EXPERIMENTAL INVESTIGATION AND PARAMETRIC ANALYSIS USING CFD SIMULATION FOR COOLING OF CABIN THROUGH AUGMENTED VENTILATION SYSTEM WITH PASSIVE HOT AND COLD SOURCES

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Passive cooling of buildings through natural ventilation has received the attention of researchers in recent years. In the present work the concept of producing cooling effect through augmented ventilation by excess hot energy available during summer days from the solar flat plate collector and by storing cool energy available during the early morning hour in the Phase Change Material (PCM) based storage system is attempted. An experimental setup is made to study the cooling potential achieved due to the novel concept of augmented ventilation system and the results are reported. A CFD analysis is carried out using ANSYS-CFX software and the results are validated using the experimental results. The CFD model is further modified for the real size configuration and using the same boundary conditions the performance of the system is analysed for various parameters of interest.

Keywords
Augmented ventilation, CFD simulation, Free cool energy, Green building, Solar chimney, Ventilation system

1. Introduction

The modern conditions of comfortable living are achieved at the cost of vast energy resources. The increasing lifestyle in some of the developing countries in the last few years, demands more energy, and this may further increase the utilization of energy resources in the world. The continuous increase in energy demand has led to environmental damage, like global warming and ozone depletion, and the escalating cost of fossil fuels over the last few years.

The energy required for buildings heating, cooling and ventilation of buildings is approximately 30 to 40% of the total world energy consumption. The increasing level of damage in the environment has created greater awareness at the international level, which has resulted in the concept of green energy building in the infrastructural sector. The practicing engineers and government are forced to re-examine the whole approach to the design and control of building energy system, energy conservation measures and utilization of renewable energy to safeguard the environmental degradation. One of the simple and effective ways to reduce the difference between inside and outside air temperature is to improve the ventilation and thereby achieving the required cooling inside the room. Natural ventilation and renewable energy utilization are widely used to improve the indoor air environment for buildings, and also to reduce the energy consumption of air conditioning. Some of the recent studies carried out by the researchers to promote passive building cooling and the ventilation effect through various measures are summarized in this section.

Buoyancy-driven stack ventilation or displacement ventilation (DV) relies on density differences to draw cool outdoor air in at low ventilation openings and exhaust warm. Zhang et al. (2005) used a validated computational fluid dynamics program to investigate and compare the performances of displacement and mixing ventilations under different boundary conditions. Yukihiro Hashimoto (2005) studied the temperature field in a modeled office room for a displacement ventilation system using three-dimensional CFD and result showed that the thermal comfort in a typical office room maintained by regulating supply air velocity as well as temperature and the stratification profiles in the room depend especially on the supply air velocity.

Gan and Riffat (1998) investigated the performance of a glazed solar chimney for heat recovery in naturally-ventilated buildings using the CFD technique. The CFD program was validated against experimental data from the literature and good agreement between the prediction and measurement was reported. The predicted ventilation rate is found to increase with chimney wall temperature and heat gain. Ding et al. (2004) examined the possibility of using solar chimney concept for natural ventilation and smoke control. The proposed prototype is an eight-storey building with a solar chimney on top of the atrium. Reduced scale model experiments and CFD analysis are conducted. Mathur et al. (2006) evaluated the possibility of making use of solar radiation to induce room ventilation in hot climates. They found out that air flow increases linearly with the increase in solar radiation or the air gap between absorber and glass cover. Macias et al. (2006) presented a practical approach to improve the passive night ventilation in social housing by applying the solar chimney concept. Chungloo and Limmeechockai (2007) studied the effect of solar chimney and water spraying over a roof on natural ventilation. Mathur et al. (2006) investigated the effect of using solar chimney for enhancing natural ventilation. They found that there was a tradeoff between the absorber inclinations and stack height. Wardah Fatimah Mohammad Yusoff et al. (2010) proposed a solar induced ventilation system for a feasible alternative in enhancing the stack ventilation. They investigated the effectiveness of a proposed solar induced ventilation strategy, which combines a roof solar collector and a vertical stack, in enhancing the stack ventilation performance in the hot and humid climate.

