

Thermal conductivity and specific heat capacity

التوصيلية الحرارية والسعة الحرارية النوعية

Conductivité thermique et capacité thermique massique

SENOUC Samra¹, AMROUNI Nawal²

¹Mohamed Khider University of Biskra, Algeria, samra.senouci@univ-biskra.dz

²Abou Bekr Belkaid University of Tlemcen, Algeria, nawelamrouni1307@gmail.com

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ملخص

تتناول هذه الورقة دراسة تجريبية للحرارة الموصلة والقدرة الحرارية النوعية لمواد البناء المحلية باستخدام طريقة درجة الحرارة التلامسية (CTM). تتبع الدراسة مفهوماً تجريبياً يستخدم مكعب قياس رخامي كجسم مرجعي لتحديد الخصائص الفيزيائية الحرارية بسرعة ودقة في ظروف رطوبة محكمة. هذا النهج ليس سهل التنفيذ تجريبياً فحسب، بل إنه دقيق للغاية في مقارنة النتائج؛ فقد قمنا بحساب قيمنا ثم قارناها مع القيم المتوفرة في الأدبيات. ويظهر الجمع بين النتائج التجريبية والنموذج النظري الموحد أهمية طريقة درجة حرارة التلامس (CTM) في التحليل الحراري للمباني الموفرة للطاقة.

الكلمات المفتاحية: التوصيلية الحرارية، السعة الحرارية النوعية، طريقة درجة حرارة التلامس، انتقال الحرارة، الكثافة، التحليل الحراري.

Résumé :

Cet article traite d'une étude expérimentale sur la conductivité thermique et la capacité thermique spécifique des matériaux de construction locaux à l'aide de la méthode de la température de contact (CTM). L'étude suit un concept expérimental utilisant un cube de mesure en marbre comme corps de référence pour déterminer rapidement et précisément les propriétés thermophysiques dans des conditions d'humidité contrôlées. L'approche actuelle est non seulement simple à mettre en œuvre sur le plan expérimental, mais également très précise pour la comparaison des résultats ; nous avons calculé nos valeurs, puis les avons comparées à celles disponibles dans la littérature. La combinaison des résultats expérimentaux et d'un modèle théorique unifié montre l'importance de la CTM pour l'analyse thermique dans les bâtiments à faible consommation d'énergie.

Mots clés: Conductivité thermique, capacité thermique spécifique, méthode de la température de contact, transfert de chaleur, densité, analyse thermique.

Abstract

This paper deals with an experimental study for thermal conductivity and specific heat capacity of local building materials by using the Contact Temperature Method (CTM). The investigation follows an experimental concept utilizing a marble measuring cube as a reference body for fast and precise determination of thermophysical properties under controlled moisture conditions. The present approach is not only simple to implement experimentally but also quite accurate for comparison of the results; we have calculated our values and then compared them with those available in the literature. The combination of experimental results along with a unified theoretical model shows the importance of CTM for thermal analysis in energy-saving buildings.

Key words: Thermal conductivity, specific heat capacity, Contact Temperature Method, heat transfer, density, thermal analysis.

I INTRODUCTION

Thermophysical properties, chiefly thermal conductivity and specific heat capacity, form the basis of the thermal behavior of building envelopes. Notwithstanding the significance of these, there is scarce experimental data on local construction materials, particularly when under realistic building environments. The Contact Temperature Method, initially suggested by Campan [4], is a rapid and convenient way for assessing these properties with constant humidity in the course of measurements. This work is an extension of earlier experimental investigation, which has been put into perspective in light of recent literature. The purpose is to develop a framework that secures the original article in a common framework of academic discourse, defined by its clarity and relevance to the established body of knowledge [1], [2], [3], [4].

II THEORETICAL BACKGROUND

II.1 THERMAL CONDUCTIVITY

The thermal conductivity is a measure of the substance's capacity to convey the heat under a temperature gradient, and it follows from Fourier's law [1,2]. This varies over material, dependent upon constituents, density, temperature and moisture content. Values for typical construction products lie between $0.1 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ for light organic materials and $3 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ or more, depending on the specific material these values correspond to.

