Evaluate heat loss through windows by using Guarded Hot Box (GHB)

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Abstract. Windows are major part of construction design providing light, air and visibility and protect it from dust, it’s also provide comfortable environment for occupants. The good design for window according to the heat losses is effect on the energy performance for constructions. Houses losses 15% and gain 50% from the heat through windows. In nowadays design of windows is very important to conserve the energy and to reduce CO2 emission. In this paper we calculate heat loss by using Guarded Hot Box (GHB) for different types of windows. Thermal transmittance has been measured by finding thermal resistance according to the ASTM recommendations by using Guarded Hot Box (GHB). The results of heat loss which have been obtained by using guarded Hot Box (GHB) with different windows were close to the manufacturing results and references.

1. Introduction
Windows supplying the houses with light, heat and ventilation. But in the other hand big amount from heating of houses lost through the windows. Houses losses 10% from the heat through the windows. Windows lose heat during different way, radiation through glazing, conduction through window frame and air leakage around opening lights and frame. Around 70% of the energy lost from a standard window is through the glazing and a small amount of heat is lost through convection. Air leakage is second contributor for heat losses through frame of windows and depends on the state of the windows (old or new) and on the frame material (timber frames perform better than metal). Windows supplying the houses with light, heat and ventilation. But in the other hand big amount from heating of houses lost through the windows.

Heat losses through window are effected by the frame around the window, where the magnitude of the U-value influence with the manufacturing of the frame materials. The frame area will increase for windows with multiple openings multiple small panes of glass. Since the U-value of the frame is more than that of the glass, then window of the smallest frame area have less U-value and less heat losses. Due to the high visibility for occupants and allowing daylight into the building, windows have less thermally efficient compared with walls [1]. Using double and triple glazed windows reduce thermal transmittance more than 70% compare with the single glass. Also, using Argon gas in double glazed windows reduce thermal transmittance by 15% [2].

Hot Box is used to test thermal properties of composition of materials in multilayer, walls cavity walls and windows structures [3]. During the steady state, heat transfer coefficient or a U-value for the sample or thermal resistance can be obtained [4].

There are two types from hot boxes; Calibrated Hot Box (CHB) and Guarded Hot Box (GHB), each types consist of different parts. Guarded Hot Box (GHB) is different of Calibrated Hot Box (CHB)
with existing the metering box inside guarded box to reduce heat loss and to keep same temperature in the two boxes. Guarded Hot Box (GHB) used in this study to evaluate heat transfer through windows. Guarded Hot Box (GHB) is used to test skylight windows with alternative designs by the National Research Council Canada [5]. University of Ulster used Guarded Hot Box (GHB) according to the BS EN ISO 8990 to test of the insulating properties of evacuated glazing [6]. Guarded Hot Box (GHB) was used to evaluate heat loss in different types of windows single, double and triple glazing.

2. Experimental apparatus
The experimental has been done by using Guarded Hot Box (GHB) which is consist of two parts (hot zone and cold zone), as shown in Figure 1.

![Figure 1. Guarded Hot Box (GHB)](image)

Cold zone has one zone with external dimensions 1200x1200x600 mm and internal dimension is 1000x1000x500 mm, it’s includes refrigeration unit and ventilation unit, as shown in Figure 2. Hot zone has two zone guard zone and measured zone with dimension 1200x1200x600 mm and 800x800x300 mm respectively.

![Figure 2. Refrigeration and ventilation units](image)

The walls of two cells are isolated by 100 mm polyurethane. The materials to be studied (wall, door and window) are placed between the two cells and formed with dimension (1200mm width and 1200mm height) and thickness from 10 to 300 mm in order to be installed with the frame of the guarded hot box. The power supply 450 W for cold zone and 200 W for each zone (guard zone and measured zone). The cold zone supplying with 8 digital temperature sensors distributed throughout the volume of the zone while the hot zone supplying with 12 digital temperature sensors (8 for measure zone and 4 for guard zone).
3. Methodology

3.1. Guarded Hot Box (GHB)

Heat transfer through test specimen \( Q_{ts} \) in the measure zone of the hot cell, shown in Figure 3 can be expressed as:

\[
Q_{ts} = Q_{in} - Q_p - Q_w
\]  

(1)

Where \( Q_{ts} \), \( Q_{in} \), \( Q_p \) and \( Q_w \) represent heat transfer through test specimen [W], total power input [W], heat transfer parallel to test specimen [W] and heat transfer through metering box walls [W] respectively.

