# Comparative study of the influence of traditional walls with different typologies and constructive techniques on the energy performance of the traditional dwellings of the Casbah of Algiers

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ABSTRACT: The Casbah of Algiers is classified world heritage in 1992. Their constructive typologies and specific equipment's of walls distinguish its traditional dwellings. They are mainly distinguished by the principles of eco-design and climatic adaptability. The present work aims knowing the influence of a traditional wall on the energetic performances of a dwelling of the Casbah of Algiers through different compositions in order to choose the most suitable typology for the ecological and environmental question. The adopted methodology is structured on the characterization of materials and an evaluation, through a series of simulations, of the influence of thermal inertia on the energy performances. The results obtained allowed us to enrich the ecological framework of the materials by determining the optimal composition to the eco-design for a better revaluation of our built inheritance and a better safeguarding of environmental resources.

## 1 INTRODUCTION

Traditional building is a living complex that reflects the needs for which it was originally constructed. The house should always respond to its inhabitants' way of life; it is characterized by centrality, introversion of the built space and arrangement of rooms around the patio.

Reading the historical development of a monument, or an urban fabric, cannot be achieved without the thorough knowledge of the used materials and techniques which help to identify the different phases of construction. The implementation of materials and work tools leave marks that cannot be interpreted and understood without a prior knowledge of construction techniques (Mileto, 2007). The identification of materials and construction techniques used locally is therefore a crucial and very substantive step to guarantee the structural homogeneity and physical integrity of the building.

It is worth noting that about 17% of World Heritage buildings are earthen constructions (Pignal, 2005), which proves the durability of the construction material used, just like several other natural and ecological materials capable of ensuring a good energy efficiency in terms of thermal inertia and resistance.

Indeed, a sufficient thermal inertia would allow the building to improve its stability in spite of the outdoor temperature variations; however, thermal inertia at night slightly raises the minimum temperatures (Cheng, 2005).

Conventional building materials could be the basis for reflection about the design of a sustainable architecture that could connect man with his natural environment (Ghaffour, 2014). In addition, earth is a biodegradable and recyclable material (Little, 2001); it does not generate, or very little, construction waste and can be mixed with a number of natural materials such as plant fibers, wood, stone, etc. (Dubost, 2011).

This material undergoes no polluting transformation from its extraction to its implementation. If a building is destroyed, it can be reused to erect other walls. It is infinitely recyclable (Moriset, 2011).

In Algeria, a vast earthen heritage is encountered throughout the entire territory; in fact, southern Algeria is well known for its Ksours and the north for its architectural heritage, particularly in the historic cities of Cherchell, Kabylie, Tlemcen, and the Casbah of Algiers, which was declared a world heritage site of Unesco in 1992. There are constructions with mixed materials, such as rammed earth, brick and stone. It is in this sitological context that the present work aims to treat the thermal properties of these materials through the assessment of the thermo-energetic behavior of four variants of a traditional house, which differ by their construction techniques and the construction materials used, namely "raw earth", "terracotta" and "rubble". In order to determine the most suitable typology with regard to the ecological and environmental issue. Furthermore, the concept of compactness is also investigated in order to address heat loss problems for the purpose of reducing energy consumption and improve the thermal comfort (Munaretto, 2014).

Human thermal comfort involves two main approaches. The first one is the classical model, called the Fanger model which, according to the ANSI/ASHRAE Standard 55-2013, considers that human comfort depends on the combined quantitative influence of six parameters, namely the metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity. The second one is the adaptive model that establishes the relationship between acceptable indoor design temperatures and outdoor meteorological and climatological parameters (IoanaUdrea, 2015).

The indoor thermal environment is affected by internal sources and external sources. Common sources of heat include electrical equipment (lighting, computers, etc.), solar radiation, and human body heat. Common sources of cold include glazed surfaces, weakly insulated walls and thermal bridges in buildings. All these sources have an impact on the perception of the environment by human beings as well as on their level of thermal comfort (Corgnati, 2011).