II.2 SPECIFIC HEAT CAPACITY

It is the amount of heat that needs to be added to one unit mass of substance to raise the temperature by one degree. It is directly related to the thermal inertia and thus to the dynamic aspects of building thermal behavior [1,8]. Since materials of high specific heat

capacity are able to store large amounts of heat, they can reduce temperature variations in the shelter.

II.3 BASIS OF THE CONTACT TEMPERATURE METHOD

The Contact Temperature Method is based on transient, one-dimensional heat flow between a measuring body having known properties and a test piece. An intermediary temperature of contact is established when perfect thermal contact between the two bodies exists. Under some reasonable assumptions, this temperature also provides a way to calculate the thermal conductivity of the tested material with analytical expressions based on consideration of heat balance.

III EXPERIMENTAL METHODOLOGY

III.1 MEASURING DEVICES

The experimental apparatus consists of a marble cube ($10 \times 10 \times 10 \text{ cm}^3$) serving as the measuring body, equipped with three iron–constantan thermocouples. These sensors monitor the contact temperature, the core temperature of the cube, and the temperature uniformity at its surface. The marble cube was previously calibrated using water of known thermal conductivity.

III.2 MATERIALS STUDIED AND SAMPLE PREPARATION

Four local construction materials were investigated: Concrete, Solid brick, Plaster, and Refractory brick. The samples were polished to ensure good thermal contact with the marble cube. Detailed specifications are as follows: A concrete sample (sand, cement, and gravel mixture in equal proportions) measuring $25 \times 25 \text{ cm}$ and 5.7 cm thick. A solid brick sample measuring $25 \times 25 \text{ cm}$ and 1 cm thick. A plaster sample measuring $24 \times 24 \text{ cm}$ and 5 cm thick. A sample of refractory brick measuring $11 \times 14.5 \text{ cm}$ and 5.5 cm thick.

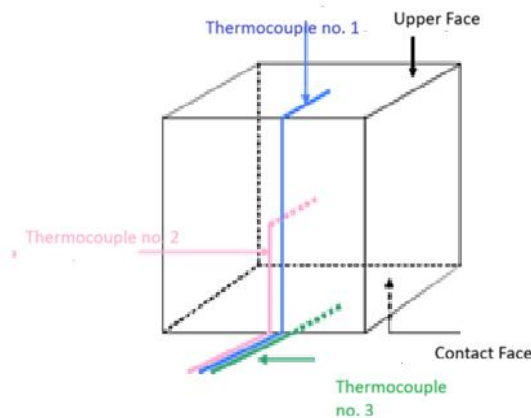


Figure.1 : Location of thermocouples in the measuring cube

III.3 MEASUREMENT PROCEDURE

The measuring cube, was heated to a homogenous temperature and subsequently touched to the test specimen at first of lesser temperature. The temporal development of

the contact temperature was measured. The first temperature plateau of no contact was used to calculate the thermal conductivity of the material.

III.4 PRINCIPLE OF THE METHOD

The test body is placed in a undisturbed atmosphere for a long period of time in order to reach a uniform temperature $t_2 < t_1$, verified using thermocouple no. 4.

When it is observed that the heat is uniformly distributed throughout the measuring body M, which is at temperature t_1 , it is placed above the test body. If the contact between the surfaces of separation is perfect, the temperature of contact takes on an intermediate value $t_m (t_2 < t_m < t_1)$, which persists for a fairly long time (a few minutes).

In the case where the two bodies in contact have infinite length, the contact temperature t_m remains constant until their temperatures become uniform [4].

The thermal conductivity (W/mK) of the body of the test is expressed by the following relationship (eq. I):

$$\lambda_{test} = \left(\frac{U_1}{U_2} \right)^2 \frac{\lambda_{marblecube} C_{marblecube} \rho_{marblecube}}{C_{test} \rho_{test}} \quad \text{(eq. I)}$$

where:

λ marble cube: the thermal conductivity of the measuring body M, in W/mK;

C marble cube: the specific heat of the measuring body M, in J/kgK;

ρ marble cube – the density of the test specimen M, in kg/m³ ;

C test – the specific heat capacity of the test body, in J/kgK;

ρ test – the density of the test body, in kg/m³ ;

$U_1 = T_1 - T_m$ decrease in temperature at the contact surface relative to the measuring body M, in K;

$U_2 = T_m - T_2$ increase in temperature at the surface of the contact relative to the test body, in K.

