Study of the indoor microclimate for preventive conservation and sustainable management of historic buildings

The case of Villa Barbaro, Maser

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Abstract – In recent years, there has been an increasing awareness of the need for proper and sustainable management of historic buildings – energy efficiency and availability must go hand in hand with preservation. To find solutions, we propose a new concept: Historic Indoor Microclimate (HIM). The HIM is used to find out the building’s history, considering how and what has changed inside and outside the building over time (destination of use, plant, climate changes, etc.). Moreover, this study identifies a magnitude index to assess the microclimatic risk. The case study presented shows the results of research carried out in 2016 and applied to Villa Barbaro, Maser, which concerns the evaluation of the indoor microclimate through monitoring and planning of the management of this building. It permits to guarantee a better energy efficiency; the preservation of the historic building and of the collections and artefacts inside it, and to increase the level of visitors’ comfort.

Keywords – historic buildings; sustainable; energy efficiency; Historic Indoor Microclimate (HIM); microclimatic risk

1. INTRODUCTION

This paper reports the results obtained from the indoor microclimate monitoring campaign of an historic building: Villa Barbaro, built in Maser between 1554 and 1560 by the architect Andrea Palladio and registered on the UNESCO World Heritage Site list from 1994, as Palladian Villa of Veneto [1].

Regarding the subject of indoor microclimate in the area of museums, it already exists literature, for example Thomson [2], Camuffo [3, 4] about deterioration and microclimate monitoring (indoor and outdoor); also in Italy this is an issue which has been particularly emphasized, for example by Bernardi [5]; others as de Guichen [6] have proposed specific methodologies for museums.

Furthermore, there is a crucial connection between indoor microclimate and architectural configuration, deduced from the study of Historic Indoor Microclimate (HIM). The definition of the HIM concept was conceived by Fabbri [7] and Pretelli [8–10], as a result of a series of research on several historic buildings on the UNESCO heritage list. The HIM approach refers to the historic buildings’ indoor microclimatic conditions, in contrast to the traditional one, which
usually consists of a study on the specific conservation artefacts’ range. Once a sound knowledge of the indoor microclimate is acquired, it is possible to verify and to simulate the state of conservation of the objects.

2. GOALS

This paper is aimed to describe a specific methodology which has proved to be successful to find the right management of historic buildings’ conservation. This methodology has proven effective in evaluating the effects of indoor microclimate parameters’ changes on the thermal comfort of visitors, and at the same time on the conservation of artefacts kept inside historic buildings.

The best strategy to preserve the cultural heritage is the one that allows to detect in time any potential risk situations, due to microclimate, and setting alert thresholds. For that reason, considering all the microclimatic variables and their continuous changes in time and space, this study wants to define and to calculate a magnitude index to assess the “Heritage Microclimate Risk” (HMR).

3. CASE STUDY

Villa Barbaro (Figure 1) is characterised by the presence of many frescoes, realised by Paolo Caliari, so-called “il Veronese” (Figure 2); it was built in a suburban estate of about 230 hectares. The central part of the building is on two levels. On each side there is a porch and the front is about 16 meters, equivalent of 1/3 of the building’s depth. Due to the tilted soil, the lower level is a basement, connected with the main floor by backstairs. The masonry structure is a typical three-layered one: the two external façades enclose an internal less regular brickwork (the so-called “a sacco” typology). The external walls of this architecture are about 0.80 m thick. The stone is used just for the decoration: capitals
and frames. The doors and the windows' fixtures are in wood; there are single-glazed windows and hollow slab roof.

Nowadays, Villa Barbaro, one of the most famous of Palladio's Villas, is used partially as a museum and partially as a house inhabited: there are only six rooms accessible to the public and three of those have been monitored during the monitoring campaign illustrated below.

4. RESEARCH METHODOLOGY

4.1 LEVELS OF ANALYSIS

The proposed methodology is structured as follows: (a) the archive search, (b) the monitoring campaign, (c) the virtual building modelling, by a dynamic software (IESVE [12]), and (d) the calculation of the percentage of the Heritage Microclimate Risk (HMR).

The first phase is about the acknowledgment of the fabric and it is constituted by the bibliographic and archival research and by the monitoring campaign. The second one is about the realization of a virtual building model of Villa Barbaro. The aim of this monitoring is to measure the Villa's indoor microclimate and the creation of a virtual building model of it, which allows evaluating the physic behaviour of the indoor microclimate through thermo/fluid-dynamic simulations, making possible the elaboration of some hypothetic microclimate improvements scenarios. Moreover, the measurements obtained from the monitoring and the virtual building simulations, allow to assess the percentage of the HMR to which the artefacts are subject.

