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Assessment of the Thermal Well being of Collective Residential Buildings: A Case Study from Annaba, Algeria

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Abstract

Many extensive studies have shown that thermal comfort in inhabited buildings has a strong influence on the quality of life of the occupants. At the same time, it is well known that poor thermal comfort can cause adverse physiological effects.This is the case in Algeria, where collective residential buildings have low thermal performance. According to this fact, most of the inhabitants of these buildings suffer from a great lack of thermal comfort. Similarly, the measurements taken of the state of the insulation of these buildings cannot exclude that a problem related to the thermogenic quality exists and needs to be corrected urgently. In this sense that the objective of this study aims to determine the level of deterioration of thermal comfort by demonstrating the unbearable periods of the year, which create a discomfort among the inhabitants of the collective residential buildings of the Bouzaaroura estate in Annaba. At first, a sociological investigation was established near the inhabitants of this housing estate in order to evaluate their feelings towards the quality of the thermal wellbeing of their housing. Second, a numerical simulation of one of the modelled buildings was carried out using the Design Builder software. The result of the comparative analysis between the results of the survey and the simulation revealed that 91.7% of the inhabitants felt very uncomfortable with the thermal discomfort in their homes, with a Predicted Mean Vote (PMV) indicator of -2.6, a Predicted Percentage Dissatisfied (PPD) indicator of 94%, and that only 44% suffered from heat in the summer, while all of them felt cold in the winter.

Key words: Thermal comfort, collective residential buildings, thermal insulation, design builder.

INTRODUCTION

People spend up to 90% of their time inside buildings, so what makes a healthy housing is a living space that promotes sanitary comfort and social well-being(Çeter, Alkan, and Turhan 2021); (Boulemaredj and Haridi 2022); (Slipek et al. 2017), therefore, it significantly impacts quality of life of the occupants (Al horr et al. 2016). Buildings should take into account the local bioclimatic conditions in order to raise the living standards of those who inhabit them(Samuel et al. 2017) and (Hailu, Gelan, and Girma 2021). The word "bioclimatic" refers to the architecture of buildings based on the context of the local climate in order to give the best possible thermal comfort of the location, according to a research by(Akande et Adebamowo 2010).

The initial function of any building is to adapt to the prevailing external climate and to provide a comfortable indoor environment conducive to the well-being of the occupants (El Akili et al. 2021). However, in the age of climate change and global warming, ensuring the comfort of the occupants of a residential building has become a real challenge and a fundamentally complex situation. The widespread introduction of mechanical and technical means to provide the desired comfort temperature in residential buildings is one of the most worrying aspects of modern development today. This troublesome phenomenon has been posed as a major problem since the 1930s.Modern housing has demanded adequate thermal comfort in this respect, leading to massive energy consumption. According to (Taleghani et al. 2013) one third of the total fossil fuel consumption occurs in the residential building stock.

In Algeria, residential buildings require a significant amount of energy for cooling and heating to achieve acceptable thermal comfort (Messaoudi et al. 2021). In addition, one of the objectives of the National Energy Efficiency Program (PNEE), concerning the realization of thermal insulation projects in housing and thermal rehabilitation (Service 2019),seeks to improve the level of insulation of the building envelope. This reduces the loss of heat energy due to lack of or insufficient insulation. Similarly to (Aslan 2021) the appropriate thermal balance between the human body and the surrounding environment is ensured by the good insulation of the building.For (Nicol 1993) understanding the importance of thermal comfort is essential for several reasons which include controlling energy consumption, preventing recommendations, setting standards and providing a pleasant living environment.

In the research literature, many studies have been conducted on the subject of thermal comfort in living spaces. Below are some useful examples of this issue.

Recent scientific studies have revealed that residents of residential buildings in many parts of the world may experience prolonged thermal discomfort due to excessive temperatures in these structures (M. Adaji, Watkins, and Adler 2015); (Adunola and Ajibola 2012) and (Adekunle and Nikolopoulou 2014).

In addition, numerous in-depth field studies in a variety of climate zones, including moderate (Lomas and Kane 2013); tropical (Nicol 2004);(Al-Tamimi, Fadzil, and Harun 2011) hot and humid (Akande and Adebamowo 2010); (M. Adaji, Watkins, and Adler 2015) climates, have shown that extremely high temperatures in residential buildings can have a negative impact on users' thermal comfort.

Furthermore,(Ealiwa et al. 2001) carried an in-situ study on thermal comfort in several buildings in Ghadames Oasis, Libya, which has a hot and dry North African climate. His findings demonstrated that individuals had an overall impression of an increased level of thermal comfort in old buildings versus new ones.

Additional research on hygrometric thermal comfort in Cameroon's various climate zones was examined(Nematchoua et al. 2014), and it was discovered that the comfort range diversified by area and was greatly influenced by the climate and regional activities.

