INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
VOL. 13 NO. 3 (2022) 15-27

IJSCET

http://publisher.uthm.edu.my/ojs/index.php/ijscet

ISSN : 2180-3242 e-ISSN : 2600-7959

International Journal of Sustainable Construction Engineering and Technology

Experimental Study on the Thermal Behavior of Building Materials in A Dry and Arid Climate

Benali Oussama[1]*, Dobbi Abdelmadjid[1], Hassini Noureddine[2]

[1]Department of Hydrocarbons and Renewable Energies and Earth Sciences and the Universe, University of Kasdi Merbah, Ouargla, ALGERIA

[2]Faculty of Sciences and informatics, University of Mostaganem, ALGERIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijscet.2022.13.03.002
Received 15 March 2022; Accepted 20 August 2022; Available online 10 December 2022

Abstract : This paper analyses the performance of material constructions in two small cubicle rooms during hot and cold periods, based on the results of experiments conducted at the University of Ouargla in southeastern Algeria. The climatic conditions in this region are extreme. The outdoor ambient temperature varies between 47 C° during the day and 30 C° at night for the hot period, and between 16 C° during the day and -1 C° at night for the cold period. The rooms of the in-situ cubicles were identical with a dimension of 1 m × 1 m × 1 m. The walls of the stone cubicles were made with Ouargla stone (15 cm) and two layers of gypsum (1.5 cm), and for brick, the walls of the cubicles were made with hollow brick (15 cm) and two layers of mortar (1.5 cm). Measurements are made of ambient temperatures, wall temperatures, and instantaneous heat flux densities through the walls. The effect of building material selection on energy consumption was also studied. During two different periods (August 28-30, 2020) and (October 21-23, 2020), the construction with stone decreased the indoor temperature by approximately 6 °C during the day and reduced the apparent thermal mass of the room in the first period, but in the second period, the indoor temperature increased by approximately 1 °C. The residential scale confirmed that Ouargla stone improves thermal comfort by providing high insulation and reducing indoor temperature oscillations. This material is abundant in nature and can be easily extracted and used directly in constructing houses without recycling it, which helps reduce CO2 emissions.

Keywords : Building, thermal comfort, energy savings, construction materials, Ouargla climate.

1. Introduction

It is well known that the private and public building sectors are important customers of the energy produced to ensure better comfort for the buildings' inhabitants. To meet the public demands for comfortable indoor environments, the energy requirements of buildings are constantly increasing. Due to the reduction of fossil fuel resources and the increase in energy needs, the production of new energy resources has become a necessity for Algerian policymakers. With more than 42% of the energy demand and 30 million tons of oil equivalent, the building sector is the sector that needs the most energy, which generates 25.3 million TeCO_2 [1] and represents 30% of carbon dioxide emissions.

*Corresponding author: benali.oussama26@gmail.com

In the Algerian Sahara, the energy demand for air conditioning is higher in summer, the climate is very hot in this season. In developing countries such as Algeria, energy consumption in buildings continues to grow [2]. This objective requires significant action on the whole real estate market (residential and tertiary). In particular, priority activities concern the implementation of energy efficiency in buildings to reduce energy use for cooling and heating of premises. To this end, an adequate audit is required before using passive and active systems. It is estimated that office construction is one of the major energy-intensive design types if we add retail buildings that account for more than 50% of energy consumption. Many studies have focused on studying the effects of climate on annual energy consumption by incorporating various passive retrofit scenarios in office buildings [3, 4].

Building components play a major role in the energy consumption process, but the building envelope is primarily responsible for heat transfer from the exterior to the interior. The environmental performance of a building is generally dependent on its structural and design characteristics that react to and communicate with external climatic factors, which influence the amount of energy consumed inside the building, data show that 20% to 50% of the energy consumption (cooling and heating) is caused by the envelope [5]. Building loss occurs through building elements such as walls, floors, roofs, windows, and thermal bridges. The rate of heat loss from these locations varies depending on the design and location of the building. One of the most sought-after solutions in recent years has been to build with materials that can minimize this energy consumption [6]. The negative effect of extreme outdoor weather conditions on building users can be minimized, and indoor thermal comfort can also be achieved by reducing the energy consumption of space conditioning systems [7]. In addition to minimizing energy consumption, buildings' environmental impact and thermal comfort are important parameters when selecting building materials. In the Mediterranean climate, houses with zero energy balance and zero local CO2 emissions have high levels of feasibility. They can be achieved by energy-efficient solutions using local materials and traditional construction processes [8,9]. In this context, several contributions have focused on reducing energy consumption for space heating and cooling, using an efficient evaluation of the envelope's thermal performance [10-12].

With the increased environmental awareness, one of the main concerns of academic researchers and construction professionals has been to reduce the energy consumption used by HVAC systems. In terms of designing better building envelopes with improved thermal characteristics, this has resulted in several attempts. The study work was numerically analyzed to improve the thermal insulation performance for the combination of insulating materials and thermal mass in the exterior walls. The authors identified the effective technique for multi-layer wall assembly to reduce the attrition factor and increase the gap, thus significantly improving energy efficiency and to decrease the overall energy footprint of various building types [13,14].

