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The Effect of Improper Restorations on Thermal Load of Traditional Houses of Yazd (Case-studies: Oloomi and Tehrani houses)

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Abstract

● Problem explaination: Traditional houses of Yazd are a valuable cultural heritage, which constitute the main part of the historic fabric of this city.

These buildings are as a manifestation of the history, civilization, urbanization, culture and identity of Yazd historic city, but - unfortunately - many of them have been evacuated and demolished over the time. Conservation, restoration and rehabilitation of this precious treasure, not only provide the opportunity to review and understand the values of these works but also it will transfer these values to future generations.

● Purpose of the paper: This paper is to study and identify common improper interventions in the city of Yazd’s traditional houses and examine the technical and functional damages caused by undesirable restorations specifically in relation to climatic conditions.

● Methodology, case-studies and the research structure: The research method in this paper is “descriptive-analytical” and based on library resources and field observations. The research methodology is of experimental and simulation studies too. This paper reviews the case studies in the city of Yazd, which includes two examples of historic houses in the historic fabric of Yazd.

● The concise results: It shows that incorrect restorations without the support of knowledge and scientific approach will have bad effects on climatic conditions in historic houses and will increase the thermal load and the costs of set the environmental conditions of the buildings at the time of utilization. The results clearly show that these kinds of interventions increase the thermal load of buildings and reduce the climatic desirability of them.

Keywords

Restoration, Traditional Houses of Yazd, Thermal Load, Oloomi House, Tehrani House, Energy Plus.

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Introduction

Traditional houses are the reflection of our ancestors' life. They carry the well-founded historic, cultural and social values, that have been based on a long sequence of experiences and trials. Today the traditional houses in historic cities such as Yazd are facing evacuation and demolishment. This can gradually lead to the evacuation and loss of dynamism in the historic fabric of Yazd. By evacuation and demolishment of the traditional houses and historic fabric, their carried historic, cultural and social values will probably be even more endangered. To prevent the progression of demolishment and evacuation it is essential to renovate and revitalize the historic houses in order to bring back life to the historic fabric of Yazd again. Although some procedures have been taken to renovate and revitalize these houses, but the evidence show that in many cases, quality has been overlooked. Sometimes the assigned function and occupation is not worthy and suitable for the house. This kind of restoration, that is not technical, not only leads to denial and decay of these values, but will also cause un-repairable damages in structural, landscape, functional and conceptual attributes of historical houses.

Understanding the different aspects of damage from these types of restorations is the first step for confronting the damage. Some of the damages due to undesirable restorations are sensible by the users and some are not easily sensed or recognized. The article is aiming to explore the question that what is the impact of the restorations of this kind on the thermal load of the historic houses. The aim of this study is achieved by calculating the thermal load of the spaces in traditional houses before and after three common restoration actions. We will introduce a portion of the functional damages that influence the not-easily-sensed climatic conditions in traditional houses. This article has studied examples of these restoration actions in Tehrani and Oloomi house by applying energy simulation software.

Research method

"The research method in this paper is "descriptive-analytical" and based on library resources and field observations. The research methodology consists of experimental and simulation studies too"; which examines three specific variables effective on thermal load of the selected buildings. The three variables are: omitting the "wind tower", presence of infiltration and permanent raising of canvas structure on the courtyard. The testing unit considered is simulation of the spaces in historic houses before and after restoration using "Energy-plus" software, version 8.1 (Groat and Wang). "Energy-plus" is one of the most reliable software among building energy stimulation software. The validity of this software was examined in the article "The cooling and heating potentials of an earth tube system in buildings". In this research, using "Energy-plus" software, stimulation and calculations have been done on the cooling potential of an earth tube system. The results on this stimulation have (fairly) matched the experimental results (Lee & Strand, 2008). The article titled "Validation of Energy Plus thermal simulation of a double skin naturally and mechanically ventilated test cell" has also evaluated the validation of Energy Plus software for thermal simulation on a building with double skin cladding system. finally with comparing the experimental results with the results from Energy Plus output it concludes that Energy plus software is a valid software for building energy simulation (Mateus, Pinto, da Graca, 2014).

This software can calculate the thermal load of buildings according to a predefined thermal comfort zone, based on the characteristics of the buildings, including physical arrangement, users, building, mechanical and electrical systems and annual weather data of the building location.

To calculate the thermal load, energy plus uses heat balance algorithm based on ASHREA formula. below is how each item of solar radiation, infiltration and "Badgir" is calculated:

A) Solar Radiation

Based on the Yazd meteorological information, hourly collected by the synoptic weather station located in this city, the solar radiation intensity information was collected. These information were gathered in year 2011 by the research center of the Ministry of Road, Housing and Urban development. And it was published by the United States Department of Energy website in the form of an energy plus file.

