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THE IMPACT OF INDOOR ENVIRONMENT QUALITY ON THE CONSERVATION PRACTICE OF HISTORICAL BUILDING THE CASE OF LEBANESE COASTAL ZONE

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Abstract

It is widely acknowledged that a multidisciplinary approach should be adopted to conserve historical buildings that include indoor environmental features. This paper discusses the effect of healthier indoor environment requirements on the conservation of historical buildings. Conservation, being an essential sustainable practice using inherited built assets to satisfy present needs, imposes limitations on the intervention that can be induced to historical buildings. Healthier indoor environment requires controlling various factors as Indoor Air Quality and Thermal Comfort, which directly affect the Heat-Air-Moisture transfer (hygrothermal behavior) of the historic building envelope and may lead to its deterioration and degradation. Focusing on the historic built fabric of the Lebanese coastal zone, this paper investigates the impact of Indoor climate control on the pathology of the historic building envelope and presents recommendations that mitigate that impact while preserving both conservation requirements and occupant comfort. A case study analysis is conducted to identify the qualitative parameters in the Indoor space of an 18th century heritage building located in the coastal zone of Lebanon and used as public building. The conclusion highlights the potential for comfort establishment in refurbished historic building through raising awareness in relation to occupant behavior and identifying scientific approaches to control hygrothermal behavior of the historic envelope, by the mean of whole building simulation software, which adds significant contribution to the conservation practice.

Keywords

Indoor environment quality, hygrothermal behavior, thermal comfort, whole building simulation, historical building

THE IMPACT OF INDOOR ENVIRONMENT QUALITY ON THE CONSERVATION PRACTICE OF HISTORICAL BUILDING- THE CASE OF LEBANESE COASTAL ZONE

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ABSTRACT: *It is widely acknowledged that a multidisciplinary approach should be adopted to conserve historical buildings that include indoor environmental features. This paper discusses the effect of healthier indoor environment requirements on the conservation of historical buildings. Conservation, being an essential sustainable practice using inherited built assets to satisfy present needs, imposes limitations on the intervention that can be induced to historical buildings. Healthier indoor environment requires controlling various factors as Indoor Air Quality and Thermal Comfort, which directly affect the Heat-Air-Moisture transfer (hygrothermal behavior) of the historic building envelope and may lead to its deterioration and degradation. Focusing on the historic built fabric of the Lebanese coastal zone, this paper investigates the impact of Indoor climate control on the pathology of the historic building envelope and presents recommendations that mitigate that impact while preserving both conservation requirements and occupant comfort. A case study analysis is conducted to identify the qualitative parameters in the Indoor space of an 18th century heritage building located in the coastal zone of Lebanon and used as public building. The conclusion highlights the potential for comfort establishment in refurbished historic building through raising awareness in relation to occupant behavior and identifying scientific approaches to control hygrothermal behavior of the historic envelope, by the mean of whole building simulation software, which adds significant contribution to the conservation practice.*

KEYWORDS: *Indoor environment quality, hygrothermal behavior, thermal comfort, whole building simulation, historical building*

1. INTRODUCTION

Heritage buildings conservation has a multidisciplinary approach (Pretelli & Fabbri, 2018), where three main categories of actors are involved: conservators, building material specialists and environmental inspectors. Architects aim is to save the building and conserve its heritage and historical value with the collaboration of the building physics engineers, who aim to improve standards that lie between building fabric physical parameters and new technologies interventions in order to protect these materials from deterioration. While the environmental specialists are focusing more on reducing energy consumption in historical buildings and on using passive ways to control the inner environment, the users' comfort play an interesting role in their approach at the same time.

Monitoring the indoor climate of heritage spaces is an essential task in many researches especially if these spaces are used as museums, art exhibitions or libraries (Ankersmit & Stappers, 2017; Pisello, Castaldo, Piselli, & Cotana, 2017). Passive control of the indoor climate conditions in such buildings is considered risky due to the high hygrothermal inertia, the poor insulation, and the poor air tightness of its historic envelope (Broström, Hagentoft, & Wessberg, 2011).

The paper discusses a comprehensive method to study the impact of Indoor Environment Quality (IEQ) enhancement in historic building on the hygrothermal behavior of its envelope, with respect to the

conservation ethics and practice. The study was carried out as part of a PhD Thesis investigation for the hygrothermal behavior impact on the conservation of the historical fabric of Lebanese coastal cities. The coastline is of 225 km in length and includes more than five major historical cores in old cities, two of which are listed as world heritage sites since 1984, Tyre and Byblos. The common material used in the Lebanese coastal built heritage is the highly porous sandstone. In the practice of conservation in these cities, there is no scientific consideration to prevent the building pathology of the heritage built asset.

