Building and Environment 82 (2014) 713–725

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Effect of installing a venetian blind to a glass window on human thermal comfort

Nopparat Khamporn [b], Somsak Chaiyapinunt [a, *]

[a] Department of Mechanical Engineering, Faculty of Engineering, Chulalongkorn University, Phayathai, Bangkok 10110, Thailand
[b] Department of Mechanical Engineering, Faculty of Engineering, Siam University, Petkasem, Bangkok 10160, Thailand

A R T I C L E I N F O

Article history:
Received 9 July 2014
Received in revised form
10 October 2014
Accepted 23 October 2014
Available online 31 October 2014

Keywords:
Glass window
Venetian blind
Thermal comfort
Mean radiant temperature
Predicted percentage of dissatisfied (PPD)

A B S T R A C T

This paper studies the effect on the thermal environment caused by installing a curved venetian blind to a glass window in a building located in a tropical climate. A mathematical model was developed to determine the mean radiant temperature affected by solar radiation on a person sitting near a glass window with a venetian blind. The concept of shading fraction of the surface temperature of the glass window and blind is introduced. The predicted percentage of dissatisfied (PPD) was chosen as the thermal comfort index for this study. The experiment was performed in a test room with a 6 mm clear glass window to which a curved venetian blind was attached. The test was performed with blind settings at three different slat angles: 0°, 45° and −45°. The accuracy of the mathematical model was verified by comparing experimental results with predicted results. Agreement between experimental and predicted results was good. The effect of surface temperature and the effect of solar radiation on the mean radiant temperature and PPD were also studied. The discomfort of the person sitting near the glass window with a venetian blind is dependent on the level of solar radiation striking the body. The slat angle adjustment does affect the amount of solar radiation striking the person and hence, dictate the thermal environment of the space.

1. Introduction

Glass windows are a common type of building envelope for most commercial buildings. The benefits they provide are visual connection to the exterior and natural light for the interior, thus reducing the need for artificial light. However, glass windows in buildings located in tropical countries near the equator, also allow a high degree of heat gain because of incident solar radiation. To reduce this solar heat gain and maintain thermal comfort for the occupants, air conditioning systems are required. A considerable amount of research has been conducted on thermal performance of glass windows in terms of heat transmission and thermal comfort: Athienitis and Haghighat [1]; Gan [2]; Chaiyapinunt et al. [3]; La Gennusa et al. [4]; La Gennusa et al. [5]; Singh et al. [6]; Chaiyapinunt and Khamporn [7]; Dong et al. [8]; Hwang and Shu [9] and Khamporn and Chaiyapinunt [10]. However, when a building is actually used, occupants often install venetian blinds as an indoor shading device to reduce glare and maintain privacy. The building envelope to be analyzed should thus be the combination of glass window and venetian blind instead of only the glass window. As a venetian blind can be set at different slat angles, it will have different optical properties dependent on the slat angle and its optical properties.

To study the thermal environment of a space installed with a glass window and venetian blind is very complex. Some work has been done to develop a mathematical model to predict the thermal performance of a glass window with a venetian blind, as the venetian blind is considered diathermanous (i.e. transmits both shortwave and longwave radiation) and nonspecular. The followings studies considered the heat transmission through the glass window with an attached venetian blind: Klems [11,12]; Klems et al. [13]; Klems and Warner [14]; Pfrommer et al. [15]; Collins and Harrison [16]; Chantrasrisalai and Fisher [17]; EnergyPlus [18]; Yahoda and Wright [19]; Khun [20,21]; Wright et al. [22]; Chaiyapinunt and Worasinchai [23,24], and Chaiyapinunt and Khamporn [25]. Only a very limited number of studies have considered thermal comfort aspects as part of the thermal performance of the glass window with the venetian blind. Bessoudo et al. [26] performed experiments and developed a building thermal model for indoor thermal environmental conditions near glazed facades with shading devices (fabric roller shade and venetian blind). The experiments were performed on the perimeter zone of a new 16 story

* Corresponding author. Tel.: +66 22186631; fax: +66 22522889.
E-mail address: somsak.ch@chula.ac.th (S. Chaiyapinunt).

http://dx.doi.org/10.1016/j.buildenv.2014.10.022
0360-1323/

office building in Montreal (latitude 44°N, longitude 74°W) during winter on both cold sunny days and cold overcast days. A building thermal model was developed and verified for glass windows with and without a roller shade; however, no verification was performed for a glass widow with an attached venetian blind. This article examines the effect of installing a curved venetian blind to a glass window on the indoor thermal environment of a building located in a tropical zone near the equator.

2. Mathematical model for the glass window with an attached curved venetian blind

In this section, a mathematical model is developed to calculate the thermal comfort condition for a person sitting near a glass window with an attached curved venetian blind.

