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Historic Indoor Microclimate, the role of HVAC in heritage buildings' restoration: the case of the Palace of Venaria Reale

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Abstract. The paper is aimed to illustrate how the study of the indoor microclimate, supported by the virtual simulation and by the knowledge of the historical evolutions of the building (managerial, usage and architectonical changes over the years), represents a preventive practice which allows to evaluate and predict the interactions between the object and the environment. To do that the authors present a case-study: room 33 in the Palace of Venaria Reale, in Turin, Italy. We have reproduced a virtual building model which presents the same indoor and outdoor microclimatic conditions of the original building. Moreover, we evaluated an alternative scenario that simulates the indoor microclimate of room 33 considering the HVAC systems continuously off. The comparison between the two virtual buildings allowed to estimate the impact of the HVAC system on the preventive conservation of the historical building, of the artefacts and of the occupants' thermal comfort. Those simulations clarified which indoor microclimatic conditions could be guaranteed by the building itself, after the restoration project of the whole Palace started in 2001.

1. Introduction

Before the XIX century, architects built private and public buildings having due regard to the natural factors on which the indoor microclimate depends [1-5], unable to relay on the Heating, Ventilation and Air Conditioning systems (HVAC). We are talking about the influence of the outdoor environmental conditions; the choice of the construction materials; the exposure of the building; its dimensioning and design; etc. Then, the introduction of systems which can control fundamental indoor microclimatic parameters, such as temperature (T) and relative humidity (RH), has had many consequences in the field of architecture, comfort, sustainability, and conservation. It means that the use of the HVAC systems in any kind of building, does not only affect the aesthetics of buildings, but it also has a great impact on the visitor's expectations in terms of indoor thermal comfort, and many natural energy resources are exploited every day to comply with these expectations. Exactly because of that gradually adaptation by systems of the buildings' indoor microclimate to the occupants' thermal comfort expectations, started between the XIX and XX Century, architecture has been defined as the act of enclosing and servicing an interior atmosphere, a notion not developed until the 20th century [6]. Moreover, the changes on the indoor microclimate which HVAC systems can lead, can affect the conservation of architecture itself and of the artifacts guarded inside it. That can result in an exposure to a risk of damage for collections which have been acclimatized for years inside museums, in microclimatic conditions totally different from those that the modern systems can guarantee. These modifications in microclimate can also affect the architecture itself, indeed, since the XIX century the HVAC systems started to be used for new constructions and to be installed in historical buildings too, without considering the bad consequences related to their introduction [7].

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One of the main results which the control of the indoor microclimate by systems has led on the architecture, is the possibility to see a building with the same shape, materials, thickness of walls and glass surfaces at the equator and at the pole, while still providing identical indoor microclimatic conditions. If we are talking about residential buildings, with no recognized historic, cultural, and artistic value, that only affects the sustainability of the building. But, if we are talking about a building which -like the case-study presented in this paper- were included in the UNESCO Heritage List, and, in addition, if it were a building open to visitors to show the valuable collections it hosts inside, the issue becomes more complicated. In fact, the introduction, and the managing of the indoor microclimate control in historical buildings used as museums, is extremely complicated because of the different needs of occupants (who expect to find a comfortable environment) and artifacts (which must be preserved from damage, and that damage can be due to microclimatic conditions). As is well known, some values of T or RH which could be favourable for occupants' comfort, could be a risk for the conservation of artifacts and vice versa [8].

The approach adopted for the case-study presented in this paper is in alignment with the research field of "Historical Indoor Microclimate" (HIM) [9-11], that aims to understand how, and which factors cause variations on the indoor microclimate during the life cycle of a building, and the correlation between those factors and the conservation of the building and its content. Recent research, (e.g. [12-14]) and the literature review published by Elena Lucchi [15] deal with the theme of the study of indoor microclimate, primarily focusing on museum buildings [e.g. 16-17]. In the literature there are many research about that issue which are aimed to present the utility of the study of monitoring data (e.g. [18-22]) to detect and control factors which affect the indoor microclimate (HVAC systems installation, flow of visitors, opening and closing windows management, …). Other studies (e.g. [23-26]), related to that theme show how the virtual simulations of the indoor microclimate allow to evaluate the consequences that any kind of those factors have on the indoor microclimate and therefore on the conservation and on the occupant's comfort. All these data are a great base of knowledge to understand the role of those factors. Indeed, each case-study makes a substantial contribution to that research field because more ample is the investigated casuistry and more knowledge we have on that issue.

