DEVELOPMENT OF A COMPUTER BASED CALORIMETER INTERFEROMETER FACILITY TO EVALUATE HIGH PERFORMANCE WINDOWS

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ABSTRACT

This report presents the results of an intensive research conducted using a state-of-the-art laser interferometer technique to evaluate the thermally induced convection heat losses in double glazed windows with or without convection suppressor in the air gaps. The local and average heat transfer distributions on the hot and cold glass vertical surfaces of the windows are investigated. Heat loss or gain through the horizontal top and bottom end wall surfaces of the air gap is investigated to provide accurate information on the temperature and heat transfer profiles along these surfaces. Here-to-fore there has been confusion over what is the realistic or the true real-world temperature boundary conditions and the heat transfer characteristics at the horizontal bottom and top end wall surfaces of the window slot. Previous researchers have assumed simplified boundary conditions of adiabatic or linear temperature profiles on the top and bottom end wall surfaces of the slot. The present study resolves this controversy and demonstrates the invalidity of the adiabatic or linear temperature boundary conditions which are different from the observed and recorded real world temperature profiles at these surfaces. The temperature profiles along the vertical centerline of the air gaps is also investigated for different air gap spacings.

The effect of the convection cooling occurring at the top and bottom sections of the window slot on the formation of surface condensation is investigated. The elimination of the surface condensation using convection suppressor of different heights is also investigated. Equations relating the overall convection heat transfer coefficients (Nu) to heat transmission (U) coefficients are presented. Correlation equations of the overall average heat transfer coefficients as a function of Grashof number are developed for the vertical surfaces and the two horizontal top and bottom end wall surfaces. Similar correlation equation for the average Nusselt number as a function of the ratio of the suppressor height to the height of the slot was also developed. The general discussion includes the observed relationship between the thermally coupled convection heat transfer in air gaps and the formation of window condensation. It is concluded that the present knowledge on the phenomenon of the coupled film coefficients and air gap convection coefficients is insufficient for detailed and accurate evaluation of thermal performance of insulated windows. Further studies are required to evaluate the coupled external and internal film coefficients in double glazing. This will require that the full-scale hot box apparatus developed in this project be equipped in future with large optical windows to facilitate simultaneous measurements of the internal and external surface film coefficients along the height of the window slot. This modification will widen the scope of this study currently limited to internal convection study to include in the future the coupling effect of the internal and external convection leading to the development of a correlation equation for the external film coefficients in double window glazing. Recommendation for future research works required to resolve the outstanding questions on window convection heat losses and condensation is offered.

Key words: Convection, condensation, heat-transfer-coefficient, film-coefficient, heat-resistance-coefficient, heat-transmission-coefficient, edge seal, interferometer, hot-box, calorimeter, temperature-profiles.

ABSTRAIT

Ce rapport présente les résultats de recherches intensives menées par une technique d'interféromètre de laser pour évaluer la chaleur de convection théramatiquement conçue de pertes de chaleur dans les fenêtres doubles vitrées avec ou sans suppressor de convection dans les poches d'air. Le transfer de chaleur moyen et sur place de distributions sur les surfaces verticales de chaleur et de froid des fenêtres est examinée. La perte ou le gain de chaleur par moyen des surfaces de mur sur les bouts horizontaux de haut et de bas de la poche d'air est étudiée afin de donner des renseignements sur la température et le transfer de chaleur sur ces surfaces. Avant cette présente étude il existait une confusion sur ce qui est la température réelle ou réalistique des conditions de frontière et les caractéristiques de transfer de chaleur à l'extrémité supérieure des surfaces de la fente. Cette étude résoud cette controverse et démontre l'invalidité des conditions de frontière de la température adiabatique ou linéaire qui sont differentes du monde réel observé et enregistré sur les profils actuels de conditions sur ces surfaces. Les profils de température le long de la ligne de centre verticale des poches d'air est également étudiée pour l'espacement des différentes poches d'air.