B) Infiltration

For calculating Infiltration flow rate (Inf) energy plus applies different method, but in our case according to the available information we applied the below algorithm:

$$Inf = (F_{Sch})\frac{A_L}{1000}\sqrt{C_s\Delta T + C_w(WS)^2}$$

C) "Badgir"

For Calculating Velocity of outlet air (Vout), the Software firstly calculates the velocity of the outlet-air as a function of the Height of the "Badgir" (H) and Wind Speed (WS), according to:

$$V_{out} = 0.7H^{0.5} + 0.47(WS - 1)$$

Then volume of outlet air (Q) from the "Badgir" is calculated as below:

$$Q_{estimate} = A.V_{out}$$

In this Formula (A) is the Area for "Badgir" outlet-air opening or vent. If moisture is added to the air inside the "Badgir" air passage or at the openings, the Exit humidity ratio (wout) is calculated based on the below equation of the conservation of mass.

$$\omega_{in}(\dot{m}_{air} + \dot{m}_{water}) = \omega_{out}.\dot{m}_{air}$$

In the above equation (win) is Inlet air humidity ratio, (ṁwater) and (ṁair) are the molar mass of water and vapor in the air.

After calculating the outlet air humidity ratio, for calculating the air's specific mass (density) (rair) and air's specific heat (cp,air) psychometric functions available in EnergyPlus, are used.

The software uses the data on: space dimensions and proportions, neighboring and adjacencies and wall thickness and material, in the analyzing process of each (Simulation) model. In our model the wall and roof material are Adobe and the roofs are considered "Doposh" or double layered and air insulated. The air insulation thickness was considered equal to the mean distance between the two layers of roofing (Table 1).

The calculated comfort zone using the "CBE Comfort Tool", based on metabolic rate (Met 1) and clothing Rate (Clo 1.1) is 20-25 degree Celsius. When the temperature drops below 20 or exceeds 25 degrees Celsius the software calculates the required energy to reach the comfort zoon. The output of this calculation is the monthly thermal load in joules, before and after restoration. The results are more clear when expressed in kilowatt per hour.

The Research Background

Criticism and evaluation are the requirements of process improvement and achieving the desired quality. This type of critical and evaluative research is less common in the field of restoration and conservation of historic buildings compared to architecture and urban design.

The article named "Conservation and Development in Iran" (Hanachi, Mahmmodinejad, Diba, 1386) studies the interactions and contrast between conservation and development in the contemporary restorations in Iran. Concerning the damage due to developments, this article expresses that "In some approaches based on development, a precipitancy accompanied by inattention to environmental, cultural, social and humanitarian infrastructure has been observed. This all leads to destruction in the cultural heritage and valuable urban fabric."

In the proceeding of the first National Conference of Understanding and Introducing the Advantages and Potentialities of Revitalization and Exploitation of Historic Places, one of the pathological and critical points of view expressed in this conference was an article named "Persian Heritage in Coma" (Owlia,

.Table 1. Properties of Adobe. Mazria, 1979: 81

0.85	(W/m-K) Heat conductivity
1760	(Kg/m^3) Density
1000	(J/Kg-K) Specific heat

2010). This article uses the word devitalization in opposite to revitalization to express that not only incorrect restorations do not lead to revitalization of Persian heritage but also lead to the perishment of cultural values. Therefore, this article observes the Persian heritage to be in coma.

Another article in this proceeding is "The Influence of revitalization and repurposing buildings on the process of contemporization and revitalization of the historic urban fabric" (Rezai & Vasagh, 2010). This article uses a questionnaire for studying and surveying the restorations and revitalization projects in Fahadan neighborhood in Yazd. The Tehrani house project is among the studied samples.

Regarding the topic of energy simulation, most researches are mainly done on examples of contemporary designed buildings. This paper is one of the few, if not the only published research on energy simulation and thermal load calculation of historic buildings. But there have been articles written on the research done on the subject of thermal load, Badgirs (wind catchers), solar radiation and infiltration, simulated and calculated by Energy-Plus software. Below are some examples of such articles. "A Study of Solar Chimney Assisted Wind Tower System for Natural Ventilation in Buildings" is the title of an article which has applied Energy-Plus software to numerically model a solar chimney assisted by wind catcher system (Banzel & others, 1994). Another article named "Experimental and Numerical Study on Natural Ventilation Performance of Various Multi-Opening Wind Catchers" has studied and analyzed the behavior and circulation of air in various multi-opening wind catchers both using (air) circulation or flow simulation software and experimentation (Montazeri, 2011). The article "Natural Ventilation Characteristics of One-sided Wind Catchers: Experimental and Analytical Evaluation" has studied the behavior of one-sided wind catchers in the region of Yazd by simulating the air flow and placing the model in wind tunnels (Dehghan, Kazemi Esfeh & Dehghan Manshadi, 2013). The article "Enhancement of Natural Ventilation in Buildings Using a Thermal Chimney" has studied the influence of the below factors on the performance of the thermal chimney in three different cities with three different climates of cold, moderate and hot. The studied factors are: height, solar absorption of the absorber wall, solar transmittance of glass cover and the empty gap between the glass and the absorber wall. The influence of the thermal chimney on the thermal load of the building was also studied (Lee & Strand, 2009).

