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Assessment of residential settlement planning in Medina, based on climate adaptability

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Abstract. The theme of World Habitat Day 2020 was Housing for All: "A Better Urban Future". In light of this postulate, this study aims to determine the climate response of traditional urban morphology to the Sousse climate, which allows us to assess the effectiveness of ancient urban planning considered a model of low-energy and low-carbon. This study purposes to help future urban planners in the early phase of the project and preserve their urban heritage. Design strategies such as indoor and outdoor daylighting and different natural ventilation conditions were studied to assess ancient city planning. The results show that the grouped houses in linear blocks with courtyards promote natural ventilation, solar gain, and thermal comfort control. This self-contained, compact urban morphology is beneficial in the semi-arid climate; it reduces heat loss through the exterior envelope and creates a comfortable atmosphere inside and outside the block, especially in summer.

1 Introduction

This research work is a bioclimatic approach of the urban morphology in Medina. Some research studies have been done in this domain. For example, work research done to examine adjustment modalities and residential carbon emissions [1]. Further studies in India under the composite climate show that free-running building depends on the behavior occupants, and the climatic adaptation In this research, the temperature combined with climatic parameters is used as a clue indicator of building thermal comfort for urban space [2]. In the literature review, many research reveal that Ecotect can be used as a scientific basis to investigate energy efficiency and to analyze climatic parameters [3]. This software is often used for thermal analysis at the micro-scale with interactive and highly visual display [4]. In this paper, we used Ecotect for quantitative and qualitative thermal analysis of ancient residential planning in Sousse city. The purpose of this study is to analyze design strategies and find a relation between traditional urban forms and climate. This objective is divided to three steps: (1) identify passive design strategies of Sousse climate, (2) examine the various passive design strategies used in traditional dwelling and urban surroundings in the medina using Weather tool, (3) Verify climate response in internal and external spaces of the Medina using Ecotect software.

2 Materials and methods

2.1 Presentation of the case study:

The city of Sousse has known three thousand years of history. December 1988, the Medina has been classified as world heritage. The Medina represents a vernacular Tunisian settlement, its urban morphology is known by an organic organization. It is bounded by ramparts on all sides, is built upon the eastern flank of hills and set near the port. It occupies 32 hectare area, the perimeter is 2.2km and 2m thick wall. And it is organized by religious, commercial spaces, and residential areas. Our study is settled on residential neighborhoods. It is located at 35°North latitude, 10° East longitude and an altitude of 30 m above the sea level.

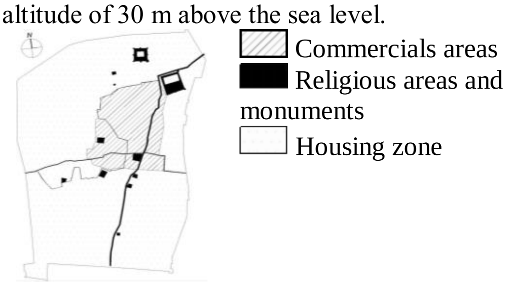

Fig. 1. Typical plan view of ancient planning of Sousse Medina.

2.2 Analysis process

This study considers four parameters to examine the adaptation of ancient residential planning to the climate. These parameters are urban morphology, the site,

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occupant's behavior, meteorological. In this context, different approaches are used in the literature as Hong [5]. develop an efficient sustainable building design approach that explores climate responsive of residential planning. Thus, meteorological data and passive design strategies have been exploited using Ecotect Weather Tool. Then, solar radiation, solar orbit and natural ventilation are analysed. Wenting Yang [6] led a study to investigate adaptive thermal comfort of vernacular dwelling typical old dwellings with an atrium in China. They examine a thermal comfort and thermal performance in the indoor environment. Our methodological approach combined two methods of research used previously by Hong et al and Yang et al and, it is divided into three steps. The first one tries to understand Sousse city climate and to determine the passive design techniques. In this part, we collected and converted the weather file (CSV) to (WEA) format. The last format is readable by ECOTECT in WEATHER TOOL. After that, we analyzed the meteorological data of our study site in Medina. In the second step, we identified the efficient design strategies and examine passive solar heating and natural ventilation which are related to the Sousse climate. Finally, in the third step, we develop the indoor thermal quality.

