E3S Web of Conferences **111**, 03003 (2019)
CLIMA 2019
https://doi.org/10.1051/e3sconf/201911103003

Comparison of the thermal performance between conventional and cob building

Kaoutar Zeghari[1], Hasna Louahlia[1,], Malo Leguern[2], Mohamed Boutouil[2], Hamid Gualous[1], Michael Marion[1], Pierre Schaetzel[1], Steeve Goodhew*[3] and F*rançois Streif*[4]

[1]Normandy University, LUSAC-Unicaen, Site universitaire Bellevue, 50000 Saint Lô, France
[2]ESITC Caen, Campus 2, 14610 Epron, France
[3]Plymouth University, Drake Circus, Plymouth PL4 8AA, UK
[4]Cotentin and Bessin marshlands regional national park, France

Abstract. The appliance of sustainable development approach in building has urged construction industry to adopt proper measurements to protect environment and reduce residential building energy consumption and CO2 emissions. Thus, an increasing interest in alternative building materials has developed including the use of bio-based materials such as cob which is studied in this paper. In the previous work, many experimental and numerical studies have been carried out to characterize thermal behaviour of earth buildings, reduce its thermal conductivity and water content. In this paper, an experimental study is carried out to determine the thermal properties and energy performance of cob building. Cob samples within different soil and fiber contents are studied using an experimental set up instrumented with flux meters and micro-thermocouples in order to evaluate the local heat flux and thermal conductivity during stationary regime. The results are analysed and compared to deduce the performant mixes in terms of thermal behaviour while respecting the French thermal regulation. A static thermal simulation based on RT 2012 calculation method (the official French calculation method for the energy performance of new residential and commercial buildings according to France thermal regulation) is used to compare energy performance between conventional and cob building using the French climate data base .

1 Introduction

Since the last past years, contemporaneous concerns about energy consumption and greenhouse gas emissions have rapidly immerged intriguing environmentalists, researchers and public consciousness. There has been an important influence of energy consumption on the economic progress leading to raise awareness about effective resources monitoring [1].

According to the last report "International Energy Outlook 2013"of the Energy Information Administration (EIA, 2013) the world energy consumption will rise to 56% between 2010 and 2040.Yet, Built environment is a substantial consumer of energy, according to Saidur R et al. [2] the residential energy consumption reached 31% of the world energy in 2009. In the USA, primary energy consumption in the residential sector is estimated around 54% of consumption in the building sector, while in the EU it has increased by around 1%/year since 1990 (Environment and Energy Management Agency, 2012).
As a response to the increasing energy consumption in buildings, many policies and means have been adopted in order to promote energy efficiency and sustainable buildings [3]. Therefore, an increasing interest in alternative building materials such as bio-based materials particularly earth has arisen because of the extensive environmental problems such as climate change and the impoverishment of resources combined with the rapid technological advancement within the building sector. Earth is often acknowledged as sustainable building material, based on its low embodied energy [4]. As described by Hamed et al [5], there are different types of earth buildings such as: Rammed earth buildings, Adobe, Wattle and Daub, Poured earth and cob that is studied in this paper.

Thus, Cob which is defined as a mixture of earth and fibers that is then mixed with water has been used long-time ago thanks to its suitable construction properties. It has the advantage of fulfilling all strength and service ability requirements for thermal building performance.
Earth construction materials are not renewable materials but can be reused while keeping their thermal properties within low thermal resistance. Many authors [6] have shown that the thermal conductivity in earth building can vary from 0.47 to 1 W/m°C according to straw content, density and water content. Many experimental and numerical studies have been carried out to characterize thermal behavior of earth buildings. Mansour et al. [7] demonstrated the use of optimal bulk density of 1750 kg.m^{-3} makes possible to reach the objective of reducing thermal conductivity of the CEB (compressed earth blocks) to 0.75W m^{-1} K^{-1}. Meukam et al. [8] have carried out an experimental study on the thermal properties of bricks made from lateritic soil. The obtained results present a rapid increase for low water content and a maximum diffusivity for a water content of 14% for laterite and 8% for laterite with addition of natural pozzolan or sawdust. Lucile Soudani, Monika Woloszyn et al [9] investigated thermal performance about a real case study. The house studied is located in Saint-Antoine l'Abbaye, in Isère, South-Eastern France. The house affords a good comfort in summer within regards to stability and level of temperatures. Besides, it provides a good energy performance in winter because temperature gets comfortable with a very low heating load. Results