The concept of storing cool energy available during the night hours for usage during the day time or to reduce the demand for air conditioning has been reported by scientists in the recent years. This concept is known as free cooling. Recently a detailed survey on free cooling of building using phase change materials was carried out by Antony Aroul Raj and Velraj (2010). First feasibility study of a free cooling system was done by Zalba et al (2004) (2002) using PCM encapsulated in flat plate with a melting temperature around 20-25°C. Marin et al (2005) made improvement to the experiment by Belen Zalba by including graphite compounded material with the paraffin PCM for heat transfer enhacement in PCM. Medved and Arkar (2008) studied the free-cooling potential for different climatic locations in Europe. Shanmuga Sundaram et al (2010) presented a new passive cooling system incorporating phase change material (PCM) and two-phase closed thermosyphon (TPCT) heat exchangers to provide thermal management for telecommunication equipments housed in telecom shelters. Takeda et al (2004) developed a ventilation system utilizing thermal energy storage using phase change material granules.

In the present work a passive cooling of building through augmented ventilation is attempted for a residential building by using the excess hot energy available during summer days from the solar flat plate collector and by storing cool energy available during the early morning hours in a cool storage system. The experimental investigation is performed in a small cabin of size 1m x 1m x 1m size and the results are compared with the CFD results for the model created similar to the experimental setup. The CFD analysis is further extended for a cabin of size 3.5m x 3.5m x 3.5m for which the analysis is carried out for various parameters of interest.

2. Experimental Set-up

The effect of improving the cooling effect through augmented ventilation was studied by conducting an experiment on a test cabin shown in Figure 1 constructed inside the laboratory building. The cabin is 1 m x 1 m floor area, height of 1 m and has a window of dimensions 20 cm x 20 cm on one side of the cabin. The cabin is connected through a heat exchanger coil with one hot storage tank at the top and one cool storage tank at the bottom with a capacity of 500 litres and 200 litres respectively.

