Thermal Analysis Laboratory for Materials

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Abstract

I This article describes the operation of a thermal analysis laboratory for construction materials. It consists of commercial equipment and equipment created in-house, with machines designed, built, and commissioned to measure variables that allow the calculation of the thermal conductivity and resistance of homogeneous and non-homogeneous materials and construction systems. The overall objective of the work is to describe the existing equipment, its characteristics and operation, but mainly the self-designed machines that work with full-scale samples of walls measuring 1.20 m at the base and 2.00 m in height. This article presents the measurement method for all the equipment, selecting a construction material as an example, and the results section presents a collection of thermal conductivity and/or thermal resistance values for various materials, components, and construction systems such as mortars, mud brick walls, hollow concrete blocks, wood, drywall, and prefabricated insulating materials.

Keywords: Thermal conductivity, thermal resistance, apparatus, laboratory, thermal analysis.

Introduction

Building materials influence the thermal behavior of building envelopes (Castillo E. et al., 2019) because they provide an interface between the external and internal thermal environments of the inhabited space. It is very important to know these properties because the thermal design of interior spaces requires calculating certain steady-state or transient behaviors, as well as knowing the properties of materials, such as thermal conductivity and specific heat. To perform calculations of the thermal behavior of horizontal and vertical elements in construction, as well as in the simulation process, such as that carried out in (Rodríguez N. et al., 2018) for the thermal balance of a building. Normally, the values of these variables are obtained from a literature review, using average values that do not represent the actual data of the local materials being worked with; this leads to errors in the results. To know the specific values of these variables, measurements must be taken in controlled environments, which is not very common due to the scarcity of laboratories with adequate equipment and procedures.

References have been found, such as that of (Tasdemir C. et al., 2017), who conducted thermal conductivity tests on lightweight concrete materials, demonstrating the variation in this property. (Cabrera S. et al. 2023) worked on determining thermal conductivity in earth elements, finding better behavior than in concrete elements, using specialized measuring equipment.

(Carbajal R. et al., 2021) conducted a study on the manufacture and thermal characterization of three natural materials agglomerated with cassava starch. The fibers used are classified as agro-industrial waste. The materials were studied using a prototype thermal conductivity meter, based on the ASTM-C177-19 standard (ASTM International, 2019) and Fourier's law of heat transfer by conduction.

(Daza C. M. et al., 2019) conducted thermal conductivity tests with a device based on ASTM-C-177-19. A device was developed to measure the thermal conductivity in solid materials for thermal insulation commonly used in buildings, following a one-dimensional heat flow model.

To measure thermal conductivity, some prototypes have been developed, such as that of (Gutierrez U. et al., 2023), in accordance with ASTM E1225-04 (ASTM International, 2008) for solid materials. (Alvarado S. et al., 2011) performed measurements with an automated system for measuring the thermal conductivity of liquids using the hot wire method. (Punzoni L. et al., 2024) worked on the manufacture, analysis, and evaluation of the thermal conductivity of plates made from mycelium, using equipment they developed themselves. (Mena W. et al., 2015) developed an experimental prototype to determine the thermal conductivity of powdered materials from the Yucatan

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Peninsula, Mexico. (Zavala L. et al., 2023) developed and validated a device for determining the thermal conductivity of materials. (Ruiz R. et al., 2024) measured the thermal properties of conventional and non-conventional materials in housing, using a device of their own creation.

This paper describes the creation and implementation of a laboratory for the thermal analysis of building materials, as well as some results of measurements of prefabricated building materials and those made on site, using equipment purchased on the international market and, above all, equipment of their own creation that has been designed, built, and put into operation. The results of measurements of various building materials and construction systems for both homogeneous and non-homogeneous walls, such as partition walls, hollow concrete block walls, and prefabricated or natural fiber insulation materials, are presented and reported in this paper.

1.1. Background

The Thermal Analysis Laboratory is part of the Civil Engineering Experimental Laboratory at the University of Sonora, Mexico. It was created as part of a doctoral project in 2010, with the design of a model and prototype of a thermal property measurement system to determine the thermal conductivity and resistance of full-scale hollow concrete block walls. Based on this idea, work continued with research projects funded by the National Council for Science and Technology (CONACyT) and the National Housing Commission (CONAVI), in Mexico, between 2011 and 2017, which made it possible to finance the project and develop new prototypes, as well as acquire specialized thermal conductivity measurement equipment for validation.