* Corresponding author: hasna.louahlia@unicaen.fr

confirm good thermal mass of the studied walls and an overall good insulation of the house and the thermal behavior of the walls reveals important time lags and low decrement factors, which constitutes an explanation of the thermal performance. Matthew et al [10] investigated the use of cob in construction in non-residential buildings based on two case studies. They showed that straw bale has a higher insulation efficiency value compared to both cob and traditional construction materials with about 250 kJ/m^{3}K while cob has the much higher value of 1900 kJ/m3K. Also, Straw bale and cob present an interesting environmental benefit. The energy involved in their creation and life cycle is very low compared to traditional materials. Garot [6] presented in his study the effect of material and building shape on interior climate shown by readings taken from two test buildings of equal volume constructed in Cairo, Egypt, in 1964. One was built of 50-cm-thick earth walls and mud brick vaults, and the other of 10-cm-thickpre-cast concrete elements with a flat roof. While the variation of the outside temperature was 13°C, the temperature inside the earth house varied only by 4°C; in the concrete house, the variation was 16°C.

In this paper, an experimental study was carried out to determine the thermal properties and behavior of cob buildings. Cob samples within different soil and fibers contents have been studied using an experimental set up instrumented with heat flux meters and thermocouples in order to evaluate the local heat transfer and local thermal conductivity during stationary regime. The results are analyzed and compared to deduce the performant mixes in terms of thermal behavior while respecting the French thermal regulation. Then, A static global thermal simulation based on the French RT-2012 thermal regulation (the official French calculation method for the energy performance of new residential and commercial buildings) is used to compare the global energy consumption and evaluate heat losses between conventional and cob building using the climate data base in France.

2 Experimental set up

Four main cob samples representing different soil and fibers contents are tested using the test bench described in the following paragraph. The selected samples are already accomplishing all strength and mechanical criterions. The experimental set up provides local heat flux and local thermal conductivity measurements on the samples based on heat flow meter method. The test section includes one heater in which input heat power is set on P=15 W and one copper multi-microchannel heat sink (250mmx250mmx3mm) of 50 parallel micro channels as a cold source connected to an isothermal bath with a temperature regulator and a 12 g/s flow rate**.** Two K-type thermocouples are inserted in the inlet and outlet of heat sink. The specimen is put between two copper plates located in direct contact with the heater and microchannel heat exchanger as shown by Figure 1.

