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Evaluation of Hygrothermal Environments in Traditional Houses with Patio: Case of an Old Mediterranean City

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Abstract

Vernacular architecture has always taken advantage of passive measures to adapt the building to the climate and protect the occupants from the rigors of the climate. Thus, traditional architecture has used many climatic adaptation solutions to achieve thermal comfort. This paper aims to evaluate and compare the quality of hygrothermal environments in two different cases of traditional houses with patio (house with open patio/house with covered patio), in a Mediterranean climatic context hot and dry in summer, cold and wet in winter. The proposed methodology is based on an objective quantitative study established on the numerical simulation of the thermal behavior in dynamic regime TRNSYS of two houses with patio (open/covered). The simulation is done during the hot season and the cold season. Two parameters were chosen to evaluate the hygrothermal comfort: the ambient temperature and the relative air humidity HR%. In-situ measurements validated the simulation results. A questionnaire survey, coupled with simulations and climate measurements, allowed for a subjective assessment of thermal comfort parameters (temperature, humidity, air movement). The results confirm the impact of the patio cover on the thermal comfort of the inhabitants.

Key words: Qualitative evaluation, hygrothermal comfort, numerical simulation, patio house, old town Constantine.

Glossary

- Aali: a small house of reduced surface, of two or three levels, located mainly at the level of the city's commercial streets and is distinguished by the elevation of its patio on the floor.
- Skiffa: a transitional space between the interior and the exterior. It has two doors, the entrance from the outside (bab eddar) and the one that gives access from a corner of the house (Bab Es-Skifa) to "ouast eddar".
- Bab Eddar: the entrance door from the outside to the inside of the house. It overlooks Skiffa.
- Bab Es-Skiffa: the front door, located on a corner of the house.
- Byout: multi-purpose rooms longer than wide, rectangular, grouped around the patio.
- Madjless: a rectangular room on the first floor with central access and two windows on either side of the door; this room is designed and furnished to receive guests.
- Ouast Eddar: central courtyard open to the sky; through the inner courtyard, the house spaces receive sunlight and ventilation.
- Sabat: covered passageway (covered tertiary way)

INTRODUCTION

The vast majority of humanity spends a significant part of its time inside buildings. A building, including its structure, envelope, lighting, energy production system, etc., must provide occupants with a pleasant indoor climate that is not dependent on external conditions, especially weather. The architectural quality participates in the conditions of comfort, or conversely, the comfort offered by a building is one of the aspects of its architecture [Roulet Claud-Alain, 2008]. The notion of thermal comfort, which represents an essential requirement in the building industry, is very complex to define because of the interaction of several physical (environmental), physiological (personal), and psychological variables.

However, it can be defined as a feeling of satisfaction expressed by the individual with regard to the thermal conditions of the environment that surrounds him. Thus, an indoor thermal environment is influenced by many parameters to which individuals are more or less sensitive depending on the context. Fig. 1 summarizes the phenomena involved in the characterization of thermal comfort.

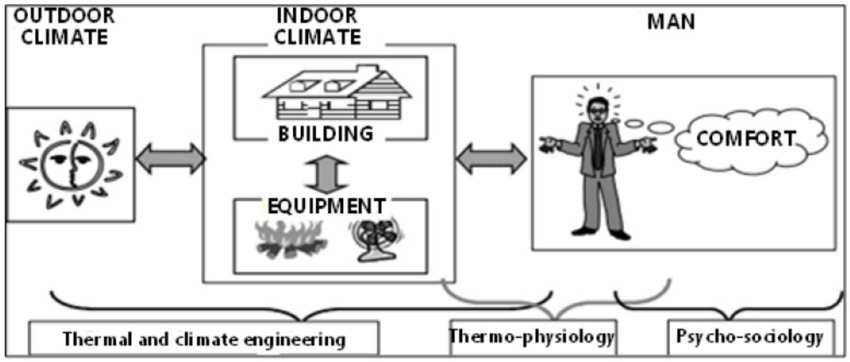


Figure 1. Sequence of the various phenomena involved in the characterization of thermal comfort

Both active and passive measures can be applied to ensure a good quality of the indoor thermal environment. The passive measures (compactness of the building, distribution of volumes and their orientation, location of openings, thermal insulation, natural ventilation) present architectural and constructive measures that allow achieving the desired goal naturally without energy input, or almost. Whereas active measures (heating, air conditioning) or technological measures allow reaching the desired goal by mechanical actions, consuming energy to compensate for the defects of the building or to complete the passive measures [Roulet Claud-Alain, 2012].

Several researchers have studied thermal comfort in traditional houses. Muhannad Haj Hussein [2012] presented a study on the abandonment of traditional courtyard dwellings (introverted) in favor of new residential concepts (extroverted). The latter are almost identical throughout Palestine despite its different climatic zones. This study investigates the quality of Palestinian habitats' thermal and lighting environments (traditional and modern). For this study, Muhannad Haj Hussein [2012] used qualitative and quantitative approaches. The author carried out an analytical and bioclimatic study of the traditional habitat in two climatically different cities in the first one. Then, the researcher investigated the characteristics and the socio-environmental dimension of contemporary housing through a survey. For the second approach, we carried out in-situ measurement campaigns in examples of different habitat typologies to validate the results obtained by the first approach. The results show that for traditional housing, the proportions and characteristics of the courtyard affect the quality of comfort. In contrast, in contemporary housing, it is the criterion of orientation that is the basis of the quality of the habitat.

Thus, in the traditional habitat, the role of the courtyard is decidedly significant in that it presents a cultural role, and sometimes, it has an impact on the environmental quality and comfort of the habitat. In modern housing, it is clear that despite the difference in climate between the two cities studied (Jericho and Nablus), the same building materials with the same construction scheme have been adopted. This aspect is a factor of discomfort. The author proposed to have envelopes in which the insulating material will be sandwiched between the stone facing and the interior part to ensure thermal inertia. Kindah and Semprini [2015] evaluated the influence of the thermal performance of the building structure and natural ventilation on the indoor thermal comfort of traditional and patio houses located in the old city of Damascus. The authors presented the monitoring data (temperature, humidity, and air movement) acquired in the summer, parallel with the occupancy survey to assess comfort conditions.

The results of the investigation of thermal comfort in some traditional buildings in the old city of Damascus show that the interior courtyards have a great influence on the passive cooling used in several regions of the Middle East (hot and arid climate) as well as different design factors, materials and operating conditions can influence on the thermal performance of the house. Thus, the structure of the building (high thermal mass on the first floor) and the height of the ceiling influence comfort. The position of the openings has great importance on the natural ventilation. Especially the stack effect (two levels of windows in the south hall with an elevation of about 8 m) and cross ventilation are better than one-sided ventilation. While, the use of the adaptive model offers results closer to the thermal comfort sensation survey, which shows large variability in subjective sensations.

Dili et al. [2010] studied thermal comfort in traditional residential buildings in Kerala, India. The authors expressed Scientific analyses of the environmental parameters determining thermal comfort have already been reported. They also compared the results of the scientific analysis with the responses of the inhabitants of traditional and modern residences. This comparison was done through a questionnaire survey. The survey is conducted in winter and summer. Three parameters of thermal comfort were studied: temperature, humidity, and ventilation. This study confirms that traditional residential buildings in Kerala effectively provide a comfortable indoor environment in different seasons.

Cho and Mohammadzadeh [2013] investigated natural ventilation systems in a traditional courtyard residence in a hot and dry climate. The study aims to analyze and evaluate passive energy systems to provide recommendations for the design of sustainable residential buildings. It was conducted in an existing traditional courtyard residence in Kashan, Iran. Jalil Shaeri et al. [2018] evaluated the thermal comfort in traditional houses in a tropical climate. The study's objective is to identify and evaluate the indoor thermal comfort of old houses in southern Iran (Bushehr). The results show that the passive techniques used in these old houses provide sufficient indoor thermal conditions.