Today, the laboratory provides services and advice to undergraduate and graduate students on student projects, support for subjects in the field, theses, and professional services to the local construction sector. It develops new prototypes and has one patent granted and another patent in process.

The laboratory has a work area of 100 m^2, with an area for the manufacture of samples of mixtures, components, and construction systems; a curing area; and an area for measuring mechanical properties such as compressive strength and thermal properties.

2. Methodology

2.1. Description of equipment

This laboratory is equipped with devices for measuring the thermal properties of materials. This section describes two devices purchased on the international market and three devices developed in-house.

The purchased equipment is: *EP-500c* thermal conductivity meter and *KD2-Pro* thermal conductivity meter and other properties such as specific heat and thermal resistivity.

The equipment created in-house are: *TR-00*, *TR-01*, and *TR-02*, which are manual and semi-automatic devices for measuring variables that allow the calculation of the thermal conductivity and resistance of homogeneous and non-homogeneous construction systems.

TR-00 is a manually operated device consisting of a removable test cabinet, where a full-scale wall measuring 1.20 m at the base and 2.00 m in height is placed and variables are measured to calculate the thermal resistance and/or thermal conductivity of the wall.

TR-01 is a semi-automatic device consisting of a test cabinet, where a full-scale wall measuring 1.20 m wide by 2.00 m high is placed and variables are measured to calculate the thermal resistance and/or thermal conductivity of the wall. This device has been granted a patent (Borbón, 2016).

TR-02 is a semi-automatic device consisting of a test cabinet for placing two 60cm x 60 cm walls that measures variables to calculate thermal conductivity and resistance.

3. Commercial equipment and its operation

3.1. *KD2-Pro* thermal conductivity meter

We have a portable device that measures thermal conductivity, thermal resistivity, thermal diffusivity, and specific heat called *KD2-Pro*, in accordance with the standards of the American Society for Testing and Materials (ASTM, E1225-04, 2008) and the Institute of Electrical and Electronics Engineers (IEEE-442-1981). It measures in ranges from 0.02 to 4 W/m°C for thermal conductivity and other ranges for resistivity, diffusivity, and specific heat, with an accuracy of ±5 to ±10% depending on the parameter. It has several sensors adapted for liquids and solids, such as a single needle sensor (conductivity and resistivity) and a dual needle sensor (conductivity, resistivity, specific heat, and diffusivity). It allows for field or laboratory measurement with configurable reading times (1, 2, 5, or 10 minutes depending on the measurement). It has storage for 4,095 readings in flash memory. It operates in a temperature range of -50°C to 150°C for the sensors. It runs on 4 AA batteries. It is a device with a 16-bit microcontroller and 24-bit A/D converter. LCD screen to display results. Includes accessories such as specialized sensors, carrying case, data download software, and utilities for calibration and pilot hole drilling. This equipment is designed to provide fast, accurate, and non-destructive measurements in various materials such as soils, liquids, nanofluids, insulators, and rocks, both in the laboratory and in the field, facilitating detailed thermal studies in short periods of time. (Decagon Devices Inc., 2019).

To measure solid materials with this equipment, they must be dry with no moisture content, can have any geometry, and be equal to or smaller than the length of the sensors and have an additional peripheral area for the measurement boundary.

Figure 1 shows some examples of specimens that have been measured, such as:

1a) Rock, 1b) Cellular concrete, and 1c) Concrete-based construction panels.

a) Measurement in rock **b) Measurement in cellular concrete** **c) Measurement on concrete panels.**

Figure 1: Measurement of materials with KD2-Pro equipment

3.1.1. Measurement procedure *KD2-Pro*

The measurement method for this equipment consists of drilling the sample with small-diameter drill bits similar to those of the sensors and inserting them. It has four types of needle sensors: *TR-1* (solids and granular materials), *RK-1* (rock or concrete), *SH-1* (concrete and other solids), and *KS-1* (insulating materials). The approximate measurement times are 5, 10, 2 minutes, and 60 seconds, respectively.

