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An Investigation of thermal comfort and assessment of energy consumption in individual vernacular and modern living space

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Abstract. The question of the city sustainability was involved in the process of sustainable development, which is considered as guarantees of a harmonious urban development for future generations. The architectural envelope of a living space includes elements that play an important role in energy consumption. The less energy it consumes, the higher energy-efficient it is. Thus, we tried to develop the basic notions and key concepts related to the research topic (energy performance and thermal comfort) of the architectural envelope and then we carried out experimental fieldwork to highlight the link between energy performance and thermal comfort, supported by simulation in order to achieve optimum real results. Our objective is to sort out the issue of energy performance and thermal comfort in living space in both vernacular and contemporary cases, and consequently develop conformations that are as autonomous as possible in terms of energy, by taking advantage of natural inputs and the application of renewable energy for housing. As a result, a survey was carried out on the inhabitants of the houses in the study corpus, and we achieved a qualitative and quantitative work that comes down to an Energetic Performance Diagnosis on a corpus study that constitutes two houses: a vernacular case versus a modern house case. Based on this social survey and energy consumption calculations, we can recommend some guiding points to achieve an architectural conformity that satisfies users' needs, and reach a long-lasting development on the matter.

Keywords: Energy performance; architectural envelope; vernacular house; cotemporary house; living space; Bejaia city

1. Introduction

In Algeria, which is the focus of this study, to live is to be in and with the world, to have a relationship with the outside world. The word living goes beyond the fact of having a house, the user is included and in an irreducible tripartite relationship through the existential dynamics of living[1]. To be in the world is to accept the world in its different spatial, temporal and coexistent dimensions, i.e. one should not limit oneself to one dimension, one should expand and deepen in all dimensions[2]. So, a habitable space is a space with a well-defined use which is habitation, but in such a way as to be with the world and not just to be in a world; it is therefore coexistence: being in and with the world[3].

The context in which an individual or a group finds itselfis defined by a set of characteristics that can be summed up in a single word: the atmosphere. This atmosphere refers to the set of thermometric and hygrometric conditions in a living space. Humans live in certain environmental conditions and consume large amounts of energy to achieve comfort[4]. The concept of sustainable development is based on the reasonable use of resources to meet the main needs of humanity[5].

Conservation of the overall balance and value of the natural heritage; equitable distribution and use of resources among all countries and regions of the world; prevention of the depletion of natural resources; Reduction of waste production (including reuse and recycling of materials); rationalisation of energy production and consumption are the conditions for sustainable development[6].The evolution of a number of concepts and notions related to the users of space have contributed to the birth of new precepts in architecture such as the revolution in the formal domain, the design of several projects, variety of trends..., This evolution has imposed a considerable energy consumption which has led to a depletion of energy which is outside the conditions of sustainable development[7], but today the will to reduce energy consumption is asserted in all domains, whether they are related to household equipment, to transport or to living space[8].

Sustainability, and in particular sustainable development in the living space, is closely linked to the energy issue, or more precisely to the problem of the increasing energy consumption. A reflection between energy losses and energy needs in the living space is therefore necessary to achieve a comfort level estimated by the users while consuming the minimum possible energy and this by using energy sources that will be derived from renewable energies, and to build with insulating materials that can reduce energy losses to the outside[9]. Living spaces must therefore be designed in such a way as to have a very good energy performance by making use of the opportunities offered by the neighbourhood and the site in which the living space is located, while at the same time achieving architectural conformations that will be designed to take into account a low energy consumption design[10].

2. Materials and method

The research work carried out aims to address the issue of energy performance in the vernacular and contemporary living space, In addition, we must:

- To think of conformations that are as autonomous as possible in terms of energy by taking advantage of natural inputs.

- And, according to the results obtained, to elaborate recommendations likely to improve the functioning of the living space in order to arrive at results that will be used by the designers to create spaces of the same or other types that are more efficient, effective, long term and above all healthy for man and the environment.

The figure below illustrates the research methodology adopted in the study (figure1).

