Designing of a Guarded Hot Box

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ABSTRACT

In 1997 several countries ratified the Kyoto protocol and so engage themselves to take into account the global warming, promote the sustainable development and act in order to reduce emission of greenhouse gases. Within this context, energy in buildings is known to be one of the first greenhouse gases emitting sector. Consequently, determination of steady-state thermal transmission properties for each kind of façade components becomes necessary in order to evaluate accurately energy loss, to develop and enhance new products. Such determination should also lead to a better understanding of physics phenomenon. One way to determine these characteristics is the guarded hot box method. This experimental process, recognizes by the international scientist community, gives an accredit measure of conductance. The experimentation consists in placing a specimen between a hot and a cold chamber in which the environmental temperatures are measured and controlled.
In 2005, the Building Science Laboratory started the designing of a guarded hot box. Several elements step in this project. Indeed, validity of measure is certified under numerous conditions presented in ISO 8990 *"Thermal insulation – determination of steady-state thermal transmission properties – Calibrated and guarded hot box"*

The work described here is the designing phase of the box, which is oriented and thought in order to assume the best accuracy, obtain the necessary conditions of homogeneity and respect prescriptive criteria list. The designing involved the creation of CFD pre-designing models as decision support system. Thus, some predictive models were created in order to approximate the main dimension of the device and then designing the box integrating general constraints as for example weight or local dimension.

KEYWORDS

Guarded hot box, thermal properties, energy performance, building

INTRODUCTION

The steady state thermal performance of building's elements can be measured by means of the guarded hot box method. The thermal properties at stake here are thermal transmittance and surface coefficient of heat transfer. Both of them represent crucial points for the reduction of energy building consumption. The guarded hot box method is a real scale experiment. It consists in recreating homogeneous conditions, close to standard values in buildings, and measuring the loss through a specimen. Those specific conditions are set in accordance with ISO 8990 and ISO/FDIS 12567:1999(E). Principally, these recommendations deal with thermal homogeneity, constant velocity of the air flows and adiabatic conditions for the metering box.

THE EXPERIMENT AND THE STANDARD RECOMMENDATIONS

The guarded hot box method

The experiment is illustrated in figure n°1. A real scale specimen (wall, window, and door) is placed between two air masses. One air mass symbolizes the warm side; it means, in winter condition, indoor. The second one symbolizes the cold side; it means, in winter condition, outdoor. Each air mass is controlled and set to fit standard indoor or outdoor values.

The real critical point and core of the experiment is the metering box where the flow injected is accurately measured. The determination of the thermal flow that passes through the specimen represents a major preoccupation. Consequently, the walls of the metering box need to be adiabatic. Furthermore, the representativeness of the measure depends on the temperature homogeneity.

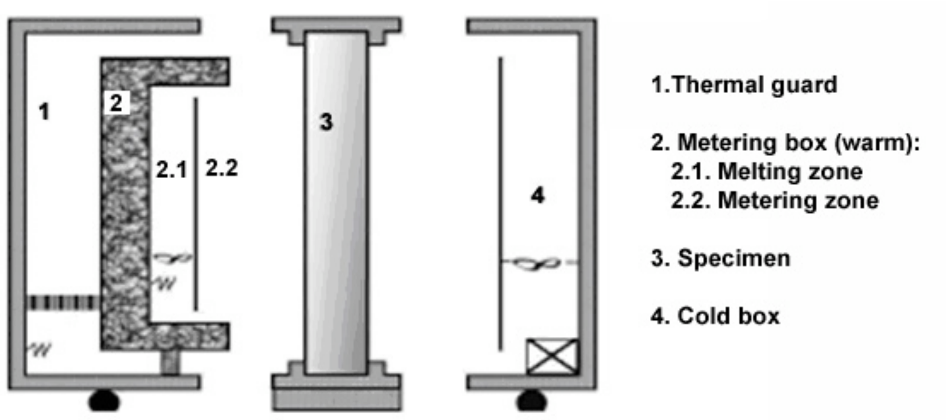

Figure 1: The guarded hot box method

Standard recommendations

Reading the norm allows to extract some useful recommendations to orientate the designing. Most of them concern the thermal homogeneity in the metering zone, with some indication about the range of values requested. Indeed, the acceptable homogeneity in the metering box is specified as inferior to 2K/m. This homogeneity has to be obtained considering some range of air velocity. Moreover, the average difference between the temperatures in each box must be around 20 degrees with respective value close to standard condition. Then, as the metering box walls can not be perfectly adiabatic, the norm defines the acceptable maximum loss as 10% of the estimated flow through the specimen. All these points were integrated as designing constraints.

