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## Effect of Traditional Persian Materials and Parametric Design on the Thermal Performance of a Generic Building in Mediterranean Climate

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# Effect of Traditional Persian Materials and Parametric Design on the Thermal Performance of a Generic Building in Mediterranean Climate

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**Abstract.** Concerns related to buildings' green-house emissions in recent years lead to the increase of architectural adaptation to local environment. While passive conditioning strategies emphasising natural ventilation are common alternatives to achieve indoor comfort in hot and humid climate, they are not widely used in temperate climates. In this context, this paper presents a computer simulation study carried out through Archsim plug-in of Grasshopper/Rhinoceros. The object of study consists of a single family housing unit (flat) with an area of 31.25 m<sup>2</sup> and a height of 2.80 m, with one user, under naturally ventilated conditions. As a reference case, the model used the climate of the city of Yazd in Iran and the simulations assessed parameters such as window-to-floor area ratios of 10% and 20%, as well as the thermal transmittance of exterior walls, considering an envelope with insulation materials, as a common European configuration, and an envelope with Persian materials, such as adobe. Two different Mediterranean climates, Palermo and Valencia, were investigated and the influence of these parameters at the building thermal performance was evaluated using cooling and heating degree-hours indicator, using as thermal comfort limits the Operative Temperature criteria established by ISO 7730. Using Persian materials at the model envelope increased its thermal inertia, thus reducing the temperature variation in the internal environment and improving its interior comfort, especially during the warmest seasons.

## 1. Introduction

### 1.1. Design strategies for climate-friendly buildings

Over the last decades, the world energy consumption generates pollution and degrades the environment, and on a global scale, the building sector contributes to a significant share of greenhouse gas emissions [1]. In response, the European Union (EU) undertook to reduce by 80–95% of these emissions by 2050 compared to 1990, and around 40% of these emissions are related to the construction sector [2].

Faced with this global awareness, many efforts concerning the retrofitting of existing buildings or the development of new constructions focus on the concept of Passive Houses [3] [4], which are structures that provide comfortable indoor conditions with low heating and cooling load. As a principle, Passive Houses have a high efficient tight building envelope and therefore use highly insulating materials, being especially suitable for central Europe climate. Schnieders et al. [5] show although that they could also be built nearly anywhere in the world, considering the local environment, shape and building orientation.



However, seeking a more sustainable environmental approach the construction industry has been interested in naturally ventilated buildings [6] [7], which are not conditioned by cooling or heating, but by the architectural structure itself, the building design and its components [8]. According to Chen et al. [6], the interest in naturally ventilated buildings has increased due to its low installation cost and energy savings and can be considered as a good alternative for places with mild temperatures.

When using natural ventilation to maintain thermal comfort and consequent energy conservation, it is necessary to establish adequate methods to predict the performance of buildings internal ventilation [9] [10]. Primarily, designers must consider the regional climatic characteristics to generate solutions that lead to environmental comfort [11].

Likewise, the demand for sustainable materials that contribute to the thermal performance of building has increased and become a research focus, either by being manufactured from renewable sources or using their hygrothermal characteristics [12] [13].

Nevertheless, many construction decisions regarding buildings comfort and thermal performance are based on a professional's empirical knowledge [14]. In this sense, simulation programs related to buildings thermal and energetic performance have been consolidated as a viable alternative in the passive buildings evaluation [15] [16]. They enable the assessment of the design, existing constructions and the investigation of options for future buildings, generating information to the new projects [17].

### *1.2. Persian materials*

Self-sufficiency and dependence on vernacular materials is one the five principles of Persian architecture. Climate influences can be seen in urban design and architectural elements. The thermal mass factor in buildings, which is due to the use of special materials, is very effective in decreasing the thermal load in the building and contribute to reduce the amount of energy required by cooling and heating equipments.

Iran's warm and dry regions are characterized by hot and dry summers and cold winters, which regarding to comfort, means avoiding winter cold and summer heat in these areas. When using appropriate materials and solar thermal storage in the building's wall one can provide sufficient comfort in five of the seven cold months of the year. However, the use of heating equipment is commonly necessary during one or two months.

In general, the materials used in the persian construction come from the site itself, and the local climate conditions are explored by the buildings's shape and orientation, in orther to provide optimized indoor comfort. Among the materials used in the constructions, one can highlights adobe (Figure 1), which is clay with straw fibres mixed with water that is moulded and then dried [18] and it is one of the most popular vernacular materials in Iran's hot and dry regions.



