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Solar ventilation and heating of buildings in sunny winter days using solar chimney

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ABSTRACT

The capability of solar chimney lonely to meet the required thermal and ventilation needs of individuals in winter days is investigated in this paper. In the analysis, the heat transfer by natural convection and surface radiation in a 2D vented room in contact with a cold external ambient is studied numerically. The dependence of the system performance on air gap depth of the solar chimney, size of openings, outdoor air temperature and solar radiation have been studied to determine the appropriate operation conditions, regarding thermal comfort criteria. The findings show that the system is capable of providing good indoor air condition at daytime in a room, even with poor solar intensity of 215 W/m^2 and low ambient temperature of 5 °C.

1. Introduction

Home windows, walls, and floors can be designed to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design. Passive solar technique is one of the most effective methods used for space heating. It can greatly increase the energy efficiency of a building and can supply 100% of a home heat in some cases. Passive solar houses include a wide variety from those heated almost entirely by the sun to those with south-facing windows that provide a fraction of the heating load. One of the most common designs of the solar passive techniques which are incorporating a thermal storage and delivery system called a trombe wall. The trombe wall is a smart device for collecting and storing heat from the sun during the day time and releasing heat into a building space during the night. However, the application of a trombe wall is restricted because of its visible black-matt surface of the blackened massive wall underneath the clear glass.

Solar chimney (SC) is a good configuration to implement natural ventilation in buildings where solar energy is available. It is usually employed in a regions with mild climate and in spaces where a little variation in indoor is tolerable. This system does not need massive wall and due to usage of fresh air for heating, can provide better indoor air conditions compared to that of trombe wall. Solar chimneys have been studied by a number of researchers and for different applications including natural ventilation of buildings, power generation, etc. For example, Bansal, Mathur, and Bhandari (1994) analytically studied a solar chimney-assisted wind tower for natural ventilation in buildings. They showed the estimated effect of the solar chimney to be substantial in induced natural ventilation for low wind rates. Gan and Riffat (1998) also investigated solar-assisted natural ventilation with heat-pipe heat recovery in naturally ventilated buildings, using a Computational Fluid Dynamics (CFD) technique. Hamdy and Fikry (1998) examined the optimum tilt angle of solar chimney system that compromises between solar heat gain factor and stack high to insure the best ventilation performance. They also showed that the air flow rate through roof solar chimney increases if the height between inlet and outlet is increased. Khedari, Boonsri, and Hirunlabh (2000) experimentally investigated the feasibility of a solar chimney to reduce heat gain in a house and the effect of openings on the ventilation rate. The results showed that when the solar chimney was in use, room temperature was near that of the ambient air, indicating a good ability of the solar chimney to reduce house's heat gain and ensuring thermal comfort. Opening a window or a door is less efficient than using solar chimneys. Rodrigues, Canha da Piedade, Lahellec, and Grandpeix (2000) numerically investigated the behavior of solar-air collectors installed on the south-facing walls of school buildings as a passive means of improving indoor air quality without prejudice to thermal comfort requirements. The fully averaged equations of motion and energy added to a two-equation turbulence model and solved using a finite volume method. Flow and temperature fields were produced and results presented in terms of temperature and velocity distributions at the exit section of the duct. Mathur, Mathur,

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Nomenclature

A	area (m^2)
ACH	air change per hour (h^{-1})
b	width of solar chimney, (m)
C_P	specific heat of air (J/kg K)
C_e, C_μ	empirical constants in the k–ε turbulence model
d	air gap depth of SC (m)
f_1, f_2, f_μ	wall damping function
g	gravitational constant
g_i	component i of the gravitation vector
G_b	buoyancy production/destruction of kinetic energy
h	convective heat transfer coefficient (W/m^2 K)
hr	radiative heat transfer coefficient (W/m^2 K)
I	total incident solar radiation on south facing of the surface (W/m^2)
k	kinetic energy of turbulence
P	gauge pressure (Pa)
P_k	turbulence kinetic energy production
Q	heat transfer to air stream (W/m^2)
S	solar radiation heat flux absorbed by plate (W/m^2)
SC	solar chimney
T_f	air temperature (K)
t	thickness (m)
u, v	x- and y-components of velocities, respectively
$\bar{u}$, $\bar{v}$	time-averaged x- and y-components of velocities, respectively
U	overall heat transfer coefficient (W/m^2 K)
V	volume of room (m^3)
x, y	coordinate system (m)
y^+	dimensionless wall coordinate (yu^*/ν)
Z	height of inlet and outlet (m)

