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The Effect of Changing Construction Materials on Historical Building Performance in Case of Restoration - Case Study of Al-Nabi Jirjis Mosque in Old Mosul City

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ABSTRACT

Choosing appropriate construction materials in restoration processes of historical buildings particularly after wars or disasters is crucial in retaining the importance of such buildings and their distinct characteristics. This study is to explore how a change of original construction materials can influence energy efficiency and thermal comfort when rebuilding the destroyed historic buildings after the war in Old Mosul, where Al-Nabi Jrjis Mosque was selected as a case study. The study has adopted a comparative method between three simulation scenarios including two sets of new materials in addition to the original one. ENVI met analysis is used as a method to simulate the three cases. Results showed that the original set of materials (stone and plaster) has characterized by the best thermal efficiency compared by new materials used in the study. However, a set of hollow concrete with PVC strip used in one of the other scenarios revealed somehow good results, which therefore can be used as an acceptable alternative if the original materials are not available.

1. INTRODUCTION

The restoration of historic buildings presents a critical challenge in balancing architectural heritage preservation with the need for improved thermal performance. Inappropriate material choices in restoration can lead to significant thermal inefficiencies, moisture-related deterioration, and loss of historical integrity. For instance, the selecting appropriate energy efficiency measures for historic buildings is a complex optimization problem due to constraints such as building characteristics and historical value [1, 2].

After the destruction of most of the historic mosques in Mosul by the terrorist militia, that occupies the city during 2014-2017. After the liberation of the city, a broad restoration movement start immediately for these historic mosques. Traditional building materials are not used anymore. Furthermore, no more specialized craftsmen are available. Therefore, new available building materials were used to restore the mosques. The purpose of this research is to examine the environmental performance of the mosque, which is restored with different building materials from its traditional materials. A comparative study should be conducted with available building materials and traditional materials that are used in the same building.

The restoration of Al-Nabi Jirjis Mosque is vital for several reasons: First, preserving cultural heritage and protect the historical identity of Mosul, ensuring that future generations can connect with their rich past. Second, symbol of resilience which reveal preserving their cultural landmarks in the face of adversity. Third, promoting religious harmony and economic revitalization between Muslim and Christian communities highlights its role as a symbol of interfaith coexistence. Restoring the mosque can foster unity and reconciliation among diverse religious groups in the region. Forth, reconstructing the mosque can stimulate economic activity by attracting tourism and creating job opportunities, contributing to the broader recovery of Mosul [3, 4].

While previous researches have examined material durability and aesthetic compatibility, there remains a gap in systematically assessing the thermal impact of alternative construction materials in restoration projects. This study addresses this gap by evaluating how different material choices influence the thermal performance of historic buildings. The previous researches, often focuses on either energy efficiency or conservation aspects separately, our work integrates both factors to provide a comprehensive assessment.

Al-Nabi Jarjis Mosque is one of the historical mosques as the case study of this research [5]. The prayer hall is the main element of a mosque as shown in Figure 1, which serves as a place for worshipers to gather and perform obligatory prayers [6]. Alsaydan and Dhannoon [7] determined nine essential elements within the prayer hall. The exterior walls represent the richness in both levels (structure and form) [8]. In addition, the external walls represent the exterior envelope that controls the environmental aspects. The external walls of Al-Nabi Jarjis Mosque need to be restored to achieve the best environmental performance.

Restoration is based on the original geometric shape and building material properties carried out on a historical masonry building [9]. Environmental performance is an important feature of the building material that should be maintained in the retorted building. The thermal comfort determines the environmental performance of the building. The selection of appropriate materials not only affects the thermal comfort of indoor spaces but also plays a pivotal role in preserving structural integrity and authenticity. Therefore, understanding the thermal behavior of building materials in historic buildings and identifying effective strategies for enhancing their thermal comfort is imperative for sustainable heritage conservation efforts [10, 11].