1.1 Hygrothermal behavior of historic building

Many factors affect the degradation of the historic building fabric or accelerate the rate of deterioration. The first step is to conduct a damage risk assessment of the historical building and to create a starting point for models that study porous materials. These materials are strongly affected by the moisture and temperature changes with time. Primarily the mechanical, hygric and thermal properties should be investigated to understand the hygrothermal behavior of the historical building envelope (Vejmelková, Keppert, Reiterman, & Černý, 2013).

In fact, there is a correlation between the porosity of the built heritage stones and the moisture expansion; "the higher the micro-porosity the larger is the moisture swelling magnitude" (Ruedrich, Bartelsen, Dohrmann, & Siegesmund, 2011). From a physical point of view, when the building material of the envelope is porous, three main mechanisms explain the variation of the moisture content inside it. These mechanisms are the Hygroscopicity, the Condensation, and the Capillarity (Delgado & Freitas, 2013).

Accordingly, the expansion processes in the natural building stones, due to the changes of moisture content, contributes in their deterioration (Ruedrich et al., 2011). In addition to the temperature fluctuations inside porous stones that cause change in relative humidity within their pores, wetting-drying cycles also cause swelling- shrinkage cycles in some kinds of stones, especially sandstones (Camuffo, 2014).

1.2 Indoor environment control parameters

The applied studies and projects of indoor environment control within the conservation process of historical buildings show that the adjustments and repair works established in the conservation process to improve their IEQ depend on the architectural construction characteristics of these buildings and cannot be generalized as standards suitable to different contexts. The factors affecting IEQ include lighting, natural ventilation, thermal quality, and indoor air quality (Kamaruzzaman, Egbu, Zawawi, Karim, & Woon, 2015).

Since the mid-20th century, the set point of relative humidity and temperature followed the technical development of climate systems. Historic building fabrics require indoor climate control that depends on the hygrothermal properties of the envelope (Ankersmit & Stappers, 2017). It is important to determine the local heat and moisture of the building envelope and its internal spaces; hygrothermal interaction in the building envelope and thermal distribution inside a building is predicted by the mean of a virtual model implemented by several available software as CFD (Taffese, 2012), Wufi Plus (Ferreira, Freitas, & Ramos, 2014) and many more programs.

There are two approaches to modeling the thermal comfort. The first one is the codified model in several standards as ASHRAE 55, EN 15251 and ISO 7730 known as Fanger model or the PMV-PPD model, where PMV stands for the predicted mean vote and PPD means the predicted percentage of dissatisfied; it is used for design and practical assessment of comfort conditions and considered suitable for practical application (Carlucci, 2013). The other approach is the adaptive thermal comfort approach, which depends on occupants input regarding their indoor comfort; it uses data from field studies and appears to be subjective depending on thermal experience and interpretation of the occupants' interaction with their environment (Djongyang, Tchinda, & Njomo, 2010).

Table 1 shows the categories of thermal comfort depending on the ranges of PPD and PMV in English standard 1525; whereas, in ASHRAE Standard 55, these acceptable thermal conditions were assumed for a relative humidity of 50%, a metabolic rate of 1.2 met, and the mean radiant temperature should be equal to the air temperature. In addition, there is recommendation for the clothing insulation measured by 'clo.' While in summer it is equal to 0.5 clo, in winter it is equal to 0.9 clo (Djongyang et al., 2010).

Table 1: The four categories classifying the thermal comfort and IAQ
Reference: Standard (2007)

Category	Explanation	Fanger	Adaptive
		PPD (%)	PMV
I	High level of expectation and is recommended for spaces occupied by very sensitive and fragile persons with special requirements like handicapped, sick, very young children and elderly persons	<6	$-0.2 \leq PMV \leq +0.2$
II	Normal level of expectation and should be used for new buildings and renovations	≤ 10	$-0.5 \leq PMV \leq +0.5$
III	An acceptable, moderate level of expectation and may be used for existing buildings	≤ 15	$-0.7 \leq PMV \leq +0.7$
IV	Values outside the criteria for the above categories. This category should only be accepted for a limited part of the year	>15	$PMV < -0.7$ or $PMV > 0.7$

2. METHODOLOGY

To establish an adequate method to study the historical fabric hygrothermal behavior in the Mediterranean climate of the Lebanese coast, a case study is conducted in this paper. Centre de Lecture et d'animation Culturelle (CLAC) is an historical building from the 18th century, and it is situated in the old city of Tyre beside the archeological site of the ancient Byzantine Cathedral. For the last decade, the building was a ruin, until the Ministry of Culture gave the attention to the historical core of the town. The sandstone building was rehabilitated and adaptively reused as public library. This case is suitable for this study for the following considerations:

- The appropriate and controlled conservation process;
- The authenticity and integrity of the building fabric, although few modifications took place to create a service sub zone;
- Its non-residential function as public library imposes a special and defined occupancy parameters.