The size of the sample where the sensor is inserted for measurement depends on the thermal properties of the material being analyzed. In general, a radius of 2 cm around the needles is sufficient for samples with thermal conductivities of around 0.5 W/m°C. Samples with lower conductivity (e.g., insulation) can be analyzed with a smaller sample size. Samples with higher conductivity (e.g., granite) will require a larger sample to avoid edge effects. Measurements are performed according to the equipment's operating instructions menu, with visual monitoring on the touch screen; the data can be stored. This article reports measurements taken on various commonly used construction materials, such as extruded polystyrene, natural mortar, cellular lightweight mortar, mineral perlite lightweight mortar, synthetic perlite lightweight mortar, and plain concrete, which are shown in the results section.

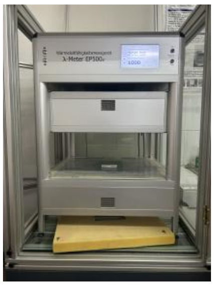
3.2. *EP500-c* Thermal Conductivity Meter

This is a thermal conductivity meter that performs tests in accordance with ISO 830 (1991) which describes the use of a protected heating plate device that offers a measurement accuracy of < 1.0% in the range of 10 to 60 mW/ (m·°C) range (generally < 0.7%) and reproducibility < 0.5% (generally < 0.2%). This meter has a cooling/heating unit with 12 high-performance air-cooled Peltier modules.

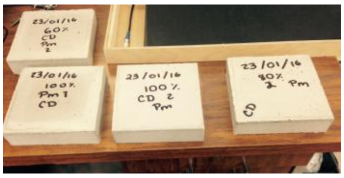
3.2.1. Measurement Method *EP500-c*

The equipment has a measurement chamber that receives square samples measuring 15 x 15 cm in a dry state, with parallel and flat sides for non-insulating materials. For insulating materials, the dimensions are 50 x 50 cm, and the thickness may vary in both cases, but is normally 4 cm. The material is placed in the center of the equipment's sample holder plate, which closes automatically, applying a pressure of 500 *Pa*, thus ensuring complete contact with the temperature plates. Insulating material protection is placed around the sample for non-insulating materials. The equipment has touch screens for display and control and connects via Bluetooth to a computer to display the progress of the measurement graphically. Based on the weight of the sample, the equipment determines the apparent density in kg/m^3. The relative humidity of the environment surrounding the equipment must be less than 36% and the temperature less than 25°C.

For the measurement, the equipment performs three measurements at temperatures of 10°C, 25°C, and 40°C. After 8 hours of measurement, the results are adjusted to the polynomial y= f(t)= 0.3263*T+123.40 to obtain the thermal conductivity value in (mW/m°C). The equipment generates a measurement certificate. Measurements were taken on several commonly used construction materials such as extruded polystyrene, glass, natural mortar, cellular lightweight mortar, mineral perlite lightweight mortar, synthetic perlite lightweight mortar, and plain concrete, which are shown in the results section. This equipment is considered primary equipment, does not require calibration, and has reference materials for insulators and non-insulators acquired from the National Metrology Center (CENAM) in Mexico. Figure 2. a), b), and c) show the measuring equipment and the type of samples for insulating and non-insulating materials.



a) *EP500* equipment



b) Samples of non-insulating materials

C) Sample of insulating material

Figure 2: *EP500-c* measuring equipment.

4. Self-developed equipment and its operation.

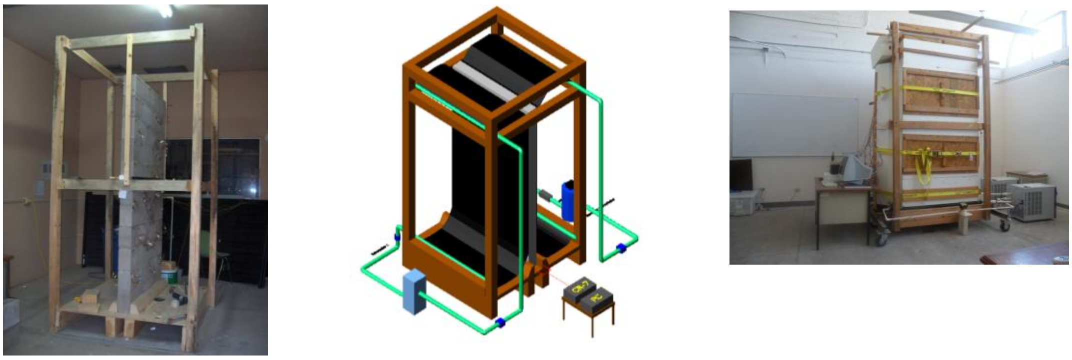
The aforementioned commercial equipment can measure small samples that represent the homogeneous part of a component or construction system, but they are not useful for determining the thermal properties of a system composed of several materials and non-homogeneous or hollow geometries. To resolve this issue, three measuring devices have been created that can measure samples of large, non-homogeneous construction systems with different solid or hollow geometries.