A Fired clay hollow brick is a building material most commonly used in many countries and Morocco for wall construction. It replaces local materials, such as mortar, mud, and lime, used in traditional buildings and other modern building materials. It has many advantages, such as ease of construction, high durability, low risk of corrosion and degradation [15]. In addition, the still air contained in the alveoli increases the insulating power of this material and causes a weakening of the external heat waves in the building. On the other hand, clay hollow bricks have the lowest thermal efficiency in regions with a dramatic climate. As in Morocco [16-19], the rapid growth of the air conditioning sector justifies this reality. To solve this problem and improve the energy efficiency of constructions, many researchers are working on improving the thermal behavior of clay bricks by incorporating PCM [20-23]. Experimental results have revealed that building materials' thermal and mechanical performance varies considerably with their saturation levels. In particular, at low saturation levels, the thermal performance of bricks degrades significantly. This fluctuation presents major confusion about the exact behavior of buildings under operating conditions [24].

The prediction gap, defined by researchers at the University of Salford in the United Kingdom, exceeds 18% in some cases. This discrepancy is attributed to an intense variability in the building structure's air permeability standards, taking into account the humidity inside the wall, and to the results of a significant difference between the actual and theoretical consumption of the building construction [25,26]. Windows are considered functional elements of the building envelope because of their major influence on the thermal activity of buildings and the amount of energy absorbed within them. Many variables in the location of these openings decide this energy and the dimensions and surface of the openings and how the shading can be used as a treatment and orientation. In addition, in the architectural appearance of the construction, windows can play an important role [27]. In offices, window openings serve many functions, such as daylighting, integration into the natural ventilation system, and visibility from the outside. However, windows are the weakest point for easy access to heat within the building enclosure, as they acquire heat in summer and lose heat in winter [28]. Heat loss and gain through windows have a very strong effect on their thermal comfort.

In this study, an experimental investigation was conducted on two identical small buildings with two different materials, the first one is a traditional material, which is stone, and the second one is a current building material, which is hollow brick, under real climatic conditions in the region of Ouargla, Algeria. This study aims to present the evaluation of the thermal performance of two rooms of cubicles and to demonstrate the contribution of stone in terms of energy saving in this building (energy storage and thermal insulation) and reduction of CO2.

2. Experimental Configuration

2.1 Experimental Cavities

This study evaluates the rationalization of energy consumption through the thermal analysis of two materials widely used in southern Algeria for thermal insulation: the local material such as stone and hollow brick.

Table 1 - Components of the brick cubicle room [29]

Wall	Composition	e (cm)	ρ (kg/m3)	Cp (kJ/ kg K)	k (W/m k)
Vertical walls	Mortar	1,5	1700	1	1.15
	hollow brick	15	900	0.936	1.72
	Mortar	1,5	1700	1	1.15
Ceiling	Mortar	1	1700	1	1.15
	Heavy concrete	15	2300	0,92	1.72
	Mortar	1	1700	1	1.15
Floor	Heavy concrete	15	2300	0,92	1.75
	Mortar	2	1700	1	1.15

Fig. 1 - Measurement of thermal conductivity of the stone

Table 2 - Components of the stone cubicle room

Wall	Composition	e (cm)	ρ (kg/m3)	Cp (kJ/ kg K)	k (W/m k)
	Gypsum	1,5	1322	1	0,45
Vertical walls	Stone	1,5	2300	0,94	0.41
	Gypsum	1,5	1322	1	0,45
	Gypsum	1	1322	1	0,45
Ceiling	Stone	15	2300	0,94	0.41
	Gypsum	1	1322	1	0,45
Floor	Gypsum	2	1322	1	0,45
	Stone	15	2300	0,94	0.41

In southeast Algeria, we conducted an experimental study in two identical small cubicles in Ouargla (31° 56’ 60” N 5° 19’ 0.001” E). The climate is dry and arid, known for its high temperatures in summer.

Fig. 2 - Overview of the cubicles

Fig. 3 - (a) stone; (b) hollow brick

Fig. 2 presents an overview of the cubicles. The dimensions of the cubicle rooms are 1 m × 1 m × 1 m. The east wall has a laminated wood door (0.65 m × 0.3 m), and the north wall has a single-pane window (0.35 m × 0.35 m).

2.1.1 Instrumentation and Measurements

The cells are equipped with type K thermocouples (2/10 mm). They are distributed on the envelopes of the cubicle rooms to allow access to the average temperatures of the walls and the centers of the cubicle rooms. Carefully fused, the thermocouples ensure that the weld has the same diameter as the two wires. Then, an error of 0.2°C is tested, and the composition is connected to a computer for data acquisition. With an accuracy of 2%, they have a response time of 0.3 s. After calibration, flux meters were mounted in the center of the inner face of the south wall, which allowed us to measure the heat flow through the wall. They have a response time of ± 3% and 0.3 s. To measure the thermal storage performance.

2.1.2 Meteorological Data of Ouargla

The meteorological data are measured with our metrological station. It measures indoor and outdoor temperatures (±0.5°C) global solar radiation (±5%) with a time step of a quarter of an hour. All the devices of the instrumentation are connected to the data acquisition. A weather station is installed in the laboratory. It is composed of a black sensor with an anemometer, which is a detectable thermo-hygrometer under shelter. It also measures the wind (speed and direction, ± 1 ms-1), precipitation, humidity under shelter with natural ventilation, indoor and outdoor humidity, and barometric pressure. The station is also equipped with a global solar radiation sensor (pyranometer).

