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Improving the indoor climate of the traditional Ottoman houses in the Medina of Algiers

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Abstract. The implementation of energy efficiency in historic buildings is limited and different parameters inhibit the improvement of microclimate conditions or energy performance. The aim of our research is to study the residential buildings of the old city of Algiers and to highlight the colonial and post-colonial transformations. The hygrothermal comfort is studied in order to identify a typical model of house having undergone transformations. This work requires a scientific and multidisciplinary approach integrating historical understanding, modern non-destructive inspection techniques and advanced experimental and numerical analysis methods (modelling and thermal dynamic simulation). The results show that in some cases of traditional houses, the transformations have been positive. The modification had a good functioning to modulate the variations of temperature and an indoor air quality allowing the occupants to profit from various zones of comfort.
In other cases the undergone transformations generated enormous disorder resulting from discomfort situations. This work will provide adequate solutions to improve energy efficiency and sustainability for this residential heritage.
Keywords. energy efficiency; sustainability; architectural transformation; residential heritage; hygrothermal comfort.

1. Introduction

Algiers is a city with a rich heritage and it has a great historical value, where different solutions meet the environmental requirements and more precisely the current comfort needs. It's the essence of vernacular architecture, represented by a process of progressive adaptation to the climate and the site.

Many scientific debates have been raised through numerous studies, economic or sociological ones [1] or dealing with site integration and urban composition [2]. The *Casbah* of Algiers has been apprehended by the history [3], religious and military [4]. Nevertheless, this work is a part of multidisciplinary focusing on the environmental issue, that is rarely been addressed, except from the view of the environment generated [5], sustainability and interior comfort of Algiers residential heritage [6].

During the colonial and postcolonial periods, these authentic houses underwent various transformations, expressing the desire of the inhabitants to rise to the norms of modernity and representing the result of the superposition of two architectural models, showing two ways of life (ancestral and contemporary) [7]. Sometimes considered positive, but often negative, they influence their hygrothermal comfort and their environment.

Basing on the two documents [8] dealing with the domestic architecture of the medina of Algiers, and Ottoman archival documents , the *Casbah* of Algiers includes three constructive typologies; house *Wast Al-Dâr* (with patio), house with *Chebâk* (in the form of a skylight and ventilation, house with *Ulwî* (attic).

In this work, we approached the typology *Ulwî* (This is a tall house without a patio which generally has no outside gate. Due to high urban concentration, it occupies a small parcel of land and is pierced with large openings to the street) and two case studies; the first will present a positive transformation and the other the negative one. In a previous research work [9], we studied the *wast-al-dâr* and *chebâk* typology [10].

2. Methodology

The applied methodology is inspired by the existing literature. In fact, many scientific studies have analyzed the interior comfort and energy performance of residential architecture [11].

First, this article briefly describes this type of vernacular architecture in order to provide exhaustive information on the configuration and characteristics (design, and distribution of the rooms) of the cases of described traditional Ottoman houses. Then, we identify the transformations during the colonial and postcolonial period (internal and external transformations).

Subsequently, measurements were made between August and January during the 2017-2018 to evaluate the indoor hygrothermal parameters. Finally, the results of the measurements are compared to a dynamic thermal simulation in order to validate the model and study the thermal behavior of the houses.

3. The Case study

3.1. The typology Ulwî at the Casbah of Algiers

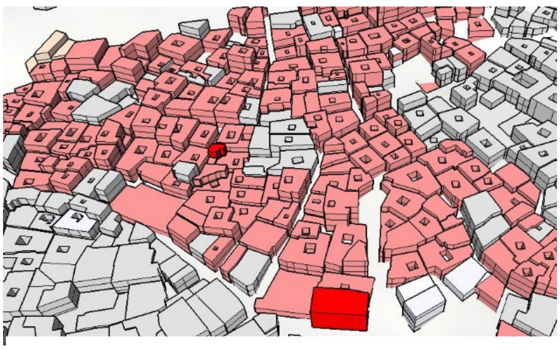

Figure 1. An aerial view of the two cases of houses at the Casbah of Algiers

The area concerned by our research corresponds to the upper *Casbah* as shown in **Figure 1**, the best preserved part, offering a high density of residential buildings, possessing the most authentic and functional houses.