## 2 METHODOLOGY

### 2.1 Simulation approach

Buildings are huge energy consumers; therefore, important research on the energy efficiency within constructions is urgently needed. Modeling of energy equipment and physical phenomena within the building is the first essential step that can help us achieve optimal management of energy flows; this would be an important stage towards the sustainable development in our society (Hoang, 2014).

The proper management of a construction's energy flows would certainly limit the energy consumption in a reasonable way. Thorough knowledge of energy flows is necessary and essential for making decisions about different tasks related to buildings (Morel, 2009).

Thermal simulation models must meet the needs of the investigation; they are supposed to materialize the combined effect of thermal phenomena, such as heat exchange through buildings by the three modes of heat transfer, i.e. conduction, convection and radiation, as well as by ventilation and air movement (M'sellem, 2007).

For cost and time reasons, simulation is an effective way to develop and study the thermal behavior of buildings under variable conditions.

Thermal analysis simulation is achieved in a perspective of integrating the climatic and physical parameters of the materials into the process of improving the thermal performances of buildings in view of exploring and optimizing certain decisions in order to achieve the best thermal comfort. This thermal analysis simulation also allows for the evaluation and thermal control of buildings.

The methodology adopted is structured based on the characterization of the materials used and also on a comparative assessment of the energy requirements and interior temperatures of four modeled variants of a traditional patio house in the Casbah of Algiers; these variants are differentiated by the materials used, i.e. terracotta, terracotta-rubble, raw earth, and brick-concrete. This was achieved based on modeling and a series of simulations using the Pleiades software, while taking into account the specific climatic conditions of the city of Algiers. The outdoor environment has a significant impact on the thermal comfort inside the houses. In addition, the geographical location, outdoor temperature and solar radiation are three environmental factors that also affect the thermal comfort (Noel, 2018).

Using this approach, we will be able to determine transiently air temperatures, heating needs and air conditioning. This provides us with the opportunity to evaluate, compare and retain the most suitable variant with regard to both climate and energy dimensions.

## 2.2 *Case of study*

Traditional houses, included in our case study, are distinguished by their very interesting constructive typologies and specific mixed walls (Opus spicatum and Opus incertum) beside other building compositions based on local materials (cooked brick, rubble, wood, etc.), with a wall thickness between 40 to 70 cm (Abdessemed, 2005). These constructions are characterized by the Ecodesign principles, as well as by an environmental symbiosis and a climatic adaptability.

More specifically, we have selected an old center house with the constructive characteristics of the traditional houses of the casbah-type (Ateliers Casbah,1980) with "Patio" porticoes down to the street of the Frères Bechara, the surface of the house is 252.42 m² and consists of a ground floor and two levels, plus an accessible terrace. The plans for the modeling are of " DAR IV.8.1 " Boussoura Abderrahmane. (Missoum, 2003)

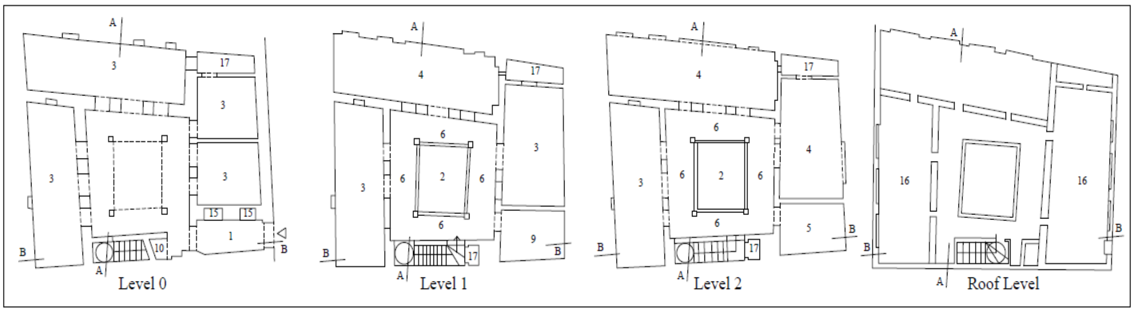


Figure 1. Plans

Legend: 1. Entrance 2. Center of the house 3. Bedroom 4. Bedroom with bathroom 5. Bedroom 6. Gallery 7. Stairs 8. Shop 9. Kitchen 10. Toilet 11. Laundry 12. Well 13. Cistern 14. Bedroom on terrace 15 Masonry bench 16. Terrace 17. Mid-height space.