2.1.3 Construction Materials

Stone is, in essence, an ecological material. It is a natural, non-polluting, and natural product that meets the new ideas of sustainable development. The different stages of transformation reduce the energy consumption compared to some materials or products that can replace the stone. It has a very low thermal conductivity that has been measured at the laboratory of the faculty. Finally, it is easy to maintain and integrate into our environment by respecting and enhancing it Fig. 3. a.

The particularity of the hollow brick is that it is of different colors depending on the region where it is produced. It is made of terracotta made from red clay and then mixed with a little sand. To give it its final appearance, it is baked at 1200 ° C after drying. Its manufacture and production require energy consumption by which it causes the emission of carbon dioxide, while the stone that composes it is available in nature and easy to extract Fig. 3. b.

3. Results and Discussions

Internal temperatures must be monitored for both cases to compare our results between the brick and local stone systems. This study considers the evolution of wall surface temperature and ambient temperatures, and heat flux densities through the envelope to qualify and quantify the contribution of the local material (stone) to the improvement of the building's thermal performance. The TRNSYS software also estimated thermal energy consumptions in the cavities.

3.1 Weather Conditions

Fig. 4 shows the variations in outdoor temperatures. During the first period of August, it varies around a significantly higher average value 25.8 °C and 45.2 °C, while during the second period, the outdoor temperature fluctuates between 13.8 °C and 30.2 °C.

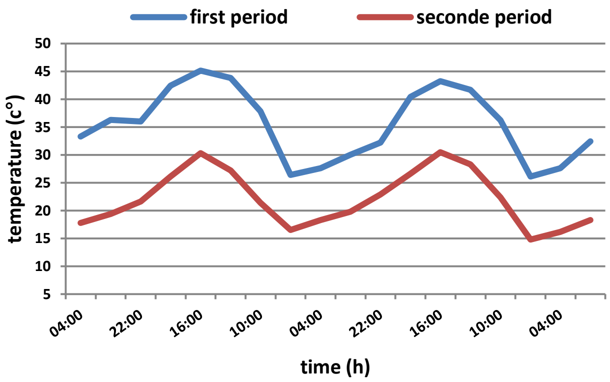

Fig. 4 - Temporal variations of outdoor temperatures

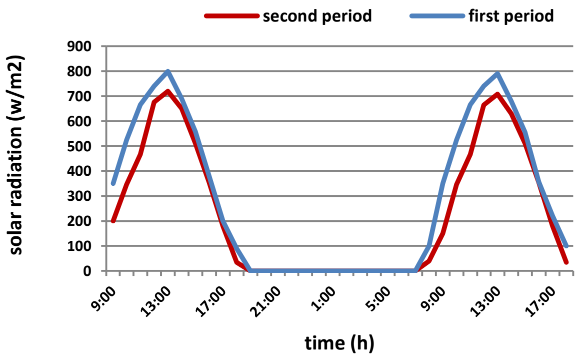

Fig. 5 - Solar flux densities

Fig. 5 shows the global solar flux densities variations for the periods studied. For the first period from August 28 to 30, 2020, the global radiation reaches a maximum value of 800 W/m^2. In October, it does not exceed 2about 690 W/m with an average value of 4402 W/m for the first period and 328 W/m^2 for the second period.

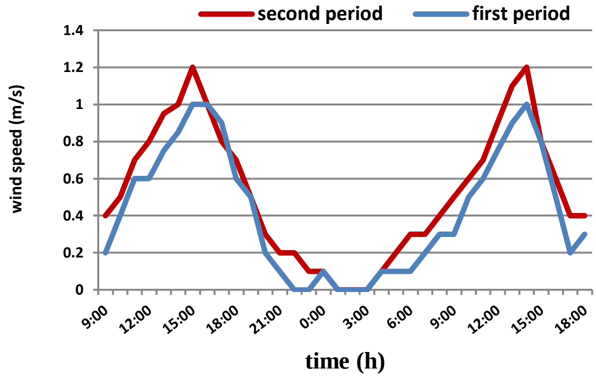

Fig. 6 - Wind speed for both periods

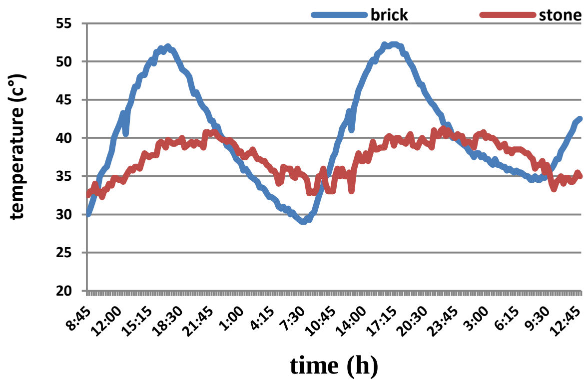

Fig. 7 - Ambient temperatures of the cells

The wind speed is more or less the same for both periods; it does not exceed 1.2 m/s[1,] as illustrated in Fig. 6. This difference between the weather conditions related to the two periods may impact the temperature evolutions of the external and internal faces of the walls and on the heat losses. However, our measurements confirm that this effect can be neglected.

