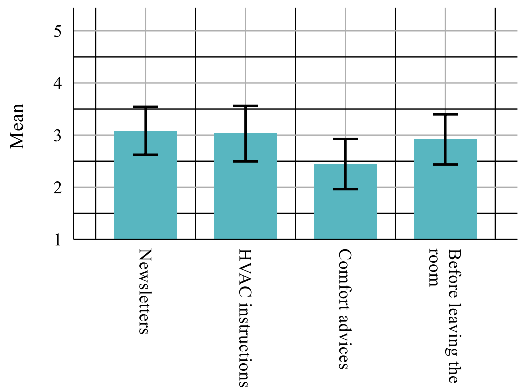


Figure 130. All case studies. Evaluation of BOs communication means.

The third investigated aspect was behavioural change. Similarly to thermal comfort, also for this evaluation both the direct and indirect assessments were proposed in the questionnaire. In the following, Figure 131 shows the results of the direct assessment, namely the perceived behavioural change towards the principal energy-related interfaces. As shown, Stupinigi had the lowest perceived behavioural change, with percentages much smaller than the other cases. However, this is partly explained by the number of strategies implemented in this case study in respect to the others. The null percentage of behaviour changed towards HVAC controls at the Rivoli castle is coherent with the fact that none of the BOs had the possibility of operate them.

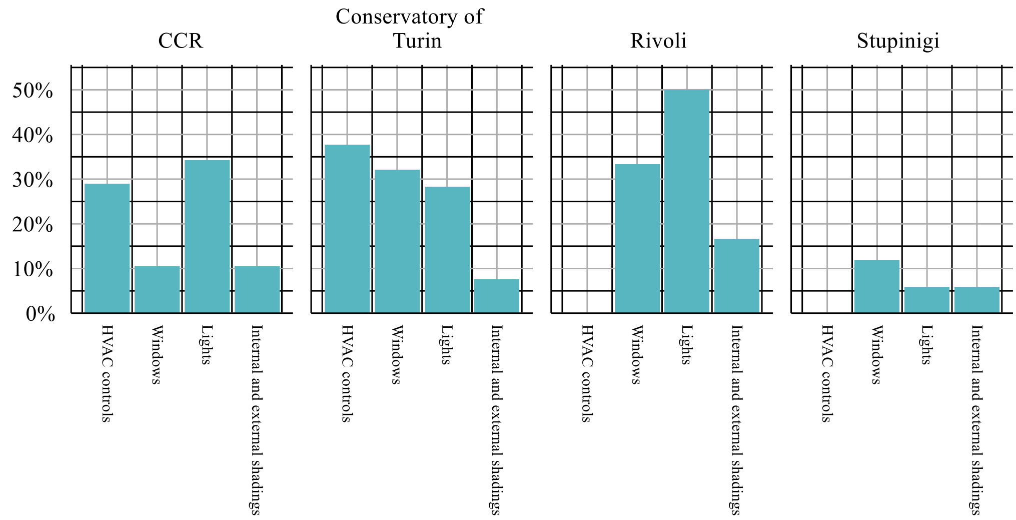


Figure 131. All case studies. Perceived behavioural change towards control interfaces.

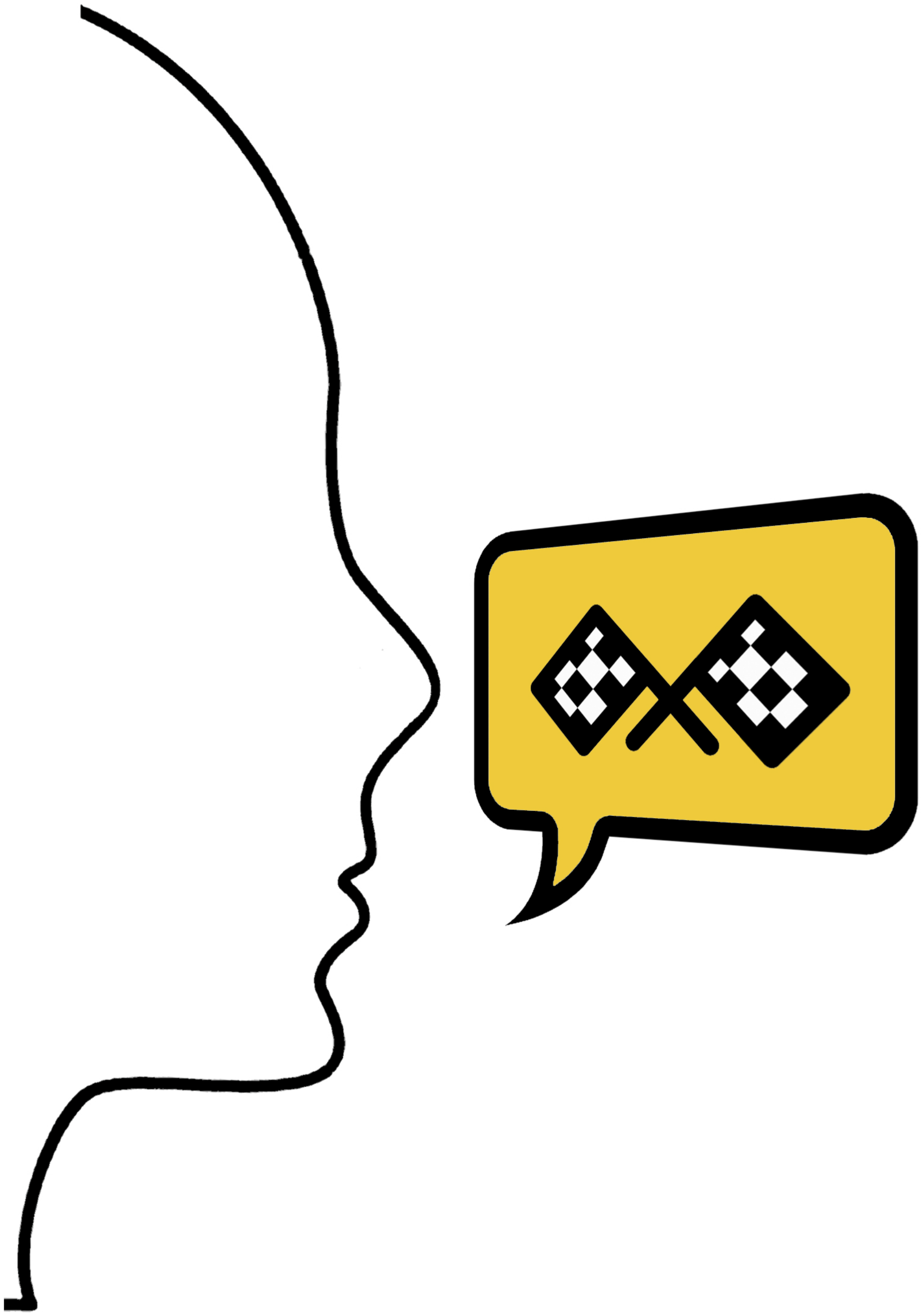
Table 68 instead, shows an indirect assessment of behavioural change that was conducted by repeating the same question ("How often do you usually perform the following actions due to thermal discomfort?") in both seasons and experimentation phases.Only three actions were selected for Table 68, as an example of a personal adjustment (clothing adjustment), an action that involves the building envelope and an action that involves the operation of a technological interface (like the thermostat, or another HVAC control). The available answers ranged from "two or more times per day" to "never". There were six available answers, progressively meaning a lower frequency of the action. These answers were scored from 1 (two or more times per day) to 6 (never). In order to verify how the strategies impacted occupants' behaviour, the means of the scores were compared. If a mean was lowered after the strategies, it meant that that specific action was less frequent, averagely. The direct assessment seems, in general, confirmed by this analysis. At the Stupinigi hunting lodge for instance, the size of the mean change is lower than in other case studies. Focusing on windows' opening, the trend shown in Figure 131 was confirmed, since Stupinigi BOs are the only ones who reported a lowering of the opening frequency. Another aspect to consider is that, generally, the information promoted by the communication means were followed by occupants. For example, for all the three actions shown in Table 68, the communication means encouraged BOs to increase the frequency of performing them. Considering the four case studies together, the objective was reached since BOs became more active (the mean was lowered). The biggest impact was on windows opening as a mean to mitigate thermal discomfort.

Table 68. All case studies. Actions in case of thermal discomfort, phase I vs phase II.

Casi Studio	Phase	Season	Open Windows	Turn Off Cooling when feeling too cold	Adjust clothing
CCR	Ph I	Sum	3.00	2.60	2.30
		Win	5.00		3.30
		Total	*4.00*	*2.60*	*2.80*
	Ph II	Sum	1.36	1.55	1.30
		Win	3.50		2.31
		Total	*2.63*	*1.55*	*1.92*
Conservatory of Turin	Ph I	Sum	1.88	2.50	4.00
		Win	2.00		3.50
		Total	*1.93*	*2.50*	*3.79*
	Ph II	Sum	1.11	1.88	1.75
		Win	2.00		2.78
		Total	*1.56*	*1.88*	*2.29*
Rivoli	Ph I	Sum	3.50	4.50	1.38
		Win	4.75		2.00
		Total	*3.92*	*4.50*	*1.58*
	Ph II	Sum	1.17	2.50	1.17
		Win	3.17		2.00
		Total	*2.17*	*2.50*	*1.58*
Stupinigi	Ph I	Sum	1.40	2.60	2.10
		Win	4.38		3.50
		Total	*2.72*	*2.60*	*2.72*
	Ph II	Sum	1.43	4.00	2.71
		Win	4.30		2.70
		Total	*3.12*	*4.00*	*2.71*
Total	Ph I	Sum	2.42	3.00	2.42
		Win	4.14		3.21
		Total	*3.17*	*3.00*	*2.77*
	Ph II	Sum	1.27	2.34	1.71
		Win	3.32		2.46
		Total	*2.41*	*2.34*	*2.14*

PART IV

Discussion of the BIOSFERA methodology, conclusions and proposals for further research



14

Limitations and ways forward of the BIOSFERA methodology

14.1 Methodology potential, limitations and results' discussion

In Part III, the application of the BIOSFERA methodology in a real context was shown through a pilot study that consisted of four case studies. Chapter 13 showed that the objectives claimed by the methodology and listed in Chapter 7 (lower the building's energy consumption, enhance comfort perception and behaviour of BOs) were successfully addressed. At the same time, various aspects, including methodology's potential and limitations, emerged from this first application. In the following, reflections on these aspects will be provided and discussed considering also the existing literature on behavioural studies, which was partly analysed in the first part of this thesis. Moreover, the obtained results will be discussed considering previous studies that explored the energy saving potential of behavioural change experiments and will be compared, in terms of energy savings, with the most frequent energy retrofit measures implemented in historic buildings.

Based on the experience gathered in the pilot study, one of the most evident advantages of the BIOSFERA methodology consists on the fact that it investigates and analyse a variety of information acquired by a variety of sources (building operators, building occupants, monitoring data etc.) and corresponding to different scales (e.g. whole building and zone evaluations). This allowed, as described in Chapters 11 and 12, to have a better insight on data and also to design custom solutions to discomfort sources. According to Wagner et al., this research method can be defined as a *Mixed method research design* (Wagner and O'Brien, 2018). In fact, the methodology takes advantage of multiple types of methods in terms of data collection (e.g. objective monitoring, surveys and interviews) and analysis (descriptive statistics, energy indicators etc.). The methodology combines quantitative and qualitative methods, even if the research question is more focused on obtaining quantitative results, so qualitative data were more often used to inform quantitative ones and provide a greater depth to results' interpretation. Another perspective to describe this prerogative of the BIOSFERA methodology could be based on the classification proposed by Creswell and Clark, classifying it as a *convergent parallel method* (Creswell and Clark, 2007), since both phase I and phase III involve the parallel collection and analysis of quantitative and qualitative data, which are then compared and interpreted to choose strategies (in phase II) or to elaborate results (phase III). In this framework, the methodology can also be classified as an *Advanced multiphase design*, since the combination of quantitative and qualitative methods inform the next phases.

In this thesis, adopting a Mixed method research allowed to couple advantages of in situ studies (normally characterized by the installation of sensors which acquire objective data) with survey prerogatives, such as the possibility of capturing failures of the building operation and provide better insights on reasons of occupants' behaviour (Gossauer and Wagner, 2008; Day, Theodorson and Van Den Wymelenberg, 2012). At the same time, psychological biases, such as the Hawthorn effect, could not be eliminated, and could have damaged the reliability of the information acquired especially from surveys (McCambridge, Kypri and Elbourne, 2014). However, the fact that surveys were periodic (once per season) and that the experimenter did not have, except exceptions, a direct contact with building occupants, should reduce the Hawthorne effect according to O'Brien et al. (O'Brien, Gilani and Gunay, 2018). Even if coupling in situ studies with surveys permitted to couple advantages and avoid limitations of both methods, there are also limitations that could not be eliminated. The most relevant is the occupants' sample size in each case study, which depends on the real number of building occupants. This limitation was not considered as a major barrier in this thesis since the objective of the work was to design the methodology and conduct a first pilot study to assess its potential. Nevertheless, it should be considered and addressed for future studies aimed at obtaining statistically relevant results.

The availability of a variety of information, which constitutes one of the main advantages of the BIOSFERA methodology, allows to highlight also one of its main limitations. In fact, as described in the pilot study chapters (11 and 12), if a problem emerged e.g. from surveys, there was not always the possibility to further investigate it with objective means (e.g. spot measurements). In fact, one of the methodology prerogatives was to only take advantage of the existing sensors' network. Nevertheless, there were cases in which the possibility of performing short term measurements in specific spots would have been useful to acquire a better understanding of the problems emerged from other analyses. The impossibility of conducting spot measurements was mainly related to the fact that the objective of the pilot study was to maintain an almost zero-costly intervention. For future implementations, the use of additional monitoring instruments, e.g. for spot measurements, is strongly encouraged.