Due to several variables, the validation and the verification of the thermal comfort models seem to be difficult. However, using the building thermal simulation model, a parametric analysis allows quantifying the impact of different cooling system on the thermal comfort and on the hygrothermal behavior of the historical envelope.

The methodology followed in this paper to study the relation between the hygrothermal behavior of the building, the indoor climate control, and the thermal comfort of the occupant, is summarized in the following steps and illustrated in figure 1:

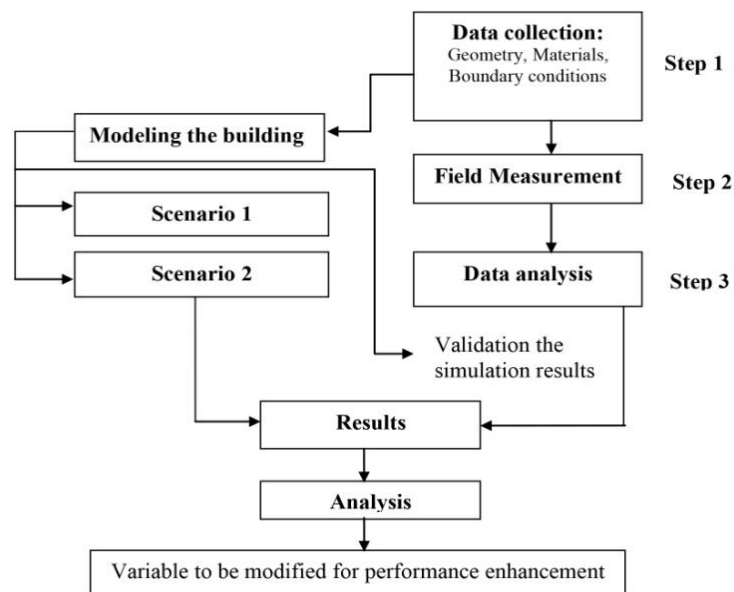


Figure 1 Methodology Flow Chart
Reference: the author

2.1 Step one

Building investigation covered the available data regarding occupants' load and behavior, clothing pattern and thermal sensation over daily time in the library. Although, other essential data were collected by the mean of architectural survey including thermal elements dimensions, specifications and physical properties of materials, to assign physical dimensions for the spaces of the study.

2.2 Step two

Field measurements were recorded for 11 consecutive days for the ambient indoor and outdoor climate temperature and relative humidity using The HOBO MX CO2 data logger, which records carbon dioxide, temperature, and relative humidity data in indoor environments.

Also, the measurements of the indoor surface temperature and surface relative humidity for all the thermal elements of the building were conducted using CA1244 thermo hygrometer. Also, a daily survey for the degree of thermal comfort satisfaction of the occupants using the survey format from appendix of standard DIN EN 15251:2007-08 (E) was documented.

2.3 Step three

The data collected from step two was analyzed to define the hygrothermal behavior of the building in the case of passive indoor climate control and to assess the occupant thermal comfort.

2.4 Step four

The building was modeled on Google Sketch up pro software to be used as 3D import in the whole building simulation software Wufi Plus, in order to:

- Evaluate the initial hygrothermal condition of the building and its thermal comfort to compare it with the onsite measurements and survey analysis.
- Assign new scenarios to upgrade the occupants' thermal comfort and indoor air quality: substitution of the glass in windows to decrease heat loss + shading the southern elevation + using mechanical ventilation in the summertime + using heaters in wintertime.

3. BUILDING PARAMETERS AND IEQ MODEL

The historical building tested in this paper is used as public library, which requires attention to the historic fabric of the building and the book collection displayed in it. A tolerance range of the indoor environment parameters is set in order to minimize the risk to the building and its contents. The indoor environment of a building is a complex entity affected by numerous uncontrollable variables that leads to spatial and episodic variations of the indoor environment parameters. Through monitoring data collection and data analysis, the hygrothermal behavior of the building can be synthesized and simulated in order to specify the intervention needed for its optimization (Corgnati, Fabi, & Filippi, 2008). The main parameters that affect the hygrothermal behavior of the building are classified as follows:

3.1 Building Geometry

Figure 2 shows the architectural drawing of the ground floor plan of the case study; the studied zone is marked as zone 1, which is the main reading hall, where two librarians are in charge. The measurement points on the outer sandstone walls, from both sides indoor and outdoor and on two levels from the Ground floor at 45 and 150 cm height respectively, were labeled in the shown figure.

The floor area is 172 square meters. Six fan-cooling units were installed at the time of the study, but the system was shut down in intent to apply passive ventilation to the building. The building height is 4.75 m.; the roof is composed of six sandstone cross vaults covered with gypsum plaster and paint from the inner side, and it is finished by an exposed concrete top layer from the outer side.

