Fraunhofer Centre
Benediktbeuern
for Conservation and Energy Performance of Historic Buildings

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May 4th/5th 2022

EEHB2022

The 4th International Conference on Energy Efficiency in Historic Buildings

The conference is organised jointly by the Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings and the Deutsche Bundesstiftung Umwelt and with the support of the Bezirk Oberbayern.

Fraunhofer IRB | Verlag

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EEHB 2022 Post Prints

The 4th International Conference on
Energy Efficiency in Historic Buildings

4th and 5th May 2022
Benediktbeuern, Germany

Balancing energy efficiency and conservation aspects of Terragni's Casa del Fascio in Como: thermal analysis, energy modelling and intervention proposals

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Abstract – This paper aims to present a methodology for planning energy improvement interventions in modern listed buildings, carried out through a combination of desk research, on-site survey, monitoring campaign and energy modelling. For this purpose, Giuseppe Terragni's Casa del Fascio has been chosen as our case study. The building is characterised by indoor microclimate conditions that are far from the standard requirements: summer is the most critical period because there is no possibility of limiting overheating due to the absence of the original devices designed by Terragni. Based on monitored data and building characteristics, an energy dynamic model was carried out with the aim of simulating the recovery of the original solutions or the addition of low-impact measures. The simulated options were eventually evaluated by taking into account their compatibility with the building features. This resulted in some strategies suitable for Casa del Fascio, that enable to reconcile the conservative goal with that of improving internal comfort.

Keywords – Modern Movement Architecture; Energy Efficiency; Restoration; Thermal analysis; Energy modelling.

1. INTRODUCTION

In the last few years, the improvement of energy efficiency of historic built heritage has become an ever more important topic within the scientific community. How to balance sustainability and energy efficiency needs, pushed by EU Directives, with the aim of preserving our heritage is still an open question. Given the complexity of this issue, the regulations in force allow the exclusion of listed building from performance requirements [1]. Hence, the focus of the question shifts from the achievement of standard values to a performance improvement which shall be "as much as possible". However, the lack of a shared decision-making method may lead to the risk of not having a complete overview on both preservation and energy efficiency aspects when approaching the project [2]. That being said, the study aims to present a methodology for planning energy improvement measures based on a combination of different knowledge in a whole building approach. Coherent, coordinated and planned activity of study, technical survey and energy modelling are combined here to improve the building efficiency and the users comfort level, with the least impact on its historical material consistency.

The occasion for the research on Casa del Fascio in Como came from a request from the Italian Superintendency of Archaeology, Fine Arts and Landscape of Milan (that promoted a restoration plan for wooden windows in 2005), after becoming aware that a general building microclimate analysis was necessary to draw up an energy-efficiency project.

2. METHODOLOGY

The proposed methodology is divided into some distinct and defined phases. It starts from a knowledge phase in which all bibliographical and archival information is collected and the building transformations from its construction to nowadays are identified. This is supported by an on-site survey: as a matter of fact, not all the building changes are documented or traceable, especially the least relevant ones linked to ordinary maintenance or to the users comfort needs (for example replacing construction elements with others that are different in terms of mode of operation, adding new services, etc.). After this phase, the investigation focuses on the building thermo-hygrometric characteristics and on the indoor microclimate conditions, examined through suitable diagnostic equipment. In this way it is possible to define the building energy profile. Finally, starting from microclimatic data and building characteristics it is possible to develop an energy dynamic model. This allows to simulate the building thermal behaviour and, therefore, evaluate the improvement made to the current situation by some low-impact intervention proposals. Choosing the best possible solutions depends on the above-mentioned analysis and the evaluation of their feasibility must take into account the compatibility with the building typological and material features. This method results in strategies able to reconcile the conservative goal with that of improving internal comfort.

3. THE CASE STUDY: CASA DEL FASCIO IN COMO

The proposed methodology is applied to Giuseppe Terragni's Casa del Fascio in Como (Italy), one of the historic masterpieces of the Italian Modern Movement[1] [3].

