TECHNIUM
SOCIAL SCIENCES JOURNAL

Vol. 38, 2022

A new decade for social changes

ISSN 2668-7798

www.techniumscience.com

Technium Social Sciences Journal
Vol. 38, 739-754, December, 2022
ISSN: 2668-7798
www.techniumscience.com

Influence of the occupant factor on the thermal quality of a high energy performance house type 80 eco-bat housing, Blida program, Algeria

Kenza Ferradji[1], Djamila Djaghrouri[2] and Moussadek Benabbas[3]

[1,2,3] Laboratory of Design and Modelling of Architectural Ambiances and Urban Forms (LACOMOFA), University of Biskra, BP 145 RP, Biskra, 07000, Algeria

Kenza.ferradji@univ-biskra.dz, Djamila.djaghrouri@univ-biskra.dz, m.benabbas@univ-biskra.dz

Abstract. This paper discusses the best way of energy management. It is an initiation for the improvement of the constructive system in Algeria. Within the framework of the ECO-BAT program, we take a unit from the 80 HEP housing units in Blida as a case study, on which we undertake in-situ measurements and the questionnaire for a subjective evaluation of the thermal environment of the dwellings and the level of awareness among the occupants. This work aims to test the feasibility of the energy solutions adopted for this system by verifying the winter thermal comfort as well as the energy consumed for heating. The solutions of this research will be the support of improvement recommendations for energy management programs in the future.

Keywords. Energy consumption, high-energy performance, thermal comfort, collective housing, thermal behavior, Blida city

1. Introduction

Building in Algeria is becoming a challenge. It is a question of confronting the housing crisis linked to the excessive increase in the population. This has required the adoption of a light, industrialized, and rapidly developed building system throughout the national territory. The result is a poor thermal quality of the dwellings, which forces the occupants to use mechanical tools to rectify the thermal ambiences. The energy consumed is fossil fuel energy. This has favoured an excessive increase in energy consumption to become 66.9 million TOE (Ton Oil Equivalent), according to the APRUE (Agency for the promotion and rationalization of energy use) in 2019. [1]

To control energy consumption by following international trends, the Algerian government has launched several programs of housing at the national level. ECO-BAT (the eco-building) is one of these programs which aims to attain high-energy performance housing, HEP (High Energy Performance). The objective is to achieve thermally pleasant homes by minimizing the amount of energy consumed. This program consists of building 600 homes throughout the national territory, according to the diversity of climatic zones.

The evaluation of physical quantities remains insufficient without the interaction of the housing occupants. It is a question of deducing an adaptive comfort by integrating the opinion of the space users.

2. Literature Review

Several studies have been carried out on the axis of thermal behavior and energy efficiency in buildings. In the context of winter comfort, some people worked on the simulation of architectural parameters of winter thermal comfort in Algeria such as Foura et al in 2007 [2]. On the one hand, they proposed conceptual software that can ensure the integration of the architectural project in its climatic context. On the other hand, they have concluded that the elements of energy efficiency are essential in the conceptual process. These are thermal insulation, the control of thermal bridges, the quality and favorable dimensions of openings, the most efficient orientations, and the obligation of thermal regulations in the conception of the new building.

In the context of the MED-ENEC (Energy Efficiency in the Construction Sector of the Mediterranean.) project, CNERIB (National Center for Integrated Studies and Research in Construction), in collaboration with CDER (Renewable Energy Development Center), has produced a prototype house in Souidania, which is characterized by the use of thermal inertia and insulation of the thermal envelope. Derradji et al, in 2012, worked on the study of the thermal performance of this prototype during the winter period [3]. The goal is to make a comparison between the prototype and reference housing by a TRNSYS (Transient System) thermal simulation. This study proved the possibility of achieving energy saving while offering adequate thermal quality in Algeria. The savings on heating can reach 78%. The authors of this article affirmed the efficiency of the energy solutions adopted for this experiment pilot.

Jaber et al. in 2012, worked on the reduction of thermal loads. This paper involves acting on elements of architectural design to promote savings on annual energy consumption, related to heating and air conditioning, by offering optimal thermal comfort. The results of this study have proven the importance of efficiency solutions in architecture conception. The adaptation of an optimal orientation, the adequate dimensioning of openings, the orientation of the facade, and their thermal protection are the most relevant solution of this research. [4]

In the context of adaptive comfort, F. M. Elaieb, in 2014, conducted research in the city of Darnah in Libya. She used the questionnaire to evaluate the thermal sensations of the occupants of 63 buildings. Her work focuses on adaptive thermal comfort. A result of dissatisfaction with the thermal situation favors the use of a thermal simulation to develop an improved version of the existing cases. The author confirms that the introduction of thermal insulation ensures a 63% reduction in energy consumption and decreases the indoor temperature by 6°C. She believes that her results can be used by the construction industry as a national guideline for architectural design. [5]

M. A. Ealiwa et al. in 2001 worked in the city of Ghadames in Libya. This is a comparative approach between the ancient fabric of the city and the contemporary type. The authors used the method of subjective evaluation of thermal comfort by the questionnaire. The objective evaluation is by the choice of in-situ measurements. The case studies are buildings with fans and courtyard or air conditioning systems. The results of this research indicate that the occupants of contemporary housing are more satisfied with their thermal situation than the occupants of other fan and yard housing. [6]

F. Azizpour et al. in 2013, worked on objective and subjective data collection in a hospital in Malaysia. The objective of this research is to evaluate the thermal comfort criteria designated by ASHRAE in a hot and humid climate and to find the correlation between the PMV index of Fanger theory and the thermal sensation index TSV. Through a questionnaire and in-situ measurements, the results indicate that occupants prefer cooler indoor temperatures than neutral temperatures. On the other hand, there is a strong correlation between PMV and TSV. [7]

3. Objectives of the research

Our study evaluates the efficiency of solutions adopted in the HEP project and their influence on thermal comfort and the quantity of energy consumed. The main objectives of this study are: (i) the evaluation of ensured thermal comfort was a result of the measuring of the three physical quantities; ambient temperature, surface temperature, and relative humidity. (ii) The quantification of the energy consumed, which reflects the need of the occupants to improve their thermal environment. (iii) Proposal of design recommendations that aim to improve the quality of thermal ambiences by rationalizing energy consumption.