The article "Solar Chimney for lightweight building in temperate and hot climates, Exploring the Use of Phase-change Materials for Performance Improvement" uses simulation models and aims to find the most appropriate type of phase-changing thermal mass material for Trombe wall, to be used in five different cities in Australia (Fiorito, 2012). In the article "Energy Benchmarking for Residential Buildings" the influence of building form on the thermal load has been tested. In this research the amount of solar radiation is a key parameter in the simulations (Tereci, Ozkan, Tahira, Eicker, 2013).

In the article "Green Roofs; Building Energy Savings and the Potential for Retrofit", the influence of green roofs on the thermal load of the building has been studied (Casleton, Stovin, Beck and Davison, 2010). Finally, the article " Exploring and Studying the Influence of Geometric form of Chalipa on the Cooling Load of Traditional Houses in Yazd" has calculated the cooling load of the houses influenced by Chalipa, by applying Energy-plus software (Kameli, Saket Yazdi and Omidvari, 2016).

Identifying Undesirable Restorations in Traditional Houses of Yazd

The restoration of a historic building is an action taken with the aim to increase the life span of the building and to conserve its values. Recognition of the values and potentialities of these buildings is indeed influential on the type or state of attitude and manner of operation and quality of restorations. It is important to consider that if restoration is done with insufficient study and knowledge, or if the restoration operation lacks artistic and technical details and principles, it will not only fail to protect and conserve the values of the building but this restoration will be harmful. This process will result in the transubstantiation of the restoration's nature and perhaps, a contrary meaning to restoration and revitalization.

The low quality restorations of Yazd traditional houses in the recent decades, is a sign of an appearance of a new approach in restoration. The fundamental goal in this attitude, instead of conversation of cultural heritage, is exploitation and maximum profit making from cultural heritage for groups or individuals. Therefore, this attitude has led to assignment of profit making and new functions such as hotels and restaurant to these buildings. The actions taken for restorations are (perhaps) not towards the conversation of the building values, but are for overtaking in the rivalry of profit making. A variety of unprincipled and nontechnical actions have taken place in these buildings. A few examples of these actions will be explored in this article. Omitting Badgir (wind catcher) from the cycle of air circulation of summer -used spaces is one example. According to the fact that repairing and rebuilding of a damaged Badgir is a costly process, therefore in the stated types of restoration it is preferred to block the vent or opening of the Badgir and omit the Badgir from the air circulation system. While Badgir can reduce the temperature, to become closer to the comfort zone, without extra energy cost. Therefore, omitting Badgir can damage the architecture, views and values of the building and also the functionality of the building.

Another common action of the stated nature is, unsuitable replacement and repairing of the wooden doors. These physical components are generally more vulnerable than other components of the building. This is due to their exposure to weathering factors and their material which is wood, and its utilization which is different from fully fixed elements. Replacing the wooden doors is preferred due to its high cost of restoration. In the process of making a new opening there are many technicalities, issues and factors that need to be taken into consideration (other than choosing the appropriate type of wood). But in most cases they are overlooked due to lack of knowledge or to decrease the costs. This will pose harm on the originality, functionality and life spam of the building. An example of the functional damages of making unsuitable openings are: the appearance of split and gap between the pair of doors and their frame. This will cause air infiltration in the buildings. The third common action popular in the restorations of Yazd traditional houses is permanently covering the courtyard by raising a type of traditional canvas structure called Poosh. Temporarily raising of the Poosh had long been a customary and standard tradition towards the preparation of the house for holding rituals and ceremonies. There are technical and non-technical values in this type of structure. The traditional houses repurposed to hotel and restaurant have applied this structure to permanently cover the courtyard as a covered public space. This action will destroy the vegetation and also deprive the winter spaces from thermal benefits of solar radiation.

Introducing the studied examples

The "Oloomi" and "Tehrani" houses are both valuable and special houses in Yazd. There have been restoration actions taken place in these houses before, some of which have caused damage to the originality and function of these buildings. Here we will briefly introduce these buildings.

● Oloomi's House

This building complex, known as Oloomi, was built about 120 years ago by Akhond Molabagher Ardakani and his son Molahosein, the forefather of the Olumi family in Yazd. The complex consists of a rectangular central courtyard along the southeast and northwest axis. There are many spaces around the courtyard on the southeast, southwest and northwest sides. In the middle of the courtyard on a much lower level and depth there is a garden with many spaces surrounding it. This type of space is called Godal-Baghche (sunken courtyard) (Haji Ghasemi, 2004:118). This house was purchased by a non-private institute, and poorly restored to become a hotel. The restoration process was left suspended until it was sold to a private university in 1392 to become the art and architecture campus of the university (Fig. 1).