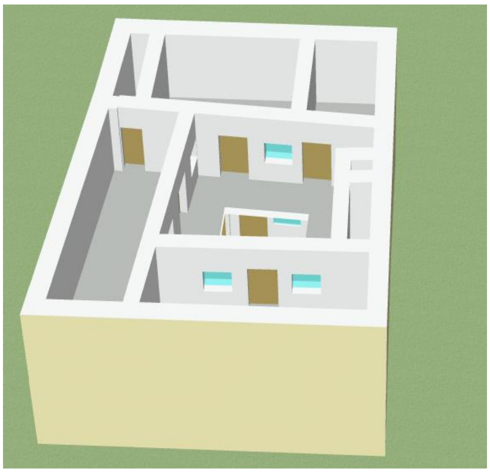

Figure 2. 3D modeling with Pleiades simulation software

## 2.3 *Specific climatic features*

Table 1 summarizes the climatic data of the city of Algiers selected during our evaluation.

Name of site = Algiers. Latitude [N] = 36°43'1′′ 'Longitude [E] = 3°15'0" Altitude [m] = 25

Table 1. The climatic data of the city of Algiers.

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Avg. T (°C) | 11,5 | 12,1 | 13,5 | 15,5 | 18,2 | 21,5 | 24,3 | 25,2 | 23,3 | 19,4 | 15,1 | 12,3 |
| Min. T (°C) | 8,1 | 8,3 | 9,7 | 11,3 | 14 | 17,4 | 20,2 | 21 | 19,6 | 05,7 | 11,5 | 9 |
| Max. T (°C) | 14,9 | 15,7 | 17,3 | 19,7 | 22,5 | 25,6 | 28,5 | 29,5 | 27 | 23,2 | 18,8 | 15,6 |

The climate of Algiers is of Mediterranean type, known for its long hot and dry summers and mild and wet winters. The rains are abundant and can be diluvian. Spades are usually from mid-July to mid-August.

### 2.4 *Technical specificities*

The study of the different variants which are distinguished by the materials used leads one to a comparative reading of the grids, which allows us to define their energy performance. The following summary table (table 2) gives the details of the technical specificities of the different building compositions used.