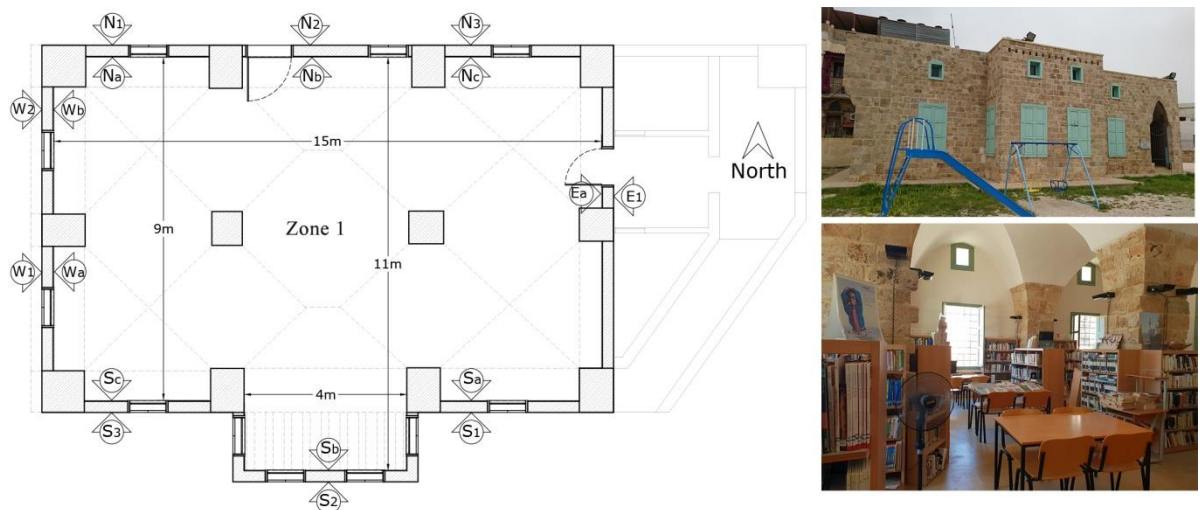


Figure 2- Architectural plan drawing for the CLAC historic building
Reference: the author

3.2 Envelope Material Properties

The physical properties of the envelope are taken from the Wufi plus material data to emulate the reality; this study focuses on the outer walls, which are defined as sandstone walls: plastered inside/exposed outside with the following parameters:

Bulk density: $\rho = 2224 \text{ kg/m}^3$, Porosity: 0.17, Specific heat capacity: $c = 771 \text{ J/kgK}$, Thermal conductivity: $\lambda = 1.684 \text{ W/mK}$, Water vapor diffusion resistance factor: 73.

Homogenous layers

Thermal resistance: $0.253 \text{ m}^2\text{K/W}$

Heat transfer coefficient (U-value): $2.363 \text{ W/m}^2\text{K}$

Thickness: 0.315 m



Figure 3 Cross-section scheme of sandstone wall that shows layers and thickness of the assembly
Reference: the author

3.3 Initial Boundary Conditions

Figures 4, 5 and 6 show the difference between the inner and outer surfaces of the envelope in terms of surface temperature and surface relative humidity. These graphs clarify the heat and moisture transfer differences between elevations according to the orientation of the building.

Due to direct solar radiation from the south, the southern elevation shows the highest heat transmission and poses serious threat of degradation damage caused by moisture expansion inside the wall.

The ambient temperature varied between 24 and 29 degree Celsius during the eleven consecutive days of the study, from the eight to eighteen May. Seven days were sunny days with 60 percent as ambient relative humidity, 3 were rainy days with high wind velocity, and the last day showed a drop in the value of the relative humidity to 30 percent with 28 degree Celsius as ambient temperature and dusty wind.

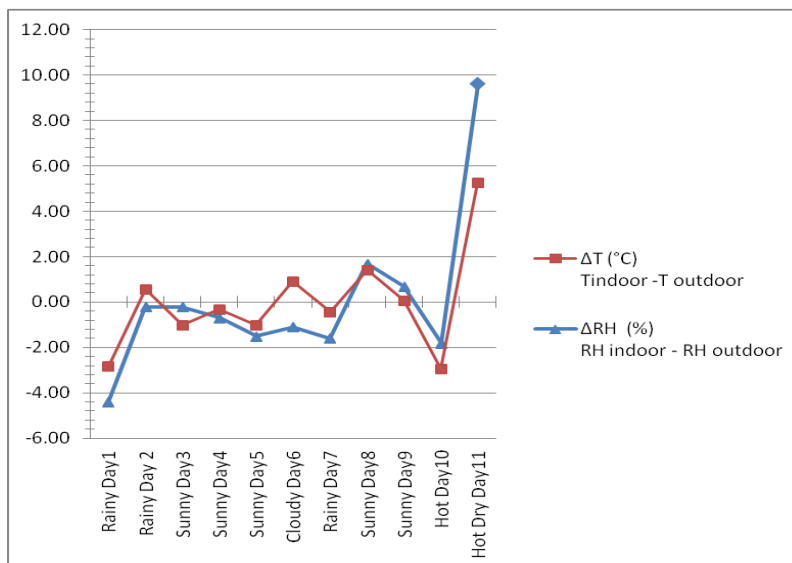


Figure 4 Difference between indoor and outdoor ambient Temperature and Relative Humidity
Reference: the author

