Trends and Developments in Window Testing Methods

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ABSTRACT

Physical testing of fenestration products is still one of the most reliable tools for determining their thermal performance. Before the wider availability of user friendly computer programs for simulating heat transfer and solar optical properties of windows, physical testing was the primary means of determining indices of performance, like U-factors, Solar Heat Gain Coefficient, Condensation Resistance, etc. Even today, with the wide availability of accurate computer programs, it is necessary to validate computer-modeling results against physical testing as a means of reality checking. This paper will primarily talk about U-factor and Condensation Resistance capable testing apparatuses, or so called Hot Boxes.

Currently there are several different designs of Hot Boxes in use throughout the world. In North America two primary hot boxes in use are; guarded and calibrated hot box. The main difference between the two is that for guarded hot box there is a dedicated guard room at the roughly same temperature as metering room, while for calibrated ones, there is no such a room, but rather the testing environment is kept at controlled conditions. In Europe, primary design in use is guarded hot box, although United Kingdom uses modified wall and edge guard design, which is somewhere between calibrated and guarded design. The common feature among all of these boxes is that extraneous loss is kept at minimum, while energy flow through the fenestration specimen is considered as a primary measurement, used for later data reduction and calculation of U-factors. On the other side, majority of countries of former Soviet Union use completely different design, where the total energy flow is not directly measured, but rather several surface heat flow meters measure local heat flow from indoor side surfaces. For this design, extraneous loss becomes irrelevant, as long as the steady temperature can be maintained on both sides.

This paper gives short overview of the most important features and issues associated with each design, and discusses next generation of testing devices that is currently under development. Sponsored by U.S. DOE, a reference Hot Box design is being developed by University of Massachusetts and National Fenestration Rating Council. International review board was established to provide comments and input into this design, with the intention to develop best design at the most economical price. Preliminary design and discussion of main features of this reference Hot Box, also referred to as Universal Hot Box, is provided in this paper, along with the discussion of future directions in testing and evaluating thermal performance of windows and other fenestration systems in general.

OVERVIEW OF FENESTRATION THERMAL TESTING METHODS

There are two main methods of measuring thermal properties of fenestration systems. Hot box methods (Integrated methods) and Local heat flux methods (Discrete methods). Both methods mainly try to evaluate total heat flow through the window, which is then converted to a heat transmission coefficient, or U-factor (referred as k-factor in some countries). U-factor is a quantity of energy flow per unit area and unit temperature difference, which makes it quite universal and applicable to wide range of sizes and temperature differences. Another use of thermal testing devices is condensation resistance of a fenestration product. Temperatures are measured on the indoor side of a fenestration product, both glass and frame surfaces, and based on those temperatures some form of condensation indices is established.

Hot box method can be roughly divided into calibrated and guarded hot box designs. Predominant design in European Union countries and North America is guarded hot box, while calibrated hot box is more used in research environment. Local heat flux methods were used in countries of former Soviet Union, and are still predominant methods in majority of those countries. In Baltics, there is a plan to migrate to CEN standards and therefore to integral, hot box method. In addition to the method of measuring energy flow through the window, other main design features are: range of testing temperatures, both on indoor (room) side and outdoor (environmental) side; air flow direction on outdoor side; air flow speed on outdoor side; shielding of heat sources and sinks, and some other minor details.

Calibrated hot box has two main chambers, warm side chamber (also known as indoor or room chamber) and cold side chamber (also known as outdoor or environmental chamber). In between them there is a surround panel, which separates two chambers at different temperatures and air movement regimes. Both chambers are made of highly insulating materials with very thick walls, so that the loss to the surrounding space in which hot box is situated is kept at the minimum. This is very important since the total (integrated) energy flow from warm to cold side is being measured, and any extraneous losses need to be kept at a minimum. The surround panel is also made of highly insulating material to reduce the heat loss. The surround panel contains an opening in which the testing specimen is being mounted. Depending on the particular country and corresponding national standard, the thickness of the surround panel is limited to the thickness of the test specimen plus some additional allowed quantity (usually 1 in. or lower). The reason to limit this thickness is to avoid significant sheltering for corner regions of the test specimen. The name “calibrated” comes from the design feature of the box to subtract all extraneous losses (any loss other than heat flow through the test specimen itself) during the calibration procedure. Therefore, homogenous surround panel (without opening for test specimen) is mounted in the box and several calibration runs are performed in which temperature differences between warm chamber and surrounding space or warm and cold chambers are kept at the minimum (but not at the same time). The temperature differential is varied during those calibration runs so that curves of extraneous heat loss vs. temperature difference across separating walls are plotted. During the actual runs, these temperature differences are measured and corresponding heat flow subtracted from the total measured heat flow:

$$Q = Q_t - Q_{mb} - Q_{sp} - Q_{fl}$$

where,

Q_t = total measured heat flow [Energy – *J* or *Btu*]