Another research conducted by Basudev Gautam et al. [2019] presents a field survey on winter thermal comfort and clothing adjustment in traditional Nepalese houses. This study aimed to investigate the clothing adjustment of Nepalese inhabitants in traditional houses during winter. This study was conducted in traditional houses located in three different climate zones: cold (Mustang village), temperate (Kavrepalanchok village), and subtropical (Sarlahi village) during the winter of 2016. In this research, temperature measurements were adopted there in addition to the comfort survey. The obtained results showed that the difference in comfort temperature differs according to the climate zone. The mean clothing insulation was 1.63 clo in the cold region and 1.32 clo and 1.15 clo in the temperate and sub-tropical regions. The study expresses that in winter, the choice of clothing is based on the building's indoor and outdoor weather conditions.

Other researchers have compared the thermal performance of traditional houses with modern housing. Maatouk Khoukhi and Naïma Fezzioui [2012] studied the thermal comfort design of traditional houses in the hot and dry regions in Algeria. An evaluation of the thermal comfort has been done in both the modern and the traditional house. The comparative analysis is performed using TRNSYS software. The analysis results show that the modern house seems unsuitable for the desert climate. Indeed, except for air conditioning in summer, no other solution can ensure thermal comfort in summer. At the same time, the traditional house remains more effective in dealing with the problem of heat in summer.

In Indonesia, Sangkertadi, Tungka, and Syafriny [2008] made a comparative reading of the thermal comfort of traditional architecture and modern housing in North Sulawesi. Sangkertadi et al. evaluated thermal sensation for both types of houses (traditional and modern). Ten traditional houses in Minahasa (North Sulawesi province) and ten modern houses were used as sample houses. Sixty inhabitants who lived in these houses were interviewed using a questionnaire. The results show that for the inhabitants, the maximum accepted air temperature (feeling comfortable) in the daytime period is 29°C, with calm air and relative air humidity of about 60%. In the afternoon, the indoor air temperature of traditional houses drops rapidly concerning the outdoor air temperature. In contrast, the modern house keeps the air temperature until the beginning of the night.

Alzoubi and Almalkawi [2019] presented a comparative study between vernacular architecture represented by heritage houses (Fallahy Houses) and typical contemporary houses in the city of Umm Qais in northern Jordan in terms of thermal performance. This study analyzes parameters of heritage houses that influence human thermal comfort and energy consumption compared to typical modern houses. The study compares vernacular houses with contemporary, traditional houses in Umm Qais. The selected samples of each type of house were taken to evaluate the impact of vernacular design, construction, and material principles on thermal performance and comfort inside the houses. Computer simulation, accompanied by measurement tools and thermal cameras, was used for thermal analysis in the selected houses. Revit software was also used to validate the results and compare them with the actual results in the field. The results show that the passive design strategy in vernacular houses is more efficient than the techniques used in modern houses.

Based on the previous literature review, it can be said that vernacular architecture has always taken advantage of passive measures to adapt the building to the climate and protect the occupants from the rigors of the climate [Roulet Claud-Alain, 2008]. At the same time, traditional building methods achieved acceptable comfort conditions for most of the year. Thus, many climatic and passive design strategies are used in traditional houses to provide indoor thermal comfort. This architecture and these elements were developed in response to adverse weather conditions [Jalil Shaeri et al., 2018;

Fezzioui et al., 2021]. Traditional architecture has used many climatic adaptation solutions to achieve thermal comfort. In the traditional patio house, the high inertia of the structure linked to the local building materials (such as mud brick, stone, wood), the thickness of the walls, and the small openings made these architectural and technical devices an integral part of the design of these houses. These techniques ensure that the occupants gain or lose heat, creating the desired physical and psychological comfort conditions while limiting mechanical heating and cooling systems [M'Sellem & Alkama, 2009].

In some cases, houses have two parts, one for summer and another for winter, thus allowing seasonal nomadism [Foruzanmehr, 2016]. Thermally, the patio house is particularly well adapted to the hot and semi-arid climate. The patio enjoys a microclimate that is more temperate than the outside climate and thus acts as a buffer space between the interior of the house and the outside environment, especially in the hot season. It offers thermal solutions that do not contradict the life of the users, their traditions, and their belief system [ZEGHONDY, 2016]. Fig. 2 summarizes the functioning of the patio according to the following regulation cycles from a thermal point of view [Muhannad Haj Hussein, 2012].

During the night	Start of the day	At noon	In the afternoon
The patio floor and facades quickly dissipate the heat absorbed during the day; their temperatures become lower	The sun is still low. The patio remains cool as it only warms the upper parts of the patio walls	When the sun is very high (at the zenith), the ground receives the direct rays and transmits them by reflection to the surrounding walls, which increases the temperature of the air in the patio and the peripheral rooms, the ceiling diffuses, by the effect of the inertia, the freshness maintained since the night towards the bottom of the rooms.	The ground gradually returns to the shade, and a watering can refresh the atmosphere in the patio until nightfall.

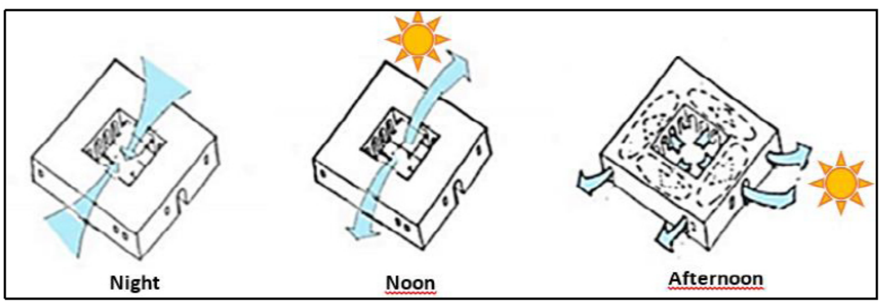


Figure 2. Thermal regulation in the patio during the day.

Many houses that border the Mediterranean basin are organized around a patio. Algeria is rich in its built heritage and traditional houses with patio, especially in Constantine as a Mediterranean country. One of the oldest Algerian cities, it is representative of the Arab-Muslim architectural heritage. Its strategic geographical position and the site's richness have given it the character of a historical city. To this end, the old town of Constantine contains an important reserve of houses whose traditional houses represent the major part of the built heritage.

This study aims to evaluate the quality of hygrothermal ambiances in two different cases of patio houses (open patio / covered patio) in this historic city. First, we introduce the subject by the thermal comfort in the buildings. Then, we focus on the thermal comfort in traditional houses and present a detailed state of the art on studies performed in different countries regarding hygrothermal comfort in traditional constructions. Section 2 presents the model adopted for the evaluation of hygrothermal comfort quality. Section 3 presents the case study and the houses selected for the study. Section 4 presents the approach we have chosen by detailing the application model and discussing the results obtained according to the methods applied. Finally, Section 5 presents the conclusions of this research.

METHODOLOGY OF APPROACH: TOWARDS A QUANTITATIVE AND QUALITATIVE EVALUATION

We used two different but complementary methods to assess thermal comfort in these two different cases of traditional houses: the objective quantitative and the qualitative, subjective methods. Fig.3 summarizes the adopted method.

