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Numerical Study of the Convective Heat Transfer Rate from a Window Covered by a Top Down – Bottom Up Plane Blind System to an Adjacent Room

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Top Down–Bottom Up plane blinds have become quite popular. However, the effects of such blind systems on the convective heat transfer from the window to the surrounding room have not been extensively studied. The purpose of the present work was therefore to numerically investigate the effect of the blind openings with Top Down–Bottom Up plane blinds on this convective heat transfer. An approximate model of the window-blind system has been adopted. The "window" considered is recessed and is assumed to be at a uniform surface temperature and to be exposed to a room in which the air temperature far from the window is uniform. The blinds are assumed to be thin and to offer no resistance to heat transfer. The walls of the room surrounding the window are assumed to be adiabatic. Fluid properties have been assumed constant except for the density change with temperature that gives rise to the buoyancy forces this being treated by using the Boussinesq approach. Radiant heat transfer effects have been neglected. The governing equations have solved using the commercial finite-volume based computational fluid dynamics (CFD) code FLUENT. The standard k-epsilon turbulence model with full account being taken of the effect of the buoyancy forces has been used. The initial work concentrated on the case where the size of the blind openings at the top and bottom are the same. More limited results for the case where there are different top and bottom blind openings were then obtained.

1. Introduction

Improved models for the convective heat transfer rate from the inner surface of a window to the surrounding room for the case where the window is fully or partially covered by a blind are needed to assist in the development of systems that reduce the overall heat transfer rate through the window. Top Down–Bottom Up plane blinds have become quite popular in recent times and have the potential to reduce energy consumption by allowing the controlled use of sunlight to illuminate the house (daylighting) and/or to use passive solar room heating while still providing shade and privacy to the occupants. However the effects of such blind systems on the convective heat transfer from the window to the surrounding room have not been extensively studied. The purpose of the present work was therefore to numerically investigate the effect of the type and extent of the blind opening with Top Down–Bottom Up plane blinds on this convective heat transfer. A recessed window with a Top Down – Bottom

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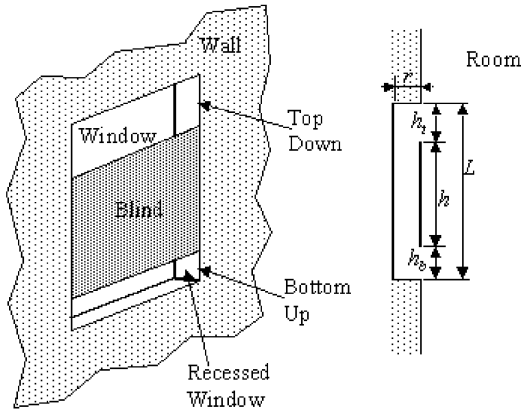

Figure 1: Situation considered.

Up blind is shown in Fig. 1. Such blinds can be open at the top and/or the bottom, the top and bottom blind openings generally being different as shown in Fig. 1. Both the size of the top and bottom openings, in general, will effect the convective heat transfer rate from the window to the room and this has been numerically investigated in the present study.

Top Down-Bottom Up blinds are often used in conjunction with other energy saving strategies such as daylighting, i.e. the use of solar radiation to replace the use of artificial lighting. In some such cases it is important to be able to determine whether the energy savings associated with the blind opening are more than cancelled by the greater heat loss or gain associated with the blind opening. The results of the present study should assist in making such decisions.

There have been many studies of the effect of blinds on the heat transfer rate between the room-side of the window and the room but these have mainly been concerned with traditional Bottom Up type blinds. Typical of studies of the case where plane blinds are being used are those of Oosthuizen et al. (2008), Oosthuizen et al. (2005), and Oosthuizen (2007, 2008). These studies are for the case of laminar flow over the window-blind system. The effect of flow transition for the case of flow over a plane blind has been considered by Oosthuizen and Naylor (2010), and Oosthuizen (2009, 2010), for example. Typical studies of the case involving Venetian blinds are those of Collins et al (2002a, 2002b), Duarte et al. (2001), Machin et al. (1998), Shahid (2003) and Roeleveld et al. (2010). The present study, as is the case in many of these previous studies, considers only the convective heat transfer. In window heat transfer situations, the radiant heat transfer can be very important and can interact with the convective flow, e.g., see Phillips, et al. (2001).

