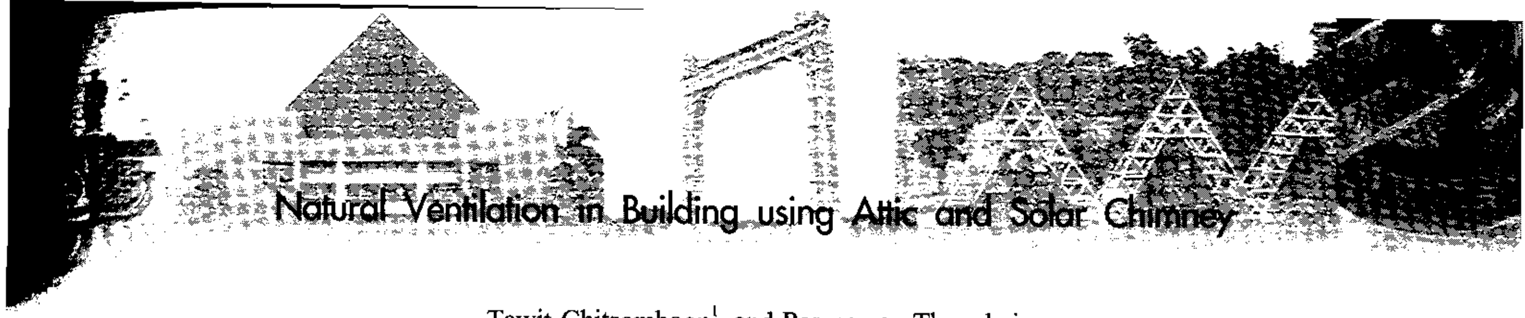

Natural Ventilation in Building using Attic and Solar Chimney

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Abstract : A new solar-induced technique for air ventilation in building is proposed, wherein transparent roof and chimney are employed to induce high volume air flow to ventilate the building as well as to cool human dwellers. The driving force for the flow is the buoyancy created by the attic room under a transparent roof. The flow is further enhanced by the chimney attached to the top of the roof. Computational fluid dynamics program was used to simulate the mentioned air flow at various significant parameters such as, roof inclinations, chimney heights, solar intensities and roof shapes. It was found that reasonable air flow rates were achieved that could result into comfortable living conditions in the rural area of the Tropic.

Keywords: Natural ventilation, Natural cooling, Solar chimney, Solar attic

1. INTRODUCTION

The ever rising cost of fuel-derived energy and the environmental awareness have prompted many researchers around the world, especially in developing countries, to search for natural means to ventilate and cool buildings (commercial as well as private dwelling.) Active methods, such as evaporative cooling, have sometimes been employed. In a dry climate, evaporative cooling could be used to lower entering air temperature; depending on the prevailing relative humidity and the maximum relative humidity allowed, in as much as 10°C lower than ambient temperature can be achieved by this method but additional sprinkler and fan systems are required. If the resulting relative humidity of evaporative cooling is too high, desiccant can be utilized to adsorb some of the humidity from the humid air and the desiccant recycled by heating, often by solar means. The other means of natural ventilation is by the assistance of 'solar chimney'. Conceptually, this involves a solar-heated space to create lighter air which flows to a taller outlet via buoyancy force, while inducing cooler air into the space to replace the hotter outgoing air.

Barozzi, et al, [1], numerically investigated the effect of solar chimney based ventilation by using a model house with corrugated metal roof of approximately 27 degree inclination together with an experimental-based hot roof temperature as the source of solar heat input. The paper concluded that while the concept seems to work but the induced air velocity is very low, perhaps not sufficient for its expected cooling effect. Bansal, et al, [2], studied the combined effects of wind tower and solar chimney to ventilate a house, by using a mathematical model. The chimney was estimated to give in as much as 60% additional wind speed over that which is caused by the wind tower alone. A derivative of solar chimney has been proposed by

Khedary [3-5], wherein solar heat is used to create suction trough a 'solar chimney' which basically is a narrow channel formed between a transparent panel and the heated wall. Other investigators have researched to advance and to confirm the viability of solar chimney as a device to naturally ventilate building spaces [6-7]. Recently, the concept of solar chimney has been investigated as a means for large scale electricity production [8]. This involves heating ambient air under a greenhouse and venting it at high velocity through a very tall chimney. The resulting kinetic and thermal energy carried along with the hot air can thus be harvested via a turbine which could be used to turn a generator.