**Figure 1.** Persian construction material, adobe

### *1.3. Adobe advantages*

Some benefits of adobe are that it does not pollute the environment, it is compatible with nature and vernacular architecture [18], besides being nontoxic and also having a low sound transmittance. The mixture of clay and water is economical and has optimal thermal mass storage and thermal transfer properties for winter heating and summer cooling. Since the soil is suitable for construction in most residential areas of the world, adobe production only requires one percent of the energy needed to produce bricks or Portland bricks. Soil can make the balance of moisture inside the building better than any other traditional construction material.

Furthermore, one of the special adobe properties is its modular production capability, with binding mortar (with 1.2 to 2.5 cm thickness) that dries rapidly. As for its shape, adobe usually has a cubic rectangular form and the bricks can have different dimensions from  $20 \times 20 \times 5 \text{ cm}^3$  to  $40 \times 40 \times 10 \text{ cm}^3$  [19]. The most outstanding physical property of the adobe among other materials is its deformability and ability to assume different shapes. Also, the bright colours from adobe help to reflect the sun's radiation [20].

#### 1.4. Adobe disadvantages

Some difficulties related to adobe include high weight, low water resistance, cracking caused by contraction and high initial moisture content. In addition, the material is fragile and has low resistance due to its heterogeneous dimensions, making its transportation problematic, also presenting desquamation and high powder amounts.

Other drawbacks include disintegration due to daily heat fluctuations, which are generally observed in shaded areas. Leaching in an adobe structure can also be observed, resulted from moisture exposure, as well crushing due to the penetration of termite in Adobe, once it is composed by straw fibres [20].

## 2. Method

The research's methodology involves performing computational simulations of the studied model (Figure 2) through Archsim, which is a plug-in for Rhinoceros/Grasshopper software. ArchSim is coupled with Energy-Plus that provides as output the Operative Temperatures (OT). The model geometry is developed in Rhinoceros while its visual programming information is inside Grasshopper, representing geometry, constructive components, internal loads, climate file and passive strategies, such as natural ventilation.

The thermal comfort limits for the OT are determined according to the criteria established by ISO 7730 [21], considering an environment with light activities ( $70 \text{ W/m}^2$ ) and a Predicted Mean Vote (PMV), category B (80% acceptability limits). The building thermal performance analyses occur by means of cooling and heating degree-hours indicator (1, 2), a climatic parameter defined by the sum of the temperature differences that are above and below the base temperature ( $T_b$ ).

$$Dh_{\text{cooling}} = \sum Th - Tb_{\text{bottom}} \quad (1)$$

$$Dh_{\text{heating}} = \sum Tb_{\text{upper}} - Th \quad (2)$$

Where:

$Dh_{\text{cooling}}$  = cooling degree-hours ( $^{\circ}\text{C}$ )

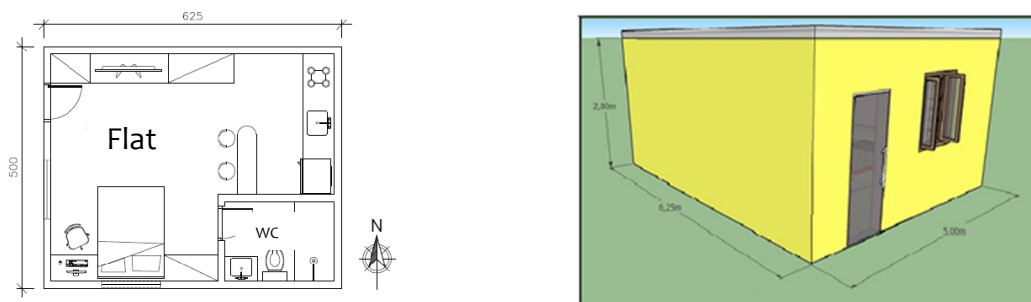
$Dh_{\text{heating}}$  = heating degree-hours ( $^{\circ}\text{C}$ )

$Th$  = Hourly temperature ( $^{\circ}\text{C}$ )

$Tb_{\text{bottom}}$  = Bottom  $T_b$  ( $^{\circ}\text{C}$ )

$Tb_{\text{upper}}$  = Upper  $T_b$  ( $^{\circ}\text{C}$ )

The studied model consists of a generic flat, under natural ventilation conditions (Table 1), with an area of  $31.25 \text{ m}^2$  ( $23.55 \text{ m}^2$  of combined area and  $3.80 \text{ m}^2$  WC) and  $2.80 \text{ m}$  high, occupied by one user [22].



