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The Algerian Experience in Energy Efficiency of High-Performance Buildings in Semi-Arid Climate

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Abstract— ***This work focuses on the experimental study of a standard dwelling and a high energy performance dwelling, located in the city of Djelfa in Algeria whose climate is semi-arid, in order to study their thermal performance for 12 months. The high energy performance dwelling was built as part of the pilot project of 600 dwellings in 11 locations spread all over the different climatic zones in Algeria and the first to be finalized compared to the other locations. According to the measurements, the temperature and the relative humidity were maintained in the thermal comfort range with the use of electricity for air-conditioning and the natural gas for heating. The results obtained from a comparison between a high-efficiency dwelling and a traditional dwelling indicate that the reduction of heating demand is about 57% and of air-conditioning is about 51% by using the passives energy efficiency techniques in the buildings. The obtained results are summarized in order to draw up recommendations on the possibility of making energy savings while optimizing occupant comfort. Thus, the study of the influence of natural ventilation and air infiltration on the energy loads of the insulated dwelling enabled us to realize that with an unsuitable scenario of opening windows during the winter season, we could end up spending the energy gains due to thermal insulation and having an over-consumption of gas during the winter period.***

Index Terms— ***Energy consumption, high performance building, semi-arid climate, thermal insulation.***

I. INTRODUCTION

Energy management is a major challenge for economic development, and one that goes hand in hand with sustainable development. All countries in the world are faced with the problem of scarce energy resources, and this scarcity poses a major challenge: how to manage these resources efficiently and, above all, reasonably, in order to meet the growing energy needs of their populations in the most appropriate way.

As a reminder, the residential sector is the biggest consumer of energy, and this is all the truer for the Algerian energy model, with sustained growth due to the increased demand for new housing, built without taking energy issues into consideration, and the ever-increasing rate of household equipment in energy-consuming appliances.

The first part of this study is devoted to analyzing the results of monitoring the thermal comfort parameters and energy consumption of two dwellings of different designs, one of which is an ordinary conventional dwelling and the other one of the 80 high energy performance dwellings in the Djelfa region. Djelfa's climate is semi-arid, hot and dry in summer and extremely cold in winter [1]. The climate in semi-arid zones is harsh, and thermal comfort for its inhabitants requires a good match between construction, climate and environment [2].

Several authors have been interested in analyzing the results of monitoring thermal comfort parameters and energy consumption in the building sector. We cite the study by X. Lianga et al [3] on the performance of a conventional and a passive house in the north-east of England during one year of monitoring thermal comfort parameters. These two houses, which differ mainly in their structures, have measured primary energy data of 169.85 kWh/m^2 for the conventional house and 64.11 kWh/m^2 for the passive house. The average annual indoor temperature of both dwellings was maintained at 17.7°C and 22.0°C respectively. Another study by H. Mastouri et al [4] on the effect of the combination of thermal insulation and high thermal inertia on the thermal performance and assessment of energy loads for heating and cooling of buildings located in a hot, semi-arid climate. The results of monitoring the thermal performance of a detached house built with local materials (hemp as insulation) located in the Marrakech region (Morocco) were compared with the results of monitoring a reference house built with conventional building materials and lacking passive energy efficiency techniques. The results show that the use of passive building systems has an impact on indoor air temperature, thermal comfort and the building's cooling/heating load (a reduction of around 81% in the annual cooling and heating load in the passive house compared with the reference case). Ozil [5] studied the thermal performance and optimum thickness of insulation for south-facing building walls with different structural materials under dynamic thermal conditions for the city of Elazig, Turkey. Two materials were investigated, extruded polystyrene and expanded polystyrene, both of which were selected for their estimated service life of 10 years. Annual cooling and heating loads were calculated using an implicit finite-difference method under constant periodic conditions, and used as inputs to an economic model, including the cost of the insulation material and the present value of the cost of

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energy consumption over the estimated 10-year life of the building, to determine the optimum insulation thickness. The results revealed that optimal insulation thicknesses range from 2 to 8.2 cm, energy savings range from $2.78 to $102.16/m² and payback periods range from 1.32 to 10.33 years. Nematchoua et al [6] adopted the method used by Ozil [5] (explicit finite-difference method) under stable periodic conditions to calculate annual air-conditioning loads in a hot, humid tropical climate. The 22-year life-cycle economic model is used. It was found that the lowest values of 9 cm insulation thickness and energy savings of around 80% were obtained, and the payback period is 4.7 years.

The second part of this work concerns the study of the impact of natural night-time ventilation and air infiltration on the energy loads for heating and air-conditioning of HPE housing located in the semi-arid climate of Djelfa. The subject of quantifying the heating needs due to air infiltration in winter is a recent one, and the large numbers of people who have died from carbon monoxide (35 people have died since the start of 2019 and 396 people have been rescued during the same period) have prompted families to use various means and solutions to escape this danger, such as leaving windows open throughout the winter nights. This behavior leads to heat loss from the inside to the outside, which results in excessive energy consumption for heating.

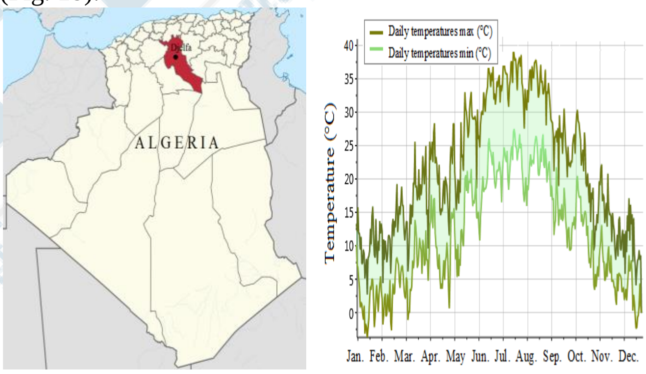
We carried out a simulation using "TRNSYS" software to assess the effect of natural night-time ventilation on cooling requirements in summer, and the influence of air infiltration through windows on heating requirements in winter. Studies based on dynamic simulation using TRNSYS software have been carried out by several authors, including G. Krausset al [7], H. Mastouri et al [4], M. Khebaz et al [8], F.B. Errebai [9] where they modeled the thermal behavior of buildings located in different countries. These buildings were designed using passive energy efficiency techniques, and the results obtained were compared with typical buildings in each country. Other researchers were interested in the influence of design parameters (orientations, facade types, glazing types, etc.) and scenarios (ventilation, infiltration, occupancy, etc.) on heating and cooling loads. The thesis work of M. A. Khadraoui [10] on the study and optimization of facades for thermal comfort and energy efficiency in tertiary buildings located in the city of Biskra (hot, arid climate) is worthy of note. Another study by I. Sobhy et al [11] on the effect of wall and roof insulation on the cooling load of a house located in Marrakech, whose climate is characterized by relatively cold winters and very hot summers, with significant temperature differences between day and night (around 20 °C).

