Abstract

The vernacular courtyard house as a traditional housing form has been viewed as a complex regulating system that creates a microclimate which historically worked, and still works, in a “passive way” to provide acceptable thermal comfort in summer.

The internal courtyard is generally described as a positive factor that can moderate extreme outdoor climatic conditions. However, some researches have shown that the courtyard could become a negative factor from climatic point of view. For this purpose, this paper is based on a research study exploring sustainable characteristics of Moroccan traditional housing and its climatic adaptation. Then, a traditional courtyard model is used in Rabat medina as a case study to analyze the indoor thermal comfort without using mechanical heating and cooling systems. The thermal behavior of the rooms surrounding the courtyard is analyzed under a temperate and humid climate using passive design of building. The simulation modeling technology by Derob-lth is carried out to analyze the effectiveness of different parameters to improve the indoor climate during summer and winter, including the façade orientation, the air infiltration, the surroundings, the ceiling height, the walls and roof/ceiling insulation and the shading devices. Tools for climatic design, Mahoney’s tables and Givoni bio climatic diagram have been also used to improve design strategies in terms of thermal comfort.

Paper concludes that the courtyard house is environmental friendly building form, and can be considered as a passive system which may help to minimize the non-renewable energy consumptions to conserve the global natural environment healthy, clean, and livable environment for future generations.

Keywords: Courtyard House, Indoor Climate, Thermal Comfort, Dynamic Energy Response of Buildings, Parametric Modelling.

1. Introduction

The different types of courtyard house design had the same principle, a central courtyard surrounded on four sides by rooms and walls. As an open space to the sky, it intensifies some aspects of the climate, such as daylight, and dilutes others, such as the wind. In winter when the sun is low in the sky, the result is mostly shade on floor and walls, with only the equator-facing wall receiving much direct sun. In the hot season, because the sun is high in the sky, the floor and several walls are sunny, with only the polar-facing wall remaining a reliably shaded surface.

The climatic behavior of the courtyard is especially important in arid areas that are characterized by hot, dry days and cool clear nights to radiate heat away to the sky (climates with high temperatures during the day and low temperatures during the night and high temperature amplitude between the seasons) or for climates with cool but sunny days at lower latitudes where sun penetration is both easy and welcome.

Some researches [1-2] have shown however that the courtyard could become a negative factor from the climatic point of view. It can be hotter than its surrounding while during the winter the temperature difference remains smaller. It seems that for courtyard comfort, the worst climates are hot and humid,
where little wind is available to relieve stuffiness; or cold and cloudy ones at higher latitudes, where little winter sun can penetrate to provide warmth.

The aim of this study is to simulate and to examine the thermal behavior of a traditional courtyard house model under a temperate and humid climate in Rabat-sale (Morocco), to explain the findings, to compare them with similar research and to evaluate the architectural parameters that create a positive climatic adaptation to the environmental climatic conditions.

2. General

2.1. The Climate

The climate varies according to the region. On the coast, the winter is cool with some rain, while the summer is sunny and mild. The mountain ranges have cold winters and fairly hot, dry summers. The mean temperature is 27 °C with a maximum value exceeding 45 °C in the centre and 50 °C in the south. The minimum temperature varies from 5°C to 15 °C with an extreme value under 0 °C in the mountain regions.

Rainfall depends on the altitude of the region and exceeds 2000 mm per year in the north (rif mountains) and 1200 mm per year in the atlas mountains. Whereas in Saharan regions, rainfall do not rise up to 200 mm per year.

2.2. The traditional house in the Medina

In this part, we shall explore the values of the Medina within an analytical analysis of domestic and public spaces [3].