Q_{mb} = heat loss through the metering box (warm chamber) walls [Energy – *J* or *Btu*]

Q_{sp} = 1-D Heat loss through the surround panel, calculated from the known thermal conductivity of the surround panel material and measured temperatures on surround panel surfaces [Energy – *J* or *Btu*]

Q_{fl} = flanking loss through the edges of surround panel [Energy – *J* or *Btu*]

Guarded hot box method is very similar to calibrated method, but the main difference is that the metering box walls loss, Q_{mb}, is kept at very minimum by utilizing an extra guard chamber surrounding metering chamber. The temperature in guard chamber is kept at the same level as in metering chamber, so that metering box wall loss is kept at minimum. This loss can not be lowered to a theoretical zero, because of local variations in temperature which are generally non zero. Still, these losses are kept very small.

It is difficult to determine which method is better, because they both have advantages and disadvantages. Guarded method generally achieves better accuracy because of lower extraneous losses. However, the main disadvantage of guarded method is that the size of test specimens that can fit into the box is smaller for the same exterior size of the hot box apparatus, due to the presence of additional guard chamber. The cost to manufacture the testing apparatus is comparable because the thickness of exterior walls can be smaller in guarded method while there is an additional cost of building guard chamber.

There is a third known design of hot box called: “Wall and Edge Guarded Hot Box”. This design utilizes the method that falls somewhere in between calibrated and guarded hot box. The metering box walls are guarded, but instead of separate guard room, unique set of plate heaters are incorporated into metering box walls so that the temperature difference is kept at minimum through the use of additional control system that turns individual plate heaters on and off. In addition, surround panel edges are guarded by metal plates (yes, metal plates!) located on the perimeter of surround panel. Plates are continuous from warm to cold side and their temperature on each end is maintained at the air temperature level for each side so that the same temperature gradient is maintained at the edge and through the rest of surround panel. This way 2-D edge effects are minimized and heat transfer through the surround panel is more uniform. The control of end temperatures is achieved through the use of additional plate heaters on the warm side and fin surfaces on the cold side. This design has the potential to provide the highest accuracy of all hot box designs, but its main disadvantage is very complex and intricate control system and requirement that test operators have high qualifications to run the test. It is more suited for the research institution than for commercial level, day to day testing.

As opposed to integrated, or hot box methods, in majority of countries of former Soviet Union entirely different method is utilized. This method, which can be called “Local Heat Flux Method” is based on measurements of surface heat fluxes at discrete locations on the window and interpolation/extrapolation of those fluxes for the remaining surfaces on the window in order to calculate the overall heat flow. The testing apparatus consists of warm and cold rooms and surround panel, just as in hot box methods. Another similarity with hot box methods is that the air is also maintained at predetermined set point temperatures and air speed is maintained at certain level through the use of fans and blowers. The main feature of this method is absence of the need to tightly control extraneous energy flow, since total energy is not measured at all. In some situations, even highly conducting surround panel walls are used to separate hot and cold side. Even though the energy going through the surround panel is not measured, use of conducting materials may contribute to non-homogenous conditions inside the hot box, and therefore higher uncertainty.

One of the big advantages of discrete methods is their inherent ability to record local information about heat transfer in certain section of the window, and therefore can be more useful in design process.

Both methods utilize thermocouples for temperature measurements, although the significance of recorded temperatures depends on a particular method and standard. In discrete methods measured temperatures have much more effect on final numbers, because those temperatures are used as additional interpolation data to calculate overall U-factor. In integral or hot box methods, temperatures may play more or less significant role, depending what kind of standardizing procedure is used, but in the absence of standardizing procedures, surface temperatures may not be necessary at all. In addition to specimen, and surround panel surfaces, temperatures may be recorded on baffles, and testing chamber walls (hot box methods).

