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Thermal Testing of Building Insulation Materials

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THERMAL TESTING OF BUILDING INSULATION MATERIALS

Eoghan Frawley and David Kennedy, CEng, both of the Faculty of Engineering, DIT Bolton Street, Dublin explore the testing of building insulation materials and the development of a suitable testing apparatus.

Basic heating accounts for some 70% of the energy costs in a typical dwelling and without suitable insulation much of this energy is wasted [1]. It is therefore, easy to see why having an energy efficient house is so important, especially with the global price rise in fossil fuels and our greater awareness of global warming and energy wastage.
The 1997 building regulations (conservation of energy) sets minimum standards that buildings must meet to conserve energy consumption.
These standards were further amended in 2002 [2].
Furthermore, a new EU directive states that new buildings must have an energy performance certificate [3].
This in effect, means that the manufacturers of insulation materials must have a certified product that meets the building regulations in order for the building to obtain an energy performance certificate. When evaluating the energy rating of a building, it is obvious that the thermal properties of the building components must be known.
One way of ascertaining these values is to test the materials in a testing apparatus known as a "hot box". This research focuses on the testing of building insulation materials and the development of a suitable testing apparatus. A number of leading Irish manufacturers produce highly efficient insulation materials and currently there is no standardised testing facility in Ireland.

Hot box testing

The main purpose of a hot box is to evaluate the thermal properties, such as U-values and R-values, of materials. This is done by fixing the desired test specimen as a border between a hot chamber and a cold chamber as shown in Figure 1.
The hot and cold temperatures are held constant and are recorded. From this the heat transfer through the material can be found and, in turn, a U-value or an overall thermal resistance (R-value) can be calculated for the material. This is referred to as steady state heat transfer since the temperatures are held constant across the test specimen.

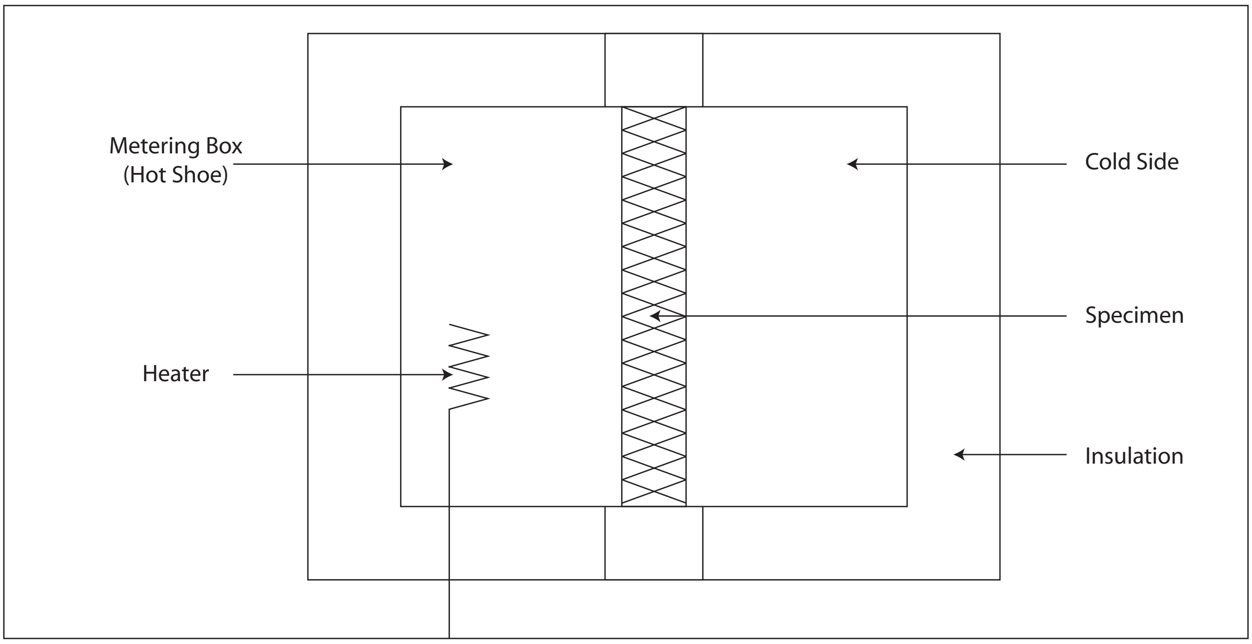
Hot box types

There are many different designs and types of hot boxes in use for experimental work. These different designs can generally be split into two groups; guarded hot box (GHB), and calibrated hot box (CHB). The GHB is the method mostly used in North America and in Europe.
The CHB is mostly used in a research environment. Other types of Hot Boxes include the wall and edge guarded hot box. This is a combination of the CHB and the GHB.