ASSISTED DESIGNING, CFD MODELS

CFD models were used in order to anticipate the performance of the box. According to the standard recommendations, the experiment was split into different parts and reproduced with CFD software. These three parts are the metering zone, the melting zone and the thermal guard. Each part was handled independently according to few hypotheses.

Thermal guard:

The thermal guard aim is to minimize the loss of the metering box so that its wall can be supposed adiabatic. This fact points up two orientations. First the metering box is obviously well isolated. Thirty cm of extruded polystyrene (thermal conductivity inferior to 0.030 $W.m^{-1}.K^{-1}$) are contemplated. Then, the temperatures into the thermal guard and the metering box are set up in a way that the temperature difference between extern and intern wall of the metering box would be close to zero. Consequently airflows around the metering box have to be constant and homogeneous. It involves that no cross flows are allowed. The design of the guard is oriented by the creation of a flow path responding to these constraints. The guard can be divided into three parts: two symmetric lateral guards and the central guard as represented on the figure 2. Assuming the homogeneity of air temperature in the metering box and that its walls are adiabatic, the three parts can be handled independently. CFD models were used here to set the minimal acceptable space between extern walls and metering box walls. The gap between the walls needs to be wide enough so that the loss from the extern wall does not disturb the thermal homogeneity around the metering box extern surface.

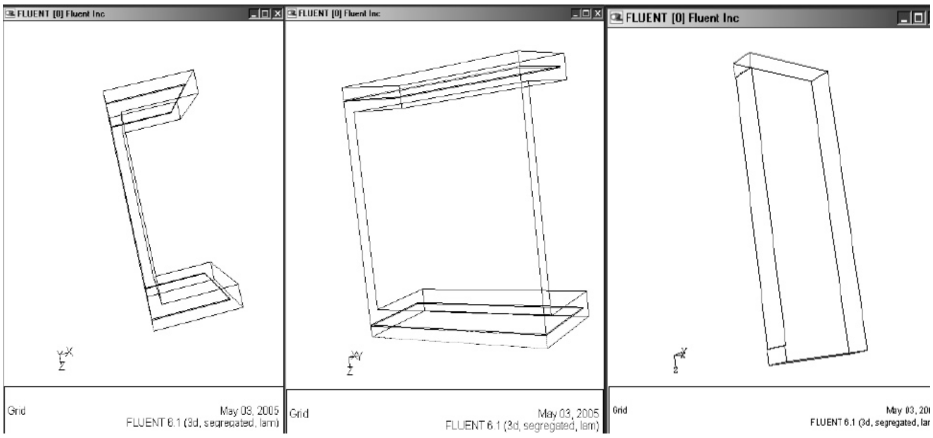

Figure 2: 3D design of the thermal guard

Metering zone:

In the metering zone, the density of temperature sensor is obviously the most important of the whole device. The main interrogation there is the representativeness of measured temperatures. No air temperature sensor should be located in the boundary layer linked to the loss through the specimen. Consequently, a CFD model was used to determine the thickness of the boundary limit and the influence of the baffle position, considering that all the other walls are adiabatic

The model is centered on the tested wall. As Fluent™ handled only one dimension conduction; the tested wall is a thin double-faced wall splitting two symmetric ambiances: one cold, one warm. In an ideal case, these zones are alimented with a homogenous constant air flow. The hypothesis of a constant and homogenous air flow input is admitted as this condition is absolutely necessary to fit the standard recommendations.

The aim is to design a metering zone wide enough to put some temperature sensor out of the boundary layer, and tight enough to have well controlled and unilateral air flow direction.