4. Case study description:

The city of Blida is located in the northern part of Algeria, 35km south of Algiers. Its altitude is 267m from sea level with a latitude of 36°28 north and a longitude of 2°50. The case study is the 80 HEP housing units in Blida. This project is located in the city of Blida, the municipality of Ain Romana. It is 20km away from the chief town of Wilaya; [9]

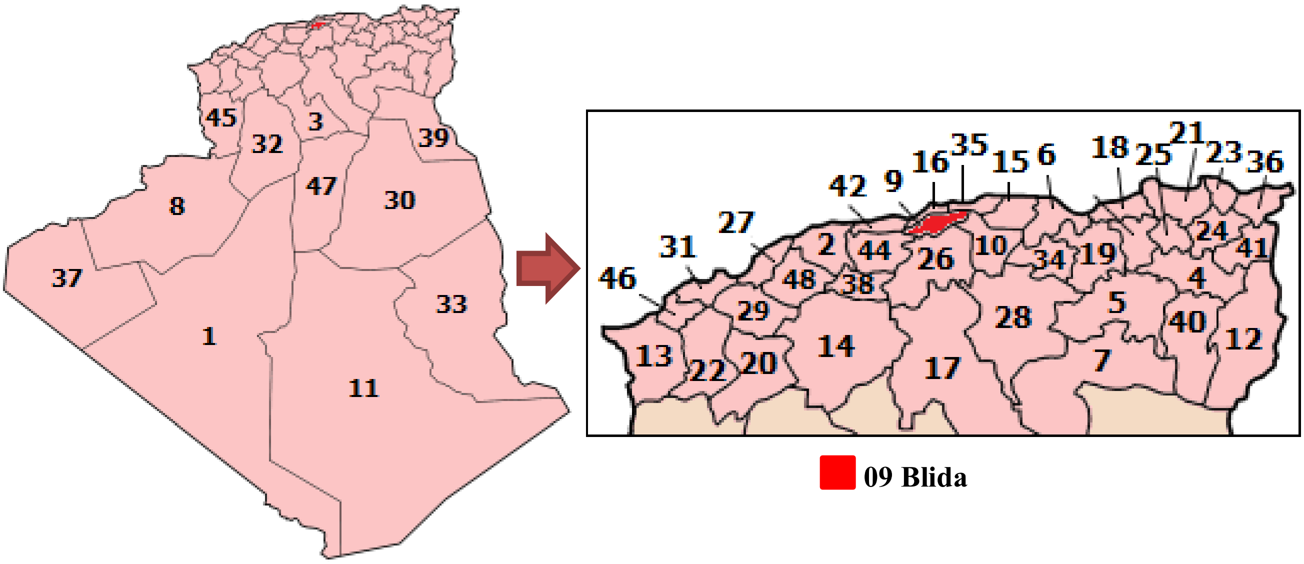

Figure 1: Geographical location of the city of Blida [8]

1. 1 *The climatic characteristics of the city of Blida*

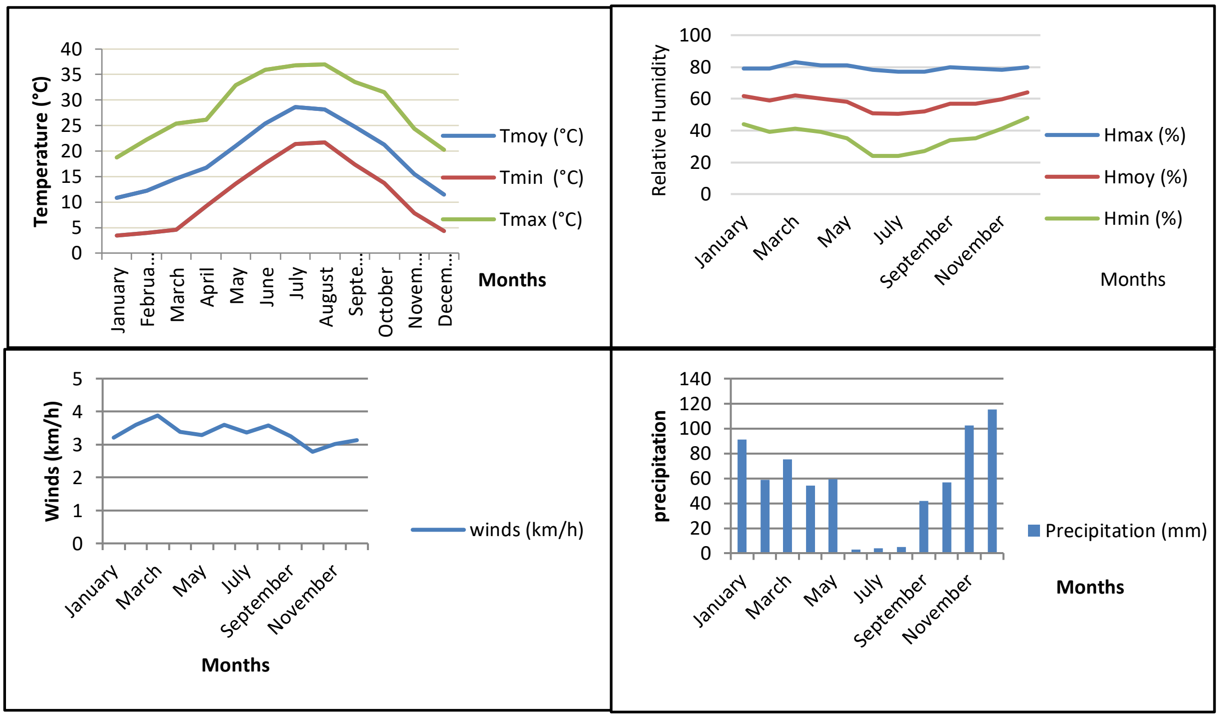

Figure 2: Climatic characteristics of the city of Blida. [10]