Greek symbols

α	absorbtion coefficient
ε	emissivity
λ	thermal conductivity (W/m K)
μ	laminar viscosity (kg/s m)
μ_t	turbulent viscosity (kg/s m)
ν	molecular kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
σ_k	Prandtl number for k
σ_r	Steffan–Boltzmann constant (5.67×10^{-8} W/m^2 K^4)
σ_e	Prandtl number for e

Dimensionless terms

Pr	Prandtl number [$C_f\mu_f/k_f$]
Pr_t	turbulent Prandtl number
Re_y	turbulence Reynolds number near the wall ($y^+k^{0.5}/\nu$)

Subscripts

a	ambient
abs	absorber wall
g	glass
i, j	index
ins	insulation
r	room
sc	solar chimney

Superscript

–	time-averages value

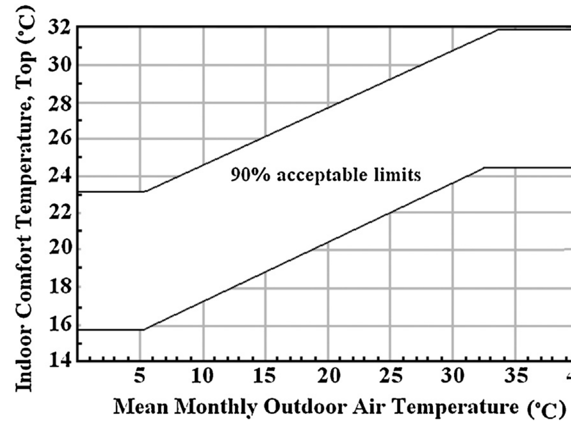

Fig. 1. Adaptive standard for naturally ventilated buildings.

and Anupma (2006) analytically studied the effect of inclination of absorber on the airflow rate in a solar induced ventilation system using roof solar chimney. The results showed that optimum absorber inclination varies from 40° to 60° depending upon the latitude of the location. They (Mathur, Bansal, Mathur, Jain, & Anupma, 2006) also experimentally investigated a small size solar chimney and showed that the rate of ventilation increases with increase of the ratio between height of absorber and gap between glass and absorber. Highest rate of ventilation was found to be 5.6 air change per hour in a room of 27 m^3, at solar radiation of 700 W/m^2 on vertical surface with the stack height-air gap ratio of 2.83. Bassiouny and Koura (2008) analytically and numerically studied the solar chimney for improving room natural ventilation. They found that the chimney width has a more significant effect on air change per hour (ACH) compared to the chimney inlet size.

The review of the related literature shows that the applicability of solar chimney lonely for winter heating of building has not been investigated yet. In the present study, a numerical investigation of air flow take place inside the solar chimney and room is performed, and the capability of the solar chimney in order to provide thermal comfort condition in a living room at winter sunny days is studied. For this purpose, the obtained indoor thermal condition is checked with the Adaptive Comfort Standard (ACS) specified for thermal-comfort in naturally ventilated buildings. The ACS is shown in Fig. 1 and is drawn based on the data reported by Brager and de Dear (2000).

2. System description and problem formulation

Fig. 2 illustrates a schematic plan of the system. The system consists of a SC and a room. The solar chimney comprises a glass surface oriented to the south and exposed to solar radiation. The

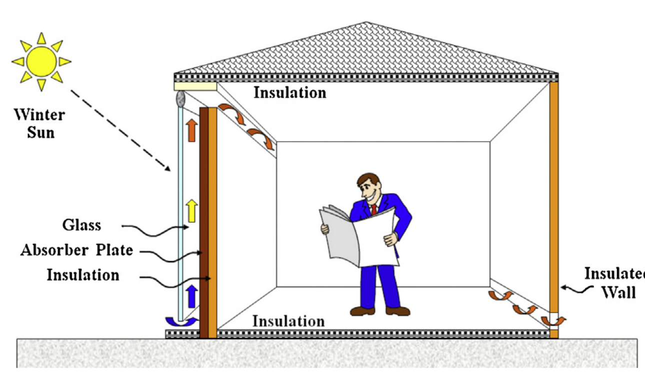

Fig. 2. Schematic diagram of passive solar system.