The two cases of houses belong to the same typology and seem to have a positive transformation (minimal changes didn't affect the interior microclimate of the house - case "A") and negative transformation (huge changes leading to the loss of authenticity of the house, creating a situation of discomfort - case "B").

To identify transformations and study their impact on comfort, we used the OGEBC archives [12]. They first allowed us to identify the home state of the study house, then we conducted a preliminary survey on the site to locate and update the condition of the house.

3.2. The nature of the transformations undergone

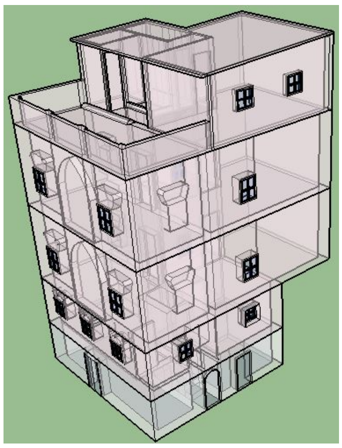

Figure 2. 3D of the house case "A"

3.2.1. Case "A". Located in Algiers (High Casbah), illustrated in **Figure 2,** it occupies a corner plot offering two facades, one on the deadlock and the other on the main facade of the street Frères Bachara, it belongs to ulwî typology, covering an area of 45 m² and a height of 12.5m. The interior space is harmoniously arranged, and the house consists of a ground floor comprising a kitchen, a storage room, a Sqifa (an entrance space, constituting a transition between public and private space). The house consists of two identical floors of two large rooms, and an elevation (Menzah) dating from the colonial period, consisting of a large room and a corner of water (bathroom and toilet). There is also accessible terrace. This house has undergone several transformations. At the level of the sqifa, there was a business office which is currently a kitchen with toilet and bathroom, two new windows were opened in the kitchen and change of Turkish WC to English WC. On the first floor there was the installation of a bathroom in one of the large bedrooms and the closing of a ventilation window. The second level is not occupied, with the closing of two windows, thus creating a loss of material and a humidity rate a little high, as for the level of the menzah (a terrace overlooking the site and the sea), there was the installation of new toilet. All floors of the house have been changed, from old Cedar wood was substituted by modern wood. Cedar wood by its nature has thermal properties far superior compared to modern wood. It has better insulation, which keeps the heat outside in the summer, and keep it inside in the winter, this which provides comfort and an incomparable atmosphere. Currently, this wood is rare and very expensive. New electronic devices were introduced, such as; fridge, a washing machine, a stove, an air conditioner, a fan and 2 televisions. The type of occupation is private and the users are the original owners (5 people), which explains the permanent maintenance of the building.

3.2.2 Case "B". Located in the high *Casbah* of Algiers, presented in Figure 3, it is inhabited by three families (5 people), whose main facade is on the street Rouane Abdelhamid. This house was divided in two at the arrival of the French, whose second part is currently destroyed. It covers an area of 30 m² and a height of 11.5 m. It consists of a ground floor where a toilet has been arranged and two identical floors consisting of a large room.

It has undergone several transformations. At the level of the entrance, a toilet was located. On the first floor, in the entrance hall, there was the arrangement of a kitchen area with the opening a new window. On the second level, there was the development of a kitchen inside the room and, at the level of the *menzah,* the enlargement of the room and the development of a room and kitchen in elevation. It is accessed with stairs on each side and under the stairs, there was the installation of two water points and the introduction of electronic devices; fridges, a boiler, a washing machine, computer, cooktops and televisions.

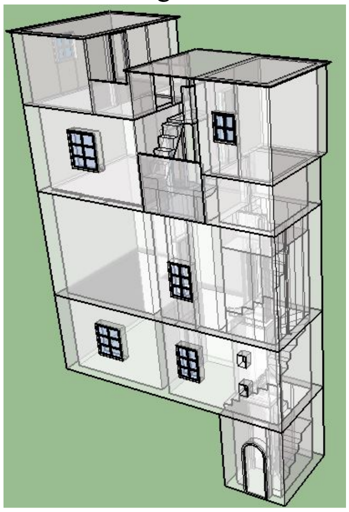

Figure 3. 3D of the house case "B"

4. Experimental measurement

The results are based on a measurement campaign conducted over two periods (summer and winter). In this work we will present the results of the summer period. Two cases of houses were identified, belonging to the same typology (case of the original and the transformed house). The measurement method was based on previous studies of the same subject [13]. In order to measure the thermo-hygrometric parameters (temperature, relative humidity and air velocity) according to the ISO 27726 standard [14], this measurement campaign was carried out according to the living conditions of the inhabitants, with the same number of occupants. We ensured that all original or transformed living spaces were measured using three instruments (see **Figure 4**), including two automatic and manual: data acquisition system (Fluke Hydra 2635A, series II, with 6 thermocouple connections, 4 K types and two T types), four internal mini temperature and humidity recorders (the Testo 174H model) and a manual anemometer (TMA5).