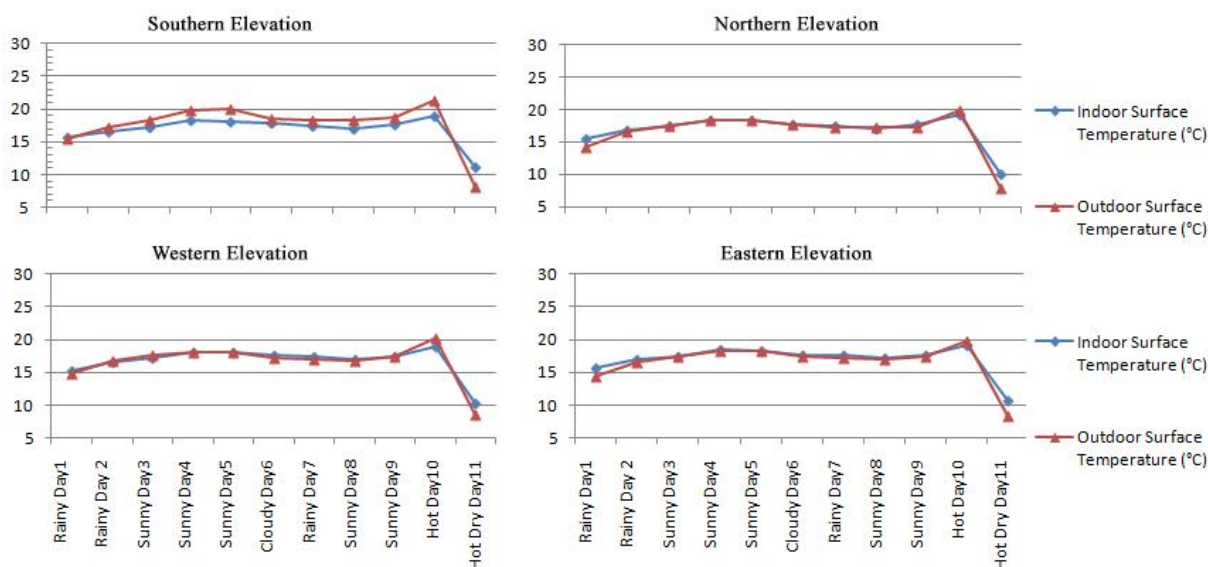


Figure 5 Surface Temperature measurements for inner and outer side of the envelope
Reference: the author