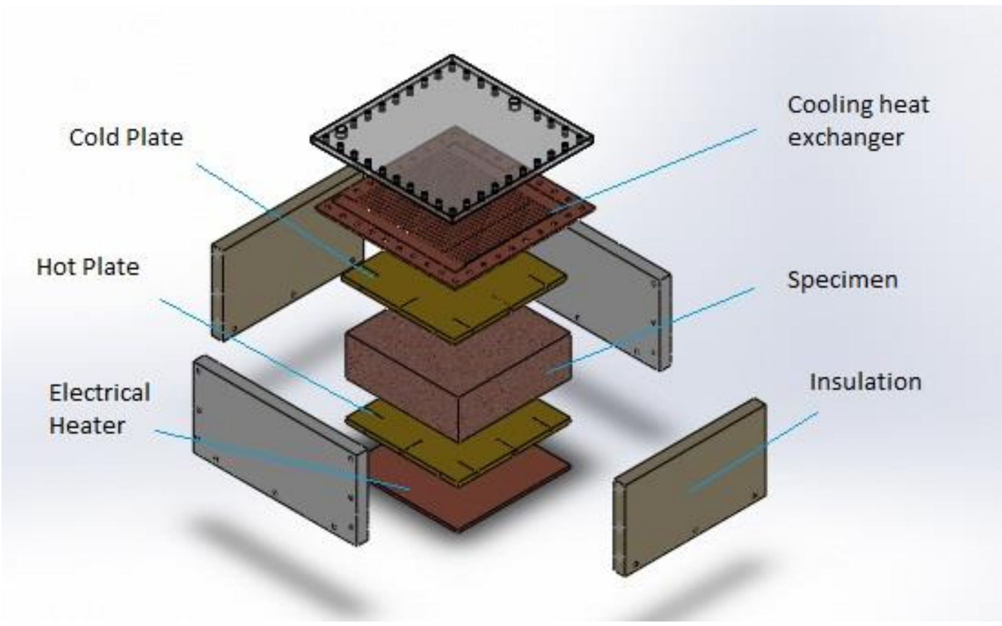


Fig. 1. The experimental set up.

The plates are used as heating and cooling plates. Both plates divided on 9 thermal zones with welded K-type micro-thermocouples (0.3mm) on both top and bottom sides for the heat flux prediction using Fourier law (Figure2). A 20 mm thick polyethylene expanded foam (PEF) is used to form an insulated cover around the sample, heating and cooling plates and 60 mm of expanded polystyrene is used for external side insulation. These insulated covers will minimize the heat transfer from the lateral side face of the sample into the surrounding environment. Accordingly, the heat transfer through the sample can be calculated assuming one-dimensional thermal condition. 9 K-type microthermocouples were inserted on each side of the sample to measure the temperature variations and heat fluxes through sample during testing processes. All sensors connected to a multichannel multimeter (NI SCXI-1303, USA) to record the data. Calibration of the thermocouples was done with internal calibration system of LabVIEW and using thermostatic bath to obtain calibration points for different temperatures. Reference temperatures were obtained with a precision thermometer. With the heat flow meter system, the thermal properties of the sample such as the thermal conductivity and diffusivity can be determined. Furthermore, it is possible to investigate the thermal performance of cob samples such as the thermal stability and power consumption to stabilize the indoor temperature.

The used thermocouples are ±0.1°C error and the heat flux measurements have a precision of ± 0.084 W.