The aim of this work is to synthesize the results of monitoring the thermal comfort parameters of the two dwellings studied, in order to draw recommendations on the possibility of making energy savings while optimizing occupant comfort. Thus, the study of the influence of natural ventilation and air infiltration on the energy loads of the insulated dwelling enabled us to realize that with an unsuitable scenario of opening windows in the winter season, we could end up spending the energy gains due to thermal insulation and having an overconsumption of gas in the winter period.

II. MATERIALS

A. Location of the studied housings

The dwellings studied are located in the city of Djelfa who represents a typical example of the steppe of North Africa. It is located in the center of northern Algeria, 300 km south of the capital Algiers (Fig. 1a). It is located between the north latitudes 33° and 35° and between the longitudes 2° and 5°. The climate is hot dry in summer and cold, dry in winter. The Heating Degree Day (HDD) for base temperature of 20 °Cand Cooling Degree Day (CDD) for base temperature of 27 °C are 2216 and 265 respectively Soufiane et al [12].The maximum temperature reaches 37 °C for the months of June and August and it reaches 39 °C for the month of July, while the minimum temperature varies between 16 and 25 °C during these months. The maximum temperatures in winter are of the order of 12 °C on average for the months of December and January. The minimum temperatures are very low and reach -5 °C in the months of December and January (Fig. 1b).



(a) (b)

Fig 1. Information about: a) localization of studied dwelling and b) maximum and minimum monthly temperatures during a typical year (Source: Meteonorm 7).

B. Description of the two dwellings

Description of the HEP dwelling

The high-energy performance (HEP) dwelling which is the subject of this study was realized in 2015 and has a living area of 72 m², located on the top floor of a building (Fig. 2a). The HEP dwelling has two rooms, room 1 is positioned on the south-east side and room 2 is on the north-east side. The living room has a large south-facing window to take advantage of the natural light by letting in a maximum of light, and finally the kitchen and the bathroom are located on the north side (Fig. 2b). The composition of the walls is as follows (Table 2):

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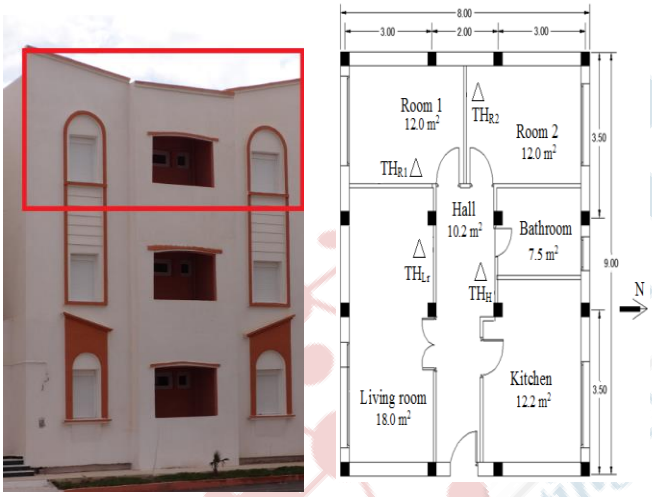
The exterior walls of the HEP dwelling are composed of two walls of hollow bricks of 10 cm separated by a 5cm expanded polystyrene (EPS) insulation, coated on the outside with 2 cm cement mortar and on the inside with 1 cm plaster coating. The inner walls are made of hollow bricks of 10 cm with two layers of 1 cm of plaster on both sides. The floor is made of hollow blocks of plaster on the outside followed by 16 cm of hollow blocks, 4 cm of concrete, 3 cm of mortar and 2 cm of tiling of 1 cm on the inside. The roof is made of 1 cm of plaster on the inside, hollow blocks of 16 cm, 4 cm of concrete, 5 cm of expanded polystyrene and 4 cm of mortar on the outside. The windows used are made of PVC frames with double-glazing and the front door is made of wood.

The heating is provided by a natural gas radiator installed in the hall. This heating system is the most used in residential buildings in Algeria, its power is 12 kW. The radiator has a yield of 0.9 and is equipped with a thermostat to regulate several temperature levels. For air conditioning, a split air conditioning system is used, its cooling capacity and heating capacity are the same (3.2 kW) and its performance coefficient (COP) is 3.2 and energy efficiency ratio (EER) is too 3.2.



(a) (b)

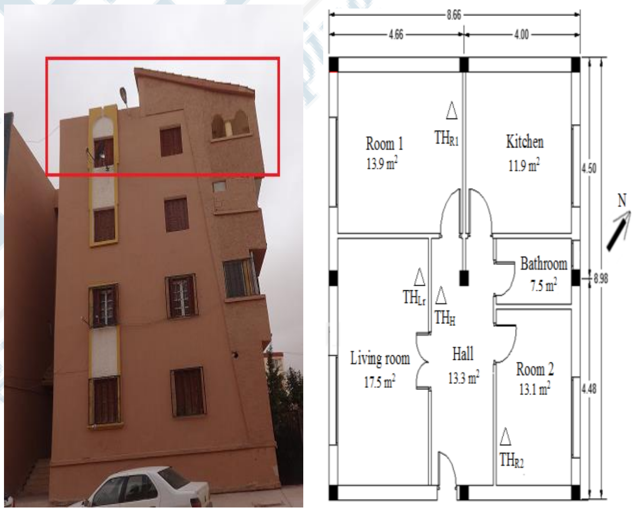
Fig 2. HEP Dwelling (a) picture of front view (b) descriptive plane.

Description of the standard dwelling

The standard dwelling has an area of about 78 m² and is located too in the top floor of building, it was built in 1980 (Fig. 3a). The dwelling consists of two rooms, room 1 is positioned on the north-west side and room 2 is on the south-east side. The living room is oriented west and finally the kitchen and the bathroom are on east side (Fig. 3b).