4.2 ARCHIVAL RESEARCH

During archival research, the geometrical, structural and thermo-physical characteristics of the historic building have been verified, as also some information about the use of the building. Moreover, an oriented reading of “The Four Books of Architecture” has been done, to find the passages in which Andrea Palladio provides indications and suggestions (Palladio [13]). We also used the graphic products elaborated between 1968 and 1981, by the International Centre of Architectural Studies Andrea Palladio (CISA [14]): the architectural surveys of Villa Barbaro, have been crucial for the realization of the virtual building model, which is fundamental for an in-depth and realistic study and energy analysis of the building.

4.3 MONITORING CAMPAIGN

The installation of the monitoring system at Villa Barbaro has been possible thanks to the collaboration with Henesis company, and the specific instrumentation used are the following: probes to monitor microclimatic parameters (air temperature, relative humidity, CO₂ concentration); Beesper bridge, that is a data grab able to transmit data to an internet platform; and Beesper console, namely an online platform used to a remotely visualization of data. The monitoring campaign had a duration of 6 months (from 21/06/2016 to 9/12/2016) and we
monitored three of the six rooms open to the public. We placed the bridge in the Croce Centrale and the probes in Croce Centrale, Stanza del Cane and Tribunale d’Amore. In the layout (Figure 3) these rooms correspond respectively to number 1, 2 and 3. Due to a failure of a probe, we could not retrieve data from the room (2) Stanza del Cane.

Figure 3. Layout of Villa Barbaro, Maser, Scale of 1:100. In red the rooms open to the public, and with numbers (1) Croce Centrale, (2) Stanza del Cane e (3) "Tribunale d’Amore": rooms where the probes have been placed. Credits: CISA A.Palladio, Vicenza.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Accuracy range</th>
<th>Measurement range</th>
</tr>
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<tbody>
<tr>
<td>Air temperature</td>
<td>±0.5 °C</td>
<td>0–50 °C</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>±3 %</td>
<td>20–80 %</td>
</tr>
<tr>
<td>CO₂ concentrations</td>
<td>±50 ppm</td>
<td>0–5000 ppm</td>
</tr>
<tr>
<td>Contact temperatures</td>
<td>±0.5 °C</td>
<td>0–50 °C</td>
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</table>
4.4 BUILDING SIMULATION

The realization of the virtual building model of Villa Barbaro, allows to elaborate selected microclimate improvement scenarios. The strength of the proposed methodology lies in the possibility to pre-emptively define, throughout a virtual building model, which actions could aid the preservation of the artefact, avoiding the risk component that would be taken working on the original.

Thanks to the layout of the building, we made a first virtual building model using the software AutoCAD, uploaded on SketchUp, to realise the 3D model of Villa Barbaro. Downloading a plug-in, we transferred the model on IES.VE (Virtual Environment by Integrated Environmental Solutions: software BIM – Building Information Modeling): a dynamic simulation software used to elaborate analysis of buildings’ sustainable energy performances. IES.VE returns information about energy use, CO₂ emissions, occupant comfort, light levels, airflow, etc., through data, images and videos.

The Building Simulation, realised through IES.VE, consists on the use of the virtual building model, which allows to examine several specific aspects of a
building. It permits to study the performance of the building: indoor microclimate, lighting, energy, human behaviour, acoustics, indoor air quality, etc. Also, IES. VE allows to assess the Computational Fluid Dynamics (CFD): a simulation of the fluid dynamic behaviour of the air, indoor and outdoor, resulting from natural ventilation. To be certain that the simulations’ outputs are reliable, we must insert geographic, architectonic, stratigraphic and climatic information about the building. In this way, the software can calculate and consider all materials’ thermo-physical properties.

5. RESULTS

The most relevant data recorded are those about air temperature (T) and relative humidity (RH), which present a rather similar trend between the two rooms analysed. About the first parameter, the probes have recorded high summer temperatures, considering the fact that we are studying an indoor environment (temperatures reach 30 °C) and low temperatures in winter (temperatures lower than 7 °C); the RH values are inversely proportional to those of the T and for each room the RH is from 35 % to 80 %. The data recorded by probes have been compared with those obtained by the IES.VE simulations and they matched: the validation of the virtual building model has been confirmed comparing the software’s result with measurements. The virtual building model has been validated through the monitoring campaign data, as reported in Table 1.