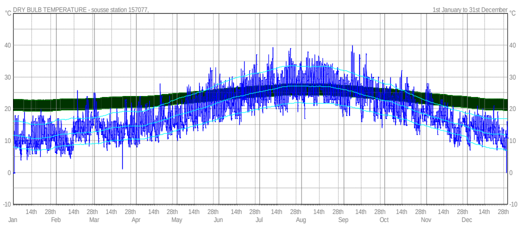
2.3 Analysis tools

Research results confirm that ECOTECT software provides a scientific basis for energy performance and climatic parameters analysis for passive designs [7]. Then, we opted for ECOTECT and its integrated tool as WEATHER TOOL. Therefore, we used the last tool for hourly simulation of dry bulb temperature and relative humidity percentage. As well, we opted for this tool: (1) to identify beneficial passive design strategies based on Psychometric chart, and (2) to examine the passive design strategies of the project based on Solar distribution and Prevailing winds chart. In addition, we rely on the ECOTECT to simulate hourly solar radiation and the indoor ambient temperature of our study case.

3 Results

3.1 Analysis of meteorological data and design strategies

The weather data results generated by the WEATHER TOOL of our study site are given in figures 2 and 3.

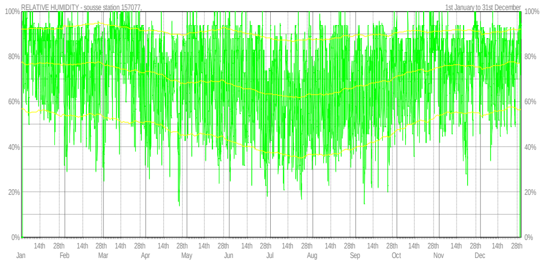


Comfort band: thermal neutrality
Dry bulb temperature
Monthly maximums, minimums, and averages temperature

Fig. 2. Annual and Distribution of annual hourly dry-bulb temperature of Sousse Medina.

Figure 2 determines the hourly data, the coldest day (average) is 11th February and the hottest day (average) is 11th July. The average dry-bulb temperature over the year is about 22.5°C.

Figure 3 displays the relative humidity in the summer from1 June to 31 August is 63.87%. The relative humidity in the winter from 1 December to 28 February is 75.79%. According to Figures 2 and 3, the weather in this region is mild and wet in winter however hot and less humid in summer. Then, the heat insulation is needed to achieve the thermal comfort of the internal environment[8]



Percentage of relative humidity
Monthly maximums, minimums, and averages relative humidity

Fig.3. Distribution of annual hourly humidity of Sousse Medina.

The psychometric chart is a graphical diagram that provides the thermal proprieties of air. This chart presents a comfort zone accepted by most persons.

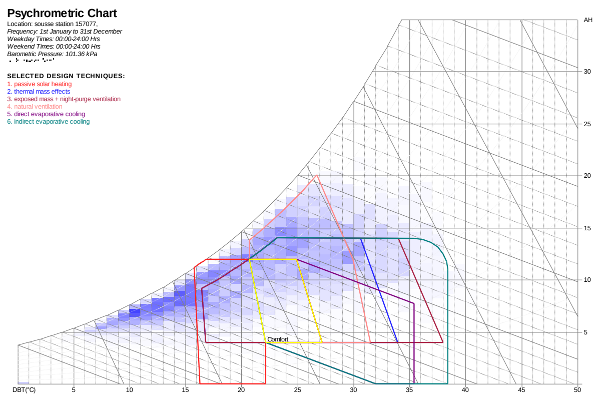


Fig.4 Effects of six passive design techniques: thermal mass effects, solar heating, exposed mass & night purge ventilation, direct evaporative cooling, natural ventilation, and indirect evaporative cooling.

In Figure 4, the comfortable zone is surrounded by yellow color. It is influenced by the analysis period and determined by the following ambient parameters: relative humidity, air temperature, radiation temperature, and airflow velocity. Climate processing shows Sousse climate is characterized by an ambient temperature that is smaller than the comfort temperature. Therefore, we must use appropriate passive strategies.

Figure 4 displays three passive design techniques: exposed mass & night purge ventilation, passive solar

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heating, and natural ventilation which provide the best thermal comfort in the Sousse climate. In this case, we can promote direct solar radiation in the winter period to provide heat and body comfort in the internal space. This can be realized directly [9] or indirectly, in the first one, we used a transparent opening to heat directly the habitable space, or indirectly through medium space like the atrium [10].

3.2 Project design analysis

3.2.1 Site radiation

In order, to evaluate the efficiency of ancient urban morphology, we need to calculate the solar radiation distribution of the southwest cluster in Medina. Then, we opted for Ecotect software to investigate solar radiation distribution respectively in winter and summer because ECOTECT can simulate annual solar trace and position accurately at any time, And, also provide accurate statistics of the planning area's solar radiation intensity.