2. Goals

The aim of this paper is to study the multiannual indoor microclimatic data of room 33 in the historical building of Palace of Venaria Reale, that has been characterized by an important restoration between 2001 and 2007. With this research we wanted to:

- apply a specific methodology consistent with the research field of HIM;
- virtually verify the consequences on the Cultural Heritage conservation and occupants' comfort resulting from the installation of HVAC systems in room 33;
- understand what kind of approach was at the basis of that intervention (conservative restoration; reconstruction; valorisation, …).

3. Case-study

The case study of this paper is the room 33 of The Palace of Venaria Reale. This room is part of the visitors' tour of the Realm. The Palace of Venaria Reale was one of the Sabauda Residences; it was buit in the province of Turin, in Italy and since 1997 the Palace is part of the serial sites that UNESCO has included on the Heritage of Humanity list. Venaria Reale has been characterized by the intervention of many architects between 1659 and 1798: Amedeo Castellamonte, Michelangelo Garove, Filippo Juvarra, Benedetto Alfieri, Giuseppe Battista Piacenza, and Carlo Randoni. The addictions, demolitions, changes in types of use, etc. which marked the history of this building have followed one another during the years. The most recent intervention that involved the Palace, is the restoration project started in 2001. It concerned reconstruction of many areas of the building and the installation of HVAC systems in the whole Palace. At the end of the restoration works, the Palace have been inaugurated as museum and Centre of Conservation and Restoration in 2007.

4. Methodology

The research methodology is composed by several steps:

- bibliographic and archive search;
- on-site visits;
- excel analysis of monitored data;
- construction of a virtual building model;
- validation of the virtual model;
- virtual building simulations;
- excel analysis of the simulations' results;
- comparation between two different scenarios' results;
- defining the main conclusions drawn.

We want to specify that:

- the monitored data have been provided by the Centre of Conservation and Restoration (CC&R) from a monitoring campaign, held during the following period: 7/08/2001 – 16/03/2017;
- to construct the virtual model of the building we used IES.VE (Virtual Environment by Integrated Environmental Solutions), a dynamic simulation software which generate data, images and videos that provide information about environmental parameters and occupants' comfort;
- the validation parameters considered to validate data produced by the virtual building model are those from the guideline 14 of ASHRAE [27].

5. Results

Room 33 is in a partition of the Palace of Venaria Reale, next to the Galleria Grande (or Gallery of Diana) on the east side. Figure 1 show the IES.VE virtual building model of that partition; the red rectangle indicates the studied room 33.

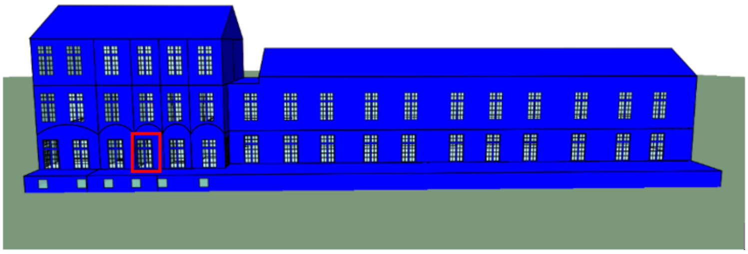

Figure 1. IES.VE virtual model of the Palace of Venaria Reale.

As we mentioned, it was possible to use T and RH data from the CC&R monitoring, dating from 2007 to 2017. As shown in Figure 2 there are some gaps in the recording of data. Some of those are due to malfunctioning of probes and others are cause by the inattention of the CC&R who didn't download data in time and consequently they have been overwritten with new ones, because of the limited memory of probes. During the whole period of the monitoring campaign the HVAC system introduced with the restoration works has been operational. T and RH results (Figure 2) show values of temperatures mostly between 20°C - 28°C and of relative humidity mainly between 30% - 60%. Those values correspond to the ranges suggested for the conservation of most materials by the Italian standards [28-31].