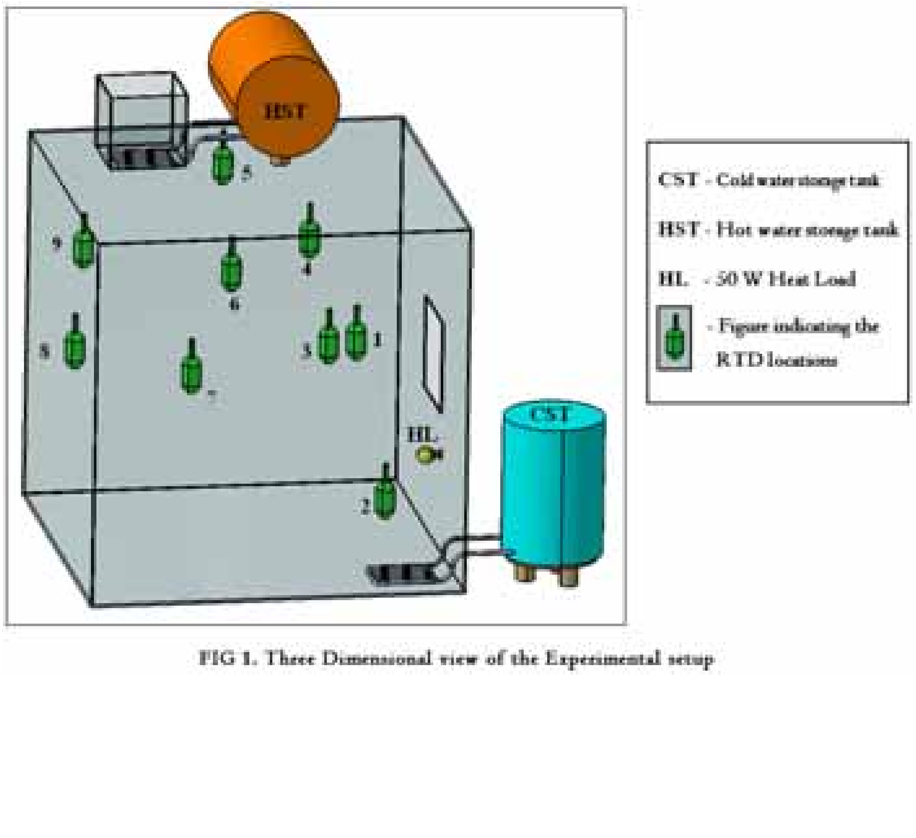


FIG 1. Three Dimensional view of the Experimental setup

The hot water from the storage tank is circulated through a copper coiled heat exchanger located at the top of the cabin. The cold water kept at the bottom storage tank is also circulated through copper coiled heat exchanger kept at the bottom of the cabin. Electric heater is used as heating source instead of solar water heater for the conduct of experiments. Similarly, to simulate the supply of free cool energy during the early morning hours the frozen PCM balls (RT 27) that changes its phase at 28°C are kept in the cool storage tank. The concept of storing cool energy in PCM during the early morning hours is known and available in the literature (Antony Arul Raj and Velraj (2011)). The circulation of water is made using a small capacity pump (0.25hp) connected at the outlet of the hot storage tank and through natural circulation in the cold storage tank. The experiment is aimed at determining the thermal behavior of the interior temperature of the cabin. Hence Resistance Temperature Detectors (RTDs) are placed at various arbitrary locations in the cabin to measure the temperature distribution. The air velocity at the entry to the chimney is measured using a vane anemometer to determine the mass flow rate of air in circulation which is used to evaluate the ventilation performance. During the experiments, an electric bulb of capacity 50 W is kept inside the cabin to simulate the heating load.

The performance improvement of the ventilative cooling is studied by conducting two different sets of experiments. In all the experiments with and without augmented ventilation a heat generation source of 50 W is provided at the bottom side of the cabin. In the first set of experiments, initially the cabin is allowed to attain steady state temperature due to the presence of heat generation source in the cabin by natural circulation. Keeping this as the initial condition of the cabin the hot and cold sources are allowed to circulate through the coiled heat exchanger kept at top top and bottom of the cabin to achieve cooling through augmented ventilation.

In the second set of experiments, the effect of augmented ventilation is studied by keeping the cabin initially at ambient condition. In both the cases, experiments are continued until the cabin attains a near steady state temperature. The temperature variation inside the cabin with respect to time and the increase in velocity of air for the cases with and without augmented ventilation are measured and the results are discussed.

3. CFD Modelling and Analysis

In the CFD simulation, initially, the cubical room used in the experimental investigation along with the ventilation effect created through hot and cold sources is modeled and analyzed using CFD software.

GAMBIT software is used to create the three dimensional geometry models. The model generated is meshed using a tetrahedral grid and the boundary conditions are then assigned to the meshed model. The window modeled on one face of the cabin is assigned with a pressure inlet boundary condition. The two plates created at the top and bottom portions of the cabin are assigned as wall boundary conditions, and the temperature of the wall could be varied to simulate the required temperature. The top and bottom plates perform the important task of providing the hot and cold sources respectively. The chimney which is kept at the top face of the model is assigned with the outflow boundary condition. A single fluid zone was generated using a fluid zone generator in the preprocessor of ANSYS-CFX. Then the numerical values for the boundary conditions are given. The temperature variation obtained at the selected RTD locations and the velocities of air at the exit location are compared with the experimental investigation and thus the model is validated for its accuracy. Further CFD analysis is extended using the similar boundary and initial condition by changing the geometrical size of the cabin to real size of 3.5 x 3.5 x 3.5 m and proportionately changing the size of the hot and cold plates (0.8 x 0.3 m) kept at the top and bottom of the cabin. Heat generation sources of 50 W and 100 W are provided at the top and bottom of the cabin respectively to simulate the heat load generated from the cabin. A chimney with a base area size of 0.3 x 0.3 m and height of 0.3 m is located at the top face of the cabin. At the right wall of the cabin a window of size of 0.75 x 0.75 m is created, that serves as an inlet for the ambient air into the cabin, and the other walls are closed completely without any openings. The simulation analysis is carried out by varying the initial, inlet, hot and cold source temperatures of the plate inside the cabin.

4. Results and Discussion

In the first set of experiments conducted without hot and cold sources, due to the presence of 50 W heat load the temperatures of the cabin increases and the maximum temperature is attained (ie attaining the steady state) around 1.30 p.m inside the cabin. Then the cooling effect achievable through the augmented ventilative cooling system is studied by circulating the hot and cold water through the heat exchanger. The temperature variation inside the cabin is monitored using RTDs placed at different locations inside the cabin. Figure 2 shows the temperature measured at various RTD locations shown in Figure 1 at three different time intervals 1.30 pm, 3.00 pm and 5.00 pm.

