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# A practical method for in-situ thermal characterization of walls

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ABSTRACT

A practical and fast method for thermal characterization of walls based on complex Fourier analysis is proposed to determine the thermal capacitance (defined as the product of density and specific capacity) and the thermal conductivity for a building wall using the monitored inner/outer surface temperatures and outer heat flux. This method is useful for in-situ determination of walls' thermal properties in stochastic regimes and therefore does not require any particular constraints in boundary condition.

The minimum measurement duration was analyzed by determining the relative deviation between consecutive optimal values for R and C in order to reduce as much as possible the monitoring duration for energy auditors without losing accuracy.



## 1. Introduction

### 1.1. Importance of thermal properties for energy simulation

Evaluating how much heat is lost through external walls is a key requirement for building energy simulators and is necessary for quality assurance and successful decision making in policy implementation and building design, construction and refurbishment. Nowadays energy audits constitute one of the best solutions to assess the energy consumption in existing buildings and to recommend energy efficiency measures in order to reach a better energy performance [1]. The thermal performance is generally estimated by using dynamic thermal simulations or steady state estimations using the degree-days method [2]. One of the most experienced locks in thermal modeling of buildings, whether in dynamic or even steady state conditions, is the determination of the thermal properties of walls, especially in existing buildings.

Energy auditors often use assumptions, sometimes aberrant, to overcome this problematic situation. In fact, new building components are usually certified and their physical characteristics can be specified in many cases, but when dealing with existing buildings the situation is more complicated since the properties are usually unknown, components have often been degraded during the time, and the tests should be easy, quick, and non-destructive.

### 1.2. Lab conditions

In the laboratory, steady state conditions can be easily imposed to any building component and then its thermal properties could be determined without major impediments [3–7].

Hadded, et al. [3] used a sample holder in copper placed between two boxes (A) and (B) for thermo physical

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**Nomenclature**

| | |
|---|---|
| $\varphi$ | heat flux (W/m$^2$). |
| T | temperature (°C). |
| R | equivalent thermal resistance (m$^2$K/W). |
| C | equivalent thermal capacitance (J/m$^3$K). |
| p | Laplace transform variable (– ). |
| A, B, C, D, E, F | constants (– ). |
| a, b, c, d | constants (– ). |
| $\alpha$, $\beta$, $\gamma$, $\varepsilon$, $\mu$ | constants (– ). |
| $W_{ij}$ | transfer matrix elements of the wall. |
| n | harmonic index number (– ). |
| N | harmonic order number (– ). |
| $\omega$, $\Omega$ | angular frequency (1/s). |
| D | data logging duration. |
| F(p) | Laplace transform function. |
| $p_1$, $p_2$, $p_3$, $p_4$ | constants (– ). |

*Subscripts*

| | |
|---|---|
| w | wall. |
| i | inner surface. |
| o | outer surface. |
| k | temperature index number. |
| cn | cosine, order n. |
| sn | sine, order n. |
| cte | constant. |
| approx | Fourier approximated. |
| meas | measured. |
| theo | theoretical. |

characterization of recycled textile materials used for building insulating. An electronic ohmmeter is used to measure the heat resistance (R), in order to evaluate the amount of heat produced in the system by joule effect. The same setup was used to determine the thermal conductivity and diffusivity. Fgaier, et al. [4] used the heat flow meter method to determine the dynamic thermal performance of three types of unfired earth bricks. The method consists of simultaneously measuring the heat flow and temperature on both faces of a sample subjected to a temperature gradient generated by two exchanger plates. The sample and flow meters assembly is surrounded by an insulating belt so as to limit the lateral heat flow losses and ensure a unidirectional flow in the central measurement area. Zhu, et al. [5] used the same method to determine thermal properties of recycled concrete blocks. Laaroussi, et al. [6] applied the steady state, hot plate method to estimate the thermal conductivity. The method is based on temperature measurements at the center of heating element inserted between the sample and polyethylene foam. The thermal diffusivity measurement is based on the flash method. An energy pulse heats one side of a plane-parallel sample and the transient temperature rise T(t) on the backside due to the energy input is recorded. Derbal, et al. [7] presented a method to identify the thermo physical properties of a given material inserted between two layers of material for which the following characteristics are known: thermal conductivity and volumetric heat capacity. The material is subjected to a unidirectional heat flux produced by a flat heating resistance.

However, one of the disadvantages of measuring the thermal properties under a laboratory-controlled climate is that the tested specimen would then be placed within a natural actual climate which differs from the testing conditions. In addition, when dealing with existing buildings, imposing boundary conditions is usually expensive and cumbersome and is often modified by natural stochastic conditions (wind, rain, sunlight, etc ...).

### *1.3. In-situ measurements*

Accordingly, some researchers began seeking a derivation for the thermal properties based upon in-situ measurements such as surface temperatures and heat fluxes.

Chaffar, et al. [8] used a flat heating resistance surface measuring 0.9 m × 1.1 m pressed against the panel by an 18 cm thickness polystyrene panel to direct most of the power dissipated by the resistance into the wall being tested. The method consists of thermally examining an access surface by applying a heat flux and studying the response in terms of the temperature recorded by infrared thermography on the opposite surface. Although it is only necessary to record the transient temperature variation history for the transient plane source (TPS) method, it is still classified as a laboratory controlled climate as the TPS element requires heating.

Even though the method is simple and gives satisfactory results, the equipment used is still expensive and cumbersome. Outdoor test cells have been developed in order to tackle the challenging issue of experimentally characterizing innovative envelope elements in real dynamic weather conditions [9]. Awad, et al. [10] Evaluated the thermal performance of a mid-rise wood-frame building using a 3 m × 6 m test house using a total of 41 sensors are installed inside the test house(24 thermocouple sensors, 10 heat flux sensors, and 7 relative humidity sensors).

However, although these methods very interesting for new envelope elements, they are not suitable to characterize existing buildings.

Some works used light equipment to evaluate thermal resistance of buildings, but they neglected the thermal capacitance which is a very important parameter for dynamic modeling. Asdrubali, et al. [11] presented the results of a measurement campaign of in situ thermal transmittance, performed in some buildings in the Umbria Region (Italy), in order to compare in situ thermal transmittance measurements and theoretical calculated U-values. Ficco, et al. [12] also presented the results of an experimental campaign and compared in situ U-values with the estimated ones from design data and field