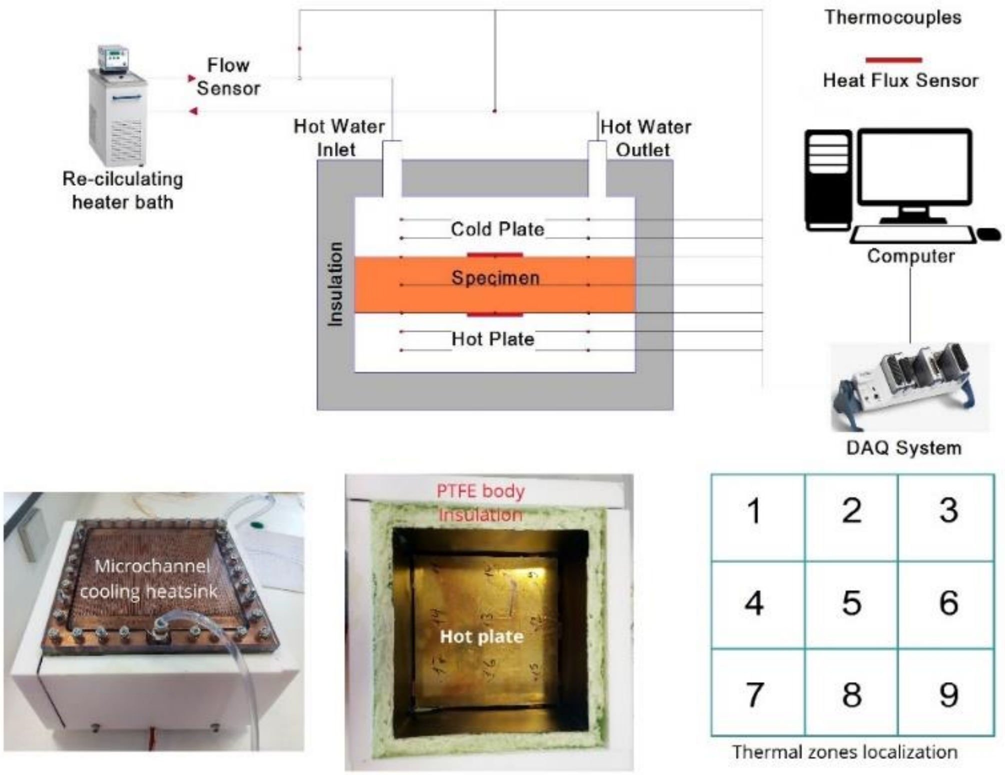


Fig. 2. Components of the test bench

3 Experimental procedure

To start experimentation, both brass plate heat exchangers firstly are kept at a constant temperature T_{init} until the heat fluxes are constant (thermal steady-state condition). Then, a temperature variation is imposed on the bottom brass plate from T_{init} to T_{end} and kept at T_{end} while the other brass plate is kept at T_{init} until a thermal steady state conditions is reached. After reaching the thermal steady state condition, the average temperature on the top (T_{top}) and bottom (T_{bottom}) faces of the block and the average heat fluxes (φ_{ave}) on both faces are recorded for thermal conductivity (λ) calculation via the following relationship:

$$\lambda = \frac{\varphi_{ave} d}{A_s(T_{bottom} - T_{top})} \quad (1)$$

Where As and d are the area and the thickness of the soil brick, respectively. In these experiments the dimension of the soil samples are As = 20*20 cm^2 and d = 7 cm. The average heat flux can be calculated via equation 2:

$$\varphi_{ave} = \frac{\varphi_{cp} + \varphi_{hp}}{2} \quad (2)$$

Where φ_{cp} and φ_{hpp} heat flux from specimen to cold plate and heat flux from hot plate of specimen, respectively.

Heat losses from silicon flexible heater to ambient through Teflon bottom wall could be calculated by Fourier law:

$$Q_{loss} = A_t \, \lambda_{tw} \frac{\Delta T_{tw}}{d_{tw}} \quad (3)$$

Where A_t and d_{tw} are area and thickness of the Teflon wall (areas of the Teflon wall, heater and specimen are the same 20x20cm), ΔT_{tw} is the temperature difference between two sides of the Teflon wall, λ_{tw} is the thermal conductivity of Teflon (0.22 W/m°C). In this study, heat input power is set to 15 W and coolant temperature is set to 5°C.

4 Experimental results

4.1. Verification of the experimental procedure

In order to verify the experimental procedure, the first tests are conducted with a wood sample as a reference sample. The wood thermal conductivity is measured using KD2-sensor with uncertainty of 13%. Figure 3 shows the local experimental data obtained using the present experimental procedure. It can be seen the average measured thermal conductivity is about 0.15018W/m°C and the value measured with KD2 sensor is about 0.155W/m°C. The difference is about 3%.

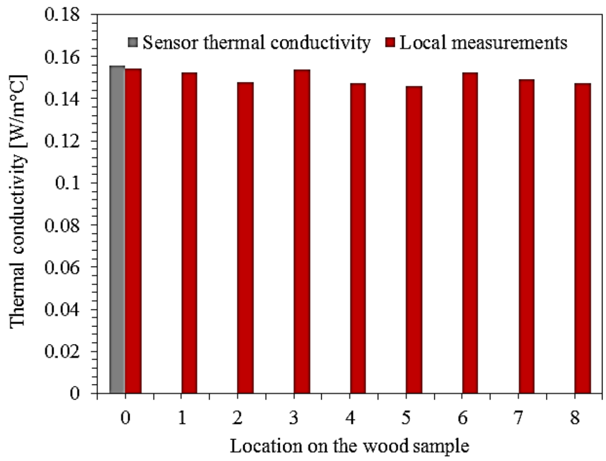


Fig. 3. Local bottom and top temperatures measurements on cob samples top and bottom surfaces.