The composition of the interior walls and the floor are the same as for the HEP dwelling. While for the outer walls and the roof, 5 cm thermal insulation layers of expanded polystyrene were used (Table 2). The windows used are made of wood with single glazing and the front door is too made of wood.

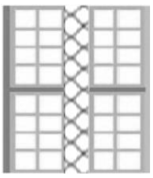
The heating is provided by a natural gas radiator installed in the hall. This heating system is the most used in residential buildings in Algeria, its power is 12 kW. The radiator has a yield of 0.85 and is equipped with a thermostat to regulate several temperature levels. For air conditioning, a split air conditioning system is used, its cooling capacity and heating capacity are the same (3.52 kW) and its performance coefficient (COP) is 3.6 and energy efficiency ratio (EER) is 3.2.

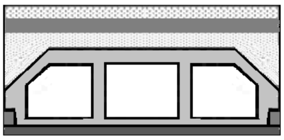
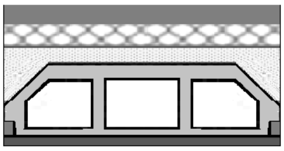
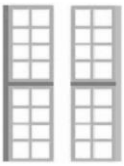
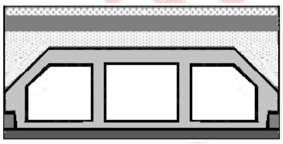
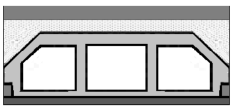


(a) (b)

Fig 3. Standard dwelling (a) picture of front view (b) descriptive plane.

Table 2. Composition of different walls for HEP dwellings and standard dwelling.

Type	Composition	e (m)	λ ($W.m^{-1}.K^{-1}$)	R ($W^{-1}.m^2.K$)	U ($W.m^{-2}.K^{-1}$)
a) HEP dwelling					
Exterior wall 	Mortar	0.02	1.4	0.01	0.54
	Hollow Brick	0.10	-	0.20	
	EPS	0.05	0.04	1.25	
	Hollow Brick	0.10	-	0.20	
	Plaster	0.01	0.35	0.03	

Type	Composition	e (m)	λ ($W.m^{-1}.K^{-1}$)	R ($W^{-1}.m^{2}.K$)	U ($W.m^{-2}.K^{-1}$)
Inner wall	Plaster	0.01	0.35	0.03	
	Hollow Brick	0.10	-	0.20	2.10
	Plaster	0.01	0.35	0.03	
Floor	Plaster	0.01	0.35	0.03	
	Hollow blocks + Concrete	0.20	-	0.14	1.85
	Mortar	0.03	1.4	0.02	
	Tiling	0.02	2.1	0.01	
Roof	Mortar	0.04	1.4	0.02	
	EPS	0.05	0.04	1.25	
	Hollow blocks + Concrete	0.20	-	0.14	0.63
	Plaster	0.01	0.35	0.03	
b) Standard dwelling					
Exterior wall	Mortar	0.02	1.4	0.01	
	Hollow Brick	0.10	-	0.20	
	Air cavity	0.05	-	0.16	1.29
	Hollow Brick	0.10	-	0.20	
	Plaster	0.01	0.35	0.03	
Inner wall	Plaster	0.01	0.35	0.03	
	Hollow Brick	0.10	-	0.20	2.10
	Plaster	0.01	0.35	0.03	
Floor	Plaster	0.02	0.35	0.06	
	Hollow blocks + Concrete	0.20	-	0.14	1.85
	Mortar	0.03	1.4	0.02	
	Tiling	0.02	2.1	0.01	
Roof	Mortar	0.04	1.4	0.03	
	Hollow blocks + Concrete	0.20	-	0.14	2.97
	Plaster	0.01	0.35	0.03	
The thermal resistance (R-values) includes inside and outside surface thermal resistances.					

C. Air ventilation of the two dwellings

The air exchange of both dwellings (HPE dwelling and standard dwelling) was done by the use of natural ventilation all year long (during the cold, mild and warmer months). The natural ventilation occurs during air movement thanks to the pressure differences due to the wind that exist between the facades of the building through the window openings and by air infiltration. This type of ventilation is the only air exchange system used in residential buildings in Algeria. This ventilation's approach has been adopted by many other studies which have proposed that natural ventilation as an effective passive cooling solution for warm climates.

In situ measurements

The measuring devices were installed in the HEP dwelling and standard dwelling to measure the indoor and outdoor

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temperatures, relative humidity and energy consumption related to heating and air conditioning. Air temperature and humidity measurements in different zones of the two dwellings are made with the thermo-hygrometers Testo 174H data loggers. For the temperature measurements, this device has a measuring range of -20 °C to+70 °C with an accuracy of ± 0.5 °C and a resolution of 0.1 °C. For the relative humidity measurements, the measuring range of relative humidities are between 0 to 100% with an accuracy of ± 3% with a resolution of 0.1% RH. The data logger features a large display and alarm indication that makes it ideal for continuous monitoring of ambient temperature and humidity. The thermo-hygrometers inside the dwellings were placed at a height of 1.7 m so that they do not disturb the occupants as schematized on the Figs. 2b and 3b.

The measurements were carried out during one year (from 2016 until 2017) to study the thermal behaviour, during the summer, winter and mid-season. The two dwellings (standard and HPE) were occupied permanently by a family of four persons, two adults and two children. The occupants, according to the different seasons of the year, managed the opening and the closing of shutters and windows.

In each dwelling, four thermo-hygrometers were installed to analyze the evolution of the temperature and to compare the thermal performances of these dwellings. The air temperature and humidity were measured every one hour. Gas and electricity meters were used to measure the heating, air conditioning and lighting consumption of the two dwellings.

The air conditioning power consumption is measured by the ENERGICAL DIN Rail meter (electronic meter of cumulative active electric energy) according to the international standards IEC 62052-11 and IEC 62053-21 with rated voltage 220 V, frequency 50 Hz and accuracy class of 1.