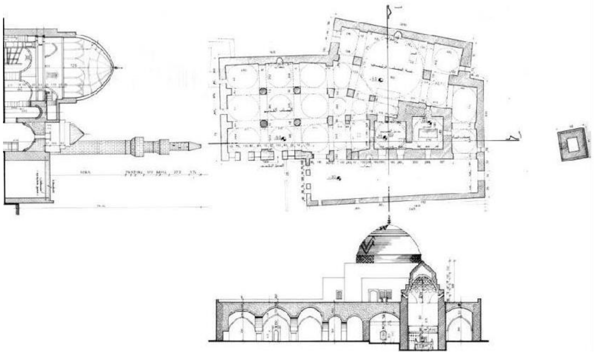

Figure 1. Plan and sections of Al-Nabi Jarjis Mosque [1]

In this context, the present study aims to investigate the thermal performance of building materials on the exterior walls of the prayer hall of Al-Nabi Jarjis Mosque. By analyzing, the thermal comfort of alternative building materials and comparing these materials with the traditional building materials used in the original structure. In summary, the research seeks to explore the intricate relationship between building materials and thermal comfort in historic buildings, with the ultimate goal of informing evidence-based conservation and restoration practices and enhancing the resilience and sustainability of the built heritage for future generations.

Al-Nabi Jirjis Mosque was completely demolished on 25 July 2014 by extremist militia (see Figure 2). Therefore, after the liberation of Mosul and the city was secured completely, a restoration of the mosque was started by a non-governmental organization called (Jamaea Feal Alkhairaat). The traditional building materials not be used in the city anymore and the expert builders vanished [12, 13]. Therefore, new building materials were used in the restoration. A need for a comparative study of the thermal comfort between two cases of building materials; the traditional materials and the used materials in the restoration (see Figure 3).

A

B

Figure 2. Plan of restoration work

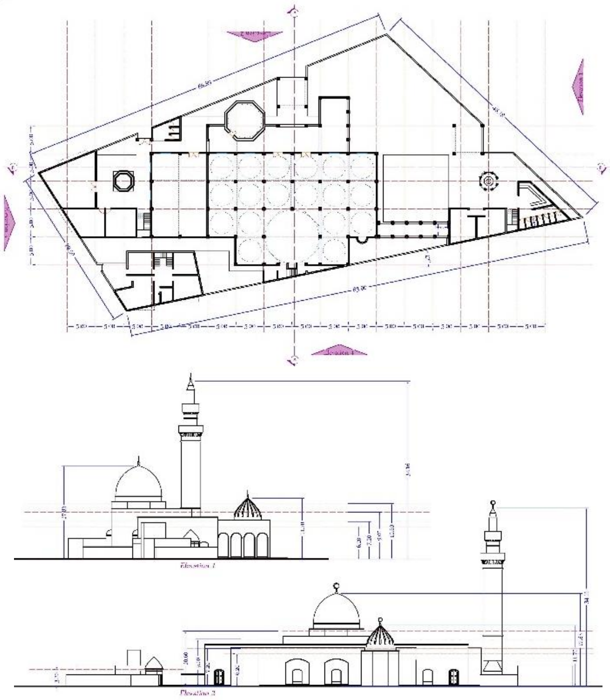

Figure 3. Plan of restoration work

2. METHODS

To meet the aim of this research, this study has followed a comparative simulation method between three scenarios related to changing the construction materials of the selected case study of building walls to discover how each set of materials can affect the thermal comfort of the interior space. For this purpose, ENVI-met analysis is applied to three sets of the building materials forming the building walls. ENVI-met is a comprehensive three-dimensional microclimate modeling software used to simulate interactions between urban surfaces, vegetation, and atmospheric conditions. It is particularly effective in assessing the thermal performance of buildings and urban areas. By using ENVI-met, users define Building geometries and Materials properties, including thermal conductivity, specific heat capacity, and albedo. ENVI-met dynamically calculates surface and wall temperatures for each facade and roof element, accommodating up to three material layers [14, 15]. ENVI-met simulations are instrumental in assessing thermal comfort within urban environments by analyzing temperature variations and their implications. Here's a detailed analysis of simulation results across different scenarios, like Air Temperature (Ta). ENVI-met models diurnal air temperature fluctuations, capturing how urban configurations influence local temperatures. For instance, simulations have demonstrated that courtyards with higher Sky View Factors (SVF) experience greater daytime heating due to increased solar exposure, leading to elevated air temperatures [16].

The limitations of the study of Al-Nabi Jirjis Mosque, a single historic building in Mosul, may limit the breadth of the results. While focusing on a specific building allows for a detailed and in-depth analysis of the thermal performance and material choices in its restoration, the findings may not apply universally to other buildings, especially those with different architectural designs, building materials, or uses.