4.2. Cob material thermal conductivity measurement

In this paper, only two cob samples are represented. S3 represents construction cob sample and T1 insulation cob sample.

The S3 sample is made of FR2 soil type, 2.5% hemp straw and 28.5% water content while T1 contains UK3 soil type, 25% hemp shiv and 107.3% water content. For all samples' preparation, the soil is mixed with water and preserved for 3 days before adding fibers. Once the fiber is added to soil the mixture is kept in 20±2°C within relative humidity of 50±5 % one day before making samples. After, the mixture is put in molds for 2 days, then is unmolded and kept in a stove within 40°C. Figure 4 represents the different Cob samples made within various soil, fibers and water contents.

Fig.4. Cob samples.

Temperatures for both top and bottom sides of the samples and heat flux measurements are recorded in steady state. Fig 5 represents temperature distribution in the 9 zones of each side with $T_{bottom,i}$ is bottom temperature and $T_{top,i}$ is top temperature and subscript i refers to the zone number. The heat source is positioned under the sample and the heat flux is transmitted from bottom to top.

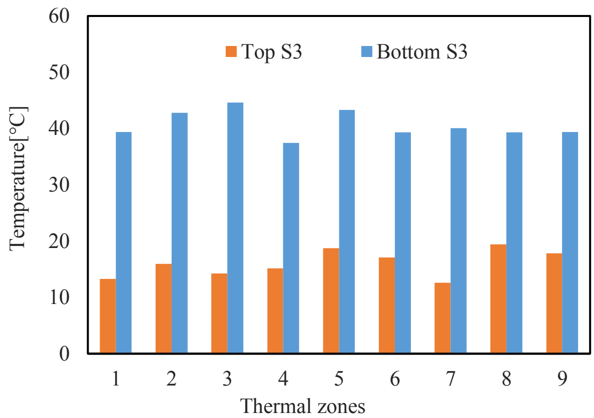


Fig. 5. Local bottom and top temperatures measurements on cob samples top and bottom surfaces.

Thermal conductivity is calculated from equation (1) using results of heat flux measurements and temperature across sectional difference.

Figure 6 represents local thermal conductivity in the different S3 sample locations. The present tested sample has an average thermal conductivity of 0.562 W/m°C. The local thermal conductivity is variable between 0.6 W/m°C and 0.88 W/m°C because of the heterogeneous distribution of fibres in the sample due to the random mixing process. Yet, the measured thermal conductivity represents good building thermal performance thanks to its low thermal conductivity in 7 zones among 9 comparing to other samples. This mix provides higher thermal resistance which means less heat flux dissipation. On the other hand, thermal conductivity measurements for T1 insulation sample are represented in figure 7. The insulation sample has an average thermal conductivity of 0.117 W/m°C. The local thermal conductivity is variable between 0.115 W/m°C and 0.123 W/m°C

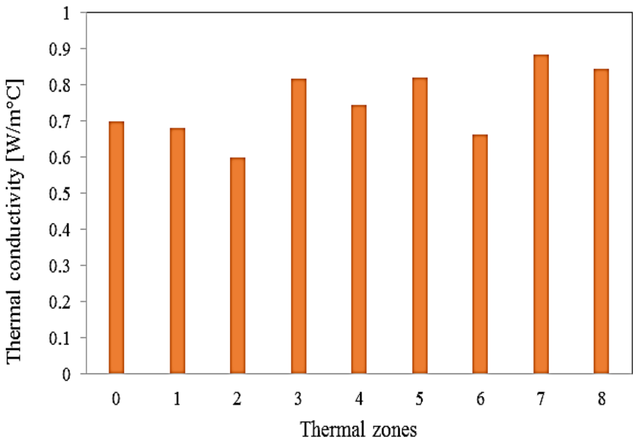


Fig. 6. Local measured thermal conductivity of the S3 sample for 10 W Heat flux, $T_{coolant}$=5°C