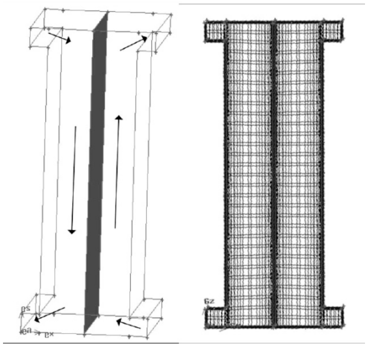

Figure 3: 3D design of the metering zone

Melting zone:

The melting zone aim is to produce a constant and homogenous air flow for the metering zone. The input flow coming from the metering zone is constant and non homogenous and its temperature ought to be colder than the reference. In this zone, the air is warmed and melted in order to produce the necessary air flow. All the walls are considered as adiabatic walls, admitting that the source of the non homogeneity is quite exclusively the loss from the specimen. Consequently, the evaluation criterion of this zone is the quality of the melting. The designing trick used to favor the melting is the installation of fins in order to extend the flow path. These fins also offered the opportunity to attach the heating system. The simulation is used to evaluate the efficiency of this solution.

RESULTS

According to these simulations (see Figure 4), some specific dimensions are settled and the main design confirmed. The model of the thermal guard allows evaluating the disturbance from the exterior temperature in standard condition. An average thermal loss per surface of extern wall is evaluated considering a 10K difference between the exterior and the thermal guard and a 10 cm thick extruded polystyrene wall. The thickness of the boundary layer defines the acceptable minimal space between the thermal guard and the metering box.

In the melting box, the results show the influence of the fins on the melting. The input flow is set as non homogenous, with a gradient greater than the 2K/m recommended by the standard. The heating system is symbolized by a cylindrical wall, dissipating a constant density of thermal flow. According to the simulation, the fins appear as a simple and efficient solution

In the metering zone, as expected, the configuration allows obtaining a homogenous vertical flow even with a non isolating specimen. As in the thermal guard, the boundary layer thickness acquaints us on the minimal acceptable gap between the baffle and the specimen.

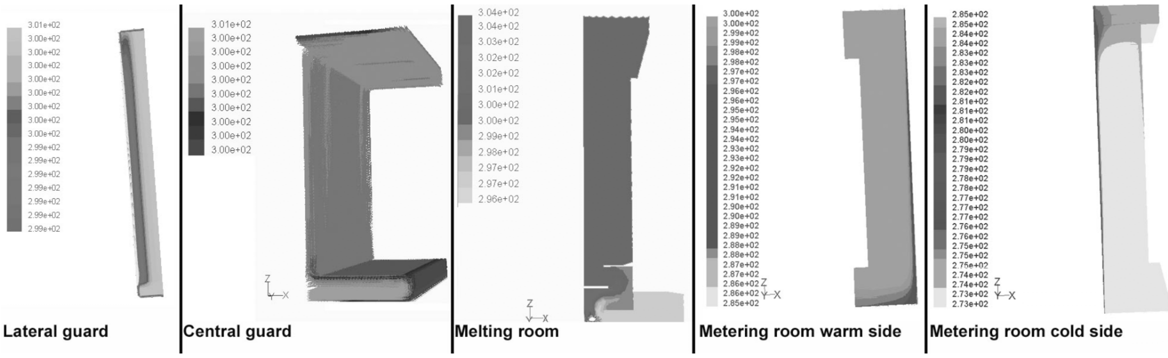

Figure 4: simulation results

CONCLUSION

The pre-designing phase enabled to insure that all the basic structure would fit to the standard recommendations. Indeed, a mistake on this basic structure can't be corrected without involving a complete reconstruction of the guarded hot box. All the dimension extract from this phase are relatives dimensions. It means that whatever are the final dimensions of the metering area, whatever the extern constraints are, these recommendations and relatives dimensions issued from this work are valid. This work also revealed some unexpected problems such as the cross flow around the metering box which oriented the designing of the thermal guard.

As a follow-up of this study, the construction of a guarded hot box has begun in June 2006 and first measurements have begun in the following months. The metering area is 1m50 by 1m50 and the total size of experiment in test conditions are 3m30 height, 2m70 depth and 3m20 wide.

Figure 5: The Guarded Hot Box, June 2006

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