Focusing on the economic viability of the BIOSFERA methodology, reflections are due, especially to evaluate its possible implementation in the professional sector. Considering the point of view of an historic building administrator, this methodology offers the possibility of enhancing the energy performance of the building not involving interventions on the building fabric, so avoiding, e.g., the necessity of closing the building or building parts for construction sites, the difficulty of dealing with protection regulations and the necessity of investing important capitals for energy retrofit operations. From the perspective of a professional promoting the BIOSFERA methodology, the most controversial aspect would be the calculation of the man-power hours to form the amount of the fee, since, as mentioned by Wagner et al., in situ studies (and surveys) require a considerable amount of time and effort to collect data, analyse them and promote the behavioural change strategies in order to reach a desirable result (Wagner and O'Brien, 2018). Considering the perspectives of the professional and the building administrator together, the major barrier to the implementation of the methodology is represented by the difficulty of estimating the result of its implementation ex-ante, if not referring to previous applications. This represents a limitation for the professional to efficiently promote its work (which in terms of energy-related results will strongly depend on building occupants' and operators' willingness to engage) and also for the building administrator, who would have to invest in an "uncertain" retrofit operation. In fact, typically, for other energy retrofit interventions (like the substitution of building or HVAC components) there are forecasts of probable energy savings derived from the interventions. For the BIOSFERA methodology, this data could be elaborated only once the sample of interventions will be sufficient to obtain statistically significant results. For example, based on a larger sample, the efficacy of single strategies (newsletters, panels, HVAC instructions etc.) could be evaluated, allowing a more accurate estimation of the intervention potential on a case by case basis. Reflecting on an eventual application of the BIOSFERA methodology in the professional sector, considerations should be addressed also to the competencies that a professional should have. In fact, this methodology relies on a multidisciplinary background, ranging from engineering to social sciences and restoration disciplines. For this reason, as other studies on the field already highlighted in past studies, also to apply the BIOSFERA methodology a multidisciplinary team (or a single professional who is provided with all the required areas of expertise) is strongly advised (Troi, Bastian and Al., 2014; Romeo, Morezzi and Rudiero, 2015).

Focusing on the results obtained in the pilot study, a number of studies already cited in the first part of this thesis were revised again, in order to put in perspective the BIOSFERA methodology potential in respect to other behavioural change experiments. As mentioned in chapter 3, the majority of studies investigating the potential of behavioural change methods were experimented in residential buildings, with an average energy saving result ranging between 15% and 20% (Pothitou *et al.*, 2016). Focusing on non-residential buildings, the same results ranges averagely between 4% and 10%, since motivating occupants in such building typologies is more challenging (they do not directly benefit of energy bills' reduction) (Barthelmes, 2019). Considering the previous evidences, the BIOSFERA methodology's results obtained in the pilot study are very promising, since the total energy savings ranged between 10% and 16%, with a seasonal peak of 36% in one case study. One of the probable reasons of this outcome is that, usually, behavioural change studies involve only building occupants, neglecting the potential of involving also building operators. The results obtained in the pilot study are particularly relevant if considering the fact that the case studies are historic buildings. In fact, the saving potential of the BIOSFERA methodology seems to be competitive also if compared with the most usual energy-retrofit interventions. Based on the report of the European project 3ENCULT (Efficient energy for EU cultural heritage), which assessed several retrofit measures considering their energy saving potential and compatibility with the historic fabric, the energy saving potential of the BIOSFERA methodology intervention is higher than the insulation of the top floor ceiling (expected savings ~5% of primary energy) and comparable to the installation of additional windows (~10%), the introduction of a mechanical ventilation with heat recovery (~8%) and the increasing of the plant efficiency (~18%) (Troi, Bastian and Al., 2014). Other interventions, such as internal or external facades insulation, could result on ~30% reduction of primary energy. However, these interventions are often not permitted in historic buildings, due to the impossibility of altering their external appearance or originality. Based on the previous comparison, it would not be correct to consider the BIOSFERA methodology as an alternative retrofit operation excluding any intervention on the building fabric or the HVAC system. Indeed, focusing only on how the building is operated, it could be implemented also to ensure that the expected savings and the expected comfort conditions consequent to other energy retrofit interventions are really met. In fact, substituting HVAC systems or implementing new services does not guarantee energy savings and enhanced comfort conditions per se, due to the rebound effect (a similar situation was described in chapter 11 regarding one of the pilot study case study, the Conservatory of Turin) (Agbota, 2014).

Focusing again on behavioural change studies in non-residential buildings, there are a few researches that obtained higher energy savings than the average range previously mentioned. For example, Fabi et al. obtained an average of 30% energy savings during their behavioural change intervention in an office building, while Kastner and Matthies reached up to 20% energy savings in their experimentation (Kastner and Matthies, 2014; Fabi, Barthelmes and Corgnati, 2016). Investigating the possible reasons of their success, one could be that they used digital devices (web-based tools and app), exploring the potential of the so-called "persuasive technology" (Fogg, 2003). In these terms, for a future implementation of the BIOSFERA methodology on a broader scale, the possibility of translating a part of the data acquisition and analysis methods, as well as the communication means (panels, HVAC instructions etc.) in digital solutions, should be accurately evaluated. The main advantage of this digital translation would be that the methodology's implementer would have a much more frequent insight on monitored data (e.g. if they were registered in cloud), as well as a more direct contact with building occupants and operators. Another benefit of this digital transformation would be the possibility of creating libraries of wisdom nuggets, comfort advices and HVAC instructions that could be easily customized and automatically sent where and when needed (e.g. they could change seasonally). Another level, which though would require the installation of a more diffused network of sensors, could be to provide occupants with feedback targeted on their actions. This possibility goes beyond the first conception of this methodology, which was intended to be an almost zero-costly energy retrofit intervention. However, further researches on the potential of this kind of development should be addressed in the future. Major limitations to consider about an eventual digitalization of the BIOSFERA methodology would concern the effective applicability on historic buildings (1) and an accurate evaluation of the usability and user friendliness of the solution (2). Regarding the first aspect, for example, in some historic buildings it is extremely challenging to install a Wi-Fi network due to walls' thickness. About the second aspect, an accurate analysis of occupants' possibility of accessing devices and use them as the experimenter expect, would be required. An example of this can be done referring to what happened in the pilot study with surveys. Most building administrators asked that, e.g., medium level of control occupants (e.g. museum staff or classroom occupants at the conservatory) had the possibility of filling paper questionnaire, expecting that they would not probably look at e-mails invitation to online surveys.

The following two paragraphs consist on a critical review of the methodology based on the lessons learned from the pilot study, with two main objectives. The first is to propose improvements to the methodology design proposed in Part II towards a more efficient applicability in terms of time effort and efficacy. In fact, one of the limitations previously mentioned, which emerged also in the pilot study (especially in perspective of its implementation on a broader scale), was the amount of man-power hours to apply the methodology. Proposals for changes of the methodology design should be based also on the possibility of perpetrating the methodology application for a longer period than the one proposed for the pilot study. In fact, for this first experimentation the time was tied to the duration of the PhD (three years). This brought to the necessity of implementing the strategies only for one cooling season and one heating season and did not allow the assessment of long-term effects of the methodology. This could obviously be changed in following experimentations. The second objective is to propose means to avoid situations that, in the pilot study, caused the interruption of the experimentation or caused unsatisfactory results.

14.2 Methodological design

In the following, aspects of the methodology design will be discussed based on what emerged during the pilot study. For each point, a possible solution is envisaged.

The first aspect to discuss about the methodology design is the **pre-test post-test** approach that has been mentioned in order to describe the logic behind the phases. In fact, Phase I could be interpreted as the pre-test, Phase II as the "treatment" (test) and Phase III as the post-test. It should be considered that the "pre-test post-test", also known as Classic controlled experimental design, is a way of designing experiments typically used in the social sciences or in the medical field (Conrad *et al.*, 2012). Therefore, for this methodology it has been adapted to the "constrains" of the context in which the methodology is applied. The main differences between the "classical" pre-test post-test design and the methodology presented in this study are the lack of a "control group" (which is countered to a "treatment group") (1) and the fact that the participants to both groups should be assigned randomly. However, for the BIOSFERA methodology it was evaluated that, since it was designed to be implemented in historic buildings, which are often characterized by a relatively small population, it would not be worthy to divide every BOs group in a control and a treatment group. This, because the objective of the methodology is to investigate the potential of the proposed strategies in respect to the objectives previously mentioned (energy saving and BOs' comfort enhancement), so dividing the already small population in two groups would reduce the number of people participating to the experiment, reducing the strategies' effect. Moreover, keeping the two samples separated (not talking or influencing each other) in such small groups would not have been possible, especially considering the duration of the experimentation (eighteen months averagely) and the fact that they usually share spaces and relations. The second aspect to be discussed is the "**linearity**" of the methodology in its first design, which is characterized by "a beginning" and "an end". Of course, as previously mentioned, this was required by the necessity of concluding the pilot study during the time of the PhD. Another aspect to be highlighted is also that in its first design (again due to the experiment constraints), the methodology was not designed in a way to assess also the **long-term impact** of the strategies.

The previous critical points could be addressed by re-conceiving the methodology. For example, the methodology could be repeated several times, or become even a permanent way to enhance the building's energy performances and continuously engage BOs towards a more conscious use of energy-relevant interfaces. In these terms, the current linear design could be modified in a virtuous circle one, in which the result of the first application inform the analyses and the strategies of the second one. In fact, after a very laborious first phase, which would give an overview on how the building has been run until that moment, and the main characteristics of his occupants, different strategies could be implemented, gradually, season after season. In this sense, the methodology could acquire a different shape and becoming more similar to a **"circular" design**, which is characterized by the fact that the future steps are influenced by the results of the previous ones, with a less rigid structure than the "pre-test post-test" model.

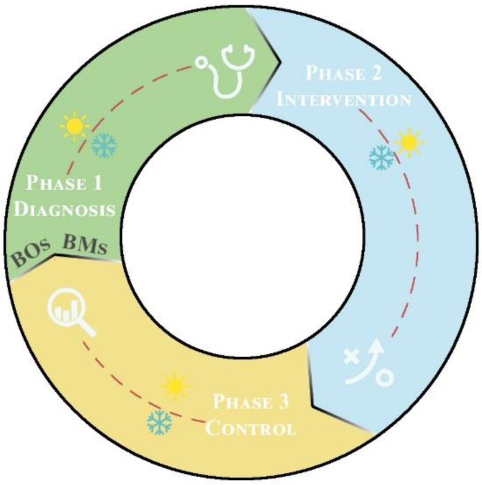


Figure 132. Proposal for a new methodology design of the BIOSFERA methodology.

Implementing this new methodology design, in which every "phase III" becomes, in a way, a "phase I" for the next season, could also allow a more progressive education of occupants, affecting their behaviour on the long-term. In fact, one of the biggest fragilities of behavioural change projects is the "long-term" effectiveness of the engagement strategies, which would require a continuous engagement and communication. In the following, Figure 132 proposes a new scheme of the methodology design. As shown, the elements are the same proposed in Chapter 4, the only changed element is the shape, which is circular.

Another critical aspect concerns the methodology **schedule**. In fact, as it is designed now, Phase I and Phase II are located in two consecutive years, and the implementation of the whole methodology requires about 18 months. This, as also experimented in the cases described in Part III, causes two problems. First, when BOs answer to the questionnaire of Phase III they are asked to refer their evaluation to the first phase, which took place over a year before. Second, after the start, the administration sees the first "results" (in terms of energy and economic savings) after one year, when phase III is concluded and reported. Moreover, during that year they have to provide many materials, motivate BMs and BOs to answer the questionnaires etc. A possible solution to this problem could be to position Phase I and II immediately after another, e.g. in summer considering June and July as phase I and August and September as Phase II. The advantages of this solution are that results are available after a few months and that BOs would be asked to refer their judge to only one or two months before. However, there could be possible problems with this solution. First, if for unexpected reasons the start of Phase II is delayed (as it happened in most of the pilot study's cases), the implementation could be too short to appreciate an impact. Second, the application of the strategies only for a short time could imply that BOs do not even have time to notice the changes and would not have sufficient time to be engaged and change behaviour. Moreover, if we refer to summer season, it should be considered that in Italy August is a month in which most of workers are on vacation, so imaging to adopt the solution assumed above most of them would experience only one month of change.

The fourth aspect to discuss is that, as it was firstly designed, the methodology did not require the establishment of a **contract** between the methodology's implementer and the building's administration. This caused problems, e.g., if the promised materials were not provided. Of course, for the experimentation of the methodology at the academic level (and the pilot study) this implied only that the experimentation was stopped. Nevertheless, in other contexts, this would have remarkable impacts. Based on what emerged from the pilot study (in which 3 out of 8 case studies were excluded from the experimentation due to lack of materials), the contract should address two principal topics. First, the commitment to provide all the mandatory materials during all the methodology (1). Second, the willingness of BMs to implement the proposed strategies (2). In fact, as it was shown in par. 11.4.1, if BMs do not actively participate to the experimentation, they could notably damage the good success of the strategies not only in terms of energy efficiency, but also in terms of BOs thermal comfort. Of course, BOs cannot be obliged to engage with the strategies, change their behaviour etc. Actually, it is part of the experimenter's responsibility to design attractive strategies to encourage BOs to participate. However, before starting the experimentation of the methodology, the administration could provide a **preliminary survey** to the building's BOs in order to ask their opinion about the possibility of implementing the methodology to verify their willingness to participate. Again, several situations during the pilot study highlighted that if BOs are motivated to participate due to uncomfortable conditions, and if they trust the good intentions of the administration, they would probably also engage in implementing the strategies and interested to give back a feedback about their efficacy. On the contrary, in those cases in which BOs i) did not have comfort-related problems or ii) did not trust the administration (thinking e.g. that "things will not change" or "they are only do it to save money, not for our comfort"), their willingness to participate was extremely lower, as well as the obtained results.