To verify what would be the conditions of the indoor microclimate in room 33 if it were guaranteed only by the building itself without the support of HVAC systems, we have simulated -through the virtual model- a hypothetical scenario in which those systems are turned off for one whole year: Virtual Building 1. Figure 3 and 4 show the results of T and RH that would have in room 33 without HVAC systems. Figure 3 shows evident values of T lowers than 20°C from January to March and from the last decade of November until the end of December. During that period, the simulated T is around 15°C: far from the above-mentioned Italian standard suggested for the most materials conservation and far from the nowadays comfort expectations too. Nevertheless, considering that the indoor microclimatic conditions have been simulated assuming the inactivation of heating systems during winter, the results obtained reveal a discreet efficiency of the envelope at retaining heat. Moreover, from mid-June to October temperatures surpass 30°C, unsuitable for both accessibility and conservation. Finally, we calculated the daily fluctuation during the whole year, which vary from as low 1°C up to 2.6°C.

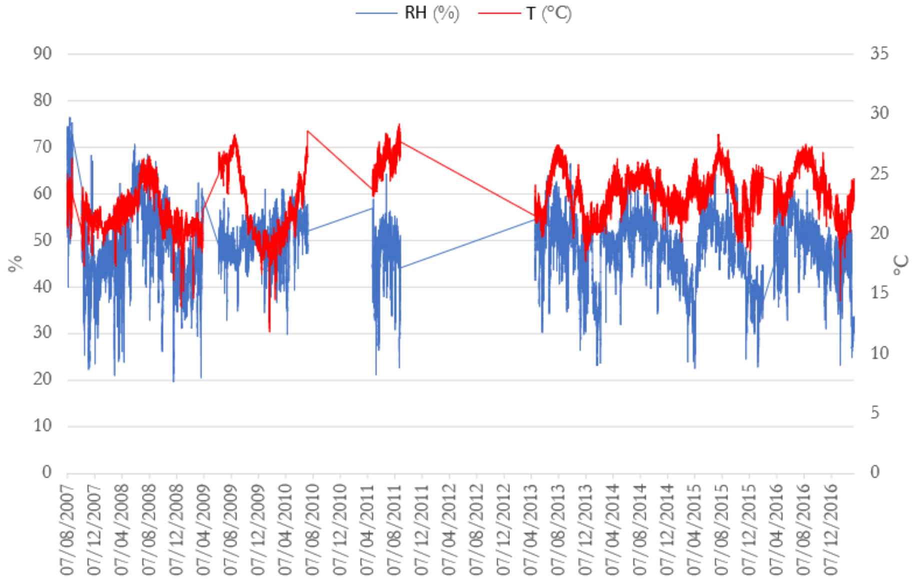

Figure 2. T and RH monitored data in room 33 from 7/08/2001 to 16/03/2017.

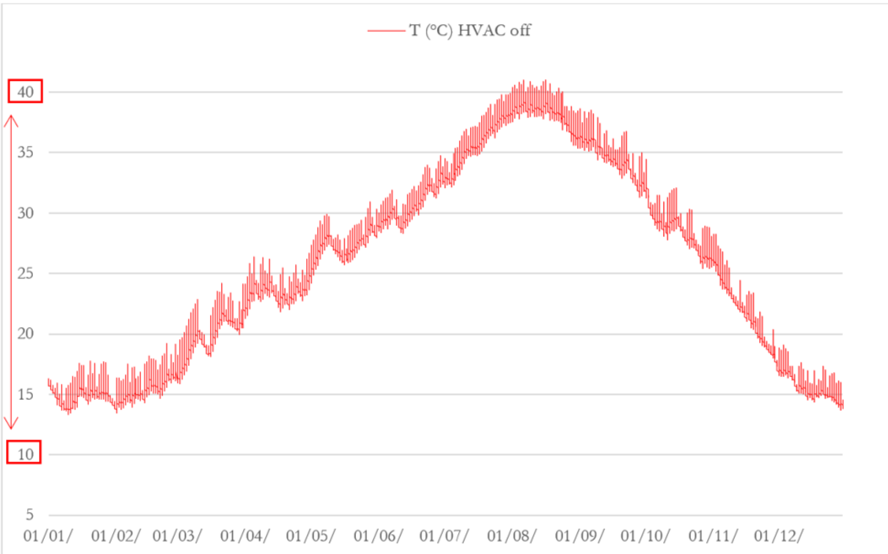

Figure 3. Virtual Building 1: simulated T values with HVAC off from 1/01 to 31/12.