● **Tehrani's House**

This house was built about 100-150 years ago by Agha-Sheykh Mehdi Arab. His family were later titled "Tehrani". From then the house was famous for "Tehrani's House". The building consists of a main part and the service section. The main part is a rectangular courtyard almost along the south and north axis with two story height (mainly) enclosed spaces surrounding it. The entrance is located on the northwest corner and consisting of a distinct entrance facade, entrance space (Hashti) and entrance corridor (Dalan). The service and attendants section, located on the south side of the house, have a separate entrance. This section is hidden behind the surrounding spaces of the central courtyard (Haji-Ghasemi, 2004:32). This house was facing demolishment due to evacuation. It was later bought by the Cultural Heritage Institute of Yazd. Today it is repurposed to a hotel by a private institute (Vasagh & Rezaei, 2010: 300);(Fig. 2).

Studying and Analyzing the Interventions

● **Ommiting wind catchers**

Wind catchers or Badgirs are characteristic and landmark elements of the skyline of traditional houses and city of Yazd. They act as the breathing vessels of the city. By the year 2006 there were 180 Badgirs on the cityscape of Yazd (Mahmoudi, 2006: 92). Badgir is a fixed system that works both as a Bad-khor or ventilator (Fig. 3) and a Bad-khan or exhaust (Fig.4) at the same time (Battle McCarthy, 2006. 32). Guiding the exterior air inside the house, to help with air circulation for relatively cooling the spaces, had been the primary function for Badgir in the traditional houses (Bahadori-nejad & Dehghani, 2008: 3). In buildings with limited access to wind flow and natural breeze, this system can bring the above wind inside. In low rise compact urban texture, it is difficult for each and every building to have access to the wind flow. In this case the Badgir system can be beneficial to guide the cooler and cleaner air from over the building's roof to the desired rooms [D. k &

Fig. 1. Oloomi's House view from "Godal-Baghche".

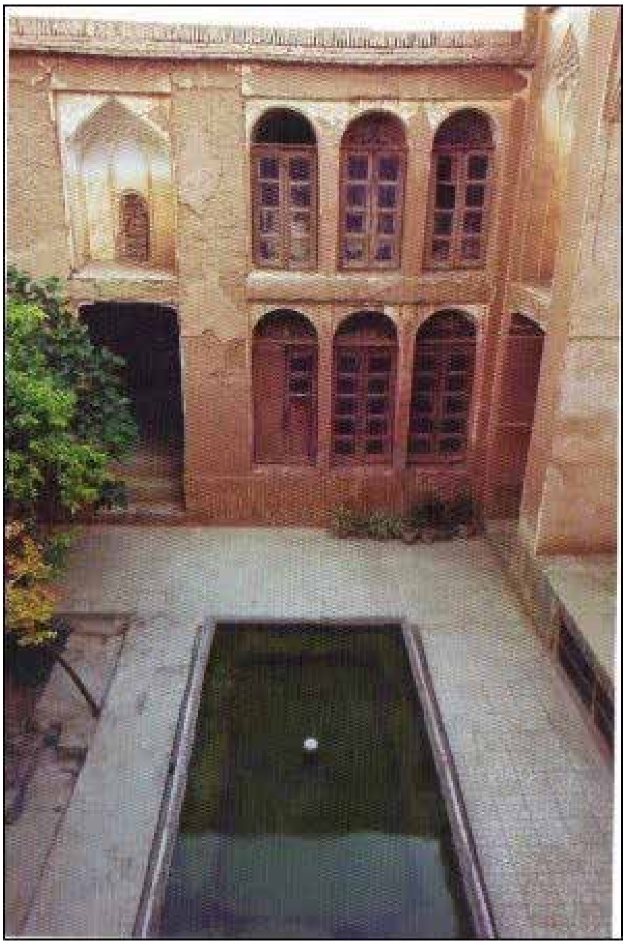

Fig. 2. Tehrani's house before repurposing.

Brown, 2010:188]. When the wind blows, it enters the Badgir and exchanges heat with its channels as it travels inside the building [Bahadori-nejad & Yaghobi, 2008:15]. In this case air circulation occurs by the ventilator effect. This effect is only effective when the air current or wind velocity exceeds 2.5 meters per second [Battle McCarthy, 2006. 24]. The natural air circulation can also be provided by the chimney effect [Bahadori-nejad & Dehghani, 2006: 269]. When the wind speed is too low or when the exterior temperature is lower than the interior such as at night, the chimney effect is beneficial for air circulation. This effect cools the building and structure at night [Koog – Nilson, 2006: 73]. So even in the absence of wind the interior hot air will raise from the Badgir and air circulation will happen (Watson and Lebz, 2009: 162); (Fig. 3,4).