The indoor thermal state of a building is deemed appropriate when 80% of its occupants are content and relaxed, according to conventional standards (ISO 2005)and the American Society of Heat, Refrigeration, and Airconditioning Engineers (ASHRAE), which define thermal comfort as a mental state that conveys happiness with the thermal environment (Kelechava 2021). Moreover, environmental and body factors interact and adapt to offer thermal comfort, which is consistent with the research of (Toy and Kántor 2017) and (Haruna, Muhammad, and Oraegbune 2018). The danger of low and high temperatures in various buildings has been evaluated using these thermal comfort criteria, such as the ASHRAE model (Lomas and Kane 2013); (Adekunle and Nikolopoulou 2014). Several researches have looked at the use of the adaptive thermal standard, and their published papers have described how well this model performs when determining comfort temperatures (Nicol 2004) and (Humphreys, Rijal, and Nicol 2013).

When examining thermal comfort, field studies have either used the static approach, also known as the predicted average vote-predicted percentage of dissatisfaction (PMV-PPD) model, which was proposed by Fanger in 1972 and is based on the heat balance approach, or the adaptive approach (Aparicio Ruiz et al. 2021) and(Wu et al. 2019), which is based on the predicted average vote-predicted percentage of dissatisfaction model findings, related to outdoor environmental conditions found throughout field surveys (López-Pérez, Flores-Prieto, and Ríos-Rojas 2019); (Asif et al. 2022) and (Jiao et al. 2020).

Despite the importance of these studies on the adaptive thermal comfort, the well-being of occupants, it was noted that the buildings for residential use in Algeria require further reflection on the thermal aspect. The objective of the present study is to determine the level of degradation of the thermal comfort of the inhabitants of the collective residential buildings of the city of Bouzaaroura in Annaba, Algeria, by highlighting the unbearable periods of the year, in an approach which helps the thermal rehabilitation of housing by effective and accessible solutions.

METHODOLOGY

Approach

The adaptation of the thermal environment of people in their living spaces is crucial to maintaining a good quality of life. To achieve this notion, the current study examines the effect of indoor thermal conditions on residents' dissatisfaction through two distinct yet correlated parts.

The first phase takes into account how residents feel in their daily experience, based on the inhabitants' responses to our stated questions. To do this, we used a descriptive method, through the investigation tool; a questionnaire distributed to a sample of 83 out of 122 inhabitants, who occupy collective residential buildings located in the 172-housing estate in Bouzaaroura, Annaba.The second phase involves the use of the Design Builder software, since it consists in setting up a modelling operation of the real situation (winter and summer period) of the studied residential buildings by aiming at the predicted average voting indicator (PMV), to test the word of the respondents in relation to the result of the numerical simulation, from which graphic diagrams were designed.DesignBuilder software (BATISIM 2018) integrates enhanced energy simulations with the fastest modelling technologies on the market to help engineers, architects, and energy planners (RT2012) build attractive, energy-efficient buildings (Figure 1).

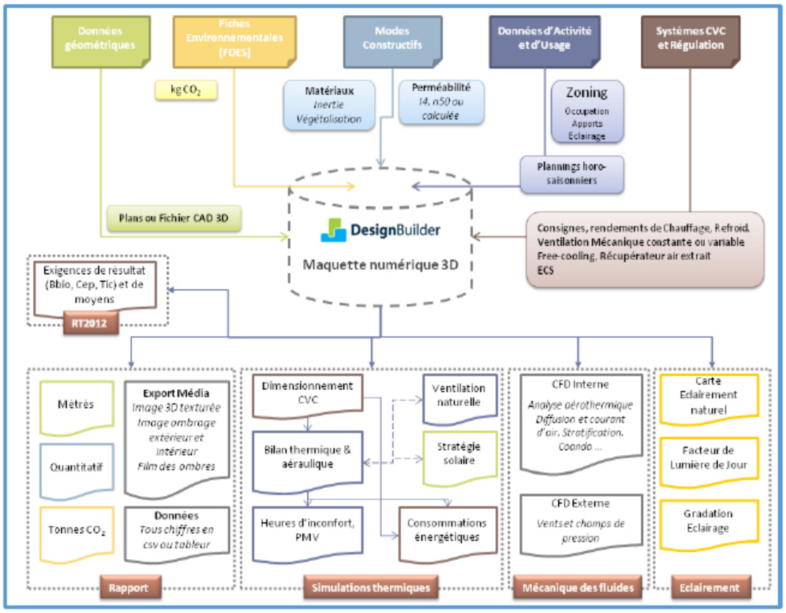

Figure 1. Design Builder software system flow chart (source, Batisim.net)

Case study presentation

The city of Annaba is distinguished by its setting, bordered from the west by the Iron Cap point and from the east by the Cap Rosa point. 600 km from Algiers and 105.7 km west of the Tunisian border, Annaba is located in the north east of the country bordered by the Mediterranean Sea from the north, with a coastal strip of more than 80km, the wilaya of Guelma from the south, the wilaya of El-Tarf from the east and the wilaya of Skikda from the west (Zineb and Dönmez 2021). The city is built at the bottom of the Edough mountains that represents a natural shelter from the north and west winds.The agglomeration comprises the communities of El Bouni, El Hadjar, and Sidi Amar, which today form a true ring surrounding Annaba city and have more dense population and strong connections with the latter (Figure 2).