NEW TRENDS IN HOT BOX METHODS

Increased use of computer modeling in evaluating fenestration thermal performance has somewhat changed requirements and expectations from hot box testing. What was only recently considered to be good enough accuracy of ± 10% in measured U-factor is being revised to be closer to ± 5%. In addition, new indices of performance, like condensation resistance index (CI) requires more precise measurement of surface temperatures on the warm side. Review of current round robin data reveals that differences in surface temperatures between various testing laboratories can be as high as 10 C (NFRC 1999 round robin data). While these numbers are certainly extremes and they are result of a problem in a testing setup, which needs to be investigated on a case-by-case basis, they do point to a problem with the measurement of localized properties that needs to be addressed. Typically, the variation in surface temperature measurements is on the order of couple of degrees, which is still too high.

University of Massachusetts and National Fenestration Rating Council are developing the new Reference Hot Box design (Curcija and Shah 2000), sponsored by U.S. Department of Energy. International review board was established to provide comments and input into this design, with the intention to develop best design at the most economical price. Preliminary design and discussion of main features of this reference Hot Box, also referred to as Universal Hot Box, is provided in this paper, along with the discussion of future directions in testing and evaluating thermal performance of windows and other fenestration systems in general.

In order to achieve better accuracy, for both U-factors as an averaged quantity, and temperatures as a local quantity, more homogenous testing conditions, along with the minimization of extraneous losses need to be achieved in a design of a hot box. Because all of European hot boxes utilize so-called parallel flow design, which refers to a direction of airflow on the cold side, this setup only will be addressed here.

One of the most important factors that affect uniformity is the uniformity of airflow around specimen. Because convection heat transfer is proportional to the velocity of the air flowing over the surface, as well as bulk temperature it is important to ensure fairly uniform velocity and temperature profiles approaching fenestration product. This can be ensured by the proper calibration process in which selected screens are placed perpendicular to the flow direction and measurement of velocity and temperature profiles of the air stream. In addition, segments of nichrome wire should be placed across the stream and selectively heated until the temperature is uniform across the stream.

Other important factor in achieving uniformity in a hot box is to have uniform baffle temperatures. Providing sufficient flow of air over the baffle surface, as well as increasing the surface heat transfer coefficient from the backside of the baffle, is one way to achieve this goal. The more isothermal the baffle is, the better uniformity in radiative heat transfer exchange is achieved and therefore, more consistent temperature readings will be achieved.

Extraneous heat loss is particularly important on the warm (measuring) side. To minimize extraneous heat loss through the metering chamber, guarded box design is recommended. The guard room is built around the metering room (see Figure 1) and temperature in the guard room is kept as close as possible to the temperature in the metering room, so that temperature difference, and therefore heat flow between the two chambers is minimized. One important detail about this design is that very often this difference is kept minimal in an average sense, but local variations could be more significant, producing non-uniformities, especially in the corners. Universal hot box design answers this challenge by introducing a box around the metering chamber and set of fans (Flow Redirection System) so that the existence of dead spots around the metering chamber is minimized. Presence of heaters as well as points of supply of cold air behind the flow redirection system provides means of precise control of temperature of the air between the guard room and metering room, while the box of the redirection system itself provides radiation shield. Some of the details of the construction of Universal Guarded Hot Box are given in Figures 2 to 6.

In addition to proper design and construction of the testing apparatus itself, it is also very important to revise and upgrade testing standards, so that results have physical meaning and that comparison with computer simulation results produces good and consistent agreement. This effort is done through the national standardization body, as well as through the International Standards Organization (ISO). Currently, ISO hot box testing standards are being revised, and a new standard method specifically formulated for testing fenestration systems is being developed (ISO 2000a, ISO 2000b). In addition to standard methods, technical reports and guidelines are being also developed to guide and help laboratory personnel execute tests properly (ISO 1997).

