Chapter 15
Thermal Conductivity Characterization of Industrial Small-Sized Building Materials: Experimental and Simulation Study

Mouatassim Charai , **Haitham Sghiouri, Ahmed Mezrhab, and Mustapha Karkri**

Abstract A new experimental procedure for determining the thermal conductivity of small-sized building materials using the boxes method setup is described. The proposed approach does not require additional sensors. Indeed, the measurement is based on the permutation of sensors and then the interpretation of the steady-state heat balance of samples. For the characterization, local earthen blocks from eastern Morocco were developed. The measured thermal conductivity values were compared with those obtained by an accurate transient hot disk method. The comparison shows a good agreement and verifies the performance of the permutation approach. To evaluate the thermal performance of the developed building materials, annual simulations were performed for a typical earthen building located in two different climates in Morocco. In this paper, hot and cold semi-arid climates were chosen to study the impact of the characterized earthen walls on the annual energy consumption of the case study building. The results show that the earthen wall reduces the annual cooling loads by 21.2% and 18.1% for hot and cold semi-arid climates compared to the reference case, respectively. In addition, the studied earthen walls show a reduction in the maximum cooling peak load of up to 20% compared to the conventional walls. However, a slight difference in heating loads for buildings located in cold semi-arid climates was observed. The experimental tests demonstrated the performance of the proposed methodology, which could be used for laboratory testing and for updating building material databases. While the building performance analysis clearly proved that earth walls can play a great role in mitigating the cooling demand and improving the thermal comfort of buildings in summer.

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1   Introduction

Material selection in the building sector has become a more demanding criterion with
regard to climate change and the energy consumption of buildings, which accounts
for the largest percentage part of their overall life-cycle impact [1, 2]. In this context,
and besides passive design measures, several codes and standards have recently been
enforced to fulfil the need for low energy-intensity buildings and to strengthen the
transition to sustainable constructions. Examples of such building standards and
normative strategies to cope with the alarming global building energy situation are
given in [3].

Building thermal regulations are one of the most energy-related standards practi-
cally used to improve the energy efficiency of buildings. These kinds of approaches
interest in the thermal performance of materials constructing the external building
envelope in order to design thermally compliant compositions. Taking as an example
the Moroccan thermal regulation program for buildings, developed in 2014 by the
Moroccan Agency for Energy Efficiency, the objective is to reduce by at least 39% the
annual energy needs of new buildings through specifying a minimum performance
threshold based on a thermal resistance estimation, which can be deducted directly
from the thermal conductivity of used materials [4].

Therefore, the characterization of the thermal conductivity of materials is of crit-
ical concern in evaluating the thermal performance of buildings. There are many
techniques available to measure the thermal conductivity of building components,
which can be divided into two main categories: steady-state and transient methods.
The first category determines directly the thermal conductivity of samples via the
analytical resolution of Fourier's law, such as the Guarded Hot Plate (GHP) method
by ISO 8302 [5] or EN 12,667 [6], while the second category of methods estimates
the thermal conductivity property using relatively complex numerical models, such
as the Hot Disk method by ISO 22,007–2 [7]. The transient methods provide rapid
measurements based on the thermal time-dependent response of studied samples.
Nevertheless, steady-state methods give much more accurate results than transient
techniques due to the well-established theoretical model, and thus the measurement
errors depend only on the experimental setup used. For this reason, several labo-
ratories are investing in the development of new steady-state apparatuses to cover
a wide range of building material samples. For instance, Buratti et al. [8], from
the Laboratory of Building Physics at the University of Perugia, have designed a
small box method apparatus with the aim of evaluating the thermal transmittance
of small, homogenous and non-homogenous building components (masonry units,
doors, windows and thermal bridges).

Indeed, the motive behind adapting large-scale experimental devices for small
samples is to achieve successful identification even if there is a lack of raw materials

and to avoid transport problems. Among methods of relatively large-scale samples is the boxes method [9], which requires samples with dimensions of 270×270 mm^2 and a thickness range from 30 to 70 mm.

In this respect, this paper focuses on the adaptation of the boxes method for small samples in order to improve the boxes method's flexibility to cover samples of various sizes and forms. The objective of the proposed experimental methodology is to characterize small-sized building material specimens without using any additional sensor. A local building material from eastern Morocco was prepared and characterized using two methods: the proposed method and the transient hot disk method that represents, in this paper, the reference method for validation purposes. The test results were used as input data to run building energy simulations using Energy Plus software to evaluate the energy performance of the building material studied at the scale of a residential building.