Blida belongs to the climatic zone 'B' according to the classification of CNERIB [11]. It is a humid temperate climate of the Mediterranean type with a double influence of the mountains surrounding the city and the Mediterranean Sea. The climate of this city is characterized by cold winters with an average monthly temperature of January of 10.83°C and a minimum monthly temperature of 3.43°C. Summers are hot with an average monthly temperature of 28.63°C and a maximum monthly temperature of 36.75°C for the month of July (see Figure 2). The relative humidity of the city of Blida reaches 83% during the rainy months and drops to 24% in summer.

1. 2 *Constructive presentation*

HEP housing is within the framework of the ECO-BAT program. The latter is launched by the state to contribute to energy management on a national scale. The dwellings presenting the case study of this study are the 80 dwellings of Blida.

The sample apartment is in Block B, on the east side of the 4th floor. This apartment is considered the most unfavorable due to its location on the river bank, having four exterior faces south, east, north, and the roof. It is an F3 type dwelling with a living area of 75.80m2.

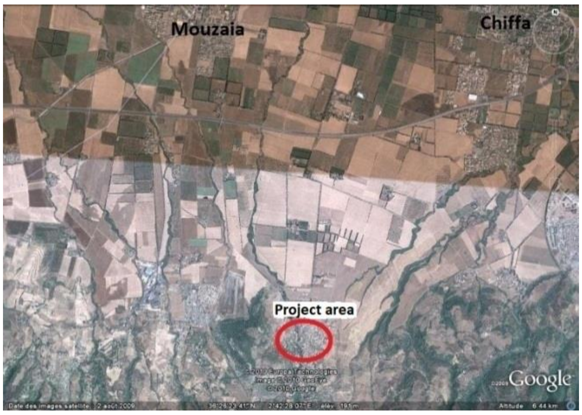

Figure 4: a, Views perspective of the HPE project [11]. b photo of the HPE project. Source author

Figure 5: View perspective of the HPE project [11].

Table 1: Thermal characteristics of the outer casing walls. [12]

+Housing (HEP)	Composition	Thickness (m)	U (W/m^2.K)
High floor	Glass wool Plaster ceiling.	0.05 0.05	0.681
Running floor	Tiling Mortar + sand Solid concrete Concrete bricks	0.02 0.03 0.04 0.16	2.395
Exterior wall	Plaster coating Hollow brick Polystyrene Hollow brick Exterior coating	0.02 0.10 0.05 0.15 0.02	0.495

The specification of this constructive system consists of applying a specific treatment of the thermal bridges by cladding with hollow bricks or thermal insulation according to the DTR regulations. The insulation of the dwellings is of fiberglass and polystyrene of 5 cm. A stone base at the ground floor level is to insulate the construction from the effects of the lower ground. The pitched roof is to help protect the top floor from the prevailing winds in winter and intensive solar radiation in summer. Solar protections are on the south side windows. The service spaces are greatly opened on the north side, whereas an adequate spatial organization is by favoring the living spaces on the south side. [13]

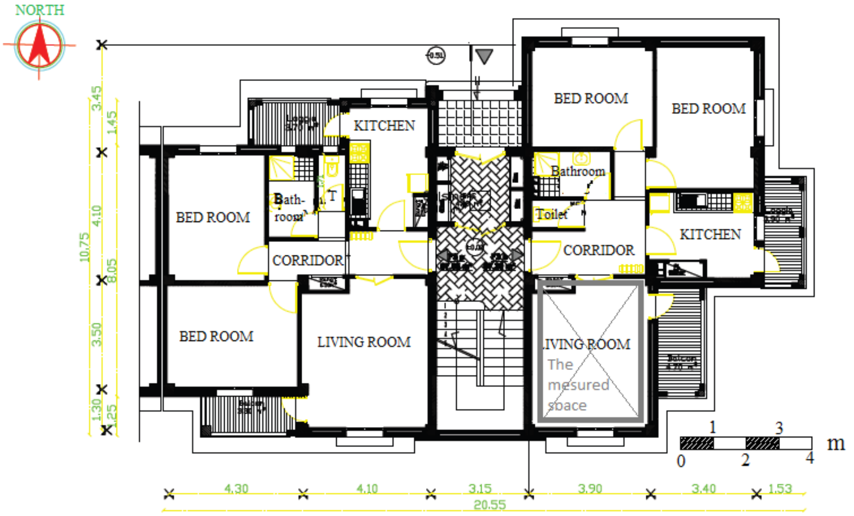

Figure 6: Current floor plan of Block B (typical apartment) [12]

5. Methodology and research tools

The methodology adopted for this work consists in using, on the one hand, the TESTO 480 for an in-situ investigation of three days in winter. This is for an objective evaluation of the indoor environments. The parameters measured are the indoor and outdoor ambient temperature, relative humidity, and surface temperatures of walls and glazing. The space measured is the living room. Its orientation is towards the south. This study is to evaluate energy consumption too.

On the other hand, the elaboration of a questionnaire is to evaluate the perception of the occupants of thermal comfort.

Figure 7: Photo of the measuring equipment
(TESTO 480)

6. Results and discussions

In-situ measurements allowed us to evaluate the physical quantities of temperature and relative humidity. Energy consumption is another factor to be assessed to control the efficiency of the energy solutions adopted by the prime contractor of this project.

The analysis of the thermal results of the interior of the dwelling, object of study, is about the thermal comfort zone created by the formula of Auliciemes.[14]

$Tn = 17.6 + (0.31 * Tav)$

$TL = Tn - 2.5$ (lower temperature of the thermal comfort zone).