The traditional house can be defined by the following elements: the entrance, the central yard or patio and its surrounding rooms. These elements make it possible to describe the components of the domestic spaces:

- The entrance: the corridor from the front door and into the house itself is often angled to minimize the view from outside into the various rooms.
- The central yard and its surrounding rooms: the central courtyard has no roof or can have an opening in the roof. The ceiling height in the rooms is very high and the rooms are often quite elongated. The use of the rooms is often non-specific and can be used for various purposes. The family life and the housekeeping take place in these domestic spaces, which can be used interchangeably for eating, sleeping, recreation and other domestic tasks. The rooms are organized around the patio which is the only space bringing in light and air to the rooms. There are usually very few or no windows facing the street, but almost all the openings and windows are facing the inner courtyard.

The opening is important because it modifies the indoor climate and contributes to natural ventilation. It also serves as protection from sun and wind, because the walls are quite high the sun’s rays doesn’t reach the courtyard until the afternoon and then the warm air rises, and convention is created which ventilates the rooms. However, some studies have shown that the roof opening in the inner courtyard can be negative, especially in hot and humid climates. In hot humid climates, the temperature in the courtyard can be higher than outdoors because there is little wind and it can become stuffy inside the house.

Common traditional building materials are stone, earth, and wood, because of capillary effect, absorb water, which can then evaporate from their surfaces and thus hinder the interior air from being rewarmed by convection.
The large residential area surrounding the city center is formed by the composition of the residential quarters. A residential quarter is formed by the composition of neighborhood units along quarter streets. The residential area and the public area are together enclosed by the city walls, and thus form a closed physical and social unit, the city or Medina.

A street in the medina is a long space between two walls which have no openings facing the street. The ratio between the height of the walls and the width of the street is big (about 10). Because of the deep and narrow streets the sun rays can’t reach the streets during the day.

2.3. Problem

Buildings and constructions in Morocco are often designed without taking the climate into consideration. Consequently a great part of the built environment has a poor climate.

A building’s indoor climate depends largely on the architecture and design of the building. Layout of the building, location and colour of walls, location, size and orientation of windows and the buildings ventilation ability largely determines the climate in the building but also the building materials matters. Building materials can affect through thermal capacity and thermal conductivity.

One of the most frequent complains among the families living in the Moroccan traditional houses, regardless of the age of the house, involves moisture. The moisture that causes condensation and creates musty odours in basement wall, the ceiling and other cold surfaces, affects approximately 50% [5] of the traditional houses.

There is also the problem of the too high and low temperatures. These thermal discomfort problems are primarily due to these factors: the climatic conditions; the thermal quality of the building materials; the ventilation and the renewal of the air; the orientation of the frontages; the lack of sun shining in the patio during the winter season.

The inquire housing in Morocco [5] confirms this thermal discomfort for the traditional houses that have the problem of low temperatures (77% in Rabat-sale region). The moisture in more than 30% of the traditional houses affects the interior basement walls and the ceiling during winter season.

3. Case Study

3.1. The region and the climate

Rabat-sale is located in latitude 34°03’n, longitude 6°46’w and at an altitude of 75.3m above sea level. The climate is temperate, Mediterranean climate, the Atlantic ocean has a cooling affect that makes the climate along the coast relatively mild.

The temperature data, given by the local meteorological station show that the coldest month is January: the mean temperature is 12.5 °C with an extreme minimum of -0.5 °C. July is the hottest month with mean air temperature of 22.3 °C and extreme maximum of 47.3 °C.

The maximum and the minimum relative humidity are also given for every month, the maximum value is 96 % and the minimum is 42 %. The maximum rainfall in Rabat-sale is 110mm in December.

The maximum sunshine hours is evaluated to 13.85 hours per day in June; the highest global radiation is observed in June-July and the lowest in December.

3.2. Hypothesis

The aim of the study is to analyse the climatic behaviour of the rooms surrounding the courtyard in a temperate and humid zone. It seems the one of the important factors is the ratio between the courtyard length to height of the rooms surrounding it. In hot and arid region for example [1], when the room walls are higher than the courtyard length, the patio climate is more comfortable than the outdoor climate, due to better shading that is provided by the surrounding walls. In contrast, it seems that when the length of the courtyard is longer than the height of its surrounding walls, the temperatures inside the patio are higher than the outdoor temperatures.

