EXPERIMENTAL DETERMINATION OF OVERALL HEAT TRANSFER COEFFICIENT ON NON HOMOGENEOUS ELEMENTS

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Abstract. *This work describes the adaptation of a calibrated calorimeter in a calibrated guarded hot box, to perform measurements of the overall heat transfer coefficient in insulating non-homogenous materials. In order to determine the maximum adaptation configuration, the requirements of the ASTM C1363-05 standards for the "Guarded Hot Box" method were analyzed, as well as the influence of the measuring instruments used, their uncertainties and the propagation of their errors. After determining the equipment behavior, under working conditions, the sensitivity analysis of the results was evaluated. Thus, it was possible to determine the influence of the elements of the guarded hot box on the results and, also, to calibrate the device in the work range. After the calibration, tests on the overall heat transfer coefficient in typical enveloping materials, fence blocks (not structural concrete bricks) were performed. A representative sample of concrete bricks was built and tested with the equipment and its overall heat transfer coefficient was raised experimentally, using the guarded hot box method.*

Keywords*: Heat transfer, thermal conductivity, calibrated hot box, overall heat transfer coefficient, fence blocks.*

1. INTRODUCTION

Technological news are shown every day, new materials, new building procedures, new solutions for large agglomerations demographic, sanitation, transport, communication, etc. However, there is no more recurring theme than energy saving way.

It is part of the human being, seek ways to provide comfort and things to facilitate their activities and, as a consequence of this, has a significant increase in electricity consumption, especially in buildings.

In Brazil, according to the National Program for Energy Conservation (PROCEL, 2010), it is estimated that approximately half the production of the country's electricity is consumed for the operation and maintenance of buildings and systems that provide environmental comfort for its users, such as lighting, air conditioning and water heating. However, also according PROCEL, this sector has a potential for energy conservation significant that exceed 50% in new buildings.

In this context, the present work is inserted, in order to contribute to a better understanding of thermal properties of a building element increasingly used, called fence concrete brick, or simply concrete brick.

Another aspect to be emphasized is that the records on the thermal characteristics of this element are rare. A likely cause of this scarcity of technical data can be attributed to the search priority of the elementary functions of mechanical strength and geometry. However, although apparently not be critical function, the thermal properties - no doubt - has fundamental importance for the determination of heat loads and specification of appropriate air conditioning equipment, providing the best thermal comfort with reduced energy consumption.

The determination of these properties can be obtained through experimental tests on standard equipment and standard procedures, as by national standards (ABNT) as international standards (ASTM, ISO).

However, the construction of a device exclusively for the determination of the thermodynamic properties of these building elements is costly, which enhances the low amount of data provided by the literature.

Are shown, therefore, a lower cost solution to make a such equipment. This is the process of adaptation of a "calibrated calorimeter" in a reversibly "guarded hot box". In other words, refers of add a new function, into an existent equipment.

Are approached, the standard's aspects of test, the instrumentation required for proper determination of the data, the measurement uncertainties and errors propagation. A test procedure is presented, so that this experiment can be replicated, and are shown final considerations about the values obtained in the experiments.

2. CALIBRATED GUARDED HOT BOX METHOD

The method of the "guarded hot box" is the most one used for the determination of thermal properties of walls, windows, floors, ceilings and building components in general. According to this method, the properties of the sample no needs to be uniform throughout the measuring area, unlike other methods. Are certain average values of a representative sample.

The equipment consists of an outer chamber, one cold chamber and another to protect the third chamber, inner hot box. The air conditions are controlled. Among the inner hot box and the cold chamber is then positioned the sample, look at Figure 1.

After reach the steady state condition, the transmittance or the overall coefficient of heat transfer in the sample, is determined through the relationship between the power required to maintain the temperature difference between hot and cold boxes, and the sample area (MOURA, 1993).

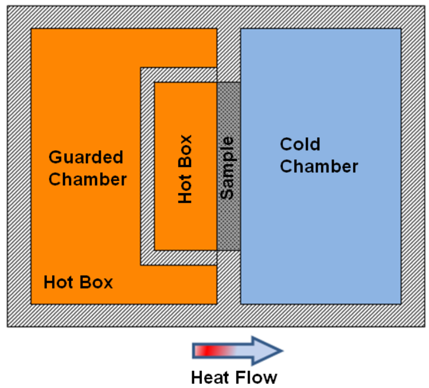

Figure 1: Guarded Hot Box, schematic arrangement of operation

2.1. TEST ROOM DEVICE

The proposed device, aims give conditions to carry out tests to determine the total flow of heat transferred or the overall heat transfer coefficient.