The use of the previous relationship requires knowledge of the thermophysical properties (specific heat and density) of the two bodies in contact and the thermal conductivity of the marble cube. The latter was calibrated beforehand using a stationary fluid (water) for which the thermal conductivity is known [RAD 72]. The thermal conductivity of marble is determined using the following equation (eq II):

$$\lambda_{marblecube} = \left(\frac{T_{contact} - T_{water}}{T_{cubemarble} - T_{contact}} \right)^2 \frac{\lambda_{water} C_{water} \rho_{water}}{C_{cubemarble} \rho_{cubemarble}}$$

(eq II)

T_{contact} : the temperature of the cube at equilibrium, in $^{\circ}\text{C}$;

T_{water} : the initial temperature of the water, in $^{\circ}\text{C}$;

$T_{\text{cubemarble}}$: the temperature of the cube after uniform heating in a thermostatic bath, in $^{\circ}\text{C}$;

λ_{water} : the thermal conductivity of water, with a value of 0.43 W/mk

C_{water} : the specific heat of water, in J/kg ;

ρ_{water} : the density of water, in kg/m^3 .

The experimental device for measuring the thermal conductivity of the marble measuring body essentially consists of:

- a thermostatic bath containing water to bring the temperature of the marble cube to a set temperature of 60°C ;
- a calorimeter containing water at room temperature;
- two iron-constantan thermocouples to measure the different temperatures.

The measuring cube is left in the thermostatic bath for approximately one hour.

($T_{\text{setpoint}} = T_{\text{cubemarble}}$) to ensure that its temperature is evenly distributed throughout its mass. The measuring cube is removed from the thermostatic bath and immediately immersed in the calorimeter containing water at 60°C . The temperatures of the calorimeter are recorded over time until equilibrium is reached (Figure. 2). The experimental value of thermal conductivity obtained for our marble cube is 2.5 W/m k .

III.5 ENSURING PERFECT THERMAL CONTACT DURING CALIBRATION

During the calibration phase of the marble cube with water, a near-perfect thermal contact was sought to minimize the interfacial thermal resistance between the probe and the reference material. To achieve this, the cube's cavity was completely filled with distilled water, thereby eliminating any air pockets that could potentially act as thermal insulators. The probe was subsequently immersed into the center of the cavity, ensuring it was entirely surrounded by water without making direct physical contact with the walls of the cube. Due to its fluidity, water perfectly conforms to the geometric contours of the probe, ensuring a homogeneous transmission of heat between the probe and the marble. Furthermore, the entire experimental setup was kept at rest until a complete thermal equilibrium was established prior to the commencement of measurements, thereby guaranteeing the stability

of the experimental conditions. These stringent precautions allow the contact resistance to be considered negligible, ensuring that the observed deviations stem primarily from the inherent thermophysical properties of the system rather than a deficiency in thermal coupling.

VI RESULTS

The Contact Temperature Method (CTM) was applied to determine the thermophysical properties of four local construction materials. The experimental contact temperature used for the calculations corresponds to the first plateau appearing immediately after the sudden temperature drop following the contact between the heated marble cube and the test specimen.

The measured thermal conductivities, along with the average density ρ_{avg} and average specific heat capacity C_{avg} for each studied material, are consolidated in Table 1 below:

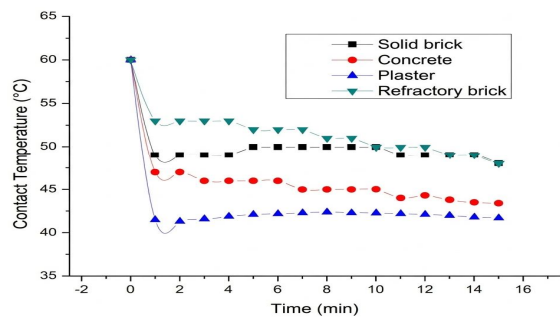


Figure 2 : Evolution of contact temperature as a function of time

Table 1 : Thermophysical Properties of Local Building Materials

Materials Studied	$\lambda_{literature}$ (W/m K)	λ_{exp} (W/m K)	ρ_{avg} (kg/m ³)	C_{avg} (KJ/kg.K)
Solid brick	0.84	0.535	2252.67	0.259
Concrete	1.75	0.738	3790.6	0.295
Plaster	1.93	1.602	1556.57	0.419
Refractory brick	0.2	0.128	1692.62	0.421

The results obtained allow us to calculate the thermal conductivity of the different materials used (solid brick, concrete, plaster, and refractory brick) using the first relationship (eq I). The contact temperature used corresponds to the first plateau appearing

just after the sudden drop in temperature. The results obtained are grouped in the following table.