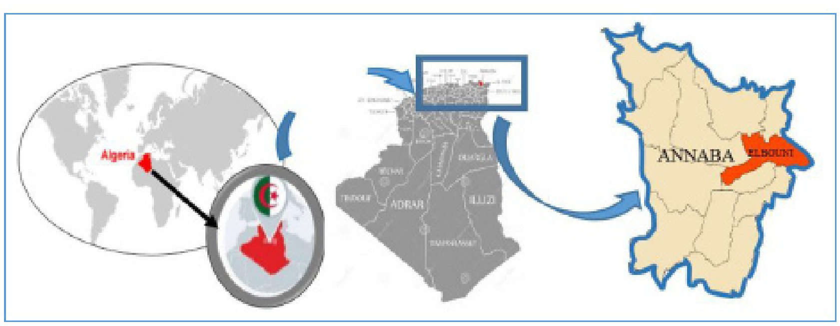

Figure 2. El Bouni community localization (source, author, 2022)

The area chosen for the current study is a neighbourhood of 172-housing in Bouzaaroura, which is among the housing estates located in the southern part of the community of El Bouni (Figure 3). The main reason why it was specifically chosen is because of the high location of this neighbourhood above the sea level, which gives a unique micro-climate to be investigated in relation to the thermal comfort of the residential buildings built there, with external walls that are double-walled.

Figure 3.172-housing location in Bouzaaroura, Annaba (source, Google Earth, modified by the authors, 2022)

Annaba metrological characteristics

The climate in Annaba is distinctly Mediterranean, characterized by long, chilly, windy and partly cloudy winters and warm, heavy, dry, and generally clear summers throughout the year. The temperature generally ranges from 8°C to 30°C and is rarely below 5°C or above 34°C. The very hot season lasts 3.2 months, from June 21 June to 28 September, with an average daily maximum temperature of over 30°C. The hottest month of the year in Annaba is August, with an average maximum temperature of 33°C and a minimum of 21°C. The cool season lasts for 3.9 months, from 30 November to 25 March, with an average daily maximum temperature of less than 18°C. The coldest month of the year in Annaba is January, with an average minimum temperature of 8 °C and a maximum of 16 °C (Figure 4).

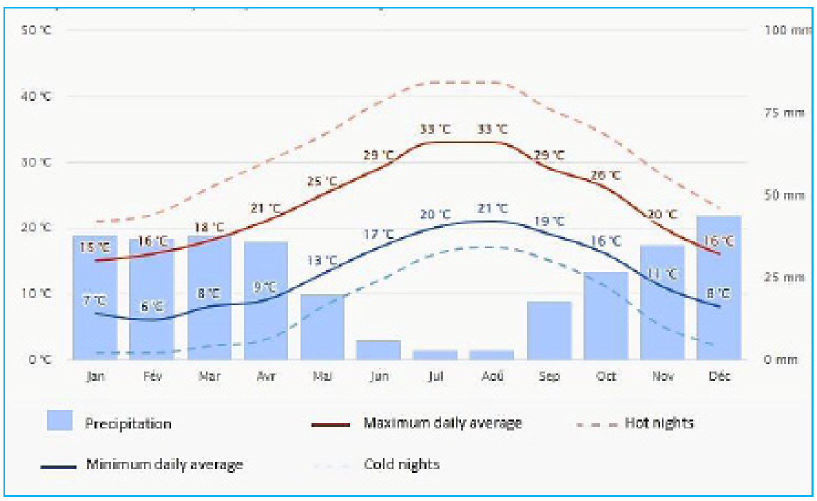

Figure 4. Average temperature and precipitation of Annaba city

Sociological Survey Design and Simulation Process

Figure 5 shows a collective arrangement of seven buildings located on the Bouzaaroura hill in El Bouni, Annaba. First, a total of 83 respondents from this housing estate participated in the sociological survey conducted in 2020-2021, through a questionnaire distributed in the following buildings (B07, B08, B12, B13, B14, B15, B16). The questionnaire survey aimed to obtain residents' thermal sensation in their dwellings.