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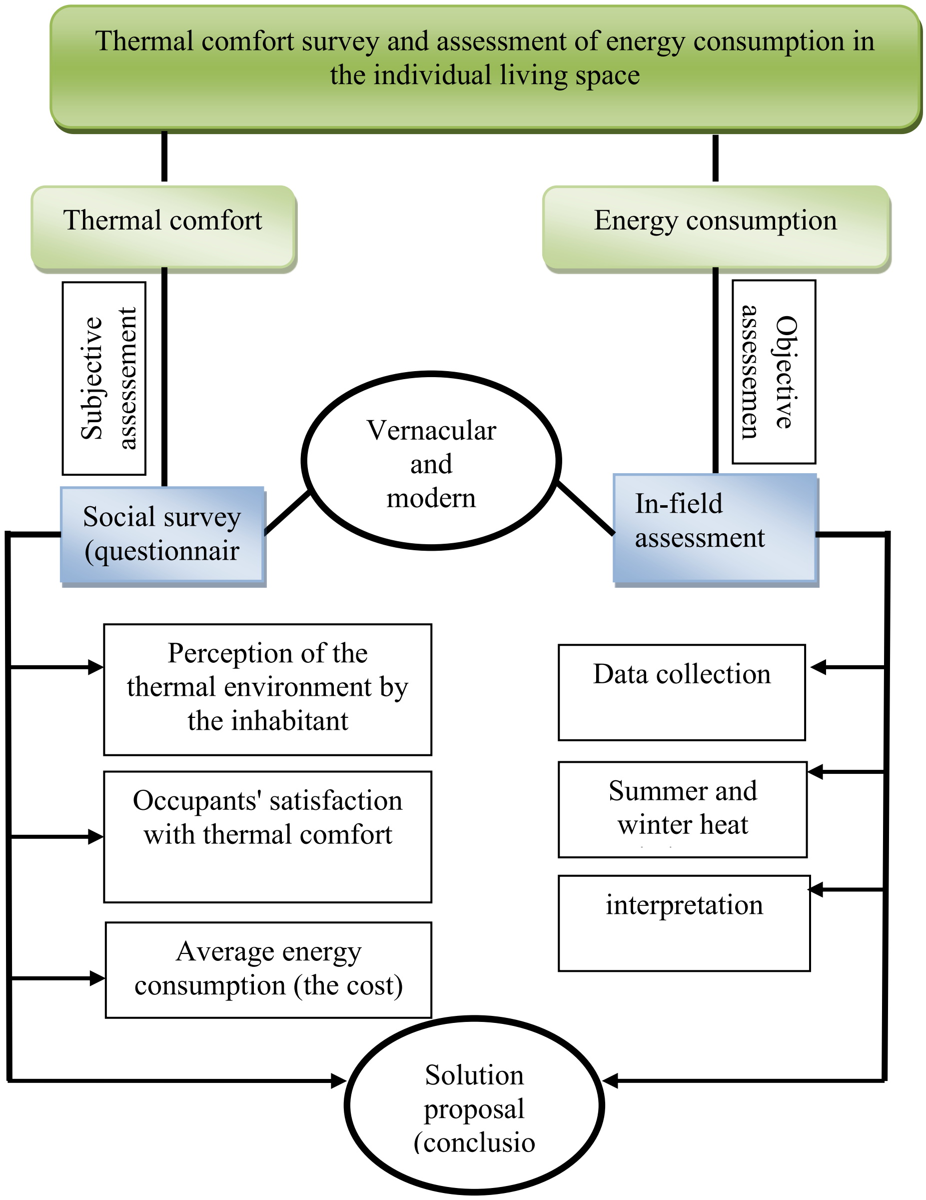

Figure 1. Flowchart of the approach taken to develop the work.

To achieve the objective of this research, a survey was carried out for the inhabitants of the two houses that make up the corpus of study. The questionnaire allowed us to know the users' sensations regarding the thermal environment, the most comfortable places in the houses, etc. The questionnaire allowed us to know the users' feelings about the thermal environment, the most comfortable places in the houses, etc. Also, the temperature and relative humidity were recorded in the two houses on the most unfavourable days (cold and hot). Since the traditional manual method is the most correct one in the diagnosis of energy performance, it was chosen as the calculation method.

Technium Social Sciences Journal
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2.1. Description of the case study

The study was made in the city of Bejaia. It is located in northern Algeria at 36.71 north latitude and 5.06 east longitude. The city of Bejaia has a Mediterranean climate, with mild, rainy, humid winters and hot, sultry summers.