By omitting the Badgir the Chimney and Ventilator effect will also be omitted from the natural air circulation of the building. To reach the comfort zone and the need for air quality and temperature control, it obligates the assistance of mechanical equipment. In other words, by omitting passive ventilation and cooling systems, the need for active cooling system and consequently, energy consumption is raised.

The studied case in this article for observing the effects of the omission of Badgir, is the summer space of Olumi house shown on figure 5. In this case the Badgir was fully decayed and damaged but not rebuilt again during the restorations. Right now the Badgir vent is fully covered and the Badgir system is omitted from the cooling and ventilation system of the building. In our research this space was modeled in Energy-Plus software and the cooling load of the space was calculated with and without the presence of Badgir.

It must be considered that the presence of Badgir on one hand is beneficial but on the other hand increases the infiltration rate. The infiltration rate depends on the air temperature and air current.

These considerations were taken into account in our modeling and calculations. The required data by the software in this stage are as followed: the space geometry, (Polar) orientation, natural ventilation rate, infiltration rate, the walls and openings material and boundary conditions, and the hourly weather data.

The output of the software is the monthly cooling load, before and after restorations (with and without Badgir). This output is presented in diagram 2.

Improper Construction and Replacement of Doors and Increasing Infiltration

Infiltration is the uncontrolled penetration of outdoor air to the building (Grondzik & Kwok: 2014, 224). An increase in the infiltration rate, will greatly cause an increscent in the thermal load. Diagram 3 shows the infiltration rates. In this diagram the coefficient of K represents the quality of sealing. For high quality sealing with a gap of less than 0.4 mm the coefficient of K is one. The K for a gap of 0.4mm to 2.4mm equals 2. A K of 6 represents a gap of more than 2.4

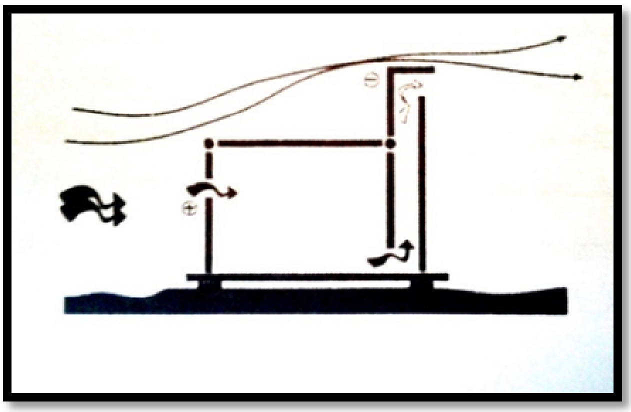

Fig. 3 Bad-khor, the ventilator effect in Badgir.

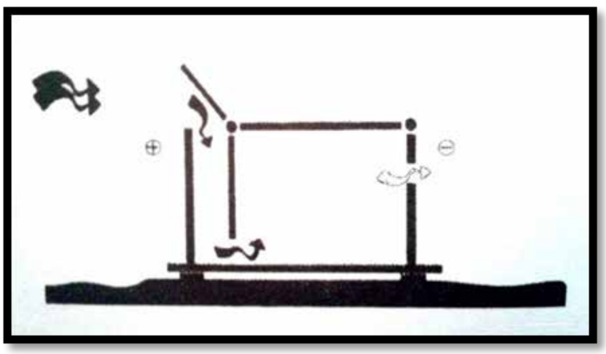

Fig.4 Bad-khan, the chimney effect in Badgir.

mm.

The Velocity head factor shown on diagram 4, is defined by considering the velocity of wind flow in summer and winter (Grondzik & Kwok, 2014: 1702). The monthly wind velocity of Yazd is shown on diagram 4.

To study and compare the influence of door replacement, before and after restoration, the space shown on figure 6 has been modeled and studied. To model this space in Energy-Plus the below data or factors have been collected. Firstly the quality of sealing and the velocity head factor is collected from table 3 and 4. Double slit glass has been used in the replaced doors. This factor has also been considered in the energy plus modeling. The required data by the software in this stage are as followed: space geometry and (polar) orientation, the wall and opening material, wind velocity head factor, the sealing quality or construction type and the hourly weather data of the region.

The software output is the monthly cooling and heating load of the building. The analytical data from before and after restoration are compared on table 6 & 7 (Fig. 6,7).

Raising a Permanent Canvas Structure on the Courtyard

The primary passive solar heating method is the application of direct solar radiation heat gain to heat interior spaces (Mazria, 1979: 29). Almost all buildings with south glazing take advantage of this heating method. The solar radiation is guided into the interior spaces and the heat is absorbed by the furniture and interior surfaces (Grondzik & Kwok, 2014: 296). This system has widely been used in traditional houses for the heating of “winter spaces”. The studied “winter space” of the “Tehrani” house is highlighted in figure 8. The heating load of this space is calculated before and after raising of the canvas structure.