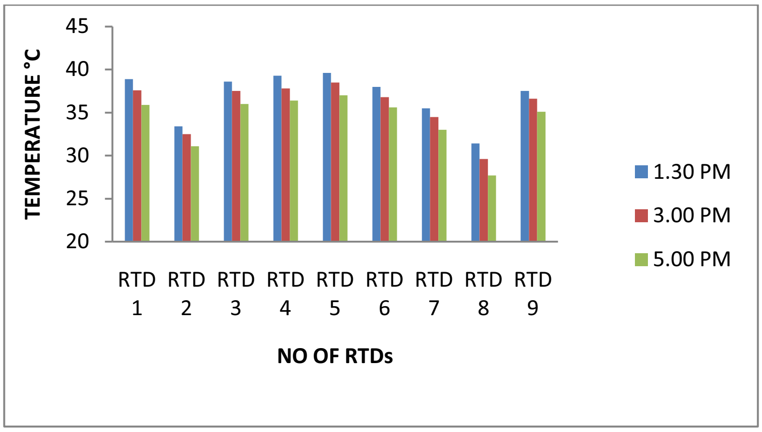


Figure. 2. Temperature variation inside the cabin at 3 different time intervals for the RTD locations shown in the experimental setup

It is seen from the figure that at all the time during the experiment, the 8th RTD shows the least temperature since it is located nearer to the wall and exposed to the nearest path of the cool air circulation. The 5th RTD shows the highest temperature at all times since this RTD is located at top of the cabin and also away from the top ventilator hole. Hence the air at this location is stagnant and also due to stratification, this region is attaining the highest temperature. The other RTDs are showing temperature in the range between these two limits and it is also observed that all the RTDs located at a height above the windows level are showing higher temperature. On seeing the temperature variation with respect to time the temperature of all the RTDs are showing decreasing trend at 3.00 pm compared to 1.30 pm and further reduced to the lowest level at 5.00 pm. This reduction in temperature is due to the induced condition initiated at 1.30 pm using the hot and cold sources which augmented the ventilation effect.

Figure 3 shows the average temperature variation inside the cabin with respect to time. There are two regions shown in the figure. The first region is the duration between 10.00 am to 1.30 pm during which the ventilation is possible only through the windows and the second region is the duration between 1.30 pm to 6.00 pm during which the hot and cold water in the storage tanks are circulated through the copper coiled heat exchangers kept at top and bottom respectively. The temperature attains a maximum level of 36.8°C around 12.30 pm and it is constant till the water circulation is made through the heat exchanger kept at the bottom. The temperature starts decreasing at 1.30 pm and around 6.00 pm, the temperature attains a minimum value of 32.8°C. When the induced circulation is initiated the temperature drop is very high which shows the higher drop in temperature due to induced circulation.