3.2 Temperature Evolution

3.2.1 First Period: August 28-30, 2020

Fig. 7 presents the evolution of the internal temperatures of the cells. The temperature of the hollow brick cavity varies between a minimum of 29.2 °C and a maximum of 52.2 °C, while that of the local stone cavity fluctuates between 32.8 °C and 41.1 °C. During this period, the outdoor temperature varies between 25.8°C and 45.2°C, as shown in Fig. 4. The temperature difference between the two cavities can reach up to 12 °C. The contribution of the local stone in terms of energy storage is clearly visible in the reduction of temperature fluctuations. During the daytime, the maximum temperature difference can reach up to 6 °C.

Since the temperature changes of the vertical walls are almost the same for the north, south, east, and west, only the eastern wall is analyzed below. The two temperature curves of the east walls made of hollow brick and local stone, Fig. 8, show that the thermal deviation due to the local stone is maximum during the day (called here the overheating phase), reaching up to 20 °C. This difference decreases during the night. Note that from 21:00 to 07:00 in the morning. After the stone is completely saturated by the sun's heat and external heat gains, it gains slowly and loses slowly. In contrast, hollow bricks greatly respond to external temperature changes due to the material's properties. This is the reason for the large thermal difference between the two curves in the different phases. The drop in outside temperature (during the night) is accompanied by high heat loss to the outside, which affects the wall temperatures. From 04:00 to 07:00 in the morning (the so-called freezing phase), the eastern wall temperatures fall to 26 °C and 35 °C for the cases with hollow brick and stone, respectively. As an important result, we confirm that the wall's temperature with stone continues to decrease until 25 °C.

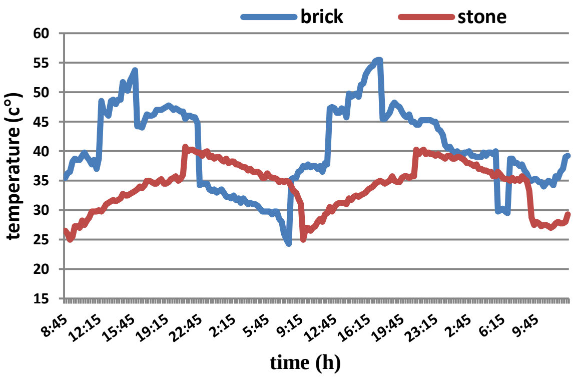

Fig. 8 - Temperature evolution of the eastern walls

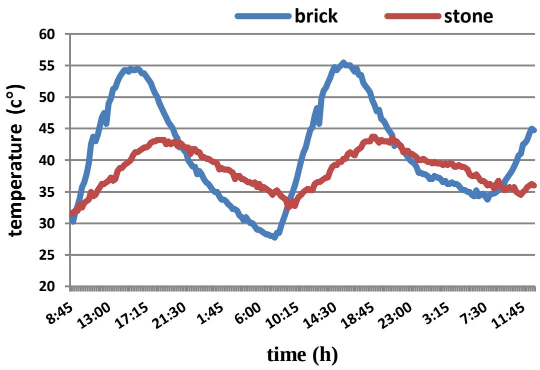

Fig. 9 - Temperature evolutions of the ceiling face

During the overheating phase, since the local stone has high thermal inertia, it stores thermal energy in the daylight and loses it when the outside temperature slowly decreases. In the case of the hollow brick wall, the surface temperature decreases to 26 °C, resulting in a significant difference between the two curves in this area. The evolution of the ceiling temperature in Fig. 9 clearly shows the effect of the local stone throughout the study period. The difference between the two curves remains large and almost constant over the two days, as for the vertical wall surface temperatures. But the difference in the response rate to the outdoor temperature changes, with the ceiling reacting faster than the wall to changes in outdoor temperature. During the overheating phase, the difference between the curves is about 15°C, and during the freezing phase, the difference has decreased to about 3.5°C. This is because the local stone reduces heat loss and destroys the stratification inside the cavity. Thus, the ceiling temperature is close to the ambient temperature (a difference of about 3°C), as shown in Fig. 11. In the cavity made of hollow bricks, the heat loss through the ceiling is (a difference of about 5.25 °C between the ambient and ceiling temperature) as shown in Fig. 10. due to the lack of insulation. The local stone construction is advantageous because it helps to reduce heat loss. The conclusion is that the local stone construction in the building envelope helps to homogenize the air temperature, certainly by natural convection.