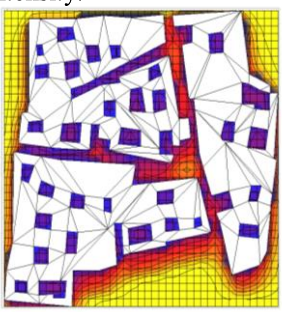

Fig.5. Solar radiation distribution of southwest clusters in the winter period

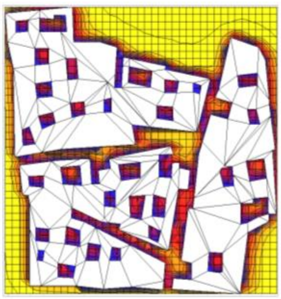

Fig.6. Solar radiation distribution of southwest cluster in the summer period

Fig.5.and Fig 6. Solar radiation distribution of southwest clusters respectively in summer and winter period.

Figure 5 shows the daily average solar radiation distribution of the southwest cluster. Moreover, it provides an idea concerning the impact of urban form on its external environment in terms of radiation. We can see from Figure 5 that solar radiation of the planning area decreases in winter. Meanwhile, it displays wide streets that have the solar radiation. On the contrary, patio and narrow streets area have poor sunlight due to excessive building shade. The chart shows the daily average intensity of solar radiation in the external environment is between 480 and 680 Wh. Therefore, it is obvious that the thermal quality of external moods is uncomfortable in the winter seasons.

According to, Figure 6, we can see that patio and narrow streets area are more comfortable than wide streets in the summer period, due to their morphology. The form of narrow streets and narrow urban canyon offering mutual shading to the dwellings. Besides, the façades of patio provide shading in bordering during harsh sunny hours and create a comfortable environment in summer.

They found the aspect ratio building height to street width written H/W as well a solar orientation have a considerable influence on the street thermal environment and consequently on the thermal sensation of people. As a result, ancient urban morphology promotes more comfort concerning the thermal quality of external moods in the hottest period. Meanwhile, we can improve the thermal quality of a wide street, which appears where comfort is the most difficult to ensure in the summer period. In this instance, galleries are efficient and therefore advisable. Planting trees in E-W streets is also sensible since the duration and area of discomfort will be, otherwise critical canyon [11]. However, deciduous trees can be planted around where the accumulative total sunshine radiation is strong to provide shade for people in summer and make people enjoy sunlight after the fall of leaves in winter. In addition, deciduous trees can be planted in the middle of the very large street.

3.2.2 Shade distribution

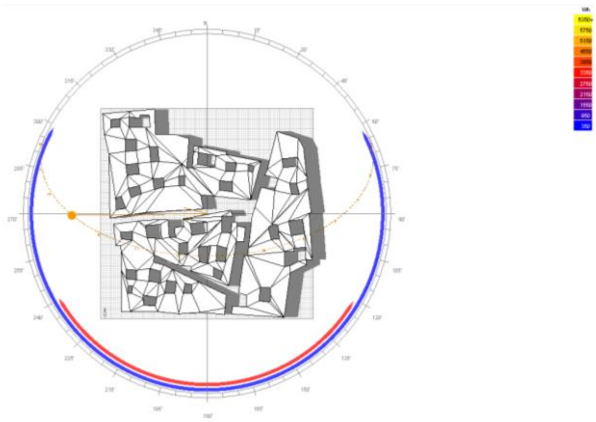

Fig. 7. Plan view illustrating the solar orbit projection and shade distribution of southwest clusters at 3:00 pm on a Great hot Day.

Figure 7. Plan view illustrating the solar orbit projection and shade distribution of southwest clusters at 3:00 pm on a Great hot Day.

Figure 7, exhibits the solar orbit projection and shows the solar position of the planning area at 3:00 p.m on the Great hot Day (11th July). At this time, the mean temperature is 39°C.

Regarding figure 7, red and blue arcs represent the range of azimuth angles that the sun travels through in summer and winter. The red arc extremities display sunrise and sunset in summer, while, the blue arc limits present sunrise and sunset in the winter period. Thus, these arcs emphasize seasonal differences, therefore, they enable the designer to quickly understand the sun path and take a decision in the early phase of conception.

In addition, figure 7, shows the shade distribution of buildings and displays the planning area and the shading relationship among adjacent buildings at a specific time.