![Figure 3. Guarded Hot Box Losses [7]](image)

Influence of the heat loss through the sample outside GHB \( Q_p \) has been investigated by using two thermocouples type T made of copper and constantan with range of temperature -200 °C to +400°C). Sensor 1 fixed outside GHB to measures the temperature of the laboratory while sensor 2 fixed inside the wall used. The wall used is composed of three layers, external and internal layer from plaster with thickness 13 mm and glass wool material between them thickness 90 mm with boundary condition as shown in the figure 4.

![Figure 4. Boundary condition of the two cells during experimental]](image)

![Figure 5. Data logger and flowmeter used in experimental]](image)

The sensitivity of flowmeters used in the hot surface of the wall is 264 μV/ (w/m²) with accuracy 0.1 °C. (MV100 by YOKQAWA) data logger has been used to store the temperature as shown in figure 5.
Figure 6 illustrate the variation of the temperature for two sensors similar, that’s mean the temperature inside the specimen is similar of the laboratory temperature. The temperature of the two sensors not affected by the temperature of the hot cell which is regulated at 30°C.

![Temperature variation of the sensors](image)

Figure 6. Temperature variation of the sensors

So we can conclude that the heat loss $Q_p$ from measured zone to ambiance of the laboratory can be neglected and the heat transfer through specimen ($Q_{ts}$) from the measured zone can be expressed by:

$$Q_{ts} = Q_{in} - Q_w$$  \hspace{1cm} (2)

The value of $Q_{ts}$ has been obtained by fixing one flowmeter with sensitivity 264 μV/ (w/m²) on the hot surface of the measured zone. The value of $Q_w$ has been calculated by using the expression:

$$Q_w = \frac{A \Delta T}{R_w}$$  \hspace{1cm} (3)

Where $A$, $\Delta T$ and $R_w$ represent surface area of the metering box [m²], temperature differences between measured box and guarded box [°C] and thermal resistance of the wall of the measure box [m² K/w] respectively.

$Q_{in}$ is calculated by Guarded Hot Box according to methodology of supplying heat power from electrical resistance. The value of $Q_w$ has been calculated experimentally from equation (2) [0.02 W] and theoretically equation (3) [0.04 W]. The differences between two values coming from the accuracy of temperature measurement (temperature measured in ambiance not in wall surface and $Q_p$ negligible. During transient state (first hour of the test) the variation of the flow $Q_{in}$ is hug and there is a need to big amount of flow to stabilise temperature in cells. After thermal equilibrium obtained, the flow reached to the stabilised and $Q_w$ can be neglected as shown in figure 7.

When steady state is reached, $Q_{in}$ and $Q_{ts}$ are very high (8W) while $Q_w$ is near (or under) 0.1 W. So, for the hot cell, equation (2) can be expressed as:

$$Q_{ts} = Q_{in}$$  \hspace{1cm} (4)
3.2. Thermal transmittance for windows

The experimental has been done to investigate transmittance value for the window, we used two difference window first one PVC single glazed window 4mm, size 650mmx650mm, second one PVC double glazed window 4/16/4, size 650mmx650mm. the window in two case fixing on the polyurethane frame (1200mm x 1200mm and 80mm thickness). Argon gas use between double glazing as shown in figure 8.

Guarded Hot Box (GHB) used to measure the thermal resistance of the window then to calculate the value of thermal transmittance $U_w$. We calculated the total thermal resistance of the window (frame and window) according ASTM recommendation [8].

According to the Fourier law and heat flow on the direction normal to the plane of the window:

$$q_{tot} = \frac{(T_{hot} - T_{cold})}{R_{tot}} A_{tot}$$  \hspace{1cm} (5)

Where $q_{tot}$, $T_{hot}$, $T_{cold}$ and $R_{tot}$ represent total flow through window and frame [W], hot cell temperature [$^\circ$C], cold cell temperature [$^\circ$C] and total thermal resistance for window and frame [m$^2$ K/W] respectively.

The total flow through the wall is equal to the sum of the flux passing through the frame (polyurethane) portion $q_f$ and the window $q_w$. 