Initially a group of vernacular and modern single-family houses was selected, after which a selection was made to evaluate only two houses in the worst case and generalize the results to the other cases. The houses in the study corpus are the most exposed to sun and wind, without party walls, and badly oriented.

In the vernacular context, the Kabyle house is the best example to study, the choice was made for a house located in the region of Djebla known for its strong winds. For the modern habitat, the choice was made for an individual house located in the region of TalaMerkha, one of the regions most exposed to the sun and winds in Bejaia with a high humidity rate (figure 2).

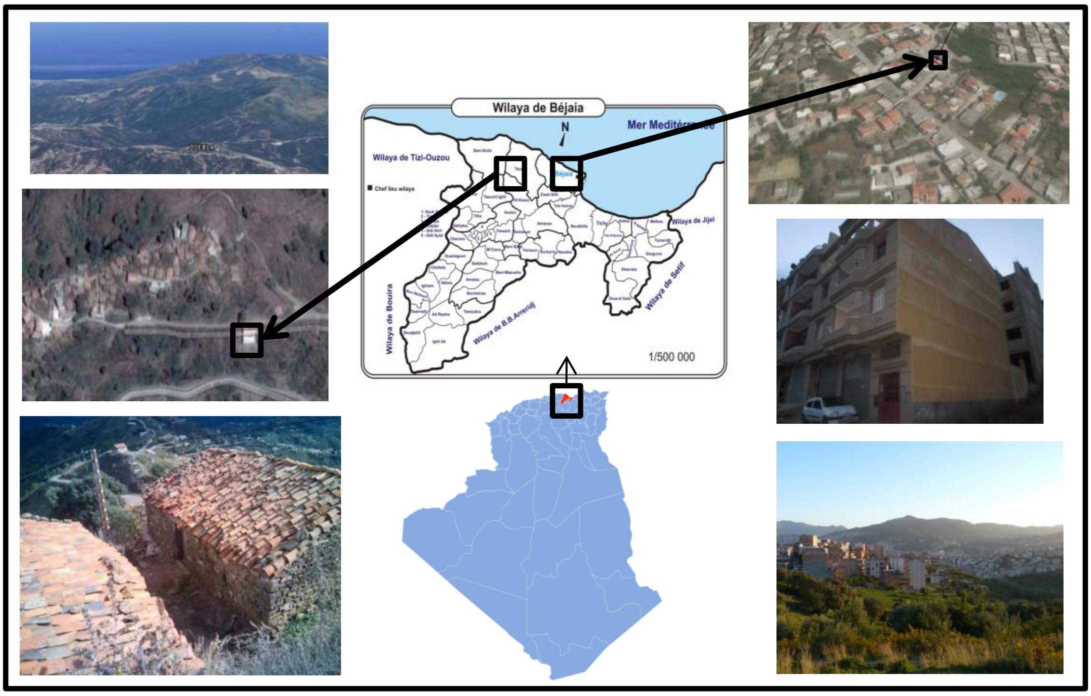

Figure 2. Location of Bejaia and the study cases.

2.2. Subjective assessment

In order to evaluate the thermal comfort, a survey was done for the inhabitants of the houses that make up the study corpus. The questionnaire allowed to know the perception and the sensations of the users towards the thermal environment, their behaviour. The first part of the questionnaire provided all the necessary information on the inhabitants such as age and gender. The second part of the questionnaire was focused on the inhabitants' feelings about the thermal comfort in their houses during the summer and winter periods. The last part allows us to know the monthly cost of the energy used (electricity and gas) during the summer and winter period, by examining the habits of the inhabitants with regard to their use of air conditioners in summer and heating in winter.

Technium Social Sciences Journal
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2.3. Objective assessment

In order to determine the capacity of the installation that must meet the criteria required in the building (comfort), it is necessary to calculate the heat balances for air conditioning and heating. The heat balance of a building consists of an inventory of all its heat losses (losses) and gains (gains).

In winter, the building loses heat by transmission and ventilation because the outdoor temperature is much lower than the indoor temperature, so cold outdoor air enters and warm indoor air leaves the building. In summer, the building gains heat by transmission and ventilation from the outside environment, because the outside ambient temperature is generally higher than the inside ambient temperature.