2   Materials and Methods

2.1   Measurement Device: Boxes Method Cell

Figure 1 shows the experimental device used in this work. It is the EI702 cell, which represents the latest version of the boxes method apparatus that has been adopted in many research studies for the thermophysical characterization of building materials. A brief review of these studies is recently given by the authors in [10].

The EI702 cell is an all-in-one measurement device, which composed of two insulated boxes for determining the apparent thermal conductivity of materials as well as their thermal diffusivity property using two different techniques. The first box serves for the thermal conductivity measurement of samples through maintaining a steady-state unidirectional temperature gradient across the sample studied. While the second box is equipped with an incandescent lamp to allow the thermal diffusivity
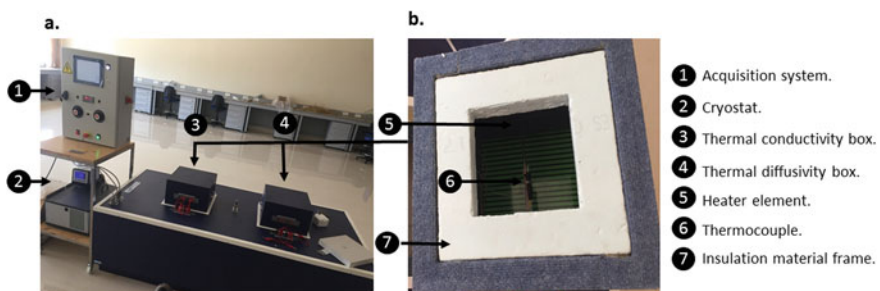

Fig. 1 EI702 cell setup: **a** overall view, **b** interior view of boxes

characterization of samples via the well-known heat-pulse flash method [2]. For the thermal conductivity measurements, the instrument's uncertainty is less than 6%.

As shown in Fig. 1, the measurement apparatus consists of the following elements:

(1) An Acquisition system: it permits the users to fix the experimental inputs using an interactive touch-screen and allows them to display and record real-time temperature variations during the experiment.
(2) A Cryostat: it is used to maintain a constant low-temperature environment of the underside of the cell through a close-cycle system.
(3) A Thermal conductivity box: this box serves for the thermal conductivity measurement of the studied sample.
(4) A Thermal diffusivity box: this box serves for the thermal diffusivity measurement of the studied sample.
(5) A Heater element: it is the electrical heat source of the system to heat the upper side of studied samples during the thermal conductivity measurement.
(6) Probes: each box consists of two thermocouples type-K to measure the temperature variation on the upper and lower sides of the sample under study.

As above-mentioned, the boxes method requires samples with significant sizes. Therefore, in this paper, and in order to characterize small specimens, an insulation material frame will be used as a sample holder to cover the entire surface of the thermal conductivity box, as shown in Fig. 1b.

The mathematical model is described in the following section.

2.2 Theoretical Model

As indicated in the title, the paper focuses on the thermal conductivity box to examine a new experimental methodology for measuring the thermal conductivity of small samples without using any additional sensor. The sketch of the thermal conductivity box for a small-sized sample case is presented in Fig. 2a. Unlike conventional samples with a surface area of 270×270 mm^2 that cover the entire box, small samples are
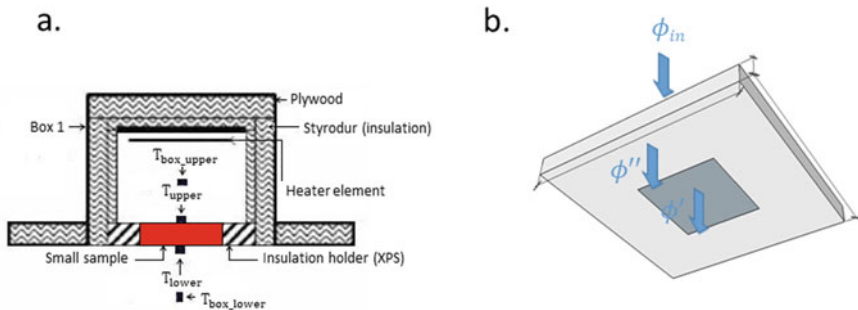

Fig. 2 Methodology illustration: **a** setup sketch, **b** sample heat balance

placed in the center of a frame made of insulation material (Fig. 2b), which serves as a holder sample to cover the box and separate the cold and hot environments. The upper side of the box represents the hot environment, which is equipped with an electrical heater element for heating the upper face of the sample with a uniform heat flow. On the other side of the sample, the ambiance is maintained at constant low temperature using a closed-cycle cryostat to ensure a steady unidirectional temperature gradient across the sample.