4.1. Device for measuring the thermal properties of building systems *TR-00*

This is a proprietary measurement system based on the hot plate method in accordance with ASTM C-177 (2019) to obtain variables that allow the calculation of the thermal conductivity and resistance of building elements such as hollow or solid walls. The system consists of a lightweight cabinet for placing a full-scale wall sample measuring 1.20 m at the base and 2.00 m in height (Figure 3a). The wall is instrumented on both sides, with 25 thermocouples on each side of the wall to sense surface temperatures. A temperature differential is created on the sides of the wall using a heat exchanger (Figure 3b), through which cold water circulates at a temperature controlled by a chiller-recirculator. The hot side is achieved with a temperature-controlled recirculator with electrical resistance. A flow meter is used to ensure that the water flow remains constant. The inlet and outlet temperatures of the cold and hot water are measured; the results of these measurements are used to make a final calculation to obtain the thermal conductivity and resistance of the wall per square meter. The system is completely isolated from the outside to ensure maximum heat flow through the wall, (Figure 3c).

The variables measured are: surface temperature on both sides of the wall, inlet and outlet temperatures of the cold and hot water at a constant flow rate, all using a data acquisition system.

Two runs are performed for the measurement; in the first, the temperature is set at 45°C, simulating a hot wall, and the cold wall is varied at 25°C, 20°C, 10°C, and 5°C; in the second run, the temperature is set at 25°C as if it were a wall at ambient temperature and the temperature of the hot wall is varied from 45°C, 55°C, 65°C, 70°C and finally a variation from 10°C to 70°C to test large temperature differentials, as shown in Table 1.



a) Preparation of a sample of hollow block wall

b) *TR-00* Measurement System Model

c) Prototype of the *TR-00* measurement system

Figure 3: *TR-00* measurement system

Table 1: Operating temperatures for the experimental runs.							
Running 1				Running 2			
Readings	Cold wall ED (°C)	Hot wall EI (°C)	ΔTop (°C)	Readings	Cold wall ED (°C)	Hot wall EI (°C)	ΔTop (°C)
1	25	45	20	1	25	45	20
2	20	45	25	2	25	55	30
3	10	45	35	3	25	65	40
4	5	45	40	4	25	70	45
				5	10	70	60

Based on these operating conditions, the measurement is performed without changing the operating temperatures until a steady state is reached in approximately 6 hours for each run. Figure 4 shows an example.

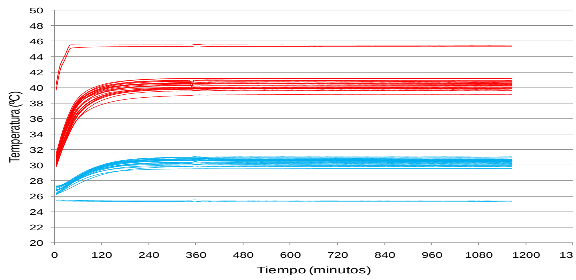


Figure 4: Steady-state measurements

Seven measurement runs with different *ΔT* are selected to determine the variation in thermal resistance and conductivity of a hollow concrete block wall, where the results at different *ΔT* are expected to vary due to the effects of the air contained in the hollow.

The results of the 7 runs are shown in Table 2, and are: Operating temperature differential (ΔTop), average temperatures of the cold side wall (*TED*), average temperatures of the hot side wall (*TEI)*, cold side water inlet and outlet temperatures (*TEF*)(*TSF*), hot side water inlet and outlet temperatures (*TEC*) (*TSC*), and cold and hot water flow (*F1*) (*F2*). With these measured values, the heat flow value *q* and thermal resistance *R* are calculated for one square meter of hollow concrete block wall, according to eq. 1 and 2.

Table 2: Summary of data resulting from the experimental runs.