Figure 1. (a) Outside view of the Casa del Fascio. (b, c) Inside view of the *Salone delle Adunate* and courtyard.

The building has four floors with a square plan, and its crux is a large central double height hall called *Salone delle Adunate* (Gatherings room). The gallery on the first floor overlooks this huge space and connects the offices. The second floor follows the distribution system of the first floor: the only difference is that the gallery opens onto the roof of the *Salone delle Adunate*, which is the floor of the inner courtyard, characterised by a skylight in concrete-frame glass blocks crossed in the middle by a walkway. On the top floor the building is divided in two parts by two open galleries: reaching this last floor is only possible by using the secondary staircase, while the other two floors

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[1] The construction works of Casa del Fascio began in July 1933 and ended in 1936, when it was inaugurated as the local branch of the National Fascist Party. It held this function for a relatively short period, from 1936 to 1945, the year in which the building was forcibly occupied by the Provincial Federations of the National Liberation Committee Parties, after the liberation of the city of Como from the Fascist Regime. Since 1957, Casa del Fascio houses the Command of the VI Legion of the Italian Finance Police, but in February 2017 a petition was launched proposing its re-use for cultural purposes, namely as a museum of rationalism.

are reachable also through the main staircase [4]. The great peculiarity of this building is its construction system: a mix of autarkic and traditional materials in a reinforced concrete structure [5]. The lack of immediate recognition of the monumental value of Casa del Fascio, listed in 1986 only, led to some maintenance actions carried out over the years by unskilled casual labour with the result that the original design intents of Terragni was altered.

3.1 DOCUMENTARY RESEARCH AND ON-SITE SURVEY

Detailed desk research and field survey are essential to develop coherent building intervention proposals. First of all, a documentary (bibliographical and archival) research was carried out. Numerous written works were consulted to reconstruct the building history and Terragni's design intents: for this purpose, the special issue of the monthly magazine *Quadrante*, published in 1936 and completely dedicated to the Casa del Fascio, is of particular interest. It includes diagrams of the orientation and exposure to solar radiation of the building drawn by Terragni on the basis of Ernst Neufert's work. This study influenced the building final position[2] and led to the creation of the open galleries of the South-West façade to cope with the outdoor climatic conditions: in the warm season they help prevent direct sunlight exposure of the façade, while in the cold season they favour the entrance of the solar radiation [6]. The other investigation reports on the building only covers the construction and architectural composition of the Casa del Fascio, not taking into account the events that took place in the course of eighty years of its life which have radically changed its material consistency. Fundamental in this regard was the investigation of two archives, whose study was very complex and extended due to the large number of documents stored there: accounting and notarial documents, unpublished photographic material, local newspapers, private and administrative memories etc.[3] [7]. The documentary research was then accompanied by an on-site survey: this has allowed to identify undocumented changes as well as building characteristics that negatively affect the internal comfort. What has emerged is that the main cause of the lack of summer and winter comfort is the high percentage of transparent surfaces (that account for about 40% of the total area) like concrete-frame glass blocks and wooden and metal windows. Wooden windows, in particular, are in a poor state of conservation due to their high technical complexity, dimensions (the most common window has a length of 4.7 m and a height of 2.63 m), weight (about 263 kg) and to the action of atmospheric agents and variations in temperature and humidity [8]. This has led to the deformation of the window frames and, as a consequence, to problems in the opening/closing system: if the window doesn't close completely there is a high loss of heat in winter, while if window doesn't open properly, the correct air exchange in summer is not allowed. Wooden windows

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[2] The building is oriented along the orthogonal axes "North-West/South-East" and "North-East/South-West" with a rotation of 25 degrees with respect to the north geographic. This orientation leads to the fact that all four façades are affected by direct solar radiation in summer: the two most stressed ones are those in Via dei Partigiani and Piazza del Popolo, but in the early morning and late afternoon the other two façades are also exposed.