CONCLUSIONS

- Window hot box testing is an essential part in the process of evaluating thermal performance of fenestration systems
- Hot box apparatus is the best way to determine thermal properties of fenestration systems
- New generation of hot box apparatuses are being developed to provide better validation point and to produce more accurate results.
- Testing standards are being revised and updated to reflect new developments in testing technology

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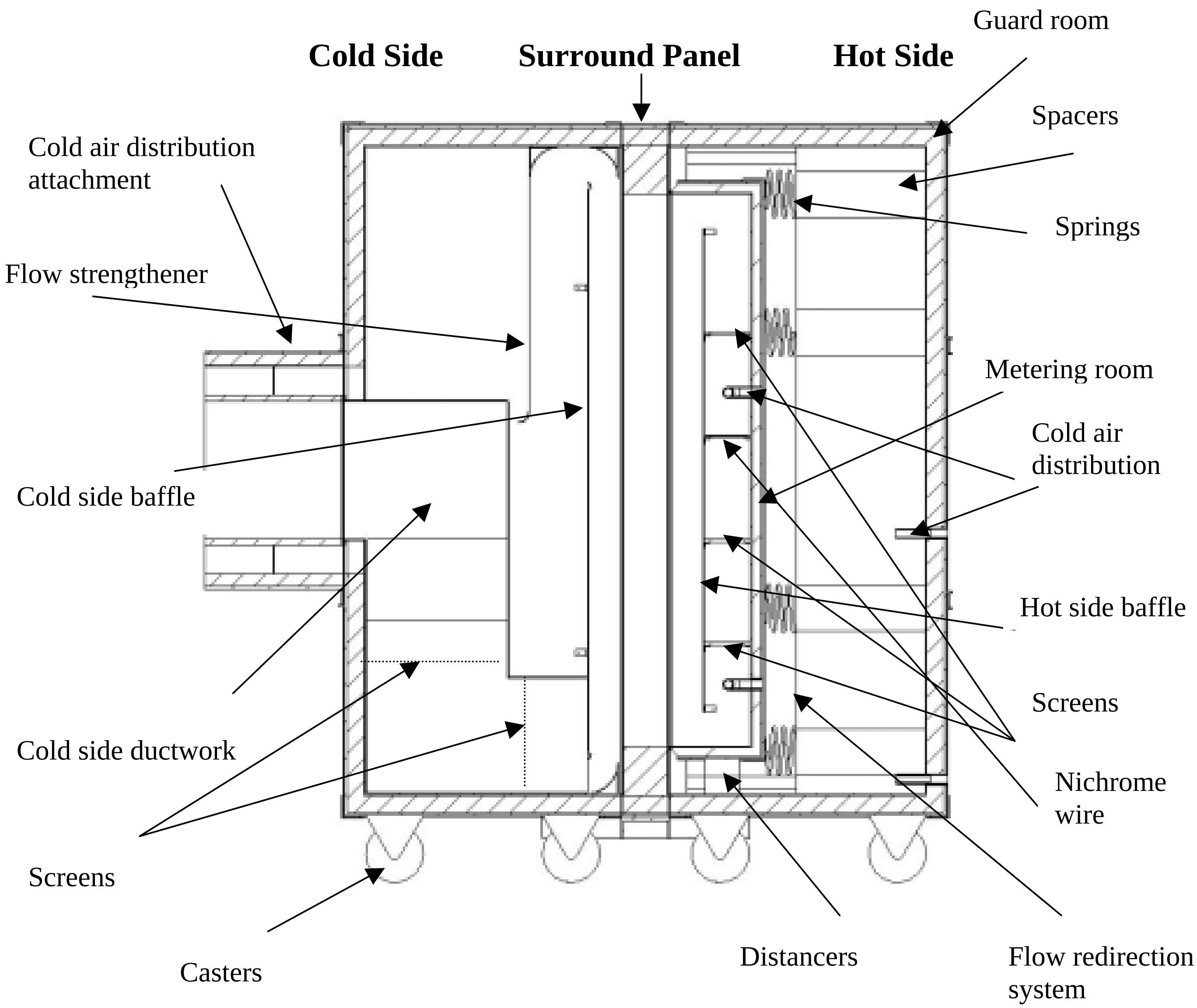