This figure proves that although the range of azimuth angles is wide thus the patio provides shading on the hottest day. In addition, patio mood has better thermal quality than mood streets, because it gives the most shading for its residents. Therefore, a patio creates a beneficent microclimate in the summer period.

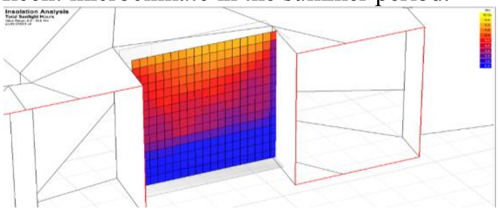

Fig. 8. View illustrating analysis of sunlight time of south elevation the patio area on a great cold day (11 February)

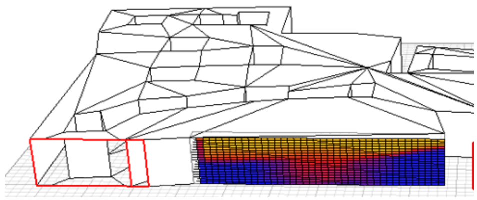

Fig. 9. View illustrating analysis of sunlight time of south of the elevation street area on a great cold day (11 February).

Figure8 and 9 Views illustrating respectively analysis of sunlight time of south elevation of patio and street area at great cold day (11 February).

Figures 8 and 9 present the analysis of the sunlight time of south elevation concerning the patio and street surface in the southwest cluster. The selected objects and the sunlight time of their south elevation are calculated in Great Cold Day. The grid calculation method is adopted and the south elevation is divided into cells and calculated one by one. The calculating result shows that the shortest sunlight time of the south elevation of the patio is 3.17 hours and the shortest sunlight time of the south elevation of the street is 3.58 hours. As a result, the thermal quality of patios and streets decreases in the winter period. Meanwhile, the patio area is more comfortable than the street area in the summer period.

3.2.3 Ventilation

As seen previously, natural ventilation presents an effective passive strategy in Sousse climate that leads and optimizes the airflow to clear the indoor air and lower the temperature. This strategy is beneficial, especially in the hottest period. It can improve indoor thermal comfort and provide fresh air without energy consumption. Therefore, we need to evaluate the response of the southwest cluster to the natural ventilation strategy.

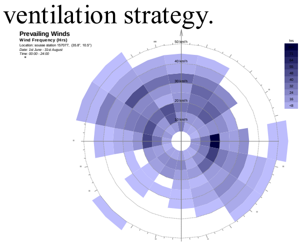

Fig. 10. The distribution of wind frequency, direction, and velocity respectively in summer.

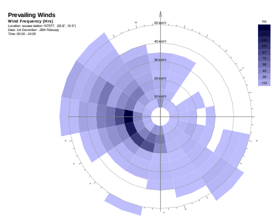

Fig. 11. The distribution of wind frequency, direction, and velocity respectively in winter.

Figure 10 shows that the main wind direction in summer is in the eastern that corresponds to wind Levante and which blows from the western Mediterranean Sea. This chart presents out that the wind Levante has 25km/h and persists for 80 hours in the summer period. This wind provides fresh air and humidity to ancient dwellings on the hottest day without energy consumption. Thus, the sea breeze provides a reduction in atmospheric urban temperature.

Figure 11 exhibits the prevailing wind in the winter period in the west and southwest that represents respectively Ponente and Libeccio wind. They have a wind velocity of 15km/h. The high street and the low window on a vertical surface of the patio protect against the prevailing wind. Ventilation represents an old strategy that emphasizes knowledge of ancient habitats to their climate especially on hottest days.

3.3 environmental analysis of climate-responsive strategies

3.3.1 Spatial organization

Layout areas in traditional dwellings depend on the main bedroom, which is oriented in southeast. Spatial organization in the traditional courtyard house is composed as following: buffer space is a semi-public space and its area is between 6 to 10 m². It gets light and aeration continuously from the patio. This last one is open air; its area is between 12 to 24 m². Rooms, kitchen and laundry are lighted and ventilated from the patio. In most cases, bathroom space is accessible from the kitchen.