Second, to confirm the opinion of the respondents on their thermal comfort, the simulation process was carried out during the winter and summer periods, mainly in a flat that occupies the first floor in the Building 13 (Figure 6), with a living area of 74m^2, consisting of a living room, a kitchen, a toilet, a bathroom and two bedrooms. This flat is oriented along with the north-south axis. The architectural design of the dwellings in Building 13 is based on a prototype plan, where we find that the rooms are organized around a clearance space (the L-shaped corridor). From a technical point of view, it is shown that these rooms have walls leading either to the outside or to an uninhabitable space, of which the living room and bedroom 2 are the rooms that have almost half of the wall surface exposed to strong wind at winter and a lot of sunshine at summer, which expresses the choice of the simulation operation afterwards.

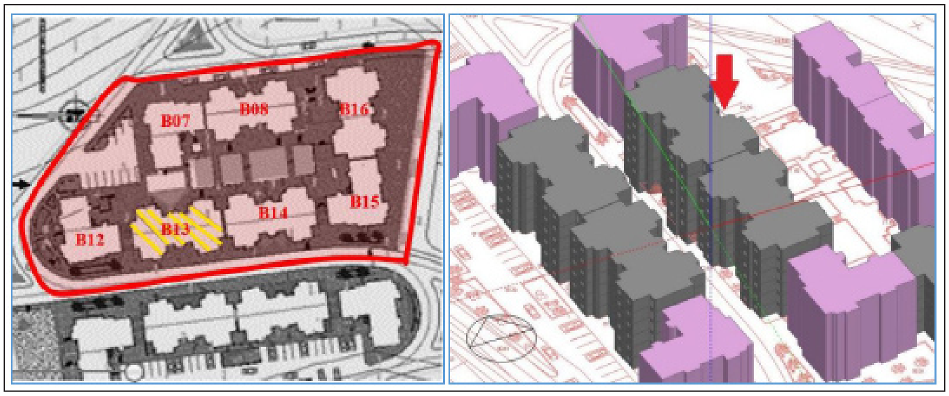

Figure 5. Mass plan (on the left) and 3D modelling (on the right) of the 172-housing in Bouzaaroura (source, authors, 2022)

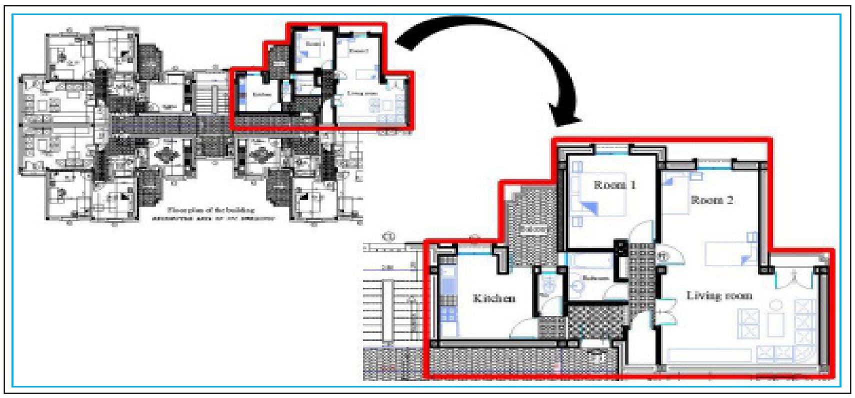

Figure 6. Floor plan of the investigated flat (source, authors, 2022)

RESULTS AND DISCUSSION

The potential presence of thermal discomfort in the collective residential buildings located in the 172-housing estate in Bouzaaroura, Annaba, led us to establish this study, whose analysis of these results is presented in the following sections.

It is shown in Figure 7 that 92% of the inhabitants of the 172-housing estate in Bouzaaroura declared a lack of thermal comfort in their living quarters, in relation to the poor thermal performance of the construction materials of these buildings with regard to summer heat and winter cold.

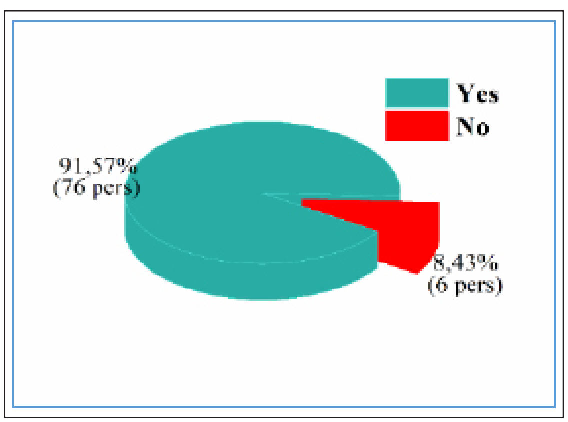

Figure 7. State of thermal comfort of the inhabitants surveyed in the 172-housing estate (source, authors, 2022)

This result is confirmed by the operation of the housing simulation of the Block 13 building, where this operation revealed that the variation of the PMV indicator (Predicted Average Vote, by Fanger calculated according to ISO 7730, varied between [-1.2, -2.6] during the winter period which corresponds to 17 November to 23 March (Figure 8), and which can reach the conventional limit. This implies that a PMV of -2.6 corresponds to the PPD indicator (Predicted

Percentage Dissatisfaction) reflecting 94% dissatisfaction of the inhabitants with the thermal well-being in their dwellings (Figure 9).