The natural gas consumption for heating is measured by the GAS AMC GALLUS 2000-G4 meter. The range of measurement of natural gas flow rate is between Q_{min} equal to 0.040 m^3/h and Q_{max} equal to 6 m^3/h. The operating temperature is between -20 °C and +50 °C and the maximum pressure is 1.5 bar. This device has a maximum tolerated error is ± 3% between Q_{min} and 0.1 Q_{max} (an accuracy maximum of ±0.018 m^3/h) and ± 1.5% between 0.1 Q_{max} and Q_{max} (an accuracy maximum of ±0.09 m^3/h).

D. Research methodology

A monitoring was conducted from October 2016 to September 2017, by measuring air temperature and relative humidity in each of the two dwellings. In each of them, five data loggers were used in the monitoring. Four Testo 174H dataloggers that measure air temperature and relative humidity were installed inside each room and one data logger is installed in the balcony to measure the outside values.

These standalone data acquisition systems were suspended from the ceiling, 1.5 m from the floor, in the middle of each room. Indoor temperature and relative humidity are recorded every 1 hour. This method is used by several authors; we cite Boudali errebai et al [13], Mastouri et al [4] , Khabbaz et al. [8], and Imessad et al. [14] .

E. Dynamic Thermal Simulation (DTS)

Dynamic thermal simulation (DTS) is a useful tool for modelling buildings and measuring the influence of each construction parameter on their energy performance. TRNSYS is a dynamic simulation software package developed at the Solar Energy Lab at the University of Wisconsin-Madison and at the Solar Energy Application Lab at the University of Colorado [15], which can be used to calculate the energy performance of single or multi-zone buildings under dynamic conditions. The software is based on a block diagram approach enabling complex problems to be broken down into several simple problems in an open environment, so that new components and concepts can be added [16]. The "TRNSYS" simulation software requires certain input parameters to run the simulation and create outputs. For the inputs, it is necessary to define the geometry of the model under study (shape and dimensions), as well as its orientation. Meteorological data for the town of Djelfa were **the** inputs.

These meteorological data were taken from the "Meteonom 7" software in "Tm2" format. Building details were then introduced using the "TRNBuild" software. At the "TRNBuild" level, it is possible to define the characteristics of walls (wall, roof, floor, etc.) and openings, the scenarios used (occupancy, window opening, infiltration, heating and cooling scenario, etc.) and internal gains (number of people and their activities, equipment....). As far as outputs are concerned, the TRNSYS software can simulate a number of different parameters. In our case, two aspects have been studied: the first concerns thermal comfort parameters (ambient temperature and relative humidity) and the second concerns energy requirements for heating and cooling. In this section, we focus on the evaluation of energy requirements in HPE housing. Following the creation of the materials library on "TRNSYS", a detailed scenario covering all parameters (infiltration, internal gains, number of people and their activities and any equipment) was integrated; the aim is to study the effect of night-time ventilation on energy consumption in summer and winter.

F. The scenarios introduced

Occupancy rate: This scenario describes the number of occupants and their presence in each room of the dwelling. In our case, the HPE dwelling is occupied by a family of 4 (2 adults and two children). We have assumed that the 4 members of the family occupy the dwelling during the week from 5 p.m. to 8 a.m. and on the two weekend days. During the day, one member occupies the dwelling from 8am to 12pm and from 1pm to 5pm, then three members occupy the dwelling from 12pm to 1pm.

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Air infiltration: This scenario defines the air exchange rates between the inside and outside of the zone. For the summer period, we set this flow rate at the hygienic flow rate of 0.2vol/h. In winter, we varied the flow rates from 1 vol/h to 3 vol/h.

Heating and cooling scenario: According to DTR C. 3.2/4 [17], during the summer season, we have assumed that for a temperature above 24 °C (enhanced summer comfort temperature), the air conditioner is switched on. During the winter season, we have assumed that for a temperature below 21°C (winter comfort temperature), the heating operates.

Night-time ventilation: We have taken night-time ventilation into consideration, as the difference between inside and outside temperatures exceeds 10°C at night.

We have assumed that all the windows in the dwelling are open at night and that the air infiltration rate is set at 0.2 vol/h during the summer season, while only two windows are open at night during the winter season. For the summer season, as shown in Table 2, we varied the night ventilation rate from 0 vol/h to 6 vol/h.

Table 2. Windows opening scenarios and air exchange rates.

Window opening scenario		8 p.m to 8 a.m						
Air change rate (v/h)	Winter	1	1.6	2	3			
	summer	0	1	1.6	2	3	6	8

According to P. Heiselberg [18] and W. Yousef Mousa et al [19], a continuous air change rate of 1 to 2 h-1 is required in summer. Night-time ventilation is needed to cool the building, which requires high ventilation airflows, generally air exchange rates of 4 to 6 h-1.

In order to estimate energy requirements, a temperature threshold was determined for equipment operation, i.e., 21 °C for heating and 24 °C for air conditioning. This interval lies within the thermal comfort zone as defined in DTR C 3.2/4 [17]. The heating degree-day (HDD) for a base temperature of 21°C and the cooling degree-day (CDD) for a base temperature of 27 °C within the comfort range of 20-27 °C are 2216 and 265 h respectively .

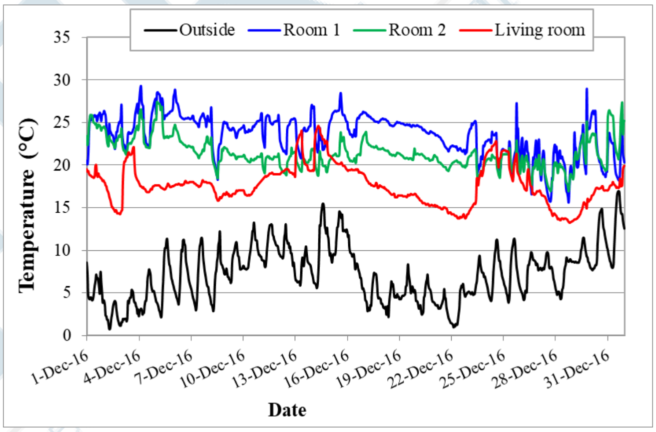
III. RESULTS AND DISCUSSION

A. Indoor temperature and relative humidity measurement

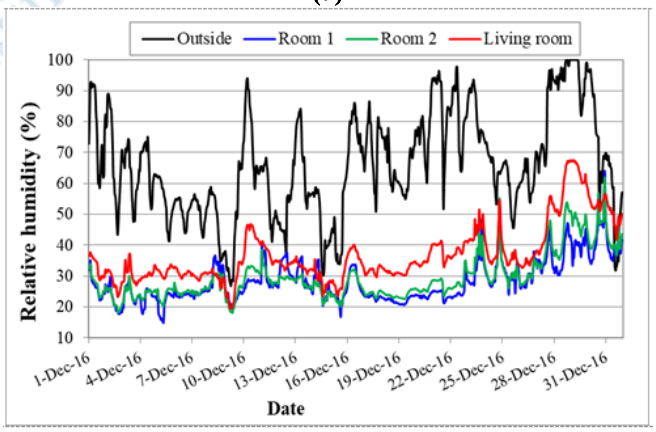
In this part, we present the variation of the indoor temperature, the indoor relative humidity of the HEP dwelling and the standard dwelling for the two periods: December for winter season and July for summer season.

