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Parametric Study on the Effect of a Domestic Wind Catcher-Solar Chimney System for Arid Regions

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Abstract**—** *To reduce dependence on non renewable energy resources for domestic cooling systems, and thereby reducing global warming, one can think of adopting passive cooling systems in combination with one another. Wind towers or wind catchers are stand alone systems widely used in hot, hot dry and (or) hot humid climates. These tall towers installed on the roof-tops capture wind for cooling the interior dwelling spaces. On the other hand, a solar chimney is a natural way of improving ventilation by virtue of thermal buoyancy effects on air. Within the regions of a room where the circulatory wind speed is low, a solar chimney can be installed in combination with a wind catcher in order to improve the efficiency of the system. We have performed various simulations on such a combinatorial windcatcher-solar chimney system for a closed dwelling space (no windows or other infiltration regions), in order to understand the parametric effects (i.e., dependence on incident (solar) heat flux, E on absorber; ambient wind speed, U_∞ and width of air gap in chimney, e) of such a system on the convective air current within the dwelling space. It became evident that substantial air motion can be attained within the closed region with such a combination. The solar chimney in such a system is found to be most effective (incremental improvement in air current) for moderate heat flux on the absorber and lower ambient air speeds (almost 60% increase in room inlet air velocity is observed for such a system with $E = 500\ W/m^2$, $U_\infty=3m/s$), while at higher wind ambient wind velocities ($U_\infty=5m/s$), the main contribution for air current within the room is due to the windcatcher (an increase of nearly 5 times when ambient air speed changes from 1m/s to 5m/s with $E = 500\ W/m^2$). Also, a change in windcatcher geometry may not always adversely affect the room air entry velocities if proper blending and smoothing of possible corners and edges are provided. However, frictional losses and thus reduction in flow velocity within the windcatcher cannot be completely avoided since the sudden bends are deliberately provided inorder to settle dust and sand particles carried by dry air in arid geographical regions where such systems are in use. A test case of such a combinatorial system applied for specific geographical location (Jaipur, Rajastan) is also presented.*

Keywords**—** *Passive cooling systems, solar chimney, wind catcher, solar irradiation, solar calculator, CFD.*

I. INTRODUCTION

Passive cooling systems for dwelling spaces can reduce the consumption of non-renewable natural resources, thereby effectively reduce global warming and check the dependence on fossil fuels. Wind towers, also called as '*wind catchers*', are used for passive ventilation and cooling of buildings in the hot and arid regions around the world. These tall towers provided with several vents to capture wind for cooling the interior spaces and installed on the roof tops of buildings, are particularly popular in Iran and other Arab countries. Such wind catchers can have different shapes and structures depending on the geographical location, and they can save a lot of electrical energy in providing thermal comfort during the hot months of a year, while ensuring sustainability.

The wind catcher openings are usually positioned facing the wind direction based on the geographical location. Knowledge of the wind flow pattern for a specific region can be of use here, while additional wind towers can be installed in several positions if the wind is accessible from several directions. Some designs for wind catchers even involve rotatable structure to face the direction of the maximum wind speed. Thus, windcatchers admit ambient air from outside and channel them into the dwelling space of a building, before which the dust (or sand) carried along is allowed to settle in a mid chamber. Hence due to these unavoidable frictional effects, the velocity of air entering the room will be much lower than the windy ambient air conditions.

Some designs for windcatcher allow the air to pass through narrow sections, thereby increasing air velocity in accordance with Bernoulli's principle. This in turn can improve convective heat transfer and result in effective cooling. Some windcatchers attempt to improve the relative humidity of admitted air by passing it over water reservoirs within the room. Thus the air entering the dwelling space will be much cooler in comparison. Usually mud walls for partition and replenishable ponds as water sources are incorporated in a wind catcher design, as improvements over standard design.

A solar chimney works on the principle of natural convection by virtue of thermal buoyancy of a heated air column. Such a mechanism can improve natural ventilation in the house. Usually a solar chimney consists of a glazing surface (also called the '*collector*') made of glass which transmits solar radiation and traps thermal energy, a solar radiation '*absorber plate*' (painted black, or coated HDPE on one side and insulated on the other) which reradiates heat energy into the air column within, and a vertical hollow shaft through which the heated gases move up. During the day, as the chimney and enclosed air are heated by solar energy, the resulting updraft in the chimney creates suction at the bottom of the chimney. This suction can mobilize air in the room, thereby ventilating the house.