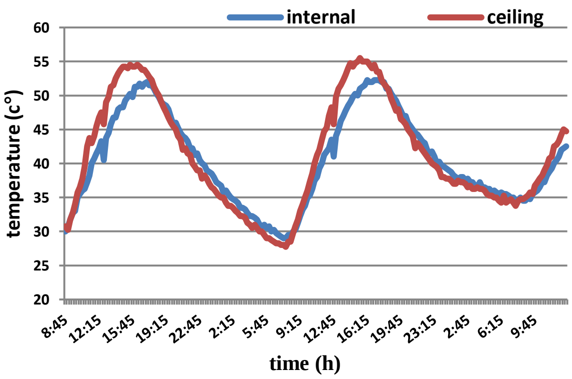

Fig. 10 - Thermal stratification in a brick cell

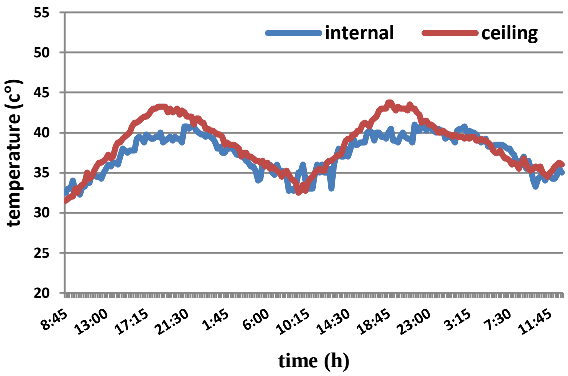

Fig. 11 - Thermal stratification in a stone cell

3.2.2 Second Period: October 21-23, 2020

Only the evolution of the east wall is presented for the vertical walls because of the similar thermal behavior of the vertical wall.

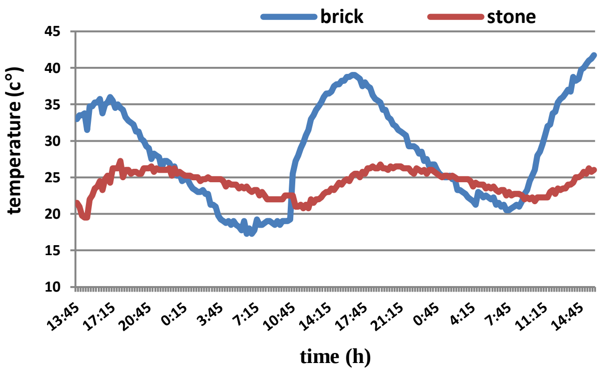

Fig. 12 - Temperature evolutions of the eastern walls of the cells

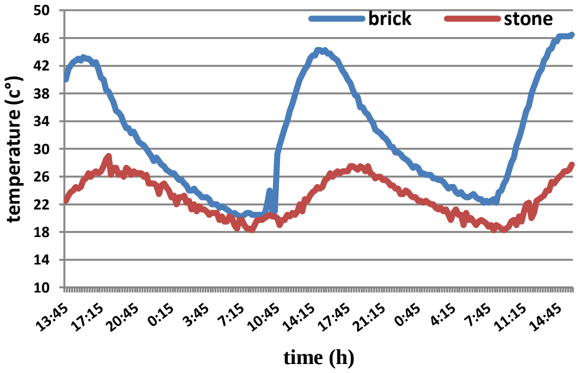

Fig.13 - Temperature evolutions of the ceilings

Fig. 12 shows the temperature evolution of the east wall during the second period from October 21 to 23, 2020. It can be noted that the temperature of the wall with stone reaches up to 26.25°C during the loading period and does not fall below 2°C even at night. The difference in temperature evolution is significant during the heating phase up to 14°C, while the curves during the cooling period converge with a maximum difference of 5°C.

Indeed, during the cooling period, it does not go below 21°C, which means that the stone releases the thermal energy stored during the overheating period. Note that when the ambient temperature is lowered, the interior temperature of the brick cavity drops faster than that of the stone cavity. The two curves overlap for a while (about 7 hours), and then we observe an increase in the temperature of the brick wall. This can be explained by the thermal inertia of the stone and thus the beginning of the release of the stored energy. The result is a gap between the two curves that widens as we approach the limit of the cooling phase.

Fig. 12 and 13 show that the temperature changes in the east generally have the same behavior as those of the ceiling walls. We can notice that the temperature difference between the two ceiling curves is very important during the overheating period. The difference is about 19°C while remaining low during the freezing phase and does not exceed

3.25°C. This means that thermal inertia is important for the stone despite the temperature drops during the night in Ouargla. As soon as the outside temperature drops, the temperature of the brick ceiling drops from 43°C to 23.5°C faster than that of the stone ceiling. The slope of the drop is about 2.5°C/h, while the slope for the stone is about 1°C/h. The stone curve keeps the same slope during the non-hot period, while the slope of the brick curve decreases from 2.5°C/h to 1°C/h when it drops below 26°C: This phenomenon is due to the release of the thermal energy stored by the stone.

Fig. 14 shows the evolution of the interior temperature of the cavities. The temperature difference can reach up to 11.5 °C during the heating phase, the curves are almost identical, and the difference is less than 2 °C. If the minimum temperature in the stone cavity is controlled by thermal inertia, which is about 26.75 °C, we find that even in the brick cavity, the minimum temperature is about 23.75 °C. The decrease of the external temperature during the night contributes to the stone's cooling by its external face. However, the temperature does not drop below 26 °C during the two nights of the experiment.