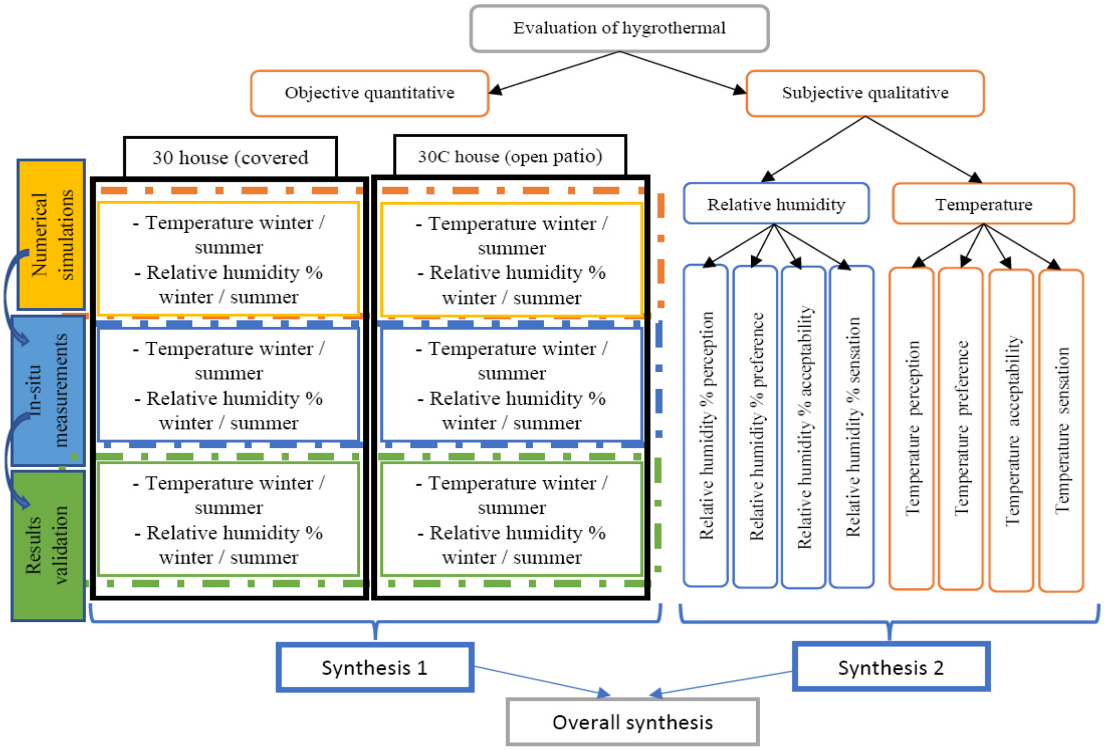


Figure 3. Working methodology. Source : Authors (2021)

Objective Quantitative Study

This quantitative study is based on numerical simulation of thermal behavior using the TRNSYS V17 computer program. The numerical simulations are done for the warm and cold seasons. For this purpose, two parameters were chosen to evaluate the thermal comfort: the ambient temperature and the relative humidity HR%. The simulation results were validated by in-situ measurements using a digital thermo-hygrometer model: C.A 846 CHAUVIN ARNOUX and a Digital Thermo-Hygrometer Htc2.

Subjective Qualitative Study

The satisfaction survey and climate simulations and measurements are the best way to obtain information on the inhabitant's atmosphere assessment. The principle consists of a questionnaire distributed to the studied houses with a patio. The questionnaire is divided into three parts. The first part concerns general information such as the date of occupation of the house, ownership of the house, number of people in the family. The second part concerns thermal comfort in winter, while the third part concerns thermal comfort in summer. We note that the second and third parts include questions of different scales (sensation, judgment, acceptability, preference) on the parameters of thermal comfort: temperature, relative humidity.

CASE STUDY: AN OLD CITY STEEPED IN HISTORY

Constantine: A Large Historic City in Northeastern Algeria With a Continental Climate

The old city of Constantine is a historical place par excellence very rich in architectural heritage, urban and landscape. It presents an incarnation of the model of the Arab-Muslim city. We find there a kind of protection of the city's inhabitants in front of the foreigner. The passage from the public space to the domestic space is ensured by a system of hierarchy allowing a progression from the outside to the inside, referring to social relationships directly inspired by Islam, regulating social and family life. The investigation was conducted in the old city of Constantine of latitude 36°16 North and 6°6 East. It is characterized by a Mediterranean climate, a cold and wet winter, and a hot and dry summer [Benharkat

& Rouag-Saffidine, 2016]. August is the hottest with an average temperature of 25.3°C, while February is the coldest with an average temperature of 7.1°C.

The Traditional House with Patio: Symbol of the Traditional Architecture of Constantine

The study conducted concerns two houses in a traditional neighborhood of the old city of Constantine (Souika). The urban typology is compact. The selected houses are traditional houses with patios, of which the first is the large house with an open patio (30Chouse). The second is an Aali-type house with a covered patio (30 house). These are located on one of the most famous Derbs in the old city, Derb Ben Elbdjaoui, located at the south-west of the upper part of Souika, straddling between the neighborhood Sidi Bouanaba and Saida. The Derb is accessed from Sellahi Taher street, where there is a passage under Sabat that leads to the selected houses.

Taher street, where there is a passage under Sabat that leads to the selected houses.

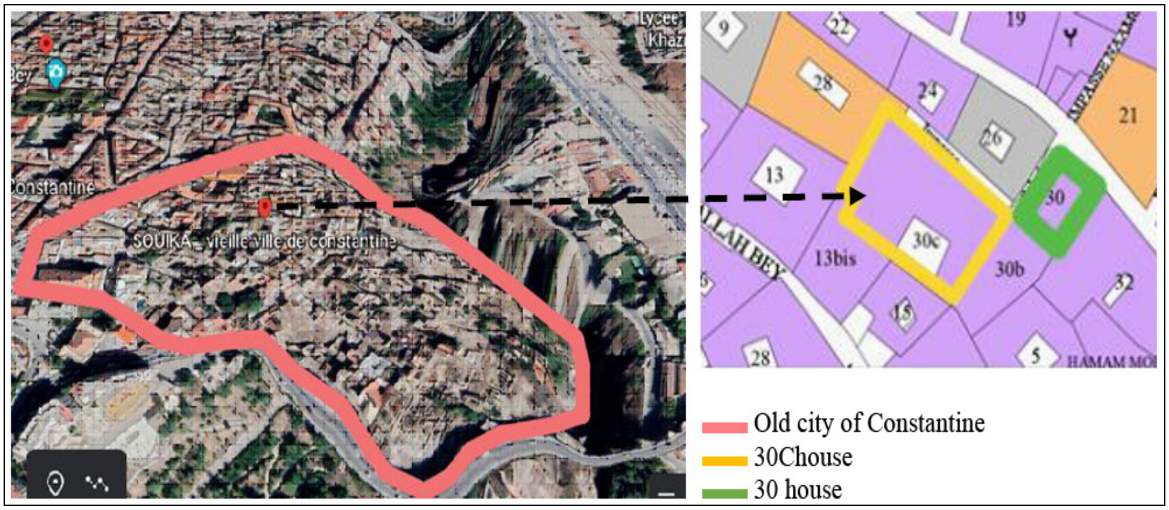


Figure 4. Location of the houses - old town of Constantine.. Source: PPSMVSS Plan (2012)

The Large House with an Open Patio (30C House)

The large house, of three levels occupying a large plot of land, is rich in architectural elements. It is a house with columns decorated with capitals. It is rich in architectural elements and has two floors. Tradition, climatic aspects, intimacy, and the separation of public and private life have dictated the interior design of this house. The internal isolation considerably reinforces the entrance to the house through a closed space, accessible from the sabat, which allows introspection from the outside thanks to a segmented area in the form of a chicane. This area is called skiffa. It has two doors, the entrance from the outside (Bab Eddar) and the one that gives access from a corner of the house (Bab Es-skiffa) to "Ouast Eddar". On the square plan of the patio, the patio is the center of the domestic environment. It is curved by three arches (Fig. 5). The three levels of the house are articulated around this space.

The first floor includes skiffa, byout (bedroom) and medjless, the kitchen and the sanitary facilities. The other levels are almost similar to the ground floor.

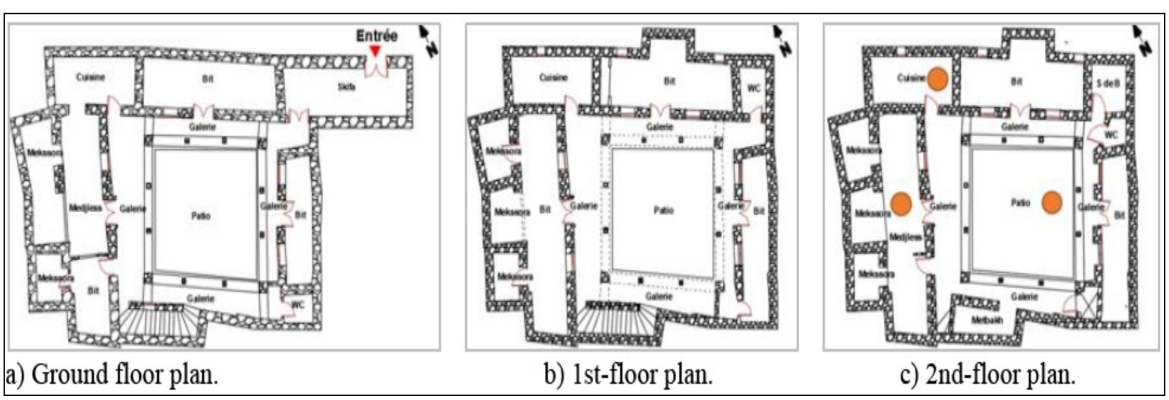


Figure 5. Floor plans of a 30C house. Source: Authors (2019)

Aali House With Covered Patio (30 House)

The house is located in a corner position of the block, overlooking a shopping street to allow the opening of windows on an open space. Shops also occupy the first floor of the house. The house, accessible by narrow stairs leading to the patio closed by a removable cover, rises on two floors. This one arranges a room of good dimension at each level that gains space by corbelling on the street.