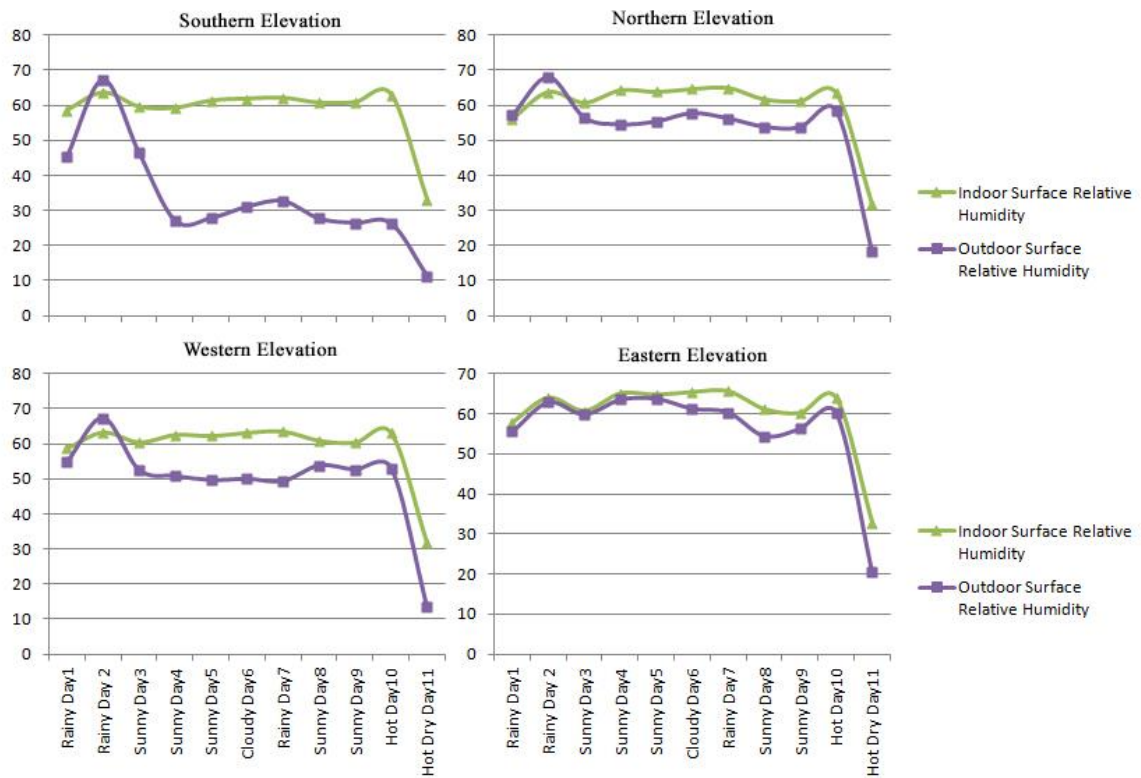


Figure 6 Surface Relative Humidity measurements for inner and outer side of the envelope
Reference: the author

The simulation model of the case study in its initial condition shows results validated by the field measurements, the moisture flux difference between inner and outer surface of the envelope has the same configuration as shown in figure 7.

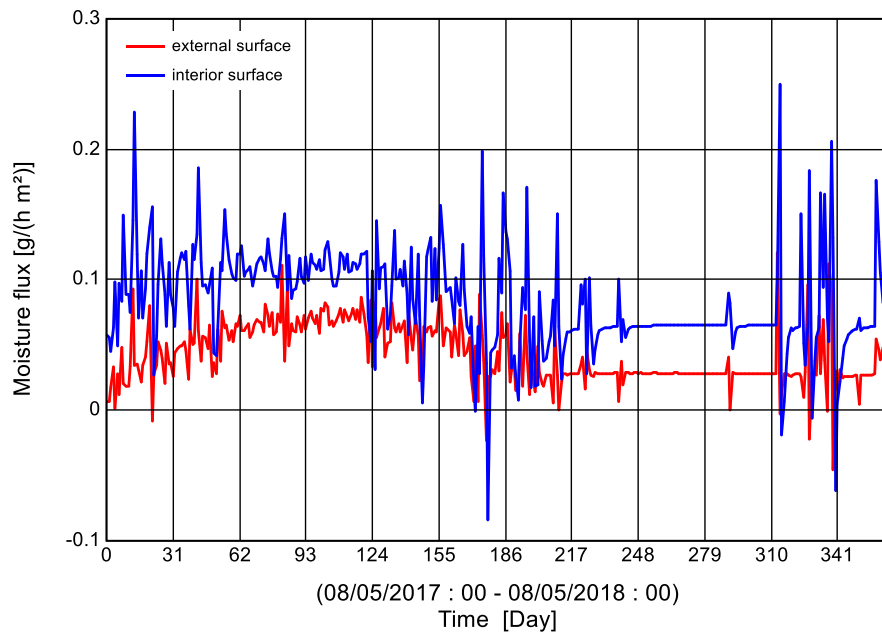


Figure 7 Configuration of moisture flux for one-year simulation in the initial conditions
Reference: experimental data by the author using Wufi plus V.3.1.1.0

3.4 Occupancy schedule

The occupancy internal load in the case study is defined during the day as follows: the library is open from 8am until 2pm, and two employers are present all the time; 15 adults and 20 minors could be added as maximum capacity in the reading hall. Each adult increases the CO2 by 59 g/h and increases the heat by an amount of 84 W as indicated by ASHRAE 55 and 62 standards.

The evaluation of the daily occupants' thermal comfort inspection showed that when the indoor relative humidity was higher than the outer one by 2 percent and more, they expressed their unpleasant thermal sensation despite the fact that the measured CO2 daily levels are in average of 400 ppm, which describes a very low pollutant indoor environment.

Table 1 shows the four categories adopted by the standard pr EN 15251:2006 used in Wufi plus to classify the IEQ.

3.5 Indoor environment and occupant modeling properties

Problems arose when the relative humidity increases and there is a need to attain the pleasant thermal comfort without using HVAC system. The final step of the study was to assign new scenarios to upgrade the occupants' thermal comfort and indoor air quality to the dynamic computer simulation applied on the CLAC historic building. Wufi plus performs a whole year simulation of the indoor environment and energy performance, which is calculating the temperature, ventilation rates, and CO2 concentration. The solution selected in this case was installing a mechanical ventilation system to change the ventilation rate in summertime in order to improve the thermal comfort of the occupants. Accordingly, the air exchange rate was increased to 0.4, and the minimum absolute humidity difference was settled to 0.4 g/m³ between indoor and outdoor. Then, the distribution of the temperatures between the four categories was calculated according to the standard (Standard, 2007).