2.1. Thermal comfort indices

Thermal comfort is defined as the condition of mind that expresses satisfaction with the thermal environment (ISO 7730 [27] and ASHRAE Standard 55 [28]). The predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) are two indices commonly employed to describe the thermal environmental condition. According to ISO 7730 [27] and Fanger [29], PMV and PPD can be expressed as.

$$\begin{aligned}\mathrm{PMV} = \left(0.303e^{-0.036\cdot M}+0.028\right)\cdot\Big[&M\left(1-\eta\right)-3.05\times10^{-3}\cdot\left(5733-6.99\cdot M\left(1-\eta\right)-P_a\right)\\&-0.42\cdot\left(M\left(1-\eta\right)-58.15\right)-1.7\times10^{-5}\cdot M\cdot\left(5867-P_a\right)\\&-0.0014\cdot M\cdot\left(34-T_a\right)-3.96\times10^{-8}f_{cl}\cdot\left((T_{cl}+273)^4\right.\\&\left.-(T_{mrt}+273)^4\right)-f_{cl}\cdot h_c\left(T_{cl}-T_a\right)\Big]\end{aligned}\tag{1}$$

$$\mathrm{PPD} = 100-95\cdot e^{-\left(0.03353\mathrm{PMV}^4+0.2179\mathrm{PMV}^2\right)}\tag{2}$$

where M = metabolic rate per unit body, (W/m^2).

P_a = vapor partial pressure, (Pa).
f_{cl} = clothing area factor.
T_{mrt} = mean radiant temperature, (°C).
T_a = air temperature, (°C).
T_{cl} = clothing surface temperature, (°C).
h_c = convective heat transfer coefficient, (W/(m^2-K)).
η = mechanical efficiency.

Clothing surface temperature can be evaluated by an iteration process shown below:

$$\begin{aligned}T_{cl} = 35.7-0.028M\left(1-\eta\right)\\-I_{cl}\Big\{3.96\times10^{-8}\cdot f_{cl}\cdot\left[(T_{cl}+273)^4-(T_{mrt}+273)^4\right]\\+f_{cl}\cdot h_c\cdot(T_{cl}-T_a)\Big\}\end{aligned}\tag{3}$$

$$h_c = \begin{cases}2.38(T_{cl}-T_a)^{0.25} & for \quad 2.38(T_{cl}-T_a)^{0.25}\rangle 12.1\sqrt{v_{ar}}\\ 12.1\sqrt{v_{ar}} & for \quad 2.38(T_{cl}-T_a)^{0.25}\langle 12.1\sqrt{v_{ar}}\end{cases}\tag{4}$$

$$f_{cl} = \begin{cases}1.00+1.290I_{cl} & for \quad I_{cl}\le 0.078\ \left(\mathrm{m}^2-\mathrm{K}\right)/\mathrm{W}\\ 1.05+0.645I_{cl} & for \quad I_{cl}\rangle 0.078\ \left(\mathrm{m}^2-\mathrm{K}\right)/\mathrm{W}\end{cases}\tag{5}$$

where v_{ar} = relative air velocity (air velocity relative to occupant, including body movements), (m/s).

I_{cl} = clothing insulation, ((m^2-K)/W).

2.2. Mean radiant temperature

Chaiyapinunt et al. [3] have shown that for a space with a glass window under solar radiation, the PPD can be divided into two components: PPD due to the effect of surface temperature and PPD due to the effect of solar radiation. Therefore, the mean radiant temperature in Eq. (1) can also be expressed as the mean radiant temperature due to surface temperature and mean radiant temperature due to surface temperature and solar radiation (striking the person). For the case of a space with a glass window with an attached venetian blind, the mean radiant temperature due to surface temperature can be calculated from the values of the surface temperature of the surrounding walls and venetian blind and their positions with respect to the person in the space. Since the slat angle of the venetian blind can be set at different positions, the surface temperature of the venetian blind as seen by the person in the enclosure can be modeled as an effective blind surface temperature, which is the weighted sum of the slat surface temperature and glass window surface temperature. The effective blind surface temperature can be written as.

$$t_{b,eff} = \left[F_{sb}(t_b+273)^4+\left(1-F_{sb}\right)\cdot(t_g+273)^4\right]^{0.25}-273\tag{6}$$

$$F_{sb} = \frac{A_{pb}}{A_{pbg}}\tag{7}$$

$$A_{pbg} = A_{pb}+A_{pg}\tag{8}$$

where $t_{b,eff}$ = effective blind surface temperature of glass window and venetian blind, (°C).

t_b = surface temperature of venetian blind, (°C).
t_g = surface temperature of glass window, (°C).
F_{sb} = shading fraction.
A_{pb} = projected area of venetian blind slat on vertical plane, m^2.
A_{pg} = area of glass window not blocked by blind slat, m^2.
A_{pbg} = sum of the projected area of venetian blind slat on vertical plane and area of glass window not blocked by venetian blind slat, m^2.