Readings	ΔT_{op} (°C)	T_{ED} (°C)	T_{EI} (°C)	T_{EF} (°C)	T_{SF} (°C)	T_{EC} (°C)	T_{SC} (°C)	F_1 (l/min)	F_2 (l/min)
1	20	28,76	42.34	25.37	25.56	45.55	45.35	14.17	14.78
2	25	24.72	41.60	20.36	20.59	45.58	45.31	14.03	14.83
3	30	30.57	50.82	25.39	25.66	55.56	55.21	14.09	15.25
4	35	16.76	40.07	10.32	10.66	45.51	45.16	13.75	15.05
5	40	32.41	59.34	25.35	25.75	65.41	64.92	14.07	14.10
6	45	33.30	63.46	25.34	25.76	70.20	69.62	14.07	14.11
7	60	21.73	61.56	10.33	10.93	70.30	69.63	13.69	15.52

$$q = G\rho Cp\Delta T_{flow} \qquad \text{(eq. 1)}$$

$$R = \frac{\Delta T_{wall}}{qA} \qquad \text{(eq. 2)}$$

Where *G* is the flow rate in l/m, *ρ* is the density of water, which is considered constant at 998 kg/m^3, and *Cp* is the specific heat of water, assumed to be constant at 4182 J/kg°C. ΔT_{flow} is considered to be the temperature difference between the inlet and outlet water flows of the heat exchangers. For expression (2), ΔT_{wall} is considered to be the difference in average temperatures of the wall surfaces in a steady state for an area of 2.4 m² of surface area. The results section shows the data from the experimental runs and the values obtained for *q* and R for each *Δt*.

4.2. Device for measuring the thermal properties of building systems *TR-01*

This is a semi-automatic device of our own design for measuring variables used to calculate the thermal properties of a building system, such as thermal conductivity and resistance.

It has a cabinet or sample holder measuring 1.20 m wide by 2.00 m high. Figures 5a and 5b show the model and prototype, respectively. The model is based on the idea of placing an interchangeable wall at actual scale from any building system; in this case, it is a brick wall (Figure 5c). The wall has a cold side and a hot side. The cold side is achieved with a system of temp plate connected to a chiller-type recirculator to maintain a constant cold temperature according to the test design. The hot side is achieved with flexible electric resistance plates connected to a power source to keep the hot plate uniform according to the design temperature.

A temperature differential is established between the cold plate and the hot plate according to the experiment design. The system is insulated to prevent losses and ensure heat flow in only one direction through the wall. The device has thermocouple temperature sensors that make contact with the wall surfaces on the cold side and the hot side. Figure 6 shows the results of measuring surface temperatures reaching steady state for a brick wall with a *ΔT* of 20°C.

a) *TR-01* Model b) *TR-01* prototype c) Brick wall

Figure 5: *TR-01* measurement system

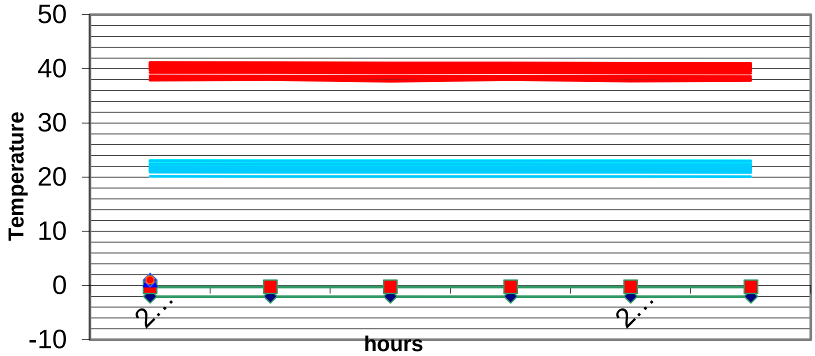


Figure 6: Temperature measurement in steady state

Table 3 shows the results of measuring a brick wall. The heat flow *q*, through the wall is calculated using the voltage information and the amperage of the power source between the wall areas. The thermal conductivity of the wall is calculated by multiplying the heat flow *q* by the quotient of the wall thickness and the wall temperature differential.

