Comparative study of the thermal performance of inclined and vertical solar chimneys

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Building ventilation plays an important role in improving the indoor air quality and thermal comfort. This process can be achieved through natural or forced convection. Natural circulation can be driven by renewable energy and consequently, it promotes sustainable exploitation of energy resources. In this regard, a solar chimney is one of the promising renewable energy technologies for building ventilation.

A solar chimney (SC), as its name suggests, requires solar radiation for its basic function. It is considered as a passive cooling strategy which can be used for ventilation purposes. It typically consists of a glazed wall, also commonly termed as glass cover, and an absorber wall parallel to each other; with an air stream inside the channel of the SC. The absorber wall in a SC maximizes the heat energy gained from the sun, thus causing a significant temperature difference between the inside and the outside of the building[1].

Incoming solar radiation strikes the surface of the glass cover and gets transmitted to the absorber wall. The temperature of air inside the chimney channel increases as it gains heat mainly from the absorber wall via convection, thus causing a temperature gradient between the air inside the chimney channel and the air at the inlet of the SC. This temperature gradient results in a density difference which in turn leads to a pressure difference between the channel and the inlet of the SC, thereby causing hot air to get expelled out of the chimney and colder air to be drawn from the adjacent room. The SC may either be vertical (Figure 1) or inclined (Figure 2). Both configurations have been analyzed in previous studies but, to the best knowledge of the authors, there is limited information on the performance comparison between the two types of SCs. The objective of this paper is therefore to compare the thermal performance of two SC designs by using a numerical method.

In this study, a mathematical model was developed based on energy balances of the glass cover, the absorber wall and the air stream. The ventilation rate was expressed in terms of the number of air changes per hour (ACH). Details of this model are reported elsewhere[3].

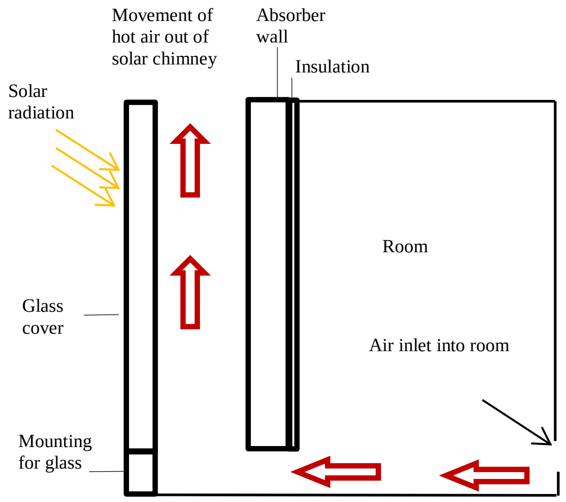

Figure 1: Schematic of a vertical SC.

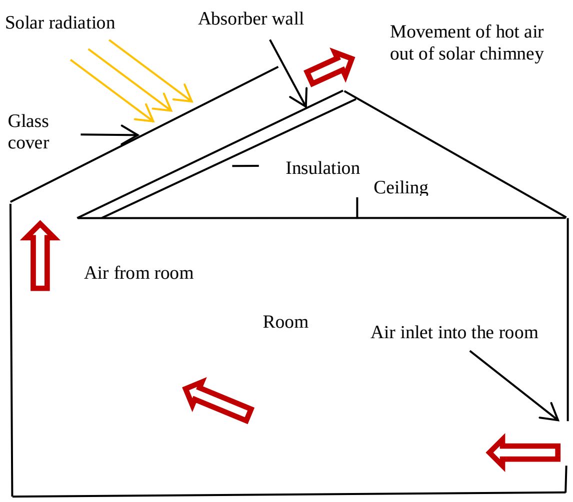

Figure 2: Schematic of an inclined SC.

