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Experimental study of convective heat transfer from windows with Venetian blinds

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ABSTRACT

To provide for more detailed and accurate load calculations and energy simulation of buildings, the effect of blinds on convection heat transfer at interior window surfaces was analyzed. Based on full-scale experiments in an office-size chamber for various diffuser locations, window geometry, and blind angles, the study provides convective heat transfer models for natural convection, forced convection due to a ceiling slot diffuser, and forced convection due to a floor register. Results are given in the form of correlations which relate either supply volumetric flow rate or room-surface temperature difference to convection heat transfer at both window and exterior wall surfaces. Results show that heat transfer is dependent on supply flow rate, blind angle, diffuser location and window configuration. Results are compared against previously reported data and show that convection in cases with blinds follows the same form as often arises in turbulent forced convection situations, but differs appreciably in magnitude from previously given models for bare windows. These results should allow for more accurate simulation of energy use in buildings and contribute to the construction of more energy efficient buildings.

1. Introduction

As load calculation and energy simulation methods become more accurate, more detailed models must be created to include the effects of different architectural components and systems in the calculations. Heat transfer processes in window assemblies strongly influence the overall thermal load in a space, and this area offers ground for additional research. While heat transfer at bare window surfaces, and in small isolated window-blind assemblies has been analyzed, little full-scale work on floor-to-ceiling windows with blinds, which exist in a large portion of commercial construction today, currently can be found in the literature. To this end, experiments were conducted to determine the effect of blinds on heat transfer through windows under a variety of thermal conditions and geometries.

Many researchers have investigated convection heat transfer at indoor surfaces. Among these, Waters [1], Alamdari et al. [2] and Lomas [3] have demonstrated the importance of selecting a proper model for indoor convection in accurately performing load calculations. Correlations pertaining to natural convection heat transfer at interior surfaces have been developed [2,4,5], while others [6–8] have analyzed forced convection from interior surfaces. Additional researchers [9,10] have created correlations for situations which could not be properly classified as either forced or natural convection.

Much effort has also been expended toward the goal of understanding the complex process whereby energy is transferred via natural convection heat transfer at a blind-window assembly. Collins et al. [11] conducted a numerical study of an isothermal flat plate adjacent to a set of Venetian blinds which were assumed to be irradiated by solar radiation with a constant flux. Shahid and Naylor [12] numerically analyzed a double-pane window with an adjacent set of Venetian blinds. Many investigations of a sealed window cavity which houses an internal set of Venetian blinds have been conducted (e.g [13–15]).

Experimental studies in the same vein have been conducted as well. Machin et al. [16] performed an experimental study of convection heat transfer from a small (0.38 m × 0.36 m) window-blind assembly. Results were reported for one surface-air temperature difference (20 °C) and four blind angles: −45°,0°, +45° and −90°. Flow visualization showed a cellular flow field between blinds, of the type expected in an enclosure. Machin et al. [16] observed that heat transfer at the window surface in some instances was greater when covered with blinds than the similarity

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solution for a flat plate without blinds. Collins et al. [11] validated their numerical study with an experimental evaluation of their results. The main limitation of the experimental setup was that it would be most valid for a small window (0.2 m × .4 m) which was embedded into a wall cavity. Cuevas et al. [17] recently studied natural convection at window surfaces with blinds in a small-scale setup.

Recently, Wright et al. [18] have attempted to synthesize most of the existing knowledge on radiative and convective heat transfer through fenestration systems into one complete model. The model includes complicated radiative heat transfer processes through systems several layers thick, and includes multiple surfaces within one system which transfer energy through convection. A full-scale floor-ceiling window, such as is present in much of contemporary commercial construction has not yet been analyzed. Forced convection in window-blind assemblies also has yet to be studied. The objective of the presented study is to bridge some of the gaps in the knowledge about convective heat transfer at complex surfaces such as windows with Venetian blinds.

The specific objectives of the present study are to: (1) determine whether existing correlations for natural convection at windows covered with blinds, which were developed for small windows, are applicable to floor-to-ceiling windows and (2) develop new correlations describing forced convection in the same situation. The two basic hypotheses investigated in this study are (A) floor-to-ceiling windows will experience heat transfer that is appreciably different from a small window under buoyant flow conditions due to the larger length scales inherent in the process, and (B) forced convection at windows with blinds will be less effective than the bare window situation.