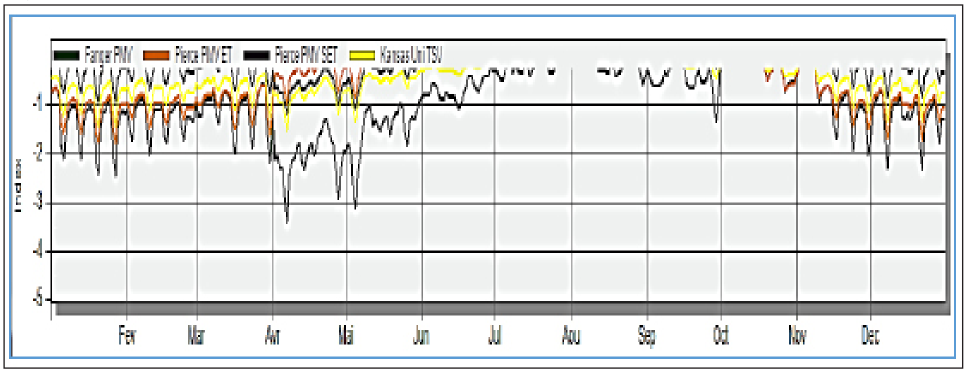

Figure 8. Change in the PMV indicator for block 13 (source, authors, 2022)

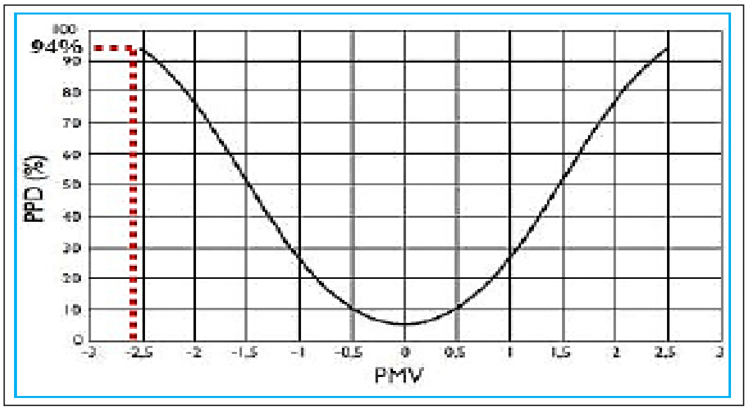

Figure 9. Graph of the correspondence of the PMV and PPD index (source, https://www.beswic.be/fr/themes/agents-physiques/ambiances-thermiques)

Figure 10 shows the percentages of the responses of 83 participants in relation to energy consumption in their homes. Based on these percentages, we can see that 87% of the respondents in the 172-housing estate in Bouzaaroura suffered from excessive energy consumption in their homes. This is due to the intense use of technical equipment during both periods (cold and hot) to ensure heating and cooling, and this has had a negative impact on the energy bills to be paid (Figure 11).

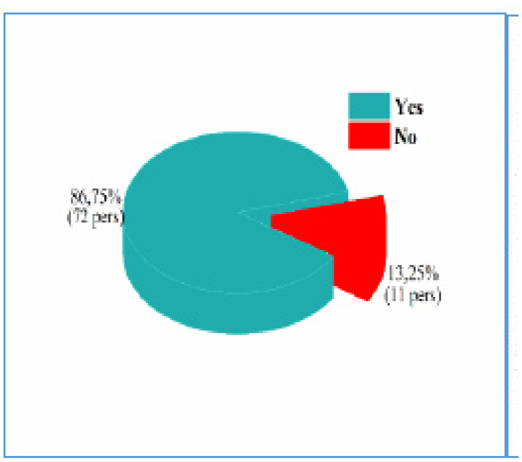

Figure 10. Percentage of respondents' answers on energy consumption (source, authors, 2022)

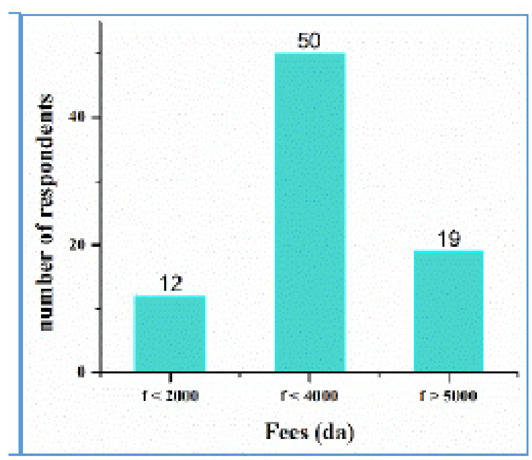

Figure 11. Energy consumption costs paid by residents (source, authors, 2022)