$TU = Tn + 2.5$ (upper temperature of the thermal comfort zone).

6. 1 Evaluation of ambient temperatures

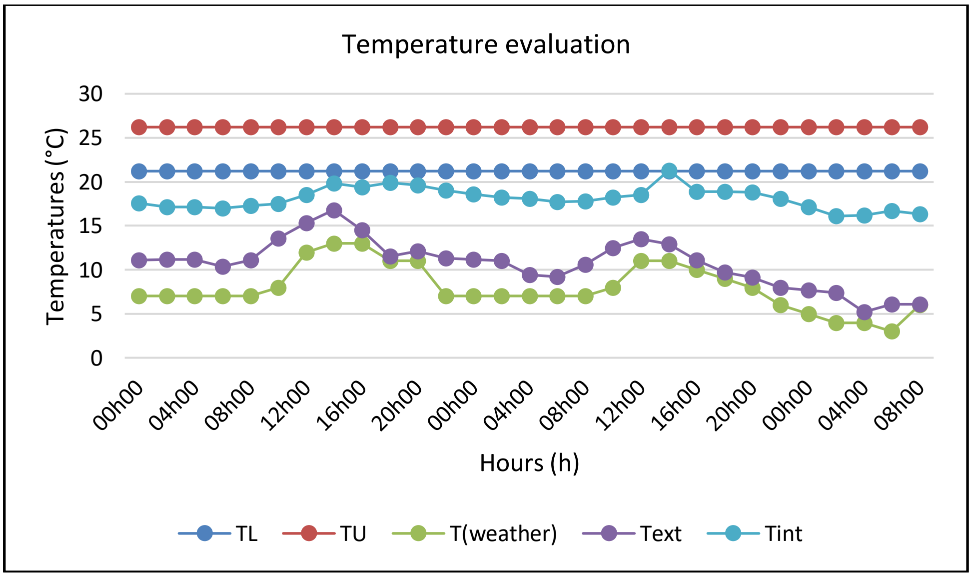

Figure 8: Evolution of ambient temperatures, (from January 15 to 16, 2021), Source author.

Ambient temperatures obtained during winter measurements indicate results between 16.1 °C and 21.3°C. Outside air measurements are between 6.1°C and 16.8°C. The maximum temperatures are midday, from 12:00 to 16:00. Although the minimum temperature values are from midnight to 6:00 a.m., this is the coldest period (see Figure 5). The comfort zone is between 21.2°C and 26.21°C according to the method of Auliciemes[14,15] with an air velocity that does not exceed 0.2 m/s. Daily temperatures belong to the comfort zone, although night temperatures reach up to 16. 1°C with a temperature range of 4°C.

The second day of the measurements is the most unfavorable, or the night temperatures decrease to 6.1° n outside. These values fall into the comfort zone. This result is explained by the low thermal inertia of the walls. It minimizes the phase shift between inside and outside temperatures. The rapid transmission of cold air from the outside to the inside indicates insufficient thermal insulation layers.

6. 2 The surface temperatures of the wall

According to the graph shown in figure 6, the surface temperatures of the three walls, east, south, and west are more stable than extreme values, between 14.6°C and 20.7°C on average.

On the other hand, the north wall, adjacent to the heating system, has higher temperature values than the other walls. These are between 18°C and 20.7°C depending on whether the heating is switched on or not.

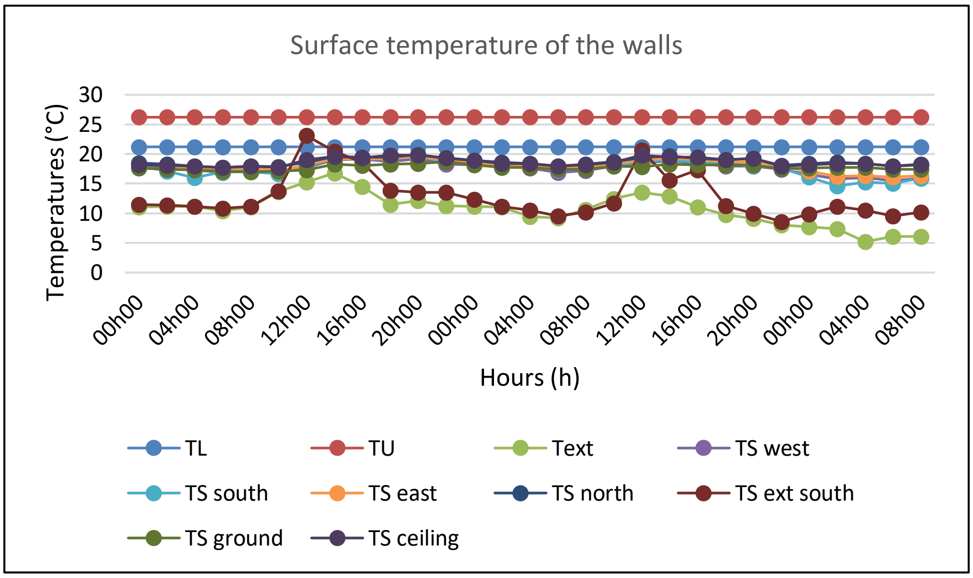

Figure 9: Evolution of the internal surface temperatures of the walls (from January 15 to 16, 2021)

The stability of the surface temperatures of the three walls west, south, and east is explained by the correction of thermal bridge defects on the topic of the DTR regulations. The north wall is adjacent to the heating system, which favors an increase in surface temperatures during nighttime heating periods.