Calibrated hot boxes (CHB)

The CHB consists of two chambers, the hot side (also referred to as the indoor chamber) and the cold side (can be referred to as the outdoor or environmental chamber). Both chamber walls are made from a material with a very high thermal resistance (usually expanded polystyrene). The walls are made very thick so as to keep the heat losses to the environment at a minimum as major losses would lead to inaccuracies in measurements.

Figure 1: Calibrated Hot box



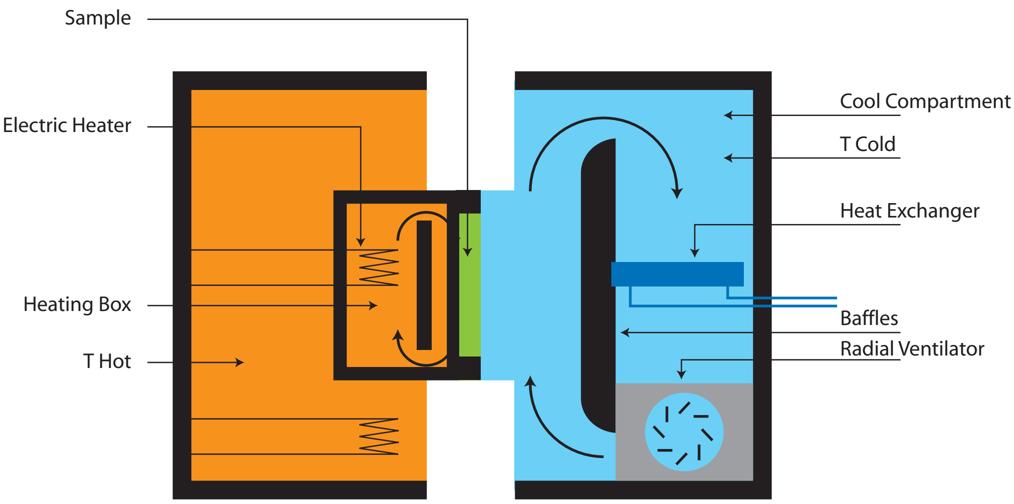


Figure 2: Guarded Hot Box

The test specimen is fixed into a surround panel that is located between the two chambers. The surround panel is also made from a highly thermal resistive material. The thickness of the surround panel varies according to the standard to which the hot box is built. Figure 1. shows a simple CHB [3].

Air is circulated in both chambers to prevent hot or cold spots occurring in the chambers.

The velocity of the air moving over both sides of the test specimen affects the heat transfer through the test specimen and this is accounted for in the calculations. Temperatures are measured at specific time intervals using thermocouples. The temperature readings are communicated via a suitable data acquisition system that store the information for the duration for the tests.

Guarded hot boxes

The GHB is very similar to the CHB. The main difference between them is that the GHB has two enclosures, instead of one, on the hot side as shown in Figure 2. These two enclosures are held at the same temperature and, because of this, little or no heat is lost through the walls of the inner box. It can be seen from Figure 2. that the air velocity is controlled by placing a baffle on either side of the test specimen (sample). A heat exchanger in the cold side, keeps the temperature there constant [3].

The GHB is, in the main, more accurate as its design results in fewer losses to the environment. One drawback with the GHB is that it takes smaller test specimens than the CHB for the same exterior size because of the extra wall on the hot side of the box.