The internal courtyard can then affect the indoor climate. Unfortunately, this space is not studied because of the limitation of the computer program, Derob-lth [6] which cannot simulate an open space, a courtyard for example. Secondly, due to the lack of the courtyard climatic measurements during the summer and winter seasons, including the temperature, the humidity and the wind velocity, the main hypothesis of the present study is to consider the courtyard as an open space and treated as outdoor. Third, the Derob-lth software used in this study does not take into account the humidity of the air, which can be the principal source of the discomfort in the Rabat-sale region.

3.3. Analysis methods

Architectural bioclimatic tools:

Givoni bio climatic diagram and Mahoney’s tables [7-8] have been used in this study. There are still useful tools to give general considerations of the comfort zone with some recommendations for passive design of building.

According to the Givoni bioclimatic diagram the comfort zone can be extended by using heating in January, in the rest of the winter months one can obtain a comfortable indoor climate with passive methods (internal gains). The diagram shows that, because of the mild climate in rabat-sale, ventilation is enough during the summer although the buildings must be designed with good ventilation possibilities and protection against solar radiation during the summer months.
Based on a diagnosis of some climatic indicators, the Mahoney tables give the performance specifications and the design recommendation for buildings in rabat-sale in order to have a best indoor climate:

- **Layout**: orientation north and south (long axis east-west);
- **Spacing**: compact layout of estates;
- **Rooms**: should be double banked, with temporary provision for air movement;
- **Openings**: medium openings, 25-40%;
- **Position of openings**: in north and south walls, at body height on windward side, openings also in internal walls;
- **Walls and floors**: light, short time-lag, low thermal capacity;
- **Roofs**: light, well insulated roofs.

**Parametric modelling:**

**Program**

Derob-lth, which is an acronym for dynamic energy response of buildings lth, is a MS Windows based flexible simulation tool using a RC-network for thermal model design. The program consists of 8 modules. Six of the modules are used to calculate values for temperatures, heating and cooling loads. The calculations are performed in a dynamic way for each hour during a specified period of simulation. The calculations are influenced by climatic factors such as outdoor temperature, solar radiation and the sky temperature. Properties for the indoor climate of the building can be calculated based on these simulated results.

Derob was originally developed at the numerical simulation laboratory of the school of architecture of the university of Texas at Austin. The derob-lth modules are further developed to suit the local needs at the department of building science at lund institute of technology.

**Project Description**

Tables 1-2 and figure 4 give the description of the traditional house model used as a case study.

<table>
<thead>
<tr>
<th>Table 1. Project dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>plotsize</strong>:</td>
</tr>
<tr>
<td>width</td>
</tr>
<tr>
<td>length</td>
</tr>
<tr>
<td>total</td>
</tr>
<tr>
<td><strong>façade facing street</strong>:</td>
</tr>
<tr>
<td>orientation</td>
</tr>
<tr>
<td>width</td>
</tr>
<tr>
<td>height</td>
</tr>
<tr>
<td><strong>façade facing backyard</strong>:</td>
</tr>
<tr>
<td>orientation</td>
</tr>
<tr>
<td>width</td>
</tr>
<tr>
<td>height</td>
</tr>
<tr>
<td><strong>façade adjacent to other buildings</strong>:</td>
</tr>
<tr>
<td>orientation</td>
</tr>
<tr>
<td>width</td>
</tr>
<tr>
<td>height</td>
</tr>
<tr>
<td><strong>windowsize</strong>:</td>
</tr>
<tr>
<td>total area</td>
</tr>
<tr>
<td>% of the façade</td>
</tr>
<tr>
<td>door size</td>
</tr>
</tbody>
</table>
is analyzed under a temperate and humid climate (rabat-sale) using passive design of building. Different simulations by Derob-lth were carried out using different parameters to improve the indoor climate. The operative temperatures in volumes 2 and 3 (Derob model in figure 5) are simulated during summer and winter using the climatic data and all information given in the project description.