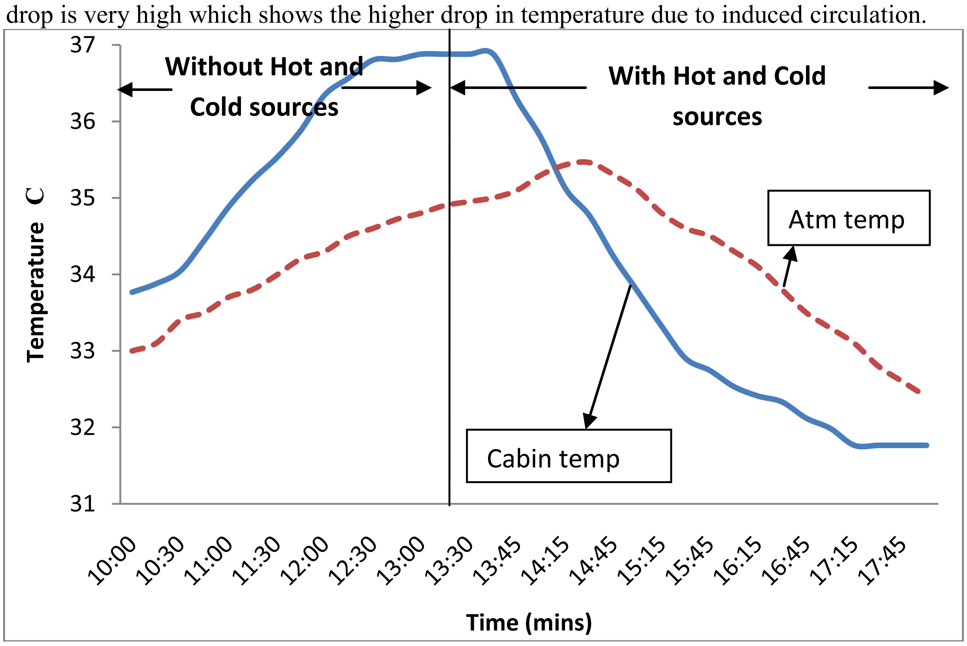


Figure. 3. Average temperature inside the cabin with and without augmented ventilation

CFD simulation is carried out for the model created similar to the experimental set up and keeping the ambient condition as the initial condition inside the cabin. Hence, for the augmented ventilation the results obtained from the second set of experiments in which the ambient condition is considered as the initial condition is used to validate the CFD results.

Figure 4 shows the temperature variation of the air in the cabin at two RTD locations L1 and L2 (RTD's 6 and 7 in the experimental setup) obtained from the experiments and the CFD analysis for the case without augmented ventilation. Initially the cabin is at 34°C which is the temperature that prevails in the ambient. Due to the presence of 50 W load in the cabin and the stagnated air without ventilation effect causes the temperature to increase with respect to time and it attains steady state after 3 hours at a temperature of approximately 43°C at both the RTD locations. The CFD results are in close agreement with the experimental results.

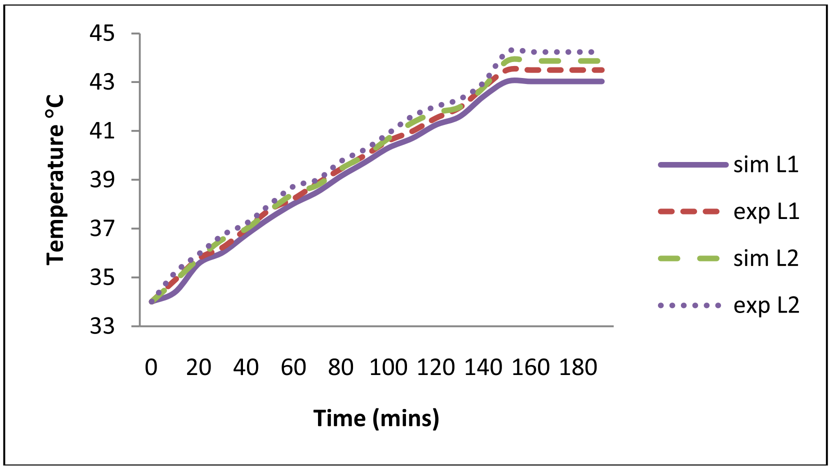


Figure. 4. Temperature variation of the air in the cabin at two selected RTD locations for the case without augmented ventilation

Figure 5 shows the temperature variation of air in the cabin at two RTD locations L1 and L2 (RTD's 6 and 7 in the experimental setup) obtained from the experiments and the CFD results for the case with augmented ventilation. During this experiment initially the cabin is at 34°C. It is seen from the figure that the temperature decreases with respect to time and it reaches a steady low value of approximately 29°C for the two selected locations. The CFD results are also showing the similar trend and the results are in close agreement with the experimental results. It is construed from the above results that a temperature drop of nearly 4 to 5°C is achieved through augmented ventilation. This is due to the hot and cold sources kept at the top and bottom of the cabin which are dissipating its energy to augment the ventilation effect and also due to the cooling effect provided by the cold source.

