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Optimizing the ventilated double window for solar collection

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ABSTRACT

Windows have been under study for the last decade due to their improvements and for being the lowest thermal resistance component of the facades. Amongst this component, the building also loses heat as a result of airing needs. Thermal losses through windows and ventilation may represent a large percentage of the whole thermal losses of the building. The double ventilated window is one of several construction systems that preheat the incoming air. It also reduces thermal losses through windows, reducing the heating load of the building. Several studies have shown the performance of the ventilated double window under different climatic conditions as well as the influence of different inputs. This paper shows how this passive air heating system can be improved in order to collect more solar heat. Thermal balance was improved by 8.4% and 12.5% in Bragança and Évora, respectively, while the delivered air temperature increased from 9.8 °C to 11.9 °C and from 13.5 °C to 17.4 °C in Bragança end Evora, respectively.

1. Introduction

Windows are commonly the façade element with the weakest thermal resistance. Besides being the thinnest constructive element, it has the highest thermal conductivity of the building'sconstruction elements as one may find in the literature. Boyano et al. (2013) have studied the improvement of window insulation and external walls to provide new data about the energy consumption and the energy demand profile of European office buildings. The lowest U-value of windows was 1.78 W/(m^2 K) and the highest U-value of the envelope was 0.49 W/(m^2 K) of the roof (Boyano et al., 2013). A new weather database compiled for Perugia was used to compare different scenarios in terms of energy demand, such as the substitution of the glazing (2.4 W/(m^2 K)) and lower U-value of the opaque envelope (0.8 W/(m^2 K)) (Buratti et al., 2014). In the energy consumption study of a large public building calculated for Leadership in Energy and Environmental Design (LEED), U-values of windows have become as low as 1.8 W/(m^2 K) and external walls as high as 0.66 W/(m^2 K) (Pan et al., 2011). One may find in several studies a higher U-value of windows against a lower U-value of the building envelope as suggested in Carlos (2016) with 2 W/(m^2 K) and 0.3 W/(m^2 K) for walls. Stazi et al. (2012) proposed one refurbishment, where optimal retrofit solutions were identified for the external envelopes with a U-value of 2.4 W/(m^2 K) for windows and 0.35 W/(m^2 K) for wall, or 3 W/(m^2 K) for windows and 0.57 W/(m^2 K) for walls in Carlos and Corvacho (2010). Although there are thermal losses in cold climates, in hot climates they allow incoming heat. They also allow excessive solar radiation during the cooling season. Thermal losses are also verified through airing. Combining a double window with an incoming air path to heat the ventilation air, thermal losses may be reduced due to windows and airing. Several solutions have been studied during the last two decades namely combining windows and passive heating of the ventilation air.

An air window collector is a double window system with a vertical blind installed between glass panes for absorbing solar energy (Onur et al., 1996). The blind works as a solar collector. The absorbed solar energy is partially transferred by convection to the passing air on both sides. It can be used as a recirculating air window collector or a ventilated one (Hastings and International Energy Agency, 2000). A supply air window is a modified double window with a ventilation path, operable between the outer and middle panes. This air path enables heated ventilation air in winter (Baker and McEvoy, 2000; McEvoy et al., 2003). Unshaded, the air supply window contributed more significantly to reducing the ventilation load than heat transmission, depending on the ventilation rate. A ventilated window composed of two glass sheets separated by a space through which air is forced to flow, was also studied by Ismail and Henríquez (Ismail and Henríquez, 2006). Part of the incident solar radiation is absorbed in the external glass sheet. Part of the solar radiation crosses the first glass sheet and is then absorbed by the internal glass sheet; finally, the air flowing in the channel exchange heat by convection increases its temperature before it is delivered to the indoor ambient. A double window system similar to the one presented in this paper was studied by Kim et al. (2011) with ventilation slits to solve the window surface