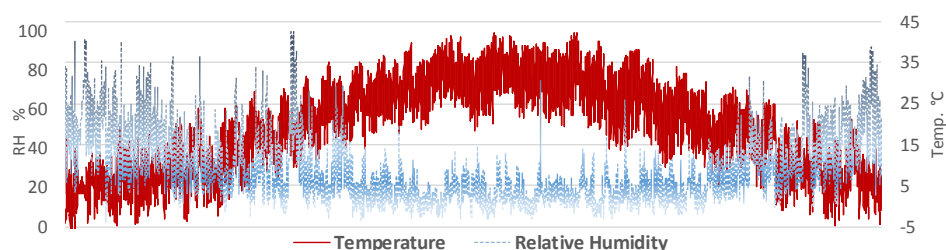
**Figure 2.** Floor plan and 3D model [22]

The window opening control for ventilation occurs by means of a temperature and humidity schedule. The window opening is allowed when the external temperature is higher than a set minimum temperature ( $T_{EXT} > T_{MIN}$ ), and the windows are closed when the external temperature is higher than the set maximum temperature ( $T_{EXT} > T_{MAX}$ ), or when the external relative humidity is greater than an established maximum humidity ( $H_{EXT} > H_{MAX}$ ), with  $T_{MIN} = 20^{\circ}\text{C}$  e  $T_{MAX} = 32^{\circ}\text{C}$ .

**Table 1.** Parameters related to natural ventilation

Parameters	Values
Discharge Coefficient (Cd)	0,65
Air Change rate/hour	1 ACH
Operable Area Ration	0,8

Two base cases were investigated, reference case and case with Persian materials, both using the climatic file from the city of Yazd, in Iran (Figure 3). Two different window-to-floor area ratios (WFR) at each simulation case, with 10% and 20% ratios were also measured, but no shading device was taken into account.



**Figure 3.** Yazd, Iran – TMY climate profile

At the reference case the model was simulated with envelope materials typically found in the European residences combined with insulation layers and its envelope thermal transmittance (U-values) are presented at the Table 2.

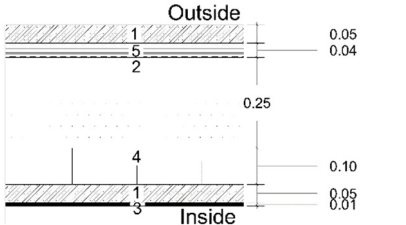
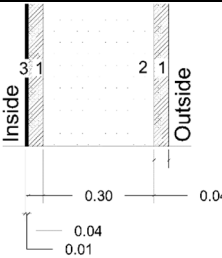
**Table 2.** Envelope U-values considered at the Reference case

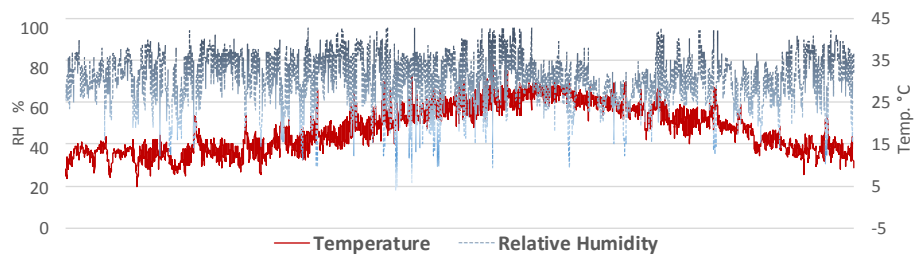
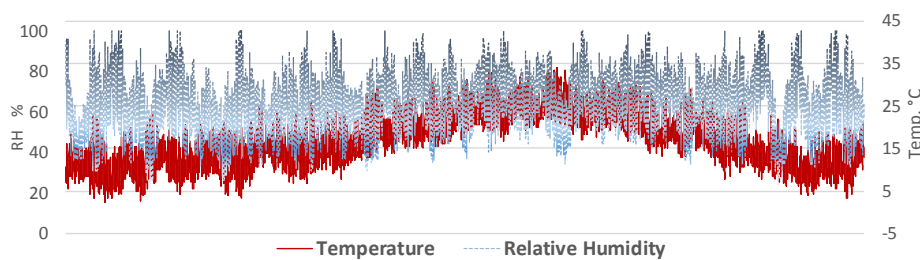
Building Component	U-value ( $\text{W}/\text{m}^2\cdot\text{K}$ )
Walls	0,62
Ceiling	1,62

At the case with Persian materials (Table 3) only Adobe were used, combined with other predominant elements from the region.

As alternative simulations, two Mediterranean climate conditions were also investigated, using the TMY climate files of Palermo, in Italy (Figure 4) and Valencia, in Spain (Figure 5). Both investigations also considered the two different WFRs, of 10 and 20%.