Importance of Considering the thermal properties of materials in historic building restoration play a crucial role in the energy efficiency and sustainability of any building, particularly in the context of historic building restoration. In these projects, it is essential to balance preserving cultural heritage with improving the thermal performance of the building. Understanding and considering the thermal properties of materials can lead to numerous benefits, including energy savings, improved comfort, and the conservation of resources [17, 18]. Restoring a historic building is not just about improving energy performance; it also involves maintaining its architectural integrity. The challenge lies in selecting modern materials that improve energy efficiency without altering the aesthetic value or historical features of the building [19, 20].

The first case included Masonry walls where stone and plaster as a blinder are used, which represents the original case of the building (see Figure 4). In the second scenario, walls consisting of two strips of 15 cm thickness for each built by solid concrete blocks and cement mortar, with a 5 cm-thickness air separating layer in between used (see Figure 5). The third case is applied on walls comprising two layers, each built by hollow concrete pieces of 15 cm- thickness with a Styrofoam board of 5 cm- thickness as an insulation material in between (see Figure 6). During each simulation case, a comparison of temperature between indoor and outdoor space is made to find out the thermal efficiency of the selected materials. Finally, a comparison between the three cases is conducted to discover which set of materials of the exterior walls can provide better thermal comfort for the indoor space when restoring a destroyed historic building.

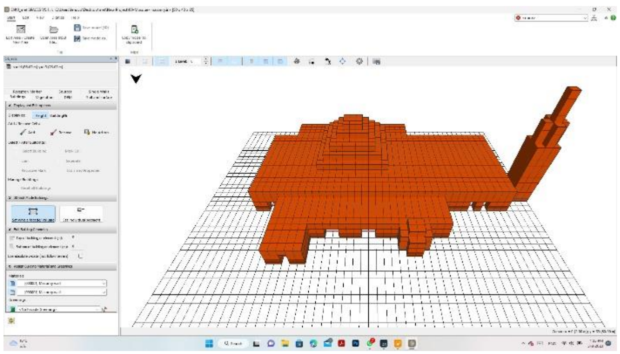

Figure 4. First case included Masonry walls where stone and plaster as a blinder is used, which represents the original case of the building

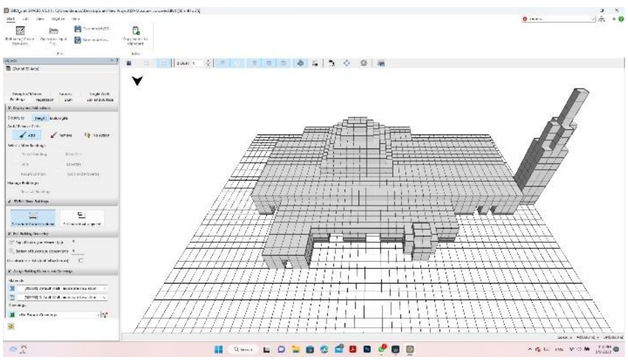

Figure 5. The second case, walls consisting of two strips of 15 cm thickness for each built by solid concrete blocks and cement mortar, with a 5 cm- thickness air separating layer in between

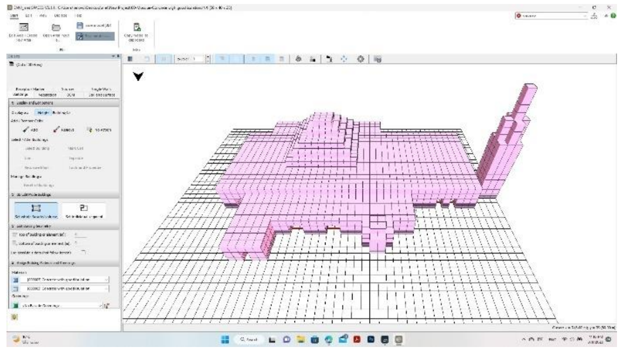

Figure 6. The third case is applied on walls comprising of two layers, each is built by hollow concrete pieces of 15 cm- thickness with a Styrofoam board of 5 cm- thickness as an insulation material in between

These three simulations were conducted through climatic data of the hottest day in the summer of 15-7-2022 .

The maximum temperature in old Mosul city is (15 July at 16:00). Thus, the Simulation test will be at 15:00, 16:00, and 17:00 than the present maximum temperature. As shown in the table below (see Figure 7).