Considering the benchmarks of T and RH, defined in UNI 10829 [15] and by the MIBACT [16], we have calculated the HMR to which the frescos inside Villa Barbaro are exposed. By reference to the category of “inorganic materials/articles”, we have considered:

- Air Temperature $t_{(set),min} = 15 \, ^\circ\text{C}$ and $t_{(set),max} = 25 \, ^\circ\text{C}$;
- Relative Humidity $h_{(RH,set),min} = 20 \, %$ and $h_{(RH,set),max} = 60 \, %$

The HMR caused by the RH is 32.31 % in the room Croce Centrale and it is 33.78 % in the room Tribunale d’Amore; instead the HMR due to the T is 86.91 % in the room Croce Centrale (Figure 4) and it is 84.38 % in the room

<table>
<thead>
<tr>
<th>Validation parameter</th>
<th>Accuracy range</th>
<th>Room Croce Centrale</th>
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</thead>
<tbody>
<tr>
<td>MBE</td>
<td>2.01 %</td>
<td>1.92 %</td>
</tr>
<tr>
<td>CV (RSME)</td>
<td>13.00 %</td>
<td>13.37 %</td>
</tr>
<tr>
<td>PEARSON</td>
<td>0.95</td>
<td>0.94</td>
</tr>
<tr>
<td>Coefficient of determination $R^2$</td>
<td>0.89</td>
<td>0.87</td>
</tr>
</tbody>
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Tribunale d’Amore (Figure 5): much higher than the percentage of risk estimated for the RH in each room.

We have calculated the HMR as follows: in Excel we estimated the number of hours in which the RH and the T do not comply with the above-mentioned range, considered optimal for the frescos’ preservation; we divided the sum of these hours – during which the frescos are under HMR – for the accumulated hours of

Figure 5. Air Temperature and Relative Humidity Trends, Room (1) Croce Centrale (top); Room (3) Tribunale D’Amore (bottom).
the monitoring campaign’s duration. The result obtained, converted in percentage, is the percentage of the HMR to which the frescos have been exposed during the six months of monitoring. \( RM = \frac{rmh}{h} \% \) where:

- “\( rmh \)” is the HMR for hours: \( rmh = 1 \) if \( RHi > Rset \) or \( Rhi < Rset \)
- “\( h \)” are the total hours on which the HRM is calculated

6. PROSPECTED SCENARIO

As showed by data presented above, the parameter which more jeopardise the conservation of the Villa Barbaro’s artefacts is the T. For this reason we propose a controlled management of the indoor T, through the activation of the HVAC system (currently inactive on the main floor of Villa Barbaro). This hypothesis leads to a marked improvement of visitors’ comfort and of the microclimatic conditions for the conservation of the frescos: we set on IES.VE a set-point of 18 °C for the heating and 24 °C for the air conditioning (Figure 4 and 5). The dotted red lines indicate the standards’ ranges defined in UNI 10829 [15] and by the MIBACT [16].

Comparing a scorching summer day, the 2\(^{nd}\) July, and a highly cold winter’s day, the 29\(^{th}\) December, the T simulated respects the regulatory standards, and the values of the Predicted Percentage of Dissatisfied (PPD) reach peaks less than 10 %, instead of the 90 % inside the analysed rooms in the present circumstances (Figure 6). Nevertheless, the visitors’ comfort can be considered irrelevant for this case study because the duration of visits is very short, about an hour.

To evaluate the PPD, we assumed a level of sedentary activity in summer (69.8 W/m\(^2\), which is the equivalent of about 1.1 met) and the use of summer

![Figure 6. Air temperature trend by building simulation HVAC-ON and HVAC-OFF Scenarios, Room Croce Centrale.](image-url)
clothes, from which a thermal clothing resistance of 0.2 clo is obtained. For the winter period, we assumed a level of sedentary activity too (69.8 W/m²), but with winter clothes: 1.2 clo of thermal resistance. Moreover, it is noted that all results over the comfort and discomfort PPD evaluation of visitors are related to a standard user, who stays in the room as provided for by ISO 7730.

7. CONCLUSIONS

The methodology adopted for this case study is extremely simple and low cost, both in terms of probes purchasing, data collection and management: characteristics that suggest a large-scale replicability. The study of buildings’ indoor microclimate permits to make decisions about architectural and managerial changes, as the choice of HVAC systems, to reduce energy consumption.

Obviously, the virtual building model has its limits: during the fluid-dynamic simulation, for example, analysing open spaces with several glazed areas, we can find thermal imbalances errors; moreover, we can’t know what happens under a layer of plaster. Nevertheless, the virtual building model allows to verify eventual building damage in a preventive way. Furthermore, the possibility of using a single indicator, as the HMR index, permits to avoid certain difficulties due to the utilisation of many different standards.

This methodology prompts the use of the building simulation to simulate the virtual environmental model of the historical buildings that, once validated, permit the hypothesis of management of present or future scenarios. Moreover, the possibility to control the environmental parameters which influence the microclimate, enables to define which actions could aid the preservation of the cultural
heritage analyzed and to understand the structural or transitional deterioration causes: crucial steps to set up a database for restoration projects. It also permits to monitor if the legally determined parameters are respected.

For all these reasons, it is considered that the case study of Villa Barbaro could show the efficacy of the methodology proposed to improve the approach of the so-called “preventive restoration”.

8. REFERENCES