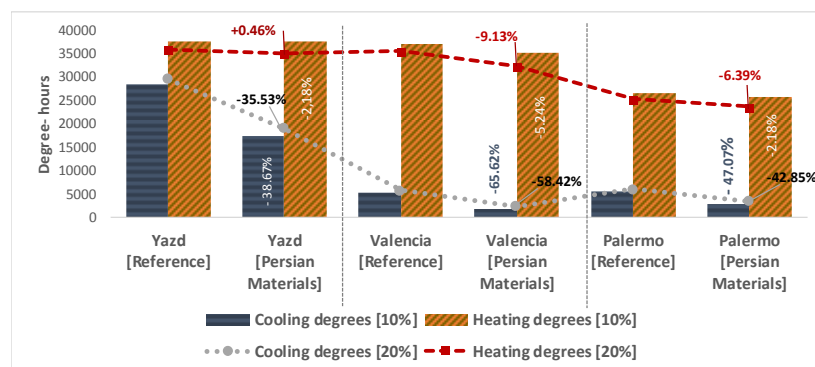
**Table 3.** Envelope sections and materials properties considered at the cases with Persian Materials [23]

Ceiling section	Wall section	Thermal Conductivity ( $\lambda$ ) – W/mK
		1. Mud straw – 1.21 2. Adobe – 1.11 3. Gypsum – 0.58 4. Wood – 0.14 5. Clay – 1.48

**Figure 4.** Palermo, Italy – TMY climate profile**Figure 5.** Valencia, Spain – TMY climate profile

### 3. Results and Discussions

The six proposed models were simulated, obtaining the OT for all 8760 year-hours. With these data, the sum of the cooling and heating degree-hours for all cases were calculated (Figure 6).

**Figure 6.** Annual cooling- and heating degrees sum (by model)

When analysing the difference of the cooling and heating degrees-hours sum between the reference cases and the ones with Persian materials, it is possible to see that the reduction of cooling degrees is greater than the heating degrees in all cases. In general, one can affirm that the use of Persian materials



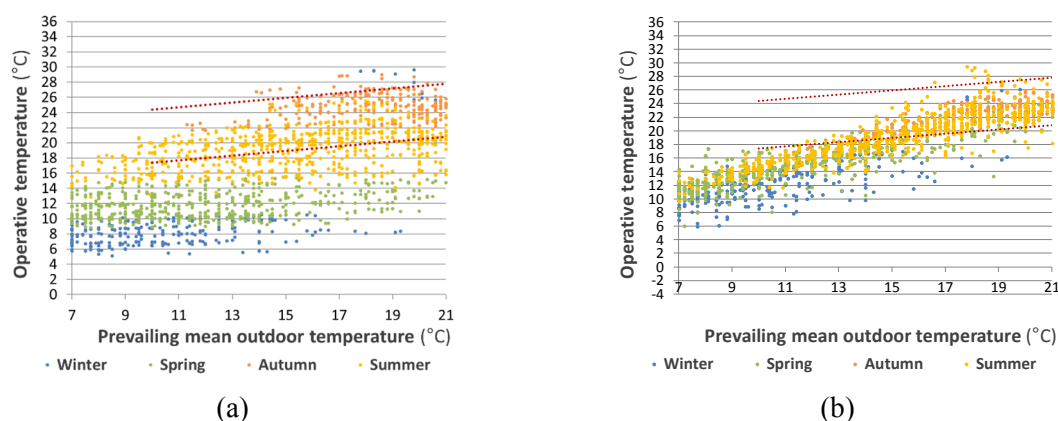
improved the thermal performance of all studied cases in relation to the reference ones, which used envelope materials typically found in the European construction.

Regarding WFR, both cases with Mediterranean climate, Valencia and Palermo, indicated better performance for cooling degrees at the scenario with smaller windows (WFR =10%), showing improvements of 65.62% and 47.07% respectively, whereas the cases with WFR of 20% had an improvement of 58.42% and 42.85%. On the other hand, the heating degrees values presented better results at the presence of larger windows, showing a reduction of 9.13% and 6.39% in comparison with the reference case, against the 5.24% and 2.18% obtained at the cases with WFR of 10%. This is justified by the solar radiation heat gains, which are directly proportional to the window glass area, considered without shadings at the simulations.