14.3 Proposed changes to the methodology phases

In this section, punctual changes to the methodology described in Part II will be proposed based on the experience gathered during the implementation on the real case studies.

Regarding **Phase I**, the proposed changes are addressed to BOs questionnaire. In particular, the first element to reconsider is the length. In fact, the questionnaire is composed by 53 questions in its longest version (the HLC one), and the length has been pointed out as a major barrier to its completion by BOs. This information was reported indirectly by two BMs of two different case studies. Another relevant aspect is that, as shown in Chapter 11 (dedicated to the detailed implementation of the methodology), analysing all data emerged from the questionnaire is very time consuming. Moreover, based on the experimenter's experience, only a part of the questions were really relevant to choose Part II strategies. For this reason, based on the experience had with the real cases studies and considering what was really decisive to choose the strategies, a proposal for a much shorter questionnaire (for HLC BOs) is provided in Table 69. As it can be seen, the questionnaire can be halved in order to acquire the most important and influencing answers. In particular, the first section was really shortened, as well as the second and the last sections. The first section would have been relevant in order to perform statistical analyses and recognize, for example, the influence of gender on the thermal sensation votes. However, this kind of analyses that are really interesting for certain comfort experiments, were not much relevant to the objectives of the BIOSFERA methodology. The same considerations can be done about the more cultural aspects that were investigated in the second section of the questionnaire. The third section, instead, was almost kept unchanged. The analyses of the answers of this section can highlight environmental problems that characterize the building indoor environment. At the same time, the fourth part of the questionnaire maintained the majority of questions, since the analysis of this section allows understanding BO's behavioural habits in order to design the engagement measures to be implemented in the strategies' phase. Finally, the fifth section changed name and was notably reduced. Indeed, also the assessment of the control's perception of occupants was considered a more academic concern. Moreover, most paper questionnaire showed that this last part was left blank by a high number of participants, maybe because of the questionnaire length but maybe also because it was not very clear. Another aspect to discuss is the complete anonymity of the questionnaire. The biggest advantage of choosing a completely anonymous questionnaire is that participants should feel free to answer sincerely. This was the reason why this choice was made for the pilot study. However, this way it is not be possible to have a direct comparison between the questionnaires done by the same person in the first phase and the one of the third phase. Nonetheless, this aspect represents a major barrier to perform statistical tests that could be applied to assess the changes of votes between the pre-test and the post-test, so also quantify the efficacy of a strategy in respect to another. The third aspect to discuss is how the environmental parameters' perception and comfort questions are expressed. The questions ask about these two aspects in relation to the entire season that just finished (Phase I questionnaire) or in relation to the months corresponding to Phase II (Phase III questionnaire). This is not common for this kind of questions, which usually ask for the right-here-right-now evaluation. In this study, this was not done because usually that kind of questions are then related to a point-in-time monitored measurement of the relevant environmental parameter. Since for the BIOSFERA methodology the presence of the monitoring system was not a mandatory requirement, the use of right-here-right-now evaluations was not chosen. Moreover, asking about the average sensation of the season, despite being less precise, could give a better picture of what the general conditions are within the space, giving the possibility to identify macroscopic trends or problems to be fixed by a strategy. In fact, asking for the instantaneous sensation could not represent the bigger picture.

Another aspect emerged from the pilot study, was the potential usefulness of providing more questions about behaviour also to MLC occupants. In fact, these questions were the principal means used, for HLC, to choose strategies specifically targeted to recognized energy-wasting behaviours or those limiting potentially positive effects on thermal comfort. In particular, it would be useful to insert those questions that could be repeated in phase III to assess behavioural change indirectly (e.g question 3,5 and 6 of "occupant behaviour" section).

Table 69. Updated version of Phase I questionnaire - HLC.

Section	Question
General information	1 Which period of the day do you usually spend at work?
	2 What of these groups the space you work in belongs?
Cultural background habits and changing attitudes	1Do you like the historic building in which you work?
	2 If you like, specify the reasons of your last answer (open question)
	3 Do you think you would profit from being given advice about your behaviour in relation to ventilating, cooling and heating at workplace?
Comfort conditions and preferences	1 Please tick the circle that best represents how you feel at workplace during this winter.
	2 Basing on the previous thermal sensation, please tick the circle below that best describes your comfort perception at workplace during this winter.
	3Please tick the circle below that best represents the quality of the air (regarding smell, presence of dust etc.) at workplace during this winter.
	4 Please tick the circle below that best represents the natural light level you perceive during the day at workplace during this winter.
	5 Please tick the circle below that best represents the natural light level you perceive during the day at workplace during this winter.
	6 Basing on the previous lighting level evaluation, please tick circle below that best describes your comfort perception (related to lighting level) during this winter.
	7 Please tick the circle below that best represents the humidity level you perceive at workplace during this winter.
	8 Basing on the previous humidity level evaluation, please tick the circle below that best describes your comfort perception (related to humidity level) during this winter.
	9 Please tick the circle below that best represents the noise level of your office.

	10 Basing on the previous noise level evaluation, please tick the circle below that best describe your comfort perception (relate to noise level).
	11 Do you recognize any of these sources of discomfort? You can choose more than one option.
Occupant behaviour	1 Do you have a specific dress code to go to work?
	2 In which of these categories do you recognize your usual clothing for the current season?
	3 How often do you usually perform these actions when feeling thermally uncomfortable in winter season? If an action is not available (e.g. opening the window, click "Never")
	4 How often do you usually perform these actions when the natural lighting level is not proper?
	5 When do you usually turn on the lights in winter?
	6 When do you usually open the windows in winter?
	7 After you opened the window, for how long it usually remains open?
	8 When the window is open, do you turn off the following systems?
	9 When you leave the workplace what of these actions do you perform?
Relationship with the BM	1 When you detect a problem related to temperature, humidity or light, do you usually call someone who can fix the situation?
	2 Have you ever made requests to the building manager (or person in charge) for changes to the heating, cooling, lighting or ventilation systems?
	3 If yes, how satisfied in general were you with the speed and the effectiveness of response?

About **Phase II**, a change that was already integrated during the pilot study was the elimination of the "seasonality" of signs. In fact, according to the methodology, signs should be positioned just before the beginning of strategies. However, when phase II is repeated in the following season all signs should be substituted. The possibility of creating "unseasonal" signs was already integrated in the pilot study and particularly for the implementation of phase II strategies in winter, which followed the previous phase II in summer. In this context, all signs containing season-related information were "adapted" in a way that they could contain useful information both in cooling and heating seasons. This choice is desirable especially if the building operators could not ensure the change of the seasonal signs at least when switching between heating and cooling seasons. In the pilot study, all case studies' administrators asked to replace the seasonal signs with unseasonal ones, since they would not have been certain that, after the end of the pilot study, someone would have regularly switched the signs when necessary. An example of this adaptation is shown in Figure 133, which shows a "revised" comfort advice panel, in which the indications related, e.g., to the use of the thermostat, are surrounded by two coloured circle which identify the energy consequence of the proposed action.

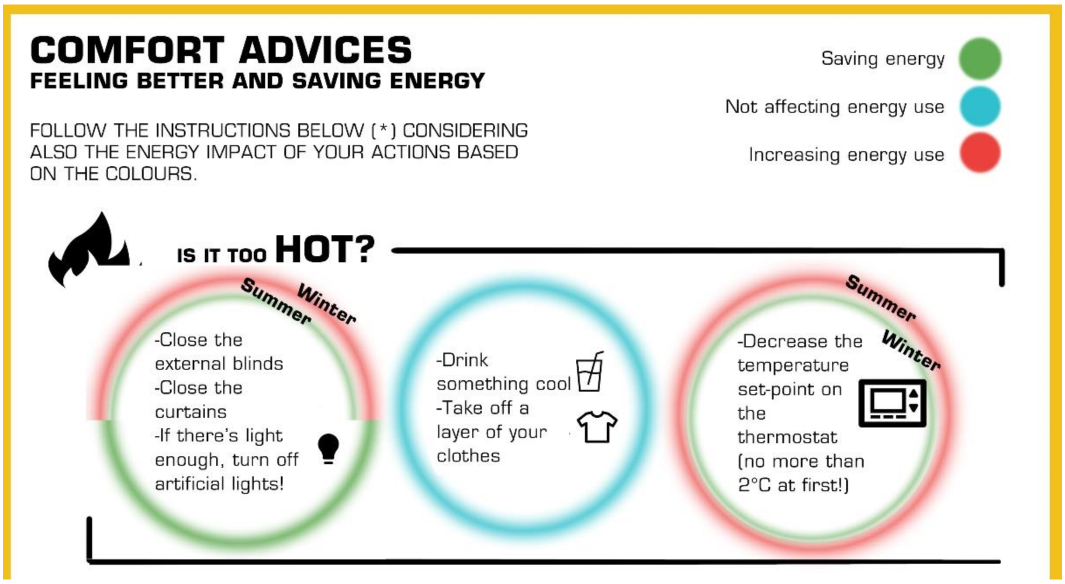


Figure 133. New "unseasonal" comfort advice sign.

Finally, regarding **Phase III**, as previously mentioned about phase I questionnaire, the most controversial aspect is that, according to the current methodology design, questionnaires filled in part III cannot be directly related to phase I in order to compare the answers of the same person before and after the implementation of strategies. This excluded, in part III, the possibility to objectively assess the efficacy of strategies by statistical tests, which would have been useful to rate the efficacy of the different communication means. Another aspect that was already mentioned for phase I questionnaire, is the insertion of indirect assessment behavioural questions also for MLC occupants. In fact, the pilot study showed how different the direct assessment (so the perceived behavioural change) was from the indirect assessment (so the repetition of the same question provided in phase I in order to capture a change of habits).

.

15

Conclusive summary

15.1 Conclusions

This PhD dissertation addressed the theme of historic buildings' energy retrofit, which has been increasingly studied in the last years, especially by the energy research sector. However, having recognized a substantial unbalance between the aims usually pursued by energy-efficiency researches and the practices of restoration and conservation, the objective of this work was to focus on a strand of the energy research (occupant behaviour, or more generally building operation) that has been identified as a potential way of balancing conservation and efficiency. This way, the long-term perspective was to contribute to a potential change of the role that the energy sector has in the practice of historic buildings' conservation and restoration, with the intention to promote it as a valorisation practice, having the social profitability as a primary objective.

The present work was focused on the elaboration and test of a methodology, which due to the uniqueness of each historic building, was considered as the best level of replicable solution that could be pursued. The methodology, called "**BIOSFERA**" (Building Intelligent Operational Strategies For Energy Retrofit Aims"), had the objective to answer the following research question: *What are the potentialities of energy saving and indoor environmental conditions' enhancement by acting only on the way non-residential historic buildings are operated by occupants and operators?*

The first step, described in Part II of this dissertation, consisted on the elaboration of the **theoretical phases** of the methodology. This operation had as a primary objective the adoption of a multidisciplinary approach and the provision of a comprehensive framework within which the most appropriate analyses could be chosen for each methodology's implementation on real buildings. Successively, **the methodology was experimented** in four case studies. This experience was described in Part III. Since the main output of this work consisted on the elaboration of methodology, its experimentation in real cases served also as an experience to **discuss and improve** it towards its applicability on a larger scale. This aspect was tackled by Part IV (Chapter 14).

The research question was answered by implementing **strategies** in order to reach two main objectives. First, to reduce the building's energy demand. Second, to ameliorate indoor environmental conditions in a way to enhance occupants' thermal comfort. The implemented strategies consisted on the promotion of a behavioural change in terms of energy-related habits and on the provision of optimized building operational practices. The recipients of these actions were two categories of people affecting buildings' energy consumption and indoor environmental conditions: building occupants (BOs) and building managers (BMs).

The obtained results (summarized in Chapter 13), were promising, especially to encourage the application of this methodology on a larger scale. In fact, in all buildings for which an energy consumption assessment was possible, the **obtained energy savings** ranged from 10% to 16% considering the whole experimentation, with seasonal peaks of more than 30%. In terms of indoor environmental conditions, the energy saving trend resulted, in the large majority of cases, on occupants' perceived **thermal comfort amelioration or stability**.

Besides the previous results, the application of the methodology resulted in other **beneficial side effects**, some of which are listed in the following:
- Occupants reported interest and engagement to the communication means diffused to increase their energy-related knowledge and influence their behaviour (see Chapter 13).
-Analyses of questionnaires allowed recognizing, in most cases, notable occupants' behavioural change towards more energy-saving habits and reduction of energy waste.
-The interpolation of information gathered from various materials and sources (like energy bills, building managers interviews and occupants' questionnaires) allowed recognizing the reasons of previously unexplained i) reasons of energy waste or high unjustified energy demand as well as ii) uncomfortable situations or apparently unreasonable occupants' behaviour. Moreover, due to the same approach, even when strategies did not result on the expected results, it was possible to understand the causes of fails.