Figure 1. Vertical cross section of the Universal Guarded Hot Box

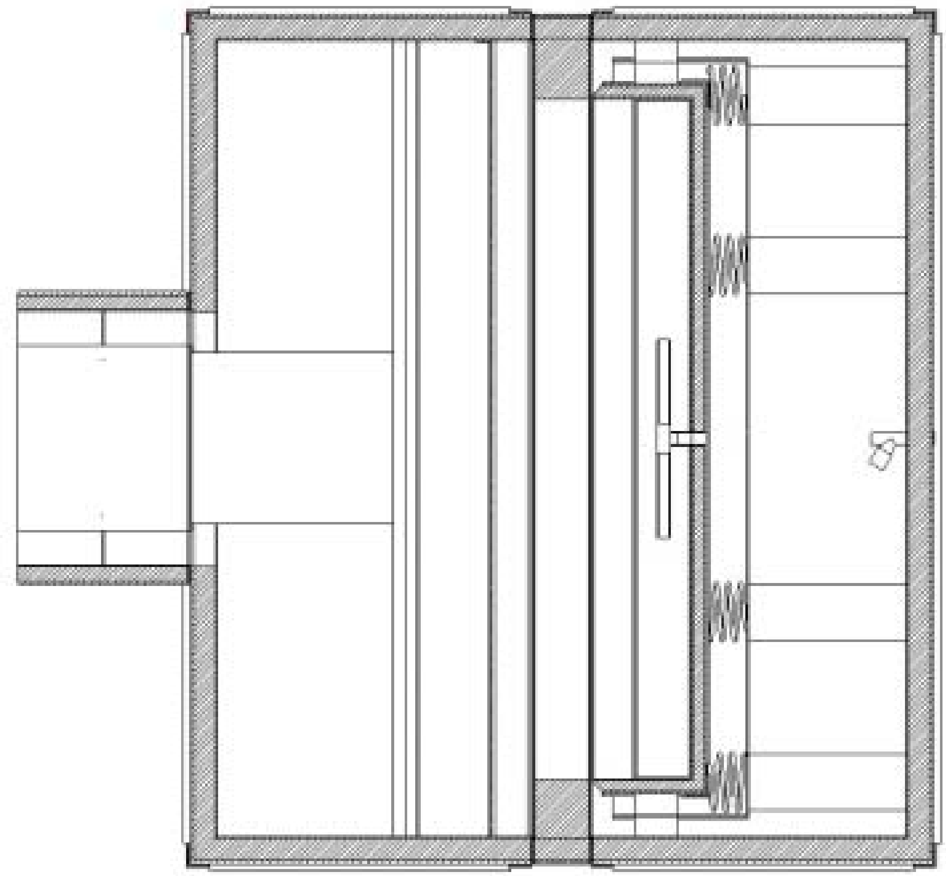

Figure 2. Horizontal Cross Section of the Universal Guarded Hot Box

Figure 3. 3-D Views of the Universal Guarded Hot Box

Figure 4. View at the Open Universal Guarded Hot Box

Figure 5. Exploded Views of the Cold Side of Universal Guarded Hot Box

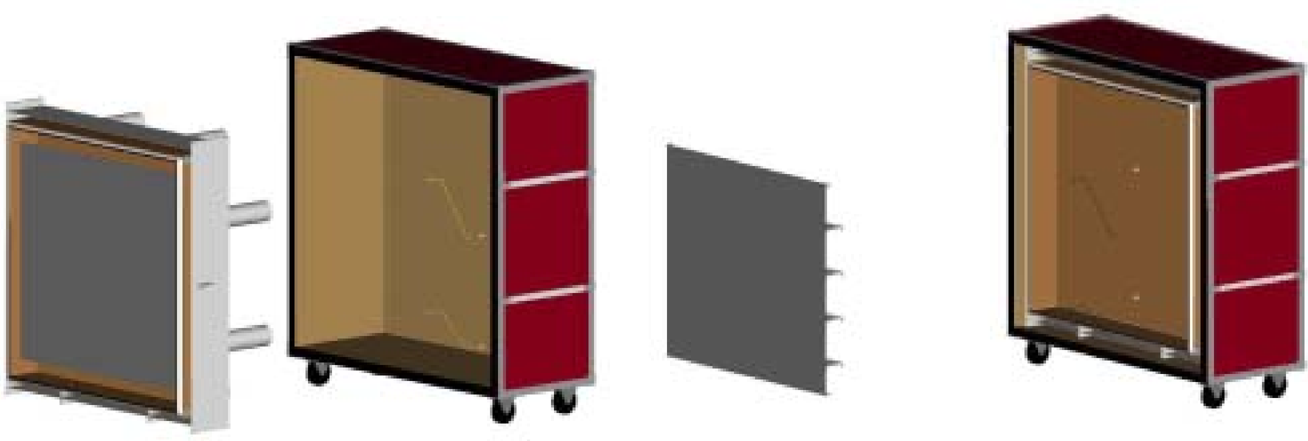

Figure 6. Exploded Views of the Hot Side of Universal Guarded Hot Box