The parameters of indoor environmental conditions and occupant properties used in thermal comfort simulation are as follow: Air speed=0.1 m/s, Relative Humidity=55 %, Metabolic Rate= 1.2 met

3.6 Results of simulation study

Tables 2 and 3 present the most important results of the simulation study; they show the indoor thermal comfort and the indoor air quality in the library. In the first case, the boundary conditions taken depend on natural ventilation only, and it points up an acceptable percentage of thermal comfort. While in table 2, a mechanical ventilation system was applied for three months in summer only, the percentage of thermal comfort slightly increased. However, comparing the PMV and PPD values in figure 8, there is an upgrading from category three to category two in the Fanger classification according to the standard 15251.

Table 2: IEQ in percentage of time in four categories defined in the standard pr EN 15251:2006, for CLAC building simulated from 21 June-21 September with natural ventilation
Reference: the author using Wufi plus V.3.1.1.0

Percentage	1	4		2	2
Thermal Environment	I	I		II	I
Percentage	2	1	1	4	
Indoor air Quality	I	I	II	I	

Table3 : Indoor Environment Quality in percentage of time in four categories defined in the standard pr EN 15251:2006, for CLAC building simulated from 21 June-21 September with mechanical ventilation
Reference: the author using Wufi plus V.3.1.1.0

Percentage	3	3	4		1
Thermal Environment	I	I	II		I
Percentage	5		2	3	
Indoor air Quality	I		I	I	

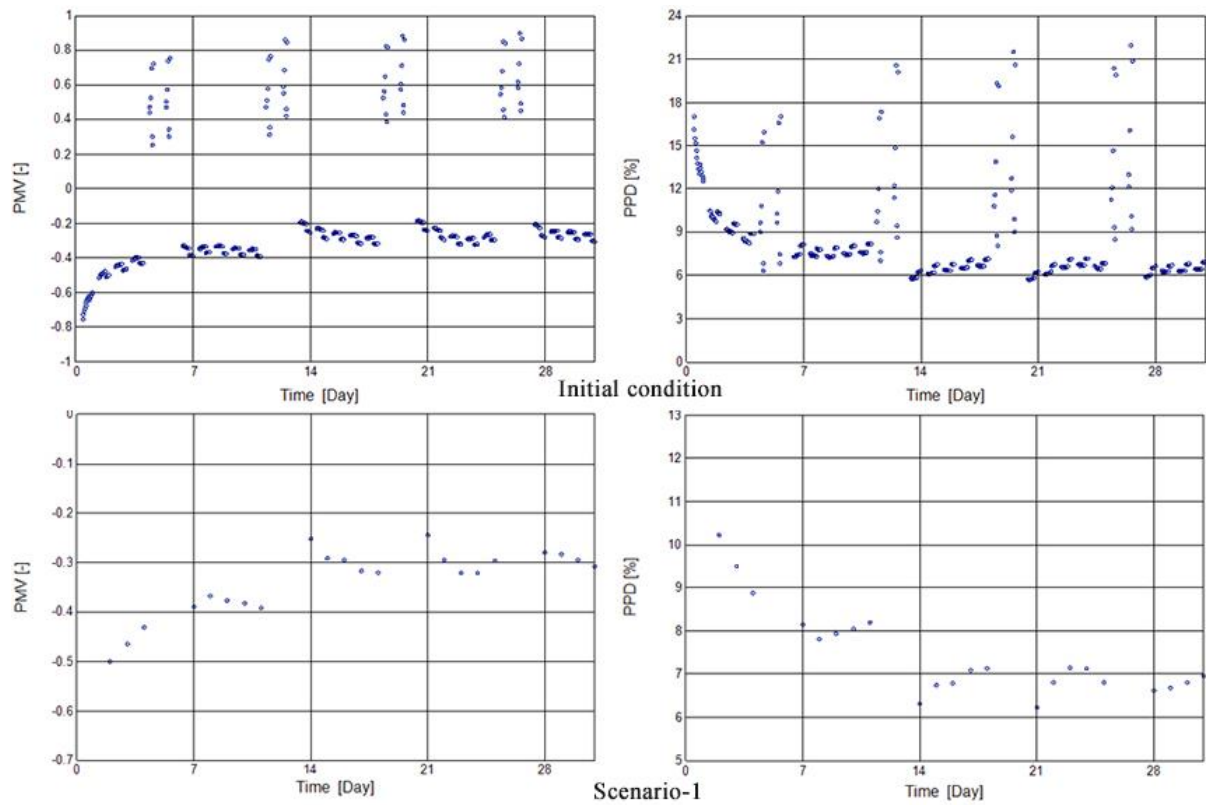


Figure 8 PMV and PPD predicted in the month of June
Reference: The author using Wufi plus V.3.1.1.0

In order to clarify the impact of scenario-1 on the hygrothermal behavior of the sandstone walls of the CLAC building, figure 9 demonstrates One-year simulation results for the hygrothermal behavior of the sandstone historic envelope. The long-term fluctuations of the RH values are obviously larger in the indoor climate control with mechanical ventilation system.