The previous results should be evaluated also considering that the implementation of strategies was almost **zero-costly** (the only cost, except time cost by the experimenter, was related to signs and questionnaires printing). This represents probably one of the strongest reasons to encourage the implementation of the methodology on a larger scale, especially in public historic buildings.

Considering that in Italy, for example, about three thousands out of the total five thousands historic buildings hosting museums, libraries and other functions are owned or handled by the public administration, with an overall energy expenditure of about 250 millions of Euros, the impact of this methodology would be extremely convenient (Mibact-ENEA, 2017). This, also considering that other energy retrofit interventions, such as the substitution or integration of building components or technological infrastructures, would require a restoration process, typically characterized by the necessity of high-level multidisciplinary professionals, long time of realization and high investment costs. Acting on the building operation and occupant behaviour, instead, would not require any intervention on the building fabric, avoiding any damage to the historic evidence and, in some cases, contributing to materials' conservation.

The results obtained by the pilot study experimentation offer important cues to reflect on the methodology's efficacy. In fact, as previously mentioned and described in Part III, the results obtained in the four case studies differed. This was expected, since every case study had its peculiar characteristics and, more importantly, **saving potential**. In fact, the experimentation demonstrated how the saving potential is affected by several factors, among which:

-the building function (e.g. necessity of fixed indoor environmental conditions that cannot be changed for occupants' comfort necessities);
-the building operation prior to the methodology application (e.g. an energy wasting operation results, of course, in a higher saving potential);
-occupants' control potential over the environment. The efficacy of the methodology relies on occupants' behavioural change, but the impact of their changed habits would clearly depend on the degree of control they have over the environment;
-building managers and building occupants' willingness to participate and engage in the methodology (which is not easy to be forecasted in advance).

Predicting the saving potential is not a simple task, especially at the state of facts, having implemented the methodology only on four case studies. However, some of the previous points could be addressed, at least statistically, if having a larger sample of buildings in which the methodology has been applied. Other points, like the ones related to occupants and their willingness to participate, could be partially addressed, as mentioned in par 14.2, by asking occupants about their availability even before the start of the methodology.

Finally, based on the experience of the pilot study, Part IV of the dissertation proposed changes to the methodology design and implementation. Among the specific changes, it seems important to highlight that the pilot study had a fixed duration influenced by the necessity of concluding a three years' PhD. Nevertheless, as it is designed, the methodology has the potential to be integrated as a continuous enhancement instrument, which progressively guide building operators and occupants towards a more efficient and comfortable building. This way, the methodology could function also as an instrument to increase the social responsibility towards a more knowledge-based and sustainable management of historic buildings.

15.2 On the horizon

The research presented in this PhD thesis represents a starting point, rather than a finished project. The previous paragraphs highlighted a series of reasons that encourage an implementation of the BIOSFERA methodology on a broader scale. In fact, the answer to the research question that guided the elaboration of the entire dissertation was only based on a pilot study. At the same time, based on the gathered experience, for a suitable and reasonable application of the methodology on a bigger sample, future implementations should consider the possibility to build an information technology system both to gather and analyse data and to provide feedbacks and communication to building occupants. The system could also enable a more "direct" communication between the methodology implementer and the participants. This solution would be particularly convenient in the case that the building's administration would like to adopt the methodology continuously. Of course, the implementation of this kind of system would require a financial investment and the involvement of internet technology experts. However, this would have notable potentialities. Moreover, having such a system would provide the opportunity of establishing a larger sample of buildings and occupants, which would result on the possibility to assess the efficacy of different communication means, feedback and behavioural triggers. Last, such technologies would simplify a continuous and documented assessment of long-term behavioural change.

References

Adams, C. *et al.* (2014) 'Building with History: Exploring the Relationship between Heritage and Energy in Institutionally Managed Buildings', *The Historic Environment: Policy & Practice*, 5(2), pp. 167–181. doi: 10.1179/1756750514Z.00000000053.

Agbota, H. (2014) 'Anticipating the Unintended Consequences of the Decarbonisation of the Historic Built Environment in the UK', *The Historic Environment: Policy & Practice*, 5(2), pp. 101–115. doi: 10.1179/1756750514Z.00000000049.

Aghemo, C., Casetta, G.C., Filippi, M. (1989) 'Optimum conservation conditions in museums: lighting and climate', *Science, Technology and European Cultural Heritage*, pp. 1–5.

ASHRAE (2011) Ashrae Handbook Hvac Applications Building Operations And Management.

AICARR (2013) *Efficienza energetica negli edifici storici*. Milano: AICARR (Associazione Italiana Condizionamento dell'Aria, Riscaldamento e Raffrescamento).

Andersen, R. V., Olesen, B., Toftum, J. (2007) 'Simulation of the effects of occupant behaviour on indoor cliomate and energy consumtpion', in *Clima 2007 - 9th REHVA world congress: well-being indoors*. Helsinki, Finland.

Ansi/Ashrae (2017) 'ANSI/ASHRAE 55:2017 Thermal Environmental Conditions for Human Occupancy', *Ashrae*, p. 30. doi: 10.1007/s11926-011-0203-9.

Arnold, P. *et al.* (2013) *Energy Efficiency in Historic Houses*. Irish Georgian Society.

Ascione, F., Rossi, F., Vanoli, G. P. (2011) 'Energy retrofit of historical buildings: theoretical and experimental investigations for the modelling of reliable performance scenarios', *Energy and buildings*, 43, pp. 1925–1936.

Ascione, F. *et al.* (2017) 'NZEB target for existing buildings: Case study of historical educational building in Mediterranean climate', *Energy Procedia*. Elsevier B.V., 140, pp. 194–206. doi: 10.1016/j.egypro.2017.11.135.

Ashley-Smith, J. (1999) *Risk assessment for object conservation*. Oxford: Butterworth-Heineman.

ASHRAE (2007) 'Museums, libraries and archives', in *ASHRAE Applications book*.

Axon, S. et al. (2018) 'The human factor: Classification of European community-based behaviour change initiatives', Journal of Cleaner Production. Elsevier Ltd, 182, pp. 567–586. doi: 10.1016/j.jclepro.2018.01.232.

Babelon, J.P., Chastel, A. (1994) *La notion de patrimoine*. Paris: Éditions Liana Levi.

Barthelmes, V. M. (2019) 'Impact of Occupant Behaviour (OB) on building energy use and thermal comfort'. Turin.

Basnet, A. (2012) *Architectural Integration of Photovoltaic and Solar Thermal Collector Systems into buildings*. Trondheim: Norwegian University of Science and Technology.

Becchio, C. (2013) 'Assessment of energy and cost effectiveness in retrofitting existing buildings', p. 99. Available at: http://porto.polito.it/2507645/1/Assessment_of_energy_and_cost_effectiveness_in_retrofitting_existing_buildings_1.pdf.

Becchio, C., Corgnati, S. P. and Spigliantini, G. (2017) 'Evaluation of refurbishment alternatives for an Italian vernacular building considering architectural heritage, energy efficiency and costs', *Energy Procedia*. Elsevier B.V., 133, pp. 401–411. doi: 10.1016/j.egypro.2017.09.370.

Becherini, F. *et al.* (2018) 'Characterization and thermal performance evaluation of infrared reflective coatings compatible with historic buildings', *Building and Environment*. Elsevier, 134(December 2017), pp. 35–46. doi: 10.1016/j.buildenv.2018.02.034.

Bell, M., Lowe, R. (2000) 'Energy efficient modernisation of housing: a UK Case study', *Energy and Buildings*, 32(2), pp. 267–280.

Ben, H. and Steemers, K. (2014) 'Energy retrofit and occupant behaviour in protected housing: A case study of the Brunswick Centre in London', *Energy and Buildings*. Elsevier B.V., 80, pp. 120–130. doi: 10.1016/j.enbuild.2014.05.019.

Bennet, I. E. and O'Brien, W. (2017) 'Field study of thermal comfort and occupant satisfaction in Canadian condominiums', *Architectural Science Review*, 60(1), pp. 27–39. doi: 10.1080/00038628.2016.1205179.

Berg, F. *et al.* (2017) 'User-driven energy efficiency in historic buildings: A review', *Journal of Cultural Heritage*. Elsevier Masson SAS, 28, pp. 188–195. doi: 10.1016/j.culher.2017.05.009.

Bertolin, C. and Loli, A. (2018) 'Sustainable interventions in historic buildings: A developing decision making tool', *Journal of Cultural Heritage*. Elsevier Masson SAS, 34, pp. 291–302. doi: 10.1016/j.culher.2018.08.010.

Bianco, L. *et al.* (2015) 'Thermal insulating plaster as a solution for refurbishing historic building envelopes: First experimental results', *Energy and Buildings*. Elsevier B.V., 95, pp. 86–91. doi: 10.1016/j.enbuild.2014.11.016.

Bonvicini, C. *et al.* (2011) 'Museums in historical buildings: actual and potential opportunities for microclimatic control', in Del Curto, D. (ed.) *Indoor environment and preservation. Climatic control in museums and historic buildings*. Nardini ed. Milano.

De Bouw, M. (2016) 'Preface', in De Bouw, M. (ed.) *EECHB 2016- Energy efficiency and comfort of historic buildings*. Brussels, Belgium, pp. i–v.

Boyce, P. *et al.* (2003) *Lighting quality and office work: a field simulation study*.

Brito, N. S. (2016) 'Mismatch, exclusion and inclusion: threats / opportunities for historic buildings in the current energy efficiency paradigm', in *EECHB*

2016- Energy efficiency and comfort of historic buildings. Brussels, Belgium.
Brown, J.P., Rose, W. B. (1996) ‘Humidity and moisture in historic buildings: the origins of building and obejct cosnervation’, *APT bulletin*, 27, pp. 11–18.
Bruno, S., De Fino, M. and Fatiguso, F. (2018) ‘Historic Building Information Modelling: performance assessment for diagnosis-aided information modelling and management’, *Automation in Construction*. Elsevier, 86(February 2017), pp. 256–276. doi: 10.1016/j.autcon.2017.11.009.
Burak Gunay, H. *et al.* (2014) ‘On the behavioral effects of residential electricity submetering in a heating season’, *Building and Environment*. Elsevier Ltd, 81, pp. 396–403. doi: 10.1016/j.buildenv.2014.07.020.
Camuffo, D. (1998) *Microclimate for cultural heritage*. Amsterdam: Elsevier.
Carbonara, E. and Tiberi, M. (2016) ‘Local Energy Efficiency Interventions by the Prioritization of Thermal Zones in an Historical University Building’, *Energy Procedia*. The Author(s), 101(September), pp. 988–994. doi: 10.1016/j.egypro.2016.11.125.
Cassar, M. (1995) *Environmental management. Guidelines for museums and galleries*. London: Routledge.
CEN (2008) ‘European Standard EN 15251, Criteria for the Indoor Environmental Including Thermal, Indoor Air Quality, Light and Noise.’ Brussels, Belgium.
CEN (2010a) ‘EN 15757. Conservation of cultural property. Specifications for temperature and relative humidity to limit climate-induced mechanicaldamage in organic hygroscopic materials’. Brussels, Belgium: European Committee for Standardization.
CEN (2010b) ‘EN 15758. Conservation of cultural property. Procedures and instruments for measuring temperatures of the air and the surfaces of objects’. Brussels, Belgium: Comité Européen de Normalisation.
CEN (2011) ‘CEN 15759. Conservation of cultural property. Indoor climate.’ Brussels, Belgium: Comité Européen de Normalisation.
CEN (2017) ‘Conservation of cultural heritage-Guidelines for improvin the energy performance of historic buildings TC 346, EN 16883:2017’. Comité Européen de Normalisation.
Chen, J., Taylor, J. E. (2013) ‘Layering residential peer network and geospatial building networks to model change in energy saving behaviors’, *Energy and buildings*, 58, pp. 151–62.
Chen, H. M. *et al.* (2012) ‘Persuasive feedback model for inducing energy conservation behaviors of building users based on interaction with a virtual object’, *Energy and Buildings*. Elsevier B.V., 45, pp. 106–115. doi: 10.1016/j.enbuild.2011.10.029.
Choay, F. (1995) *L’allegoria del patrimonio*. Roma: Officina edizioni.
Co2olBricks (2013) *Integration of Climate protection and cultural heritage: aspects in policy and development plans*. Hamburg: Free and Hanseatic City of Hamburg, Department of Heritage Preservation.
Commission, E. (2010) ‘Directive 2010/31/EU of the European Parliament and of

the Council of 19 May 2010 on the energy performance of buildings, 18 C.F.R.'

Commission, E. (2012a) 'Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, 315 C.F.R.' Brussels, Belgium.

Commission, E. (2012b) 'Roadmap 2050'. Brussels, Belgium, pp. 1–9. Available at: http://www.roadmap2050.eu/.

Commission, M. G. (1992) *Standards in the museum care of archaeological collections*. London.

Conrad, E. et al. (2012) 'Domain 4: Software Development Security', CISSP Study Guide. Syngress, pp. 169–211. doi: 10.1016/B978-1-59749-961-3.00005-4.

Corgnati, S.P.; Filippi, M.; Perino, M. (2006) 'A new approach for the IEQ (Indoor Environment Quality) assessment, research in building physics and building engineering.', in Proceeding of 3rd international conference on research in building physics IBPC 2006. Montreal.

Corgnati, S. P. *et al.* (2014) *L'Edificio Museo : energia , impianti , sicurezza Fondazione Musei Senesi in collaborazione con e con*. Edited by F. M. Senesi and L. M. Di Corato. Regione Toscana - Fondazione musei senesi.