For this purpose, was used a calorimeter existing and in one of its sides was added one controlled chamber. Thus, it is possible to cause a controlled temperature difference on the walls of the interest element, and adjust the speed of air passing through these surfaces, thereby controlling the coefficient of heat transfer by convection.

In Figure 2, it can be seen a schematic representation of the air flow inside the chambers, where the right side seek to simulate the lower temperature region, represented by T_{AF} and the left side, the region of higher temperatures, represented by T_{AQ}. It also possible to see the presence of guarded chamber, that seeks to keep the outer side of the hot box closest to the temperature of T_{aq} (its inner side), thus minimizing the transfer of heat by these walls.

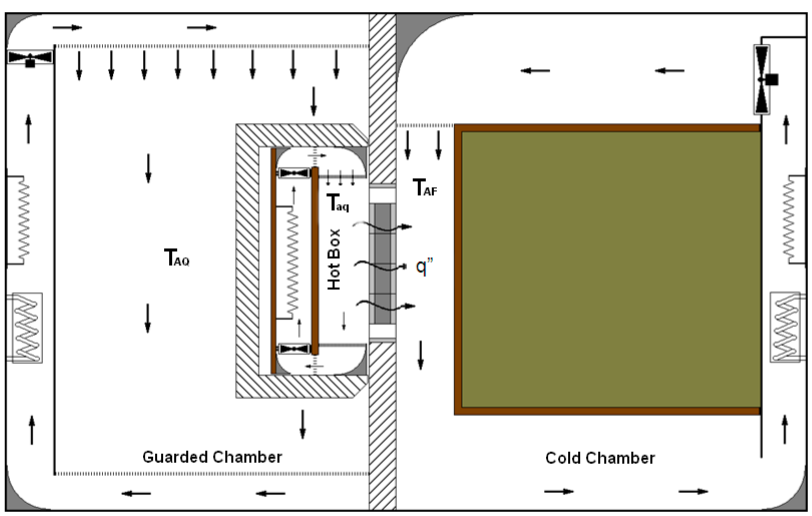

Figure 2: Schematic representation of the air flow within the chamber

2.2. STANDARD REQUIREMENTS

The standard used as reference for the experiment was the ASTM C1363-05, where also there are the dimensions and criteria to be followed to obtain reliable results and that can be comparable.

Under this Standard, the dimensions commonly used to build a hot box are 2.5m to 3.0m high, occurring the same dimensions for width. The floor varies between 4,0 m and 6,0 m. There is no determination of a minimum size for the device. However, must be ensured that the air circulation be uniform in the region of interest, that there is a good control of temperature and also that there is a volume of air around the sample to protect it from undesirable temperature gradients.

The main part of the equipment is hot box itself, its depth should be no greater than necessary to accommodate the heating and air circulation.

The Standard ASTM C1363-05 does not specify minimum measures for the hot box, only alert for possible errors, i.e., if a device is built with an area less than 1 m^2, but encompass a representative section of the element of interest, it will be complying with the requirements of the standard, however, their levels of uncertainty may be greater than a device with an area greater than 1 m^2.

Making a comparison between the dimensions commonly used in "Guarded Hot Box", according to ASTM C1363-05, and the dimensions of a calorimeter, it is observed that this device meets the standard's requirements, and the same thing can be said about the temperature ranges. Thus, the main analysis for this adaptation are focused on the dimensions of the sample, because it must be representative, and on the requirements of the hot box.

2.3. MEASUREMENT UNCERTAINTIES AND ERRO PROPAGATION

Sure that between the value read by a measuring instrument and the actual value of physical quantity there is an uncertainty inherent in the process, so, is necessary to know the factors that influence these errors and find ways to minimize them. According LIRA (2001), the main factors that influence a measurement are: environmental conditions where the instrument is exposed, the mathematical operations involved in indirect methods, the rounding, the conversions of units, estimated readings and the instruments involved.

The measured quantities in the specific test, in the "guarded hot box" are: temperature, electric power and length. Since the input quantities have uncertainties and that these values are used to find new quantities of interest, the results of these calculations are also subject to an error which must be considered.