Generally, there are a number of studies separately carried out in the installation of different types and shapes of wind catchers and solar chimneys for various types of buildings. We initially carried out a review of the past research works conducted by various researchers in the field of installation of wind catchers and solar chimneys in the buildings. Bahadori is a pioneer in research on wind towers, and has worked on wind

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towers operation and efficiency for almost 40 years [2-4]. The works of Bahadori et al. on the operation and efficiency of wind towers are exhaustive. Designs incorporating wetted column and wetted surfaces (evaporative cooling by uniformly spraying water on the surface of the wind-tower column) are their main contributions, which were improvements from conventional designs.

Dehghan et al. investigated both experimentally and theoretically, the influence of wind speed and direction on the ventilation capacity of one-sided wind towers [5]. A windtunnel was used to obtain the experimental results. The roof of one-sided wind towers used during the experiment was flat, inclined or curved. Results showed that the internal pressure field and induced airflow rate inside the wind towers were strongly influenced by the geometry of the wind tower's roof and wind direction. They improved the design of one-sided wind towers with the help of these results. In another study, the smoke visualization method was used to obtain empirical results for the main flow characteristics around and inside different types of one-sided wind towers. Their method showed that the wind tower with a curved roof had better performance than other types.

Ghadiri et al., proposed the usage of wind towers as a green ventilation system capable of increasing the air quality inside buildings with minimum energy consumption. They carried out extensive numerical investigations on the performance of square wind towers with different dimensions in hot and arid regions [6].

In another study, Ghadiri et al., examined the effect of geometry of traditional wind towers on the internal thermal behaviour of a building [7]. Their software based simulations of two different square wind towers have provided valuable insight on how the traditional wind towers actually work.

Montazeri et al., have carried out numerical, analytical and experimental investigations on the operation of a two-sided wind tower in order to improve its design [8]. They tested a model wind tower connected to a model house through wind tunnel experiments. The pressure coefficient distribution and airflow pattern around and through the wind tower at various wind angles were evaluated both experimentally and numerically in their studies. According to these studies, maximum performance for a two-sided wind tower is obtained when the sides are at an angle of 90 degrees.

Chergui et al., presented the study related to heat transfer and airflow modelling analysis in solar chimneys, in terms of some dominant parameters [9]. A typical case of analysis was the natural laminar convective heat transfer problem taking place in a chimney. Heat transfer and fluid dynamic aspect of the air flow, through an axis symmetric system in a dimensionless form with well defined boundary conditions was thus examined. This work involved solving the energy equation, and the Navier-Stokes equations, using finite volume method. Results were then related with temperature distribution and the velocity field in the chimney and in the collector.

Goudarzi et al. carried out theoretical and experimental studies for a new design of wind tower with a four- quadrant-peak wind-catcher rooftop, nozzles, and turbines [10]. They proposed a mathematical model for investigations and further improved the mathematical model using the experimental results. They proved that the wind power in their conceptual wind tower was a strong function of speed and direction of ambient air flow around the building. They proposed the usage of their conceptual wind tower design for power generation in residential and commercial applications.

While using a wind catcher for passive cooling, we may have regions within the dwelling space where the wind speed is low and has almost stagnated. To improve the efficiency of such a system, a solar chimney can be installed in that part of building where the air has slowed down. The glazing and absorbent surfaces in such systems should be placed facing the sun, making effective utilization of solar irradiation for heating the air column within chimney. Such combinatorial wind catcher-solar chimney systems can improve the efficiency of the stand alone passive cooling systems when considered separately. Research works that combine both the effects of wind catchers and solar chimneys are few. Tavakolinia [11] suggested using both wind tower and solar chimney in a building for natural ventilation and heating. A passive cooling system was used to create thermal comfort for inhabitants by combining the wind tower and solar chimney with an underground air channel. Such system was found to reduce energy usage, CO_2 emission, and pollution. However, extensive studies in this field are still required to fully realize the benefits of using these combinatorial passive cooling systems. Here we attempt to detail the effect of various influencing parameters (*viz.*, dependence on incident (solar) heat flux, E on absorber; ambient wind speed, U_∞; width of air gap in chimney, *e;* and the basic geometry of wind catcher) on the performance of such a combinatorial system.

II. Methodology

Numerical simulations on the steady state airflow due to pressure/thermal gradients, the influence of various structural parameters and, the weather conditions were carried out using the customized CFD solver Fluent® of ANSYS Workbench.