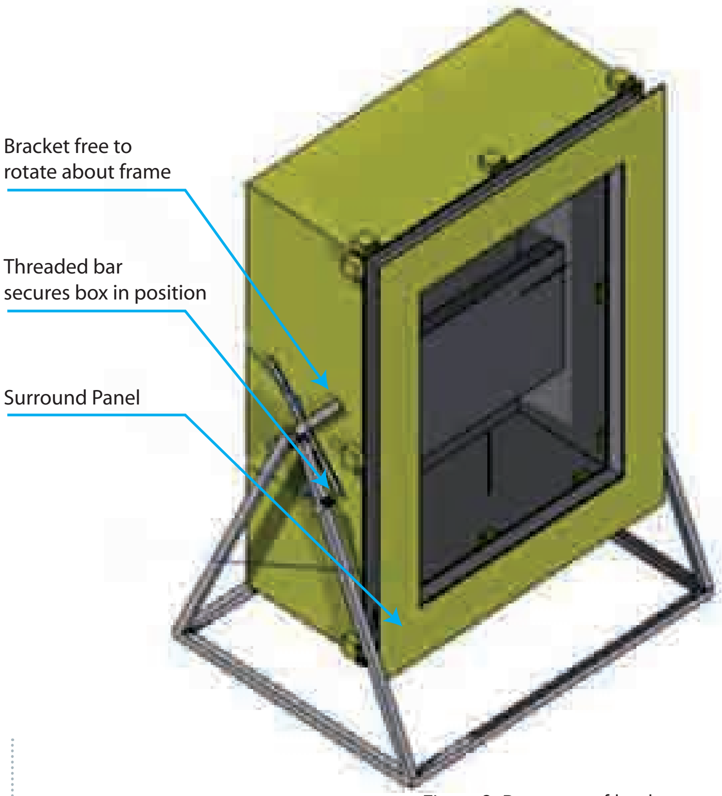


Figure 3: Prototype of hot box

The costs to produce either unit would generally be the same as the cost of having very thick walls for the CHB would approximately be equal to the cost of constructing an extra wall in the GHB. Further details on the GHB and the CHB can be found in the literature [4,7].

Design and development of hot box

In the process of designing and developing a hot box for thermal testing, the two types of hot boxes were examined in detail from international standards [4,6] and through analysis of various case studies on the subject. From these investigations, a simplified test rig was designed and developed in 2005 taking into account the following considerations:

(i) the design had to be simple and inexpensive. This resulted in a simplification of the control system and adaptations of the standardised test procedure and test rig design

(ii) to enable the test facility to be rotatable through 360º

(iii) to meet industry needs for testing.

Description of the designed test rig

Figure 3. shows the initial hot box prototype. The walls were made of highly thermal resistive material and plywood was screwed on either side of the insulation to add structural stability. It can be seen that the hot chamber was rotatable though 360°.

Six thermocouples were positioned inside the hot chamber and one thermocouple outside the hot chamber.

An electric fan circulated the air inside the box to create a

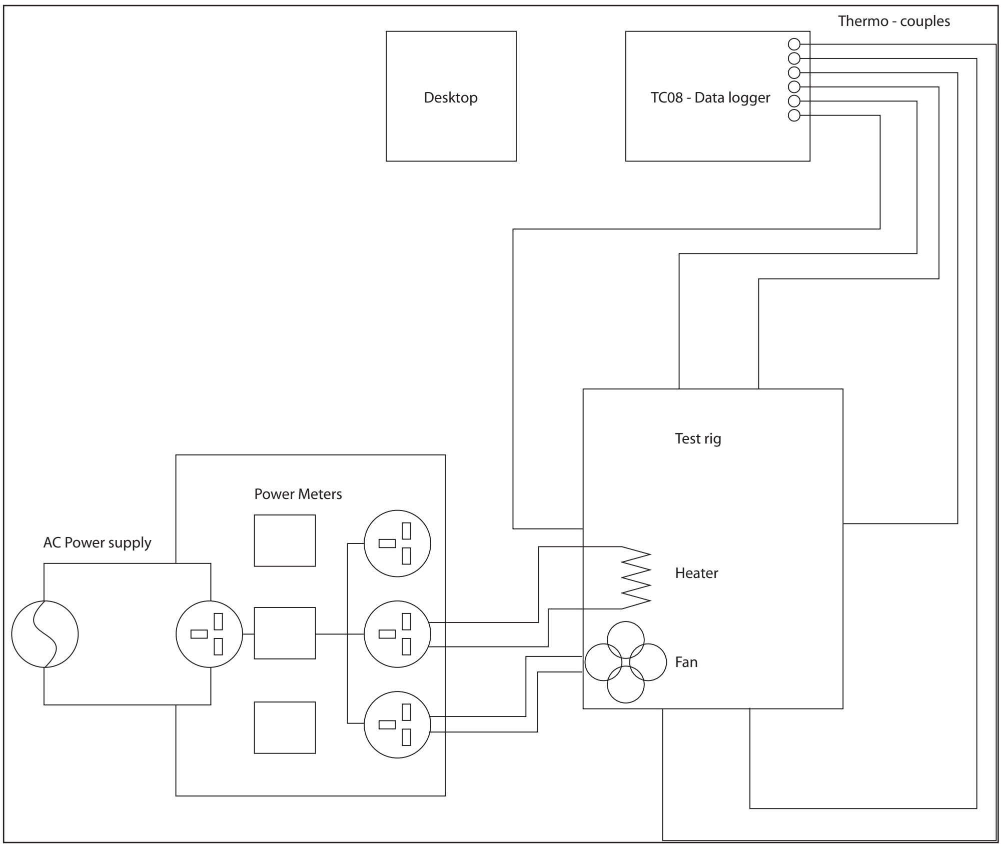
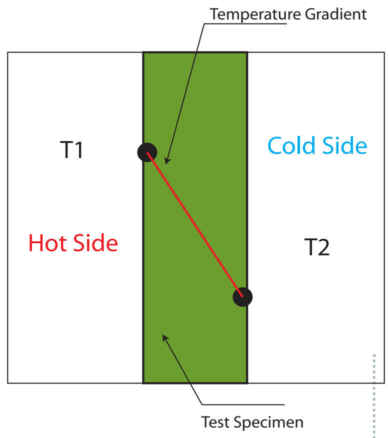