Table 3: Measurement results with *TR-01* brick wall *ΔT* = 18.20 °C				
Power supply	7	Amperes	16.15	Volts
Recirculator chillers	15	**°C**		
Average hot surface temperature	40.11	°C		
Average cold surface temperature	21.91	°C		
ΔT	18.20	**°C**		
Dimensions				
Width	1.23	m		
High	2.11	m		
Area	2.59	m^2		
Thickness	0.17	m		
q	**43.55**	**W/m^2**		
k	**0.41**	**W/m°C**		
R	**0.41**	**m^2 °C /W**		

The results section shows the values of various construction systems that were measured.

4.3. Device for measuring the thermal properties of medium-scale building systems *TR-02*.

This is a device of our own design consisting of a machine for measuring variables used to calculate the thermal properties of homogeneous and non-homogeneous building systems, such as building systems made of different solid and/or hollow materials. Unlike the *TR-01* system, the *TR-02* analyzes a sample of two medium-scale walls measuring 60 cm x 60 cm. It works in a similar way to the previous system, the difference being the size and number of samples, but it is governed by the same operating principles. Figures 8a) and 8b) show the model and prototype, respectively, and Figure 8c) shows some samples of 60 cm x 60 cm building systems.

As an example, the procedure for measuring a 60 cm x 60 cm wall of insulating material with a *ΔT* of 26.77°C is presented. Figure 7 shows the measurement of surface temperatures when a steady state has been reached.

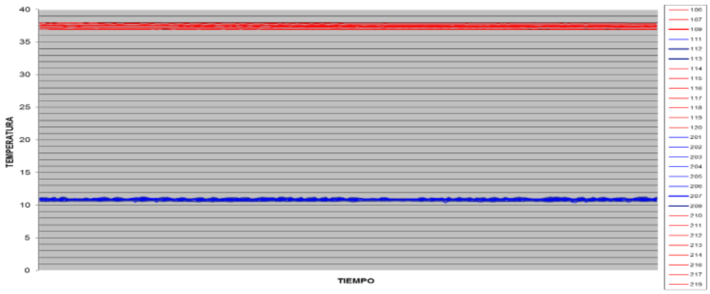


Figure 7: Measurement of temperatures in steady state -Insulating material.

a) Model *TR-02*

b) *TR-02* prototype

c) 60x60 wall measurement samples.

Figure 8: Model and prototype of *TR-02*

The heat flow and thermal resistance of the wall per square meter are calculated using the same procedure as in Table 3, with the difference that in this case the surface area is double because the sample consists of two walls. Table 4 shows the data and results for heat flow *q*, conductivity *k*, and thermal resistance *R* for one square meter of insulating wall material.

Table 4: Measurement results with *TR-01* insulating material ΔT = 26.77 °				
Power supply	**2**	Amperes	**20.5**	Volts
Recirculator chillers	10	**°C**		
Average hot surface temperature	37.49	°C		
Average cold surface temperature	10.27	°C		
ΔT	26.77	**°C**		
Dimensions				
Width	.6	m		
High	.6	m		
Area	0.36	m^2		
Thickness	0.0254	m		
q	**56.94**	**W/m^2**		
k	**0.054**	**W/m°C**		
R	**0.47**	**m^2 °C /W**		

The results section presents the measurement values for different construction systems.

5. Results and discussion

Tables 5 and 6 show the results of thermal conductivity measurements taken with the *KD2Pro* and *EP500c* equipment, respectively, for various materials. The objectives of these measurements were for research activities, to support undergraduate and graduate thesis students in the preparation of their theses, and to provide laboratory services to the local construction sector to determine the properties of materials and their commercialization in the local market in accordance with current regulations.

Table 5: Thermal conductivity of building materials using *KD2-Pro* equipment, according to ASTM D5334-08 e IEEE 442-1981.

Material	Thermal conductivity (W/m°C)	Origin of the sample
Common brick	0.340	Commercial market
Hollow concrete block, continuous part of the block	0.612	Commercial market
Heavy adobe	0.610	Commercial market
Natural mortar	0.770	Research
Recycled mortar	0.667	Research
Plaster	0.400	Research
Extruded polystyrene	0,026	Commercial market
Expanded polystyrene	0.040	Commercial market

Table 6: Thermal conductivity of building materials using *Ep500c* equipment According to: Thickness EN 823; Thermal conductivity ISO 8302.