A. Governing Equations

The air motion is governed by the continuity equation (conservation of mass) and the Navier-Stokes (momentum transport) equations extended to include thermal buoyancy forces.

$$\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \mathbf{V}) = 0 \tag{1}$$

$$\frac{D(\rho \mathbf{V})}{Dt} = -\nabla p + \nabla \bullet \boldsymbol{\tau} + f_b \tag{2}$$

where,

ρ is density of air (kg/m^3) , V is the velocity (m/s), p is the static pressure (N/m^2), τ is the stress tensor (N/m^2) and $\boldsymbol{f_b} = f_b(Gr, Pr)$is the body force on air per unit volume accounting for the net effect under gravity and thermal buoyancy forces (N/m^3). Here, Grashof Number, $Gr = \frac{g\beta(T-T_\infty)L_c{}^3}{\vartheta^2}$ and Prandtl number, $\mathrm{Pr} = \frac{\mu C_p}{k}$, g is acceleration due to gravity (m/s^2), β is the coefficient of thermal expansion for air (1/K), T is the absolute temperature of air (K), T_∞ is the

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absolute temperature of ambient air, L_c is the characteristic length (m), C_p is the specific heat of air at constant pressure (J/kg-K), μ is the dynamic viscosity of air (kg/m-s), and $\vartheta = \frac{\mu}{\rho}$ is the kinematic viscosity of air (m^2/s).

Additionally, energy equations have to be solved simultaneously, as

$$\frac{D(\rho h)}{Dt} = -\frac{Dp}{Dt} + \nabla \bullet (k \nabla T) + \Phi \qquad (3)$$

where,

h is is the specific enthalpy which is related to specific internal energy, e_{int} as $h = \left(e_{int} + \frac{p}{\rho}\right)$, k is the thermal conductivity of air (W/m-K), and $\emptyset = (\boldsymbol{\tau}.\nabla)\boldsymbol{V}$ is the dissipation function representing the work done against viscous forces, which is irreversibly converted into internal energy.

B. Geometry and Boundary Conditions

A simple model dwelling space with a combinatorial wind catcher-solar chimney system can be as in Fig. 1. Table I details the geometrical specifications for the same. The space is closed otherwise for the wind catcher inlet and solar chimney exit (*i.e.*, no windows, doors, or ventilation for the room). This ensures we can obtain results with the various combinations of the stand alone systems in the way we may require it. This dwelling space will have the realistic size of a normal room and we make no attempt to non-dimensionalize any parameters in the present study. However, this will be attempted in future.

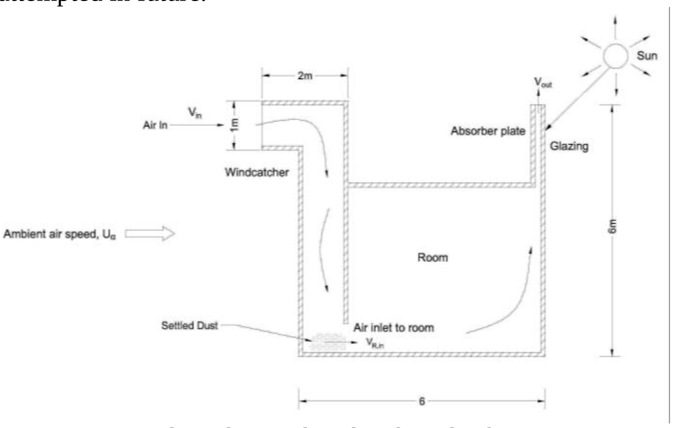

Fig. 1. A simple combinatorial wind catcher-solar chimney system.

TABLE I. Geometrical specifications of the system.

S. No.	Geometry	Measurement
1	Area of wind catcher opening	2 m^2
2	Room inlet opening area	1.4 m^2
3	Length of the collector (glazing)	2 m
4	Breadth of the collector	1.5 m
5	Air gap in the chimney, *e*	0.15 m
6	Distance between inlet and outlet of collector	2 m
7	Area for chimney inlet and outlet openings	0.225 m^2