2.4. Calculation method

The heat balance of a building must be calculated for the most unfavourable conditions, i.e. for the coldest days of the year, in this case of study February 4 was chosen as the unfavourable day in winter and August 1 for the summer season. These two dates were chosen together with the design day.

In order to calculate the heat demand of a building, it is first necessary to calculate the heat losses by transmission and ventilation[11], the total heat loss is represented by "Qv" , where : Q0v = Q0 + Qv. below are the steps of calculation.

2.4.1. Heat loss through transmission « Q0»

The wall of a heated room in winter loses heat either to the outside or to the adjoining room, the heat flow is given by the following relationship:

Q0= K.S. (Ti-Te) + K.L. (Ti-Te) with:

K.S. (Ti-Te) Surface loss of the wall.

K.L. (Ti-Te) Linear loss (thermal bridge).

Q0 = heat flux lost through the wall (w).

K: overall heat transfer coefficient (w/m. °C), $K=\frac{1}{\frac{1}{hi}+\frac{1}{he}+\frac{e1}{\lambda 1}+\frac{e2}{\lambda 2}+\frac{e3}{\lambda 3}+\cdots\ldots\ldots\frac{en}{\lambda n}}$.

2.4.2. Heat loss through ventilation « Qv »:

Ventilation heat loss "Qv" means heat loss (cold outside air enters and the same amount of warm air leaves the building). There are two types of ventilation

Controlled ventilation loss i.e. the building has a controlled mechanical ventilation system with:

Qv = G.C (Ti - Te)

Qv: heat loss through ventilation (W).

G: airflow (m3/ s).

C: heat density of the air (1.224 Kj / m3.c°).

Loss through uncontrolled ventilation:

Qv = $\sum_{i=1}^{n}(\mathrm{ai\ li})\mathrm{A.R.h.Ze}\ (\mathrm{Ti}-\mathrm{Te})\mathrm{with}$:

Qv: heat loss through ventilation.

$\sum_{i=1}^{n}(\mathrm{ai\ li})\mathrm{A}$: Wind permeability of doors and windows (m3/h). When the windward wall contains n openings, its permeability is given by:$\sum(\mathrm{ai\ li})\mathrm{A}$ = a1l1+a2l2+a3l3+……. a n.

R: characteristic of the room (without dimension).

H: building characteristic.

Ze: Corner window surcharge (no dimension).

2.4.3. Global heat needs

These requirements represent the algebraic sum of the heat requirements relating to transmission and ventilation losses and internal heat gains, i.e.:
Q0= Qt+Qv- CONTRIBUTIONS(w).
Qt : Les besoins de chaleur par transmission
Qv: Ventilation heat needs
The summer heat balance must also be calculated for the worst day, in this case the heat gain calculation with: Q = K.S.(Δt) = K.S. (Tf - Ti).
Q: heat gain.
K: transmission coefficient.
S: surface area retained.
Tf: fictitious temperature
Ti: indoor temperature

3. Results and discussion

The table below shows the results of the calculations of transmission and ventilation losses followed by the energy requirements and heat gains for the vernacular and modern house, using measurements that were taken in situ on days with unfavourable temperatures.

Table 1. Winter and summer heat balance for the vernacular and modern house.

Vernacular house	
Winter heat balance Transmission loss	
Exterior wall: $K=\frac{1}{0.06+0.11+\frac{0,5}{2,3}}=\frac{1}{0,387}$ K=2,581 w/ m²c°	**Interior wall:** $K=\frac{1}{0,11+0.11+\frac{0,5}{2,3}}=\frac{1}{0,437}$ K=2,286 w/ m²c°
Terrasse : $K=\frac{1}{0.09+0.05+\frac{0,06}{1,15}+\frac{0,04}{0,24}}=\frac{1}{0,358}$ K=2,786 w/ m²c°	**Flooring:** $K=\frac{1}{0.06+0.11+\frac{0,15}{2,3}+\frac{0,05}{1,2}}=\frac{1}{0,276}$ K=3,611 w/ m²c°