Corgnati, S. P., Fabi, V. and Filippi, M. (2009) 'A methodology for microclimatic quality evaluation in museums: Application to??a temporary exhibit', *Building and Environment*. Elsevier Ltd, 44(6), pp. 1253–1260. doi: 10.1016/j.buildenv.2008.09.012.

Corgnati, S. P. and Filippi, M. (2010) 'Assessment of thermo-hygrometric quality in museums: Method and in-field application to the " Duccio di Buoninsegna" exhibition at Santa Maria della Scala (Siena, Italy)', *Journal of Cultural Heritage*. Elsevier Masson SAS, 11(3), pp. 345–349. doi: 10.1016/j.culher.2009.05.003.

Cornaro, C., Puggioni, V. A. and Strollo, R. M. (2016) 'Dynamic simulation and on-site measurements for energy retrofit of complex historic buildings: Villa Mondragone case study', *Journal of Building Engineering*. Elsevier, 6, pp. 17–28. doi: 10.1016/j.jobe.2016.02.001.

Coscia, C. and Fregonara, E. (2004) *Strumenti economico-estimativi nella valorizzazione delle risorse architettoniche e culturali*. Celid. Torino.

Costanzo, S. *et al.* (2006) 'Preservation of the artistic heritage within the seat of the Chancellorship of the University of Palermo. A proposal on a methodology regarding an environmental investigation according to Italian Standards', *Building and Environment*, 41(12), pp. 1847–1859. doi: 10.1016/j.buildenv.2005.06.010.

Council, E. (2011) *Faro Convention. (CETS no. 199)*. Faro. Available at: http://www.ufficiostudi.beniculturali.it/mibac/export/UfficioStudi/sito-UfficioStudi/Contenuti/Pubblicazioni/Volumi/Volumi-pubblicati/visualizza_asset.html_917365394.html.

Council of Europe (1985) 'Convention for the Protection of the Architectural Heritage of Europe'. Granada: Treaty Office.

Creswell, J. and Clark, V. (2007) Designing and conducting mixed mode methods

research. Thousand O. Sage.
Crockford, D. (2014) ‘Sustaining Our Heritage: The Way Forward for Energy-Efficient Historic Housing Stock’, *The Historic Environment: Policy & Practice*, 5(2), pp. 196–209. doi: 10.1179/1756750514Z.00000000051.
Curtis, R. (2016) ‘Energy efficiency in traditional and historic buildings: keeping it simple’, in *EECHB 2016- Energy efficiency and comfort of historic buildings*, pp. 174–180.
D’Agostino, D. *et al.* (2017) ‘Energy retrofit of historic buildings in the Mediterranean area: The case of the Palaeontology Museum of Naples’, *Energy Procedia*. Elsevier B.V., 133, pp. 336–348. doi: 10.1016/j.egypro.2017.09.359.
Dalla Mora, T. *et al.* (2015) ‘Retrofit of an historical building toward NZEB’, *Energy Procedia*. Elsevier B.V., 78, pp. 1359–1364. doi: 10.1016/j.egypro.2015.11.154.
Darby, S. (2000) ‘Making it obvious: designing feedback into energy consumption’, in *International Conference on Energy Efficiency in Household Appliances and lighting proceedings*.
Darby, S. (2003) *Awareness, action and feedback in domestic energy use*. University of Oxford.
Darby, S. (2006) ‘Social learning and public policy: Lessons from an energy-conscious village’, *Energy Policy*, 34(17), pp. 2929–2940. doi: https://doi.org/10.1016/j.enpol.2005.04.013.
Day, J. K., Theodorson, J. and Van Den Wymelenberg, K. (2012) ‘Understanding controls, behaviors and satisfaction in the daylit perimeter office: a daylight desgin case study’, Journal of Interior Design, 37(1), pp. 17–34.
de Dear, R., Brager, G. and Cooper, D. (1998) ‘Developing an adaptive model of thermal comfort and preference’, *ASHRAE Transactions*, 104(Part 1), pp. 1–18. Available at: https://escholarship.org/uc/item/4qq2p9c6.pdf%5Cnhttp://escholarship.org/uc/item/4qq2p9c6.pdf%5Cnhttp://repositories.cdlib.org/cedr/cbe/ieq/deDear1998_ThermComPref.
De Dear, R. J. and Brager, G. S. (2002) ‘Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55’, *Energy and Buildings*, 34(6), pp. 549–561. doi: 10.1016/S0378-7788(02)00005-1.
Deuble, M. P. and de Dear, R. J. (2012) ‘Green occupants for green buildings: The missing link?’, *Building and Environment*. Elsevier Ltd, 56, pp. 21–27. doi: 10.1016/j.buildenv.2012.02.029.
Dowson, M., Poole, A., Harrison, D., Susman, G. (2012) ‘Domestic UK retrofit challenge: barriers, incentives and current performance leading into the green deal’, *Energy Policy*, 50, pp. 294–305.
Emeakaroha, A. *et al.* (2014a) ‘A persuasive feedback support system for energy conservation and carbon emission reduction in campus residential buildings’, *Energy and Buildings*. Elsevier B.V., 82, pp. 719–732. doi: 10.1016/j.enbuild.2014.07.071.
Emeakaroha, A. *et al.* (2014b) ‘Integrating persuasive technology with energy

delegates for energy conservation and carbon emission reduction in a university campus', *Energy*. Elsevier Ltd, 76, pp. 357–374. doi: 10.1016/j.energy.2014.08.027.

Emiliani, A. (1974) *Una politica dei beni culturali*. Torino: Einaudi.

Emiliani, A. (2015) *Leggi, bandi e provvedimenti per la tutela dei beni artistici e culturali negli antichi stati italiani, 1571-1860.* Edizioni P. Firenze.

ENEA (2017) 'Patrimonio culturale in Classe A'. Roma.

Endrejat, P. C., Baumgarten, F. and Kauffeld, S. (2017) 'When Theory Meets Practice: Combining Lewin's Ideas about Change with Motivational Interviewing to Increase Energy-Saving Behaviours Within Organizations', Journal of Change Management. Taylor & Francis, 17(2), pp. 101–120. doi: 10.1080/14697017.2017.1299372.

Endrejat, P. C. and Kauffeld, S. (2017) 'From "I should" to "I want": Increasing the internalization of organizational members' energy-saving motivation through participatory interventions., Vom "Sollen" zum "Wollen": Wie partizipative Interventionen dazu beitragen, dass Organisationsmitglieder', Umweltpsychologie, 21(2), pp. 56–73. Available at: http://ovidsp.ovid.com/ovidweb.cgi?T=JS&PAGE=reference&D=psyn&NEWS=N&AN=0340081.

English Heritage (2010) 'Energy efficiency and historic buildings. Application of part L of the Building Regulation', (November), pp. 1–72.

English Heritage (2012) 'Energy Efficiency and Historic Buildings : Application part L of the Building Regulations to historic and traditionally constructed buildings. Revision Note.'

Erhardt, D., Tumosa, C.S., M. M. F. (2007) 'Applying science to the question of museum climate', in Padfield, T., Borchersen, K. (ed.) *Museum microclimates*. Copenhagen: National museum of Denmark, pp. 11–18.

Eriksson, P., A. Egusquiza, A., Broström, T. (2016) 'The potential for implementing a decision support system for energy efficiency in the historic district of Visby', in *EECHB 2016- Energy efficiency and comfort of historic buildings*. Brussels, Belgium.

Eriksson, P. *et al.* (2014) 'EFFESUS Methodology for Assessing the Impacts of Energy-Related Retrofit Measures on Heritage Significance', *The Historic Environment: Policy & Practice*, 5(2), pp. 132–149. doi: 10.1179/1756750514Z.00000000054.

European commission (2002) 'DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings', pp. 65–71.

European Renewable Energy Council (2010) 'New energy for Old buildings – Promoting the integration of RES & RUE measures in historic buildings'. doi: 10.1016/S0140-6736(01)11379-6.

Fabbri, K., Tronchin,. L., Tarabusi, V. (2014) 'Energy retrofit and economic evaluation priorities applied at an Italian case study', *Energy Procedia*, 45, pp. 379–84.

Fabbri, K., Zuppiroli, M., Ambrogio, K. (2012) 'Heritage buildings and energy performane: mapping with GIS tools', *Energy and Buildings*, 48, pp. 137–145.

Fabbri, K. (2013) 'Energy incidence of historic building: Leaving no stone unturned', *Journal of Cultural Heritage*. Elsevier Masson SAS, 14(3 SUPPL), pp. 25–27. doi: 10.1016/j.culher.2012.12.010.

Fabbri, K. (2016) 'How to use online surveys to understand human behaviour concerning window opening in terms of building energy performance', *Advances in Building Energy Research*. Taylor & Francis, 10(2), pp. 213–239. doi: 10.1080/17512549.2015.1079242.

Fabbri, K. and Pretelli, M. (2014) 'Heritage buildings and historic microclimate without HVAC technology: Malatestiana Library in Cesena, Italy, UNESCO Memory of the World', *Energy and Buildings*. Elsevier B.V., 76, pp. 15–31. doi: 10.1016/j.enbuild.2014.02.051.

Fabi, V. *et al.* (2012) 'Occupants' window opening behaviour: A literature review of factors influencing occupant behaviour and models', *Building and Environment*. Elsevier Ltd, 58, pp. 188–198. doi: 10.1016/j.buildenv.2012.07.009.

Fabi, V. (2013) *Influence of Occupant's Behaviour on Indoor Environmental Quality and Energy Consumption.* Politecnico di Torino.

Fabi, V., Andersen, R. and Corgnati, S. (2016) 'Accounting for the Uncertainty Related to Building Occupants with Regards to Visual Comfort: A Literature Survey on Drivers and Models', *Buildings*, 6(1), p. 5. doi: 10.3390/buildings6010005.

Fabi, V., Andersen, R. V. and Corgnati, S. P. (2013) 'Influence of Occupant's Heating set-point preferences on Indoor Environmental Quality and Heating Demand in Residential Buildings', *HVAC&R Research*, 19(October 2013), pp. 37–41. doi: 10.1080/10789669.2013.789372.

Fabi, V., Barthelmes, V. M. and Corgnati, S. P. (2016) 'Impact of an engagement campaign on user behaviour change in office environment', in *Indoor Air Conference*.

Fabi, V. and Corgnati, S. (2014) 'Indoor climatic control level, energy demand and CO2 emissions in museum environments', in *14 th CIRIAF National Congress in museum environments* ., pp. 1–12.

Fanger, P. O. (1982) 'Thermal comfort'. Malabar, Florida: Robert E. Krieger publishing company.

Feldmeier, M. and Paradiso, J. A. (2010) 'Personalized HVAC control system', *2010 Internet of Things, IoT 2010*. doi: 10.1109/IOT.2010.5678444.

Ferrari, O. (1998) 'Beni culturali', in *Enciclopedia del Novecento.* Treccani. Roma.

Filippi, M. (2015) 'Remarks on the green retrofitting of historic buildings in Italy', *Energy and Buildings*. Elsevier B.V., 95, pp. 15–22. doi: 10.1016/j.enbuild.2014.11.001.

De Fino, M. *et al.* (2017) 'Methodological framework for assessment of energy behavior of historic towns in Mediterranean climate', *Energy and Buildings*. Elsevier B.V., 144, pp. 87–103. doi: 10.1016/j.enbuild.2017.03.029.

Fogg, B. J. (2003) *Persuasive technology: using computers to change what we think*

and do. Morgan Kau. San Francisco.
Fouseki, K. and Cassar, M. (2014) ‘Energy Efficiency in Heritage Buildings — Future Challenges and Research Needs’, *The Historic Environment: Policy & Practice*, 5(2), pp. 95–100. doi: 10.1179/1756750514Z.00000000058.
Franco, G. *et al.* (2015) ‘Towards a systematic approach for energy refurbishment of historical buildings . The case study of Albergo dei Poveri in Genoa , Italy’, *Energy & Buildings*. Elsevier B.V., 95, pp. 153–159. doi: 10.1016/j.enbuild.2014.10.051.
Frontczak, M. (2011) Human comfort and self-estimated performance in relation to indoor environmental parameters and building features.
Garau, G. and Rosa-Clot, M. (2017) ‘Supplying historic buildings with energy, without impinging on their historic and cultural values’, *Energy Procedia*. Elsevier B.V., 134(2016), pp. 244–255. doi: 10.1016/j.egypro.2017.09.614.
Genova, E., Fatta, G. and Vinci, C. (2017) ‘The Recurrent Characteristics of Historic Buildings as a Support to Improve their Energy Performances: The Case Study of Palermo’, *Energy Procedia*. The Author(s), 111(September 2016), pp. 452–461. doi: 10.1016/j.egypro.2017.03.207.
Giombini, M. and Pinchi, E. M. (2015) ‘Energy functional retrofitting of historic residential buildings: The case study of the historic center of Perugia’, *Energy Procedia*. Elsevier B.V., 82, pp. 1009–1016. doi: 10.1016/j.egypro.2015.11.859.
Giuliani, M. (2016) ‘A new tool for accurate energy and comfort assessment of historic building’, in *EECHB 2016- Energy efficiency and comfort of historic buildings*.
Godbolt, A. L. (2014) ‘Market, money and morals: the ambiguousshaping of energy consumption in Norwegian households’. Trondheim: Norwegian University of Science and Technology.
Gossauer, E. and Wagner, A. (2008) ‘Occupant satisfaction at workplaces - a field study in office buildings’, in Windsor conference on Air-conditioning and the Low Carbon Cooling Challeenge. Windsor: London Metropolitan University.
De Guichen, G. (1980) *Climate in museums*. Roma: ICCROM.
De Guichen, G. (2003) ‘Introduzione alla conservazione preventiva’, in Menegazzi, C., Silvestri, I. (ed.) *Servizi e professionalità ‘nuove’ per la tutela. La cosnervazione preventiva delle raccolte museali.* Firenze: Nardini Editore.
Gulbinas, R., Jain, R. K. and Taylor, J. E. (2014) ‘BizWatts: A modular socio-technical energy management system for empowering commercial building occupants to conserve energy’, *Applied Energy*. Elsevier Ltd, 136, pp. 1076–1084. doi: 10.1016/j.apenergy.2014.07.034.
Héberlé, E., Burgholzer, J. (2016) ‘Guidance for finding a sustainable balance between energy efficiency, comfor, moisture damage and cultural heritage value in historic buildings’, in De Bouw, M. (ed.) *EECHB 2016- Energy efficiency and comfort of historic buildings*. Brussels, Belgium.
Hellwig, R. T. (2015) ‘Perceived control in indoor environments: a conceptual approach’, *Building Research & Information*, 43(March), pp. 302–315. doi:

10.1080/09613218.2015.1004150.
Heritage, E. (2008) *Energy conservation in traditional buildings*. London: Energy saving trust.
Heritage, E. (2012) *Climate change and the historic environment*. London: English heritage.
Herkel, S., Knapp, U. and Pfafferott, J. (2008) 'Towards a model of user behaviour regarding the manual control of windows in office buildings', *Building and Environment*, 43(4), pp. 588–600. doi: 10.1016/j.buildenv.2006.06.031.
Historic England (2011) 'Energy efficiency and historic buildings. How to improve energy efficiency', *Structural Survey*, 29(3), pp. 16–17. doi: 10.1108/ss.2011.11029caa.019.
Historic England (2015) *Energy Efficiency and Historic Buildings. Energy Performance Certificates*. Edited by C. Pickles, D.; Cattini. Available at: www.HistoricEngland.org.uk/advice/technical-advice%0Ahttp://www.english-heritage.org.uk/publications.
Hong, T., Lin, H. W. (2012) 'Occupant behavior: impact on energy use of private offices', in *ASim 2012 - 1st Asia conference of International Building PerformanceSimulation Association*.
Humphreys, M., Nicol, F., Roaf, S. (2011) *Keeping warm in a cooler house - Creating thermal comfort with background heating and local supplementary warmth*.
ICOM (2008) *Terminology to characterize the conservation of tangible cultural heritage*. Available at: http://www.icom-cc.org/242/about/terminology-for-conservation/#.Xe5jW-hKg2w (Accessed: 9 December 2019).
ICOMOS (2013) 'The Burra charter. The Australian charter for places of cultural significance'. Burra: Australia ICOMOS.
Invitalia (2012) 'Investment Opportunities'. Roma: Invitalia.
ISCR (1972) *Carta Italiana del Restauro*. Roma: Ministry of public education.
ISCR (2019) *Il restauro in italia*. Roma: Gangemi editore.
ISO, U. E. (2006) *UNI EN ISO 7730_Determinazione degli indici PMV e PPD e specifica delle condizioni di benessere termico*.
Italian Ministry of economic development (2015) 'Decreto interministeriale 26 giugno 2015 - Adeguamento linee guida nazionali per la certificazione energetica degli edifici'.
Italian Parliament (2013) 'DPR 16.04.2013, n. 74. Regolamento recante definizione dei criteri generali in materia di esercizio, conduzione, controllo, manutenzione e ispezione degli impianti termici per la climatizzazione invernale ed estiva degli edifici (…).
Janda, K. (2011) 'Buildings don't use energy - People do!', *Architectural Science Review*, 54(1), pp. 15–22.
Jenkins, M. (no date) 'Historic Scotland's approach to training and education for energy efficiency in traditional buildings', in *EECHB 2016- Energy efficiency and comfort of historic buildings*, pp. 128–134.
Junta de Castilla y Leon (2012) 'RENERPATH. Guía de aplicación para la rehabilitación energética de edificios patrimoniales'. Junta de Castilla y

Leon.
Jurošević, S., Grytli, E. R. (2016) 'Energy efficiency retrofit of historic buildings: concepts, approaches and interventions', in *EECHB 2016- Energy efficiency and comfort of historic buildings*. Brussels, Belgium.
Karjalainen, S. (2007) 'Why It Is Difficult to Use a Simple Device: An Analysis of a Room Thermostat', *Human-Computer Interaction. Interaction Design and Usability*, pp. 544–548. doi: 10.1007/978-3-540-73105-4_60.
Karjalainen, S. (2009) 'Thermal comfort and use of thermostats in Finnish homes and offices', *Building and Environment*. Elsevier Ltd, 44(6), pp. 1237–1245. doi: 10.1016/j.buildenv.2008.09.002.
Karjalainen, S. (2011) 'Consumer preferences for feedback on household electricity consumption', *Energy and Buildings*, 43(2), pp. 458–467. doi: https://doi.org/10.1016/j.enbuild.2010.10.010.
Kastner, I. and Matthies, E. (2014) 'Implementing web-based interventions to promote energy efficient behavior at organizations - A multi-level challenge', *Journal of Cleaner Production*. Elsevier Ltd, 62, pp. 89–97. doi: 10.1016/j.jclepro.2013.05.030.
Lambert, S. (2014) 'The early history of preventive conservation in Great Britain and the United States (1850-1950)', *CeRoArt*, 9.
Langevin, J., Wen, J., Gurian, P. L. (2016) 'QUantofying the human-building interfaction: considering the active, adaptive occupant in building performance simulation', *Energy and Buildings*, 117(372–86).
Leaman, A. and Bordass, B. (2001) 'Assessing building performance in use 4: the Probe occupant surveys and their implications', *Building Research & Information*. Routledge, 29(2), pp. 129–143. doi: 10.1080/09613210010008045.
Litti, G., Audenaert, A., Braet, J. (2013) 'Energy retrofitting in Architectural heritage, possible risks due to the missing of a specific legislative and methodological protocol', in *ECSEE 2013 - The European Conference on Sustainability, Energy and the Environment*. Brighton, United Kingdom: ECSEE 2013.
Lodi, C. *et al.* (2017) 'Improvement of thermal comfort and energy efficiency in historical and monumental buildings by means of localized heating based on non-invasive electric radiant panels', *Applied Thermal Engineering*, 126, pp. 276–289. doi: 10.1016/j.applthermaleng.2017.07.071.
Lucchi, E. (2018) 'Review of preventive conservation in museum buildings', *Journal of Cultural Heritage*. Elsevier Masson SAS, 29, pp. 180–193. doi: 10.1016/j.culher.2017.09.003.
Mahdavi, A. (2011) 'The human dimension of building performance simulation', in *Building simulation 2011 - 12th conference of International Building Performance Simulation Association*. Sidney, Australia.
Mancini, F. *et al.* (2016) 'Energy Retrofit of a Historic Building Using Simplified Dynamic Energy Modeling', *Energy Procedia*. The Author(s), 101(September), pp. 1119–1126. doi: 10.1016/j.egypro.2016.11.152.
Marchi, M. *et al.* (2018) 'Environmental policies for GHG emissions reduction and

energy transition in the medieval historic centre of Siena (Italy): the role of solar energy', *Journal of Cleaner Production*. Elsevier Ltd, 185, pp. 829–840. doi: 10.1016/j.jclepro.2018.03.068.

Martínez-Molina, A. *et al.* (2016) 'Energy efficiency and thermal comfort in historic buildings: A review', *Renewable and Sustainable Energy Reviews*, 61, pp. 70–85. doi: 10.1016/j.rser.2016.03.018.

Mauri, L. (2016) 'Feasibility Analysis of Retrofit Strategies for the Achievement of NZEB Target on a Historic Building for Tertiary Use', *Energy Procedia*. The Author(s), 101(September), pp. 1127–1134. doi: 10.1016/j.egypro.2016.11.153.

Mazzarella, L. (2015) 'Energy retrofit of historic and existing buildings . The legislative and regulatory point of view', *Energy & Buildings*. Elsevier B.V., 95, pp. 23–31. doi: 10.1016/j.enbuild.2014.10.073.

McCaig, Iain; Pender, Robyn; Pickles, D. (2018) 'Energy Efficiency and Historic Buildings: How to Improve Energy Efficiency', pp. 1–50. Available at: https://historicengland.org.uk/images-books/publications/eehb-how-to-improve-energy-efficiency/heag094-how-to-improve-energy-efficiency/.

McCambridge, J., Kypri, J. and Elbourne, D. (2014) 'Research participation effects: a skeleton in the methodological cupboard', Journal of clinical epidemiology, 67(8), pp. 845–849.

Meinke, A. *et al.* (2016) 'Comfort-related feedforward information: occupants' choice of cooling strategy and perceived comfort', *Building Research & Information*, 3218(December 2016), pp. 1–17. doi: 10.1080/09613218.2017.1233774.

Mibact-ENEA (2017) 'Patrimonio Culturale in classe A".

Michalski, S. (2007) 'The ideal climate, risk management, the ASHRAE chapter, proofed fluctuations and towards a full risk analysis model', in AA.VV. (ed.) *Proceedings of an Experts Roundtable on Sustainable Climate control strategies*. Los Angeles: Getty conservation institute.

Ministero per i beni e le attività culturali, M. (2001) 'Atto di indirizzo sui criteri tecnico-scientifici e sugli standard di funzionamento e sviluppo dei musei, D.M. 10.5.2001, G.U. n. 238; 19.10.2001'.

Moschella, A. *et al.* (2013) 'Historic buildings in Mediterranean area and solar thermal technologies: Architectural integration vs preservation criteria', *Energy Procedia*. Elsevier B.V., 42, pp. 416–425. doi: 10.1016/j.egypro.2013.11.042.

National Park Service (1999) *Museum handbook*. Washingtone: NPS.

Negro, E. *et al.* (2016) 'Italian Guidelines for Energy Performance of Cultural Heritage and Historical Buildings: The Case Study of the Sassi of Matera', *Energy Procedia*. The Author(s), 97, pp. 7–14. doi: 10.1016/j.egypro.2016.10.008.

O'Brien, W., Gilani, S. and Gunay, H. B. (2018) 'In situ approaches to studying occupants', in Exploring Occupant Behavior in Buildings. Springer.

O'Brien, W. and Gunay, H. B. (2014) 'The contextual factors contributing to occupants' adaptive comfort behaviors in offices - A review and proposed modeling framework', *Building and Environment*. Elsevier Ltd, 77, pp. 77–88. doi: 10.1016/j.buildenv.2014.03.024.

Orland, B. *et al.* (2014) 'Saving energy in an office environment: A serious game intervention', *Energy and Buildings*. Elsevier B.V., 74, pp. 43–52. doi: 10.1016/j.enbuild.2014.01.036.

Padfield, T. (2007) *Museum microclimates*. Copenhagen: The National Museum of Denmark.

Parkinson, T., Parkinson, A. and de Dear, R. (2019) 'Continuous IEQ monitoring system: Performance specifications and thermal comfort classification', Building and Environment, 149(December), pp. 241–252. doi: 10.1016/j.buildenv.2018.12.016.

Parliament, I. (2004) 'D.Lgs. 22/01/2004 n. 42, Codice dei Beni Culturali e del Paesaggio (Code for Cultural Heritage and Landscape)'.

Peng, C. *et al.* (2012) 'Quantitative description and simulation of human behavior in residential buildings', *Building Simulation*, 5(2), pp. 85–94. doi: 10.1007/s12273-011-0049-0.

Pisello, A. L. *et al.* (2014a) 'Energy refurbishment of historical buildings with public function: Pilot case study', *Energy Procedia*. Elsevier B.V., 61, pp. 660–663. doi: 10.1016/j.egypro.2014.11.937.

Pisello, A. L. *et al.* (2014b) 'On an innovative integrated technique for energy refurbishment of historical buildings: Thermal-energy, economic and environmental analysis of a case study', *Applied Energy*. Elsevier Ltd, 162, pp. 1313–1322. doi: 10.1016/j.apenergy.2015.05.061.

Plenderlith, H. J. (1958) *The conservation of antiquities and works of art:tratment, repair and restoration*. Oxford: Oxford university press.

Poggi, M. (2016) *La nuova prestazione energetica dell'edilizia storica e monumentale*. Roma: ENEA.

Polinder, H. *et al.* (2013) *Final Report Annex 53 - Occupant behavior and modeling (Separate Document Volume II)*. Available at: http://www.iea-ebc.org/fileadmin/user_upload/images/Pictures/EBC_Annex_53_Appendix_Volume_2.pdf.

Pothitou, M. *et al.* (2016) 'A framework for targeting household energy savings through habitual behavioural change', *International Journal of Sustainable Energy*, 35(7), pp. 686–700. doi: 10.1080/14786451.2014.936867.

Pracchi, V. (2014) 'Historic Buildings and Energy Efficiency', *The Historic Environment: Policy & Practice*, 5(2), pp. 210–225. doi: 10.1179/1756750514Z.00000000052.

Ragni, M. *et al.* (2013) 'Linee di indirizzo per il miglioramento dell'efficienza energetica nel patrimonio culturale. Architettura, centri e nuclei storici ed urbani', pp. 1–200.

RESSEEPE Consortium Partners (2017) *The RESSEEPE Project 2013-2017 Best practices for retrofitting Public buildings*. Edited by RESSEEPE Consortium Partners.