As per the problem specifications, on achieving steady state, the various parts can have the following boundary conditions (Fig. 2). The chimney height was fixed at 2 m for all simulations. One wall of the chimney is a glazing collector (usually glass) at a constant temperature T_c. Its opposite facing wall is heat absorbent coated with HDPE and at temperature T_h. Both walls take part in radiative heat transfer. Solar heat flux boundary condition will be specified on the absorber surface. Rear surface of the absorbent plate is insulated, and hence absorbent plate acts as a re-radiating surface with radiosity equal to its black body emissivity. Both the temperatures T_c and T_h will be calculated by the solver through energy balance equations (refer to equation 3), as per the radiation model. The other two side walls of the solar chimney are insulated, hence adiabatic. Walls of the dwelling space are assumed not to take part in heat transfer, such that the solar chimney is solely responsible for the thermal buoyancy effects on air. Ambient atmospheric air temperature (T_∞) and ambient air velocity (U_∞) are usually specific to a geographical location for a particular day/month of a year. Here we assume T_∞ to be at a constant value of 300K for the various U_∞. All walls of the dwelling space were assigned no-slip boundary condition for air flow. The computational domain extends 5 m to the front and 20 m downstream, as well as 5 m to either sides of the geometry. Inlet velocity boundary condition is imposed on the inlet of the computational domain, while pressure exit boundary condition is imposed far downstream at rear. No-specified shear boundary conditions at the side faces and top face of the computational domain ensure the velocity gradients are non-existent at the sides and top $\left(\frac{\partial u}{\partial y} = 0, \text{or } \frac{\partial u}{\partial z} = 0 \text{ accordingly}\right)$.

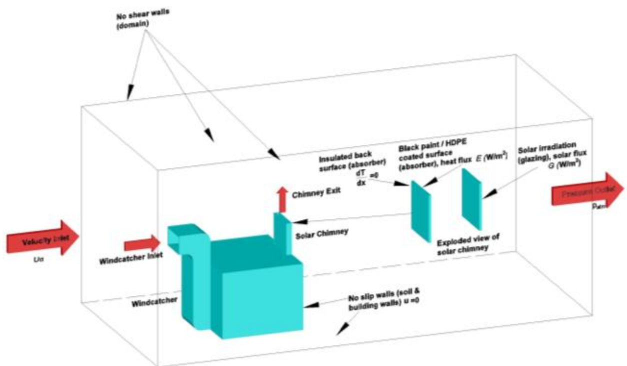

Fig. 2. Boundary conditions for simulations on the combinatorial system.

C. Scheme for Numerical Simulations

The numerical scheme has been implemented separately for simulations with and without solar heat flux. For the former, the air flow was found to be turbulent even for ambient air velocity of the order $U_\infty = 1\, m/s$ (the lowest ambient condition in our simulations). This was based on Reynolds number, $Re = \frac{\rho U_\infty L}{\mu} > 2\text{x}10^5$, where L is the characteristic length of the building (here, roof length). For the turbulent flow, viscous realizable *k-ε turbulence model* was selected with near wall treatment based on scalable wall functions. For the simulations with solar heat transfer, we had to additionally switch the energy equations and radiation models on. Since Rayleigh number, *Ra* (= *GrPr*) based on the chimney height was >10^9 for the even a moderate temperature difference *i.e.*, $(T - T_\infty)$ under 20K, for which Bousinessq approximation for thermal buoyancy is valid, the numerical model selected (in ANSYS Fluent®) was '*turbulent flow*' with

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energy equation '*on'*. For the radiation heat transfer, Discrete Transfer Radiation Model (DTRM) was activated. Even though Fluent® has an option to associate 'Solar ray tracing algorithm' along with DTRM radiation model, we decided not to utilize it. Instead, the DTRM model was used in association with specified heat flux imposed, E as boundary condition on the absorber surface (can be computed based on the solar radiation flux incident, G on glazing collector and the transmissivity of glass). This allowed us to have a much desired control on the input parameters for system simulations. Assuming, the flow to be predominantly pressure driven in most regions, a steady state solution was sought with pressure based solver for Navier-Stokes equations. However while specifying the fluid properties, we allowed density variations for air based on Boussinesq approximation. This would suffice for thermal buoyancy effects for air in regions of importance. A detailed explanation on the reasons for the various models selected and property specifications can be accessed in standard text books and (or) ANSYS Fluent® help documentation for users. We resorted for residuals $\leq 10^{-3}$ for mass, momentum and energy equations to attain global convergence. The computational grid had 5365724 tetrahedral mesh elements with 989292 nodes and maximum face size less than 0.1m

III. Results and Discussion

Separate simulations were carried out to study (i) air flow without (solar) heat flux, *i.e* with the effect of wind catcher alone, (ii) with heat flux on absorber plate, *i.e* with combined effect of wind catcher and solar chimney, (iii) influence of chimney width, *e* on air flow, (iv) seasonal variation in the performance of the system, and (iv) with a change in basic geometry of windcatcher (*i.e.*, circular sectional area instead of rectangular, and no heat flux). These are discussed below in detail, under relevant sections.

