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Effect of an incompletely closed window shutter on indoor illuminance level and heat gain

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ABSTRACT

Exterior window shutters are used in hot climate regions to reduce the heat gain, and they are commonly kept incompletely closed during the daytime to illuminate the indoor space. This practice could potentially degrade the thermal effectiveness of the shutter, and increase the heat gain. In this study, experimental measurements are employed to study the effect of keeping the shutter incompletely closed on the illuminance level and heat gain through the window. The shutter is opened for a distance of 10, 20, and 30 cm, and the heat gain at the indoor surface of the window are measured. The illuminance level in the indoor space, outdoor air temperature, and global solar radiation in the site are measured. In May, the net heat gain through the window for a closed shutter during the daytime is 92.6 MJ/m^2. If the shutter is opened for 10 cm, the heat gain is increased by 22.1%, and insufficient illuminance level is achieved. If the shutter is opened for 30 cm, a sufficient illuminance level can be achieved, but the heat gain is increased by 73.4%. It is recommended to keep the shutter completely closed during the daytime, and relay on the high energy efficient artificial lightings.

1. Introduction

In hot climate regions, air-condition units are responsible of the most of electrical power consumption in buildings during the summer months, and about 70% of generated electrical power is consumed by these units in Kuwait [1]. The building's envelope is the physical barrier that separates the indoor controlled environment from the outdoor unstable environment. Therefore, the envelope's design and thermo-physical properties have a significant impact on the comfort of the occupants and energy consumption. The envelope of a building is composed of roof, walls, doors, and windows. For walls and roof, thermal insulation materials are extensively used, and confirmed to reduce the heat gain [2]. However, windows are account for a large percent of the cooling load [3], and they are considered as a weak link for heat flow between indoor and outdoor spaces, and contributed for about 32% of the total cooling load [4]. Reducing direct solar radiation and convective heat transfer through windows are one of the key factors for reducing energy consumption in buildings [5], and many techniques have been applied for windows to reduce the heat gain were discussed in literature [6]. The newly developed materials, innovative techniques for reducing heat gain, and new firm regulations regarding low energy buildings are all led to energy efficient windows. In this regards, modeling of a simple glass window model was addressed in literature with aim of understanding the effect of glass thermo-physical on the heat gain. In the model, the reflected, transmitted, and absorbed incident solar radiation by the glass are considered [7]. Modeling a conjugate heat transfer of a double panes window using numerical method was addressed to determine the optimum air layer thickness between the two panes [8], and minimizing thermal bridging through window was also investigated [9]. Window with blinds was investigated by Cuevas et al. [10], and heat transfer coefficient for the window was obtained. Double glazed windows with an enclosed plated blind was theoretically analyzed by Dalal et al. [11]. Conjugate convection, conduction, and radiation heat transfer in a double glazed window with a ventilated type blind was developed by Naylor and Collins [12]. Naturally ventilated and gas filled windows for hot climates were investigated by Ismail et al. [13], and they highlighted the influence of the reflectance of the glass on the total heat gain.

The most effective technique to reduce heat gain through windows is to install exterior shading devices [14], such as window shutter. The window shutters are typically made of foam filled aluminum rolling shutter slat. Fig. 1 shows residential buildings in Kuwait with shutters installed on the windows. Heat gain in a window with shutter has investigated in literature as a technique for reducing heat gain [15]. Energy saving using a dynamics

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Fig. 1. Residential buildings in Kuwait with shutters installed on the windows.

external shutter in an office building was investigated by Hammad and Abu-Hijleh [16]. The proposed dynamic shutter system with light dimming can save up to 34.02% of energy used in lightings. The performance of the shutter shading device in Egypt was presented by Palmero-Marrero and Oliveira [17]. The shading device decreases total energy consumption by 55% compared with no shading case. The phase change material is incorporated in a shutter to reduce the heat gain [18]. The shutter with phase change material reduces heat gain through the window by 23.3%. A comparative analysis of energy performance of traditional wooden and Aluminum roller shutters was investigated by Yazicioglu [19]. It was reported that the *U*-value of the window system with wooden shutter is twice more than the window with aluminum shutter. Freewan [20] examined the effect of using shading devices on the indoor air temperature, and visual environment. The results indicate that temperature was reduced with the shading device to an acceptable level, and the illuminance level was adequate.

Practically, the shutters are kept incompletely closed during the daytime to illuminate the indoor space. In this situation, a relatively outdoor hot air is directly in contact with window, the outdoor surrounding radiation, and solar radiation are directly transmitted to indoor space. An increase in the heat gain through the window is expected. Fig. 2 shows outdoor and indoor photos of the window with an incompletely closed shutter used for the present research. As shown in Fig. 2b, the outdoor light passes through the opening distance of the shutter to illuminate the indoor space. The objective of the present research is to study the heat gain of a window with an incompletely closed shutter, and compare it with window with a completely closed shutter. Additionally, the effect of the incompletely closed shutter on the indoor illuminance level is investigated.

(a)

(b)

Fig. 2. (a) Outdoor and (b) indoor views of window with shutter.

2. Problem description

The outdoor surface of the shutter is subjected to solar radiation, surrounding radiation, and convection, while the indoor surface of the glass is subjected to convection and radiations boundary condition. Solar and surrounding radiations are transmitted to the indoor space through the opened portion of the shutter. Additionally, the shutter's indoor surface also emits radiation to the window. Fig. 3 depicts the geometrical configuration of a window with an incompletely closed shutter, and the boundary conditions. The thickness of the shutter and window are (L_s) and (L_w), respectively, and they are spaced with distance (L_a). The height and width of the window are (H) and (W), respectively, and the window is facing the west direction.

In general, the heat transfer in the window with shutter is in three-dimensional space. Since the width and height of the window is typically large compared to its thickness, the ends effect has a negligible effect on the heat transfer in the window, and temperature and heat flux are assumed uniform in the shutter, spacing, and window. There is a significant temperature difference between the window and shatter, and natural convection flow of air in the spacing is induced. Air recirculation in the spacing causes some air to flow out of the spacing through the opened portion of the shutter. Therefore, a relatively cold air in spacing is replaced by outdoor hot air, as illustrated in Fig. 3. Energy is transferred from the outdoor to the indoor space through the window by convection and radiation.