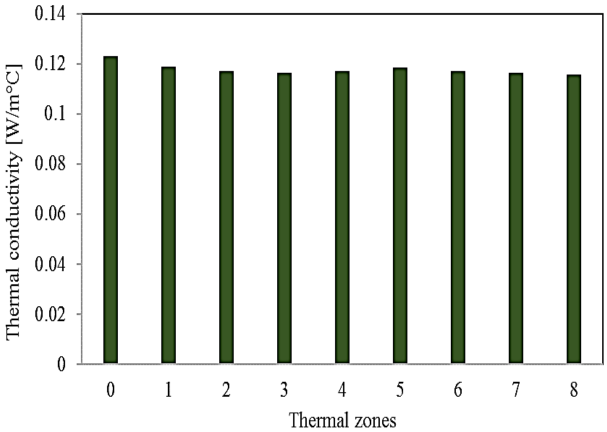
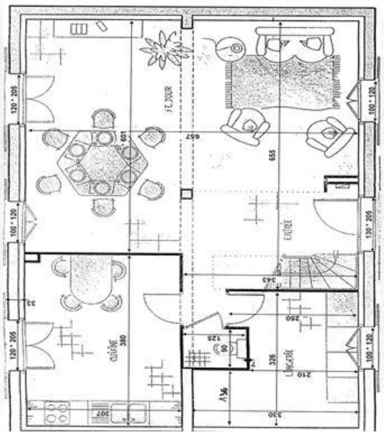


Fig. 7. Local measured thermal conductivity of the T1 sample for 10 W Heat flux, $T_{coolant}$=5°C

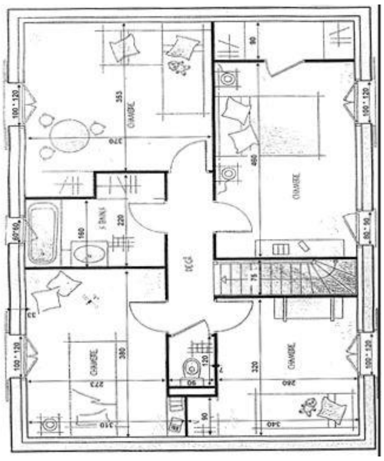
4.3 Thermal performance of cob-building walls

Thermal performance of cob-building is evaluated using building heat losses simulation program. This program is strictly compliant to EN 12831 and NF P52612 standards for buildings heat losses calculation. It incorporates the calculation elements imposed by French RT 2012 which represents French energy efficiency standard.
The RT 2012 indeed requires residential buildings to have a primary energy consumption lower than 50 kWh/m²/year against 150 kWh/m²/year under the regulations RT 2005.

In this paper, a single residential house with two floors is simulated and studied within different climatic zones including France and UK. The house consists of: 4 bedrooms, one living room, kitchen, bathroom and 2 WC. The study focuses only on wall heat losses since their structure will variate between bio-based materials and conventional construction materials. Figures 8a and 8b represent the house plan for the ground and the first floor**.** In this study, walls heat losses are investigated for two different construction materials. The first incorporates the conventional building materials: Parget (13mm), Rockwool (150 mm) for insulation, concrete for construction (200mm) and Bauding (15 mm). While the second embodies the bio-based materials (cob) for insulation T1 (λ=0.1 W/m°C) and construction S3 (λ=0.494 W/m°C). The walls composition for the two cases are represented in Figures 9a and 9b.

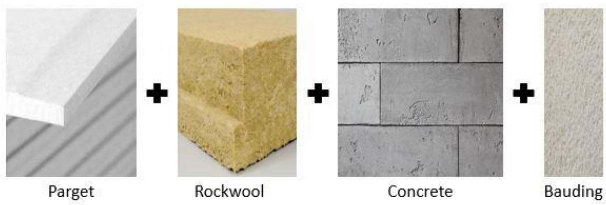


(a)



(b)

Fig. 8. House plan for: (a) the ground floor, (b) the first floor.



(a)

(b)

Fig. 9. Walls composition for: (a) conventional building, (b) cob building.