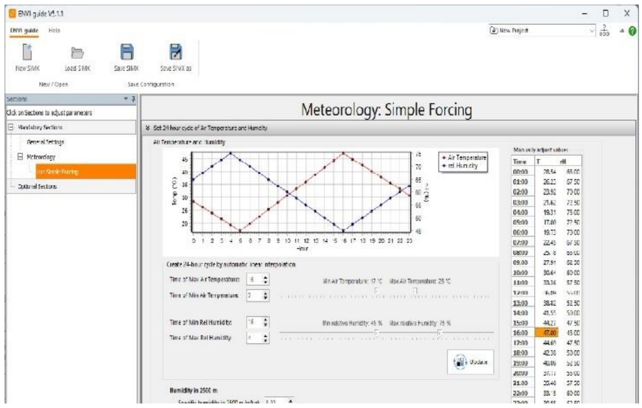

Figure 7. Simulation test in 15:00, 16:00, and 17:00 than present maximum temperature

3. RESULT AND DISCUSSION

The main results of the empirical study, as shown in Table 1, indicate a clear variation in the thermal behavior of the historic building depending on the type of materials used during the reconstruction or maintenance process. In the first case, when using plaster and stone as original building materials for the walls with a thickness of (40-60 cm), acceptable results are achieved in terms of the thermal behavior of the building's interior. We observe lower temperatures inside the building during the period (15:00 – 17:00), ranging between (27-38 degrees). It is noteworthy that the temperatures approach only 40 degrees at the peak hour (15:00), as illustrated in the Figures 8, 9, 10.

In the second case, when using ordinary concrete material with the presence of air insulation between the two layers of the concrete wall (20 cm concrete, 5 cm air, 20 cm concrete), acceptable results in terms of thermal behavior are not achieved. Higher temperatures inside the building are recorded during the period (15:00 – 17:00), ranging between (40-43 degrees), which are unsuitable temperatures for indoor spaces. This is illustrated in the Figures 11, 12, 13.

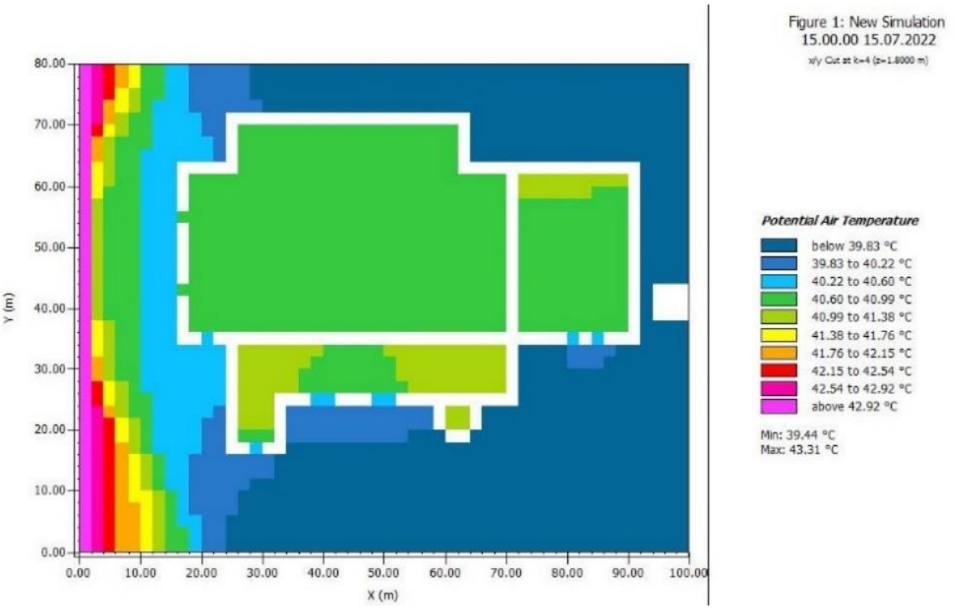

Figure 8. Temperatures inside the building at 15:00 on 15/07/2022, using plaster and stone as the original building materials