3.3.2 Indoor thermal quality simulation

In the Tunisian climate context, traditional dwellings represent bioclimatic buildings not conditioning. A condition to assess the thermal quality of this dwelling is based on minimum comfort to achieve naturally and not using energy savings. To investigate the indoor thermal condition of the southwest cluster, a geometric model was done using Revit software and conceptual mass was adopted then export to Ecotect for simulation. Ecotect is a complete building design and environmental analysis tool that covers a broad range of simulation and analysis functions [12]. A model imported in Ecotect is divided into three series of individual mass zones. We assumed that a zone presents a set of grouped houses. The thermal zones in the case study model were divided into 3 zones namely: mass zone 1, mass zone 2, and mass zone 3. The mass zones present respectively a top part, bottom part, and right part of the southwest cluster. The three zones are composed of ordinary houses and the occupancy represents a 15m² floor area per person. Like seen previously, the weather data file concerning Revit's station ID 157077 for Ecotect is loaded for simulation. We selected simplified building materials from the Ecotect library based on material description in

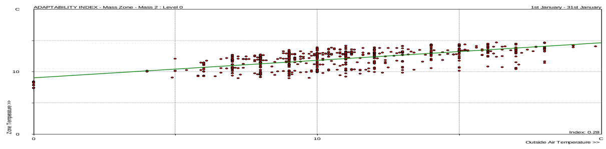

table1. The physical properties for these materials are calculated using Ecotect material property (table1).

Table 1 displays the material descriptions of the simulated southwest cluster.

Material description		U-Value (W/m^2K)
Floor	Concrete slab-tiles with 20cm soil, 100mm concrete, 0.5cm concrete screed and 1cm ceramic tiles	0.880
Wall	Rammed earth 50cm	1.2
Roof	concrete roof asphalt with 15cm concrete, soil 15cm, and 10cm thick plaster	0.896
Window	Material single glazed timber frame	5.1

For simulation, we consider the internal openings correspond to windows and doors surfaces, which are setting in east, west, north, and south walls into the patio as displayed in table2. Further that, total surface and windows area of thermal zones are necessary for simulation (table 3).

Table 2 Shows percentage interior opening on vertical surfaces that opens into the patio of the south-west cluster project.

Opening orientation	Percentage opening (%)	Height(mm)
Facing East	20	750
Facing west	13	750
Facing North	20	750

Table 3 figures out the areas of the thermal zones in the southwest cluster project.

All Visible Thermal Zones	Area (m^2)
Total Surface Area	20000m^2
Total Exposed Area	14366 m^2
Total South Window	209 m^2
Total Window Area	722 m^2

Fanger approach that expresses people's discomfort degree named PMV (Predicted Mean Vote) is widely used. This approach does not present correct reality; it does not take account of the thermal adaptation of people in their spaces. Meanwhile, the adaptive approach takes account of personal behavior to achieve thermal comfort [13]. Numerous field studies conducted around the world have confirmed the effectiveness of the adaptive approach [14], [15] [16]. There are currently two international standards that have incorporated assessment methods based on an adaptive approach, namely ANSI/ ASHRAE 55 and the European standard EN 15251. The adaptive approach adopts the equation of internal comfort temperature for free running as a function of outdoor temperature [17], [18]

$$Tc = A \times Ta + B \ \ (1)$$

Where Tc = internal comfort temperature [◦C]

Ta = monthly mean outdoor air temperature [◦C]

A and B are constants that will be determined based on experimental measurements and linear regression techniques.[19]

$$Tc = 0.5\, Ta + 12.16 \ \ (2)$$

As seen prior, traditional dwelling is not equipped with a system for heating and cooling. It used only an artisanal device for heating and use natural ventilation for cooling. Thus, for simulation, we assign natural ventilation and unconditioned zones. The indoor environment is considered effective only if it achieves a minimum comfort without conditioning equipment. This kind of building has adaptive comfort linked to human behavior to the mix. People will generally change their behavior and act to restore indoor comfort when the indoor environment produces thermal discomfort. Among these actions putting on and removing clothes, reducing activity levels, and opening windows. According to equation (2) and our location, a comfortable temperature is 27.66°C on the hottest day (11th July). In addition, comfort temperature is 15.66°C on the coldest day (11th February).

4 Discussion

The passive The passive adaptivity index graph in Ecotect allows you to evaluate the passive performance of a structure. This thermal calculation estimates the temperature of the selected zone against the prevailing outside temperature for the selected period and then draws a line of best fit. This gives an index value between 0 and 1, where a lower index value depicts better passive performance (Jagruthi and Kannan 2014). Figures 12 and 13 determine the passive adaptivity index. They show respectively 0.28 for the coldest month (January) and 0.22 for the hottest month (August) thus a traditional dwelling is more efficient in the cooling period.