In general, when the steady-state is achieved, the relevant heat balance in the thermal conductivity box is expressed as follows:

$$\phi_{in} = \phi_{system} + \phi_{loss} = \frac{U^2}{R} \tag{1}$$

where ϕ_{in} is the heat flow generated by the heater element, U and R are the injected voltage and the heater element resistance, respectively, ϕ_{system} is the heat flow crossing the studied system (i.e. large sample or small sample with sample holder) and ϕ_{loss} is the heat loss through the box caused by the temperature difference between the upper side of the box T_{box_upper} and the room temperature T_{room}, which is described by the relationship:

$$\phi_{loss} = C(T_{box\_upper} - T_{room}) = C\Delta T_{loss} \tag{2}$$

Here, C is the heat loss coefficient of the box. This constant property is calculated theoretically according to the Carslaw and Jaeger formula [11] or experimentally by performing two thermal conductivity experiments on a well-known thermal conductivity material.

For the heat flow across the system, two main cases are to be considered according to the sample dimension: large samples and small samples with an insulation material frame. Therefore, the heat flow of the whole system can be expressed as follows:

$$\phi_{system} = \begin{cases} \phi_{sample} & \text{large sample} \\ \phi_{sample} + \phi_{frame} & \text{small sample} \end{cases} \tag{3}$$

where $\phi_{sample}, \phi_{frame}$ are the heat flow through the sample the insulation frame, respectively.

According to Fourier's law of heat conduction, it is well known that:

$$\phi_{sample} = \frac{\lambda S_s}{e_s}(T_{s\_upper} - T_{s\_lower}) = \frac{\lambda S_s}{e_s}\Delta T_s \tag{4}$$

$$\phi_{frame} = \frac{\lambda_f S_f}{e_f}(T_{f\_upper} - T_{f\_lower}) = \frac{\lambda_f S_f}{e_f}\Delta T_f \tag{5}$$

where λ is thermal conductivity of the sample, λ_f is the thermal conductivity of the insulation material frame, e, S, T_{upper}, T_{lower} are the thickness, surface, temperature of the upper and the lower sides of both solids, respectively.

Equations (2–5) may be substituted to Eq. (1) to express the thermal conductivity of studied samples as:

$$\lambda = \begin{cases} \frac{e_s}{S_s \Delta T_s}\left(\frac{U^2}{R} - C.\Delta T_{loss}\right) & \text{Large sample } .a \\ \frac{e_s}{S_s \Delta T_s}\left(\frac{U^2}{R} - \left(\frac{S_f \Delta T_f}{e_f} + C.\Delta T_{loss}\right)\right) & \text{Small sample } .b \end{cases} \qquad (6)$$

Equation 6 is the main formula for measuring the thermal conductivity using the boxes method. Unlike large samples, where the characterization is done by recording only the temperature variation of the upper and the lower faces of the sample, the characterization of small samples requires the addition of two thermocouples to monitor the temperature difference across the insulation material frame ΔT_f, and thus to evaluate the heat fraction dissipated by the frame.

In order to not use additional sensors and increase the flexibility of the boxes method, this paper characterized the thermal conductivity property of small-sized building material using a new, easy-to-use methodology presented in the following section.

2.3 Experimental Procedure

As indicated in the title, the paper focuses on the thermal conductivity box to examine a new experimental methodology for measuring the thermal conductivity of small samples without using any additional sensor.

In general, the thermal conductivity of large samples is characterized on the basis of Eq. 6a. The samples are placed in the thermal conductivity box and subjected to two different environments (cold and hot). The upper side of the sample is heated by the electrical heater element, while the upper side is kept at a constant low temperature via a controlled closed-cycle cryostat. In addition, the thermal conductivity chamber consists of four thermocouples, which are placed as illustrated in Fig. 2a. the thermocouples are used to monitor the temperatures required by the equation until reaching constant temperature signals. Two thermocouples are placed on either side of the sample to measure the temperature difference between the sample ΔT_s and the other two probes are placed on the upper and the lower side of the chamber. Another thermocouple is placed outside the chamber to measure the ambient temperature so that the fraction of heat loss can be deduced using the term $C.\Delta T_{loss}$. Finally, the thermal conductivity of large samples is simply calculated when equilibrium is reached.

On the other hand, the thermal conductivity of small samples can be characterized using Eq. 6b. As can be seen, the monitoring of the temperature of the upper and the lower faces of the sample holder is indispensable for the characterization. For this

reason, some researchers added two supplementary sensors to take into account the heterogeneity of studied samples, as discussed in [12, 13]. Other researchers proposed to introduce a correction term to calculate the thermal conductivity of small samples [14]. However, the above-mentioned approaches have two main disadvantages. First, the addition of two sensors that increase the cost, calibration time, and experimental errors. Second, the correction term should be recalculated for each experiment when the insulation material or the sample dimensions are changed, which led to lengthen the duration of the experiment.