6. 3 *Temperatures of the glazing surface*

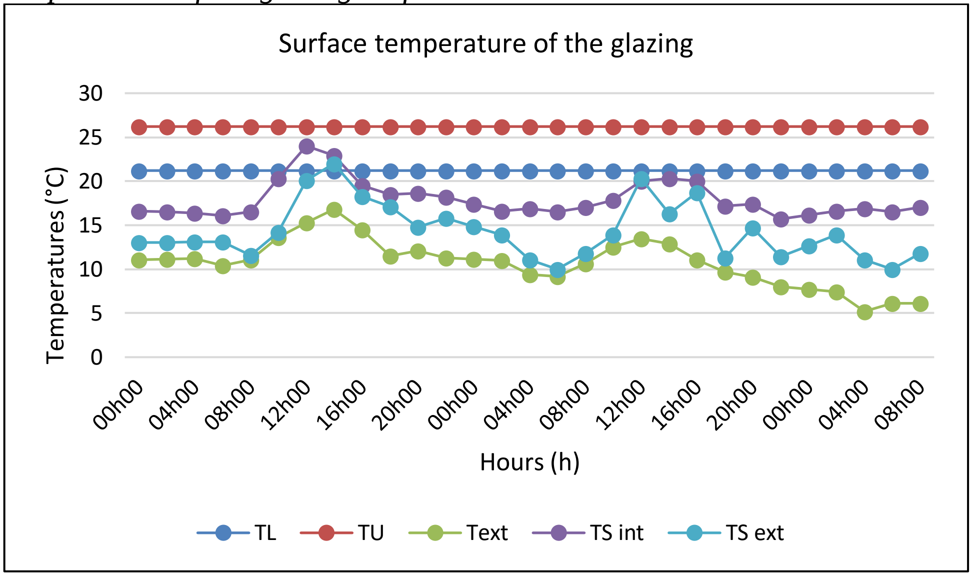

Figure 10: Evolution of the glass surface temperature (from January 15 to 16, 2021), source author.

The internal surface temperature of the glazing (see fig. 7), has lower temperature values than those of the walls. For two days of measurement, the temperatures are between 16.1°C and 21.3°C for the inner side. The external side is characterized by temperature values between 6.1°C and 15.5°C. The fluctuation of the surface temperatures of the glazing is directly related to the values of the outside temperatures.

The excessive decrease in the internal surface temperatures of the glazing is less than the thermal comfort values. It creates a feeling of thermal discomfort for the occupants due to the effect of the cold wall. This phenomenon is explained by the use of single glazing, which increases heat loss.

6. 4 *Relative humidity*

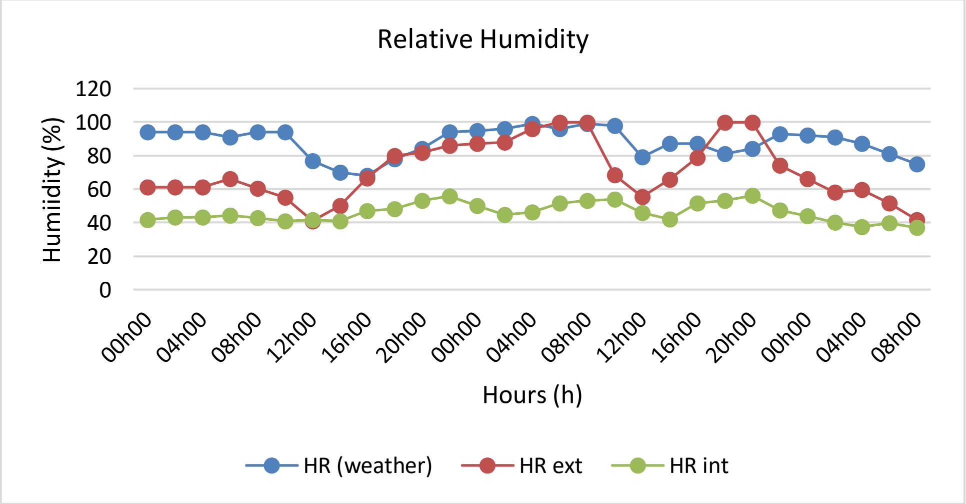

Figure 11: Evolution of relative humidity (from January 15 to 16, 2021), source author.

According to Figure 8, the outdoor relative humidity values show an intensive fluctuation between 23% and 99.99%. This fluctuation is closely related to the weather conditions. Precipitation has favored an increase in the relative humidity percentage (from 41.5% to 99.99%) and vice versa. However, the relative humidity interior is more stable than the exterior and varies between 39% and 56.1%. It is due to the effect of the absence of natural or artificial ventilation. The moisture by metabolic production is ignored due to the absence of an occupant in the measured space.

7. Energy consumption in Winter

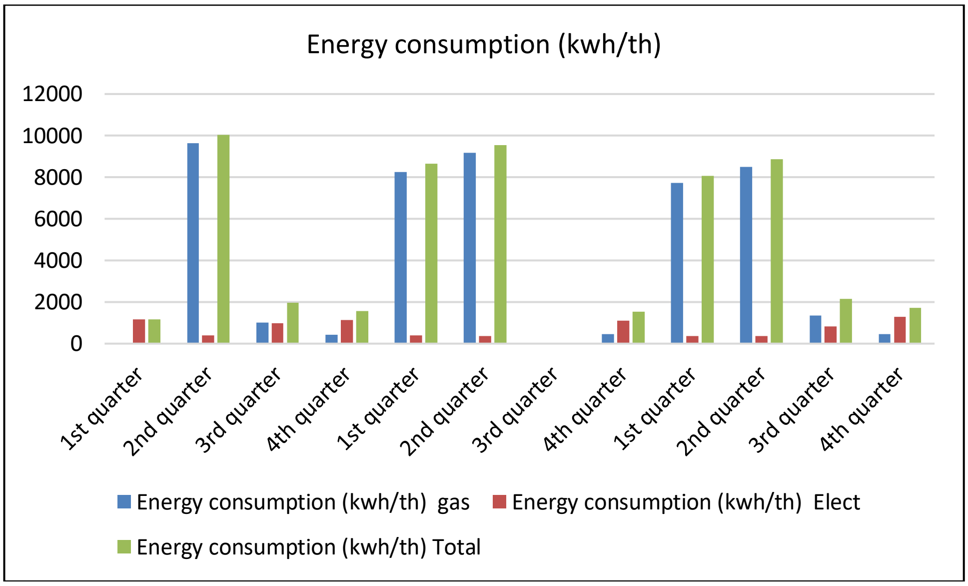

Figure 12: Evolution of the quantities of energy consumed during three years of occupation.