V DISCUSSION

The experimental results demonstrate that the measured thermal conductivities λ_{exp} are systematically lower than the reference values reported in the literature λ_{lit} . While this deviation remains relatively small for plaster and refractory brick, it becomes significantly more pronounced for solid brick and concrete.

- **Solid Brick:** The experimental thermal conductivity (0.535 W/m·K) is approximately 36% lower than the literature value (0.84 W/m·K). This difference is primarily attributed to variations in mineralogical composition, manufacturing conditions, inherent porosity, and moisture content

Concrete: This material exhibited the most substantial deviation, with an experimental value (0.738 W/m·K) roughly 58% lower than the literature reference (1.75 W/m·K). Such a gap can be explained by the specific nature of the aggregates, the water-to-cement ratio, the presence of internal air voids or

- microcracks, and a significantly drier state of the experimental sample, given that concrete's thermal conductivity is highly sensitive to moisture levels.
- **Plaster:** The measured conductivity (1.602 W/m·K) is closest to the bibliographical data (1.93 W/m·K), representing a minor deviation of about 17%. This proximity confirms that the thermal behavior of the tested plaster sample aligns well with standard academic expectations.
- **Refractory Brick:** The experimental conductivity was found to be 0.128 W/m·K) against (0.20 W/m·K) in the literature, yielding a 36% deviation. This variation is tied to a higher volumetric porosity, the specific raw materials used, or the firing/baking conditions during production, which directly dictate the performance of refractory elements.

General Assessment of Deviations

On a broader scale, these observed discrepancies remain entirely compatible with the typical variations encountered within characterizations of building materials. The slight deviations are fundamentally driven by two primary factors:

Material Variability: Differences in the local composition, density, and specific nature of the materials compared to standard textbook references.
Experimental and Measurement Uncertainties: Challenges in precisely capturing the specific

heat capacity (C_{avg}) and average density (ρ_{avg}) due to the materials' high porosity and subsequent water absorption capacity. Additionally, physical factors such as the thermal contact resistance between the probe and the specimen, the validity of the semi-infinite medium assumption, and minor calibration variations contribute to these differences. Nevertheless, the overall consistency with published data ranges validates the Contact Temperature Method as a reliable, rapid, and precise approach for the thermophysical characterization of building envelopes under controlled environments.

Influence of Thickness Variations on the Semi-Infinite Medium Model

For thin samples ($\approx 1\text{cm}$), heat quickly reaches the rear face of the specimen. Consequently, boundary effects become significant, potentially causing a discrepancy between the experimental results and the predictions of the semi-infinite medium model. Conversely, as the thickness increases (up to 5.7 cm), the influence of the rear face is strongly attenuated, and the material behaves more closely to a semi-infinite medium. Under these conditions, the experimental results are more accurately described by the theoretical model, provided that the total duration of the test remains shorter than the characteristic time required for the thermal perturbation to reach the opposite boundary. Therefore, increasing the specimen thickness generally enhances the validity of the semi-infinite medium hypothesis by mitigating boundary and edge effects. However, it is highly recommended to verify this criterion quantitatively by comparing the experimental measurement time (t_{exp}) to the characteristic thermal diffusion time (τ).

VI APPLICATIONS IN BUILDING DESIGN

Correct values of thermal conductivity and specific heat are crucial for choosing proper materials used in energy-effective construction. The data collected can be incorporated into steady-state and transient thermal models to evaluate the performance of insulation material and thermal mass distribution in different climates.

VII. CONCLUSIONS

The combined method increases the scientific validity of the original study and maintains consistency with existing literature. The approach is useful for thermal characterization and embodies rational material selection in sustainable building design.

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