In this paper, the thermal conductivity of small samples was characterized using a switching approach. The proposed methodology consists of three steps:

- Step 1: placing thermocouples on the upper/lower sides of the sample until thermal equilibrium is reached.
- Step 2: Switching thermocouples from the sample to the insulation material frame.
- Step 3: recording the upper/lower temperature changes in the insulation material frame.

The permutation of sensors is performed after the observation of constant temperature signals of the upper/lower faces of the small sample studied. The thermal conductivity box should be made as quickly as possible to prevent any disturbance of the permanent regime of the EI702 cell. Then, the box is returned to its place to monitor the missing temperature difference of the upper/lower faces of the insulation frame. The thermal conductivity thus is calculated using Eq. 6b.

It should be noted that the EI702 cell is equipped with a real-time touch screen interface for the calibration of the thermocouples used. For more details on the calibration process, please refer to [10]. For validation purposes, the measured thermal conductivity values were compared to those obtained by the Hot Disk (TPS 2200) method. This method is based on a transient plan source technique that allows fast and accurate measurements according to ISO 22,007–2 [7]. The characterization requires two identical specimens (Fig. 3b). The TPS sensor is sandwiched between the samples to electrically heat them with constant electrical power. At the same time, it also monitors its temperature time-dependent response. Then, the thermal response is interpreted with a Thermal Constants Analyzer (TCA) to identify the thermal conductivity of studied samples using a parameter identification algorithm [15].

2.4   Used Material

In this work, a local earthen block from eastern Morocco was characterized. The samples were prepared in such a way as to have homogenous mixtures. For this purpose, the fine soil particles (<2 mm) were separated using a 2 mm sieve opening, as shown in Fig. 3.a. Furthermore, the particle size analysis showed that the soil used is a clayey soil with a clay fraction of 59%. The earthen blocks were prepared by hand mixing soil at constant water-to-clay ratio of 0.5. The mixture was then molded
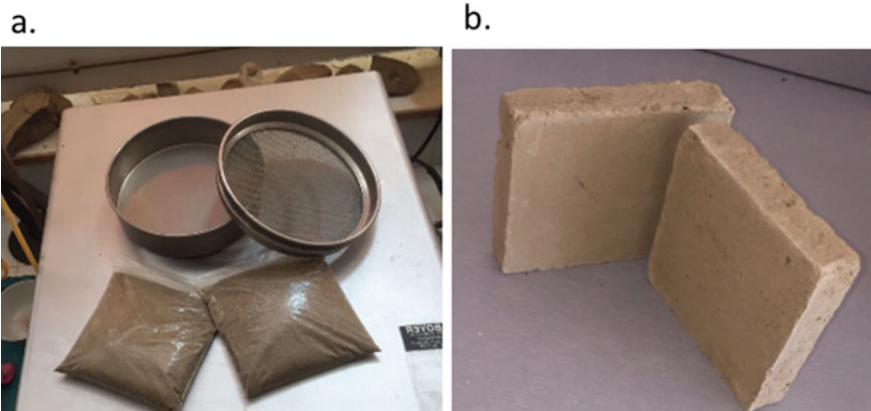
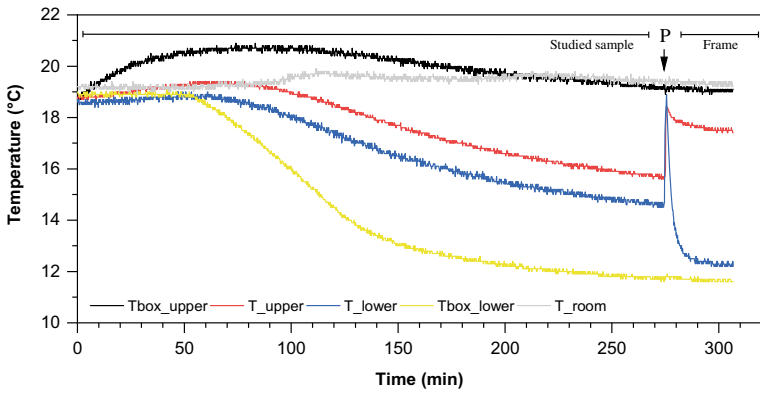**Fig. 3** Used soil: **a** sieving process, **b** final earthen blocks