L'effet de refriodissement de convection qui a lieu aux sections inférieures et supérieures de la fente de fenêtre sur la formation de la condensation de surface est égalements étudiée. L'élimination de la condensation de surface employant des suppressors de convection des hauteurs différentes est aussi examinée. Les équations se rapportant aux coéfficients (Nu) de transfer de chaleur par convection globale aux coéfficients de transmissions de chaleur (U) sont également données. La correlation d'équations du transfer de chaleur en moyenne comme une

fonction du nombre Grashof est développée pour les surfaces verticales et les deux surfaces - haut et bas. Une correlation similaire du chiffre moyen Nusselt comme équation vue en fonction de la ratio de la hauteur de suppressor à la hauteur de la fente fut également étudiée. La discussion générale comporte le rapport observé entre la chaleur de convection théramatiquement couplée de transfer de chaleur par convection dans les poches d'air et dans la formation de condensation des fenêtre. On conclut que ce que nous savons actuellement sur le phénomène des coéfficients couplés de films et des coéfficients de convection pour les poches d'air est insuffisant pour une évaluation détaillée et juste de la performance thémale des fenêtres isolantes. D'autres études sont nécessaires afin d'évaluer les coéfficients de surface de film intérieur et extérieur le long de la hauter de la fente de fenêtre. Cette modification étendra la portée de cette étude limitée actuellement à l'étude de convection intérieure et extérieure menant au developpement d'une équation de correlation pour les coéfficients de film dans les dou les fenêtres vitrées. Il est offert une recommendation à la recherche éventuelle nécessaire à résoudre les questions qui restent sur les pertes de chaleur de convection de fenêtres et la condensation.

MOTS CLEFS Convection, condensation, coéfficient de transfer de chaleur, coéfficient de film, coéfficient de résistanfe à la chaleur, coéefficient de transmission de chaleur, scellement de bord, interféromètre, boite chaude calorimètre, profil de température.

RECOMMENDATIONS

The versatility and the uniqueness of the laser interferometer is demonstrated in this report. It is a design and research tool that was employed in this study to remotely investigate convection phenomena in a confined window slot environment. To the best of the author's knowledge no other methods will provide a more detailed and accurate information on confined heat convection in sealed double glazed windows than the laser interferometric technique. It is therefore recommended that the laser interferometric technique be modified accordingly and used in future studies on the coupled internal and external convection heat transfer in a double or multi-glazed advanced windows (see Figure ia). To accomplish this goal the small scale apparatus will be replaced with a larger apparatus which could hold a large size window glazing. The present optical window (see Figure 2.6a to c) will also be replaced with a large optical window shown in Figure i.a. The large optical window will serve a dual purpose of providing a permanent or semi-permanent vertical seal for the double glazing while permitting, without any obstruction, the transmission of the laser beam through the air gap enclosure along the entire height of the glazing with no need to adjust or traverse the optical window (see Figures i.a and b). In the present arrangement the small optical window has to be traversed or shifted at 8 cm. interval along the height of the vertical slot for the laser beam to transmit through every section of the air layer. With the proposed large optical window for the future study only the laser beam need be shifted using a traversing mechanism while the test section and the optical window remain stationary. This arrangement will prevent disturbing the vertical seals and hence improve the accuracy of the experiment.