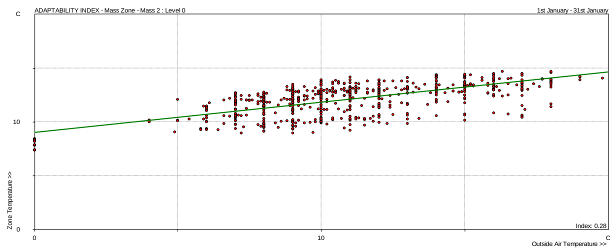

Fig. 12. Index Adaptability of outside temperature and temperature of thermal zone 2 in south-west cluster project in the coldest month (January).

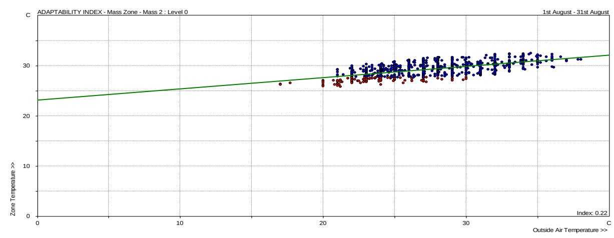

Fig. 13. Index Adaptability of outside temperature and temperature of thermal zone 2 in south-west cluster project in hottest month (August).

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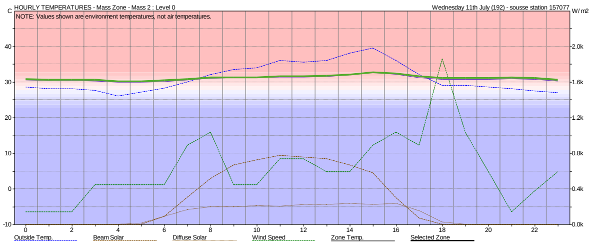

Fig. 14. The distribution of Hourly temperature of thermal zone 2 in the southwest cluster project over 24 hours on the hottest day (11th July).

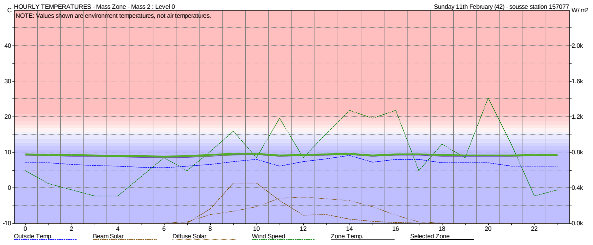

Fig. 15. The distribution of Hourly temperature of thermal zone 2 in the southwest cluster project over 24 hours on coldest day (11th February).

Fig. 14 and Fig. 15. The distribution of Hourly temperature of thermal zone 2 in the southwest cluster project over 24 hours respectively on the hottest and coldest day.

Diagrams 14 and 15 represent different parameters of the outside conditions (outside temperature, beam solar, diffuse solar, wind speed) and the internal ambient temperature of the considered zone. On the same diagram, we have positioned the ideal comfort zone, the white colored band. The red band corresponds to an uncomfortable situation in which the user is in excess heat. The blue band is always a noncomfortable situation with a sensation of cold. Figure 14 shows that in summer, the indoor temperature is almost constant throughout the day and it is at the upper limit of the comfort zone (white band), therefore, the occupant is in a comfortable situation. However, Figure 15 displays that in winter, the indoor temperature is in the blue band, and thus the occupant is in an uncomfortable situation.

5 Conclusions

A simulation of bioclimatic architecture on the Mediterranean climate is carried out. It shows that ancient planning is more efficient in the summer than winter period. Thus the traditional residential planning inspired by vernacular architecture, mainly based on natural ventilation, sun shading, thermal buffering, and heavy thermal mass is effective in hot summer. It needs definitively further improvements for the winter period (Gou et al. 2015). In ancient residential planning, the inside thermal comfort depends primarily on knowledge of people, physical characteristics of building and site integration, and occupation mode of living space (Bennadji 1999). The high thermal capacity stabilizes a room temperature and it plays an essential role for cooling when coupled with night ventilation Meanwhile, people living in naturally ventilated buildings can solve discomfort problems in winter by wearing more clothes or using an artisanal device of heating, and further, improvements of the building airtightness can reduce a thermal loss [16]. The method of assessment of traditional cities introduced in this work can help urban planners to improve the thermal behavior of future planning and to produce sustainable cities. These planning actions influence the urban climate Moreover, the integration of courtyards in actually planning provide a thermal regulation in semi-ari region [20]. Finally, we believe that passive design strategies used in the early phase of urban planning can reduce the carbon bill and improve the energy efficiency of the city.

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