Figure 4: Wiring diagram of the testing facility.

Figure 5: Temperature gradient across specimen.



uniform temperature on the inside. A baffle was placed in front of the heater and the inside surfaces of the hot chamber were painted matt black to reduce radiative effects on the test specimen.

The surrounding room that the hot chamber was situated in acted as a cold chamber. The test specimen was fixed into the surround panel and sealed around its perimeter to ensure that no mass transfer (air in this case) occurred.

All the temperature readings were fed back to a data logger and that in turn stored readings of the thermocouples every minute. This was then displayed in a simple spread sheet. Wattmeter's also recorded the power input to the hot box. A wiring diagram for the test rig is shown in Figure 4.

Testing

The initial tests determined the heat losses through the box walls. This was done by testing specimens with known thermal properties.

If the thermal resistance of the specimen was known, the losses could be found by using the temperature differences across the specimen and the amount of power entering the hot chamber. These losses were then represented by a U-value for the whole box.

For the calibration panels

The box is heated up to steady state for that panel.

Each panel will have a different steady state temperature difference (ΔT). The surface temperature of the specimens for all tests was assumed to equal the air temperatures on both sides of the test specimen.

Equation1 was used as follows.

$Q = UA\Delta T$ .... (1)
Where;
Q = power (W)
U = Overall heat transfer coefficient (W/m^2K)
T = Change in temperature (K) (T1-T2)
A = Area (m^2)

Qin (the power supplied by the heaters) was measured using a wattmeter.

$$Qin = Qout$$

$$Qout = Qbox + Qspecimen$$

The following values for the materials were known:
Q panel, U panel, A panel, ΔT, Q in, A box

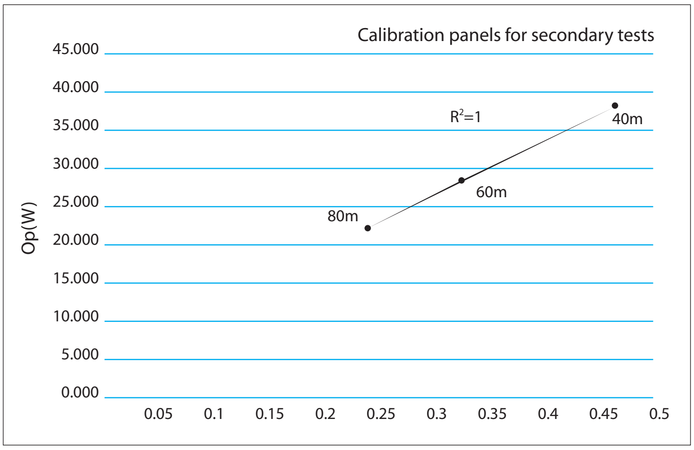
This only leaves one unknown:
U box :

$$Q\ box = Q\ in - Q\ specimen$$

$$(UA\Delta T)\ box = Q\ in - (UA\Delta T)\ specimen$$

$$\therefore\ UA\ box = \frac{Q\ in - (UA\Delta T)\ specimen}{(\Delta T)\ box} \quad \ldots\ldots\ldots\ldots.(2)$$

Figure 6: Graph for insulation panels.



Once the U-value for the box was known, specimens of unknown thermal properties could be tested.
Three tests were performed on known specimens and a U-value was found for the box walls. A graph was plotted of the heat flow(in watts) through the test specimen against the U-value of the three different insulation panels. As these two parameters are directly proportional, the graph would have to be a straight line. The graph for the three insulation panels is shown in Figure 6. It can be seen that the results gave a straight line and that also ensured that the losses calculated for the box walls were correct. A list of typical U values for building products are shown in Table 1.
Figure 7. shows a graph of three insulation panels and two PVC windows that were tested. The aim of these tests was

Table 1. Typical U values of Building products.