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Nomenclature

A_g	area of the glazing (m^2)
a_p	surface azimuth (degrees)
a_s	solar azimuth (degrees)
A_{sf}	sunlit frame of the window (m^2)
A_{sg}	area of the sunlit glazing (m^2)
A_w	area of the window (m^2)
B	thermal balance (W)
d	day of the year (1–365)
h	angle of solar altitude (degrees)
H_g	height of the glazing (m)
i	angle of the incidence solar beam (degrees)
I_b	hourly beam irradiation (W h/m^2)
I_d	hourly diffuse irradiation (W h/m^2)
I_g	hourly solar irradiation on tilted surface (W h/m^2)
I_h	hourly global solar irradiation on a horizontal surface (W h/m^2)
I_r	hourly irradiation being reflected (W h/m^2)
K	surrounding reflectivity or albedo
kd	percentage of diffuse radiation in the global solar radiation
kt	clearness index
L	latitude of the place (degrees)
l	depth (m)
LST	local solar time (hour)
Q_{air}	heat loss through ventilation (W)
Q_{sol}	solar heat gains (W)
Q_{use}	heat recovered by the air (W)
Q_{win}	heat loss through window (W)
s_{wg}	horizontal shading of the glazing (m)
s_{vg}	vertical shading of the glazing (m)
$T_{o,ave}$	average outdoor temperature (°C)
$T_{o,max}$	maximum outdoor temperature (°C)
$T_{o,min}$	minimum outdoor temperature (°C)
W_g	width of the glazing (m)
y	azimuth angle (degrees)
β	angle between a tilted surface and the horizontal plan (degrees)
δ	solar declination angle (degrees)
ω	hour angle (degrees)

condensation problem in apartment units without balconies. Initially, ventilation slits were designed to introduce natural ventilation with improved thermal performance. The thermal performance of an airflow window with triple glazing and internal cavities of various thicknesses was studied by Diomidov et al. (2012). They found that the thermal resistance of the transparent window part increased when compared to a standard triple glazing. The heat loss through the inner pane of the window unit decreased. It has also shown that airflow windows with triple glazing and natural ventilation ensure a higher temperature of the inner pane when compared to the window without air flow.

Some other works have been carried out on the response of such a system considering the incident solar radiation and also the heat loss from inside. The study of the heat source influence was carried out by using a prototype of a supply air window (McEvoy et al., 2003) and a ventilated double window (Carlos et al., 2012). It was found in both studies that the heat recovered from indoors surpassed the absorbed solar heat that was transferred to the air; thus, when solar radiation was present, thermal conduction through the windows was also verified. The objective of this research, which has never been done, is to take advantage of solar radiation and therefore improve the efficacy of the ventilated double window. Consequently, this study aims at the optimization of the ventilated double window for solar collection under Portuguese climatic conditions through:

- System design: searching for a good system design in order to obtain the best thermal performance, under incident solar radiation;
- Physical proprieties: study the physical proprieties of the components to get the overall higher solar gains without reducing its overall thermal performance.

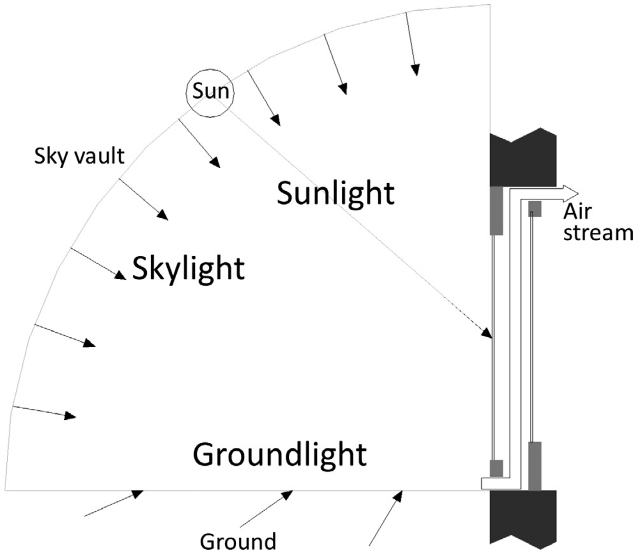

Fig. 1. Skylight, reflected light and sunlight on the ventilated double window.

2. Physical model and mathematical formulation

The influence of the solar incident radiation on the ventilated double window is presented. Fig. 1 shows a basic configuration of the ventilated double window section with daylight source from the sun, sky and reflected from the ground. The model contains the following assumptions: (i) the diffuse daylight from the sky is always downwards, therefore the upper part of the inner window does not receive any diffuse daylight; (ii) the reflected light from the ground is always upwards, therefore the lower part of the inner window does not receive any reflected light; (iii) the direct sunlight depends on the location of the sun, the geometry of both windows and the cast shadow on the inner window due to the outer frame.

The angle of the incidence solar beam (i, in degrees) is found by (da Piedade et al., 2000):

$$\cos(i) = \cos(\beta)\sin(h) + \sin(\beta)\cos(h)\cos(y) \tag{1}$$

where β is the angle between a tilted surface and the horizontal plan (in degrees), h is the angle of solar altitude (in degrees) and y is the azimuth angle (in degrees), meaning the difference between the solar and the surface's azimuth, being:

$$y = |a_s - \alpha_p| \tag{2}$$