Similarly, the results of these variables are confirmed by the operation of the simulation assisted by the Design Builder software (Figure 12) where it is shown that the values of sensible heat of the area are higher from December to March where it reaches a maximum value of 1.52kwh/m^2 day, on December 17 and 24 and January 28. On the other hand, it was found that the sensible cooling of the studied flat is increased in the hot period from June until the end of September where it reaches a maximum value of 1.2 kWh/m^2 day, on 23 and 26 August. This confirms the opinion of the surveyed inhabitants about their situation with respect to thermal comfort.

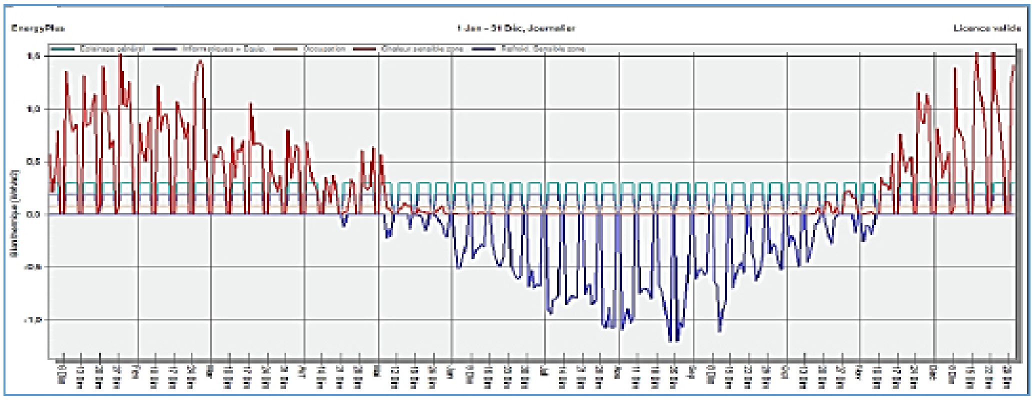

Figure 12. Simulation of the thermal review (source, authors, 2022)

Furthermore, based on the respondents' answers to the question of the state of thermal comfort in winter in the surveyed buildings, the lack of thermal satisfaction among all respondents can also be seen. Therefore, 65 people (78%) stated that it was very cold and 20% (17 people) answered just that winter cold in their dwellings is tolerable (Figure 13).

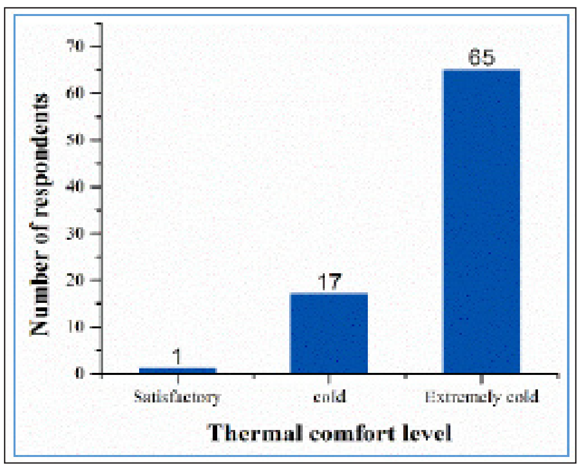

Figure 13. Thermal comfort level in winter (source, authors, 2022)

In relation to the execution of the simulation, Figure 14 showed that the operating temperature (TO) obtained (from October to 10 November) was between 18°C and 25°C, which corresponds to a PMV (-0.8) suitable for the zone that is a little cold, and from 10 November to the end of March, the TO values reached up to 13.7°C, which corresponds to a PMV (-3) indicating that the zone is very cold. This caused a sensation of thermal discomfort among the occupants of the flat.

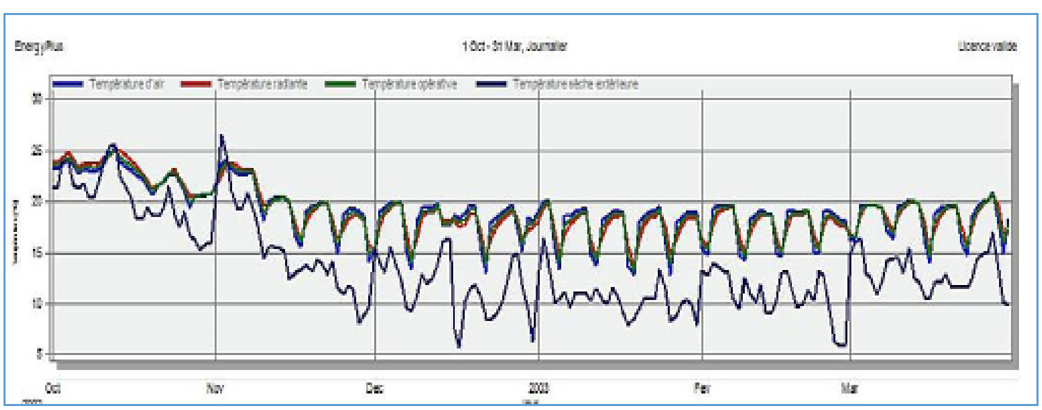

Figure 14. Simulation of the temperature in winter (source, authors, 2022)