For the standard dwelling: The monitoring results were conducted from November **the 1st** to March **31st** for the winter season, December is the coldest month of this season, and we presented the monitoring results for this month. Figure 4 showed the assessment of indoor temperature**s** and indoor relative humidity in the different rooms of the standard dwelling. For the summer season (Fig. 5), results were presented for the hottest month (July) for different rooms of the standard dwelling.

In the purpose of the analysis of the thermal behavior of standard dwelling during the cold season, December is the coldest and the most humid month. The outside air temperature and relative humidity reaches 0 °C and 100% respectively, with an average of 10 °C and daily amplitude up to 5 °C and an average of 20% for the outside relative humidity. Figure 4 presents indoor temperature**s** and indoor relative humidity inside the rooms of the standard dwelling for December and its coldest week. We notice that the indoor temperature and relative humidity are respectively 20 °C and 35% in the living room while the outdoor temperature and relative humidity are respectively close to 7 °C and 70%. The measurement in the rooms is influenced by the heating equipment installed in the hall.



(a)



(b)

Fig 4. Month of December in the standard dwelling: (a) indoor temperature measurements and (b) indoor relative humidity measurements.

For summer season, July is selected, it represents the hottest and the driest month. The outside air temperature and relative humidity reaches 37 °C and 45% respectively, with an average of 27 °C and daily amplitude (peak-to-peak

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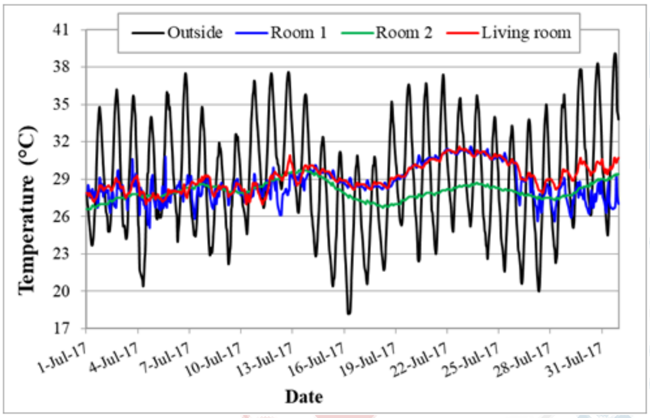
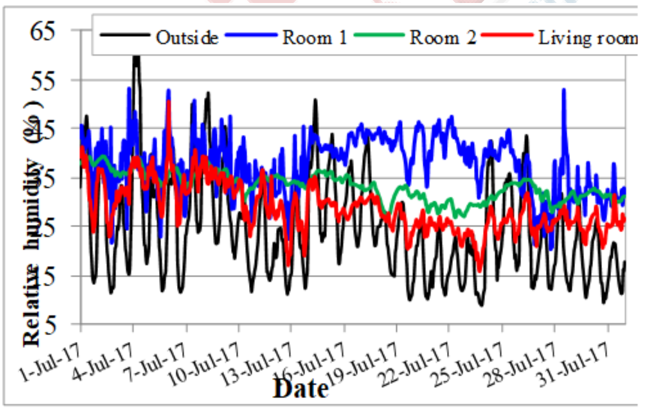
difference) up to 11°C and an average of 35% for the outside relative humidity, these outdoor values are obtained from the data logger installed in the balcony. Figure 5 presents indoor temperature and indoor relative humidities inside the rooms of the standard dwelling for July (hottest month), indoor temperatures differed from one room to another with a difference of more than 4 °C. Indoor relative humidities also differed from one room to another with a difference of 10% as it can be seen in Fig.5b. This difference of temperature and relative humidity is due to the fact that the standard dwelling is not isolated and these rooms are oriented West. In the rooms, the indoor temperature is in the range of 25 °C to 31 °C and a relative humidity ranging between 30 to 45% because the air conditioner is placed in the living room. However, for this month, we notice that the indoor temperature and the relative humidity of almost all the rooms are in the range of thermal comfort, according to the recommendations given by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE Standard 55 [20]). This is due to the night ventilation where the dwelling occupant opened windows at night to unload the walls of the stored heat (the night temperature of Djelfa is in a range of 11 °C).



(a)

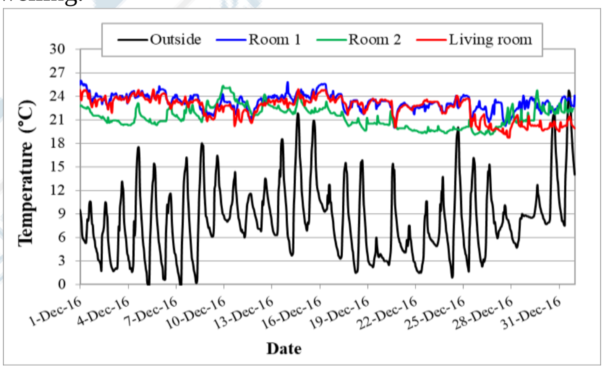


(b)

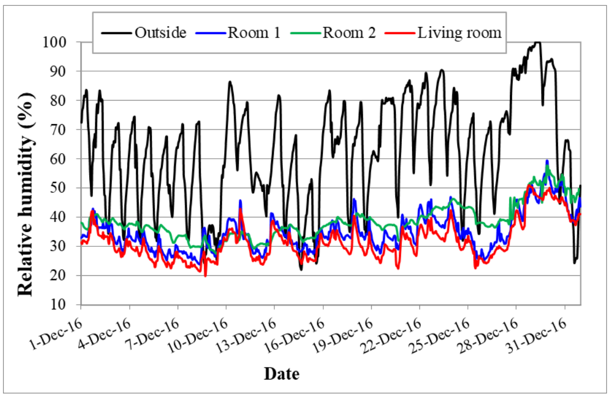
Fig 5. Month of July in the standard dwelling: (a) indoor temperature measurements and (b) indoor relative humidity measurements.