		U-Value (W/m2-K)
Wall (outer)	9" solid brick	2.2
	11" brick-block cavity - unfilled	1
	11" brick-block cavity - insulated	0.6
Wall (internal)	plaster, 4.5 inch brick, plaster	2.2
	plaster, 4 inch heavyweight block, plaster	2.5
	plaster, 4 inch lightweight block, plaster	1.2
	plasterboard, 4 inch studding, plasterboard	1.8
Floor (Ground)	solid concrete	0.8
	suspended - timber	0.7
Floors (Intermediate)	Plasterboard/ 8 inch joist space/ T&g boards - heat flow up	1.7
	Plasterboard/ 8 inch joist space/ T&g boards - heat flow down	1.4
Roof	pitched with felt, 50mm insulation	0.6
	pitched with felt, 100mm insulation	0.3
	flat, 25mm insulation	0.9
	flat, 50mm insulation	0.7
Window	wooden/uvpc frame, single glazed	5
	wooden/uvpc frame, double glazed	2.9
(the post April 2002 standard)	wooden/uvpc frame, double glazed - 20mm gap, Low-E	1.7
	metal frame, single glazed	5.8
Door	external solid timber	2.4

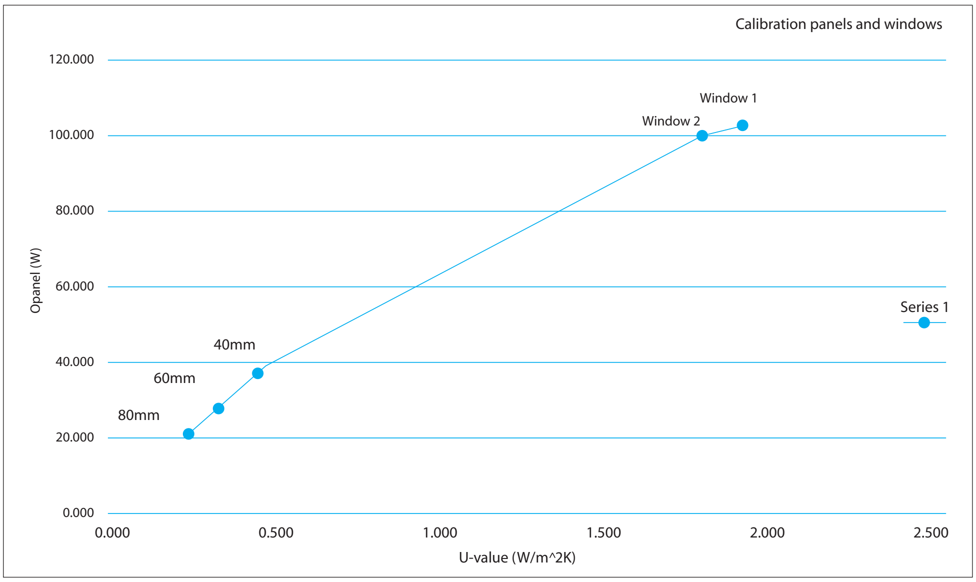


Figure 7. Graph for panels and windows.

to observe and plot the results to see if the straight line was continued. It can be seen from the graph that the windows did not follow the trend of the line and this showed the limited capabilities of the test rig developed.

From these tests conducted; it became obvious that the test rig would only work if the calibration panels (i.e. the three insulation panels of known thermal properties) have similar surface properties and have similar R-values to the specimens with unknown thermal properties.

This can be done by looking at the specimen with unknown thermal properties and making an educated guess of what range the thermal properties might be.

Calibration panels can then be chosen so that a more accurate value can be obtained for the unknown specimen. For example, suitable calibration panels for the windows that were tested would be other windows with known values. The test equipment is best suited to test a range of materials with high thermal resistances, the most obvious example of this being insulation materials used in buildings.

At the Department of Mechanical Engineering in DIT, a research project is currently underway to build a more sophisticated thermal testing facility to meet industry needs.

The scope of this project is to build a hot box with a hot chamber (similar to the chamber described in this article) and to add a cold chamber. This will require a more advanced control system and test procedure. This will result in a test with higher accuracy with a capability of measuring the thermal properties of a wider range of building materials. Φ

Acknowledgements:

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