Borrowing the idea from the electricity generating solar chimney, the present paper proposes to use a transparent roof, together with the attic room underneath, to create the driving force to induce a natural convection in building. While the concept proposed herein is not new, the methodology is quite different from [1]. The concept proposed in [1] seems to revolve around the idea to use the 'leaking' heat from the roof to the most advantageous way possible; but the current proposal intend to maximize the solar heat as much as possible in ways similar to that of [3-5]. The difference from [3-5] is that the heated space, instead of being a narrow channel, now includes the entire attic room. Moreover, solar chimney in the traditional sense (a vertical chimney) is also employed to give extra suction. As a result, ambient air is entrained through strategically located channels surrounding the building, cooling and ventilating the building in the process, before venting through the heated roof and chimney. This methodology aims at removing the heat accumulated in the house while at the same time provide the cooling effect by the wind velocity. To prove the validity of this concept, numerical computations are made using CFX: a well proven commercial computational fluid dynamic software. Before the real computation was done, the CFD code was validated by solving a natural convection boundary layer flow over a vertical flat plate. The numerical results obtained were in excellent agreements with the known theoretical solution.

2. Physical Model and Assumptions

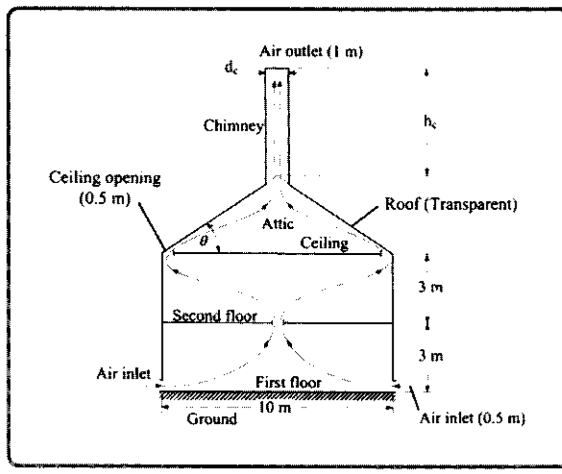

Fig. 1 Physical model of the building

The basic building model in this research is a two-storey house as portrayed in Fig. 1. In this research Since this is the initial phase of the research, prove of concept, rather than accuracy, is the main objective. Thus two dimensionality is assumed in order to save computer run time of the many cases that were investigated. Inlet channels are located nearer to the ground level than the window of a typical house in order to allow the incoming air to blow at about waist level of a typical human dweller. A hole at the middle of the second floor is employed to vent the air to the second floor. Ceiling holes near walls receive the flow before sending it to the attic. To enhance the natural draft, a chimney is also attached at the rooftop. Chimney, with 1 m. gap, of heights 3, 5 and 7 m. (measured relative to of the 45° roof) were investigated. Other building and environment parameters investigated are: roof inclination of 15°, 30°, 45° and 60; solar radiation intensity (insolation) of 300, 550 and 800 w/m². The roof is assumed to be transparent and the air in the attic is assumed to be receiving solar heat via direct solar radiation. The solar heat acquisition of the attic air is thus modeled to be that of a uniform heat source that is evenly distributed through the attic space. Ceiling and housing walls are assume to be perfect adiabatic surfaces. Steady, laminar flow is also assumed because of the low velocity involved. Boussinesq buoyancy model was also presumed.

3. RESULTS AND DISCUSSION

Typical streamline patterns and velocity vectors within the model house are as shown in Figs. 2 and 3.