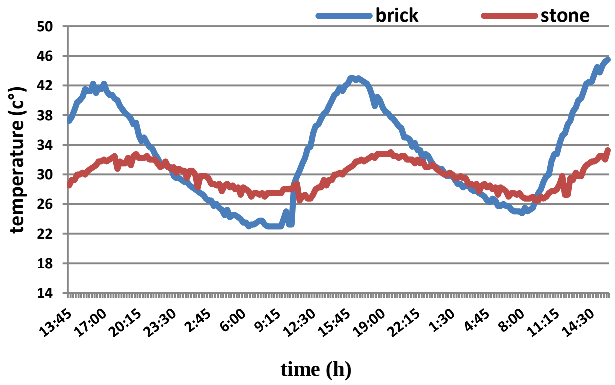

Fig. 14 - Ambient temperature evolutions of the cavities

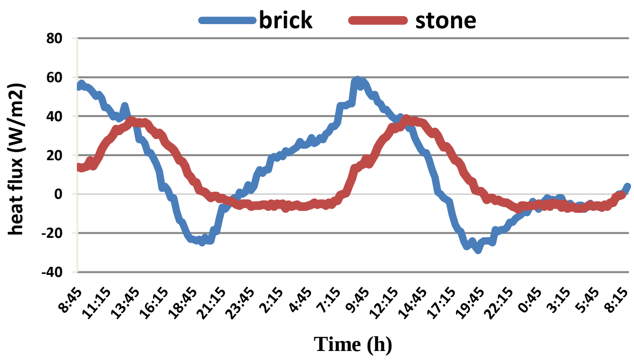

Fig. 15 - Heat flux density variations with time through the south walls, first period

3.3 Heat Transfer

3.3.1 First Period: August 28-30, 2020

The heat transfer is studied by the densities of the instantaneous heat flow through the different walls of the cells. It is measured with very sensitive flux meters previously calibrated to evaluate the heat transfer through the walls of the two cells (considering the ideal contact between the sensor and the surface, whose contact area has been specially treated). We considered the flux densities through the southern walls as a case study. Fig. 15 presents the temporal evolution of the brick and stone cells. It can be seen that during the freezing period, the heat flux density is low for the stone. Still, the heat flux of the brick cavity is large compared to the stone cavity (there is a difference of 26 W/ m2)since the brick cavity in both periods there is a significant exchange, In the period of overheating, the heat transfer is important from the outside to the inside, and during the period of freezing, it is the opposite, but for the stone cavity, the exchange is important during the period of overheating. We note that the two curves do not coincide in the two periods. Moreover, for the brick cavity, it decreases to a value of (-26 W/m2) (on the second day) while the stone wall remains higher (-6 W/m2). The stone cavity remains warmer than the brick cavity, so once the outdoor temperature drops, the heat loss through the brick cavity becomes greater than the stone cavity.

3.3.2 Second Period: October 21-23, 2020

In addition to comparing the heat exchange between the two cells and the exterior, the objective of this study is to evaluate the heat stored in the local stone. As shown in Fig. 16, during the overheating period, the flux density entering the brick cavity is higher than that of the stone cavity, which means that the local stone is not considered to be a good thermal conductor (this means that the local stone obstructs the heat transfer from the outer surface to the inner surface, which means that the external losses are higher in the stone cavity compared to the brick).

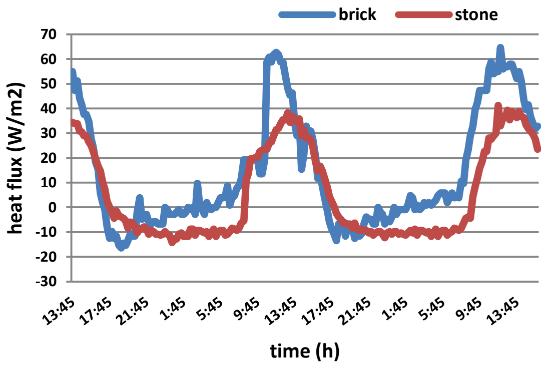

Fig. 16 - Flux density variations with time, through the southern walls, second period

The curves converge during the freezing period: the surface flux density in the brick cavity decreases and converges with the surface flux density in the stone cavity. The latter releases some of the stored heat to the cavity, thus reducing the net inflow flux density.

4. Energy Consumption

Using TRNSYS software for energy demand modeling, we can better understand the benefits of using local stone in building construction and its contribution to reducing energy consumption. Fig. 17 and 18 show the energy consumption curves. It can be seen that the stone cavity achieved the lowest heating energy demand in winter (the maximum value in January 350 kJ/hr) compared to the brick cavity for which the heating demand is (725 kJ/hr). This is due to the fact that the stone stores energy during the load period, while the stored heat is released during the cold period when the outside temperature drops.

It can be seen that the stone cavity achieved the lowest cooling energy demand in summer (the maximum value in August is 250 kJ/h) compared to the brick cavity, for which the cooling energy demand is (740 kJ/h). Therefore, during the winter, the use of stone in the building walls increases the interior temperature of the cavity and reduces the heating demand of the cells. The thermal demand varies from month to month (Figures 17 and 18) because the outdoor conditions are not the same all the time. It was recorded that during the months (January, February, March, October, November, and December), the thermal demand is greater compared to other months, while during the summer, it was recorded that during the months (April, May, June, July, August, September), the thermal demand is greater compared to other months.