[3] Particularly rich and never systematically explored is the *Municipal Archives in Como* which preserves all the documentation issued by the municipal officers on post-war maintenance interventions. The archive of the Italian Superintendency of Archaeology, Fine Arts and Landscape of Milan has also proved to be very useful: it preserves documents, projects, cost estimate and photographs of the latest restoration works, linked to the institutional activity of historical-artistic protection carried out by the institution on the building from 1986 to the present day.

restoration was partially carried out in 2005, when the Superintendency obtained specific funding: the restoration work on a sample window ended in 2006 and concerned the frames' structural stiffening through the insertion of steel tubulars and the replacement of the single glazing with a safety one [8]. In 2016, two other windows were restored, for a total of three refurbishment projects that were completed. Generally speaking, windows restoration would allow not only to recover their movement system, based on a counterweight mechanism, but also to implement the glass U-value with its replacement.

In addition to the replacement of some building components (e.g. all the metal windows, most of the glass blocks, etc.) [9, 10] and changes in materials and colours [11], the documentary research and the on-site analysis revealed that Terragni (in addition to open galleries) designed some experimental solutions to mitigate the indoor microclimate conditions during summer: the roller blinds on the main façade (Piazza del Popolo)[4], the awnings on via Pessina and on the perimeter walls of the inner courtyard[5] and the air conditioning system[6]. However, these devices were prematurely abandoned due to some problems deriving from their technological inadequacy as a result of their high experimental character. All this led to a drastic worsening of the indoor comfort conditions of the Casa del Fascio.

3.2 DIAGNOSTIC ANALYSIS AND MICROCLIMATIC DATA

The field survey is followed by a diagnostic analysis that involved the building's internal microclimate and the properties of its building components. The analysis of the indoor thermo-hygrometric conditions of the Casa del Fascio was carried out using six microclimatic probes[7], located inside and outside the building according to the results of the preliminary psychrometric analysis. This was performed inside the building twice during the day, in the morning and in the afternoon, thus allowing to identify the points in which the greatest daily thermal range occurred, i.e. the most critical issues [12]. In the next phase, the microclimatic probes were positioned in these points: in total five internal points and one external point were identified[8]. The monitoring campaign began on

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[4] They consisted of a piece of fabric connected to a roller (inserted in a special cavity of the open galleries ceiling) through four cables that formed two inverted V. The surface of the fabric did not entirely cover the span but, with the curtain unrolled, a portion of empty space remained on the top. The particular characteristics of these curtains probably made them very sensitive to the wind action and for this reason they lasted for a very short time. The rollers are still in place.

[5] The structure of the awnings is composed of a roller supported by two side arms. Currently only one window of the inner courtyard still has the piece of fabric.

[6] The air conditioning system consists of air vents located on the floor of *Salone delle Adunate*. During the summer period, the air vents used to introduce fresh air into this huge space while the natural action of the stack effect extracted warm air. The offices could also benefit from this system through the door transom opening, that brought about air circulation. Unfortunately, the system worked for a very short time: most of the air vents were sealed and the door transoms remained blocked in the closed position due to their weight.

[7] EL-USB-2, temperature and humidity datalogger with USB provided by Lascar Electronics.

[8] Probe n°1 was placed at the entrance; Probe n°2 inside the *Salone delle Adunate*; Probe n°3 in a room facing North-West with a damaged window, which remains open throughout the day and night; Probe n°4 in

13th December 2014 and ended on 5th May 2016, for a total of approximately one-and-a-half-year. The monitoring phase showed a strongly oscillating behaviour of both temperature and relative humidity which are the result of the influence of the external climate. By looking at the graph of the daily average temperatures it can be seen that the days in which the values fall into the winter and summer comfort zones (provided by the current standard) are very limited [13]. In winter, the heating system[9] is only partially able to guarantee comfort conditions: the air temperature inside the rooms seldom reaches 20°C. The summer period turns out to be the most critical because there is no possibility of limiting overheating. The microclimatic probes measured internal temperatures very close to those external: the highest recorded temperature is around 35°C (in July). The graph of daily average relative humidity confirms a strong sensitivity to external variations during the year, which corresponds to a significant fluctuation of the indoor conditions [7]. Generally speaking, the indoor microclimate conditions of Casa del Fascio are far from complying with the standard requirements and the main cause is the use of lightweight construction techniques, typical of the 20th century architecture: as a matter of fact, large windows and thin walls favour a strong heat loss in winter and a considerable solar gain in summer when the external temperature rises.