2. Solution Procedure

The mean flow has been assumed to be steady and the Boussinesq approach has been used. It has been assumed that the "window" is at a uniform temperature, T'_H, and that this window temperature is higher than the temperature of the air in the "room" to which the window is exposed T'_F. The solution has been obtained by numerically solving the governing equations subject to the boundary conditions using the commercial CFD solver, FLUENT. Although the flow considered is fundamentally two-dimensional, the possibility existed that three-dimensional flow would develop in the transition region. For this reason the full three-dimensional governing equations were solved for a finite window width. However, such three-dimensional flow was not found to exist in any of the flows considered here. In the situation considered here both laminar and turbulent flow can occur. The k-ε turbulence model with the full effects of buoyancy forces accounted for and with standard wall functions has been used in obtaining the solutions. This turbulence model has been found in past studies to give moderately good predictions of when transition to turbulence occurs and of the flow and heat transfer in the laminar, transitional, and turbulent regions. Extensive grid- and convergence criterion independence testing was undertaken. This indicated that the heat transfer results presented here are to within 1% independent of the number of grid points and of the convergence-criterion used.

The mean convective heat transfer rates from the window have been expressed in terms of the mean Nusselt number defined by $Nu = \overline{q'} L / [k(T_W - T_F)]$ where $\overline{q'}$ is the mean heat transfer rate from the window considered, k is the thermal conductivity, T_W is the window surface temperature, T_F is the room air temperature, and L is the height of the window. The Rayleigh number used in presenting the results is also based on L and on the overall temperature difference between the window temperature and the room air temperature, i.e. is defined by $Ra = \beta g \rho^2 c_p (T_W - T_F) L^3 / \mu k$ where β, ρ, and μ are the bulk expansion coefficient, the density, and the viscosity .

3. Results

The solution parameters are the Rayleigh number, Ra, the Prandtl number, Pr, the dimensionless "depth" to which the window is recessed, $R = r / L$, r being the window recess depth, and the dimensionless top and bottom blind openings, $H_t = h_t / L$ and $H_b = h_b / L$, where L is the overall height of the window and h_t and h_b are the top and blind openings as shown in Fig. 1. Results have only been obtained for $Pr = 0.74$ which is essentially the value for air. Values of the Rayleigh number based on L, i.e., Ra, of between 10^3 and 10^{16} have been considered. Results will only be presented here for $R = 0.05$, results for other values of R showing the same basic characteristics.

Consideration was first given to the case where the top and bottom blind openings are the same, i.e., where $H_t = H_b$. Typical results for this case are shown in Fig. 2 which shows variations of Nusselt number with Rayleigh number for dimensionless top and bottom openings of 0.375, 0.25, and 0.1. It will be seen from Fig. 2 that except at very low Rayleigh numbers the Nusselt number variations for all dimensionless blind openings are essentially the same. This is also shown by the results given in Fig. 3, which shows typical variations of Nusselt number with dimensionless blind top and bottom opening for various larger Rayleigh number values.

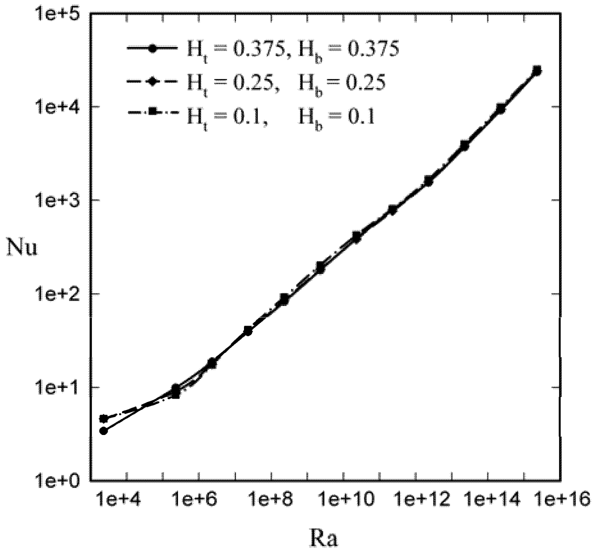

Figure 2: Variation of Nusselt number with Rayleigh number for the case where the top and bottom blind openings are equal for dimensionless top and bottom openings of 0.125, 0.25, and 0.375.