Figure 4. Measuring instruments

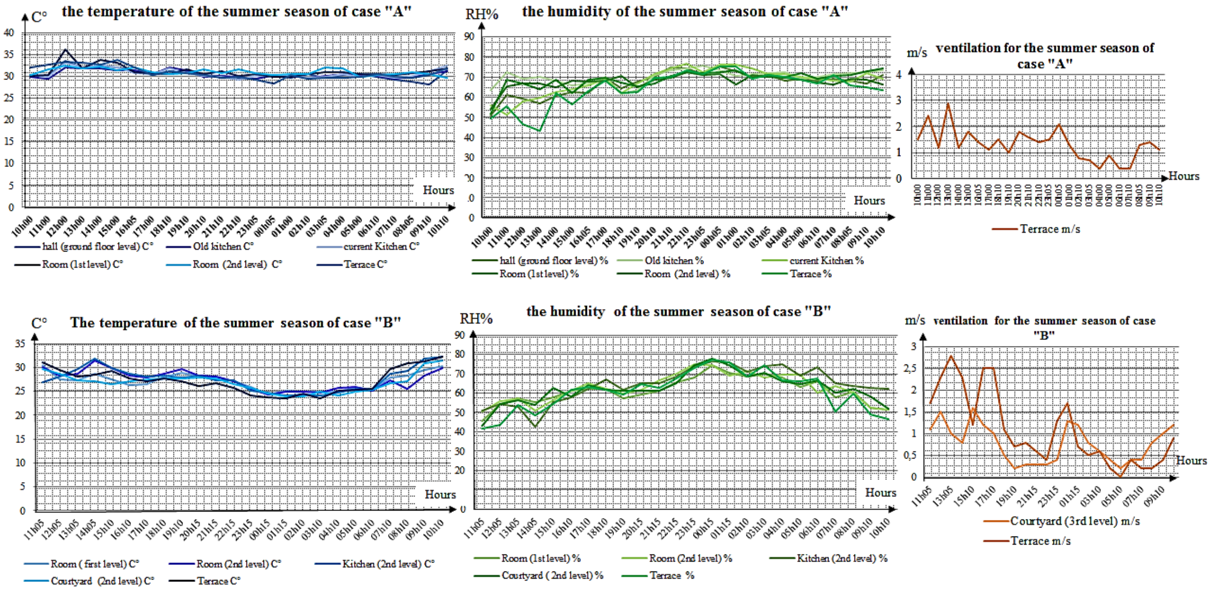

Figure 5. The results of temperature, humidity and ventilation obtained by the measurement campaign for the summer period

For the in situ measurement, as shown in the graphs of cases "A" and "B" for the summer period, illustrated in **Figure 5**, the temperatures vary between 25 C° and 30 C ° for the case "A" and between 30 C° and 35 ° C for the case "B". Regarding the rate humidity, it varies between 40% and 70% for the case "A" and 40% and 80% for the case "B". The houses of the *Casbah* suffer from high humidity in summer due to the use of new materials, such as concrete, which prevent the old walls from breathing, causing high humidity. For ventilation, the flow of air for case "A" is quite important and evolves between 1m/s and 3.5 m / s which show that the house "A" is airy in summer. The case "B" shows low and inconsistent ventilation, modulated between 0.5m/s and 2.5 m/s.

5. Thermal dynamic simulation

Thermal dynamic simulations were performed using the Design Builder v.4.8 software. Our work with Design Builder began with the construction of our models, selecting the site (geographical location defined as "Algiers") and its climatic data (introduced by the meteorological file). The results obtained were established by designing the parameters of the activity data, construction data, the openings and the HVAC data.