Thus, using a suitable mathematical development, there is an expression for calculating the uncertainty of the output pattern. (TOGINHO FILHO et al. 2009).

$$\sigma_{\bar{R}} = \sqrt{\left(\left(\frac{\partial R}{\partial a_1}\right)^2 (\sigma_{\bar{a}1})^2 + \left(\frac{\partial R}{\partial a_2}\right)^2 (\sigma_{\bar{a}2})^2 + \ldots + \left(\frac{\partial R}{\partial a_n}\right)^2 (\sigma_{\bar{a}n})^2\right)} \quad (1)$$

Thus, the uncertainties are determined from measurement of output quantities, or secondary, considering the propagation of errors. It was found that after the calibration of temperature sensors, and applying the correction curve, the final value of the overall heat transfer coefficient, presented by the new device has a measurement uncertainty of ± 0.086 W /(m²·K).

2.4. TESTS AND RESULTS

The procedure for measurement of heat transfer characteristic of a wall, made with concrete brick, has started by the preparation of a representative sample. The elements were arranged in the typical configuration of a wall, using a dry mortar (Votomassa Multiple Use) and interlocking elements in order to provide rigidity and stability to the wall. The sample was made directly on the measuring window and enclosed by the EPS mask.

As the purpose of this paper discusses about a building element with nominal dimensions of 0.40m x 0.20m x 0.15m, the most appropriate and feasible option is use of an hot box area of 1m^2 (1m x 1m), with 6 full elements and 4 half elements, furthermore, is necessary to use an enclosing mask made with expanded polystyrene (EPS), as provided in standard. Thus the interest area becomes 0.64 m^2 (0.80m x 0.80m).

Temperature sensors were placed in the four quadrants of the sample on both sides, and also inside the central element in contact with the walls.

This representative sample was then tested in three different temperatures, so that the material was under typical conditions of use. Thus, take results enough to create of a behaviour curve, relating the overall coefficient of heat transfer in response to the temperature difference in which the material is exposed, i.e., differences in temperature of 30K, 25K and 20K on the sample.

These results demonstrate that a concrete block, used in buildings in Brazil, has insulation thermal characteristics, having thermal conductivity of about 0.86 W/(m • K) and if the air speeds on the sample surfaces has been kept at values lower than 0.3 m/s, the overall heat transfer coefficient of this wall will be about 3.37 W/(m² • K) ± 0.086 W/(m². K).

From the surface temperature of the brick, was possible to determine the thermal conductivity of the concrete used to manufacture the blocks. For this calculation, was applied the assumption of one direction (1D) to heat transfer, regardless of the brick geometry. Was used the wall temperatures, both internal and external side of the block, and yet, the rate of heat transferred through the wall. Thus, the value found for the thermal conductivity of the material is 1.67 W/(m•K) ± 0.1 W/(m•K).

2.5. FINAL REMARKS

This study concludes that it is possible both an adaptation of a calorimeter for a hot box protected as its reversal. It is necessary to use an insulated box within one of the chambers, sealing elements, and a special attention to the question of the minimum size of sample to be tested, in order to meet the requirements of ASTM C1363-05.

To the adaptation be possible, and because are used commercial elements to seal buildings which has fixed dimensions, was chosen a configuration with a smaller dimension than the calorimeter window space, and the use of a device predicted in ASTM C1363-05 said enclosing mask, which allows the sample be involved and ensure a minimum area of 1m² in the front area of the hot box.

Were calculated the uncertainties of each measuring instrument that makes up the equipment and also that uncertainties related of the thermal properties calculations. It was found that, after the temperature sensors calibration, and the correction curve application, the final value of the overall heat transfer coefficient, presented by the new device has a measurement uncertainty of ± 0.086 W/(m² • K)

The test results confirmed the thermal insulating characteristics of the concrete brick, and revealed the thermal conductivity of this sample as being of the order of 0.86 W/(m•K) and the overall heat transfer coefficient of vertical wall, around 3.37 W/(m²•K) ± 0.086 W/(m²•K).

Through the temperature readings at the surface of the concrete brick, it was determined that the thermal conductivity of concrete used to manufacture the block is about 1.67 W/(m•K) ± 0.1 W/(m•K), which revealed a large difference between measured data and literature data, which showed values of around 0.90 W/(m•K) for lightweight concrete. This difference may be attributed to several factors, since the type of material used, the porosity of the sample to the amount of moisture present in the sample, since there are in literature values of the specific thermal conductivity ranging from 0.12 W/(m•K) to 1.40 W/(m•K).

However, this fact does not invalidate the work done, but reinforces the need for a more thorough survey of these values, focused on the materials used in Brazil, not only for the concrete bricks as well as for ceramics, and other settings coating, since these data will be part of the thermal load of buildings and thus will influence the proper selection of HVAC equipment in search of a better thermal comfort and lower energy consumption.

3. ACKNOWLEDGEMENTS

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