Fig. 4 Earth block thermogram

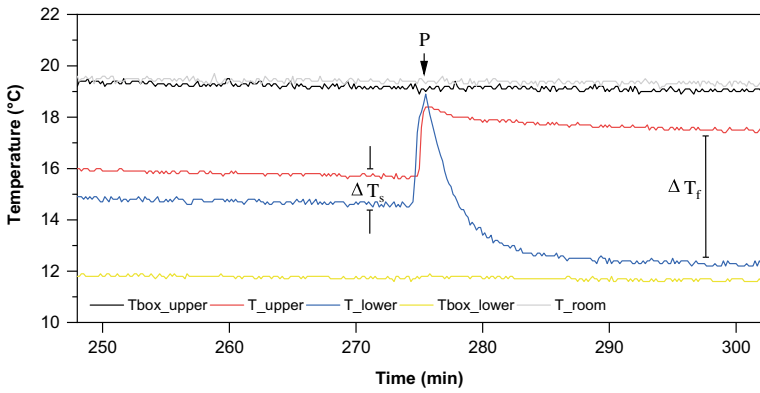**Fig. 5** Steady-state thermogram

and manually pressed into a square shape 15 cm × 15 cm. The samples were dried at room temperature for one month before the characterization.

3 Results and Discussion

3.1 Thermal Conductivity Measurement

Prior to the thermal conductivity measurements, all used temperature-sensing probes were calibrated using a touch-screen interface. It should be noted that this latest version of the boxes method (EI702 cell) is equipped with a real-time touch-screen interface for the calibration of used thermocouples. For more details about the EI702 calibration process, please refer to [10].

Three tests were conducted under the experimental conditions listed in Table 1.

Figure 4 shows a typical thermogram of the small sample studied using the proposed methodology. Once the steady-state of the small sample is established, the thermocouples on the cold and hot faces of the sample were quickly replaced on the insulation material frame. The permutation is clearly indicated by the appearance of the peaks seen in Fig. 4. The experience is left for a few minutes (approximately 30 min) to record the evolution of temperatures measured by different sensors for each face of the frame. This permutation step allows the evaluation of the heat dissipated by the frame and then deduced the thermal conductivity property of the small sample from Eq. 6a.

To be practical, the steady-state thermogram of the small sample was drawn in Fig. 5. It can be seen that the permutation peaks separate the constant signals of the small sample and the material frame from each other. As can be seen, the temperature difference between the thermal conductivity box and the room must be very small to limit losses and must be constant after the permutation to ensure the steady-state regime of the box. Finally, the thermal conductivity property of the small sample is directly deduced from the steady-state thermogram based on Eq. 6a.

The average measured value of the thermal conductivity is presented in Table 1. This value is compared to the results obtained by the reference (hot disk) method.

Table 1 Experimental conditions

Device	Loss coefficient (W/K)	Cryostat set point (C)	Voltage (V)	Resistance (Ω)
EI702	0.96	10	35	1800

Table 2 Measured thermal conductivity of studied material (W/mK)

Property	Proposed methodology	Hot disk method
Thermal conductivity	0.819 ± 0.004	0.807 ± 0.002

Results show a good agreement. The present approach was also tested to characterize different building materials (cement, plaster and XPS) with small dimensions. The finding results show the effectiveness of the proposed methodology (deviation lower than 3%).

The thermal conductivity is of great interest in building applications. In fact, knowledge of thermal conductivity of building materials permits the estimation of the annual energy consumption of buildings, with which the thermal performance of the building material is evaluated. In what follows, the potential use of the prepared local earthen blocks for residential buildings was discussed in order to promote the earthen construction in eastern Morocco.

3.2   Simulation: Case Study Building

Earthen construction is one of the great ecological alternatives to build low-environmental impact houses and to reduce the total carbon footprint of buildings. In this study, and for evaluating local earthen constructions in Morocco, a single-story building (Fig. 6) defined in [16] is used to present a typical residential building in Morocco. As shown in Fig. 7, the house is a one-floor building with a total area of 40 m^2. The ground floor contains two bedrooms and a living area. The building simulation was carried out under two different climatic conditions of Morocco (Oujda and Marrakech) using the EnergyPlus program, version 9.0 [17]. Here, Oujda city represents the cold semi-arid climate, while Marrakech represents the hot semi-arid climate. The climatic information of Oujda and Marrakech are listed in [18].