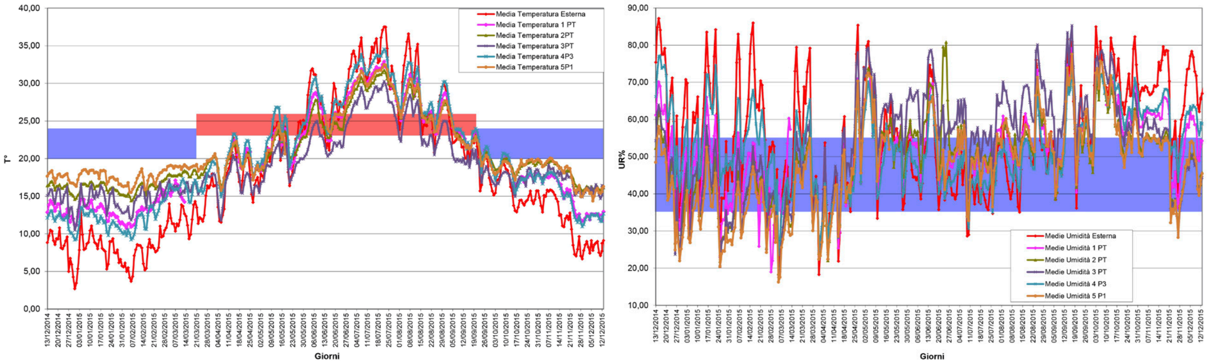

Figure 2. (a) Graph of daily average temperature. (b) Graph of daily average relative humidity.

The diagnostic investigation ended with the measurement of the U-value of the North-West and North-East external walls through a heat flow meter[10]. They were carried out according to the procedures provided by the international standard ISO 9869. The final thermal transmittance was then calculated by entering the collected data into a dedicated software (U calc): the U-value of the North-West wall is 1.4 W/m^{2}K while the one of the North-East wall is 1.5 W/m^{2}K [12]. These values were useful for the following energy modelling phase.

3.3 DYNAMIC ENERGY MODEL OF THE BUILDING

Starting from the building characteristics and the data monitored, a dynamic energy model was created, in order to simulate the building thermal behaviour. For this purpose, the EnergyPlus simulation engine software was used [14]. The first step was the definition of the model geometry

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the gallery of the top floor; Probe n°5 in the *Sala del Direttorio* on the first floor and, finally, Probe n°6 was placed externally, on the open gallery of Piazza del Popolo, protected from direct sunlight.

[9] The heating system is characterised by the presence of a centralised boiler, located in the basement. The terminal units are radiators (of different types) positioned in each room. In winter these are accompanied by electric heaters, as reported by the building users.

[10] ThermoZig system, wireless heat flow meter provided by Optivelox.