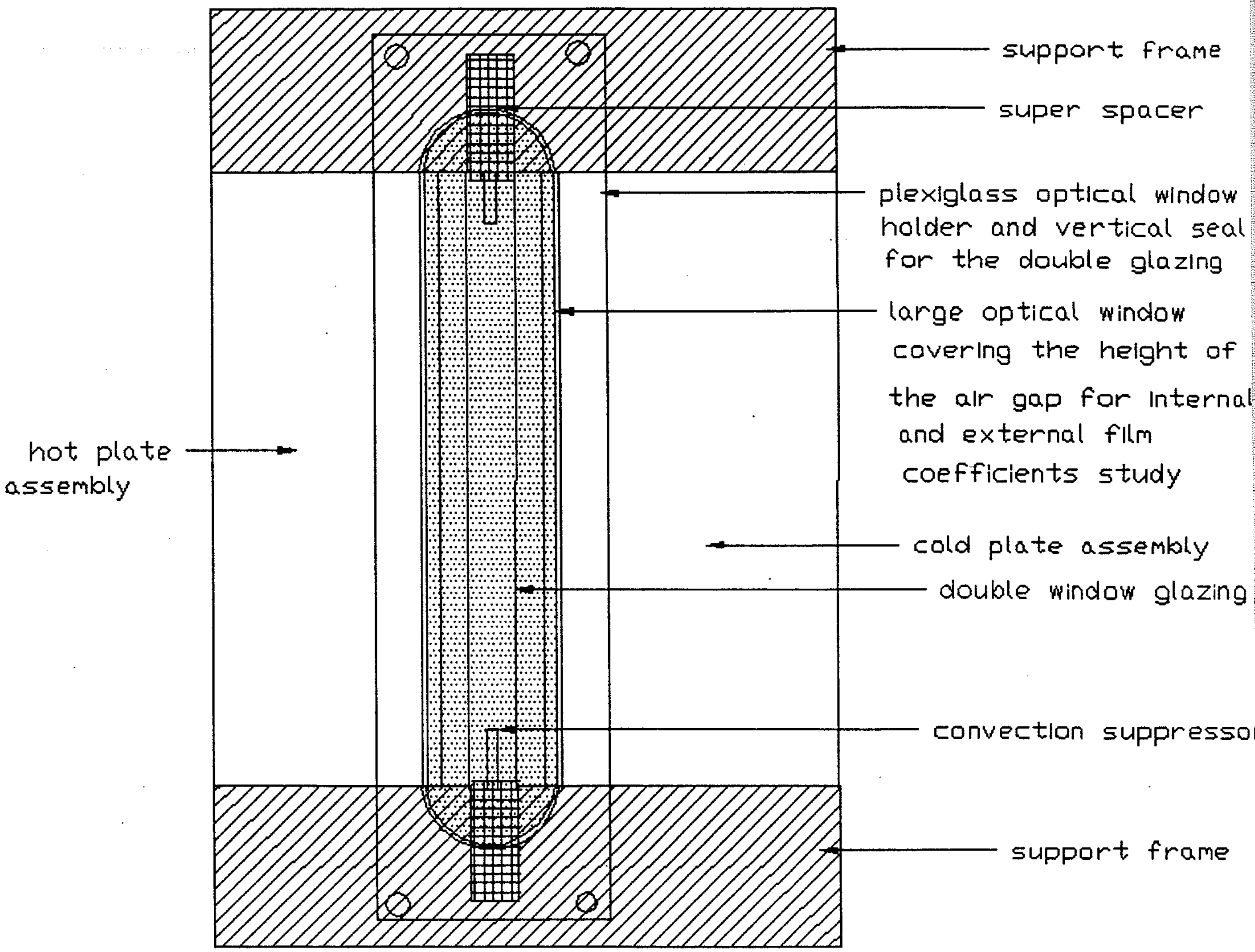

Fig. ia **Front View of the Hot-Cold Plate Apparatus Showing the Proposed Large-Size Optical Window for Future Studies on the Coupled Internal and External Film Coefficients in Double Window Glazing**