Meteorological data was obtained from a Stellenbosch weather site (33° 56' S and 18° 46' E), located in the Western Cape Province of South Africa. The raw climatic data (on an hourly basis for the year 2007) comprised: (a) the intensity of global and diffuse radiation on a horizontal surface, (b) wind speed and (c) ambient air temperature. It was essential to calculate various astronomical parameters, solar radiation on a tilted surface, solar radiation attenuation, and heat transfer coefficients for solving the the system of equations. These parameters were were computed according to Duffie and Beckman[2].

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Correlations for temperature-dependent physical properties were developed in Excel using data from Welty et al[4]. The mathematical model was then solved iteratively using a code written in the MATLAB computer program.

Figure 3 and Figure 4 respectively show the effect of inclination angle on ACH and thermal efficiency of the SCs. It was found that the mean monthly hourly ACH increases with the inclination angle of the SC to an optimum value of 60° while the vertical SC gave the worst values of ACH, having the lowest ACH throughout winter (June, July and August) and summer (December, January and February). This observation is attributed to the variation in the transmission of solar radiation through the glass cover. The angle of incidence of solar radiation is affected by the inclination angle of the cover. It decreases to minimum level (as the inclination angle increases), resulting in maximum transmission of solar radiation and therefore thermal energy transferred to the air inside the chimney.

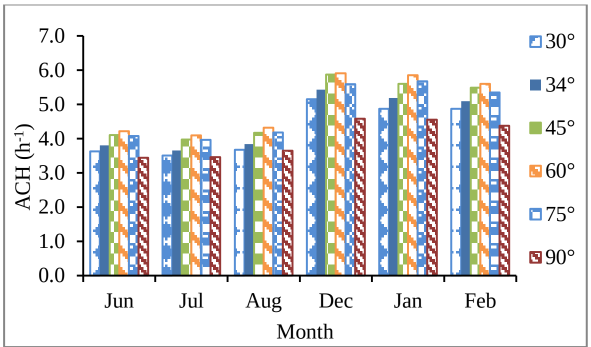

Figure 3: Effect of inclination angle on mean monthly hourly ACH in winter and summer for inclined and vertical SCs; with channel space d=0.25 m and length of absorber $L_{abs}=L_g=2$ m.

As can be depicted from Figure 4, the thermal efficiency of the SC increases as the inclination angle increases from 30° to 60°, but a further increase in the inclination angle causes the thermal efficiency to decrease. The highest thermal efficiency was observed when the SC was inclined at 60° while the lowest thermal efficiency was obtained from the vertical SC. This can be attributed to the fact that more solar radiation can be absorbed by the inclined SC than the vertical one, thereby causing a higher increase in the temperature of the air stream. This results in a larger difference between the temperatures of the air stream and the air at the inlet of the solar chimney, which accounts for the observed higher thermal efficiency exhibited by the tilted SC at optimal inclination.

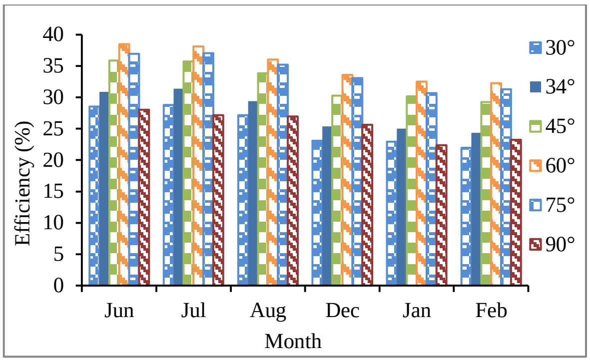

Figure 4: Effect of inclination angle on mean monthly hourly thermal efficiency in winter and summer for inclined and vertical SCs; with channel space d=0.25 m and absorber length $L_{abs}=L_g=2$ m.

The overall conclusion is that an inclined SC performs better than a vertical one, under the same meteorological conditions. Moreover, it can be deduced that the optimum angle of inclination of a SC for Stellenbosch is 60°.

References:

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4. Welty, J.R., Wicks, C.E., Wilson, R.E. & Rorrer, G.L. *Fundamentals of Momentum, Heat and Mass Transfer*. John Wiley & Sons, Inc United States of America, 2008.