and the reconstruction of the surrounding context with its shading surfaces. Then, the thermal zones were defined: to avoid any kind of problem, the model was kept as simple as possible with a total of 31 thermal zones, considering the *Salone delle Adunate* as a single unheated area (stairwells and galleries included). After that, a material characterization of the opaque and transparent envelope was done: the comprehension of the exact building components stratigraphy was possible by combining the data from documentary research, direct observation and diagnostic analysis. Two different types of brick masonry, a type of concrete and hollow tiles mixed floor and all the recognised transparent surfaces were included in the energy model. Once it is geometrically completed, it becomes a reliable tool by means of the use of specific parameters: in addition to the on-site measurements, the parameters available are the boiler fuel consumption and the electricity bills. These data were processed to calculate the real primary energy, used as a comparison value in the final phase. But first of all, the energy model must be calibrated and for this reason a schedule for each thermal zone was created by indicating the electrical equipment, the outdoor airflow rate and the heating set-point. In general, the entered data vary over time according to the real use of the rooms. First of all, the internal loads of electrical equipment (number of lights, computers, people, telephones, printers, radio, etc.) were added. Then, the outdoor airflow rate value was calculated based on the volume of the rooms and the air infiltration factor through the windows (as mentioned above, windows are in a poor state of conservation). Finally, two different schedules were created for the heating set-point according to the daily use and type of space, public areas or offices. The temperature values (18°C for public areas and 23°C for offices) were obtained by cross-referencing the data from the microclimatic probes and the psychrometer. The simulation was run with these settings in order to validate the model: what we have obtained is the energy demand, converted into primary energy. In conclusion, the real primary energy (239,088 kWh) was compared with the energy calculated through the model (219,176 kWh) and a deviation of 9% was detected [12].

3.4 INTERVENTION PROPOSALS

Thanks to the analyses that were previously described as well as the energy model, it was possible to simulate and then verify the technical compatibility, feasibility and effectiveness of various low impact retrofit interventions, able to combine conservation aspects with those on energy. Interventions have been defined considering both winter and summer periods.

The microclimatic study showed that winter is the least critical period, even if the heating system is not completely able to guarantee acceptable internal comfort conditions according to the current standard. Excluding some very impactful interventions, the restoration of all wooden windows was proposed. Although this intervention is expensive and complex, this would make it possible to safeguard the integrity of a unique and unrepeatable system, while obtaining a 15 percent reduction in heating consumption [12].

As we have seen, summer is the most critical period since there is no possibility of limiting overheating except with the use of existing wooden roller shutters which, however, obstruct the passage of natural light. One of the aims of this study was to insert *ex-novo* internal curtains and to recovery and assess the effectiveness of the external solar shading systems designed by Terragni (roller blinds and awnings), currently no longer in use. From a conservation point of view, their impact on the building is very low because they are removable devices already partially included in the original project. According to these solutions, the addition of interior and exterior high-performance fabrics was proposed: for this purpose, a market survey was carried out. Different types of fabrics were studied by analysing their performance in terms of sun protection, visual permeability, privacy, passage of natural light and ventilation, thickness, weight and fire and wind resistance. The fabrics were then grouped into four categories: coated fabrics and dyed PET fibre fabrics, suitable for both indoor and outdoor use; mixed metal-plastic fabrics for outdoor uses; honeycomb or cellular shades for indoor uses. Finally, the fabrics were compared with each other in order to determine which ones best suit the needs of Casa del Fascio[11] [7]. With regard to the roller blinds, a further fundamental step was the development of a system that enables to recall the compositional features of Terragni's solutions. The most convincing one is a roller, with two side rails, connected with the fabric by means of three stiffening belts. However, this system, being very sensitive to the wind action would require very frequent, complicated and costly maintenance. Our final proposal is therefore a classic roller blind with two side rails and a piece of fabric that, in its open configuration, occupies the entire span up to the banister. In conclusion, the comparison between the dynamic simulation of the external shading systems with the insertion of new internal curtains and the external shading systems with the correct management of the wooden roller shutters has shown that this latter is the most effective scenario as it could lead to a reduction in the internal temperature of min 0.4°C and max 3°C [7]. The microclimate improvement is not enough to ensure acceptable comfort conditions for workers.