Table 2. The details of the technical specificities of the various compositions

| | Variant 1 | Variant 2 | Variant 3 | Variant 4 |
|---|---|---|---|---|
| Floor | Solid brick 5.5cm<br>Lime mortar 4cm<br>Raw earth 15cm<br>Log of wood 10cm<br>Total: 34.5cm<br>R=0.76 Ms=589 | Solid brick 5.5cm<br>Lime mortar 4cm<br>Raw earth 15cm<br>Log of wood 10cm<br>Total: 34.5cm<br>R=0.76 Ms=589 | Solid brick 5.5cm<br>Lime mortar 4cm<br>Raw earth 15cm<br>Log of wood 10cm<br>Total: 34.5cm<br>R=0.76 Ms=589 | Concrete hollow 16cm<br>Concrete 5cm<br>Cement screed under flooring: 3cm<br>coating 2cm<br>Total: 26Cm<br>R=0.18 Ms=438 |
| External wall | 2 * Lime plaster 0.7cm on both sides<br>2 * Mortar 5cm on both sides<br>Raw earth 50cm<br>Total: 61.4cm<br>R=0.55 Ms=1163 | 2 * Lime plaster 0.7cm on both sides<br>2 * Mortar 5cm on both sides<br>Solid brick 25cm * 2 (Control wall with double switchgear)<br>Total: 61.4cm<br>R=0.54 Ms=1170 | 2 * Lime plaster 0.7cm on both sides<br>2 * Mortar 5cm on both sides<br>Control wall with mixed equipment (terracotta + rubble) 50cm<br>Total: 61.4cm<br>R=0.46 Ms=1229 | 2 * Cement plaster 2cm on both sides<br>Hollow brick 15cm<br>Blade of air 5cm<br>Hollow brick 10cm<br>Total: 34cm<br>R=0.85 Ms=301 |
| Internal wall | 2 * Lime plaster 0.7cm on both sides<br>2 * Mortar 3cm on both sides<br>Raw earth 20Cm<br>Total: 27.4cm<br>R=0.26 Ms=517 | 2 * Lime plaster 0.7cm on both sides<br>2 * Mortar 3cm on both sides<br>Solid brick 10cm * 2 (Control wall with double switchgear)<br>Total: 27.4cm<br>R=0.25 Ms=520 | 2 * Lime plaster 0.7cm on both sides<br>2 * Mortar 3cm on both sides<br>Control wall with mixed equipment (terracotta + rubble) 20cm<br>Total: 27.4cm<br>R=0.22 Ms=540 | 2 * Cement plaster 2cm on both sides<br>Hollow brick 10cm<br>Total: 14cm<br>R=0.36 Ms=136 |

| | | | | |
|---|---|---|---|---|
| Roof | Lime sealing 5.5cm<br>Lime mortar 4cm<br>Raw earth 15cm<br>Log of wood 10cm<br>Total: 34.5cm<br>R=0.79 Ms=572 | Lime sealing 5.5cm<br>Lime mortar 4cm<br>Raw earth 15cm<br>Log of wood 10cm<br>Total: 34.5cm<br>R=0.79 Ms=572 | Lime sealing 5.5cm<br>Lime mortar 4cm<br>Raw earth 15cm<br>Log of wood 10cm<br>Total: 34.5cm<br>R=0.79 Ms=572 | concrete hollow slabs 16cm<br>Concrete 5cm<br>Polystyrene 4cm<br>lime plaster 3cm<br>Heavy protection in rolled gravel 4cm<br>Total: 32cm<br>R=0.25 Ms=548 |

Note that: R = thermal resistance ($m^2.K$ / W) and Ms = surface density (kg / $m^2$)

### 2.5 *Simulation*

Computer simulation evaluation, using an efficient software program, offers a significant advantage due to its flexibility and the very interesting data it can predict. This approach is highly recommended for this kind of tests. It offers the possibility to vary different parameters relating to the building and to the climatic data of the site to be studied.

The Pleiades V4.19 software, developed by Izuba Energies, is used in this study; it is a comprehensive software program intended for building design, and energy and environmental assessment of constructions. The first step consists of creating a "virtual" volume using the Alcyone graphical modeler, and the second one concerns the entry of the building envelope and its characteristics.

The selected scenario is the same for all 4 variants where only the materials used differ.

• The occupancy scenario corresponds to a minimum occupancy of a family of 4 persons.

• The heating scenario considers a set point of 19 ° C from 7 am to 8 pm and a set point of 15 ° C the rest of the time.

• Standard air conditioning 25 °.

• A breakdown of 0.6 vol / h.

• The lighting: the rooms: 300 Lux, and for the gallery and sanitary 50 Lux.

• The simulation covers the period of one entire year and the data for the city of Algiers are downloaded using the MétéoCalc complementary extension.

• Compositions: One of the 4 previously mentioned variants is considered in each simulation.

The software used makes it possible to determine the heating and cooling requirements for each zone; it also helps to find the minimum, maximum and average temperatures.

## 3 RESULTS AND DISCUSSIONS

Thermal comfort is studied from the following graphical results, indicating for the four variants the heating requirements (fig 3), the cooling requirements (fig.4) and the total energy required (fig 5). In this section, the internal temperatures are also studied based on the data generated by different simulations (Fig 6 and 7).