Richards, A., Clarke, A., Hunt, M. (2016) 'Cornwall Council - skills training and energy saving initiatives', in *EECHB 2016- Energy efficiency and comfort*

of historic buildings, pp. 135–142.
Riegl, A. (1903) *Il culto moderno dei monumenti. Il suo carattere e i suoi inizi.* Edited by S. Scarrocchia. Milan: Abscondita.
Righi, A. *et al.* (2017) 'Historical buildings retrofit: The city hall of the city of Motta di Livenza (TV)', *Energy Procedia*. Elsevier B.V., 133, pp. 392–400. doi: 10.1016/j.egypro.2017.09.368.
Rijal, H. B. *et al.* (2007) 'Using results from field surveys to predict the effect of open windows on thermal comfort and energy use in buildings', *Energy and Buildings*, 39(7), pp. 823–836. doi: 10.1016/j.enbuild.2007.02.003.
Roberti, F. *et al.* (2017) 'Energy retrofit and conservation of a historic building using multi-objective optimization and an analytic hierarchy process', *Energy and Buildings*. Elsevier B.V., 138, pp. 1–10. doi: 10.1016/j.enbuild.2016.12.028.
Roberti, F., Oberegger, U. F. and Gasparella, A. (2015) 'Calibrating historic building energy models to hourly indoor air and surface temperatures: Methodology and case study', *Energy and Buildings*. Elsevier B.V., 108, pp. 236–243. doi: 10.1016/j.enbuild.2015.09.010.
Romeo, E., Morezzi, E. and Rudiero, R. (2015) 'Industrial heritage: Reflections on the use compatibility of cultural sustainability and energy efficiency.', *Energy Procedia*, 78, pp. 1305–1310. doi: 10.1016/j.egypro.2015.11.145.
Rosina, E. (2018) 'When and how reducing moisture content for the conservation of historic building. A problem solving view or monitoring approach?', *Journal of Cultural Heritage*. Elsevier Masson SAS, 31, pp. S82–S88. doi: 10.1016/j.culher.2018.03.023.
Rota, M., Filippi, M. (2009) 'Confidential Facility Report: a tool for the evaluation of quality in museums', in *4th International Congress 'Science and Technology for the Safeguard of Cultural Heritage in the Mediterranean Basin'*. Cairo (Egypt).
Di Ruocco, G., Sicignano, C. and Sessa, A. (2017) 'Integrated Methodologies Energy Efficiency of Historic Buildings', *Procedia Engineering*. The Author(s), 180, pp. 1653–1663. doi: 10.1016/j.proeng.2017.04.328.
Schakib-Ekbatan, K. (2016) 'Bürogebäude auf dem Prüfstand: Zufriedenheit mit Raumklima und Raum. Einbindung der Nut-zerInnenperspektive in die Nachhaltigkeitsbewertung'. Südwestdeutscher Verlag für Hochschulschriften.
Schibuola, L., Scarpa, M. and Tambani, C. (2018) 'Innovative technologies for energy retrofit of historic buildings: An experimental validation', *Journal of Cultural Heritage*. Elsevier Masson SAS, 30, pp. 147–154. doi: 10.1016/j.culher.2017.09.011.
Schweiker, M. (2010) *Occupant Behaviour and the Related Reference Levels for Heating and Cooling*, *PhD Dissertation*.
Schweiker, M. *et al.* (2018) 'Occupancy and Occupants' Actions', in Wagner, A., O'Brien, W., and Dong, B (eds) *Exploring Occupant Behavior in Buildings*. Springer, p. 310. doi: 10.1007/978-3-319-61464-9.
Schweiker, M., Hawighorst, M. and Wagner, A. (2016) 'The influence of

personality traits on occupant behavioural patterns', *Energy and Buildings*. Elsevier B.V., 131, pp. 63–75. doi: 10.1016/j.enbuild.2016.09.019.
Schweiker, M. and Shukuya, M. (2009) 'Comparison of theoretical and statistical models of air-conditioning-unit usage behaviour in a residential setting under Japanese climatic conditions', *Building and Environment*. Elsevier Ltd, 44(10), pp. 2137–2149. doi: 10.1016/j.buildenv.2009.03.004.
Settis, S. (2010) *Paesaggio Costituzione Cemento. La battaglia per l'ambiente contro il degrado civile*. Turin: Einaudi.
Stazi, F., Naspi, F. and D'Orazio, M. (2017) 'A literature review on driving factors and contextual events influencing occupants' behaviours in buildings', *Building and Environment*. Elsevier Ltd, 118, pp. 40–66. doi: 10.1016/j.buildenv.2017.03.021.
STBA (2015) *Planning responsible retrofit of traditional buildings*. Sustainable Traditional Buildings Alliance (STBA). Available at: www.stbauk.org.
Stolow, N. (1979) 'Conservation standards for works of art in transit and on exhibition', in *Museums and monuments*. Paris: Unipub.
Thomson, G. (1978) *The museum environment*. London: Butterworths.
Toftum, J. (2010) 'Central automatic control or distributed occupant control for better indoor environment quality in the future', *Building and Environment*, 45(1), pp. 23–28. doi: 10.1016/j.buildenv.2009.03.011.
Tombazis, A. N. (1998) *Retrofitting of museums for antiquities in the mediterranean contries. Case study: the archaeological museum of Delphi*. Athens: Kakkizas S.A.
Troi, A. (2013) 'RES integration in historic buildings'. EUROPEAN COMMISSION DG Research and Innovation.
Troi, Bastian and Al., E. (2014) *Energy Efficiency solutions for historic buildings. A handbook.* Birkhauser. Edited by A. Troi and Z. Bastian. Basel.
Trust, E. saving (2005) *Energy efficienct historic homes - Case studies (CE138)*. London: Energy saving trust.
Trust, T. N. (2006) *Manual of Housekeeping*. Oxford: Elsevier.
UNESCO (2019) *World Heritage List*. Available at: https://whc.unesco.org/en/list/ (Accessed: 2 December 2019).
UNI (1995) 'Impianti aeraulici al fini di benessere. Generalità, classificazione e requisiti. Regole per la richiesta d'offerta, l'offerta, l'ordine e la fornitura.'
UNI (1999a) 'Beni di interesse storico e artistico. Condizioni ambientali di conservazione. Misurazione ed analisi'.
UNI (1999b) 'Condizioni climatiche per gli ambienti di conservazione di documenti grafici e caratteristiche degli alloggiamenti'. Milano: UNI.
UNI (1999c) 'UNI 10829. Beni di interesse storico artistico. Condizioni ambientali di conservazione. Misure ed analisi.' Milano: UNI.
UNI (2002) 'UNI 10969. Beni culturali. Prinicipi per la scelta ed il controllo del microclima per la conservazione'. Milano: UNI.
UNI (2016) 'Riscaldamento e raffrescamento degli edifici - Dati climatici - Parte 1: Medie mensili per la valutazione della prestazione termo-energetica dell'edificio e metodi per ripartire l'irradianza solare nella frazione diretta

e diffusa e per calcolare l'irradi'.
UNI EN (2019) 'UNI EN 16798-1:2019. Prestazione energetica degli edifici - Ventilazione per gli edifici - Parte 1: Parametri di ingresso dell'ambiente interno per la progettazione e la valutazione della prestazione energetica degli edifici in relazione alla qualità dell'aria.
UNI EN ISO (2008) 'Prestazione termoigrometrica degli edifici - Calcolo e presentazione dei dati climatici - Parte 6: Differenze di temperatura cumulate (gradi giorno)'.
Union, E. (2018) 'Directive (EU) 2018/844 of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency'.
Veitch, J. A. and Gifford, R. (1996) 'Assessing beliefs about lighting effects on health, performance, mood and social behaviour', *Environment and Behavior*, 28(4), pp. 446–470. doi: 10.1177/0013916596284002.
Vieites, E., Vassileva, I. and Arias, J. E. (2015) 'European Initiatives Towards Improving the Energy Efficiency in Existing and Historic Buildings', *Energy Procedia*. Elsevier B.V., 75, pp. 1679–1685. doi: 10.1016/j.egypro.2015.07.418.
Wagner, A. *et al.* (2007) 'Thermal comfort and workplace occupant satisfaction-Results of field studies in German low energy office buildings', *Energy and Buildings*, 39(7), pp. 758–769. doi: 10.1016/j.enbuild.2007.02.013.
Wagner, A. and Brien, W. O. (2018) *Exploring Occupant Behavior in Buildings*, *Exploring Occupant Behavior in Buildings*. Edited by B. Wagner, Andreas; O'Brien, Wiliam; Dong. Springer. doi: 10.1007/978-3-319-61464-9.
Wargocki, P. (1999) 'Perceived air quality, sick building syndrome (SBS) symptoms and productivity in an office with two different pollution loads', Indoor Air, 9(3), pp. 165–179. doi: 10.1111/j.1600-0668.1999.t01-1-00003.x.
Xing, Y., Hewitt, N., Griffiths, P. (2011) 'Zero carbon buildings refurbishment - a hierarchical pathway', *Renewable and Sustainable Energy Reviews*, 15(6), pp. 3229–3236.
Yan, D., Hong, T., Dong, B., Mahdavi, A., D'oca, S., Gaetani, I., Feng, X. (2017) 'IEA EBC Annex 66: Definition and simulation of Occupant Behavior in Buildings', *Energy and Buildings*, 156, pp. 258–270.
Yoshino, H. and Al., E. (2013) 'Final Report Annex 53. Total energy use in buildings Analysis and evaluation methods', *International Energy Agency Programme on Energy in Buildings and Communities*, (June), p. 132.
Zhang, Y. et al. (2018) 'Rethinking the role of occupant behavior in building energy performance: A review', Energy and Buildings. Elsevier B.V., 172, pp. 279–294. doi: 10.1016/j.enbuild.2018.05.017.

Appendix A

Summer questionnaire for HLC occupants[1]

[1] MLC and LLC questionnaires for both seasons, as well as winter questionnaires for HLC BOs can be found in the Annex CD attached to the printed thesis

Comfort conditions of historical buildings users (HLC occupants)

Dear participant, this questionnaire will take about **25 minutes** of your time.

This research is conducted for a doctoral thesis lead by the Polytechnic University of Turin and the Karlsruhe Institut of Technology. The people in charge are Giorgia Spigliantini (Ph.D. student), Professor S.P. Corgnati and Dr. M. Schweiker (Tutors).

This research is addressed to understand perception of thermal comfort of people working in historical buildings. Your participation is very precious because your answers will be used to elaborate **strategies to ameliorate your working conditions and reduce the energy use** of the building you work in.

Taking part in this research, you will be able to evaluate your thermal comfort through your working space. In particular, you will express opinions about your thermal and lighting conditions and preferences, but you will express also your satisfaction about how your environment is managed and what you would wish for.

Data you will provide will be collected according to the Italian D.Lgs. 196 of 30.06.2003. With this disclaim you authorize the Politecnico di Torino and the KIT University of Karlsruhe to treat your data for research activity and publish them in aggregated form; it will not be possible to individuate individuals from the results.

- ○ I authorize the treatment of data according to the D.Lgs. 196/2003.

Your participation is volunteer.

- ○ I am participating voluntarily

I really thank you for your participation. I hope I really will be able to ameliorate your working environment in the near future.

Giorgia Spigliantini

Part I – General information

1. Which of these age groups do you belong?
    - Under 20 years of age
    - 20-40
    - 40-60
    - Over 60
    - Do not like to specify

2. Which of these groups do you belong?
    - Female
    - Masculine
    - Trans-gender
    - Do not like to specify

3. What is your educational qualification?
    - Diploma
    - Bachelor
    - Master Degree
    - Other: ___________

4. Which period of the day is it now?
    - Morning
    - Afternoon
    - Evening

5. Which period of the day do you usually spend at the office?
    - Only morning
    - Only afternoon
    - Sometimes morning / sometimes afternoon
    - Morning and Afternoon

6. How much time do you usually spend in your office per day (not considering breaks, meetings etc.)?
    - Less than 2 hours
    - 2 to less than 4 hours
    - 4 to less than 6 hours
    - 6 to less than 8 hours
    - 8 or more hours

7. How are distributed the following working activities during your usual working day?
    - ___ % desk works (including computer work and phone)
    - ___ % meetings with clients or colleagues (inside the office)
    - ___ % work somewhere else in the office building
    - ___ % other activities (e.g. work outside the office building)

8. What of these groups your office belongs?
    - Single office
    - Small office (between 2 and 3 people)
    - Large office (more than 3 people)

Part II – Cultural background, habits and changing attitude

1. Are you currently living in a different city than your city of origin?
   - ○ Yes (If you like, specify: ____________)
   - ○ No

2. Please mark which of the following action you normally do (you can choose more than one option):
   - ☐ I buy biological or eco-labelled products
   - ☐ I buy products in refillable packages
   - ☐ I have pointed out unecological behaviour to someone
   - ☐ I read about environmental issues
   - ☐ I keep the engine running while waiting in front of a railroad crossing or in a traffic jam
   - ☐ I own a fuel-efficient automobile (less than 7 litters per 100 km)
   - ☐ I ride a bicycle or take public transportation to work or school
   - ☐ In winter, I turn down the heat when I leave my apartment for more than 4 hours
   - ☐ In the winter, I keep the heat on so that I do not have to wear a sweater

3. What of these effects do you think have the following actions for your thermal comfort in your work environment in summer season (please mark one cell per row)?