	M	**M**	**M ²**	**M ²**	**M ²**	**w/ m²c°**	**c°**	**W**
Name of the element	Length	L or height	Surface	S reduced	S maintained	k	Δt	Q_0
Door	1,5	1,7	2,55	/	2,55	3,5	15	**133.875**
North wall	6,2	2,5	15,5	0,3	15,2	2,581	15	**588,468**
South wall	6,2	2,5	15,5	0,3	15,2	2,581	15	**588,468**
East wall	8 ,7	2,5	21,75	2,55	19,2	2,581	15	**743,328**
West wall	8 ,7	2,5	21,25	---------	21,75	2,581	15	**842,05**
Terrace	8,7	6,2	67,425	----------	67,425	2,786	15	**2817,69075**

Flooring	8,7	6,2	53,94	----------	53,94	3,611	15	**2921,6601**
Q_0 total	**8635,539**							
Ventilation loss does not exist, because the house has no openings (windows).								
Energy requirement / transmission Qt =Q_0. (1+zh+za+zu). Za+zu=zd=0,07. Qt=8635,539 (1+0,07) **Qt=9240,026 w**								
Total heat requirement by transmission and ventilation Q_0= Qt + Q v-apport Q_0=9240,026 +0-0=**9240,026 w**								

Summer heat balance (heat gains)					
	M ²	**w/ m²c°**	**c°**	**c°**	**W**
Element	S maintained	K	T fictive	Δt	Q
Door	2,55	3,5	37,5	13,5	**120,4875**
South exterior wall	15,2	2,581	34	10	**392,312**
East exterior wall	19,38	2,581	37,5	13,5	**675,26703**
West exterior wall	21,25	2,581	30,05	6,05	**331,819813**
Flooring	53,94	3,611	42	18	**3505,99212**
Terrace	67,425	2,786	45	21	**3944,76705**
Qt	**8970,6455**				

Modern house	
Winter heat balance Transmission losses: Qt= 32264.2252 w Losses through ventilation. Qv= 7931.4858 w Energy needs: Q**0 = 40195.711 w**	**Summer heat balance** Heat gains: **Qt = 104529.5698 w**

3.1. Interpretation of heat balances according to living space

An analytical reading was made of the living space for each case study.
For the vernacular house, it is the living space that consumes the most energy in winter and gains the most heat in summer(Figure 3).
For the modern house, on the ground floor the garage loses more heat in winter, in summer it gains about nine times more heat than the stairwell. On the first and second floor it is the living room that loses more heat in winter and gains more heat in summer, which explains the feeling of discomfort declared by the inhabitants of the house during the survey (figure 4). For the top floor (laundry) it is the two bedrooms that lose more heat in winter and gain more in summer. For both houses it is always the living space with more openings that loses and gains more heat.