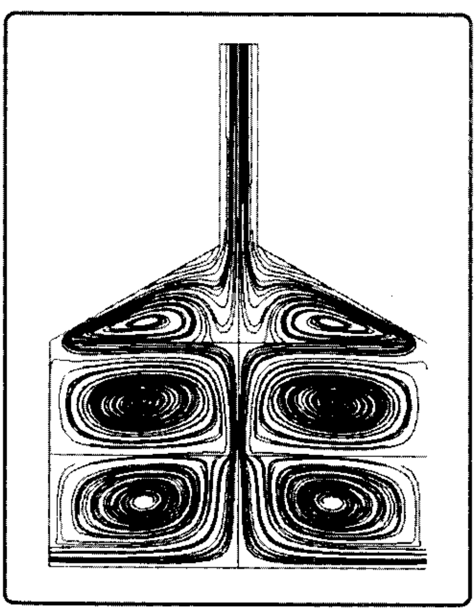

Fig.2 Streamline patterns

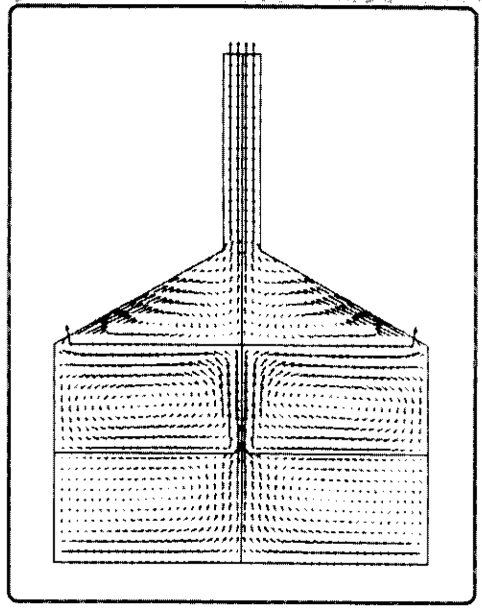

Fig.3 Velocity vectors patterns

The main convective flow paths can be seen (in Fig. 2) as bended straight lines starting from the inlet channels from the left and right walls, rising through the middle hole in the second floor, entering the attic, before venting through the chimney. Between the walls and the main flow paths, large vortices of relatively low velocity are formed. Representative quantitative results will be shown along a selected flow path as indicated in Fig.4

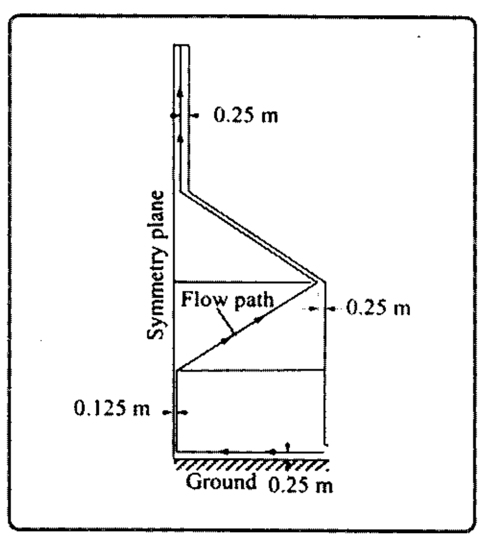

Fig.4 Flow path along which data are plotted

Fig.5 shows velocity distribution along the selected flow path at various roof inclination angles with chimney height of 7 m. It can bee seen that the overall average velocities increase with the roof inclination (note that the top of the chimney is at the same height above ground regardless of roof inclination.)

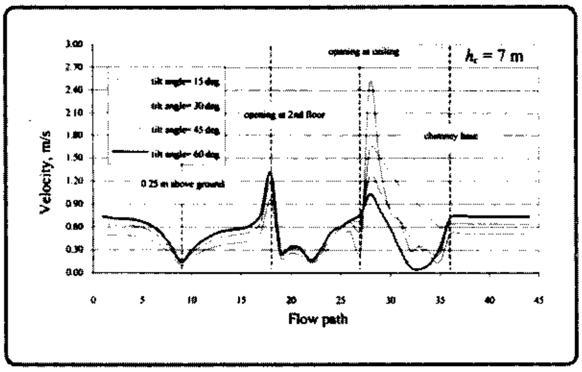

Fig.5 Velocity distributions for 7m chimney

Fig. 6 shows the same plot as Fig. 5 except that it is for the case of 3 m. chimney height. Comparing with Fig.5, it is noticed that overall average velocity is lower; this is simply because of the decreased chimney height produces less suction than the taller one.