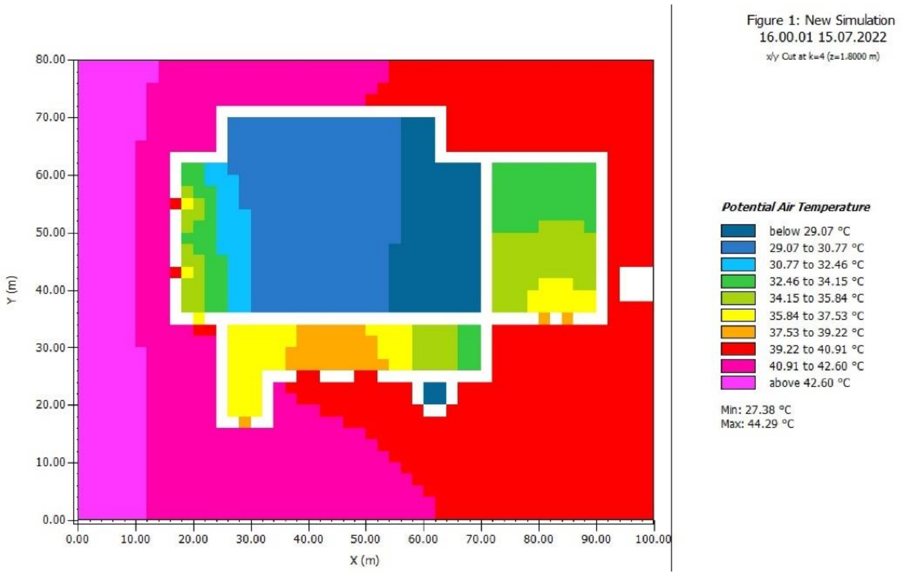

Figure 9. Temperatures inside the building at 16:00 on 15/07/2022, using plaster and stone as the original building materials

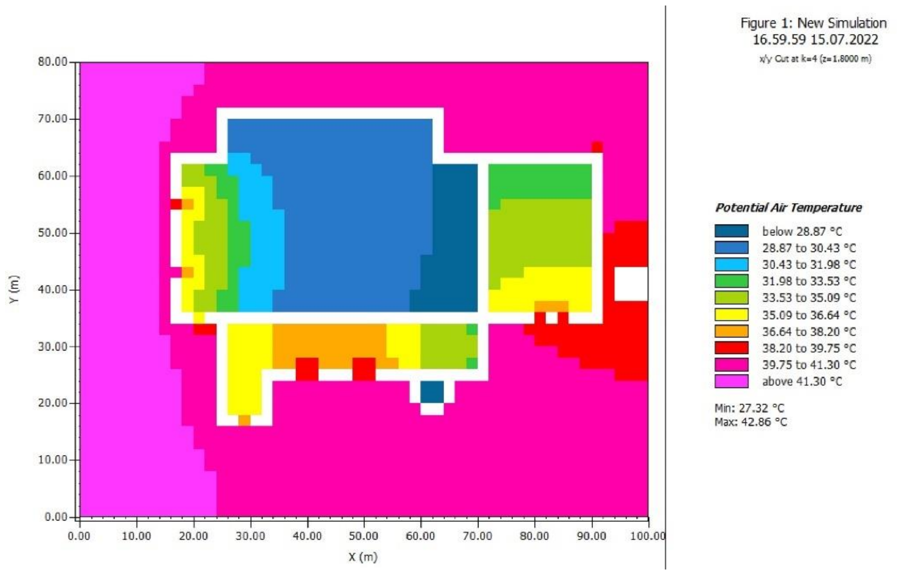

Figure 10. Temperatures inside the building at 17:00 on 15/07/2022, using plaster and stone as the original building materials

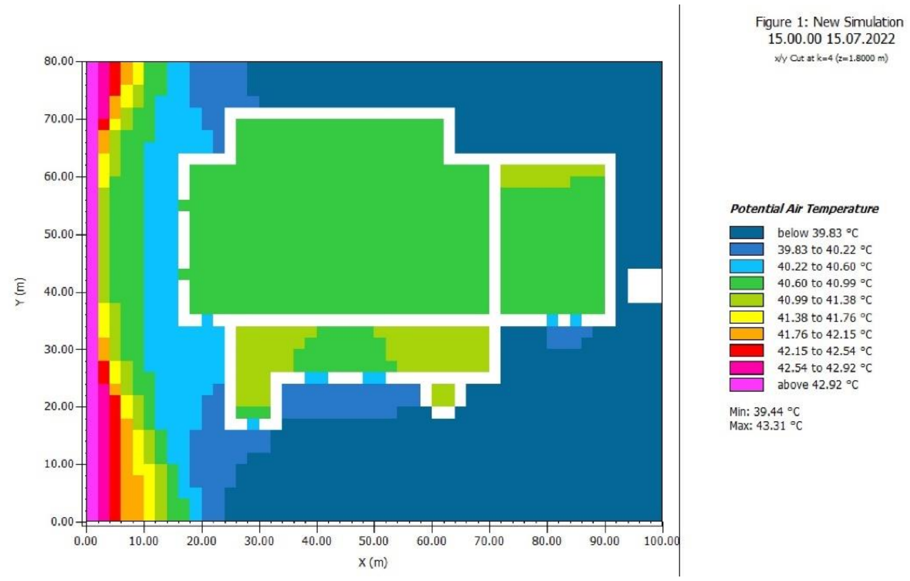

Figure 11. Temperatures inside the building at 15:00 on 15/07/2022, using dual concrete material with air insulation

