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Energy Saving Passive Ventilation Strategy Using Solar Chimney

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Abstract

Ventilation has been becoming essential since the last decade in modern buildings due to increasing environmental pollution, desire of clean indoor environment, and occupant comfort. Conventional space ventilation strategies rely on mechanical ventilation systems which consume huge amounts of energy in their operation. Passive ventilation strategy is a potential alternative to this and has reduced or no operational cost and energy consumption. Passive ventilation systems based on solar chimneys are naturally driven by solar energy. Since last two decades, research work on this passive ventilation strategy through solar chimney is gaining attraction among researchers. This article presents the overview of outcomes of considerable work taken place in passive ventilation through solar chimney. Experimental and numerical simulation using Computational Fluid Dynamics (CFD) are rigorously utilized by the researchers for analysis of various passive ventilation systems. CFD simulations have been used in much research on solar chimney since last few years. However, the experimental works majorly available in literature have been performed using small scale set-up. Previous research works mainly show the design of solar chimneys and their potential in producing air flow in a duct. It is therefore concluded that there is a huge scope of research work on full scale solar chimney system-based ventilation in buildings. This will enable better understanding of passive ventilation strategy which is still not well understood.

Keywords

Computational fluid dynamics, Solar chimney, Ventilation

Introduction

Buildings are the biggest energy consumers in the world. Tropical countries like India have about 32% of the nation's total energy use. Heating Ventilation and Air Conditioning systems used in buildings consume a major part of building energy, about 56%. Buildings ventilation has been becoming essential in modern buildings due to increasing environmental pollution, desire of clean indoor environment and occupant comfort since last decade [1]. Conventional space ventilation strategies rely on mechanical ventilation systems which consume huge amounts of energy. The generation of conventional energy as electricity is mainly based on the combustion of fossil fuel which requires huge amounts of coal to be burnt. Burning of coal greatly contributes to carbon emission apart from that produced from automobiles and contributing to environmental pollution. Throughout the world, many alternative ways of reducing air pollution from burning of coal are continuously being sought. It is majorly done in the generation of electricity, the same could be significantly reduced by the reduced usage of electricity [2].

Passive Ventilation

The ventilation in buildings provides clean air for breathing into the buildings. With ventilation the pollutants originate in the building, and both diluted and some of them are continuously removed to the lowest safe level [3, 4]. It is essential for the health, comfort, and improved productivity of the occupants that the building is effectively ventilated. Ventilation standards are suitably prepared and are being used in many countries accordingly [5].

As mechanical ventilation systems are driven by electricity, a huge amount of electricity is consumed in its operation. With rapid urbanization, increasing desire of comfort and clean environment, energy requirements in building ventilation have substantially increased since last two decades. Passive ventilation strategy where solar energy is employed is a potential alternative of having reduced or no operational cost and energy consumption [6, 7]. Passive ventilation systems using solar chimneys are naturally driven by solar energy. Table 1 provides a comparison between the mechanical and passive ventilation system.

Solar Energy

Solar energy is a massive source of energy on earth. This energy is being used in many ways including photovoltaic and thermal energy utilization in heating and cooling of air and water apart from many other applications. One of the possible and potential applications of solar energy is in driving the air to flow. Solar energy is used to heat the air and causes natural ventilation through chimney operation [8].

Ventilation Performance

Performance of a ventilation system is often evaluated with the following aspects:

- Ventilation rate
- Direction of air flow
- Air distribution efficiency
- Efficiency of the system to remove the airborne pollutants and other contaminants.

Two overall performance indices commonly used for the ventilation system performance evaluation are [3]:

Table 1: Comparison between mechanical and passive ventilation systems.

Feature	Mechanical Ventilation System	Passive Ventilation System
Ventilation Consistency	Most Consistent	Poor Consistency
Sustainability	Low	Moderate
System Life	Low	High
Performance Dependency on weather	Low	High
Ventilation Regulation	High	Low
Setup Cost	High	Low
Emissions	High	Low
Source of Energy	Renewable	Non-Renewable

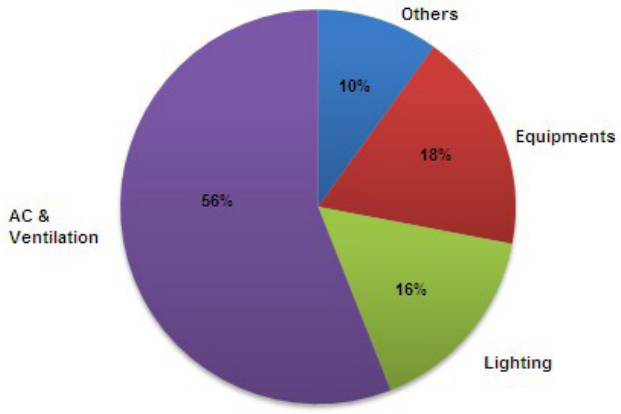

Figure 1: Building energy use in tropical countries like India.

(i) Air change per hour (ACH) and

(ii) Ventilation effectiveness.

For the fully mixed type of ventilation system the ventilation efficiency is 50% while for the piston-type ventilation system it is 100%. The displacement ventilation system has the ventilation efficiency in between these two. The ventilation effectiveness is the airborne pollutants removal, and this performance parameter is analyzed by simulation methods [9]. CFD is the most powerful tool used to measure the air distribution and the air flow rates in the model analysis.