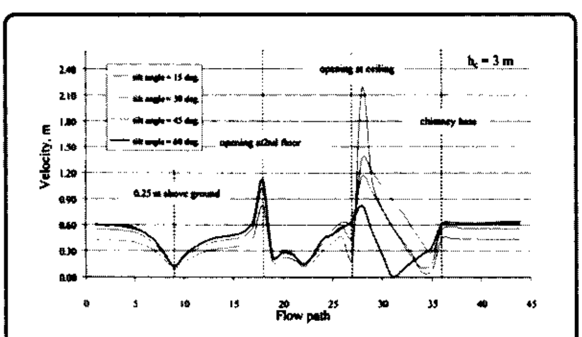

Fig.6 Velocity distributions for 3m chimney

Distributions of pressure, temperature and density along the flow path are indicated in Figs.7, 8 and 9, respectively (for the case of 7 m. chimney.)

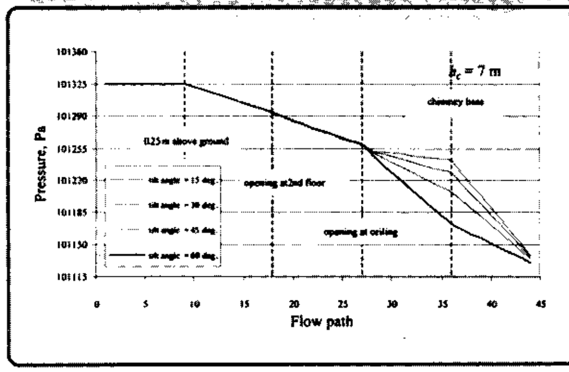

Fig.7 Pressure distribution along the flow path

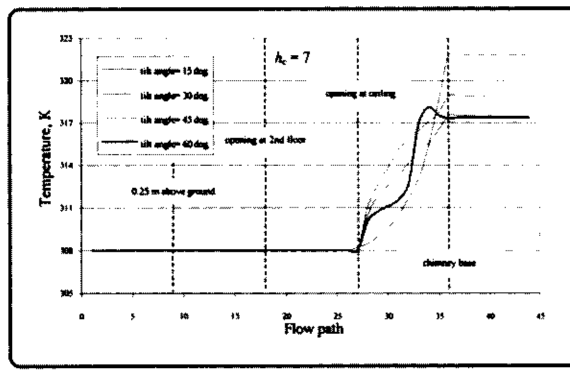

Fig.8 Temperature distribution along flow path

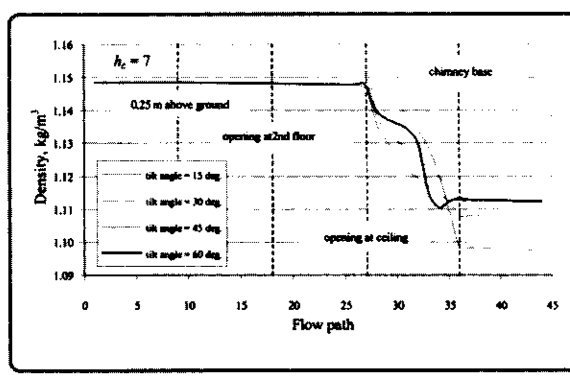

Fig.9 Density distribution along flow path

It can be seen that, upstream of the roof, the pressure drop linearly due to hydrostatic pressure distribution; they drop further in the roof at different rate depending on roof inclination before converging to the same level at the chimney exit which is corresponding to the exit hydrostatic pressure level. Temperature rises (Fig.8) are seen to occur only within the roof portion, in correspond with density falls (Fig.9.)