The results are presented in **Figure 6**. All the values collected over the 24 hours of a typical day give an average hourly reading, which was compared to the one simulated under the same conditions and for the same spaces. By using a specific mathematical equation (see (1)), we were able to calculate the error rate in accordance with the method developed by [15].

$$\boldsymbol{Error} = \frac{\textbf{\textit{the measured value}} - \textbf{\textit{the simulated value}}}{\textbf{\textit{the measured value}}} \times \mathbf{100} \quad (1)$$

In our research, based on the obtained numerical calculations, the error rate was relatively low: the simulation values were sufficiently close to those taken on site. The curves of the graph show a high degree of convergence. Thus, we were able to conclude that the model presented was accurate enough and could be used for the thermal calculations of the building.

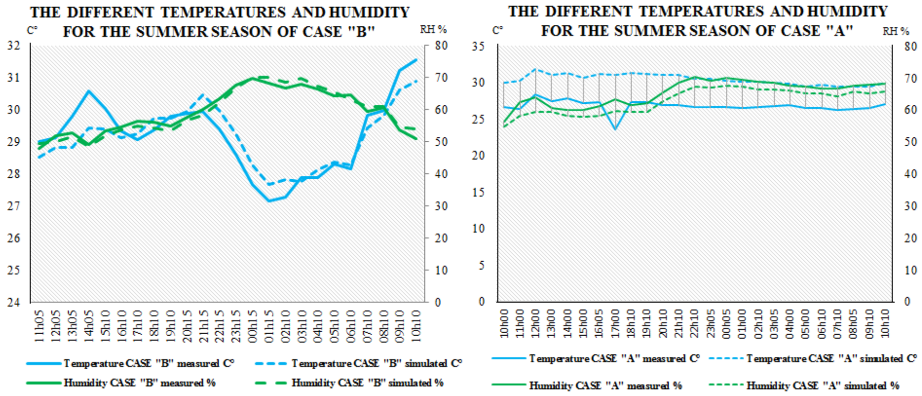

Figure 6. The results obtained by model validation of case "A" and "B" for the summer period

For Case A, the difference in temperature fluctuations, humidity, and ventilation are presented in **Figure7** between the house in its original and current state. The average maximum temperature in both cases is 25 ° C due to thermal inertia, which reduces fluctuations and serves as a temperature stabilizer. However, the disturbances are significant, which confirms the destabilization of the air circulation. In both cases, the humidity is estimated between 50% and 60%, which can be explained by the different thermal gradient associated with the thermal inertia of the walls. In the original case, the air distribution is natural, while for the transformed case, it is mechanical and the value vary between 0 and 2 vol /h, coinciding with the increase or the decrease of the temperature.
According to [16], relatively low levels of humidity, optimum temperature and air velocity levels contribute to creating a situation of optimal comfort.