Figure 15 shows the percentages from the answers of the inhabitants regarding the level of thermal comfort in the homes in hot periods. The majority of the respondents (55.5%) were thermally satisfied, while 44.5% of them expressed their dissatisfaction with the thermal situation in their dwellings. Mainly in the high-summer weather conditions which show a high degree of heat especially for the month of August.

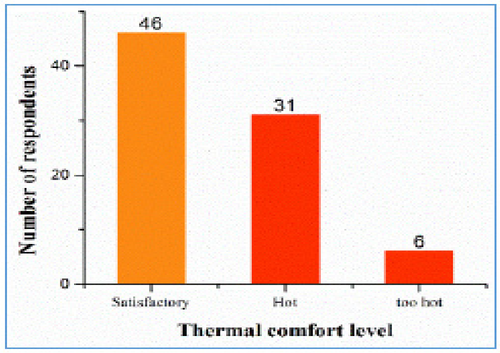

Figure 15. Level of thermal comfort in summer (source, authors, 2022)

The results of the simulation at this point (Figure 16) validated the answers with respect to the variable on the state of thermal comfort in summer, where it was indicated that the TO values of the operating temperature are between 16 °C and 25 °C from April to 06 June, from this date the TO remained at 25.5 °C only until August, when it could reach 27 °C.

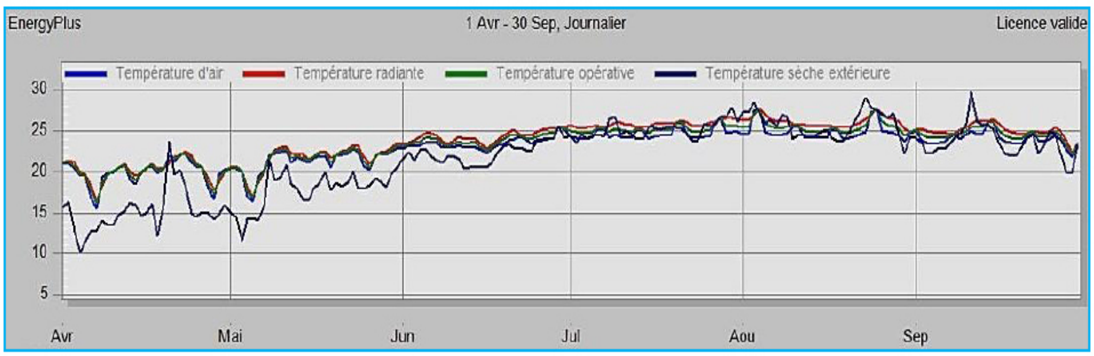

Figure 16. Level of thermal comfort in summer (source, authors, 2022)

Moreover, an insufficient temperature-humidity comfort range has a very dangerous impact on the health of the occupants. As shown in figures 17 and 18, we found that 1/3 of the respondents suffer from chronic diseases, (i.e., 58% of the inhabitants surveyed are confronted by chronic morbidities), allergy, blood pressure instability, and diabetes are the main effects of a bad thermal comfort. Also, since the results showed that more 39/83 respondents have allergy and respiratory disorder, 20/83 respondents have diabetes, and 16/83 have blood pressure(Peter R. Woodhouse, Khaw, and Plummer 1993),(Pedley, Paterson, and Morrison 2002). On the other hand, rheumatism and osteoarthritis are diseases with low temperatures in winter found in 8/83of the respondents. Similar findings on health complications due to thermal discomfort in residential buildings were established in a study conducted by (Haruna, Muhammad, and Oraegbune 2018).