The following sections describe the experimental methodology used to analyze convection in blind-window assemblies. Results of these experiments are then given and compared with existing work. Models for predicting convection in these situations are given and their applicability is discussed.

2. Methodology

The basic research tools for the investigation described in this paper were experiments in a full-scale test room. The experiments were conducted in the Center for Energy and Environmental Resources (CEER) at the University of Texas at Austin. This section provides a description of the experimental setup used, the methods employed in the experiments, methods and assumptions made in calculation of radiative and convective heat transfer, and the method used for the formulation of the experimental results.

2.1. Test room setup

Experiments were conducted in a full-scale test room/environmental chamber at the CEER. The environmental chamber has interior dimensions of 4.5 m × 5.5 m × 2.7 m high. *U*-values of the chamber walls are 0.2 W/m^2 K. For experiments analyzing forced convection from surfaces near a ceiling slot diffuser, a 0.3 m deep drop ceiling was built into the chamber. The ceiling was sealed on its bottom surface to prevent air infiltration between the space proper and the plenum above the ceiling. The drop ceiling housed an insulated flexible duct along its length leading to two diffuser boxes and two ceiling double-slot diffusers (Titus ML 39), 1.2 m long each, spaced 0.5 m apart. For floor register experiments, the ceiling was removed, and the duct placed in a 0.3 m high raised floor. The plenum beneath the floor was sealed and the duct attached to diffuser boxes were fitted with two standard, 1.2 m long grille registers with 0° pitch (Titus CT-PP-0).

The chamber itself has a dedicated and modifiable control system capable of supplying air between 6 and 50 °C, with a relative humidity between 2% and 99%. Flow rates corresponding to ventilation rates between 0 and 15 air changes per hour (ACH) are achievable. The chamber contains supply and return fans capable of maintaining a pressure of 0 ± 0.5 Pa gage in the chamber. Flow rate measurements were calibrated prior to commencement of the experiments and found to be accurate within 5%. The chamber also contains hydronic cooling coils embedded into one wall capable of simulating a winter condition. Thin electrical resistance heaters are placed on walls and floor to simulated internal loads and conduct natural convection investigations.

The chamber walls, floor and ceiling were divided into 14 sections as shown in Fig. 1. Short-wave solar radiation transmitted through the window and internal loads such as computers and occupants were also simulated with electrical resistance heaters on the floor and portions of the side walls, respectively. In calculating the radiation heat transfer during the course of the experiments, each section was assumed to be isothermal and the temperature of the surface was given as the average of at least two temperature measurements on the surface.

One wall of the environmental chamber was designated the "window" of the chamber (see Fig. 1) and was heated with thin electrical resistance heaters to simulate a pane of glass absorbing long-wave solar radiation. For the winter condition, the window was cooled with hydronic cooling coils to simulate losses to the exterior environment. Two window configurations were analyzed, corresponding to the two most common window configurations found in typical contemporary commercial construction. A

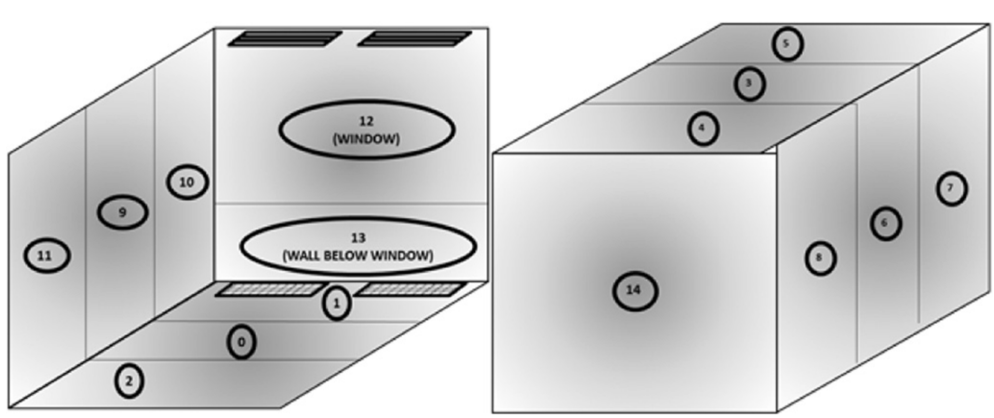

Fig. 1. Schematic of chamber characteristic surfaces with wall, window, and diffuser location.