Solar Chimney

Many passive methods of heating and cooling of buildings are used where solar energy is being used. Passive means of air conditioning is an alternative to mechanical Heating Ventilation and Air Conditioning in which solar energy is used to control the humidity and air temperature [10]. These are not new and have been used since centuries ago [11, 12].

Solar chimneys are the main part of a solar based passive ventilation system; this is also used in solar chimney-based power plants. The performance of the solar chimney-based ventilation system and power plants depend upon the design and construction of the solar chimney. The important design parameters of a solar chimney are its diameter and the height. These design parameters are decided on the basis of the desired temperature difference between the inlet and exit air of the chimney. This temperature difference causes the air to flow through the chimney.

Working of solar chimney

Solar chimney is constructed with a solar absorber plate. Solar radiation falling on this absorber plate is absorbed and the heat of radiation is transferred to the air above or beneath the plate. The air is allowed to enter the chimney and a flow is established through the chimney figure 2. For the chimney to receive solar radiation throughout the day, it is kept facing the south direction [13].

To produce ventilation in the building the solar chimney is connected to the building through ducts. Air flow takes place through the chimney when the solar radiation falls on the ab-

Figure 2: Solar chimney [2].

sorber plate and thus ventilation in the building is created.

Apart from solar chimneys, a few other techniques are being used where the flow of air is created to produce ventilation as provided in table 2.

Design parameters of solar chimney

The major parameters to design a solar chimney include as follows [13]:

1. Solar chimney geographical location,
2. Chimney inclination angle,
3. Geometrical dimensions of solar chimney, and
4. Orientation of the absorber.

Experimental and Numerical Simulation

Many experimental and numerical simulations for the evaluations of performance of solar chimneys have been carried out since last decade. Experimental work on a tilted chimney was performed in 2012 to determine its performance [14]. A study was also performed on solar chimney for performance evaluation and a steady state mathematical model was developed [15]. Numerical and analytical investigations were also performed to study the effect of width of vertical chimney on space ventilation.

Apart from the mathematical and experimental studies, numerical studies using CFD were performed by many researchers on the solar chimney performance in ventilation and power generation. Some CFD analysis presents the validation of experimental and mathematical results. CFD analysis on solar chimney performance was used to determine its optimum parameters [16].

A mathematical model was developed using the heat transfer equation with assumptions including steady state one dimensional heat transfer. It is also assumed that the temperature at all the points of absorber plate is the same. Neglecting the heat loss and flow loss, the air flow rate Q through the chimney is given [17].

$$Q = C_d A_o \sqrt{\frac{2g\Delta TL}{T_{a,i}\{1 + (A_o/A_i)^2\}}}$$

In this equation, C_d is the discharge coefficient, cross sectional areas at outlet and inlet sections are given by A_o and A_i, respectively. The temperature difference is given by ΔT. The temperature of air at inlet is $T_{a,i}$ and the stake height is L. For the ventilation studies, value of discharge coefficient, C_d gives accuracy for values between 0.65 and 0.7 [17].

Among much small-scale experimental research works and numerical studies using CFD, experimental research work on a full-scale solar ventilation system is not available and the actual potential aspects of the solar chimney and scope of energy saving is not fully understood.

Conclusion

Energy needs in buildings for producing and maintaining indoor environment comfortable to the occupants has been increasing rapidly. Passive ventilation systems over mechanical ventilation systems are gaining importance in the research community due to this increasing need for energy in buildings and due to the rapid rate of increasing environmental pollution. Mechanical ventilation systems do not have long life and the cost of their operation is also very high. Passive ventilation systems are efficient, feasible, and economical in operation and provide sustainable solutions for the environment. Their use will enhance the usage of renewable energy and lead to energy conservation. The literature review presented in this article shows the comparison between mechanical and passive ventilation systems while also focused on the previous research works on the solar chimney based passive ventilation strategy. The article concludes that both the experimental and numerical studies using CFD are being used by the researchers in performing analysis on solar chimney-based ventilation. Due to the economical solution provided by the

Table 2: Techniques employed for ventilation through wind.

S. No.	Ventilation through wind energy	Feature/application	Typical flow rate
1	Natural ventilation	Wind passes through opening which creates pressure difference	It is separate method for ventilation
2	Chambers and yards	Aesthetic appearance is required in buildings especially in hot temperatures	NA
3	Oblique retaining wall	Wind pressure plays vital role for achieving natural ventilation in buildings.	The share of wind speed i.e., resides outside is 40 %
4	Passages and chimney	Chimneys are usually placed on the top of the buildings to facilitate ventilation	This can be applied as per the capacity and size of building

numerical techniques, it is mostly being used at present among the research community. Many experimental works show their results obtained while performing tests on the small-scale test set-up. Full scale experimental study is having huge scope. Previous research works mainly show the design of solar chimneys and their potential in producing air flow in a duct. It is therefore concluded that there is a huge scope of research work on full scale solar chimney system-based ventilation in buildings. This will enable better understanding of passive ventilation strategy which is still not well understood.

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Conflict of Interest

None.

Credit Author Statement

Jitendra Raghuwanshi: Formal analysis, Investigation, Writing - original draft preparation, Writing - review and editing; Vishvendra Nath Bartaria: Conceptualization, Methodology, Writing - review and editing, Supervision. All the authors read and approved the manuscript.

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