For the HEP dwelling: The monitoring results are presented for December 2016, the coldest month of the winter season. The figures showed the measurements of the indoor temperature and indoor relative humidity in different rooms of the HEP dwelling (Fig. 6). For the summer season, the results were presented for the hottest month (July 2017), of the different rooms of the HEP dwelling (Fig.7).

For the winter seasons, December is the coldest and the most humid month. The outside air temperature and relative humidity reaches 0 °C and 100% respectively, with an average of 10 °C and daily amplitude up to 5 °C and an average of 20% for the outside relative humidity. Figure. 6 presents the indoor temperature and indoor relative humidity inside the rooms of the standard dwelling for December and its coldest week. We notice that the indoor temperature and relative humidity reach 23 °C and 35% in the rooms and in the living room while the outdoor temperature and relative humidity are respectively are close to 8 °C and 65%.The indoor temperature of the dwelling is relatively good (between 20 °C and 25 °C) and relative humidity is low (between 25% and 40%) according to ASHRAE Standard 55 [20]), because of the influence of the heating equipment installed in the dwelling hall. We noticed an improvement in thermal comfort of about 3 °C compared to the control dwelling, mainly due to the thermal insulation of the HEP dwelling.



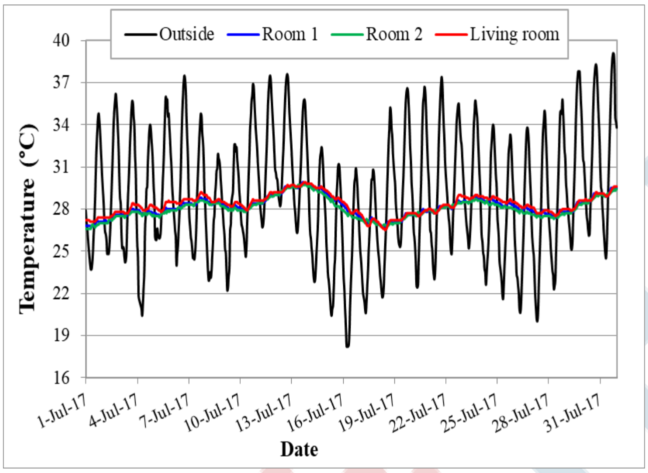
(a)



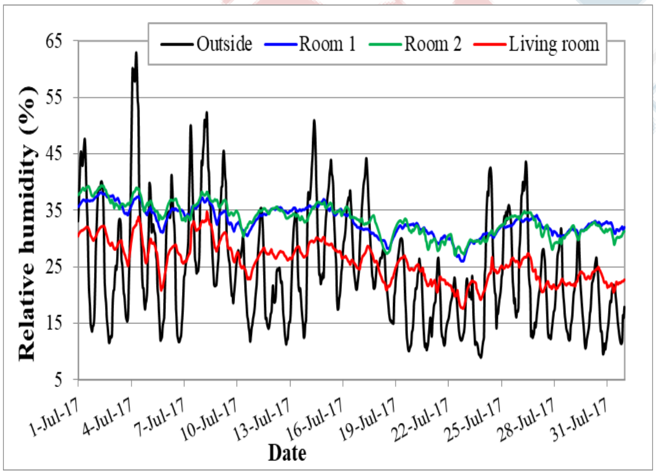
(b)

Fig 6. Month of December in the HEP dwelling: (a) indoor temperature measurements and (b) indoor relative humidity measurements.

For the summer season, the outside air temperature and relative humidity **are** about 39 °C and 60% respectively, with an average of 27 °C and daily amplitude up to 11 °C and an average of 35% for the outside relative humidity. These outdoor values are obtained from the data logger installed in the balcony. Figure 7 presents indoor temperature and indoor relative humidity of the rooms of the HEP dwelling for July and its hottest week. The indoor temperature and relative humidity remain almost constant in all the rooms of the HEP dwelling, at about 28 °C. This uniformity of temperature and relative humidity values is due to the use of insulation in walls, to the dry climate which gives a sensation of thermal comfort, to the double-glazing windows and to the night ventilation. The use the air conditioner in this case is only for a short time.



(a)



(b)

Fig 7. Month of July in the HEP dwelling: (a) indoor temperature measurements and (b) indoor relative humidity measurements.

B. Energy consumption

The annual energy consumptions of the HEP dwelling and the standard dwelling for heating and cooling are shown in Table 3. This energy was measured by using auxiliary electricity and gas meters described in paragraph D. In situ measurements. For the use of natural gas, the annual energy consumption of heating was 21403 kWh (leading to a 274.4 kWh/m^2.year) for the standard dwelling and 9157 kWh (leading to a 127.3 kWh/m^2.year) for the HEP dwelling. For electricity, the annual energy consumption for cooling was 1308 kWh (leading to a 16.8 kWh/m^2.year) for the standard dwelling and 644 kWh (leading to 8.9 kWh/m^2.year) for the HEP dwelling.

Table 3. Annual energy consumption of heating and cooling.

	Standard dwelling	HEP dwelling	Difference
Natural gas (kWh/year)	21403	9157	12246
Electricity (kWh/year)	1308	644	664
Total energy consumption (kWh/year)	22711	9801	12910

Indoor temperature is maintained in the thermal comfort range (21-24 °C in winter and 24-27 °C in summer) with the use of natural gas for heating. These temperatures range are in accord with the definitions given by ASHRAE Standard 55, 2017. Figure 8 presents the monthly energy consumption of natural gas in standard and HEP dwellings. The heating months are November, December, January, February and March. For the standard dwelling, the monthly recorded gas consumptions were respectively: 2889 kWh on November, 5308 kWh on December, 5030 kWh on January, 4816 kWh on February, and 3360 kWh on March. For the HEP dwelling the monthly recorded gas consumptions were respectively: 1053 kWh on November, 2454 kWh on December, 2308 kWh on January, 2079 kWh on February, and 1264 kWh on March.