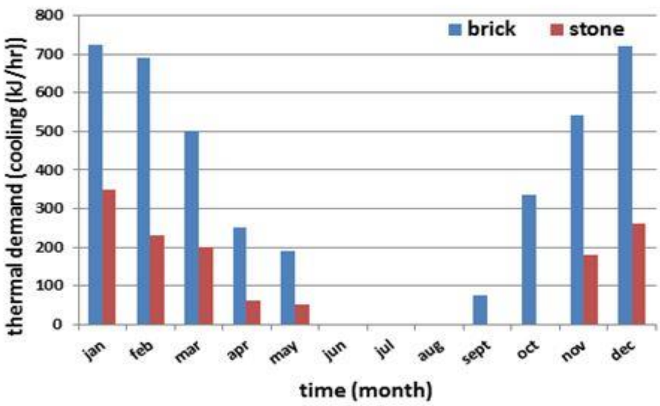

Fig. 17 - Thermal demand (heating) in the cavities

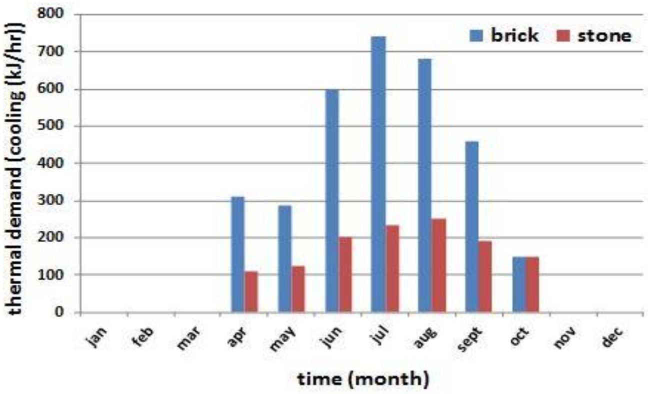

Fig. 18 - Thermal demand (cooling) in the cavities

5. Conclusion

The paper experimentally investigated the effect of local stone on the envelope of a residential room. The stone is used in the walls and ceiling. We used small-scale cells to compare room and wall temperature changes, heat flux densities, and energy consumption for rooms created with stone and brick walls. The two cells are placed under normal atmospheric conditions and at two different periods to estimate the potential effects of using local stone. The main findings of our study are as follows:

- In cold periods, the local stone keeps the cell's temperature higher than that of the brick cavity. The thermal difference reaches up to 11.5°C.
- The use of local stone in the envelope destroys the thermal stratification in the cavity.
- A significant reduction in heat loss through the wall. On average, these losses are reduced by 60%.
- As the heating of both cavities is provided by electrical energy, the construction of the cavity shell in local stone reduces the energy consumption by 50% compared to the case of brick.
- Since the cooling of both cavities is provided by electrical energy, the enclosure of the cavity with the local stone reduces the energy consumption by 60% compared to the case of brick.

In arid regions, local stone offers the best compromise of thermal comfort compared to hollow bricks. By using local stone, there is no need to improve the thermal insulation of the exterior envelope; thermal insulation is important for energy conservation, and it is a good insulator. Thermal insulation reduces construction costs and energy consumption. Local stone improves energy efficiency and reduces greenhouse gases, thus helping to mitigate climate change. With increased environmental awareness, the focus is now on saving energy in residential buildings. It is estimated that just 1% of the cost of a building can reduce energy consumption by 30 to 40%. But the only negative thing about local stone is that it is eroded by rain or its presence in areas with high humidity.

Acknowledgment

The authors would like to thank the University of Kasdi Merbah for giving me the opportunity to conduct this research.

References

[1] M.H. Benzaama, S. Menhoudj, K.J. Kontoleon, A.M. Mokhtari, M.C. Lekhal, Investigation of the thermal behavior of a combined geothermal system for cooling with regards to Algeria's climate, Sustainable Cities and Society 43 (2018) 121–133, https://doi.org/10.1016/j.scs.2018.08.016

[2] R.Ghedamsi, N.Settou, A.Gouareh, A.Khamouli, N.Saifi, B.Recioui, B.Dokkar. Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach. Energy and Building 121 (2016) 309–17

[3] E.Dascalaki and M.Santamouris, On the potential of retrofitting scenarios for offices, Building and Environment, 37 (2002) 557–567 https://doi.org/10.1016/S0360-1323(02)00002-1

[4] N. Eskin, H.Tu¨rkmen, Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey, Energy and Building,40(2008)763–773 doi : 10.1016/j.enbuild.2007.05.008

[5] J.Yu, L.Tian , X.Xu , J.Wang, Evaluation on energy and thermal performance for office building envelope in different climate zones of China, Energy and Building 86 (2015) 626–639 http://dx.doi.org/10.1016/j.enbuild.2014.10.057