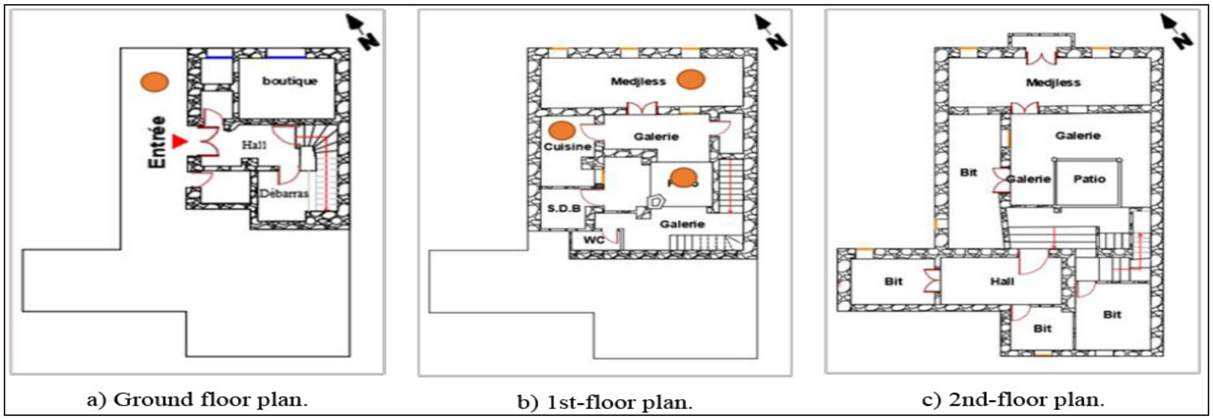


Figure 6. Floor plans of a 30 house. Source: Authors (2019).

RESULTS AND DISCUSSION

Objective Assessment of Hydrothermal Environments in Patio Houses

Simulations of Hygrothermal Environments in Patio Houses

The simulations are carried out with the TRANSYS software, which integrates all the characteristics of a building and its equipment (heating systems, air conditioning) to carry out a detailed single or multi-zone study of its thermal behavior. The simulations are performed during the summer's hottest day (August 29, 2020) and the coldest in winter (January 14, 2020).

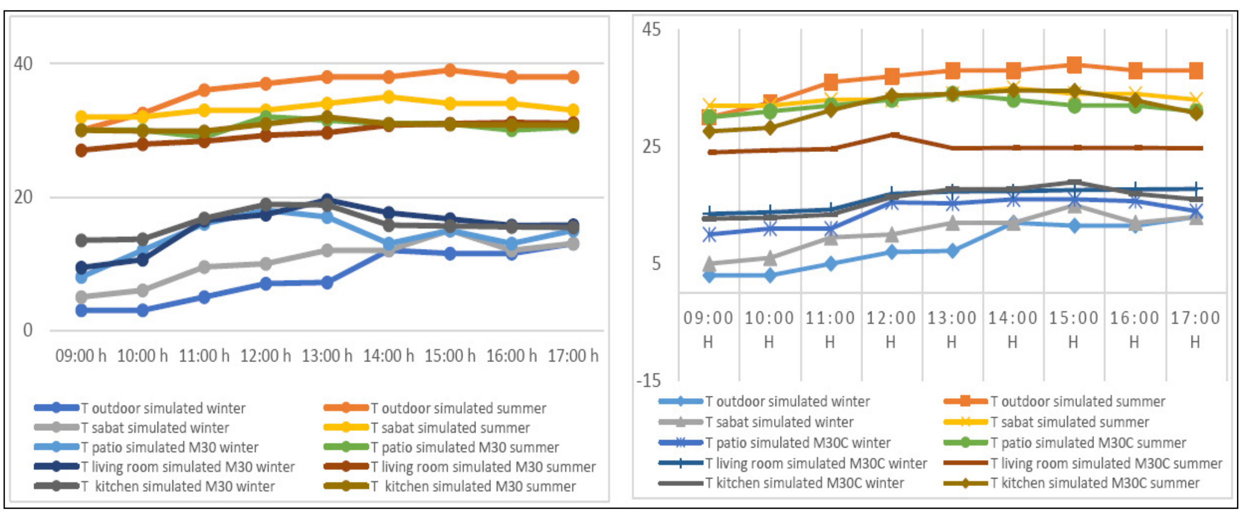


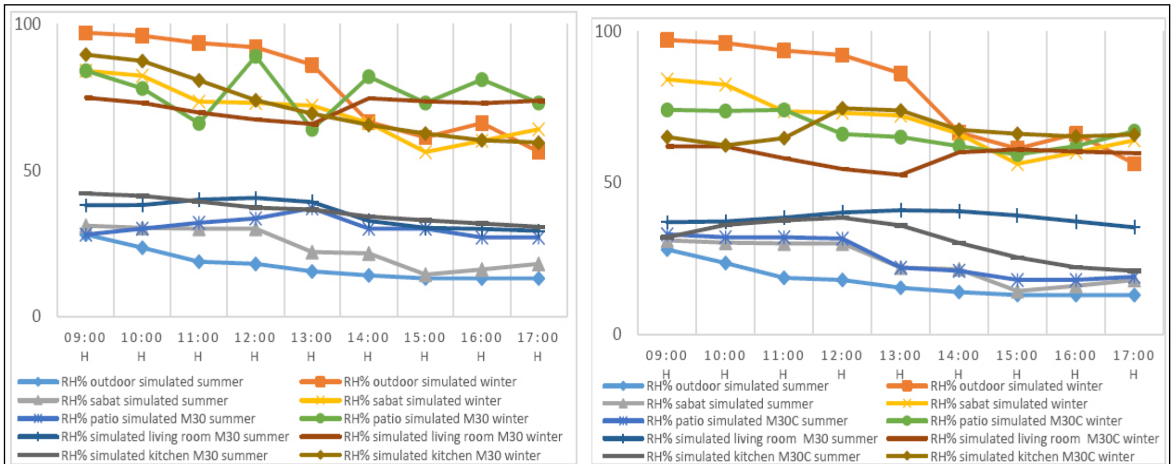
Figure 7. Simulated temperature variation (winter/summer) in M30 house and M30C houses. Source: Authors (2020)

Comparing the temperatures of the covered and open patio, we observe that the temperature of the open patio is slightly lower than the temperature of the sabat. This one varies between 30ºC and 34ºC, with a difference of 4ºC. The temperature of the covered patio reached its maximum value of 32ºC at 12:00 (at the time of the cooking). We conclude, therefore, that the temperature of the covered patio is lower than the temperature of the open patio because the covered patio is protected from the summer sun. The simulated indoor temperatures of the kitchen and living room in the open patio house vary between 24 ºC and 34.6 ºC. The highest temperature (34.6 ºC) is found in the kitchen at 14:00 (during cooking time). While the kitchen temperature in the covered patio house is almost constant, it varies between 29.86°C and 31.97°C, and the living room temperature varies between 27°C and 31.17°C.

In winter, we see a gradual evolution for the outside temperature and the temperature of the sabat in the time slot 09h -14h. It increases slightly in the last hours of the afternoon (towards sunset). This temperature variation corresponds to the degree of intensity of the solar radiation received.

In contrast, the temperature of the open patio is always higher than the outside temperature, with a maximum difference of 7ºC at 3 pm. This difference is due to the high thermal inertia of the stone that presents the main element in the composition of the walls. The marked difference for the covered patio is greater than that recorded in the open patio (11 ºC). The indoor temperatures of the open patio house are very close due to the absence of cooking activities in the kitchen. They are varied in a range of 12.7 ºC to 18.95 ºC. In the house with a covered patio, we notice that the kitchen's temperature is almost always higher than that of the living room due to the use of this space for cooking. We also note the increase in the temperature of the patio in parallel with the evolution of the kitchen's temperature, which is due to the opening of the kitchen to the patio.