The required data by the software in this phase are as followed: the space geometry, (Polar) orientation, natural ventilation rate, infiltration rate, the walls and openings material and boundary conditions, and the hourly weather data of the region. The software output is the monthly heating load as represented on the diagram 7 (Fig. 8,9).

Analyzing the results

The results from analyzing the omitting of Badgir show an increase in cooling load of the 3-door room of Oloomi house to increase from 7280 kilowatts per hour (kW.h) to 11720 kW.h. This 4491 kW.h increase is equal to 61.6 percent of the entire energy consumption of the space before restoration. The non-technical replacement of the openings in the underground 2-door space of Oloomi house has resulted in an increase in the infiltration rate and therefore the thermal load. The thermal load has increased from 1868 kilowatt per hour to 3784

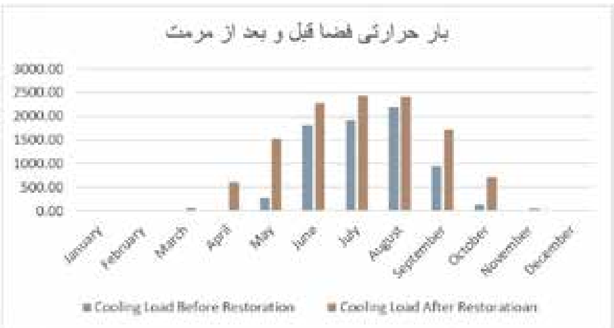

Diagram 1. Thermal load for "3-door" room in Oloomi’s house before and after restoration. Source: authors.

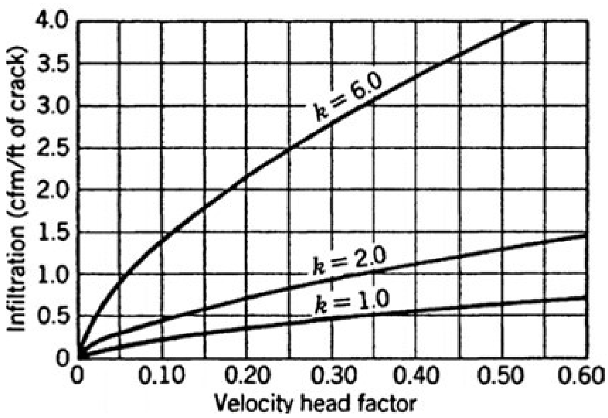

Diagram 2. Infiltration rate based on coefficient of K and Velocity head factor. Source: Grondzik & Kwok, 2014: 1701.

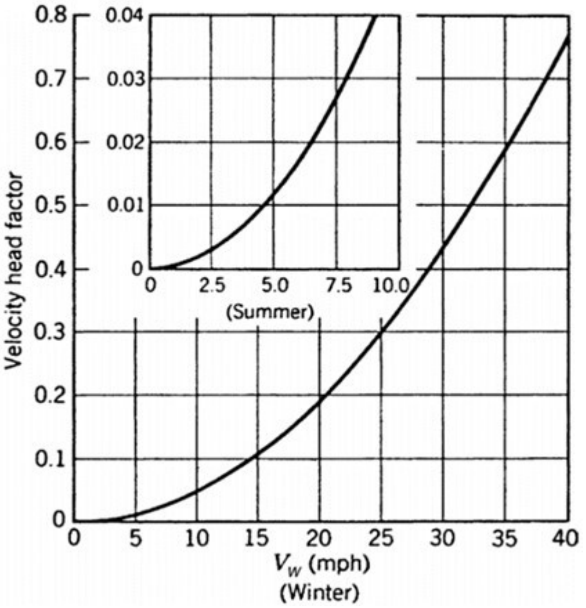

Diagram 3. Velocity head factor based on the velocity of wind flow in summer and winter. Source: Grondzik & Kwok, 2014: 1702.

Diagram 4. The monthly average wind velocity of Yazd expressed in miles per an hour Source: Energy-plus.

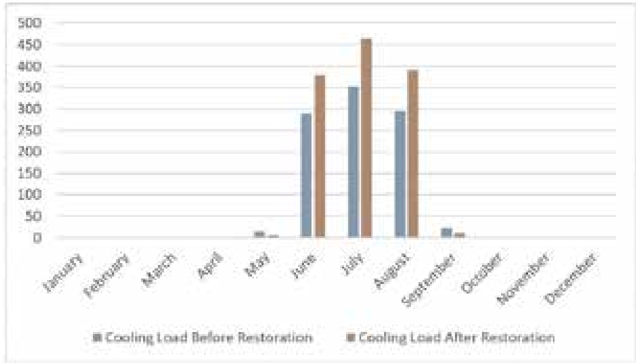

Diagram 5. Cooling load of Dodari room in Oloomi's house before and after restoration. Source: authors.