Based on the energy consumption bills for the three past years (see Figure 9), we see excessive energy consumption in every quarter. An in-depth reading shows us that during the six cold months, gas is the most consumed energy, although, during the hot months, it is electricity that is consumed the most. In this respect, the increase in energy consumption is explained by the use of mechanical tools, heating, and air conditioners to rectify indoor thermal ambiences.

The following table shows the months, making up each quarter. We see that the first and second quarters are the cold months, although the third and fourth quarters are the months where the need to heat is reduced or even absent.

1st quarter (January)	November, December and January.
2nd quarter (April)	February, March and April.
3rd quarter (July)	Mai, June and July.
4th quarter (October)	August, September and October.

$$Q\ energy = Q\ gas\ winter\ -\ Q\ gas\ summer$$

Q energy: the amount of energy (gas) consumed for winter heating.

Q winter gas: the total amount of gas consumed in winter.
Q gas summer: the quantity of gas consumed in summer. We consider it stable data.
Q gas summer = 443.4 kwh/Thermie

The following graph (Figure 12) shows the averages of gas quantity consumed per quarter during the cold period of the year.

Table 3: the amount of gas consumed for heating.

The year	The quarter	Total gas consumption. (kwh/th)	Gas consumption for heating. (kwh/th)
2017	1st quarter	/	
	2nd quarter	9622,61	9 179,19
	3rd quarter	1000,13	556,71
	4th quarter	427,24	/
2018	1st quarter	8243,79	7 800,37
	2nd quarter	9166,24	8 722,82
	3rd quarter	/	/
	4th quarter	456,37	/
2019	1st quarter	7719,45	7 276,03
	2nd quarter	8505,96	8 062,54
	3rd quarter	1349,69	906,27
	4th quarter	446,66	/

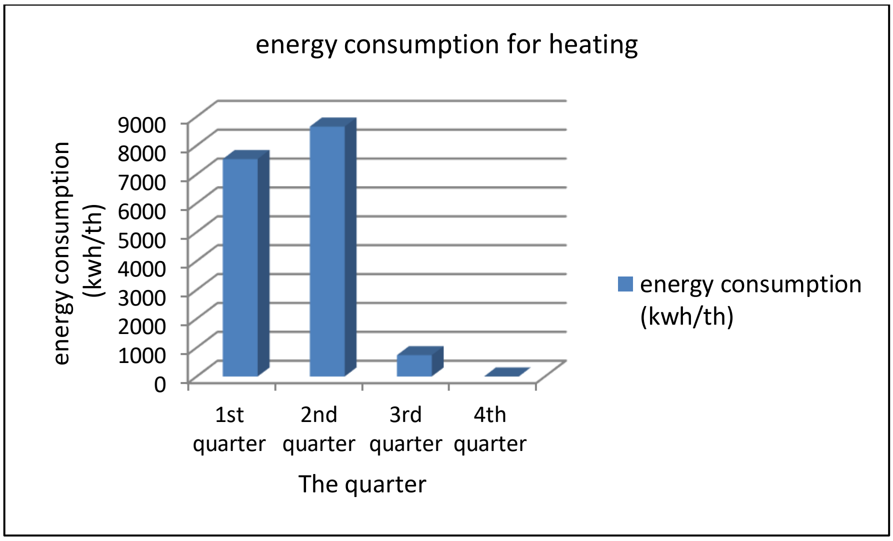

Figure 13: The amount of energy consumed for heating.

8. The questionnaire

The questionnaire is intended for the inhabitants of the HEP housing of Blida. The objective is to introduce the opinion of the occupants to have adaptive thermal comfort. On the other hand, this research tool consists in knowing the level of consciousness of the inhabitants to control the thermal situation at home.

8. 1 knowledge of housing type

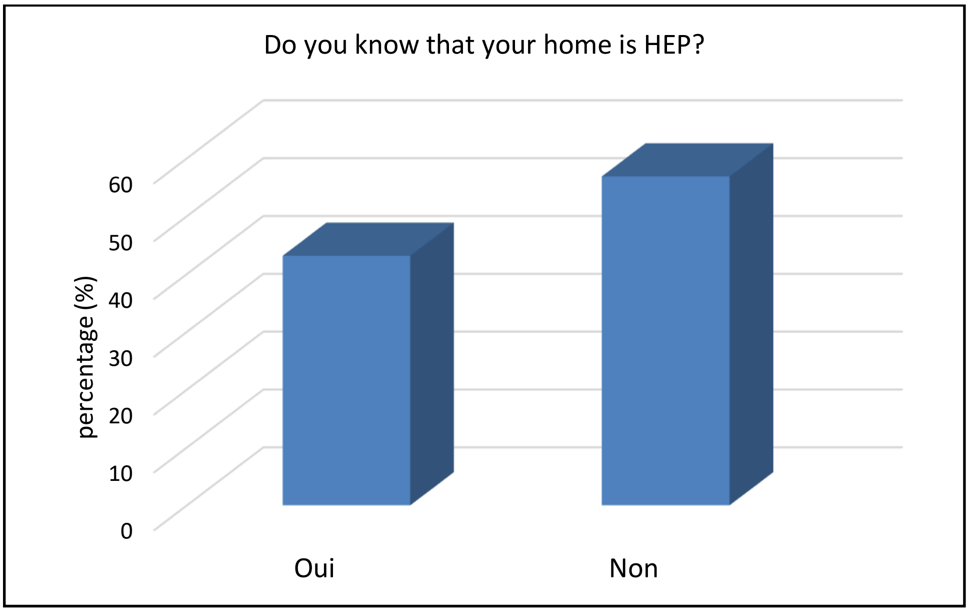

Figure 14: Variation of knowledge of housing type

The first question is to know if the interviewee knows that his house belongs to the constructive system of high energy performance (HEP). The result states that 56.86% of the interviewed occupants do not know and consider it ordinary housing. Although 43.14% have the information. This result influences the behavior of the occupants inside the dwellings to improve the thermal quality by minimizing mechanical rectification.