Relative humidity % simulated winter/summer in M30 and M30C houses



a) M30 house b) M30C house

Figure 8. Variation in simulated relative humidity % (winter/summer) in the M30 house and M30C houses. Source: Authors (2020)

Fig. 8 shows that the outdoor relative humidity in summer at 9 am is 29%. It starts to decrease to reach its minimum value at 5 pm (14%). Thus, the relative humidity of the sabat is higher than the outdoor relative humidity, with a difference of 12% at noon. This result is explained by the lack of wind in the sabat. In the house with an open patio, the relative humidity of the patio is slightly higher than the relative humidity of the sabat, with a maximum difference of 3.7% recorded at 15h. Also, the relative humidity of the house's interior rooms (living room, kitchen) is in the range of 20% and 40.93%, while the relative humidity of the covered patio varies between 28% and 37%. We note a large difference between the humidity of the patio and that of the sabat (15.7%). The relative humidity inside (living room, kitchen) is always higher than outside. They vary between 29.24% and 42%. The maximum value (42%) is recorded in the kitchen at 9 am.

In winter, the outdoor relative humidity is very high in the morning. It starts to decrease from 98% to its minimum value of 56.3% at 5 pm. To this effect, the relative humidity of the sabat is always lower than the external relative humidity, with a maximum difference of 21% located at 11 am. The relative humidity of the open patio is almost constant from 9 am to 11 am. After this time slot, it starts to decrease to reach its minimum value (59.3%) at 3 pm, and then it starts to increase. It can be noted that the relative humidity is very high in the covered patio (89%), generated by the closure of the patio and the lack of ventilation. In the open patio house, the lowest relative humidity is recorded in the living room in the range of 52.59% and 62%. This is due to the absence of human activity in the living room. While, the relative humidity in the kitchen is higher than that of the living room, reaching its maximum value (74%) at 13:00 when preparing lunch. Therefore, in the house with a covered patio, the relative humidity of the living room and kitchen is high, varying from 59.43% and 89.50%. We explain this result by the presence of people in the spaces (production of water vapor that increases the humidity) and cooking.

In-Situ Measurements

We carried out in-situ measurements with the help of measuring devices (digital thermo-hygrometer C.A 846 CHAUVIN ARNOUX and a digital thermo-hygrometer Htc2). The hourly temperature and relative humidity readings were measured (from 09:00 to 17:00) during the same days selected in the simulations (August 29 and January 14). The space object of the experimentation is the patio, the living room and the kitchen, and the sabat and the street. Figures 5 and 6 show the rooms selected for this measurement campaign. The devices are placed in the geometric center of the spaces in question, at the height of 1.1 m from the floor level, as recommended by the ISO 7726 standard.

Winter/summer measured temperature in M30 and M30C houses

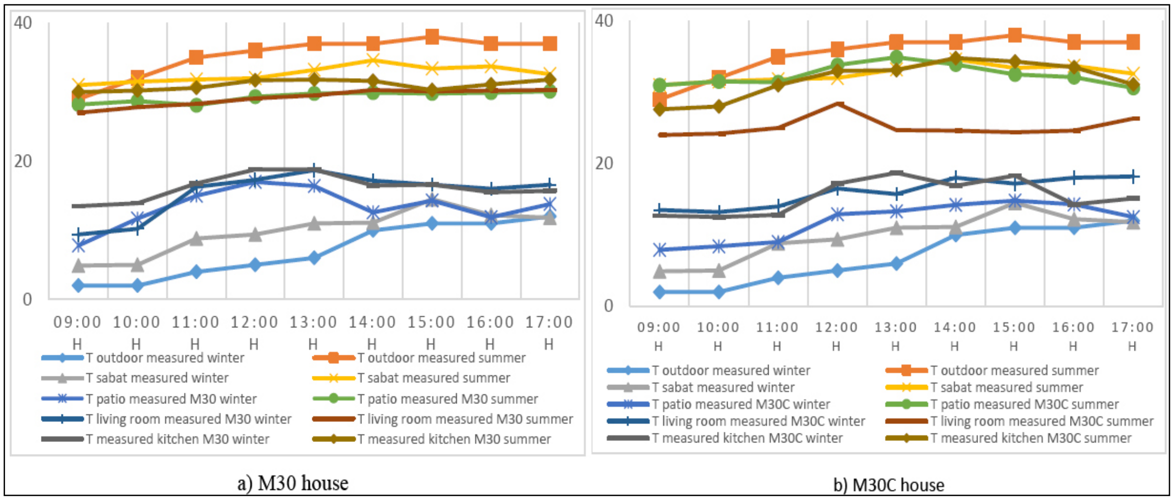


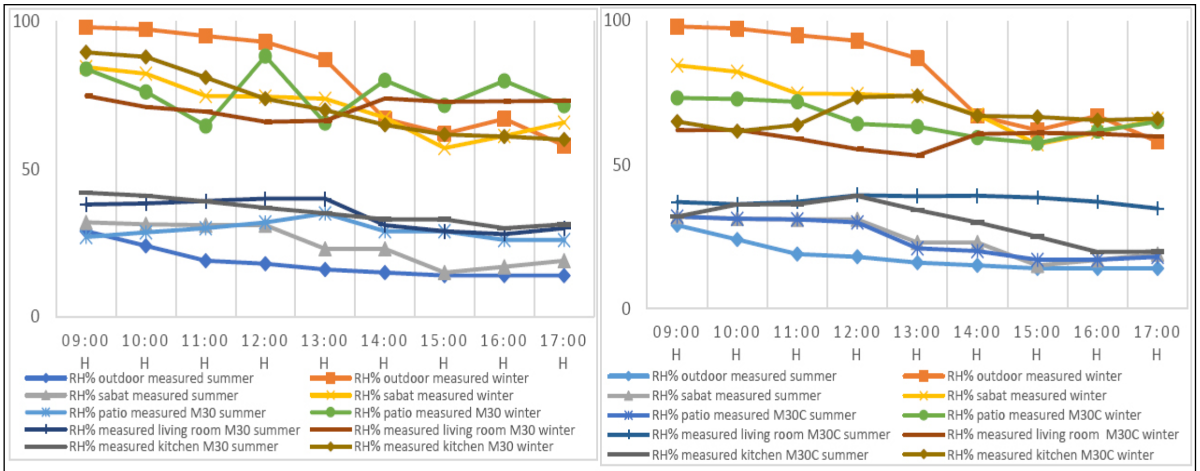
Figure 9. Variation of measured temperatures (winter/summer) in the M30C houses. Source : Authors (2020)

Fig. 9 indicates that in summer, the temperature of the patio is almost always lower than the outside temperature, with a difference of 4.6 ºC recorded at 3 pm. Comparing the patio temperatures, we distinguish that the temperature of the open patio is always higher than that of the covered patio. The maximum temperature of the open patio is 34.9°C, while the highest temperature of the covered patio is 29.9°C. Also, the temperature of the covered patio is almost constant, with a slight amplitude of 2.01 ºC. Concerning the interior temperatures of the house with a covered patio, that of the kitchen is constant from 09h to 10h. After 10 am, it starts to rise and reaches its maximum value (34.80°C) at 2 pm. The lowest temperature curve is recorded in the living room (24°C to 28°C). It is also observed that the kitchen temperature in the house with a covered patio (between 27.6 ºC and 34.80 ºC) is higher than the temperature of the living room (24 ºC and 28.40 ºC). We found that the kitchen's temperature is always high because of the great frequentation of this space and its use for cooking.

In winter, the reading of the recorded temperature curves shows that the outdoor temperature is the lowest. It varies between 2°C and 12°C. In addition, the temperature of the sabat is higher than that of the outside, with a maximum difference of 5°C recorded at 13h. This is due to the thermal inertia of the stone and the coverage of the sabat. In contrast, the temperature of the open patio is recorded in a range of 7.9°C to 14.8°C. The temperature of the covered patio differs between 7.8°C and 16.4°C. We notice that the temperature of the covered patio is higher than the temperature of the open patio. Concerning the interior temperatures (kitchen, living room) of the house with an open patio, they have a range of 6.2°C. We notice that the curve of the kitchen's temperature is close to that of the stay. We observe that the interior temperature is homogeneous despite the existence of the patio. Fig. 9.a shows that the temperature curves of the kitchen and the living room of the house with a covered patio are almost similar. The big difference between them is 4 ºC recorded at 09h.