These data show that the investigated architecture, for its construction features, couldn't guarantee optimal T conditions for conservation and thermal comfort for a whole year, without HVAC system support. Figure 4 show RH values mostly between 30% - 55%, with rare positive and negative picks until 65% and 15%. Even these conditions do no differ much from the ones recorded during the monitoring campaign the values are a bit lower than the recorded ones: the period during which the collections hosted in room 33 could be exposed to risk of damage is between August and October, when the results show the typical values of a dry environment: RH between 20% - 40 %.

To support the assumptions about the comfort of visitors expressed remarking T and RH data of room 33 shown in Figure 2, 3, and 4, we compared the results of PPD (Predicted Percentage of Dissattisfied) and PMV (Predicted Mean Value) [32] simulations of virtual building 1 (without HVAC systems) to the ones of virtual building 2, which reproduces the actual indoor microclimate of the building for one year, considering HVAC systems on, as they really are today and they were during the CC&R monitoring campaign. Data obtained from these virtual CFD (Computional Fluid Dynamics) simulations by IES.VE allow to compare the thermal comfort of visitors considering two specific days: a very hot day (3/08) and an especially cold one (30/12).

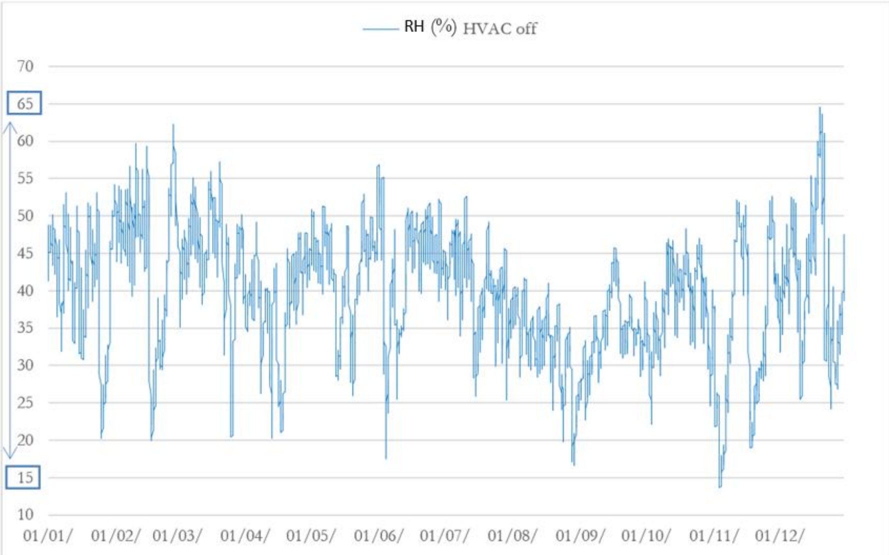

Figure 4. Virtual Building 1: simulated RH values with HVAC off from 1/01 to 31/12.

We run these simulations during the opening hours of the Palace of Venaria Reale (between 9:00 a.m. and 5:00 p.m.). Moreover, we defined some specifications about the clothing and the typology of activity carried out in room 33 (visiting): the level of activity assigned is very low for both periods - winter and summer-, equal to 69.8 W/m2; the clothing considered for the winter period is 1.2.clo and 0.2clo for the summer. Figures which follow (Figure 5, 6, 7, 8) show the results of PPD and PMV parameters on the x axis, in room 33, at 1m from the floor.

From Figure 5, 6 emerge that the mean value of thermal comfort is better in Virtual Building 2, for both considered days. During the winter's day the PMV of Virtual Building 2 shows optimal values of occupants' comfort: between -0.273 e +0.273; instead, the simulation of Virtual Building 1 predicts a thermal sensation more adverse: -1.909 PMV. It is recalled that a PMV equal to -3 indicates a very cold thermal sensation; +3 indicates a too hot microclimate; rather, values between -0.5 and +0.5 are index of optimal occupants' thermal comfort. In summer too, Virtual Building 1 show a condition of higher discomfort (PMV=2.455) than Virtual Building 2 (PMV= 1.264).