[6] Olomolaiye,O.Paul,Akadiri,O.Peter, Olomolaiye, Paul; Chinyio and Ezekiel A, Multi-criteria evaluation model for the selection of sustainable materials for building projects, Automation in Construction, 30 (2013) 113–125. https://doi.org/10.1016/j.autcon.2012.10.004
[7] J.C. Damfeu, P. Meukam, Y. Jannot, E. Wati, Modelling and experimental determination of thermal properties of local wet building materials, Energy and Buildings, 135 (2017) 109–118doi: 10.1016/j.enbuild.2016.11.022
[8] A.Ferrante, M.T. Cascella. Zero energy balance and zero on-site CO2 emission housing development in the Mediterranean climate. Energy and Buildings, 43 (2011) 2002–2010. DOI: 10.1016/j.enbuild.2011.04.008
[9] F.Stazia, C. Bonfiglia, E. Tomassonia, C. Di Pernab, P. Munafòa. The effect of high thermal insulation on high thermal mass: Is the dynamic behaviour of traditional envelopes in Mediterranean climates still possible. Energy and Buildings, 88 (2015) 367–83. doi: 10.1016/j.enbuild.2014.11.056
[10] M.Ciampi, F. Fantozzi, F. Leccese, G. Tuoni. On the optimization of building envelope thermal performance. Civil Engineering and Environmental Systems, 20 (2003) 231–54. https://doi.org/10.1080/1028660031000140224
[11] Y.Jinghua, L. Tian, X. Xu, J. Wang. Evaluation on energy and thermal performance for office building envelope in different climate zones of China. Energy and Buildings, 86 (2015) 626–39. http://dx.doi.org/10.1016/j.enbuild.2014.10.057
[12] B.N.Khalid, External load-bearing walls configuration of residential buildings in Iraq and their thermal performance and dynamic thermal behavior. Energy and Buildings, 84 (2014) 169–81. doi: 10.1016/J.ENBUILD.2014.07.064
[13] S.A.Al-Sanea, M.F.Zedan. Improving thermal performance of building walls by optimizing insulation layer distribution and thickness for same thermal mass. Applied Energy, 88 (2011) 3113–24. DOI: 10.1016/j.apenergy.2011.02.036
[14] M.Ozel, Effect of insulation location on dynamic heat-transfer characteristics of building external walls and optimization of insulation thickness. Energy and Buildings, 72 (2014) 288–95. DOI: 10.1016/j.enbuild.2013.11.015
[15] D.G. Leo Samuel, K. Dharmasastha, S.M. Shiva Nagendra, M.P. Maiya, Thermal comfort in traditional buildings composed of local and modern construction materials, International Journal of Sustainable Built Environment, 6 (2017) 463–475. DOI: 10.1016/j.ijsbe.2017.08.001
[16] A.S. Jihad, M. Tahiri, Forecasting the heating and cooling load of residential buildings by using a learning algorithm ‘‘gradient descent”, Morocco, Case Studies in Thermal Engineering, 12 (2018) 85–93. https://doi.org/10.1016/j.csite.2018.03.006
[17] S. Hamdaoui, M. Mahdaoui, A. Allouhi, R. El Alaiji, T. Kousksou, A. El Bouardi, Energy demand and environmental impact of various construction scenarios of an office building in Morocco, Journal of Cleaner Production, 188 (2018)113-124. 10.1016/j.jclepro.2018.03.298
[18] H. Sghiouri, A. Mezrhab, M. Karkri, H. Naji, shading devices optimization to enhance thermal comfort and energy performance of a residential building in Morocco, Building Engineering, 18 (2018) 292–302 https://doi.org/10.1016/j.jobe.2018.03.018.
[19] B. Chegari, M. Tabaa, F. Moutaouakkil, E. Simeu, H. Medromi, Local energy selfsufficiency for passive buildings: Case study of a typical Moroccan building, Journal of Building Engineering, 29, (2020), 101164.https://doi.org/10.1016/j.jobe.2019.101164
[20] E.M. Alawadhi, Thermal analysis of a building brick containing phase change material, Energy and Buildings, 40 (2008)351–357.DOI: 10.1016/j.enbuild.2007.03.001
[21] K. Kant, A. Shukla, A. Sharma, Heat transfer studies of building brick containing phase change materials, Solar Energy, 155 (2017) 1233–1242. DOI: 10.1016/j.solener.2017.07.072
[22] C-m.Lai, C-M.Chiang, How phase change materials affect thermal performance: hollow bricks, Building Research and Information, 34 (2006) 118–130. DOI: 10.1080/09613210500493197
[23] R. Saxena, D. Rakshit, S.C. Kaushik, Experimental assessment of Phase Change Material (PCM) embedded bricks for passive conditioning in buildings, Renewable Energy, 149 (2020) 587–599, https://doi.org/10.1016/j.renene.2019.12.081.
[24] V.Vitielloa, R.Castelluccio, M.Del Rio Merino, Experimental research to evaluate the percentage change of thermal and mechanical performances of bricks in historical buildings due to moisture, Construction and Building Materials, 244 (2020) 118107 DOI: 10.1016/j.conbuildmat.2020.118107
[25] K. Gaspar, M. Casals, M. Gangolells, A comparison of standardized calculation methods for in situ measurements of façades u-value, Energy and Buildings, 130 (2016) 592–599. DOI: 10.1016/J.ENBUILD.2016.08.072
[26] E. Troppová, M. Švehlík, J. Tippner, R. Wimmer, Influence of temperature and moisture content on the thermal conductivity of wood-based fibreboards, Materials and Structures, 48 (2015) 4077–4083. https://doi.org/10.1617/s11527-014-0467-4

[27] S. B.Sadineni, S.Madala, R. F.Boehm. Passive building energy savings: A review of building envelope components. Renewable and Sustainable Energy Reviews, 15 (2011) 3617–3631. doi: 10.1016/j.rser.2011.07.014

[28] H.Sozer, Improving energy efficiency through the design of the building envelope. Building and Environment, 45 (2010) 2581–2593. doi: 10.1016/j.buildenv.2010.05.004

[29] B.Hebbal, Y.Marif , M.Hamdani , M. Mustapha Belhadj , H.Bouguettaia , D.Bechki. The geothermal potential of underground buildings in hot climates: Case of Southern Algeria 2021. case Studies in Thermal Engineering, 28 (2021) 101422 https://doi.org/10.1016/j.csite.2021.101422