Yet, determining wall thickness while using cob is very important due to its significant influence on the thermal resistance rather overall heat transfer coefficient. This coefficient which is inversely proportional to thermal resistance characterizes the heat transfer through walls and should be low to reduce heat losses through buildings. Figure 10 shows the effect of variation of insulation thickness on the overall heat transfer coefficient for different values of wall construction thickness.

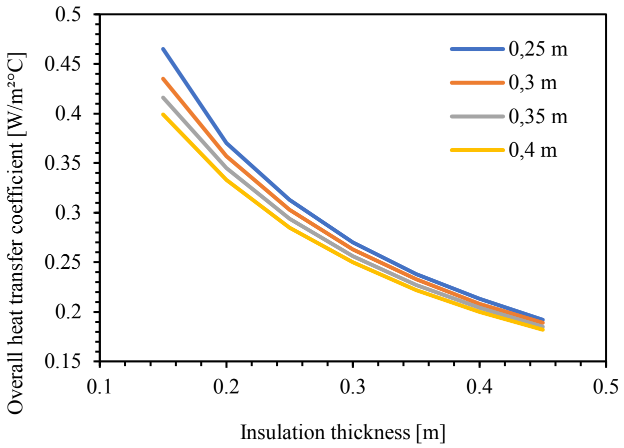


Fig. 10. Overall heat transfer coefficient variation within insulation thickness variation.

According to the French thermal regulation RT2012, external wall's thermal resistance should be between 3 and 9 m²K/W. Therefore, in this study insulation thickness was determined into 350 mm and construction thickness for about 300 mm which mainly respects the RT 2012. Heat losses through the house walls are calculated using Caen climate data and reference temperature called outside base temperature $T_{ref\text{-}Caen}$= -7°C . This temperature (according to the French standard NF EN 12831 that defines the table of basic outdoor temperatures within different parameters: proximity to the sea, altitude, climate, etc.) represents the lowest temperature found in each department for at least 5 days in the year. These very low temperatures are often reached during the night. Heat losses are calculated for two cases with insulation and without insulation for conventional and cob building figure 11.

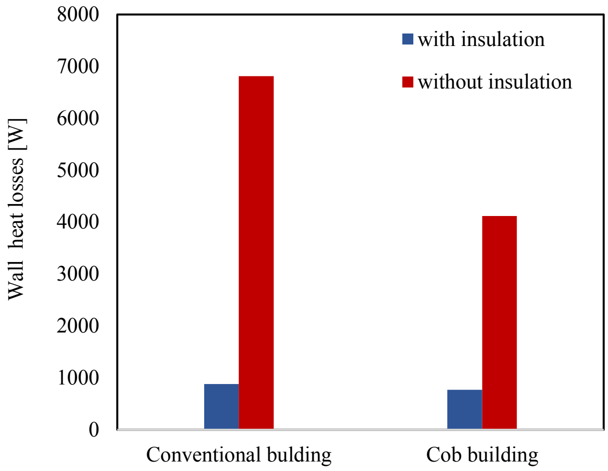


Fig. 11. Wall heat losses for conventional and cob building.

For both cases heat losses are greater in conventional building. The calculated wall heat losses reach 6815 W without insulation using conventional construction materials and 4116 W using cob. Yet, with insulation, the thermal losses are nearly close which means that cob could be a good natural alternative for industrial construction materials.

Regarding the influence of climate characterization on the thermal performance of buildings, heat losses in the studied house are investigated for the three climatic zones in France and London. Figure 12 represents the localization of these zones on the France map. Figure 13 shows that using cob reduces heat losses through the house walls within different climates including the toughest conditions.