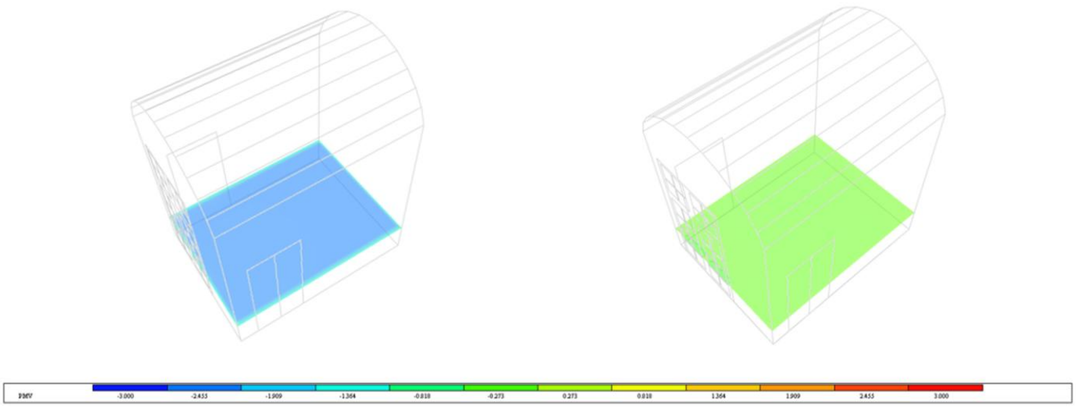

Figure 5. PMV – 30/12: *Virtual Building* 1 (on the left), *Virtual Building* 2 (on the right).

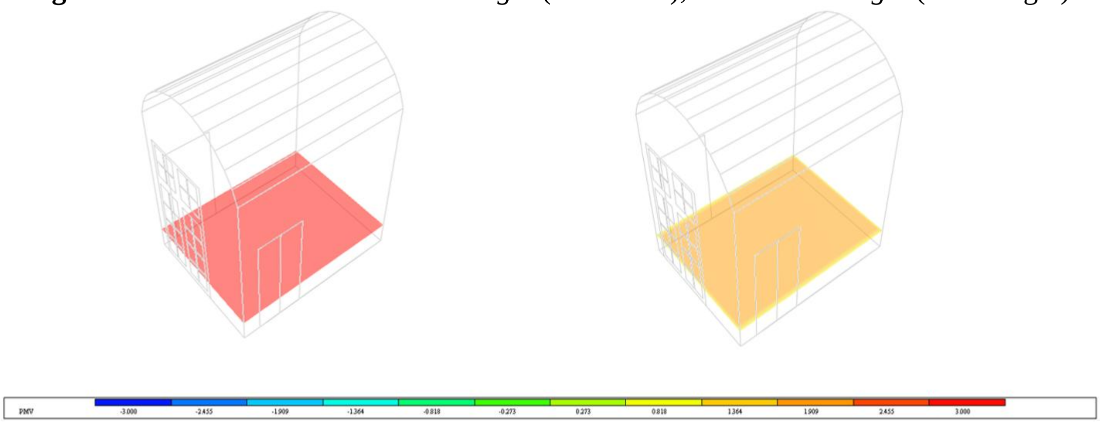

Figure 6. PMV – 3/08: *Virtual Building* 1 (on the left), *Virtual Building* 2 (on the right).

6. Conclusions

The methodology adopted on the case-study of room 33 in Palace of Venaria Reale, concerned to combine: 1. the knowing of historical changes in the building cycle life; 2. the evaluation of the consequences on conservation and fruition due to those variations. The results show that, without the HVAC systems the building itself couldn't guarantee proper indoor microclimatic conditions for the occupants' comfort and not even for the preventive conservation of the artifacts and the building: in this case the HVAC systems allows to dissociate the formal and material characteristics of the building from its microclimatic performances. That means that all the technicians who intervened for the restoration works between 2001 and 2007: architects, restorers, systems designers, etc., agreed to entrust to the HVAC systems' control all the aspect of the indoor microclimate. The restoration of the Palace has not been conservative restoration, but it was a requalification and valorization of the building, with the introduction of new materials and contemporary HVAC systems when obsolete or absent. This logic contrasts with the design logic of the pre-industrial architects and to the principles and criteria which guided Juvarra, Castellamonte, Garove and the other architects who designed the Palace of Venaria Reale.

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