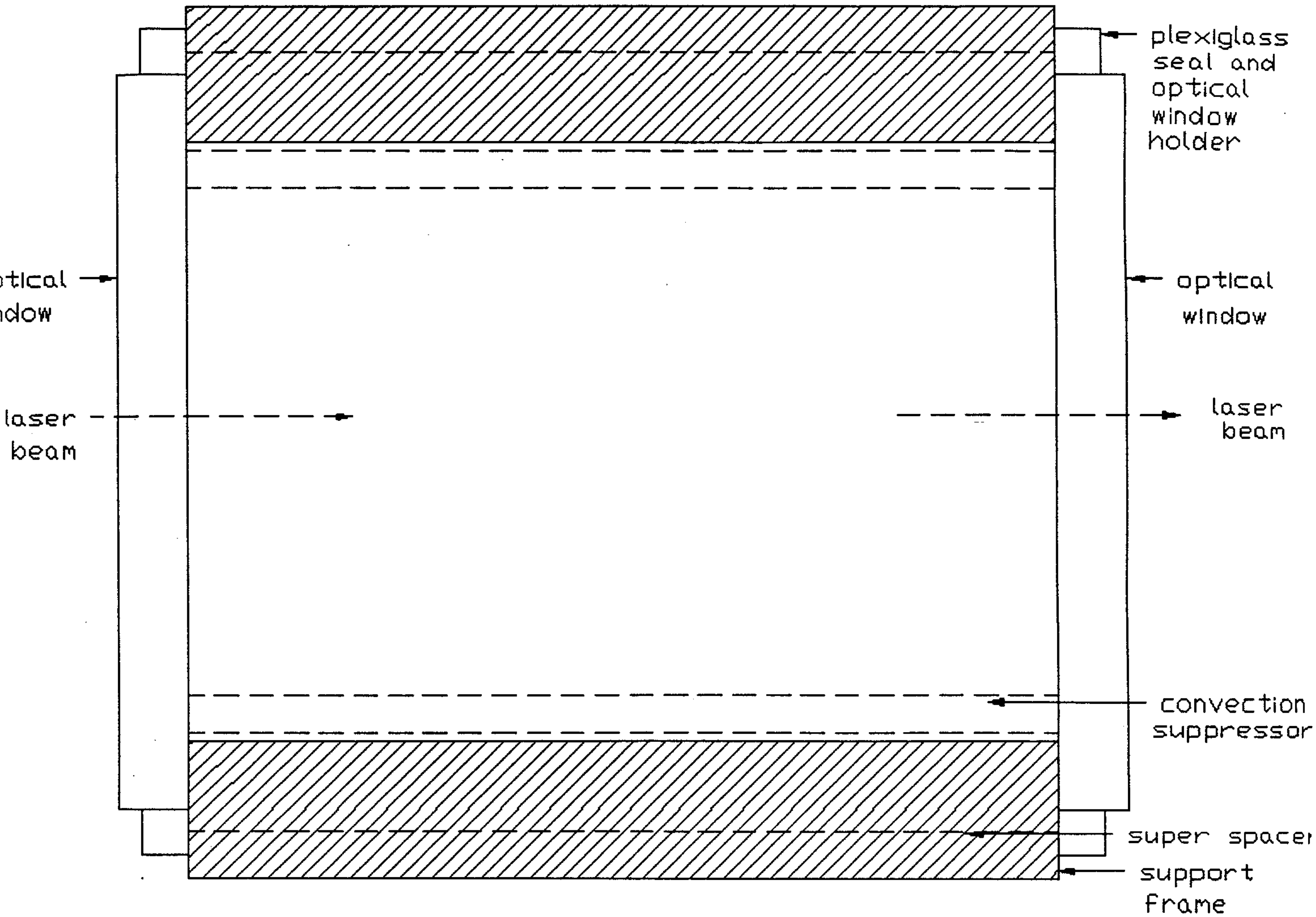

Fig. ib **The Side View of the Hot-Cold Plate Apparatus Showing the Proposed Large-Size Optical Window**