The important data concerning ventilation is the air mass flow rate measured in air change per hour (ach). One ach is an air volume equals to the volume of the ventilated space, herein is counted as the volume of the 1st floor space (excluding the 2nd floor.) Fig.10 illustrates the amount of ventilation as a function of the roof inclination with the chimney heights and insolations as parameters. It is easily noticed that ventilation increases with the roof inclination but levels off at about 45°. As expected, Higher chimney as well as higher insolation increase ventilation. The unexpected result, perhaps, is the increase of ach with roof inclination. Perceivably, a smaller attic room should be hotter than a larger room receiving the same amount of solar heat; and the hotter air should rises faster due to the increased buoyancy force. The results shown in Fig. 8, however, testify to the opposite in that the larger room (higher inclination) shows higher temperature. The reason behind this paradox is probably that the smaller room produces higher velocity (not necessarily higher ach) which promotes higher convective heat transfer away from the attic room, resulting in a lower temperature, thus lower suction and lower mass flow rate. The asymptotic behavior of ventilation suggests that 45° is the optimal inclination.

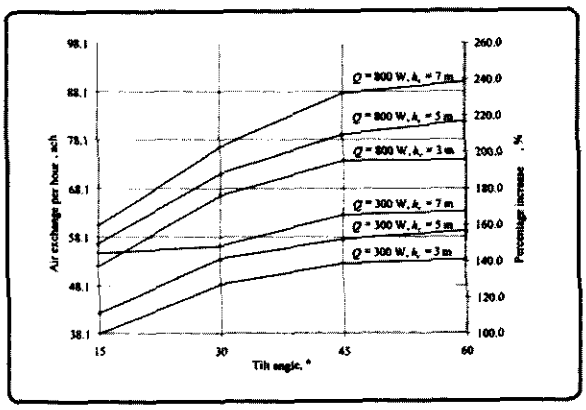

Fig. 10 Amount of ventilation as function of roof inclination

4. CONCLUSION

The CFD results have confirmed that the proposed methodology is a viable option for the ventilation of building. Among the various roof inclinations studied, the 45° proved to be the best, inducing air speed of about 0.8 m/s , while still maintaining structural integrity and architectural appeal. The roof top chimney (3, 5 and 7 m) helped induce additional air speed, resulting in ventilation volume of up to 90 air change per hour.

ACKNOWLEDGMENTS

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REFERENCES

[1] Barozzi, G.S., Imbabi, M.S.E., Nobile, E. and Sousa, A.C.M. (1992) Physical and Numerical Modelling of a Solar Chimney Ventilation System for Buildings, *Building and Environment,* **27**, (4), pp. 433-445.

[2] Bansal, N.K., Mathur, R. and Bhandari, M.S. (1994) A Study of Solar Chimney Assisted Wind Tower System for Natural Ventilation in Buildings, *Building and Environment*, **29**, (4), pp. 495-500

[3] Khedary, J., Hirunlabh, J. and Bunnag, T. (1997) Experimental Study of a Roof Solar Collector towards the natural Ventilation of New Houses, *Energy and Building*, **26**, (2), pp. 159-164.

[4] Khedary, J., Mansirisub, W., Chaima, S., Pratinthong, N. and Hirunlabh, J., Field Measurements of Performance of Roof Solar Collector, (2000), *Energy and Building*, **31**, (3), pp. 171-178

[5] Khedary, J., Yimsamerjit, P. and Hirunlabh, J. (2002) Experimental Investigation of Free Convection in Roof Solar Collector, *Building and Environment*, **37**, (5), pp. 455-459

[6] Afonso, C. and Olivera, A. (2000) Solar Chimney: Simulation and Experiment, *Energy and Building*, **32**, (1), pp. 71-79

[7] Hirunlabh, J., Kongduang, W., Namprakai, P. and Khedary, J. (1999) Study of Natural Ventilation of Houses by a Metallic Solar Wall Under Tropical Climate, *Renewable Energy*, **18**, (1), pp. 109-119

[8] Chitsomboon, T. (2001) A Validated Analytical Model for Flow in Solar Chimney, *International Journal of Renewable Energy Engineering*, **3**, (2), pp. 339-346.