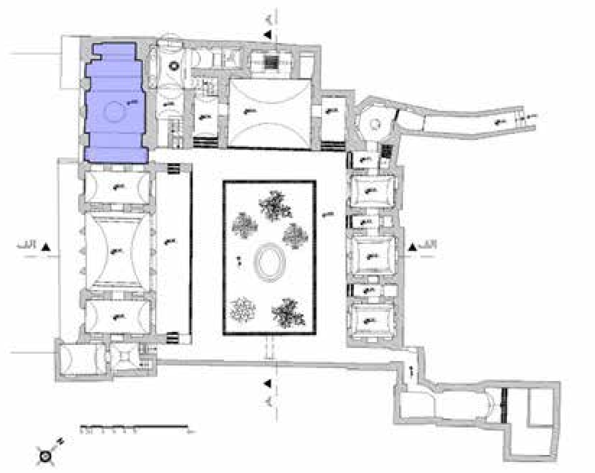

Fig. 5. Ground floor plan of Oloomi's house and the analyzed room. Source: authors.

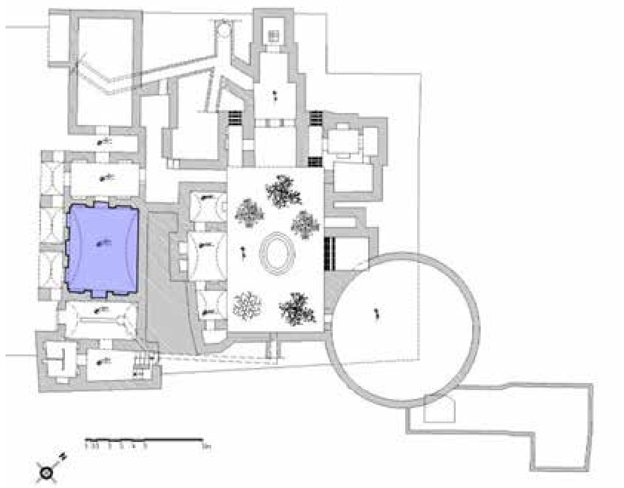

Fig. 6. Underground floor plan of Oloomi's house and Dodari (2- door-room). Source: Cultural heritage institute of Yazd.

kilowatts per an hour. This 1915 kilowatt per hour of increase is equivalent to 102.5 percent of the entire thermal load of the space.

The cooling load has increased from 973 kilowatts per hour to 1252 kilowatt per hour. Showing an increase of 278 kilowatts per hour, equivalent to 28.6 percent of the entire cooling load of space. The permanent canvas covering of the "Tehrani" courtyard has increased the thermal load of the 3-door winter space from 3842 kilowatts per hour to 6159 kilowatts per an hour. This is an increase of 2317 kilowatt per hour of energy consumption equivalent to 60 percent of the entire heating load of the space.

Fig. 7. The gap between the door and frame in "2- door" room of Oloomi's house causing infiltration. Source: author.

Figure 9. Raising permanent canvas structure on the courtyard and preventing direct solar absorption. Source: author.