Attention will next be turned to the case where the top and bottom blind openings are not the same. Typical results for this case are shown in Fig. 3 which shows variations of Nusselt number with Rayleigh number for dimensionless top and bottom openings of 0.125 and 0.375, 0.375 and 0.125, and 0.375 and 0.375. It will be seen from these results that again the size of the gap has only a small effect on the Nusselt number except at the lowest Rayleigh numbers considered.

4. Conclusions

The results of the present study indicate that except at the lowest Rayleigh numbers considered the size of the top and bottom blind openings has a very small effect on the heat transfer rate from the inside of the window and, therefore, provided that the blind is open at both the top and the bottom, in evaluating the net effect of top-down, bottom-up blinds the convective heat transfer rate from the inside of the window can be assumed to be constant. This will not be true when the blind is only open at the bottom or the top.

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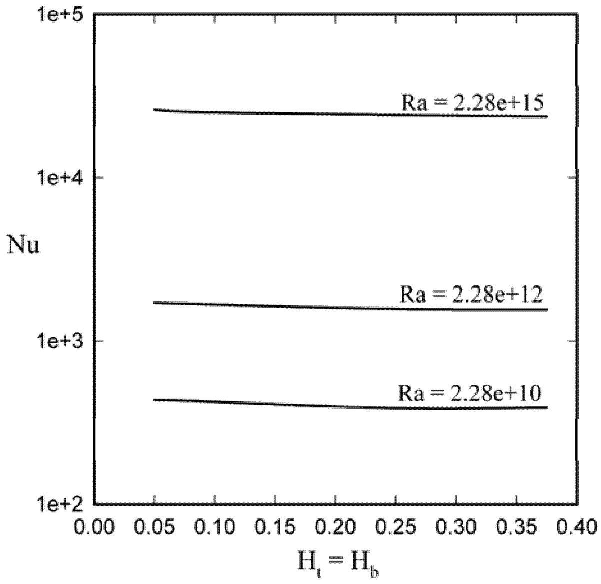

Figure 3: Variation of Nusselt number with dimensionless blind opening for various Rayleigh number for the case where the top and bottom openings are equal.

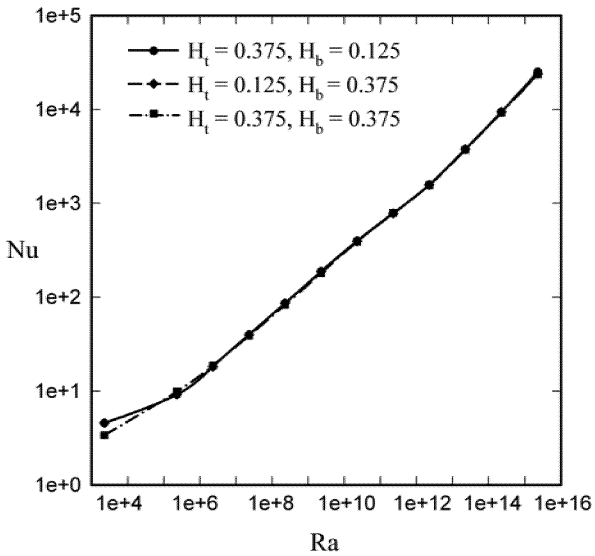

Figure 4: Variation of Nusselt number with Rayleigh number for dimensionless top and bottom openings of 0.125 and 0.375, 0.375 and 0.125, and 0.375 and 0.3.75.

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