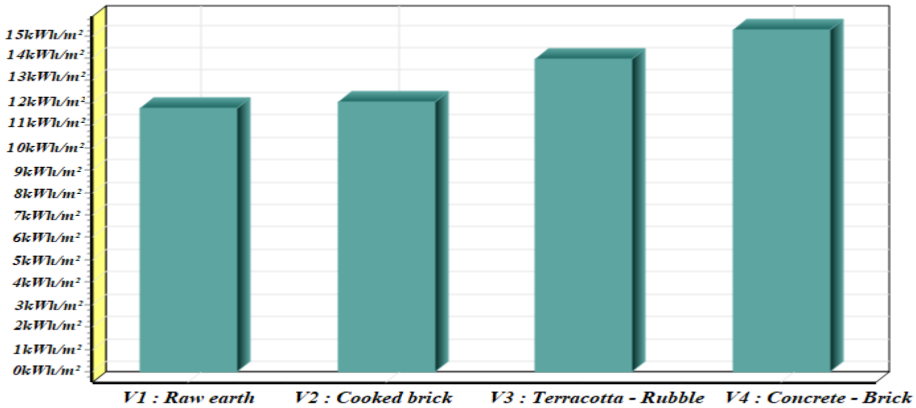


Figure 3. Heating needs.

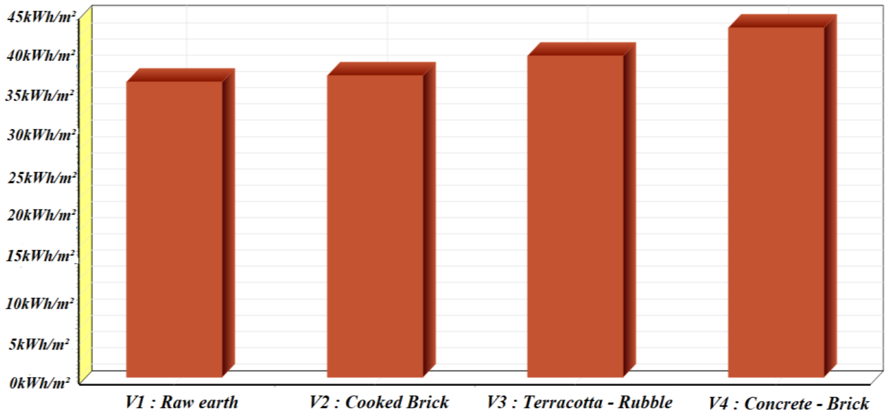


Figure 4. Air conditioning needs.

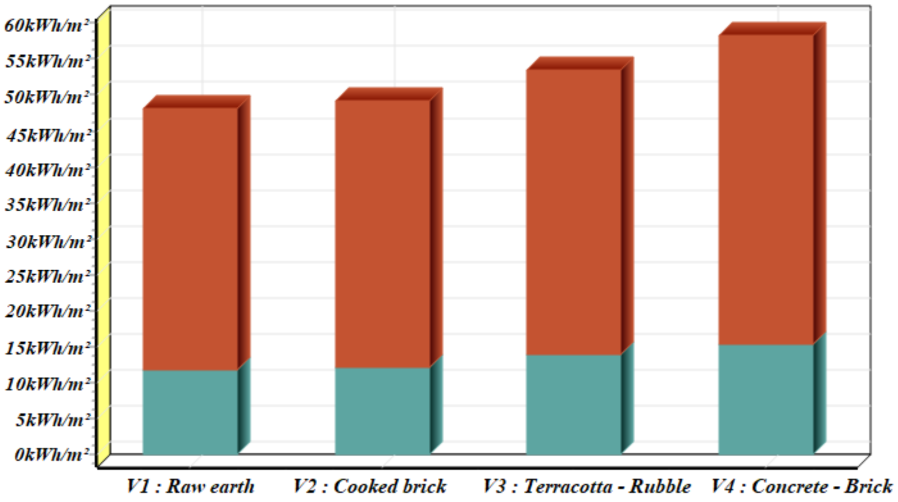


Figure 5. Energy needs.