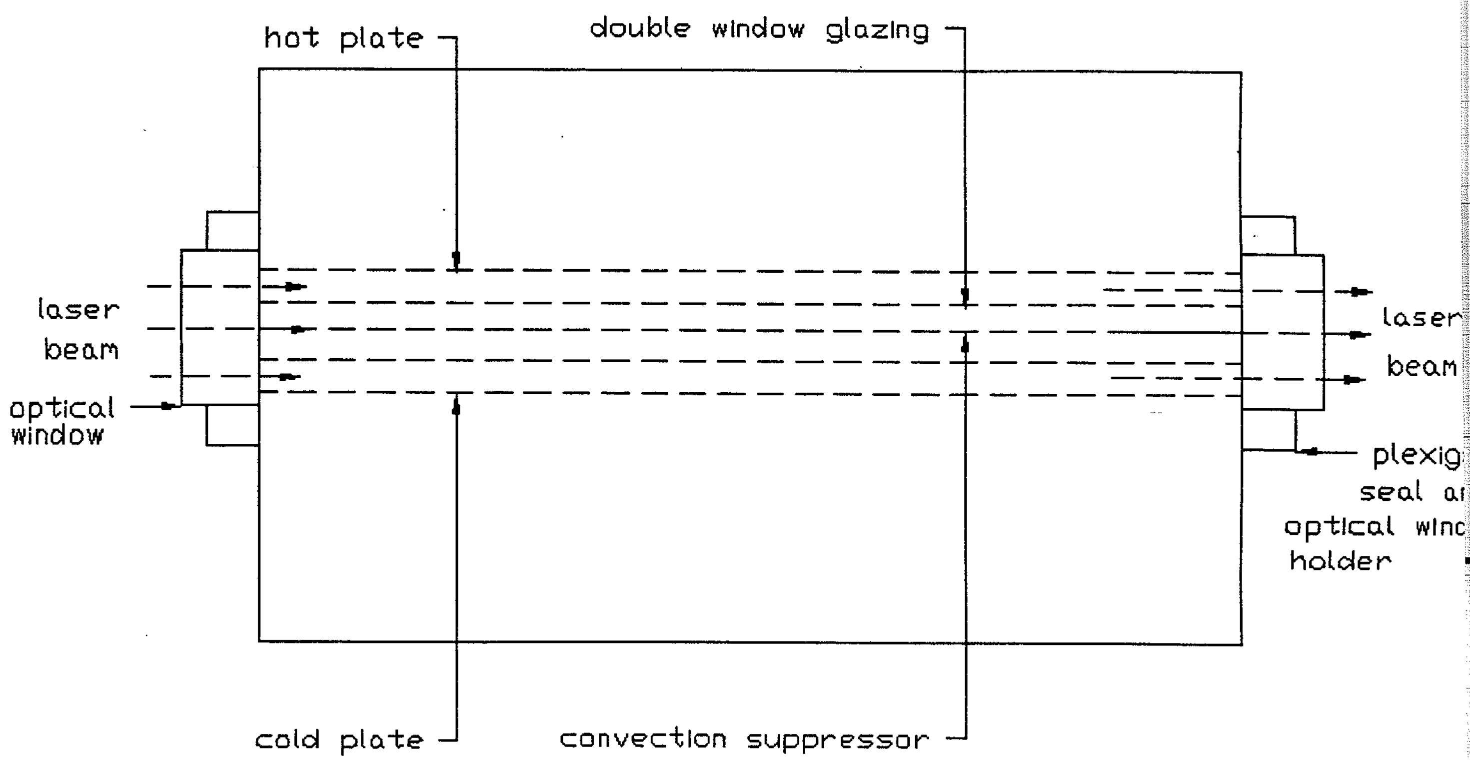

Fig. ic **The Top of the Hot-Cold Plate Apparatus Showing the Proposed Large-Size Optical Window**

The present study examined and provided correlation equations for the convection heat transfer coefficients in window air gap enclosure. Further studies are recommended, with modification to the present experimental apparatus as discussed above, to develop similar correlation equations for the coupled external and internal film coefficients. No such correlation equation, which is absolutely important for window design and evaluation, is available at present.

The external film coefficients on hot and cold glass surfaces of windows and their interaction or coupling relationship with the internal heat transfer coefficients require a detailed study to provide the badly needed external and internal film coefficients data and correlations often required by window designers, manufacturers and computer simulation programmers. The coupled internal and external film coefficient correlation data is required for the calculation of the heat resistance value (R-value) and overall heat transmission value (U-value) of double glazed window. The fact that the internal and external film coefficients are coupled phenomena which co-exist and interact means that they must be studied together to obtain accurate data and develop realistic design correlation equations. A random selection of these data from tables of data developed from experiments which do not take into consideration the couple phenomenon of the internal and external film coefficients, is outdated and inaccurate procedure. We recommend that the interferometric technique be used to carry out this important study in order to develop correlation equations for the coupled external and internal film coefficients and hence update window design procedure with the changing technology.

To complete the convection heat loss and condensation studies, we recommend that the analysis of the external film coefficients and its coupling relationship with the internal heat transfer coefficients be made the second phase of the proposed study. We also recommend that the study be carried out using the modified UWO facility which comprises a well controlled hot box apparatus to be equipped with large size optical windows and modified laser interferometer. The modified apparatus will be unique and suitable for a simultaneous study of the coupled internal and external film coefficients in double or multiple window glazing. Moreover the real world temperature distributions on the non-isothermal window glass surfaces and non-adiabatic top and bottom surfaces of the enclosure can be accurately measured using the modified UWO apparatus. The new apparatus with the laser interferometer - a special optical arrangement, can provide temperature map of the window glass surfaces enclosed in the hot box while the experiment is in progress. No other technique including thermography can be used to accomplish this task. No need of thermocouple installation or weighted average temperature calculation. Because the hot box cannot be accessed while the experiment is in progress, therefore, the **infrared thermography** cannot be used to map the glass surface temperature of the double window glazing undergoing thermal testing and evaluation. With the large optical window and the modified laser interferometer apparatus, the mapping of the surface temperature of the window glazing being tested in the hot box can be carried out while the experiment is in progress (see Figures ia to c and 2.1) using the laser interferometer. So no other apparatus or experimental technique other than the laser interferometer can be used to study the coupled internal and external film coefficients in the confined environment of the double window glazing. In carrying out the future study the laser interferometer will be used to evaluate

* the temperature map in the air gap enclosure needed for the calculation of **internal heat transfer coefficients**

* the temperature map on **the external hot and cold glasss surfaces** needed for the calculation of the **external film coefficients on hot and cold glass surfaces** as well as for the **surface condensation analysis**
* the correlation equations for **internal heat transfer and external film coefficients**

It is recommended that a comprehensive energy balance study be carried out in the laboratory to simultaneously measure conductive, radiative and convective heat transfer coefficients in order to obtain for new advanced windows, the standard R-value and U-value which accurately account for the coupled external and internal film coefficients. Presently the values for these coupled parameters are randomly selected from tables of data developed from empirical or analytical equations. The modified UWO apparatus can measure the convective heat transfer coefficient accurately as mentioned above, and can be used through calorimetry capability of the equipment to determine the conductive and the radiative heat transfer coefficients.

The infrared thermography is an apparatus which has been demonstrated to be suitable for field measurements of the temperature of opaque surfaces when properly calibrated. The laser interferometer can be used to map the temperature of both the opaque surfaces and transparent media as well. Because of its versatility and accuracy we recommend that the laser interferometer apparatus be used in future to calibrate and validate infrared thermography.

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