![Figure 7. Heat losses during the experimental test](image-url)

![Figure 8. Window use in experimental](image-url)
\[ q_{tot} = q_f + q_w = \frac{A_f}{R_f} + \frac{A_w}{R_w}(T_{hot} - T_{cold}) \]  

(6)

Hence, by identifying:

\[ \frac{A_{tot}}{R_{tot}} = \frac{A_f}{R_f} + \frac{A_w}{R_w} \]  

(7)

Where \( A_f, A_w, R_f \) and \( R_w \) represent area of frame [m²], area of window [m²], thermal resistance for frame [m² K/w] and thermal resistance for window [m² K/w] respectively.

By definition:

\[ R_f = \frac{d_f}{\lambda_f} \]  

(8)

\[ R_w = \frac{1}{U_W} \]  

(9)

Where \( d_f, \lambda_f \) and \( U_W \) represent thickness of the frame [mm], thermal conductivity for frame [w /m K] and thermal transmittance for window [w /m² K] respectively.

Therefore:

\[ U_W = \frac{1}{A_w} \left( \frac{A_{tot}}{R_{tot}} - \frac{\lambda_f A_f}{d_f} \right) \]  

(10)

Where \( U_W, A_{tot} \) and \( R_{tot} \) represent thermal transmittance for window [w /m² K], total area for window and frame and total thermal resistance for window and frame [m² K/w].

The principle of Measurement depends on the heat transfer from the hot cell to the cold cell and observe the temperatures on both sides of the window, we deduce the value of thermal resistance and thermal transmittance.

The window is place between the two cells and select the boundary conditions (25 C° and 10 C°) inside hot and cold cell respectively. We wait until the two cells are reached to the thermal equilibrium then the results can be collected for the variation of temperature, variation of flow and variation of thermal resistance.

As mentioned previously, the most heat losses through windows accrue during the conduction (this study neglected the convection).

The heat losses through the surface (window) is calculated as equation:

\[ H = U \cdot A \cdot \Delta T \]  

(11)

Where \( H \) and \( U \) represent heat loss [W] and thermal transmittance [W/m².K] respectively.

Using double and triple glazed windows reduce thermal transmittance more than 70% compare with the single glass. Also, using Argon gas in double glazed windows reduce thermal transmittance by 15% [9].

Thermal transmittance for single glass is about 6 [W/m²K] and it’s less during use double glass filling with air or Argon [10].
4. Results and discussion

The experimental procedure measurement stabilization the temperature of the hot side and cold side of the cells at 25 °C and 10°C respectively. The temperature variation reached to the steady state after half an hour as shown in figure 9.

![Figure 9. variation of temperature during the test](image)

Heat flow (W) transmitted from hot cell to the cold cell according to the test time shown in figure 10. Heat flow has been reached to the stabilization after one hour. The huge variation in the first half hour due to the regulation between two cells before reached to the steady state.

![Figure 10. variation of flow (w) during the test period](image)

During experimental procedure, total thermal resistance of the window by using the average value has been investigated. The calculated thermal resistance is 0.92 [m²K/W] as shown in figure 11.
Referring to equation (9) and according to the ASTM recommendations, thermal transmittance $U_w$ for single and double glazing window were 5.6 [W/ m²K] and 1.09 [W/ m²K] respectively. Heat losses through the surface (window) have been calculated for single and double glazing window according to the equation (11). The heat loss for single glazing window was five times of the double glazing window. Table 1 illustrate the results of thermal transmittance and heat loss for two tests (single and double glazing).

**Table 1. Thermal transmittance and heat loss**

| Glazing types                  | $U_w$ [W/m²K] | Heat loss [W] |
|-------------------------------|---------------|---------------|
| Single 4 mm                   | 5.6           | 53.8          |
| Double with argon (4/16/4)    | 1.09          | 10.5          |

### 5. Conclusion

Thermal performance of the glazing has been investigated by using Guarded Hot Box (GHB). This device can be considered suitable to create realistic climatic conditions during measurement of thermal properties of windows. Two cells of guarded hot box (GHB) have been calibrated by using multilayer wall (plaster+ glass wool + plaster). Thermal transmittance investigated for single glazing 4 mm and for double glazing 4mm glass, 16 mm gap with argon and 4 mm glass. The experimental results were agreement with the references and showed importance of double glazing for saving heat in buildings.

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