Other data include air changes and internal heat loads during winter and summer (day and night ventilations) for both volume 2 (room 1) and volume 3 (room 2).

The operative temperatures in volumes 2 and 3 are first simulated during winter and the variants are:

- The façade orientation: the orientation for solar access is important, especially in the winter. The four orientation cases, the façade facing to south (case 0), east (case 1), north (case 2) and west (case 3) were analyzed separately. Next simulation cases, the parameters were studied in combination in order to improve the indoor climate.

- The shading devices: the gallery in the traditional house is a covered space of the circulation and the transition between the courtyard or patio and the rooms. In winter, the galleries make it possible to circulate when it is raining. In summer, the galleries create shade and become an obstacle for the intense sun rays access. The shading device in the courtyard has a width of \( l=0.7 \) m in the baseline case. In cases 4, 5, 6 and 7, the shading device is out (\( l=0.0 \) m) in the courtyard.

- The ceiling height: the traditional house rooms have generally a high ceiling height (more than 3.0 m). In the baseline case, the ceiling height \( h=3.5 \) m, which is reduced to \( h=3.0 \) m in cases 8, 9, 10 and 11.

- The surroundings: the site layout in terms of the width street and the surroundings height were analyzed in

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**Table 2. Description of materials**

<table>
<thead>
<tr>
<th>NAME</th>
<th>CONDUCTIVITY (W/MK)</th>
<th>SPECIFIC HEAT (W/KGK)</th>
<th>DENSITY (KG/M³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAMMED EARTH / PISE</td>
<td>0.80</td>
<td>0.20</td>
<td>2000</td>
</tr>
<tr>
<td>EARTH</td>
<td>1.40</td>
<td>0.22</td>
<td>1300</td>
</tr>
<tr>
<td>SAND</td>
<td>0.40</td>
<td>0.24</td>
<td>1700</td>
</tr>
<tr>
<td>CLAY MIXED WITH 40% SAND</td>
<td>1.20</td>
<td>0.23</td>
<td>2000</td>
</tr>
<tr>
<td>LIME PLASTER</td>
<td>0.80</td>
<td>0.24</td>
<td>1700</td>
</tr>
<tr>
<td>PLASTER</td>
<td>0.35</td>
<td>0.30</td>
<td>900</td>
</tr>
<tr>
<td>LIME CEMENT PLASTER</td>
<td>1.00</td>
<td>0.24</td>
<td>1800</td>
</tr>
<tr>
<td>CEMENT MORTAR</td>
<td>0.93</td>
<td>0.29</td>
<td>1800</td>
</tr>
<tr>
<td>ZELLIGE / CERAMIC</td>
<td>0.80</td>
<td>0.24</td>
<td>1900</td>
</tr>
<tr>
<td>WOOD</td>
<td>0.16</td>
<td>0.70</td>
<td>700</td>
</tr>
<tr>
<td>MINERAL WOOL</td>
<td>0.04</td>
<td>0.24</td>
<td>50</td>
</tr>
</tbody>
</table>

**Derob Modelling**

The thermal behaviour of the volumes surrounding the courtyard...
The surrounding variation facing building height (h=3.5 m and h’=7.0 m) and the small width street (1.5 m) are examined in the case 12.

- The roof/ceiling and walls insulation: thermal insulation of the roof and the walls is also important for better comfort. Composite insulating panels (woodwool/mineralwool) for walls and woodwool slabs for roof were used (cases 13 and 14).

- The air infiltration: the ventilation is an important factor for comfort, especially the night and day ventilations. The air change hour is reduced from 4 to 2 ach during evening (between 19 and 24), and from 3 to 1 ach during night (between 01 and 07). This corresponds to the case 15.