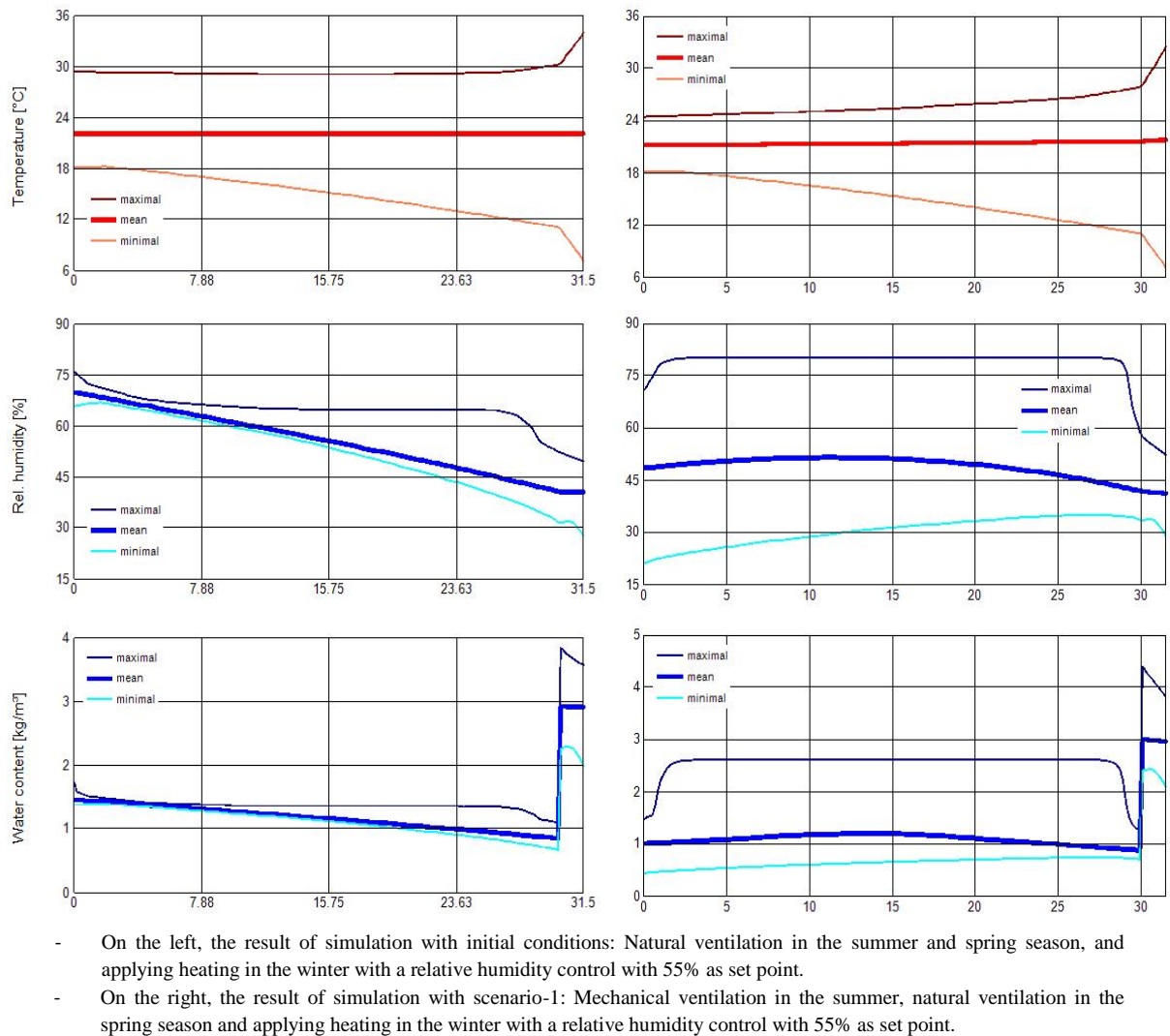


Figure 9 One-year simulation results for the hygrothermal behavior of the sandstone historic envelope
Reference: The author using Wufi plus V.3.1.1.0

1. CONCLUSIONS

The purpose of this work was to study how the enhancement of thermal comfort and indoor air quality directly affects the hygrothermal balance of historic porous materials of the envelope and how the introduction of mechanical ventilation system, which is considered low energy consumption application, can affect indoor thermal comfort.

The methodology followed in this study, which is comparing the occupants comfort from the Whole-building simulation results in two different scenarios, could be applied when making other alterations as changing type of glazing, adding trees to shade the southern and western elevation, which reduce the heat and moisture transfer, or adding shading devices.

This paper is a part of a PhD research conducted to study preventive conservation of built heritage asset in Lebanese coastal cities; further research will investigate improving performance of historic building by controlling its hygrothermal inertia by means of comparing case studies and using field measurements and building simulation tools.

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