The monthly energy consumptions of natural gas for standard dwelling were more than twice the monthly energy consumptions of the HEP dwelling. The total annual energy consumption of the standard dwelling was 22711 kWh, while the total annual energy consumption of the HEP dwelling was 9801 kWh, which represents a ratio of 57%. These energy consumptions are important due firstly, to the climate of Djelfa, which is extremely cold in winter and the fact that the dwelling is located on the top floor where heat loss is mostly by the roof.

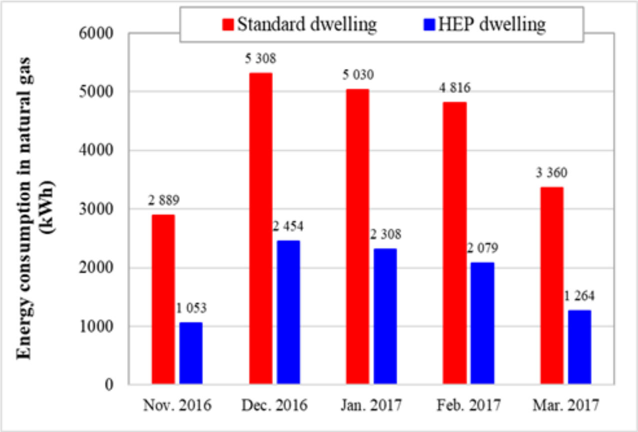


Fig 8. Annual energy consumption of natural gas for heating.

The indoor temperature and the relative humidity are maintained in thermal comfort range with the use of electricity for summer air conditioning. Figure 9 presents the monthly energy consumption on electricity in standard and HEP dwellings. The air conditioning is used for the months of June, July and August. For the standard dwelling, the monthly recorded electricity consumptions were respectively: 392 kWh on June, 564 kWh on July and 352 kWh on August. For the HEP dwelling, the monthly recorded electricity consumptions were respectively: 177 kWh on June, 306 kWh on July and 161 kWh on August.

The monthly electricity consumptions of standard dwelling were almost twice the monthly energy consumptions of the HEP dwelling. The annual energy consumption of electricity for the standard dwelling was 1308 kWh, while the annual energy consumption of electricity for the HEP dwelling was 644 kWh, which represents a difference of 51%.

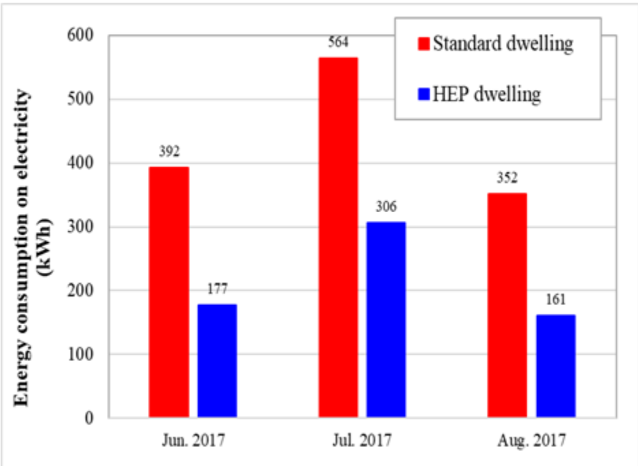


Fig 9. Annual energy consumption of electricity for cooling.

It was noted between Figs. 8 and 9 that there is a significant gap between electricity and natural gas consumption. Indeed, natural gas consumption is more than 10 times of electricity consumption. This is due to the semi-arid climate of Djelfa, whose HDD20 and CDD27 are 2216 and 265 respectively (C.f. 2.1).

Mastouri et al. [4] works use a reference study which presented the annual heating and cooling energy consumption of two houses located in a semi-arid climate in Morocco. The external walls of the standard house are made of porphyry layer, air gap, hemp insulation, Bouskoura rock and cement mortar. The annual heating and cooling energy consumption was about 38544 kWh for the standard house and 10758 kWh for the passive house, which means a reduction of 72%. For the present study, the annual heating and cooling energy consumption are about 22711 kWh for the standard dwelling and 9801 kWh for the HEP dwelling, which means a reduction of 53%.

C. The effect of night ventilation and air infiltration on the energy requirements of HPE dwelling

The simulation was run for one year with a time step of one hour, and the results were exported in (xls) format. Subsequently, histograms of energy requirements were produced by the "Excel" program for the hottest and coldest periods, depending on the climate file used.

For the summer season

In this section, we have evaluated the air-conditioning requirements for a number of night-time ventilation rates, as shown in Table 2. This involves analyzing the results of a series of models for each assumed rate over the course of a year. As a reminder, we have assumed that all the windows in the dwelling are open for each flow rate. The results of the air-conditioning requirements for the different assumed flow rates are shown in Figure 10.

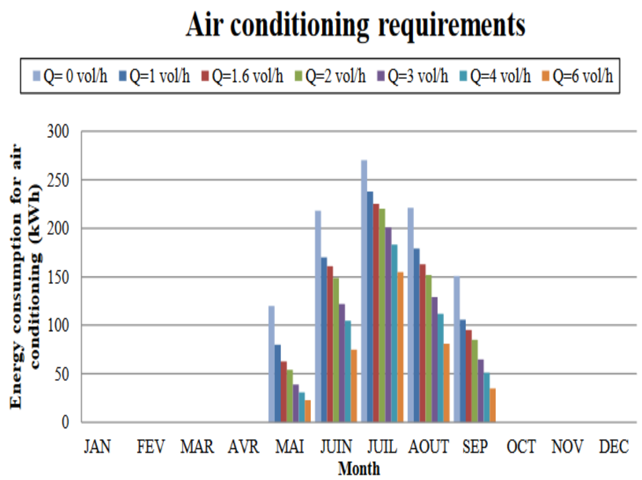


Fig 10. Cooling requirements of an HPE home over a year.