A. Simulations on the Combinatorial System without Heat Flux

The first set of simulations was carried out without the influx of solar radiation. The ambient wind velocity, U_∞ was varied as 1 m/s, 3 m/s, 5 m/s of which the results for U_∞ = 1 m/s and at ambient temperature T_∞ = 23°C is presented below. The velocity vectors for air motion are plotted below (Fig. 3).

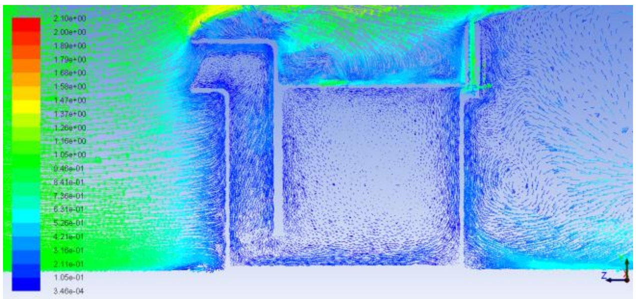

Fig. 3. Velocity vectors for airflow (U_∞ = 1 m/s, no heat flux)

Recirculation regions for air outside the building is observed behind the chimney and rear walls at the back .The air motion within wind catcher and room is also visible. The air velocity gets reduced as it passes through the wind catcher, at the exit of which it is 0.045 m/s (see Table III for all results). This velocity of air entering the room from wind catcher exit will be hereafter referred to as $V_{R,inlet}$. A gentle air movement of 0.025m/s is observed in the mid-plane of the room in this configuration. An increased flow velocity is observed in chimney due to reduction in cross sectional area (0.65 m/s at chimney exit).

The pressure contours (Fig 4) signify gentle pressure drops in regions of higher flow velocities on the top surface of windcatcher, whereas relatively higher pressure is observed within the room due to the slowing down of air flow. The values in contour plot signifies gauge pressure (ie, with respect to the ambient pressure of 1 atm).

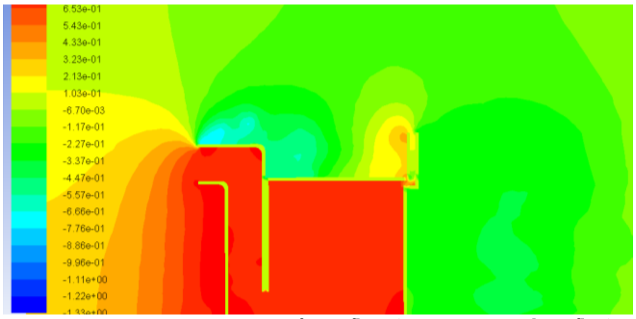

Fig. 4. Pressure contours vectors for airflow (U_∞ = 1 m/s, no heat flux).

B. Simulations with Varying Heat Flux on Absorber Surface

In order to study the effect of increasing solar irradiation on the drafting capability of the combinatorial system, a second set of simulations was carried out with three increasingly different specified values for solar radiation, *i.e.*, E = 250, 500 and 1000 W/m^2 normally incident on the absorber plate. These values of heat flux were imposed as boundary conditions on the absorber plate, as previously explained in *Section II. B.* This heat flux is actually a result of the solar irradiation on the glazing surface (collector). Transmissivity of glazing collector is thus an important consideration here. The various thermo-physical specifications employed in this set of simulations are as detailed in Table II.

TABLE III. Thermophysical specifications for the system**.

S. No.	Property	Value
1	Internal emissivity (thermal) of collector plate *i.e.*, 'glazing'	0.8
2	Transmissivity (thermal) of collector plate	0.1
3	Transmissivity (solar incidence) of collector plate	0.9
4	Internal emissivity of absorber (black paint, HDPE)	0.98
5	Absorptivity of absorber (HDPE)	0.98
6	Specific heat of air, *Cp*	1 kJ/kg-K
7	Convective heat transfer coefficient (low speed air flows), *h*	15 W/m^2-K

**Heat and mass transfer data book (Kothandaraman & Subramanyan)

The contour plots of results (velocity and pressure) only for simulations at free stream air velocity U_∞ = 1 m/s and solar influx, E = 250 W/m^2 is presented below. The air velocity within the windcatcher is higher when compared to the system without solar radiation influx (Fig. 5). At the inlet to room it is 0.079 m/s. An improved drafting by virtue of the thermal

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buoyancy results in increased flow velocity in the chimney in addition to the reduction in cross sectional area (1.25 m/s at chimney exit). The pressure contours show a further pressure drop with in the room (when compared to the simulations without heat influx) signifying effective drafting (Fig. 6).