3.5 TESTING OTHER SOLUTIONS

In view of what emerged in the previous paragraph, the pros and cons of some more invasive interventions were evaluated [7]. A first design solution concerns the shielding of the roof of *Salone delle Adunate* with the insertion of a textile shade sail above the inner courtyard, capable of preventing solar radiation from passing through the skylight. The results show a temperature reduction of 2.5°C in the *Salone delle Adunate* (in July), while the temperature reduction in the other rooms is insignificant. This is therefore an expensive and impactful intervention not justified by the small improvements in terms of thermal comfort. A second solution regards the insulation of the flat roof, i.e. the installation of a reflective insulation material (approximately 4 cm thick) under the original roof finishing layer made of white cement grit tiles. The findings show a benefit in the internal microclimate conditions in winter and a worsening in summer. During the hot season the low thermal inertia of the envelope allows heat to enter during the hottest hours and to come out in the evening and night. The installation of an insulating layer prevents this process causing a greater accumulation of heat during the summer. This is the reason why this intervention was not considered advantageous. The last intervention we took into account is the replacement of the glass blocks with insulating ones. This would make it possible to level out the building appearance while improving the energy performance of the transparent envelope. However, the results of the simulation indicate a situation similar to the flat roof insulation. As a consequence, even this strategy is not feasible. That said, some alternative solutions that could be considered for future assessment are the recovery of the air conditioning systems and the insertion of new high-performance systems.

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[11] "Soltis 92" and "Soltis 99" by Serge Ferrari (coated fabrics) were selected respectively for the external roller blinds of the main façade and the internal curtains, while "Tempotest Star FR" by Parà (dyed PET fibre fabric with flame retardant properties) was chosen for the awnings of via Pessina and the inner courtyard.

4. CONCLUSIONS

Within the restoration project, the definition of energy efficiency retrofit interventions starts from the recognition of the architectural composition and geometrical studies, archival and bibliographic research combined with on-site survey. All this made it possible to define a picture of the historical changes and stratifications. These results, together with the microclimatic and diagnostic analysis, allowed to create an optimized energy model capable of identifying the thermal performance data and assessing the energy impact of few feasible retrofit options, already verified from the conservation point of view. Hence, a prudent and careful choice of techniques and materials was made, also giving priority to the recovery and enhancement of the existing building elements designed by Terragni. So, a first conclusion regards the importance of considering this aspect inside the typical methodology of a conservation design process. Usually, the improvement of energy efficiency is considered a specialized sector and it is treated separately. A second conclusion, more referred to this experience, shows the difficulties in reaching the current parameters of internal temperature and relative humidity without inserting a new impacting air conditioning system. Should the building turn into a new museum, this part will be necessary, taking into consideration the interaction between systems and interior design. The Superintendency considers this experience and the acquired data as the basis for a dialogue between conservation and energy needs.

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EEHB2022

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In order to achieve the ambitious governmental and societal goals in CO_2 reduction that are needed to mitigate global climate change, the contribution of all sectors including buildings and the construction industry is required. Historic and traditional buildings compose a considerable part of the worldwide building stock. In this context solutions are needed that respect the historic fabric of these buildings and yet contribute to energy efficiency improvements and CO_2 reduction.

This volume collects papers given at the 4th International Conference on Energy Efficiency in Historic Buildings EEHB2022 at the Fraunhofer Centre for Conservation and Energy Performance of Historic Buildings at Benediktbeuern Monastery, Germany, from May 2nd to 5th 2022. Scholars presented new research and best practices on a wide range of topics relating to energy efficiency in historic buildings.

The EEHB2022 conference especially addressed issues related to the role digital technologies can play in improving the energy performance of historic buildings, whilst respecting the principles of conservation. In this context, the aim was and is to take a closer look at the interfaces between digital building models and the building simulation and the question of the necessary accuracy of both 3D digitisation and hygrothermal or building energy performance simulation tools. Both technologies – 3D scans and building simulation – have been available for a long time, but so far there are no automated processes for converting 3D scans into the energetic building simulation, also concerning the degree of accuracy of the building survey using digital methods in order to represent a historical building accurately. This volume provides an insight on current themes and scholarly efforts around the world. These topics were also treated during the two-day-long workshop entitled »Recording historic buildings using digital workflows – Designing the intersection from 3D model to building simulation« that preceded the EEHB2022 conference. This volume provides an insight into current research efforts around the world.

ISBN 978-3-7388-0779-0

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Fraunhofer IRB | Verlag