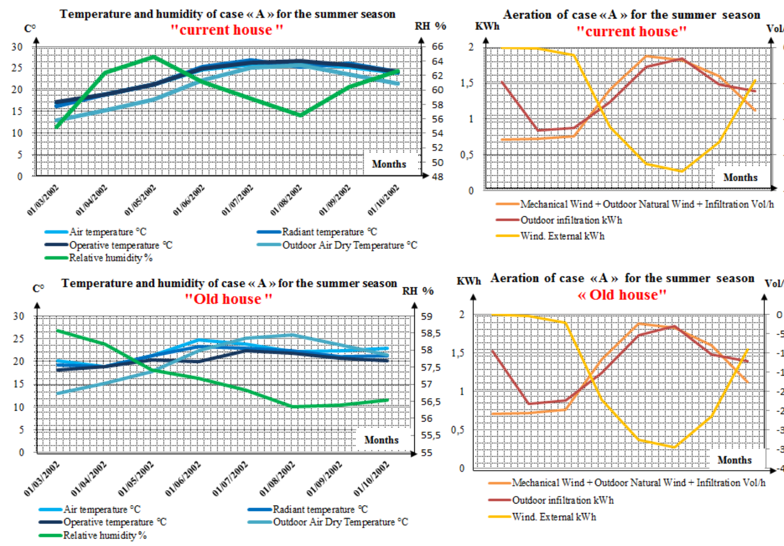

Figure 7. The results obtained by simulation of case "A" for the summer period

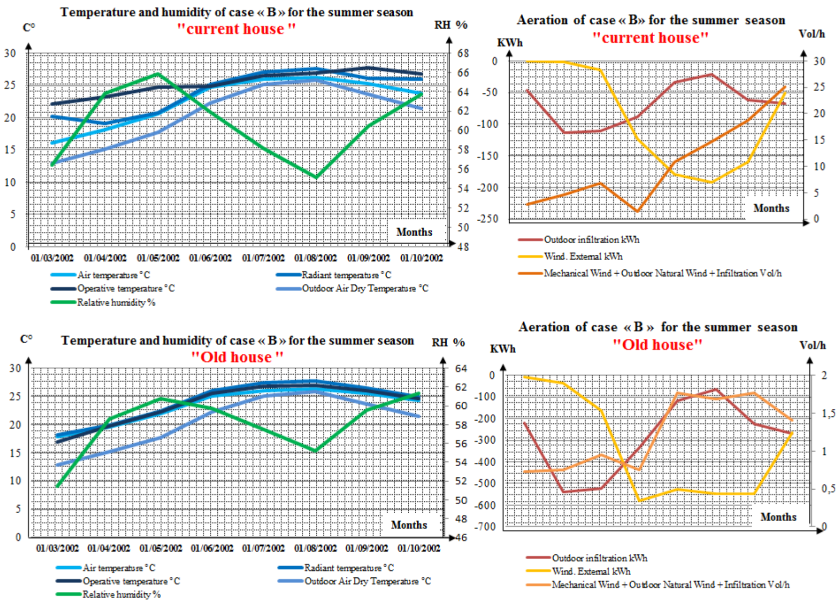

Figure 8. The results obtained by simulation of case "B" for the summer period

For Case B, as illustrated in **Figure 8**, the house in its original state shows a constant difference between the indoor and outdoor temperatures, confirming a balanced temperature transmission. However, the house in its current state shows no difference between interior and exterior temperatures, indicating insufficient transmission created by the architectural changes. With regard to humidity levels, significant differences between the two house states can clearly be seen, ranging from 50% to 62% for the house in its original condition, and from 60% to 70% for the house in its current state, during the summer season. For the former case, ventilation is natural and air transmission inside the house is constant, with no disturbance. For the latter, peaks of 2,5 vol/h can be observed. These figures can be explained by the phenomena of thermal inertia, humidity, due to the presence of heating and cooling appliances (air conditioning) which affect the temperature.

It is recommended that for optimal comfort, an air temperature of about 22°C should be maintained, with a relative humidity level of between 40% and 60%. The movement of air should be at a rate of 0.5 to 1m/s allowing people with little activity to feel a comfortable freshness. In warmer places, to provide satisfactory relief, speeds of 1.25 to 2.5m/s are needed [17].

6. Conclusion

In recent years, the trend has been towards the renovation of existing structures, taking into account current comfort conditions. This study takes a novel approach in assessing both the impact of the historical indoor climate on traditional houses of the *Casbah* in Algiers and the risk of deterioration of their indoor comfort. The methodology developed has shown that the reconstruction of the historic climate of a house is possible and may determine optimal changes that could meet the demands of current comfort.

The results obtained by simulation and in situ measurements, show that house B suffers from overheating. This is due to the different alterations that have been carried out by the residents without expert advice. It is, therefore, a case of negative transformation on the indoor climate of the house. The house A shows a positive transformation in terms of indoor climatic conditions. The minimal and well-established alterations have not affected the indoor comfort of the house.

The aim on this work is to build a detailed knowledge of the functioning of these traditional houses representing this rich residential heritage and taking into account its degradation according to the conditions of the indoor microclimate. We will also propose a series of renovation solutions and recommendations likely to improve the conditions and requirements of the current comfort in the houses of the Casbah

They are illustrated through Case "A", that fulfil the current comfort requirements of the occupants. The **natural ventilation** of the house can be improved by avoiding the obstruction of apertures or the opening of new ones. The installation of **modern ventilation** devices should be undertaken in a calculated way (**need**, **functionality**, **position**). **Traditional construction techniques** should be adopted and **local materials** used in order to improve the **durability** of the building. **Toilets**, **bathroom** and **water points** should be installed along the **same axis** as waste water evacuation. The installation of **kitchen appliances**, **computers**, **air conditioning** and **heating** equipment must be done, not only according to need but also in consideration of their strategic position so as to avoid overheating which inevitably leads to discomfort.

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