8. 2 Thermal satisfaction of the dwelling in winter

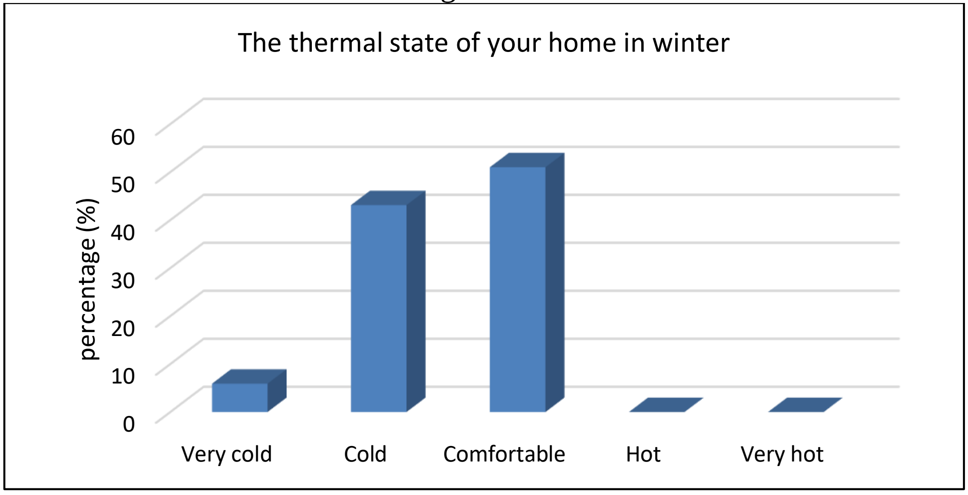

Figure 15: Variation of the occupants' feelings about the thermal quality of housing

51% of the occupants participating in the survey considered that their homes are comfortable in winter. While 43.1% consider that it is cold in winter and even very cold 5.9%. These results indicate that the thermal sensation is linked to other criteria that will be the answers to the following questions.

8. 3 Availability of mechanical heating:

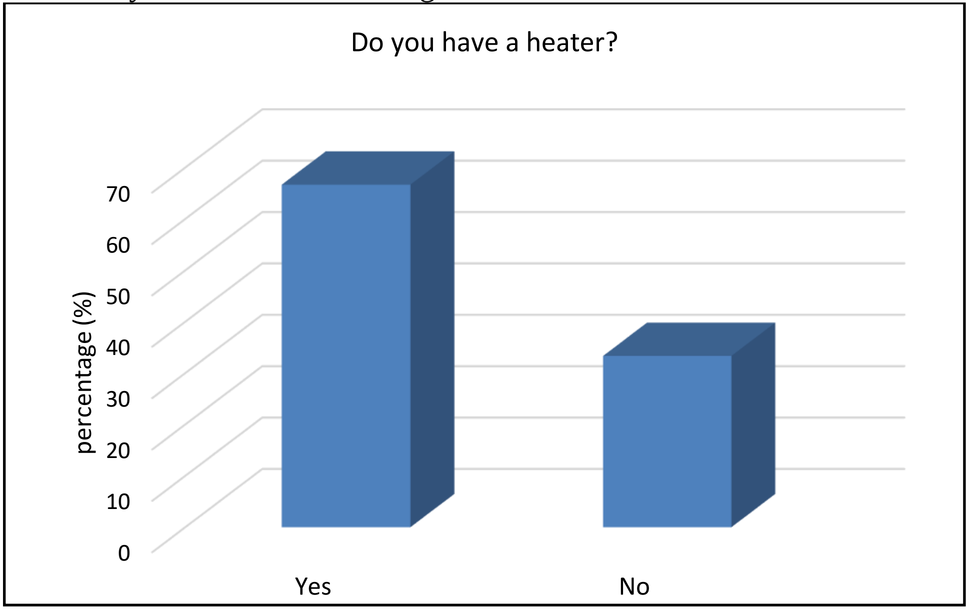

Figure 16: Variation in the availability of heating.

33.33% of the interviewees do not have a mechanical heater. This is related to the financial situation of the family.

8. 4 The frequency of heating use

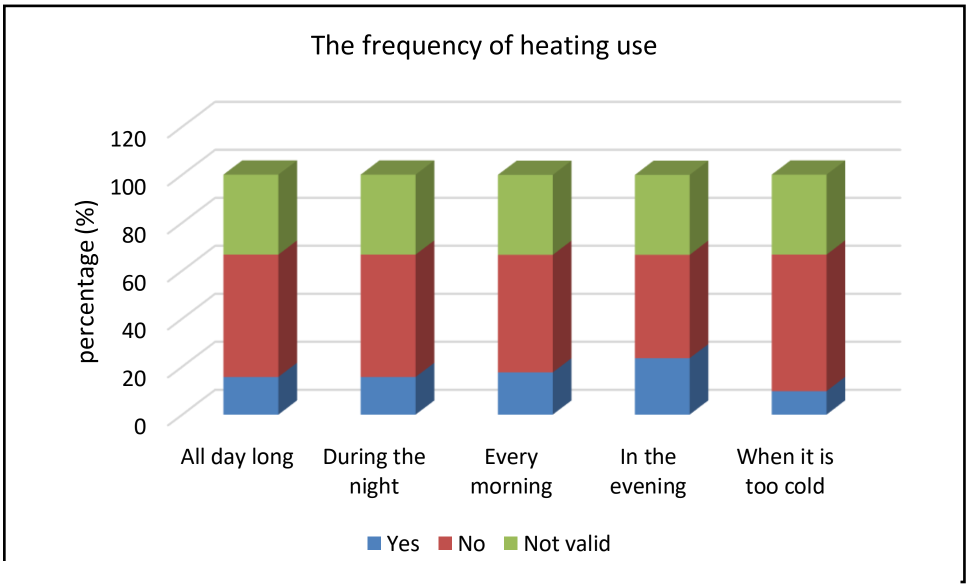

Figure 17: Variation of the frequency of use of the heater.