	It increases my comfort	There are changes in comfort (but I don't know if they're good or not)	It worsens my comfort	No idea	This does not change anything related to my comfort
To drink something cool					
To open windows					
To close windows					
To close curtains					
To wear light clothes					
To switch on air-conditioning					
To use electric fan					

4. Do you like to work in a historical building?
   - ○ Yes
   - ○ No
   - ○ I don't care

5. If you like, specify the reasons of your last answer (open question)

____

6. Suppose that you can choose the building you can work in. Which of the following option would you prefer?
   - ○ Working in a modern building

- Working in a historical building with notable historical elements (paintings, curtains etc.)

7. If you like, specify the reasons of your last answer (open question)

___

Let us suppose that the building you work could acquire the following facilities. Generally, these facilities make your comfort higher. However, their installation would cause damages to the historic building. Below you have to choose if you would renounce to these appliances to preserve the historical building, even if maybe your "comfort" would not be the same as modern buildings.

	I would renounce even if my comfort level could be lower than in a modern building
Cooling system	
Fans	
Personal Heaters	
Automatic switch on/off of lights	
Elevator	
Automatic opening/closing Of windows	
Automatic solar shadings	

8. Do you think that historical buildings are more or less energy-costly than more recent ones?
    - More
    - Less

9. Do you think you would profit from being given advice about your behavior in relation to ventilating, cooling and heating at workplace?
    - Yes, I would profit a lot
    - Yes, I would profit a bit
    - No, I would not profit so much
    - No, I would not profit at all
    - I do not know

Part III – Comfort conditions and preferences

1. In your opinion, how important the following points are to feel comfortable at workplace?

	Very Important	Important	Not important	Don't care	Other
Natural light from windows					
Room Temperature					
Architectural Aesthetic of roo and furniture					
A view out of the window					

2. Please tick the circle that best represents how you feel at workplace during this summer.

Cold	Cool	Slightly Cool	Neutral	Slightly warm	Warm	Hot
◯	◯	◯	◯	◯	◯	◯

3. Basing on the previous thermal sensation, please tick the circle below that best describes your comfort perception at workplace during this summer.

Very Uncomfortable	Moderately Uncomfortable	Neutral	Moderately comfortable	Very Comfortable
◯	◯	◯	◯	◯

4. Please tick the circle below that best represents the quality of the air (regarding smell, presence of dust etc.) at workplace during this summer.

Clearly acceptable	Just acceptable	Just not acceptable	Clearly not acceptable
◯	◯	◯	◯

5. Please tick the circle below that best represents the natural light level you perceive during the day at workplace during this summer.

Dark	Very low	Slightly low	Neutral	Slightly high	Very High	Dazzling
◯	◯	◯	◯	◯	◯	◯

6. Basing on the previous lighting level evaluation, please tick circle below that best describes your comfort perception (related to lighting level) during this summer.

Very Uncomfortable	Moderately Uncomfortable	Neutral	Moderately comfortable	Very Comfortable
◯	◯	◯	◯	◯

7. Please tick the circle below that best represents the humidity level you perceive at workplace during this summer.

Very dry (dry mucosa)	Moderately dry	Slightly dry	Neutral	Slightly humid	Moderately humid	Very humid (sweating)
○	○	○	○	○	○	○

8. Basing on the previous humidity level evaluation, please tick the circle below that best describes your comfort perception (related to humidity level) during this summer.

Very Uncomfortable	Moderately Uncomfortable	Neutral	Moderately comfortable	Very Comfortable
○	○	○	○	○

9. Please tick the circle below that best represents the noise level of your office.

Silent	Very low	Slightly low	Neutral	Slightly high	Very High	Deafening
○	○	○	○	○	○	○

10. Basing on the previous noise level evaluation, please tick the circle below that best describe your comfort perception (relate to noise level).

Very Uncomfortable	Moderately Uncomfortable	Neutral	Moderately comfortable	Very Comfortable
○	○	○	○	○

11. Do you recognize any of these sources of discomfort? You can choose more than one option.

- ☐ Too much air movement
- ☐ Not enough air movement
- ☐ Drafts from windows
- ☐ Hot/cold surrounding surfaces (floor, ceiling, walls or windows)
- ☐ Incoming sun
- ☐ Other: ______________________________

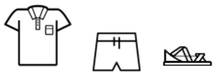
12. Some people think that they work best when they are not in a state of thermal comfort (e.g. they feel slightly cold), others think that when feeling cold or warm they cannot work. When you think you are in a state of thermal comfort, does this condition enhance the quality of your work (+3), it has no effect (0) or it worsen the quality of your job (-3)?

(-3) Maximum interfering	(-2)	(-1)	(0)	(+1)	(+2)	(+3) Maximum enhancing

Part IV – Office behaviour

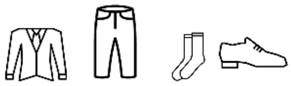
1. In which of these categories do you recognize your usual clothing for the current season (summer)?

o Light summer clothing: t-shirt, light skirt or short pants and sandals;



o Medium summer clothing: light pants/skirt, short-sleeved shirt, light socks and shoes;

o Heavy working clothing: cotton shirt (long-sleeved) work pants, wool socks and shoes.



2. Do you have a specific dress code to go to work?

o Yes (If you like, specify: ____)

o No

3. Have you tried to find information about how to solve the indoor environmental problems (related to temperature, air quality, lighting etc.) you may have? You can choose more than one option.

- No, I know what to do and I do not need more information
- No, I do not know where to look for information
- No, the problem is not serious enough to take action
- No, it is not my responsibility
- Yes, I asked my colleagues
- Yes, I asked my family
- Yes, I asked an expert (not relatives) / a company specializing in the field
- Yes, I searched on the internet
- Yes, I asked my doctor
- Yes, I contacted the authorities
- Other: ___________________

4. 4. How often do you usually perform these actions when feeling thermally uncomfortable in summer season? If an action is not available (e.g. opening the window, click "Never"). Please mark one cell per row.

	Two or more times per day	Once per day	Once every 2-4 days	Once per week	Less than 4 times per Month	Never
Opening window						
Closing window						
Opening window and door together						

Regulating internal shadings (e.g. curtains)	
Regulating external shadings (e.g. shutters)	
Drinking cold beverages	
Turning on the cooling/fans when feeling hot	
Turning off the cooling/fans when feeling too cold	
Removing/adding extra layers of clothing	
Other ______________________	

5. How often do you usually perform these actions when the natural lighting level is too low in the winter season? Please mark one cell per row.

	Two or more times per day	Once per day	Once every 2-4 days	Once per week	Less than 4 times per Month	Never
Opening internal shadings (e.g. curtains)						
Opening external shadings (e.g. shutters)						
Turning on the artificial lights on my desk						
Turning on the general lights of my office						

6. How often do you usually perform these actions when the natural lighting level is too high in summer season? Please mark one cell per row.

	Two or more times per day	Once per day	Once every 2-4 days	Once per week	Less than 4 times per Month	Never
Closing internal shadings (e.g. curtains)						
Closing external shadings (e.g. shutters)						
Turning off the artificial lights on my desk						
Turning off the general lights of my office						

7. How often do you usually perform these actions when feeling that the indoor air quality is low in summer season? Please mark one cell per row.

	Two or more times per day	Once per day	Once every 2-4 days	Once per week	Less than 4 times per Month	Never
Opening windows for airing the space						
Closing windows (the bad smell usually comes from outside)						
Opening the door						
Turning on the fan						

8. How often do you usually perform these actions when feeling that the humidity is not proper in summer season? Please mark one cell per row.

	Two or more times per day	Once per day	Once every 2-4 days	Once per week	Less than 4 times per Month	Never
Opening windows						
Closing windows						
Turning on the dehumidification (if you have it)						
Turning on the cooling/fans (if you have it)						

9. When do you usually turn on the lights in summer? Tick all that apply

- ☐ When I arrive at the office in the morning
- ☐ In the afternoon
- ☐ Only when I perceive that the natural lighting is not sufficient
- ☐ Never (e.g. because lights are switched automatically)
- ☐ Other (Please specify: ______________________)

10. When do you usually open the windows in summer? Tick all that apply

- ☐ When I arrive at the office in the morning
- ☐ Only when it's too hot
- ☐ Only when it's too cold (due to the cooling system)
- ☐ Only when the air quality is not proper
- ☐ Never (e.g. because lights are switched automatically)
- ☐ Other (Please specify: _____________________)

11. After you opened the window, for how long it usually remains open?
    - Only the time to restore the proper condition
    - Less than 30 minutes
    - Less than 1 hour
    - More than 1 hour
    - Until the end of the working day
    - I cannot open the windows

12. When the window is open, do you turn off the following systems?
    - Fans
    - Cooling system
    - Window is never open
    - neither

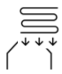
13. When you leave the office what of these actions do you perform and when in summer season? Tick all that applies.

	At the end of the day	Every time I leave the office	Never
Turn off artificial lightings (if turned on)			
Closing windows (if open)			
Turn off the computer (if turned on)			
Put the computer in stand-by mode (if turned on)			
Turn off fans/cooling system (if turned on and if you can control it)			

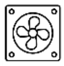
Part V – Control opportunities and preferences

1. Which of these systems do you have in your office to control indoor environmental conditions in summer? Tick all that applies.

☐ Cooling system (indicate the type)

- o Fan Coils 
- o Multi-split 
- o Radiant floor 
- o Radiant ceiling 

☐ Fan 

☐ Air Handling Unit 

☐ Ceiling fan 

☐ Dehumidification system 

o There are not systems for cooling or ventilation.

2. Do you personally manage the cooling system/fan in the summer season?

o Yes
o No

3. If you cannot control the system personally, do you know the person in charge of this duty?

o Yes, and I can communicate with him/her
o Yes, but I cannot communicate with him/her
o No

4. In the following some actions are listed. Select one cell considering two aspect. 1) if you can perform the action and 2) if the possibility of performing this action is important to you or not.

	I have it and I wish to remain like this	I have it but I'm not interested in it	I don't have it and I'm not interested in it	I don't have it but I wish to
Opening/closing windows				
Turning on/off artificial lighting				
Regulate artificial lights (intensity of light)				
Turning on/off cooling system/fan (if present)				
Regulate the cooling system/fan (if present)				

Regulate internal shadings (if present)	
Regulate external shadings (if present)	

5. If during summer the temperature is too high and you don't have a cooling system, are you allowed to bring/or have your persona fan?
   - Yes
   - No

6. Which of these operations are automatic (or you wish to be automatic) through your working environment (please thick one cell per row)?

	It is automatic and I like it	It is automatic but I don't like it/don't care	It is not automatic and I wish it to be	I don't care
Opening/closing windows				
Turning on/off artificial lighting				
Regulate artificial lights (intensity of light)				
Turning on/off cooling system/fan (if present)				
Regulate the cooling system/fan (if present)				
Regulate internal shadings (if present)				
Regulate external shadings (if present)				

7. Have you ever made requests to the building manager (or person in charge) for changes to the heating, cooling, lighting or ventilation systems?
   - Yes (If you can, please give brief details: ________________________________)
   - No

8. If Yes, how satisfied in general were you with the speed of response? Please thick one option in the scale.

Unsatisfactory overall (1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**Satisfactory overall (7)**

9. If Yes, how satisfied in general were you with effectiveness of response? Please thick one option in the scale.

Unsatisfactory overall (1)	(2)	(3)	(4)	(5)	(6)	Satisfactory overall (7)

In recent years, the topic of historic buildings’ energy retrofit has been investigated increasingly by the energy research sector, especially in the European area. This phenomenon is related to a number of reasons, among which the increasing awareness of the role that this category of buildings have to reach the European carbon emissions’ reduction targets by 2050. In fact, more than 14% of the European building stock dates from before 1920, but this percentage rises to 50% in several urban centres. Despite the increasing interest on the topic, several studies on historic buildings’ energy retrofit seems not aware of cultural heritage protection and conservation legislations and practices. For this reason, nowadays, the objectives of these two sectors seems to be unbalanced. Since the tradition of heritage conservation and protection are rooted in the society’s cultural background, there is the necessity of proposing a change of perspective about the role of the energy sector in the restoration field. Primarily, energy retrofit should be addressed at increasing the liveability and economic sustainability of historic buildings, having their social profitability as a central scope. In terms of solutions, the architectural heritage is characterized by a great variability, so its energy retrofit requires a high level of multidisciplinary knowledge. Moreover, due to the uniqueness of historic buildings, the necessity of individuating replicable solutions for their energy retrofit can be satisfied at a maximum degree by proposing a common procedural approach, which could be realized thorough the elaboration of a methodology. Based on the previous aspects, for the present work a strand of the energy research has been individuated as a potential ground to balance heritage conservation and energy efficiency aims. This strand is occupant behaviour or, more generally, building operation. This PhD dissertation tackled the previous aspects by proposing the elaboration and test of a methodology called “BIOSFERA” (Building Intelligent Operational Strategies For Energy Retrofit Aims”). Testing the methodology on a pilot study, which consisted on the experimentation on four case studies, a first answer to the following research question was provided: What are the potentialities of energy saving and indoor environmental conditions’ enhancement by acting only on the way non-residential historic buildings are operated by occupants and operators? The results obtained in the pilot study were promising, especially in perspective of a broader application of this methodology on a larger scale. In fact, in all buildings for which an energy consumption assessment was possible, the obtained energy savings ranged from 10% to 16% considering the whole experimentation, with seasonal peaks of more than 30%. In terms of indoor environmental conditions, the energy saving trend resulted, in the large majority of cases, on occupants’ perceived thermal comfort amelioration or stability.