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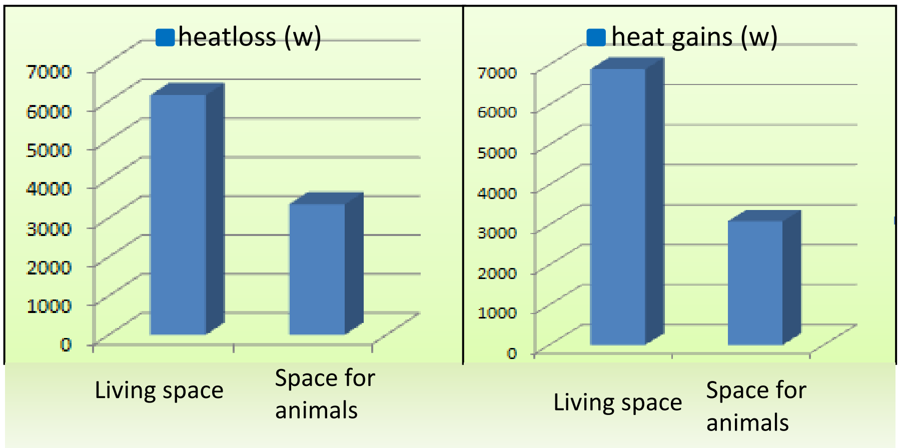
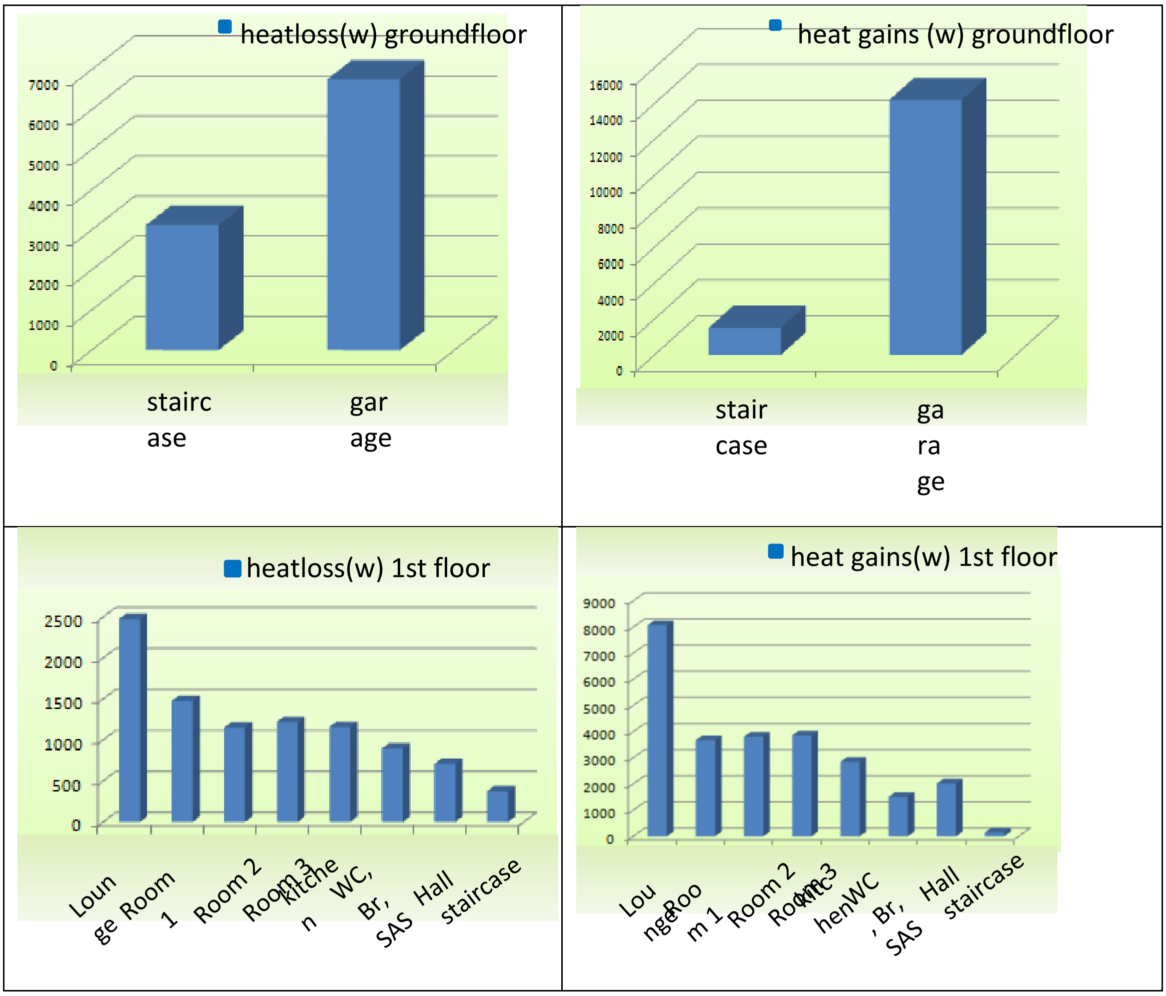
Figure 3. Heat loss and heat gain for the vernacular (Kabyle) house.