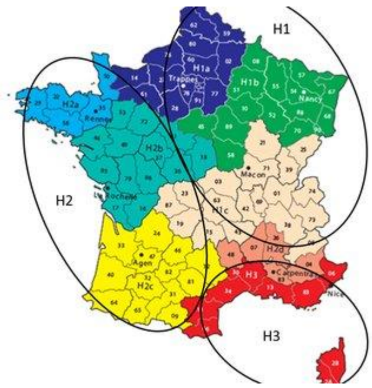


Fig. 12. French climatic zones. [11]

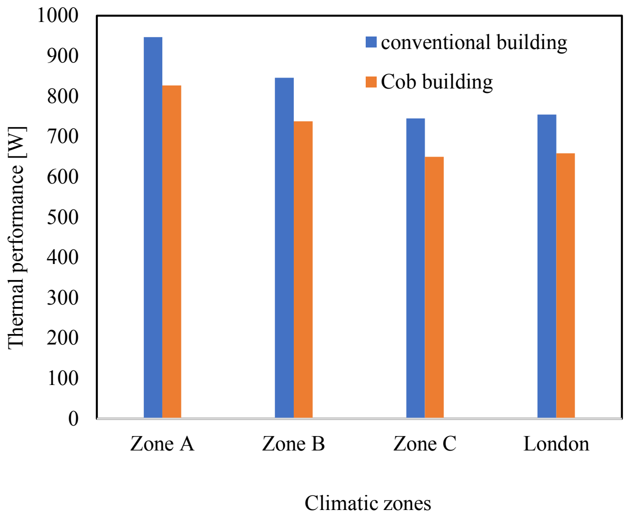


Fig. 13. Building thermal performance for different climatic zones.

5 Conclusion

Due to the growing need to reduce energy consumption in building and construction field, natural alternatives are investigated regarding energy efficiency optimization and reducing heating costs. In this paper, cob samples thermal properties are investigated including local thermal conductivity and heat transfer. A comparative study on a two floor simulated house considering climate conditions is carried out in two cases for conventional and cob buildings. Walls heat losses are calculated for the two cases compared and analysed. The results show that cob could be an efficient alternative for conventional construction materials thanks to its thermal properties and low construction and demolition costs besides being eco-friendly.

6 Acknowledgement

This work is conducted under CobBauge project selected by the European cross-border cooperation program INTEREG V France (Manche)-England. The authors would like to thank ERDF for the funding of this work.

7 References

[1] Asafu-Adjaye, *«The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries,» Energy Econ.,* vol. **22**, pp. 615-625 (2000).

[2] SAIDUR, Rahman, MASJUKI, Haji Hassan, et JAMALUDDIN, M. Y. An application of energy and exergy analysis in residential sector of Malaysia. Energy policy, vol. **35**, no 2, p. 1050-1063 (2007).

[3] PAINULY, Jyoti P., PARK, He, LEE, M.-K., *et al.* Promoting energy efficiency financing and ESCOs in developing countries: mechanisms and barriers. Journal of Cleaner Production, 2003, vol. **11**, no 6, p. 659-665 (2003).

[4] MOREL, J. C., MESBAH, A., OGGERO, M., *et al.* Building houses with local materials: means to drastically reduce the environmental impact of construction. Building and Environment, vol. **36**, no 10, p. 1119-1126 (2001).

[5] H. Niroumad, M. Zain et M. Jamil, «Various Types of Earth Buildings,» chez *2nd Cyprus International Conference on Educational Research* (2013).

[6] G. Minke, *Building with Earth Design and Technology of a Sustainable Architecture*, Basel · Berlin · Boston: Birkhäuser (2006).

[7] T. et M.L.P, «Evaluating rammed earth walls: a case study,» Solar Energy, vol. **76**, pp. 79-84 (2004).

[8] L. Soudani et a. , «Assessment of the validity of some common assumptions In hygrothermal modeling of earth based materials,» *Energy and Buildings,* vol. **116**, pp. 498-511 (2016).

[9] A. Mansour, «Optimizing thermal and mechanical performance of compressed earth blocks (CEB),» *Construction and Building Materials,* vol. **104**, pp. 44-51 (2016).

[10] M. Kutarna, K. Li et N. Radebe, «An Investigation Into the Use of Cob and/or Straw Bale Construction in Nonresidential Buildings,» vol. **262** (2013).

[11] Available online: econologie.com, consulted on 21/11/2018