Table 3. Insulation materials for walls and roof

<table>
<thead>
<tr>
<th>Insulation Materials</th>
<th>Conductivity (w/mk)</th>
<th>Thickness (cm)</th>
<th>Density (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite Insulating Panel</td>
<td>0.04</td>
<td>5</td>
<td>200</td>
</tr>
<tr>
<td>Woodwool slab</td>
<td>0.07</td>
<td>3</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 4 gives the results relating to winter parametric modelling: starting from case 0 which is the baseline case to case 15 (yellow box in table 4) which is the best possible solution found during the parametric modelling process and obtained by reducing the air changes hour during evening and night, combining case 10 (blue box in table 4) corresponding to reduction of the ceiling height with case 14 (orange box in table 4) using roof and walls insulation.

The operative temperatures in volumes 2 and 3 are then simulated during summer and the variants are:

- The ceiling height: the ceiling height is increasing from h=3.0 m to h=3.5 m in the case 17.

- The shading devices: in the case 18, the shading device in the courtyard has a width of 1.0 m instead of 0.7 m.

- The air infiltration: the air changes rates for the day ventilation (case 19) and night ventilation (case 20).

Table 5 gives the simulation results relating to summer parametric modelling: starting from case 16 which is the baseline case similar to the case 15 obtained in winter but with specific ach values for summer.

The yellow box (case 20 in table 5) corresponds to the best possible solution obtained in the parametric modelling process by increasing the ceiling height and the dimension of the shading device in the courtyard and by adopting the option of the night ventilation.
3.4. Results

Winter

The operative temperature in the volumes 2 and 3 (the main rooms 1 and 2 of the house) are displayed in figures 6-7 for the baseline case (case0).

The winter indoor climate has also shown only small difference between the orientation cases (façade facing to the south, east, north and west) and the shading devices of the courtyard. Indeed, these orientations are equal for this house model while north orientation combining with the ceiling height reduction give higher indoor temperatures. The north orientation in the present case means that the rooms (volume 2 and volumes 3) have west and north windows.

Thermal insulation of the roof and the walls is important for better comfort. We considered walls and roof ceiling with additional insulation: an inner insulated layer of 50mm using composite insulating panels (woodwool/mineralwool) for walls and an outer insulated layer of 30mm of woodwool slabs for the roof. In wintertime, this type of insulation gives a better performance than the previous cases.

An other important factor relating to the comfort is the air infiltration, especially the day ventilation which is useful to improve the indoor climate during the winter. Operative temperatures in figure 8 show the effect of the ventilation when reducing the ach during evening and night. An important increasing of 3 degrees is observed. Finally, the case 15 is the best possible solution obtained in the winter parametric modelling process.
Summer

The baseline case for summer parametric modelling is the case 16 which is similar to the case 15 but with specific ach values for summer. The influence of the following parameters was studied: the ceiling height, the shading devices of the courtyard and the air infiltration in terms of day and night ventilations. During winter, the main rooms should be closed at night and open during the day to maximise the indoor temperatures. The reversed method (night ventilation) should be used in the summer.

![Operative Temperature in Volume 3 Day and Night Ventilations](image)

Figure 9: Operative temperature in volume 3 and ventilation, August (cases 19 and 20)

It seems that the case 20 is the best possible solution obtained in the summer parametric modelling process by increasing the ceiling height and the dimension of the shading device in the courtyard and by adopting the option of the night ventilation.

4. Conclusion

We can conclude through all simulations that in order to keep traditional courtyard house in Rabat-sale region being thermally comfortable during both seasons, some actions should be made.

In winter:
- Reducing the ceiling height,
- Adopting an insulated roof and walls but the insulation walls might be bad in summer,
- Reducing the air changes hour (ach) during evening and night. However this rate must not be too low for health reasons.

In summer:
- Increasing the ceiling height as much as possible,
- Increasing the dimensions of the shading devices of the courtyard,
- Increasing the night ventilation as much as possible and a low air changes rate is recommended during daytime.

New courtyard buildings should be designed in such a way that thermal comfort is enhanced.

References