Differently, the Yazd analyses for heating degree-hours at the larger windows (WFR=20%) scenario showed an increase of 0.46%, meaning a lower performance during the cold seasons in comparison with the reference model. Thus, the solar heating gains due to window area increase, and consequently the transparent area, did not have the same positive impacts at the Yazd model interior comfort, as in the cities with a Mediterranean climate, or do not overcome the thermal mass effect resulted from the Adobe walls. One explanation lays on the fact that the relative humidity in Yazd, for instance, stays lower than 40% most of the year, affecting the heating of the air mass by means of solar radiation. In addition, it should be noted that the reference case does not represent in fact a Persian context, once it uses European materials in its envelope, being simulated with the same characteristics of the other models for the sake of the methodology aspect.

Among the investigated models, Valencia's case is the one with the highest reduction rates of both heating (65.62%) as well cooling degree-hours (58.42%). This is mainly due to the small climate fluctuation of the city, regarding the other cases, showing a more significant benefit of the use of Persian materials in this context, although the Yazd climate itself presents wide variation.

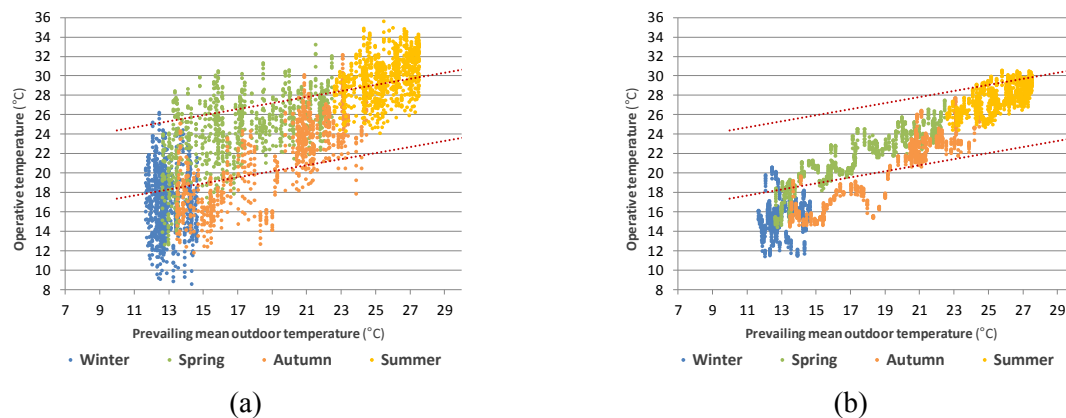
In Figure 7 and Figure 8 the OT are presented only for the Yazd and Palermo models with WFR of 10% and 20% respectively, due to space constraint. The graphs show the OT distributed throughout the four seasons of the year, considering the comfort levels established by ISO 7730, where the dotted red lines represent acceptability limits of 80% (PMV – category B).



**Figure 7.** Yazd OT through the year (WFR=10%): a) reference, b) with Persian materials

One can note a difference in the OT's points distribution between the reference cases and the ones with Persian materials in both Yazd and Palermo models. Comparing the diagrams it is possible to see that when using Persian materials the OT are clumped and near to the comfort limits (Figure 7, Figure 8 -b), while at the reference cases (Figure 7, Figure 8 -a), which use regular European materials with insulation the OT are scattered and away from the dotted red lines. Using Persian materials at the model envelope increased its thermal inertia, thus reducing the temperature variation in the internal environment and improving interior comfort, especially during the warmest seasons.

As a result, at Yazd's climate better interior comfort performance in summer and autumn is observed (Figure 7), whereas in the Mediterranean climates investigated, represented here only by Palermo, improvements are also seen in spring (Figure 8).



**Figure 8.** Palermo OT through the year (WFR=20%): a) reference, b) with Persian materials

#### 4. Conclusion

This work presented the thermal performance analysis of a single-family dwelling (flat), naturally ventilated, combining different WFR and traditional Persian materials, such as adobe, under two Mediterranean climate conditions (Palermo and Valencia). The primary goal was to evaluate how passive design strategies could impact the buildings thermal performance in european milder climate places, seeking different solutions from the diffused ones, such as Passive Houses concept, for instance. At the same time, the alternatives should meet the aims for a sustainable environment and constructions with a greater symbiosis with the climate where they are inserted.

The results showed that the use of Persian materials under mediterranean climate context leads to a higher performance related to the internal temperatures, especially in the hottest seasons, generating better thermal comfort for users. However, the OT at the cold seasons are outside the comfort limits showing that natural ventilation during this period should be avoided. Closing the windows would solve the problem, however openings selective control was not considered at the simulations, and the windows remained always opened.

Finally, the main contribution of this article was the combination among Persian materials and natural ventilation analysis in small buildings, and their impact on the user thermal comfort, evidencing the importance of the computational simulations as an aid tool in the architectural design. Once the variables that affect the thermal performance of a building are defined, it is possible to adopt constructive solutions that are more climate-friendly.

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