Technium Social Sciences Journal
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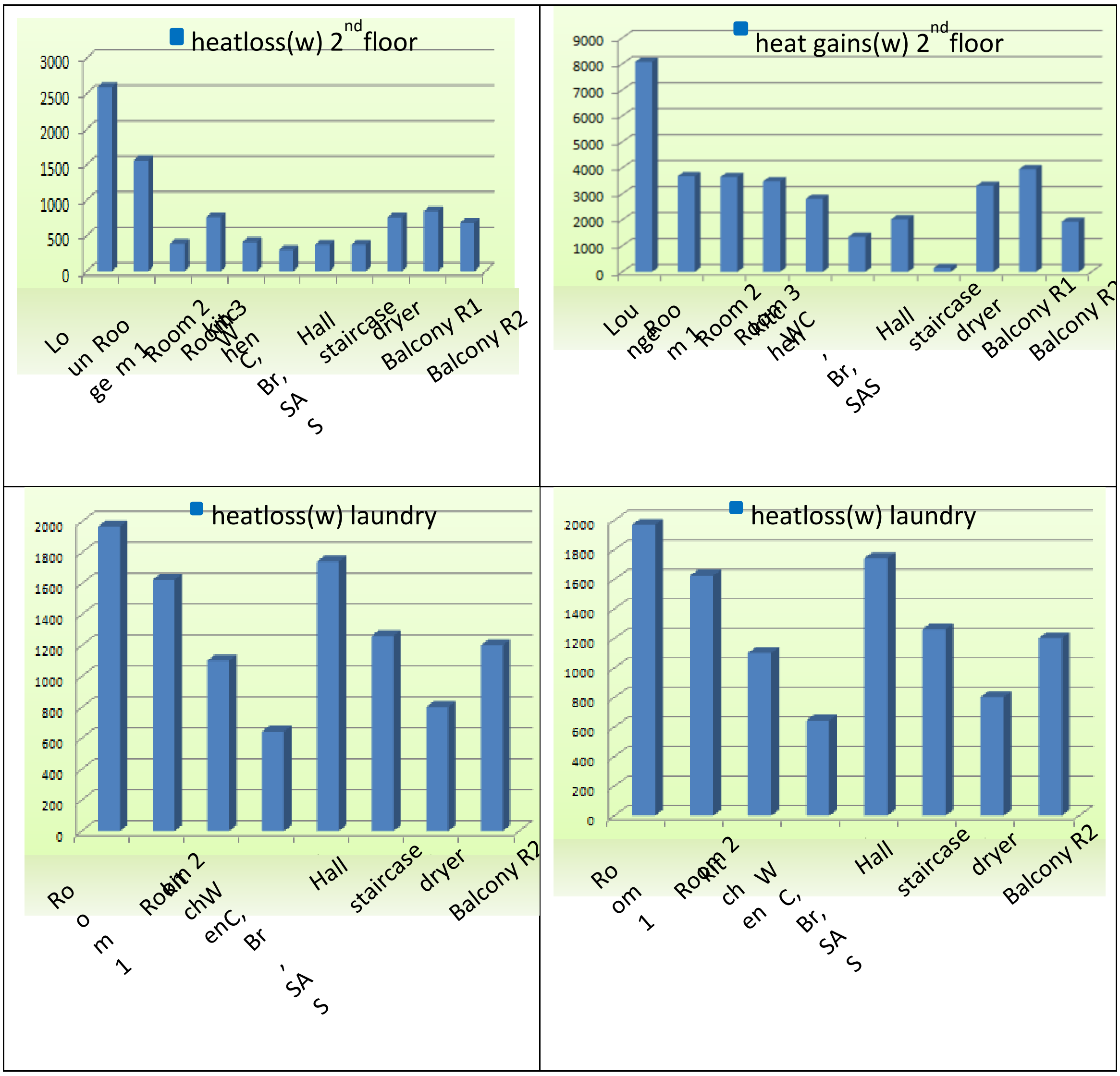

Figure 4. Heat loss and heat gain for the modern house.

The following histogram shows a comparison between the two vernacular and modern houses. Even with living areas that are practically the same, it is still the vernacular (Kabyle) house that offers a good model in terms of heat loss or heat gain and thermal comfort, which confirms the answers of the inhabitants in the questionnaire.

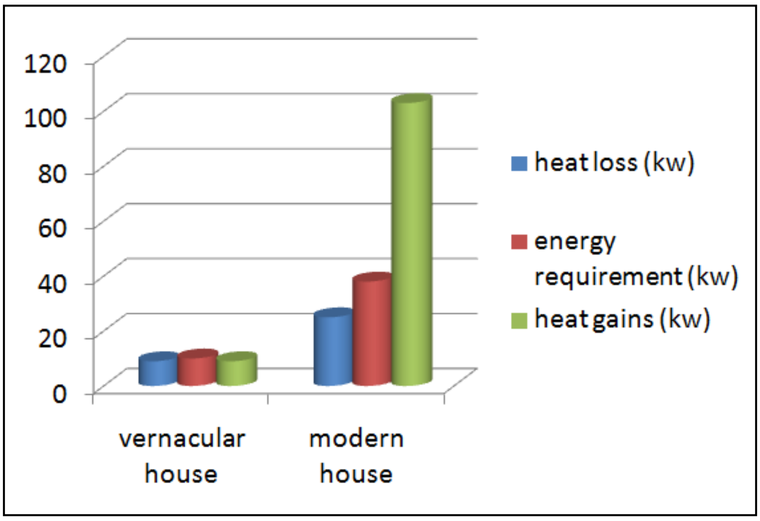

Figure 5. Heat loss, energy requirement and heat gains for both housing types.