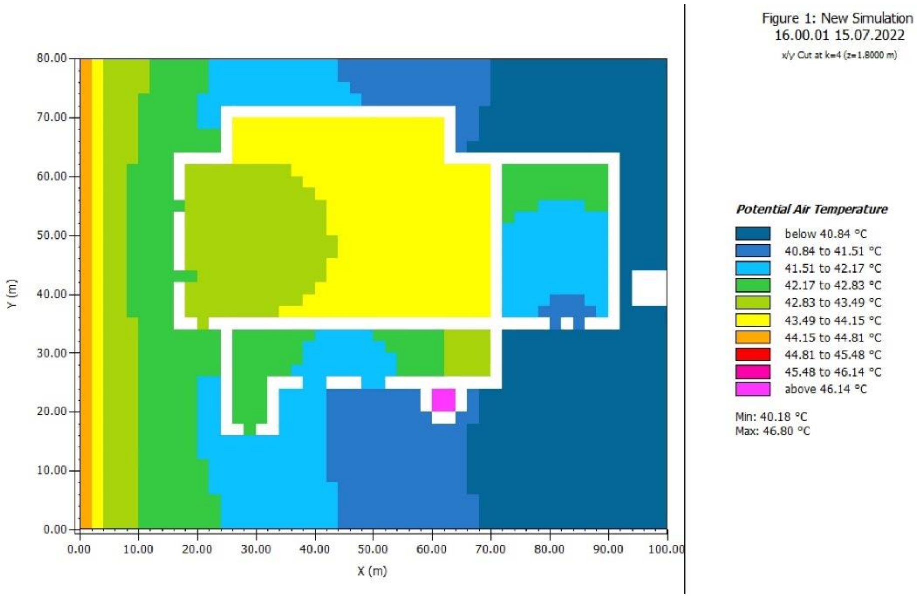

Figure 12. Temperatures inside the building at 16:00 on 15/07/2022, using dual concrete material with air insulation

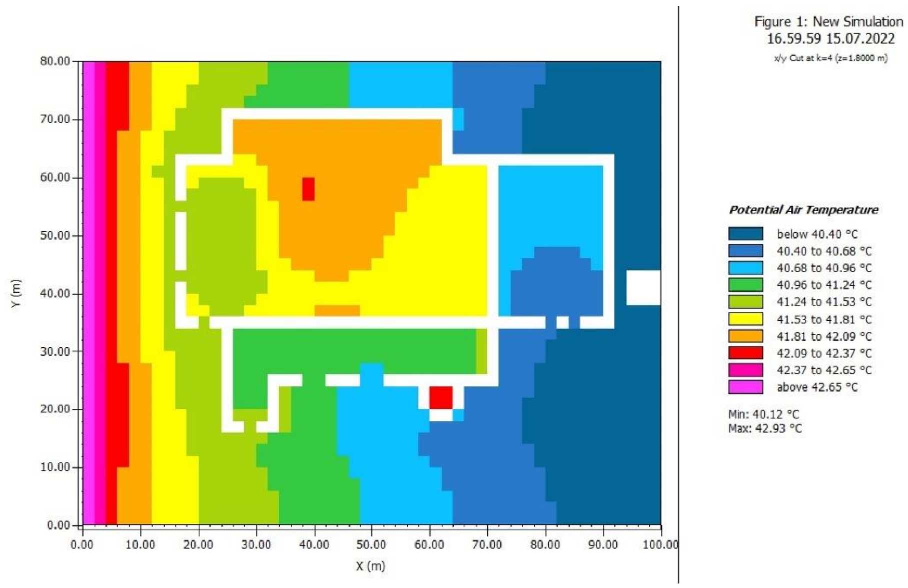

Figure 13. Temperatures inside the building at 17:00 on 15/07/2022, using dual concrete material with air insulation