The first three figures (3, 4, and 5) give a comparison of the energy needs for all four variants, based on the different simulations performed. Examining the results presented in Figure 3, which displays the heating requirements, one should note that the heating needs partly decrease as the thermal conductivity of the different materials used goes down.

The results obtained for both variants 1 and 2 (raw earth and cooked brick) are very interesting and promising; their heating needs are estimated at 12 kWh / m² / year. However, for variant 3 (Terracotta – rubble), these requirements are 14kWh / m²/ year. The difference is justified by the material used (rubble) whose thermal conductivity is 1.700 W /m.K, while those of the materials terracotta and raw earth, they are equal to 1.150 and 1.100 W/m.K, respectively. Regarding variant 4 (Concrete - Brick), although the wall conductivity is better than that of terracotta or raw earth (0.82 W/m.K against 1.150 W/m.K and 1.100 W/m.K, with a smaller wall thickness, i.e. 34 for variant 4 and 61.4 for the others), the floor conductivity remains very important, with 1.56 W / m.K for variant 4 (Concrete Brick) against 1.03 W / m.K for the other variants.

Similarly, for the air conditioning needs illustrated in Figure 4, it is noted that the variants with raw earth and cooked brick are those that need less air conditioning, with 36 kWh / m² / year and 37 kWh /m² / year, respectively. However, the variant with Terracotta and rubble needs 40 kWh / m² / year and that with concrete and brick demands 43 kWh / m² / year.

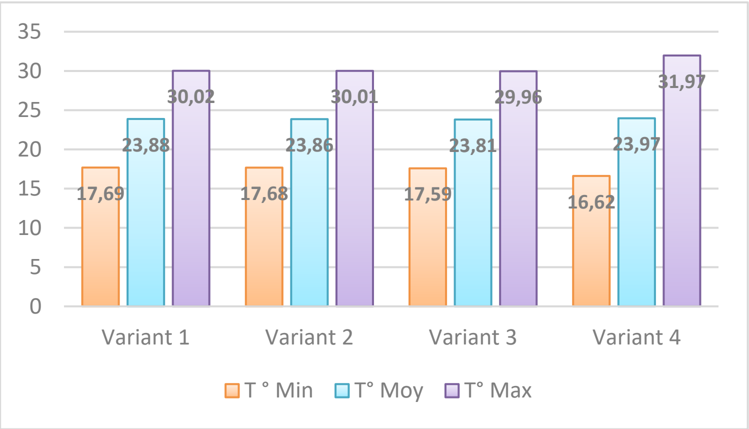


Figure 6. Internal temperatures of different variants.