Fig. 10 shows that the highest relative humidity of the outdoor air in summer is recorded at 09h (29%). It starts to decrease to reach its minimum value at 15h. The relative humidity is constant between 15 h to 17 h. Thus, the relative humidity of the sabat is almost constant during the morning slot from 09h to 12h. The amplitude of the latter is 12% during the time slot 12:00 to 17:00. We observe that the relative humidity of the sabat is higher than the outdoor relative humidity, with a maximum difference of 13%, marked at 12:00. The relative humidity of the open patio is almost similar to that of the sabat (from 18% to 32%). At the same time, the relative humidity of the covered patio varies between 26% and 35%. Therefore, it can be seen that the relative humidity of the covered patio is higher than that of the open patio.

Relative humidity % measured winter/summer in M30 and M30C houses



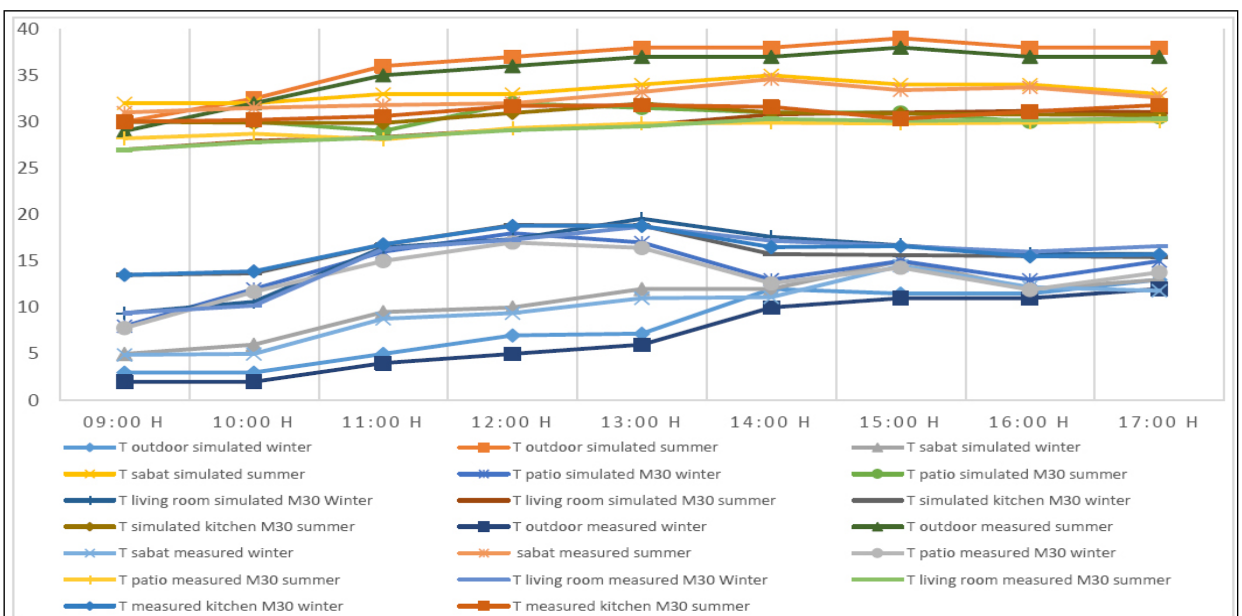
a) M30 house b) M30C house

Figure 10. Variation in relative humidity % measured (winter/summer) in the M30 and M30C houses. Source: Authors (2020)

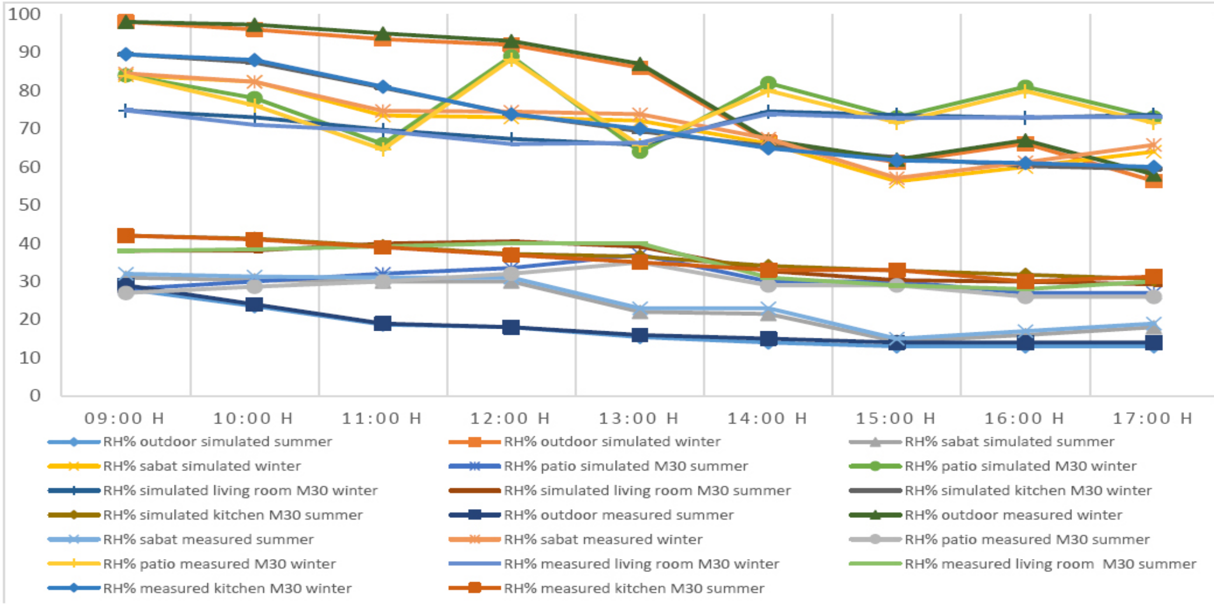
However, the relative humidity of the living room (open patio house) is almost constant throughout the day, with an amplitude of 4.6%. At the same time, the relative humidity of the kitchen has a high amplitude of 19.4% between the maximum relative humidity, 39.1% recorded around 12:00, and the minimum 19.7% marked at 16:00. Nevertheless, the indoor relative humidities (living room, kitchen) of the covered patio house vary between 28% and 42%. In winter, the outdoor relative humidity is very high in the morning, during the time slot 09h to 13h. While from 13:00, it begins to decrease to reach its minimum value (58%) at 17h. Thus, the amplitude of the relative humidity of the sabat is 27.4% due to the air fog that is very high in the morning. The relative humidity of the sabat is higher than that of the open patio. The big difference is recorded at 12:00 (28%). We note that the relative humidity of the covered patio is higher than that of the sabat. To this end, the relative humidity of the kitchen in the open patio house is higher than the relative humidity of the living room. This is explained by the cooking and the high use of the kitchen, where the maximum relative humidity (74%) was recorded during lunchtime. However, the relative humidity recorded in the kitchen of the covered patio house is very high (89.5% at 09h). However, it decreases to a minimum value of 60% at 17:00.

Validation of Results: Measured and Simulated Values

We compared the simulated and measured values (temperature/humidity) to validate our results.



a) Validation of winter/summer temperatures for the 30 house.



b) Validation of relative humidity % winter/summer for the 30 house.