Table 3 lists the thermal properties of the external walls. The thermal properties of the other building envelope elements are summarized in Table 4. The thermal transport properties of the building components were chosen based on the Moroccan building database [19]. Two variances of the external building envelope were considered to evaluate the thermal performance of earth walls compared to conventional building materials, as shown in Table 3. The first variance represents the case study

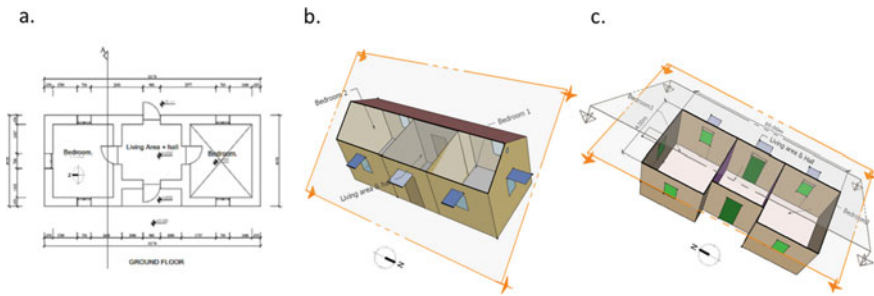**Fig. 6** Case study building [16]

Fig. 7 Case study model: **a** 2D [16], **b-c** our sketch

Table 3 Thermophysimcal characteristics of external walls

	Thickness (cm)	λ (W/mK)	ρ (Kg/m^3)	Cp (J/KgK)	R (m^{2}K/W)
Earth wall: Earthen blocks 45 cm + earthen coating (U = 1.32 W/m^{2}K)					
Earthen coating [a]	2	1.5	1500	2000	– -
Earthen block [b]	45	0.8	– -	– -	0.56
Earthen coating [a]	2	1.5	1500	2000	– -
Conventional wall: Concrete blocks 20 cm + cement coating (U = 1.64 W/m^{2}K)					
Cement coating [a]	2	1	1700	1000	– -
Concrete block [c]	20	0.925	2100	920	– -
Cement coating [a]	2	1	1700	1000	– -

[a]Binayate database [19]; [b] Our work; [c] ASHRAE Handbook-Fundamentals [20]

Table 4 Material properties of the building elements

Element	Composition	Thickness (cm)	λ (W/mK)	ρ (Kg/m^3)	Cp (J/KgK)	U-value (W/m^{2}K)
Roof	Wooden stand/Clay tiles [a]	10	1	2000	800	– -
Floor	Soil [a]	30	1.5	1500	2000	– -
Doors	25 mm heavy wood [a]	2.5	0.29	1035	1600	– -
Windows	Simple glazing with wooden frame (SHGC [b] = 0.86)	0.6	0.9	– -	– -	4.07 [a]

[a]Binayate database [19]; [b] National Renewable Energy Laboratory [21]

building built with the prepared earthen blocks, while the second variance represents the reference case where external earthen walls are replaced by concrete blocks. As the thermal heat capacity of the studied earthen blocks is unknown, the earthen walls were defined by their thermal resistance using the no-mass material feature in EnergyPlus software. Indeed, the thermal resistance of a wall with a total thickness e and a thermal conductivity λ is given by the expression:

$$R_{th} = \frac{e}{\lambda} \qquad (7)$$

The case study building is assumed to be occupied by three persons in accordance. With the annual occupancy schedule illustrated in Fig. 8a, and electrically lighted according to the lighting schedule shown in Fig. 8b. Lighting and electrical home appliance power densities were defined equal to 3 and 4 W/m^2, respectively. The building is naturally ventilated through openings and the passive night ventilation is considered during summer period, as indicated in Fig. 8c. The HVAC system was set to operate continuously at 20 °C for heating and 26 °C for cooling, according to the Moroccan thermal regulation code [4]. The input simulation data are listed in Table 5.

Table 5 Simulation parameters

Input	Value	Schedule
Heating Thermostat [a]	20 °C	ON if $T_{in} < 20$ °C
Cooling Thermostat [a]	26 °C	ON if $T_{in} > 26$ °C
Number of people	3 persons	Occupancy schedule (Fig. a)
Activity level [b]	70 W/m^2 (Standing/Relax)	Occupancy schedule (Fig. a)
Home appliance	4 W/m^2	Occupancy schedule (Fig. a)
Lighting	3 W/m^2	Lighting schedule (Fig. b)
Infiltration	0.5 ACH	Ventilation schedule including infiltration (Fig. c)

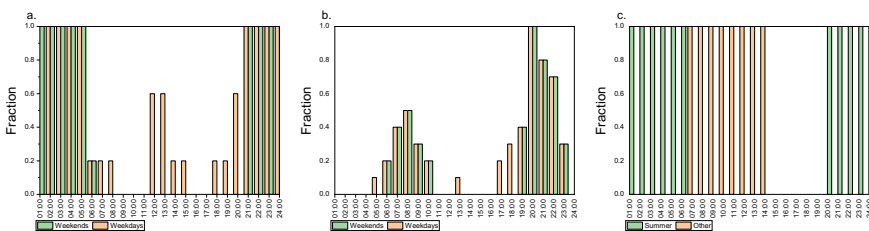[a]Moroccan thermal regulation code [4]; [b] DOE Energy Plus [22]