66.67% of the people interviewed who have a heater have a different frequency of use. 9.8% use the heating only during the coldest period, while the rest use it daily. 23.5% use the heater in the evening. Every morning, 17.6% of the interviewees turn on the heating 15.7 turn on the heating during the night or all day.

8. 5 The occupants' reaction to a cold day

This question highlights the level of awareness of the occupants with regard to the thermal environment. The choice of how to fight against the cold is between the simple gesture of turning on the heating all the time or reacting with a gesture that minimizes the negative impact of the overconsumption of energy.

The result of this question indicates that 50.98% of the occupants chose to use the heating all the time.

For the other variants of the question, the use of an auxiliary heater is represented by 25.49% of the occupants. Adjusting clothes is represented by 23.53% of occupants. Finally, 16.61% of occupants opted to close the blinds. Figure 18.

All these actions can improve the quality of thermal environments without consuming excessive energy

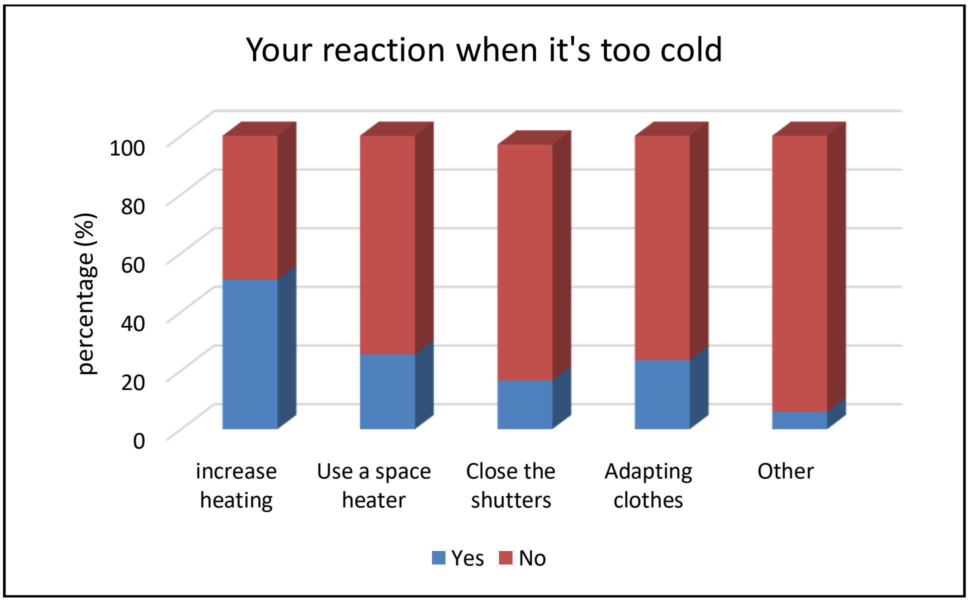

Figure 18: Variation of reactions when it's too cold

.Conclusion

The thermal and energy assessment of the typical HEP project housing has favored the advantages and disadvantages of the solutions adopted by the project owner. On the one hand, the stability of the internal surface temperatures of the walls and the daily temperatures that belong to the thermal comfort range indicate an improvement compared to the existing building system in Algeria. On the other hand, the drop in nighttime temperatures and the drop in the internal surface temperature of the glazing, the excessive increase in energy consumption reflects an anomaly in the design process. The increase in the energy consumption of gas in winter is due to a feeling of thermal discomfort of the occupants, which favors the use of mechanical heating to rectify the interior thermal ambiences.

Referring to the Souidania prototype, (Derradji et al., 2012; Derradji et al., 2011) the disadvantages, already mentioned, are explained by the low thermal inertia associated with using lightweight walls. It minimizes the restitution of daily temperatures during the night. The use of single glazing favors an increase in thermal losses. To this effect, we note that the HEP type dwelling is better than an ordinary house considering the energy solutions, which are adapted. However, this improvement remains insufficient to ensure high-energy performance.

The answers to the questionnaire indicate a minimal level of awareness among the occupants of the dwellings of the thermal and energy specificity of the project. To this end, the capacity of the user of the space is essential to maintain the thermal quality of the dwelling while minimizing the energy consumption of fossil fuels. It is a question of creating a collaboration between the occupants and the technical team to succeed the energetic solutions proposed to the project of high-energy performance and to achieve the proposed objectives.

To minimize the thermal losses as much as possible, it is interesting to improve the quality of the solutions to achieve a more efficient building system. This efficiency conception is enabled by the increasing of the thermal envelope inertia, which ensures the restitution of the accumulated calories lost during the day by passive heating during the most unfavorable moments. Therefore, it is reducing the fluctuations between day and night. Replacing single glazing with double-glazing minimizes the thermal losses in the construction. This energy management program has yet to evolve to reach its initial objectives of ensuring high-energy performance.

Acknowledgements

This research was supported by the (LA.CO.MO.FA) laboratory that is related to the department of Architecture at the University of Biskra, under the supervision of a research team of the laboratory, currently involved in a research project titled “Building and sustainability “.

The authors are most grateful to the laboratory members who helped us with the measuring tools.

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