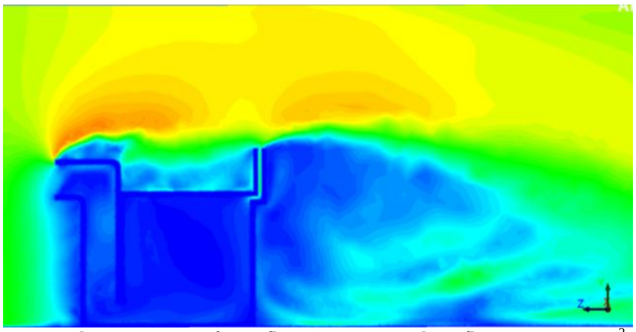

Fig. 5. Velocity contours for airflow (U_∞ = 1 m/s, heat flux E = 250 W/m^2).

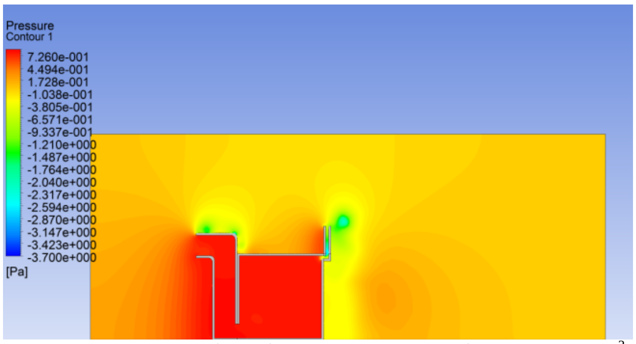

Fig. 6. Pressure contours for airflow (U_∞ = 1 m/s, heat flux E = 250 W/m^2).

The simulations show that the effect of solar chimney with incident heat flux is to increase the velocity of air entering the room inlet, $V_{R,inlet}$ (Table III, Fig. 7), as the heat flux, E on the absorber plate increases.

TABLE III. Results of simulations without (wind catcher alone) and with heat flux (wind catcher-solar chimney coupled) at various ambient air speeds.

Ambient wind speed, U_∞ (m/s)	**Wind speed on entering room inlet (outlet of the wind catcher), $V_{R,inlet}$ (m/s)**			
	Effect of wind catcher alone (m/s)	Wind catcher-solar chimney coupled		
		Heat flux on absorber , E (W/m^2): 250	500	1000
1	0.045	0.079	0.12	0.128
3	0.167	0.303	0.35	0.39
5	0.507	0.515	0.56	0.59

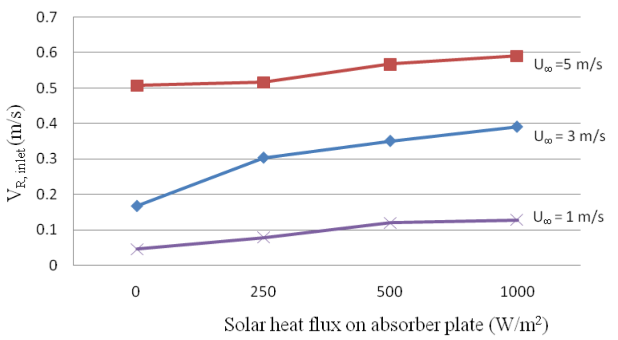

Fig. 7. Variation of room inlet air velocity with chimney effect.

C. *Simulations with Varying Solar Chimney Width*

Further simulations were carried out to study the effect of increasing chimney width (*i.e.*, air gap in the chimney) influencing the air motion within the room. Three increasingly different chimney widths (e = 0.15m, 0.30m and 0.45m) were considered for simulations, while the dwelling space encounters the same ambient air flow of 1 m/s. For each of these cases, drafting tendency of the solar chimney at two different solar heat flux configurations (E = 250, 1000 W/m^2) was simulated. It was found that, while a narrow chimney is effective in drafting air out of a closed room, its efficiency decreases as the geometric width is increased for the same heat influx on the absorber surface., *i.e.*, only negligible contribution is experienced from solar effect of wider chimneys in comparison to the wind catcher effect (Fig. 8). Considerable thermal buoyancy effects may not be developing in wider configurations which in-turn could have lifted heavier air columns within a wider chimney (Since thermal buoyancy, $\boldsymbol{f_b}= f_b(g,\beta,\Delta T,L_c)$, very high values for ΔT cannot be expected with normally experienced solar radiation flux. With Boussinesq approximation, such variations contributing thermal buoyancy could be within 20-30^{o}C. Hence in such cases, wind catcher is undoubtedly the main reason for air movement within the room.