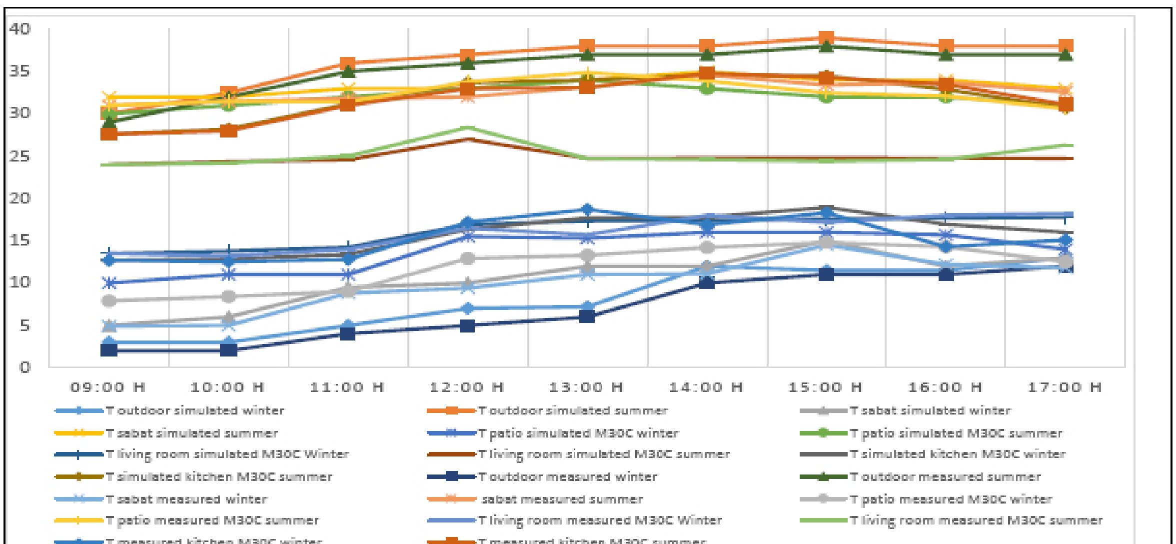
Figure 11. Validation of temperatures and relative humidity % winter/summer for the 30 house.

M30 house

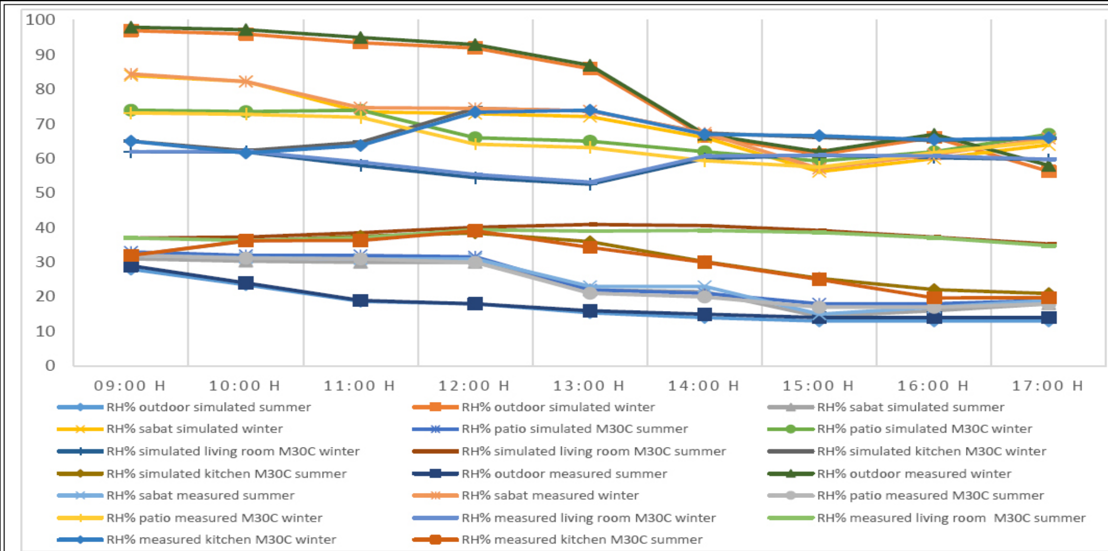
The comparison of variation of measured and simulated ambient air temperatures shows a slight difference of 0.86 ^{0}C between the highest temperature in winter and 0.12 ^{0}C for the lowest temperature in summer. Fig. 11.b shows the simulated and measured relative humidity. We notice a maximum difference of 2% between the measured and simulated relative humidity in summer. Concerning the winter relative humidity, we recorded a difference of 1.9%. The consistency ween simulation and measurement results is generally acceptable.

M30C house

The comparison of measured and simulated ambient air temperature variations shows a difference of 2 ºC for the winter temperature and 1.57 ºC for the summer temperature. Fig. 19 compares the actual relative humidity measurements and the simulated values. It is noticeable that the percentages of relative humidity measured and simulated are close. The maximum difference between the two in summer is 2.3%, while the percentage is 2% during winter. The agreement between the two is generally acceptable. However, the differences in results recorded for temperature and humidity prove the reliability of the simulation model.



a) Validation of winter/summer temperatures for the 30C house.



b) Validation of relative humidity % winter/summer for the 30C house.

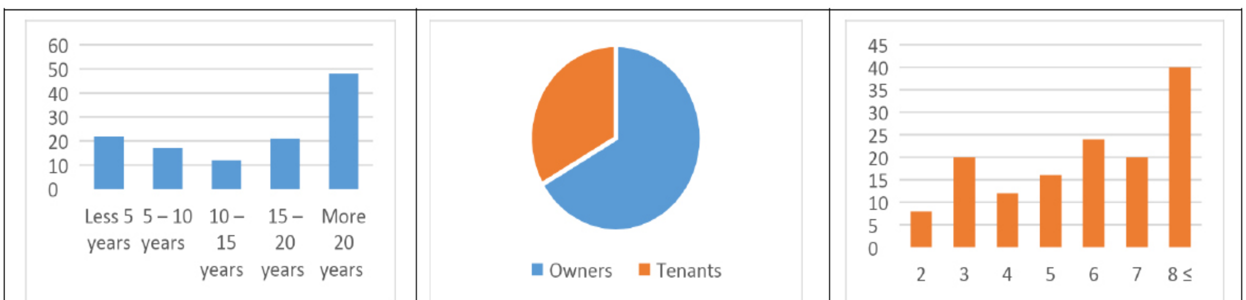
Figure 12. Validation of temperatures and relative humidity % winter/summer for the 30C house. Source: Authors (2020)

Perception of Thermal Comfort Through Surveys

Several methods can be used in thermal comfort perception studies. For this study, we used the questionnaire, a fairly common instrument in this field, is adopted to obtain answers regarding the perception of thermal comfort parameters in traditional housing. For this purpose, 240 questionnaires were filled in and returned through two investigation periods (winter/summer).

General Information on the Inhabitants

The results indicate that 40% of the inhabitants are former occupants of the traditional patio houses (living in the houses for more than 20 years), while 17.5% have been living in them for 15 to 20 years, against 10% of the inhabitants living in them for 15 to 10 years and 14.17% for 10 to 5 years. The rest of the inhabitants live in the houses for less than 5 years (Fig. 13-a). Concerning their status, 67% of the inhabitants are owners of the houses against 33% are tenants (Fig. 13-b). 33.33% of the families in the patio houses are families of 8 persons and more, while 15% are families of 7 persons. The other families vary between 2, 3, 4, 5, and 6 persons (Fig. 13-c). It is noticeable that most families in traditional houses are large families.



a) Date of occupation of the house. b) Homeownership c) Number of persons in a family.

Figure 13. General information on the inhabitants. Source: Authors (2020)

Perception of Hygrothermal Comfort Parameters

Temperature perception

In summer, the thermal atmosphere is qualified as "slightly warm" by 71% of the inhabitants interviewed, while 17% indicate a "war" sensation. The other percentages differ between slightly cold (3.33%), neither hot nor cold (5%), and very hot (4%). The highest level of judgment is obtained by the direct vote "comfortable". It presents the percentage of 46%

against 29.16% of the inhabitants who consider that the thermal environment is “not very comfortable”. The percentage of judgment “not very comfortable” presents 16.66%. 8.33% of the inhabitants consider the thermal environment as “uncomfortable”. 67% found the thermal environment “quite acceptable”, while 21% found the acceptability “just acceptable”. In addition, 8.33% of the inhabitants find the thermal environment “just unacceptable” while 4.16% find the temperature “quite unacceptable”. 50% of the answers are in favor of not changing the room temperature “without change”. Finally, 33.33% prefer a “slightly colder” temperature, while 16.66% prefer a “colder” thermal environment.