3.2. Comparative reading of balance sheets with standards

In order to be able to superimpose the results obtained on the standards (the building classification labels according to the energy performance diagnosis), we have converted the calculated values into MJ/ M². The results are shown in the table below:

Table 2.conversion of the calculated results to MJ/M².

Houses	Wh/M^2		MJ/MM^2	
	Winter	Summer	Winter	Summer
Vernacular (Kabyle)	9240,026	8970,6455	33,26409361	32,29432381
Modern house	40195,711	104529,5698	144,7045595	376,30645128

According to the building classification labels, and depending on the results obtained, the houses will be classified as follows:

The calculated energy needs being 33.26409361 MJ /M^2 during the winter period and 32.29432381 MJ /M^2, the vernacular (Kabyle) house is thus classified in category A (less than 50 MJ /M2) with a very good energy performance.

With a value of 144.7045596 MJ /M^2in winter and a value of 376.30645128 MJ /M^2 in summer, the modern house is classified as a category F, which is a house that is out of the norm.

During the winter period: in order to achieve thermal comfort, the users of the Kabyle house use wood (combustion) as a local energy source. Its losses are less important compared to the modern house. This is explained by the considerable thickness of its stone walls (50 cm).

During the summer period: It should be noted that the vernacular (Kabyle) house is sunny during the whole morning during the whole summer period. Its heat gains are less important compared to the modern house. This is explained by the coolness of the stone.

The quantity of energy consumed for heating is lower than the energy requirements calculated in the winter heat balance. This difference is explained by the use of only two oilfilled radiators, which do not give off large amounts of heat and do not meet the needs of the users. This results in low indoor temperatures in winter. This is confirmed by the responses of the residents in the questionnaires. The energy consumed during the summer period is very low compared to the heat gains calculated in the summer heat balance. This difference is explained by: the absence of air conditioning. This leads to a feeling of thermal discomfort. The thermal atmosphere of this house in summer is unpleasant.

The façade is sunny during the whole morning during the whole summer period.

4. Conclusion

This research work aims to study the energy performance in traditional and contemporary living space. Every living space is characterised by a certain ambience, and this ambience contributes to making it either desirable or undesirable, depending on the quality of this ambience.

Sustainability, and in particular sustainable development in a living space, is closely linked to the energy issue, or more precisely to the problem of the increasing energy consumption. In order to achieve a comfort level that is valued by the users while consuming as little energy as possible, it is necessary to use energy sources that will be derived from renewable energies, and to build with insulating materials that can reduce energy losses to the outside, in the end it is to think of living spaces in a way that has a very good energy performance by using the opportunities offered by the neighbourhood and the site in which the living space is located while achieving architectural conformations that will be designed to take into account a low energy consumption design.

In terms of thermal comfort, the vernacular (Kabyle) house is a typical model compared to the modern house, it consumes energy in a reasonable way, is characterized by a good thermal insulation in winter and uses natural local materials which do not harm the environment. The stone used in its construction allows for coolness during the summer period, the vernacular (Kabyle) house is perfectly integrated with the environment and is very economical and efficient, but it also has some negative points; it does not contain any openings or transitional spaces. The modern house is more energy consuming according to the results, to minimize these consumptions it is recommended to use low consumption lamps, to benefit from a wood stove. For comfort during the summer period, natural shade is provided by planting. Insulation of the façade of the walls with a veneer-type insulation with incorporated skin.

Energy performance diagnostics should be carried out before construction work is undertaken, either with the heat balance method or with simulation. For future designs, the use of an energy performance diagnosis (EPD), for example, with the aim of improving energy performance, may be essential. This kind of device is usually accompanied by recommendations for works, in order to have a good ecological architectural conformation that meets the needs of the users, but also the principles of sustainable development.

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