Fig. 8 Schedules: **a** occupancy, **b** artificial lighting, **c** ventilation

3.3 Simulation Outputs

Figure 9 shows the annual energy needs for the earthen walls and the reference case for Oujda and Marrakech. One can note that for both locations, the earthen walls are effective in reducing the total energy needs of residential buildings compared to conventional walls. Simulation results for these two locations show that the use of earthen walls has led to a reduction in heating and cooling needs, with a rate of 10.7% and 12.5% compared to the reference case for Oujda and Marrakech, respectively. These results demonstrate the potential use of earthen walls in semi-arid climate for reducing the annual needs of buildings.

To separately evaluate the impact of earthen walls on passive cooling and heating of the case study building, a monthly quantitative study of the heating and cooling loads were carried out. Figure 10 shows the monthly cooling needs of the case study building for Oujda and Marrakech. Cooling demand is predominating for Marrakech city with a peak monthly cooling demand of nearly 28.7 kWh/m^2 in July and a total yearly cooling demand of 96.9 kWh/m^2. However, the results show that the replacement of the reference case walls with the studied earthen walls has led to a significant reduction of about 23.4% of the maximum cooling peak and 21.2% of the total cooling needs compared to the reference case. In addition, the total cooling demand in Oujda was reduced from 59.4 to 48.6 kWh/m2. This amounted to a total reduction of about 18.1%. Furthermore, the use of earthen walls passively decreased the maximum cooling peak in July from 20.2 to 16 kWh/m^2, resulting in a reduction of about 20.6% compared to the reference case.

In terms of heating loads, Fig. 11 shows the profile of monthly needs for studied walls under Oujda and Marrakech climates. The finding results show that the use of
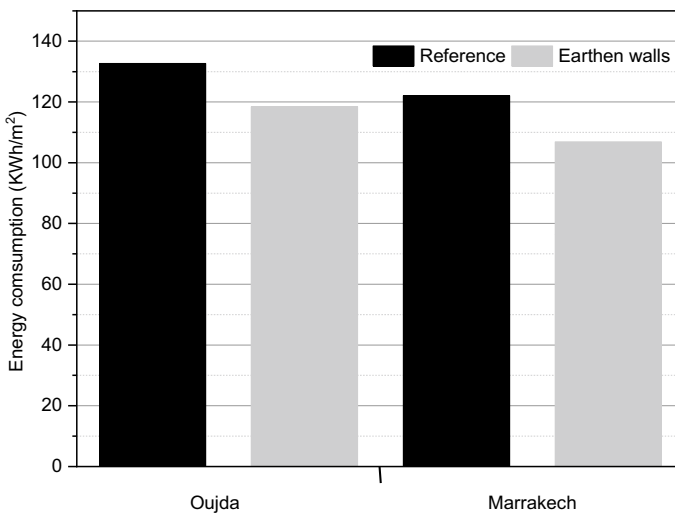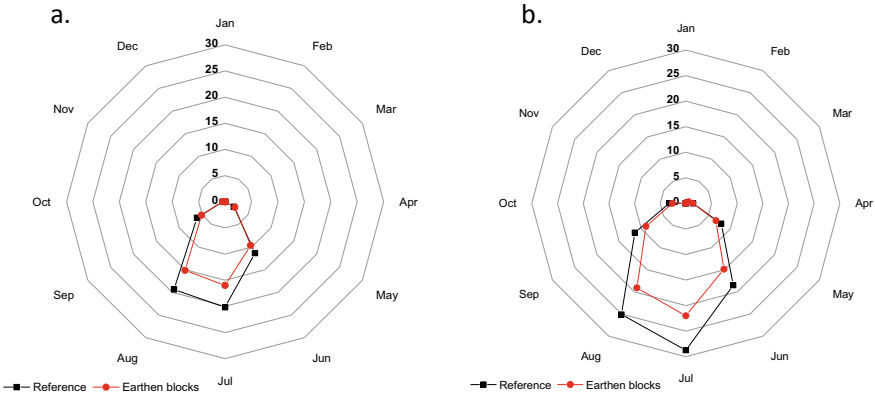