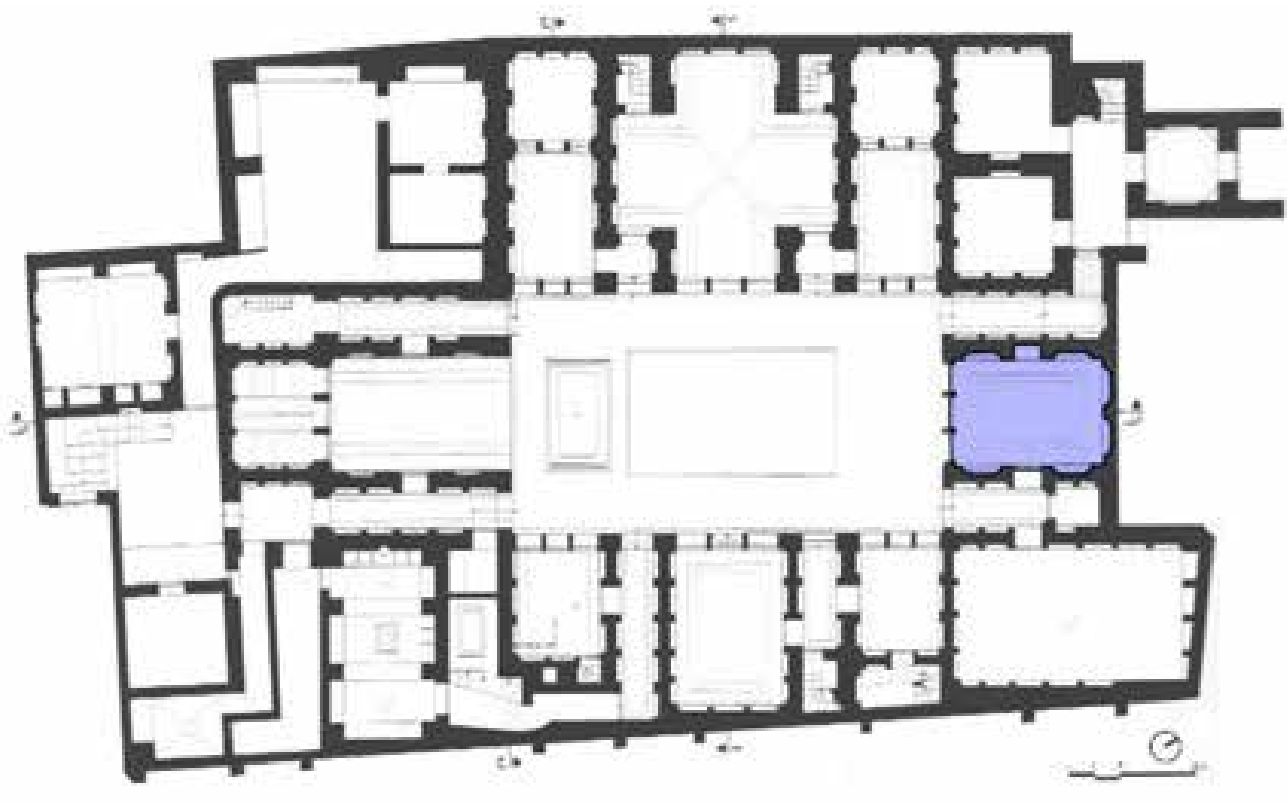

Fig. 8. Ground floor plan of Tehrani's house and 3-door room. Source: Haji Ghasemi, 2004.

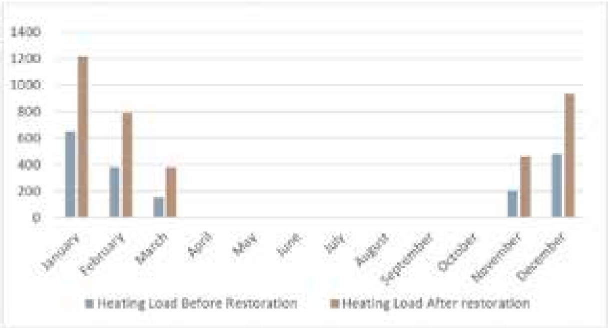

Diagram 6. Heating load of Dodari room in Oloomi's house before and after restoration. Source: authors.

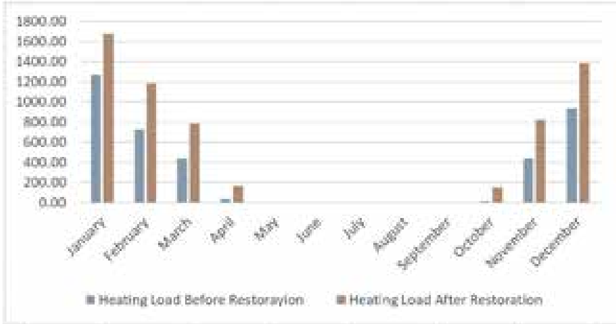

Diagram 7. Heating load of Sedari (3-door) room in Tehrani's house before and after restoration. Source: author.

Conclusion

The results from studying the three common intervention for the restoration of Oloomi and Tehrani houses in Yazd has shown the conclusion below. Omitting wind tower in Oloomi house has increased the cooling load of the studied space by 61.6 percent. Improper replacement of doors has increased the heating load of the studied space in Oloomi house by 102.5 percent and the cooling load by 28.6 percent. Raising a permanent canvas structure on the Tehrani's courtyard has increased the heating load of the studied space by 60 percent. The traditional houses in Yazd have this potential and ability to take advantage of the passive methods, all year around, to reach the comfort zoon. The improper actions and restorations not only increase the thermal load and interfere with the building function; But also obligate the use of mechanical equipment, cooling and heating systems in the building to reach the comfort zone by consuming energy. Besides the increase in energy consumption, on a broader perspective, the presence of these equipment might damage the principles, architecture, urban scape, function and the structural effectiveness of the building. Therefore, bringing about this massage that if the restoration actions are unprincipled and lack artistic and technical details, they may have a reverse effect on the conversation and life span of the building. These damages might be permanent and irreparable because some of the prerequisite conditions for creation of these valuable works do not exist or are not accessible anymore. Many of these historic pieces and places are unique and un-repeatable and the quality of restoration is of great importance. Therefore, the unique and un-repeatable nature of these historic pieces and places require a high quality of restoration. To stop further damage caused by low quality restorations to the cultural heritage, a systematic approach towards principled, knowledgeable and technical restoration must be planed and pursued.

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