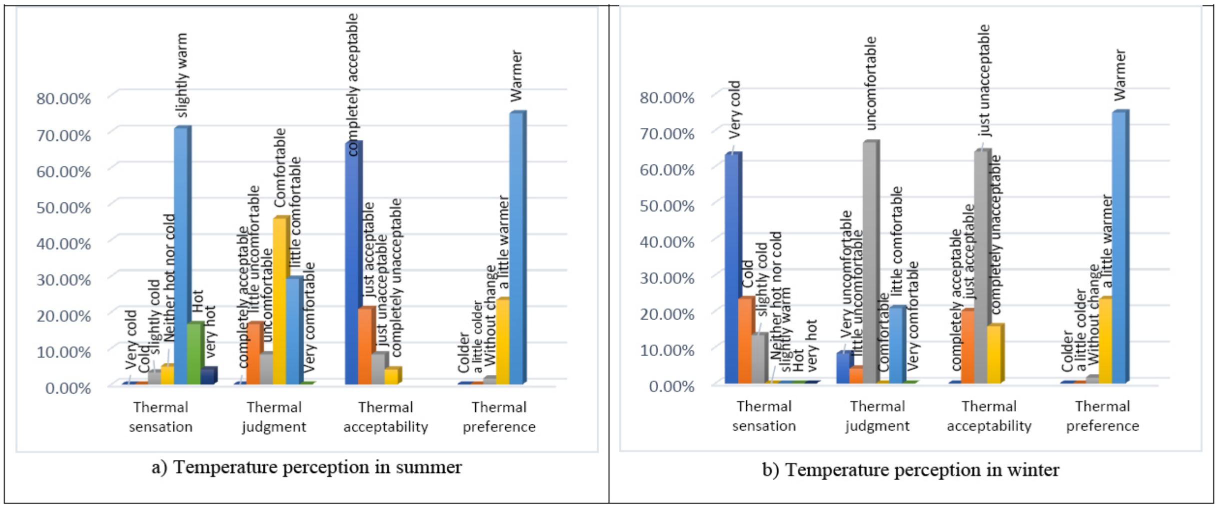


Figure 14. Temperature perception. Source: Authors (2020)

According to Fig. 14-a , the thermal sensation “very cold” represents 63.33% of the votes while the sensation “cold” represents 23.33%. The sensation of “slightly cold” is expressed by only 13.33%. The thermal judgment “uncomfortable” is the most important (66.66%). However, the percentage of 8.33% presents “very uncomfortable”. The rest of the percentage varies between “little uncomfortable” (4.16%) and “little comfortable” (20.83%), only by 13.33%.

Perception of relative humidity %

The sensation of humidity “neither wet nor dry” presents 59.16% of the votes, as well as the sensation “slightly wet “represents 23%. While the sensation “slightly dry” presents 11%, the sensation “humid” is expressed by only 8% of the inhabitants. According to Fig. 13-a, the highest level of humidity perception is the one obtained by the direct vote “normal” of the inhabitants, which shows that 75% consider the environment normal. 16.66% consider the environment “humid”. 8.33% presents the percentage of the dry environment. The percentage of “completely acceptable” moisture acceptability is the highest, “66.66%”, while the percentage “just acceptable” is equal to 29%. %. 4.34% presents the “just unacceptable” percentage. 83.33% of the inhabitants are in favor of the humidity remaining as it is “without change”, while 16.66% prefer a drier temperature.

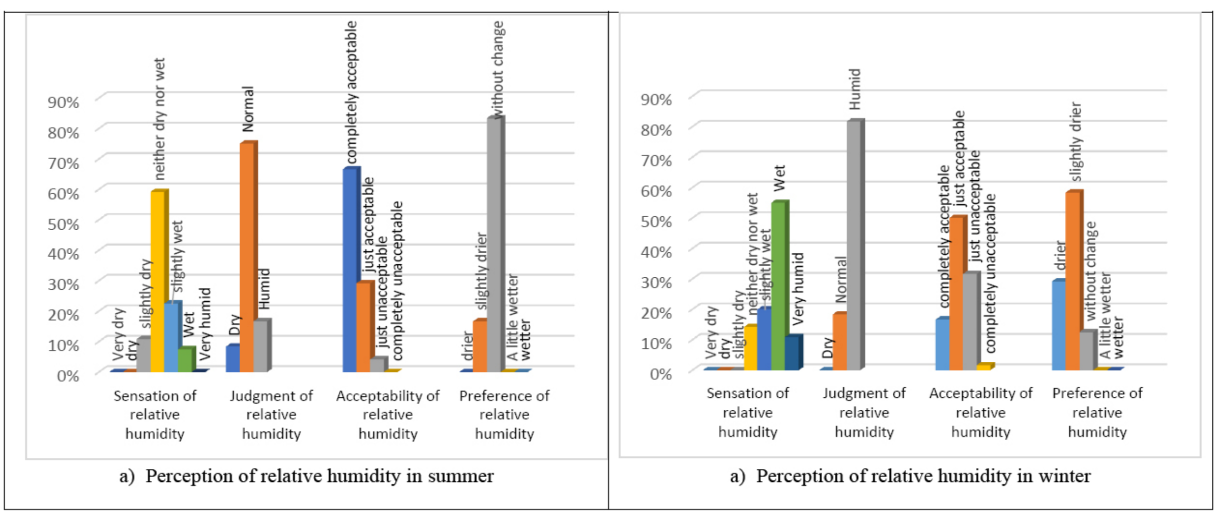


Figure 15. Perception of relative humidity. Source: Authors (2020)

In winter, the sensation "wet" presents 55% of the votes, against 20% that the sensation "slightly wet" represents, while the sensation "neither dry nor wet" is expressed by only 14.16% of the inhabitants. According to Fig. 15-b, the highest level of the humidity perception was obtained by the direct vote "humid" of the inhabitants with 81.66%. 18.33% consider the environment "normal". The percentage of acceptability of relative humidity% "just acceptable" is the highest "50%" while the percentage "just unacceptable" is equal to 31.66%. 16.66% has the "just acceptable" percentage while "just unacceptable" has 1.66%. 58.33% of the inhabitants prefer a "slightly drier" atmosphere. The percentage of "drier" presents 29.16%, whereas 12.5% of the inhabitants attest that the humidity remains "without change".

Based on the perception of the different thermal comfort parameters, it can be noted that the traditional patio house is comfortable in summer and less so in winter.

CONCLUSION

This study highlighted the hygrothermal performance and behavior of the traditional house in Constantine and how it reacts to climatic conditions using natural and passive methods to ensure comfort. This work evaluates and compares the results of an objective analysis of the hygrothermal comfort in two different traditional houses located in the north of Algeria exactly in the old town of Constantine. In contrast, the subjective evaluation is based on the hygrothermal comfort perception responses of the inhabitants of the traditional houses. The results indicate that the composition of the traditional fabric of the old town contributes to the improvement of the outdoor thermal comfort thanks to the winding and narrow streets which are shaded during the day, except when the sun is high in the sky.

Thus, the streets, sabat, and dead ends are protected by the projection of rooms built in cantilever over the road, thus decreasing the temperature in relation to the outside temperature. Beyond the classical construction techniques that improve the quality of the interior atmosphere of the traditional house, such as the reduced dimensions of the openings, the orientation of the constructions or the construction materials, the combination of certain architectural elements (vegetation, fountain) associated with the behavior of the occupants, these techniques participate in the improvement of the feeling of comfort inside the house.

Furthermore, the results indicate that both house typologies share several common advantages and failures with regard to the study of hygrothermal comfort. Nevertheless, both houses seem to be unsuitable for winter. Therefore, there is no other solution to ensure thermal comfort apart from heating in winter. Therefore, the open patio typology design has fewer deficiencies concerning temperature and humidity in summer than in providing comfort conditions in winter. However, the house with a covered patio is more comfortable in winter than the one with an open patio, but it presents the problem of humidity. The measurement campaign validated the results of the numerical simulations.

In addition, the subjective investigation of the quality of thermal comfort in the traditional patio house indicates that the hygrothermal comfort in the traditional patio house is acceptable in summer. It also states the crucial role of the courtyard on the hygrothermal comfort quality. On the other hand, the traditional house in Constantine shows several deficiencies in winter. This survey confirms the results of the objective analysis. In our future study and based on the results obtained, we can propose solutions that fall within the scope of artificial intelligence to find alternatives to the problems of hygrothermal comfort in the traditional house of Constantine. Indeed, this can only be done if we combine the advantages of thermal comfort and a hygrothermal environment, which can lead to an intelligent house.

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