Material	Thermal conductivity (W/m°C)	Origin of the sample	Density (kg/m^3)
Cement mortar sand	0.647	Experimental	2066
Lightweight cement mortar sand.	0.15	Experimental	716
Cement mortar sand and graffito + zeolite	0.560	Expermental	2007
Cement mortar with 60% synthetic perlite	0.430	Experimental	1158
Cement mortar with 100% synthetic perlite	0.131	Experimental	512
Drywall	0.1569	Comercial	619.40
Expanded polystyrene	0.039	Comercial	30.0
Ceiling	0.063	Comercial	240
Concreto cellular 1400	0.300	Experimental	1400
Poliestireno extruido	0.025	comercial	33
Clay brick	0.252	Experimental	1500
Glass	0.756	Comercial	2527
Pine wood	0.105	Comercial	585.5
Gypsum mortar	0.250	Comercial	1200
Carbon replacement mortar	0.389	Experimental	1958

Table 7 shows the values of variables measured with the *TR-00* equipment in 7 runs at different *ΔT*, from which the results of heat flows (*q*), conductivity *(k)*, and thermal resistance *(R)* of a hollow concrete block wall at different *ΔT* are obtained.

Table 8 shows the conductivity and thermal resistance measurement values of various building systems using the *TR-01* equipment.

Table 8: Conductivity and thermal resistance of building systems with TR-01 equipment

Material/ thickness	Thermal Conductivity (W/m°C)	Thermal resistance (°Cm²/W)	Heat flow (W/m²)	Origin of the sample
Polystyrene 0.025m	0.035	0.709	22.286	Commercial market
Drywall 0.0125 m	0.142	0.088	215.6	Commercial market
Pine wood 0.0126 m	0.100	0.126	161.41	Commercial market
Brick wall 0.17m	0.414	0.417	43.55	Commercial market

Table 9 shows the conductivity and thermal resistance measurement values of various building systems using the *TR-02* equipment.

Table 9: Conductivity and thermal resistance of building systems with *TR-02* equipment

Material	Thermal Conductivity (W/m°C)	Thermal resistance (°Cm²/W)	Heat flow (W/m²)	Origin of the sample
Polystyrene 0.025m	0.05	0.47	56.94	Commercial market
Drywall 0.0125 m	0.141	0.08	122.50	Commercial market
Hollow concrete block wall	0.79	0.15	127.91	Commercial market

Table 7: Heat flows, resistance, and thermal conductivity of hollow concrete block walls using the *TR00* measurement system.

Run	*q(W)*	*ΔT_{wall} (°C)*	*T_{wall}*	*R (°Cm²/W)*	*k (W/m °C)*
1	187.28	13.58	28.76	0.174	0.69
2	224.47	16.88	24.72	0.180	0.66
3	269.95	20.05	30.57	0.178	0.65
4	325.20	23.31	16.76	0.172	0.71
5	391.49	26.93	32.41	0.165	0.71
6	411.06	30.16	33.30	0.176	0.68
7	571.37	39.83	21.73	0.167	0.74

Table 10: Comparison of results for devices TR-01, TR-02,* and *EP-500.

Material	**λ (W/m°C) TR-00**	**λ (W/m°C) TR-01**	**λ (W/m°C) TR-02**	**λ (W/m°C) EP-500**
Wood 0.0126 m	-	0.100	-	0.100
Drywall 0.0126 m	-	0.140	0.150	0.150
Polystyrene 0.0254 m	-	0.040	0.040	0.039
Brick wall	-	0.71	-	-
Hollow concrete block wall	0.73	-	0.79	-

The results obtained from the measurements are highly consistent with the references found in other measurements and in the commercial technical data sheets of some construction products. This similarity allows for the comparison of value ranges; however, it should be reiterated that the results of material measurements must be specific, unless representative samples of a material in a given region are measured and an average value can be established. In the case of measurements with commercial equipment, these are guaranteed according to the error ranges contained in the instructions and the standards that support them. In the case of self-made equipment, they are supported by the methodology with which they were designed in accordance with current regulations and knowledge of the methodology applied.

Conclusions

It is concluded that it is important to develop technology that allows the thermal properties of materials to be measured, given the demand for specific knowledge of these values, as well as enabling the development of new material proposals that can be used to design more efficient buildings. It is important to mention that one of the most significant contributions of this project is the ability to measure these variables for non-homogeneous construction systems.

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