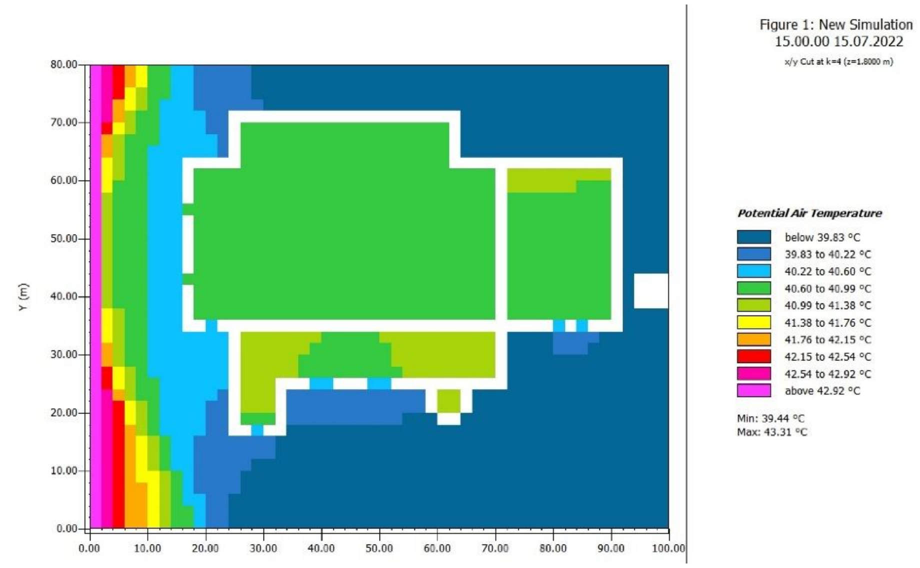

Figure 14. Temperatures inside the building at 15:00 on 15/07/2022, using dual hollow concrete material with good insulation

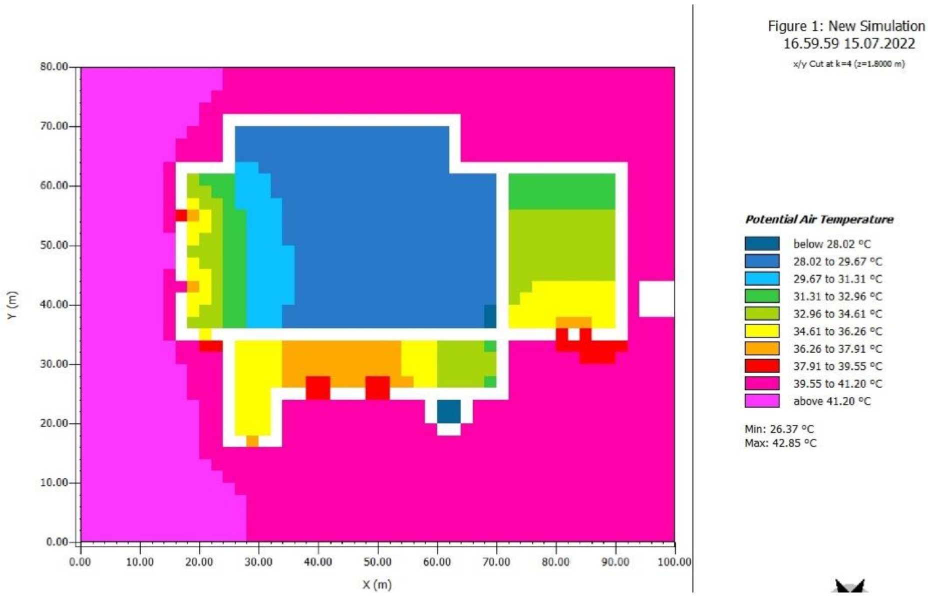

Figure 15. Temperatures inside the building at 16:00 on 15/07/2022, using dual hollow concrete material with good insulation