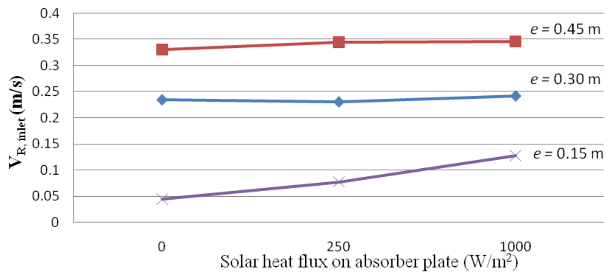

Fig. 8.Variation of room inlet air velocity, $V_{R,inlet}$ with chimney width, e (for U_∞ = 1 m/s, and various heat flux on absorber).

D. *Seasonal Performance of the Combinatorial System*

For any particular geographical location with arid and windy weather, solar irradiation data and wind velocity data can be used appropriately in the simulations. For *e.g.*, we have selected a semi arid region- Jaipur in the state of Rajastan for the simulations in this section (75.88^o E Longitude, 26.91^o N Latitude and time zone +5.30), for which the average seasonal wind speed is not above 10km/hr [12]. In Fluent®, solar ray tracing model offers the calculation of illumination parameters (direct and diffused solar radiation in W/m^2) to be provided as input to the simulations. This data can be generated for any particular day of any month in a year. For simplicity, we will be considering only the direct normal solar irradiation hence generated, for our computations. The sun direction vector was also generated by the solar ray tracing algorithm with respect to the mesh orientation (which was provided explicitly). The sun direction vector can be resolved appropriately to the area normal to any surface in order to calculate the net normal irradiation on the surface. This specifies the heat flux boundary condition on the absorber plate (Fig. 9).

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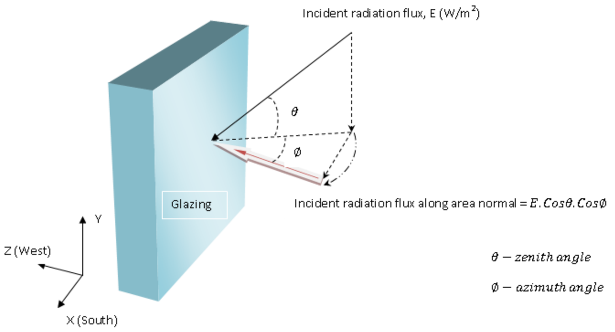

Fig. 9. Calculation of incident (direct) irradiation flux on solar chimney along the area normal.

For the present simulations, two different days over the year (21st of March and 21st of September at 14:00 hrs) has been chosen to study the seasonal performance of the combinatorial system (with a chimney width, e = 0.15 m) under the incident solar radiation conditions for the respective months. This data was generated assuming fair weather conditions with '*sunshine factor*' = 1 (no cloud cover) over Jaipur (Table IV).

TABLE IV: Two cases of seasonal variation in the solar radiation flux on solar chimney for the present configuration, based on solar calculator.

Sl No	**Date and time**	**Sun direction vector (X,Y,Z)**	**Direct normal solar radiation as per solar calculator, *E* (W/m^2)**	**Solar radiation flux along area normal to glazing**
1	March 21st, 14:00 hrs	(0.4069,0.8141,0.4142)	979.19	394.68
2	Sept 21st, 14:00 hrs	(0.3899,0.7921,0.4694)	920.535	358.70

Since the normally incident radiation flux is below 500W/m^2, we can interpolate the result from the results of previous simulations (Table III, Fig. 7), in order to identify the seasonal performance of the combinatorial cooling system (Fig. 10).

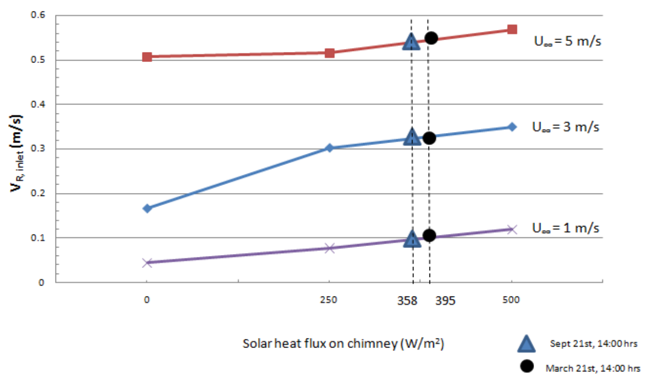

Fig. 10. Seasonal performance of the combinatorial system for two specified days in a year (interpolation method).