Figure 10 shows the annual air-conditioning requirements for the dwelling studied with thermal insulation. The results show that for an unventilated dwelling (minimum air change rate of 0 vol/h), we obtained the highest air-conditioning requirements. July is the hottest month of the year, requiring the highest cooling load, with a maximum of 270 kWh. We

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noted that the increase in night-time air exchange rate results in a reduction in air-conditioning requirements. Maximum values dropped from 270 kWh to 155 kWh for flow rates of 0 vol/h and 6 vol/h respectively. This reduction in air-conditioning requirements with the increase in night-time ventilation rates is due to the cold air (temperature difference between inside and outside at night exceeds 10°C) that passes through the walls of the HPE dwelling spaces and enables it to relieve the insulated walls of the dwelling of the heat stored during the day. We have also confirmed the studies by P. Heiselberg [18] and W. Yousef Mousa et al [19], that from a flow rate of 4 vol/h, we can reduce the cooling period. A comparison between the air-conditioning requirements of the dwelling without night-time ventilation and with ventilation while increasing the values of air exchange rates enabled us to identify the need for night-time ventilation and its role in reducing air-conditioning requirements.

For the winter season

We have evaluated the heating requirements for a number of air change rates, as shown in Table 2. The results of a series of models are analyzed for each assumed air change rate. As a reminder, we have assumed that only two windows in the HPE dwelling are open for each airflow rate. The results of the heating requirements for the different assumed flow rates are shown in figure 11.

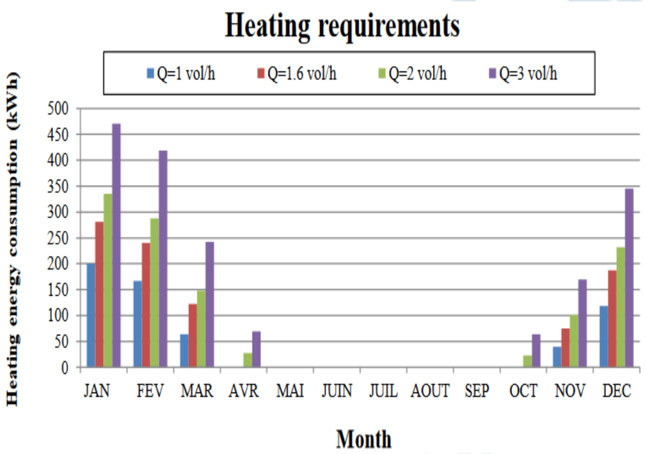

Fig 11. Heating requirements of HPE homes over one year.

Figure 11 illustrates the heating requirements of the HPE dwelling for different air change rates. As a reminder, in this section we studied the effect of air infiltration on heating requirements. We found that increasing the air exchange rate generates a high demand for air-conditioning. We obtained a maximum value of around 471 kWh during the month of January, for an air exchange rate of 3 vol/h. This value drops to 69 kWh in April, for the same air flow rate (3 vol/h). We have noticed that from airflow Q=2 vol/h, the heating demand period increases from 4 months to 6 months. The increase in heating demand as the air exchange rate rises is due to the infiltration of air from the heated interior of the dwelling to the cold exterior (the temperature gradient between inside and outside is significant) through the two open windows.

For this reason, opening windows at night during the winter period generates intense heating requirements, in addition to the natural gas consumption for heating in winter without opening windows, as shown in figure 8.

IV. CONCLUSION

The use of a number of passive energy efficiency techniques (thermal insulation, south-facing orientation, double glazing, etc.) when designing HPE homes has enabled us to achieve savings of around 60% on the gas used for heating and around 40% on the electricity used for air conditioning.

The second part of this document deals with the effect of natural ventilation and air infiltration on energy requirements in HEP housing. In this part, we used the "TRNSYS" software to estimate air-conditioning requirements through various natural ventilation rates, and heating requirements through various air infiltration rates. Analysis of the results led to the following conclusions:

Natural night-time ventilation unloads the walls that have stored heat during the day, thus reducing the overheating period in summer and lowering the rate of air-conditioning use for cooling. The simulation results did indeed show a reduction in air-conditioning demand by increasing the night-time ventilation rate. The values dropped from 270 kWh to 155 kWh for flow rates of 0 vol/h and 6 vol/h respectively. Air renewal in winter leads to an increase in heating demand. Simulation results showed that with an air exchange rate in excess of 2 vol/h, the heating demand period rises from 4 months to 6 months, with heating requirements increasing from 200 kWh to 470 kWh for air exchange rates of 1 vol/h and 3 vol/h. Finally, the solution found for evacuating carbon monoxide gases in winter is not economical. The third part of this document estimates the payback time for thermal insulation in HPE housing, based on several scenarios. Analysis of the results has enabled us to draw the following conclusions: The type of energy used is an important and decisive factor in the profitability of an insulation system, and the higher the energy price, the **faster** the thermal insulation system pays for itself, and the higher the subsidies, the **faster** the thermal insulation project pays for itself

V. RECOMMENDATIONS

The following points should be taken into account to ensure that data is collected correctly when monitoring is carried out:

- Homes must be occupied when thermal comfort parameters are measured.
- Measuring instruments must be calibrated and positioned correctly (thermo-hygrometers should be positioned in the middle of each room).

- Power outages must be avoided to ensure that measures can be taken.
- The occupants of the dwellings must be cooperative in order to be able to collect as much information as possible, particularly on the daily behaviour of the occupants (occupancy of spaces, time windows are open, energy consumption patterns, etc.).

It is also recommended that the following points be taken into consideration to improve the thermal comfort of inhabitants and the energy performance of buildings located in a semi-arid climatic context:

- Use a thermal insulation system in all living areas (walls, floors, ceilings and especially roofs (30% heat loss) to reduce thermal bridges.
- Reinforce thermal insulation with double-glazed windows that are thermally efficient and airtight.
- Orient the facades and distribute the different rooms so as to benefit from the winter sun's rays, but also to protect from the summer sun as follows:
- Day areas (living room, kitchen, office, etc.) facing south to benefit from maximum natural light.
- Night spaces (bedrooms) facing south and east to benefit from maximum natural light and keep cool at the end of the day.
- Spaces with little or no heating (garage, workshop, storeroom, laundry room.... etc) face north or west to protect them from the cold and buffer them from heated, insulated rooms.
- Build with walls made of high-inertia materials (raw earth, terracotta, stone, etc.) to store daytime heat.
- Take advantage of the temperature differences between day and night, when outside temperatures are lower, to ventilate the building and dissipate the heat accumulated throughout the day.
- Define ventilation strategies by acting on:

The position of openings in relation to wind direction, and the size of openings in relation to circulating air flow and wind speed.

- Incorporate window accessories to optimize ventilation (e.g. movable downward-facing louvers).

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