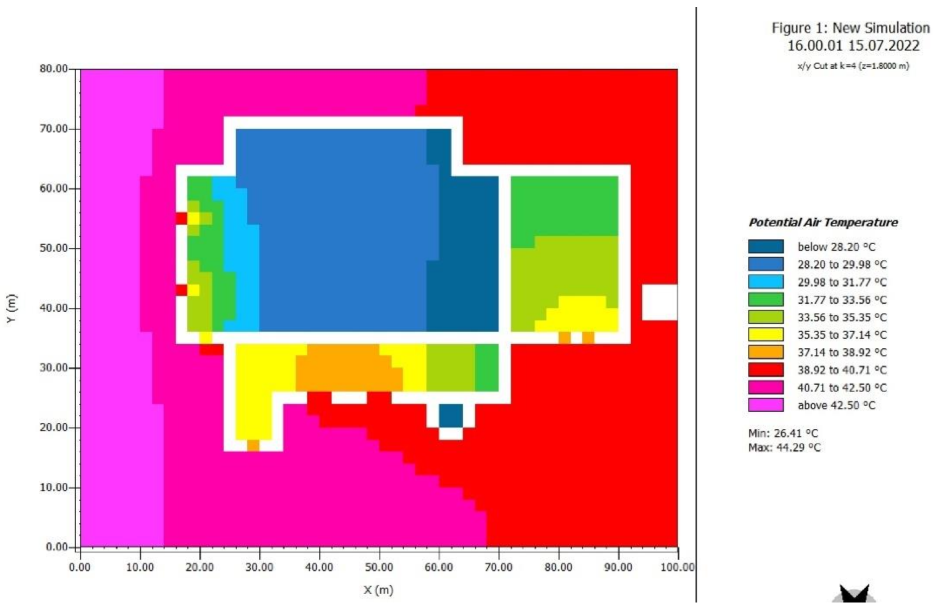

Figure 16. Temperatures inside the building at 17:00 on 15/07/2022, using dual hollow concrete material with good insulation

Table 1. The results of the three simulation cases of walls of mosque

	Materials	Thickness	Results Time	(Temperature)
Case 1	Masonry wall (stone wall with plaster (original material)	(40-60) cm	15:00	27-38
			16:00 -17:00	39
Case 2	Concrete wall material with air as an insulator	(concrete 20 cm, insulation 5 cm, concrete 20 cm)	15:00 -17:00	40-43
Case 3	Concrete hollow wall material with good insulator	(hollow concrete 20 cm, insulation 5 cm, hollow concrete 20 cm)	15:00	40
			15:00 -17:00	28-39

As for the third case, when using hollow concrete material with good thermal insulation between the two layers of the concrete wall (20 cm concrete, 5 cm good insulation, 20 cm concrete), the results were somewhat acceptable. Temperature recordings inside the building during the period (15:00) approach 40 degrees, while between the times (16:00 – 17:00), recorded temperatures (27-38 degrees) are acceptable and suitable for indoor spaces. These results are comparable to those obtained using original building materials, as shown in Figures 14, 15, 16.

The results of the three cases above are represented in Table 1.

4. CONCLUSION

According to the results of the study, used construction materials play a major role in thermal performance in such historical structures during reconstruction or maintenance.

The use of original building materials such as stone and plaster in masonry walls demonstrates acceptable thermal performance, with lower temperatures recorded inside the mosque during peak hours. However, substituting these materials with concrete, even with air insulation, leads to higher indoor temperatures, which are unsuitable for comfortable indoor spaces.

On the other hand, employing two-layer hollow concrete material in masonry walls, with good thermal insulation between them yields somewhat acceptable results, comparable to those achieved with original building materials. This indicates the importance of selecting appropriate construction materials with adequate thermal insulation properties to ensure the thermal comfort of indoor spaces in historic buildings. The results of the three cases above are represented in Table 1.

The study reveals clear changes in the building's thermal efficiency due to the alteration of construction materials during the maintenance process of the historic building. The research emphasizes the necessity of using original materials whenever possible to preserve the building's thermal efficiency. Alternatively, at least, contemporary materials with good characteristics can be used to maintain good performance inside the building or its thermal efficiency.

In all, comparative studies of the thermal performance of historic buildings before and after restoration could shed light on the effectiveness of different restoration techniques and materials. By evaluating the impact of interventions of construction materials over time, researchers can identify best practices for preserving thermal comfort while maintaining historical integrity.

In the context of historic building restoration, considering the thermal properties of materials is essential for achieving energy efficiency, enhancing thermal comfort, and promoting sustainability. Proper material selection can improve indoor climate control, reduce energy consumption, and ensure that historic buildings remain resilient and adaptable to modern-day environmental challenges. By carefully balancing the need for thermal improvement with the preservation of a building's historical and architectural integrity, we can help extend the lifespan of these cultural assets while contributing to a more sustainable built environment.

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NOMENCLATURE

ENVI-met	Enabling Sustainable Urban Simulation and Analysis
Ta	Air Temperature
max	Maximum temperature, C
k	Thermal conductivity, $W.m^{-1}. K^{-1}$