It is clear that the same combinatorial system performs better on hotter months of the year, for the same ambient air flow velocity, since the heat flux on absorber increases. Likewise, one can opt for a full set of simulations or choose interpolation method as described above to generate data for the performance of the system.

E. Effect on the Change of in Basic Geometry of Windcatcher (rectangular to circular cross section, no heat flux)

We also studied whether the velocity of air entering the room is affected by a change in the basic geometry of wind catcher. A circular cross section was chosen instead of the previously rectangular geometry. While keeping the cross sectional area the same as that of the original system (= 2 m^2), simulations were performed for an ambient speed U_∞ = 5 m/s and with no solar heat flux (Fig. 11). This allowed us to compare the effect of the change in geometry alone in the velocity of air entering the room.

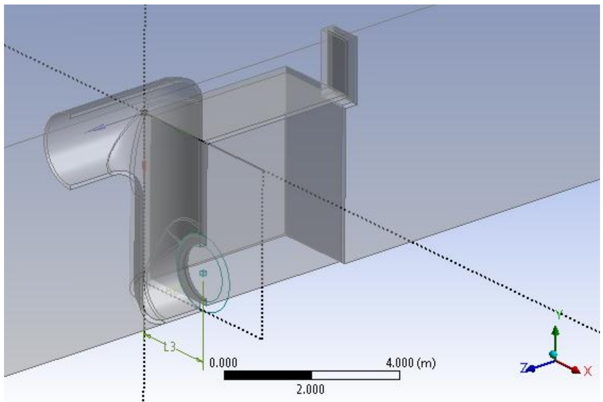

Fig. 11. Change in windcatcher geometry (rectangular to circular cross section, area remaining the same).

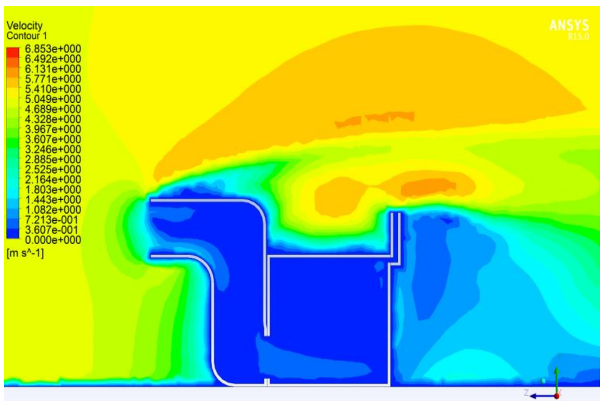

Fig. 12. Velocity contours for air flow with changed wind catcher geometry, and no heat flux (effect of wind catcher alone); U_∞ = 5 m/s.

The velocity contours for this set of simulations are presented in Fig. 12. The room air inlet velocity ($V_{R,inlet}$) changed only nominally (under 4%) in comparison with previous simulations under similar conditions. (This was obtained to be 0.49 m/s). This negligible change may be due to the effective blending of the corners (radius of 0.8 m in both the cases), which ensured smooth flow of air through the wind-catcher in either case for the same height.

Hence basic geometry was not found to play a significant role on room air inlet velocity, due to the effective blending of corners for the given height of wind catcher.

IV. Conclusion

From the various simulations performed on a combinatorial windcatcher-solar chimney system for a closed dwelling space (no windows or other infiltration regions), it was evident that substantial air motion can be attained within the region with such a combination. The solar chimney in such a system is found to be most effective for moderate heat flux on the absorber and considerable temperature difference with ambient air (almost 60% increase in room inlet air velocity is observed for such a system with E = 500 W/m^2, U_∞ = 3m/s), while at higher wind ambient wind velocities (say, U_∞ = 5m/s), the main contribution for air entering the room appears to be due to the windcatcher (for *e.g.*, an increase of nearly 5 times, when the ambient air speed changes from 1 m/s to 5 m/s with E = 500 W/m^2).

On widening the chimney, a heavier air column has to be lifted. Hence for normal values of solar irradiation flux on this chimney, a drastic improvement in thermal buoyancy and hence drafting cannot be expected. Only moderate improvement is contributed by the same.

A change in windcatcher geometry may not always adversely affect the room air entry velocities if proper blending and smoothing of possible corners and edges are provided (as observed from the simulations in this regard). However, frictional losses and thus reduction in flow velocity within the windcatcher cannot be completely avoided since the sudden bends are deliberately provided to settle dust and sand particles carried by dry air in arid geographical regions where such systems are in use.

As expected, a windcatcher-solar chimney system has better seasonal performance during hotter months, as evident from the simulations based on solar calculator and wind data for a specific arid geographical location.

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