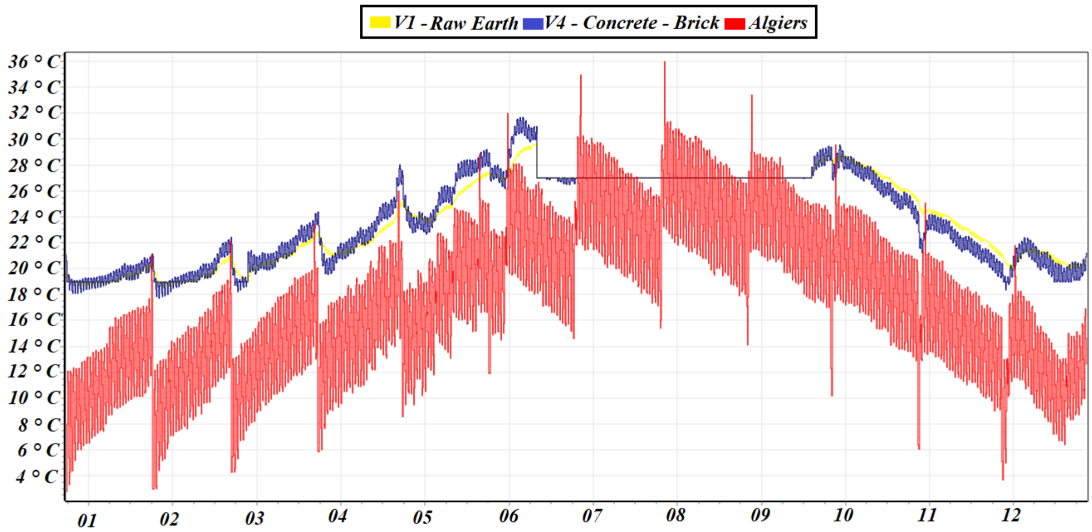


Figure 7. Opérative temperatures/Outdoor temperature

It should also be noted that, according to Figure 6, the internal temperatures of the different variants are satisfactory and offer good thermal comfort due in part to the type of construction of the patio house. Nevertheless, one can notice that through the variants with cooked brick (variants 2 and 3) and variant 1 with raw earth, up to 2 °C of cooling comfort in T ° Max and 1 °C of heating comfort for T ° Min are gained in comparison with variant 4 (concrete - brick).

- For Maximal Text of 36 °C: Variants 1, 2, 3 (T = 30 °C) - Variant 4 (T = 31.97 °C)
- For Minimal Text of 2 °C: Variants 1, 2, 3 (T = 17.6 °C) - Variant 4 (T = 16.6 °C)

Figure 7 illustrates the highest global operative temperatures of the different variants as well as the outdoor temperature of the city of Algiers, based on an annual balance sheet. Variant 4 with concrete and brick is shown in blue color. The results for variants 1, 2 and 3 are similar and are therefore superimposed; they are represented in yellow color on the graph. It is interesting to note that during the cold season, from October to April, the operative temperatures are within the comfort standards, i.e. 16 ° < T ° < 27 °. Moreover, the energy efficiency for variant (V1) has a better yield than V4; on the other hand, in the hot season, i.e. from April to September, the overall thermal behavior of variant (V1) is better than that of V4.

From the results presented above, and based on the energy performance given in Figure 4, it appears that variants 1 and 2 are the best and most efficient from the energetic and thermal comfort points of view, 48kWh / m² / year for V1 and 49kWh / m² / year for V2. Note that variant 2 with cooked brick is the most optimal; it deserves serious consideration in any environmental program and also in the overall energy balance of a building.

Furthermore, it is worth noting that raw earth is very vulnerable to humidity and bad weather. In spite of this, its use can be recommended by applying the appropriate coatings or incorporating adjuvants to improve its performance.

## 4 CONCLUSION:

The present research work allowed us to examine and determine the influence of construction materials on the thermal behavior of a building, in terms of heating and cooling needs of a patio heritage house located in the Casbah of Algiers, by considering different wall compositions.

It is thus possible to know the most optimal variant in terms of energy, through a series of simulations. The results obtained make it possible to say that the cooked brick and the raw earth offer the best results in comparison with the variant with a mixture of terracotta and rubble and the variant in traditional masonry and concrete whose energy requirements are 48 and 49. kWh / m² / year and the heating requirements are 12 kWh / m² / year.

The values obtained make it possible to place the two variants 1 and 2 in the low energy consumption building (Bâtiment *Basse Consommation* - BBC) label, since their heating needs are lower than 50 kWh / m² / year. These values can therefore be considered as close to the passive house label whose heating needs are 10kWh / m² / year.

In addition, it was possible to determine the influence of these materials on the thermal behavior for different wall compositions for which a reduction in temperature could be obtained, since for a maximum outdoor temperature of 36 °C, the indoor temperature was 30 °C. However, for a minimum outdoor temperature of 2 °C, the indoor temperature was 17.6 °C. The average annual room temperature was 24 °C.

These encouraging results urge us to optimize the use of these materials and integrate them into the wall composition of our buildings for better indoor hygrothermal comfort, without major energy consumption, in order to better enhance our built heritage and therefore protect our environmental resources.

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