Fig. 9 Annual heat loads

Fig. 10 Monthly cooling needs, **a** Oujda, **b** Marrakech
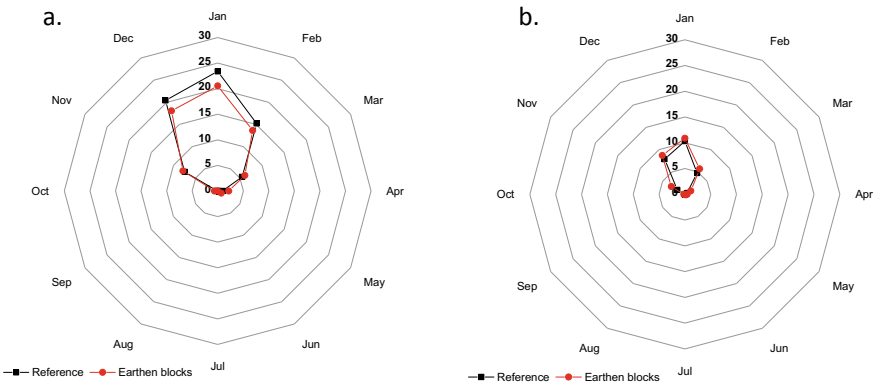

Fig. 11 Monthly heating needs: **a** Oujda, **b** Marrakech

earthen walls has a slight impact on the energy demand for heating as it reduced it by 4.7% in cold semi-arid climate compared to the reference case, while it does not change much for buildings located in hot semi-arid climate.

All these findings demonstrate the importance of earthen walls in passive cooling and reducing the annual energy needs of buildings in semi-arid climates, which is explained by the high thermal inertia of earthen building envelopes.

3.4 Discussion

The findings of the present work highlight the performance of a new easy-to-use methodology to measure the thermal conductivity of small building material samples

using the boxes method, which is an industrial method commonly used for the characterization of samples with significant sizes. Also, in this work, local clay-based building material was developed and characterized. The experimental tests show that the thermal conductivity of studied earthen blocks is 0.819 W/mK. This thermal conductivity value was verified using the hot disk method.

Indeed, this new methodology could be used for measuring the thermal conductivity of industrial building materials of different sizes (large and small) and forms (solid, hollow, cubic or cylinder, etc.) without using additional sensors as discussed by Lachheb et al. [13], they characterized small building material composites using the boxes method. However, to take into account the whole system including the material frame, they used two additional sensors to measure the thermal conductivity of spent coffee plaster-based composites.

Concerning the experimental duration, the boxes method is a steady-state method that requires approximately 3 h to characterize conventional samples. For small samples and based on the proposed approach, the experimental duration increases by 30 min after the sensors' permutation in order to evaluate the steady-state temperature gradient across the insulating material frame.

In terms of performance, the studied earthen blocks show a good thermal resistance 1.32 m^2/W compared to concrete blocks 1.64 m^2/W, which can lead to a significant reduction in energy consumption of buildings. Simulation results indicate that earth walls significantly influence the energy consumption profile of buildings located in semi-arid climates and play an important role in passive cooling, highlighting the effectiveness of earth walls for improving the summer thermal comfort of buildings.

4   Conclusion and Perspective

This paper presents an experimental methodology to measure the thermal conductivity of building materials with different sizes via the boxes method set up in order to increase its flexibility in the laboratory testing. A local clay-based building material with small dimensions was prepared and characterized using the proposed methodology. The experimental tests show that the thermal conductivity of studied samples was 0.819 W/mK. The thermal conductivity characterization was also carried out using the hot disk method. It was found that the measured thermal conductivity values obtained by both methods show quite similar results (deviation smaller than 3%), highlighting the performance of the proposed methodology. By using this experimental approach, the boxes method could determine the thermal conductivity of specimens of different sizes (small and large) and forms (cubic, cylinder, etc.).

For performance analysis, numerical simulations were performed to study the impact of the prepared earthen block on the thermal performance of residential buildings in Morocco using Energy Plus software. The case study building was chosen to be located in two different semi-arid climates (hot and cold), represented respectively by the cities of Marrakech and Oujda. The simulation results show that the earthen

wall reduces the annual cooling loads by 21.2% and 18.1% for hot and cold semi-arid climates compared to the reference case, respectively. In addition, the earthen walls studied show a reduction in the maximum cooling peak load of up to 20% compared to the conventional walls. However, a slight difference in heating loads for buildings located in cold semi-arid climates was observed. All these findings demonstrated the potential use of earth masonry for passive cooling and for constructing high-performant, low-environmental impact building envelopes in semi-arid climate.

The future work will be focused on the characterization of locally marketed and innovative building materials using the proposed methodology in order to develop local building material databases, which can be used in building retrofit and multi-objective studies.

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