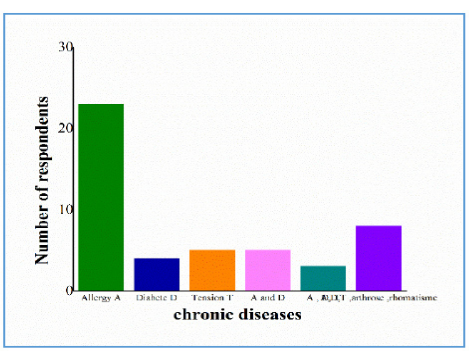

Figure 17. Percentage of the respondents with and without sickness (source, authors, 2022)

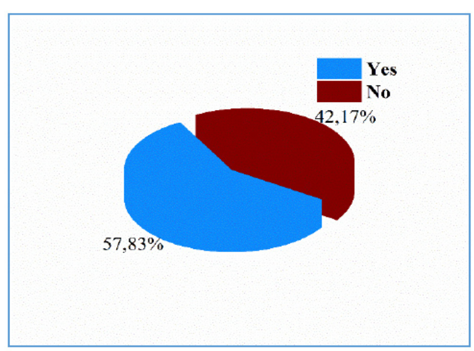

Figure 18. Number of sicknesses found throughout the survey (source, authors, 2022)

In summary, by the results obtained from the sociological survey and the established simulation, it was evident that about 90% of the surveyed occupants suffer from a level of thermal comfort with a high degree of deterioration (PMV = -2.6), in a first step to propose passive solutions to reduce the discomfort is to understand the temperatures that individuals suffer in their homes and the upper limits that the occupants can withstand. Other studies have been conducted on residential buildings in other regions in the world, such as Nigeria (Akande and Adebamowo 2010), Semera in Nigeria(Hailu, Gelan, and Girma 2021)where it was obtained that people were not in an acceptable thermal conditions in their residences. In addition, the study conducted by(M. Adaji, Watkins, and Adler 2016), showed that the occupants of the studied buildings in Abuja, Nigeriaare not satisfied with the thermal environment of their living places. In another study, (Yu et al. 2017) showed that the thermal comfort temperature range is acceptable for residential buildings produced in Tibet region of China.(Zhang L. et al. 2015) revealed that the indoor thermal comfort of residential buildings in Kangle village is slightly worse.The research by(Mahar, Amer, and Attia 2018)) revealed that the majority of the houses examined in Quetta, Pakistan, did not offer its tenants the level of comfort they desired. Due to scorching summers and chilly winters, residents need active systems to maintain thermal comfort. More than two-thirds of urban dwellers in Nigeria were not satisfied with their thermal environment, according to research (M. U. Adaji et al. 2019). Furthermore, the results of this investigation have confirmed that the lack of thermal well-being of the inhabitants affects their sanitary conditionand it was found that they suffer from chronic morbidities (allergy, rheumatism, diabetes, tension).

Numerous studies have been conducted on the consequences of exposure to low and high temperatures on human health. The severity of the potential health impact increases as the temperature falls below 18°C.Blood thickening and hypertension are two bodily reactions to cold temperatures(P. R. Woodhouse, Khaw, and Plummer 1993) and in (Saeki et al. 2014) around 16°C, respiratory stress occurs (collins 1993). Which explains the presence of chronic diseases (allergy and tension) in this study where the TO is lowered to 15°C. Additionally, exposure to high temperatures results in respiratory-related hospitalizations and fatalities (Näyhä et al. 2013). Studies have connected Indoor Environment Quality (IEQ) to mental health and conditions including obesity, cardiovascular disease, and asthma-related issues that are not immediately obvious but may cause serious issues in the future(Houtman et al. 2008); (Jaakkola et al. 2013). All these studies and more show the importance of preserving the human health regarding the thermal aspect, mainly in residential buildings.

CONCLUSION

The perception of the inhabitants of a residential housing estate in Bouzaaroura, Annaba with regard to the interior environment experienced on a daily basis and their degree of satisfaction concerning the interior thermal comfort has been studied.From the answers of the 83 respondents and the graphic diagrams acquired by the software DesignBuilder, the conclusive points are the following:

- It was found from the responses of the respondents that there is a real problem of thermal discomfort that the inhabitants suffer in their dwellings.
- The inhabitants surveyed reported discomfort mainly in the winter period due to low temperatures caused by insufficient thermal insulation of the external walls, in contrast to the warm period, when the majority of the inhabitants expressed their tolerance for the temperature of the interior environment of the dwelling.
- The concern expressed by all the inhabitants about the lack of thermal comfort led them to adopt technical heating and cooling installations, which resulted in excessive energy consumption and this was reflected in the rates to be paid.
- According to the ASHRAE scale, the PMV (Predicted Average Vote) indicator reached a maximum value of -2.56, which in the very low temperature range is equivalent to a significant level of dissatisfaction of the inhabitants (PPD: Predicted Percentage Dissatisfaction) equal to 94%.
- In summer, the operating temperature from June to the end of September is admissible (16 - 25°C).
- The results of the sociological survey showed that the indoor climate of the inhabited places affects the physical health of the inhabitants, which evoked the occurrence of many chronic diseases.
- The correlation of the simulation results with the Design Builder software is highly consistent with that of the sociological survey conducted in this neighborhood.

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Competing of Interests

The author(s) declare that they have no competing of interests.

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