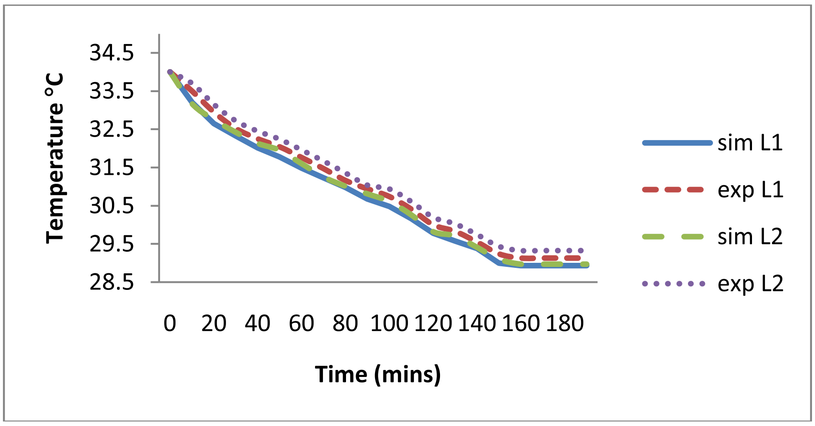


Figure. 5. Temperature variation of the air in the cabin at two selected RTD locations for the case with augmented ventilation

The CFD parametric analysis is further carried out for the conventional cabin size of 3.5 x 3.5 x 3.5 m by varying the initial, inlet, hot and cold source temperatures of the plates inside the cabin and the range of parameters used in the analysis is given below.

Initial room temperature - 30°C, 32°, 34°C

Inlet room temperature - 30°C, 32°, 34°C

Hot source temperature - 60°C, 50°C, 40°C

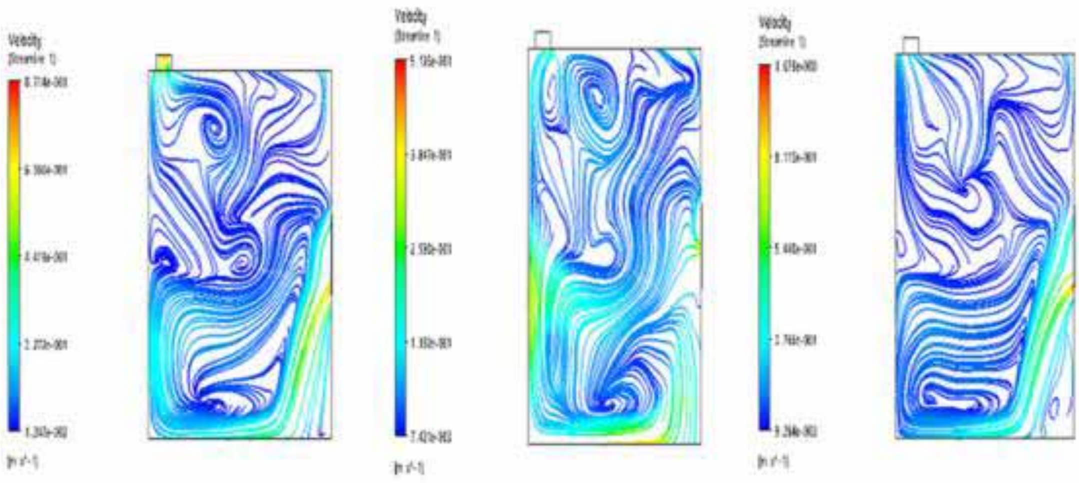
Cold source temperature- 28°C, 26°C, 24°C, 22°C

In the parametric analysis, velocity obtained from the CFD analysis is used as the parameter to measure of ventilation effectiveness. The velocity and temperature variation inside the cabin and performance parameters like ventilation effectiveness and cooling efficiency are evaluated and presented. Ventilation effectiveness is defined as the ratio between the surface integrated average velocity at the outlet in the augmented ventilation system, to the surface integrated average velocity at the outlet in the case without augmented ventilation system. Cooling efficiency is defined as the percentage through which the initial temperature approaches the cool source temperature in the augmented ventilation system.

The velocity and temperature variation inside the cabin are shown in the velocity streamline and temperature contour graphs respectively, for the case with and without augmented ventilation system. Figure 6 (a to c) shows the streamlines in the XY plane inside the cabin for the case without augmented ventilation system at three different Z locations for the case with the inlet temperature of air at 30°C and the initial temperature of the cabin at 34°C. It is seen from the figures that the flow pattern in 6a and 6c have some uniformity in the lower half of the region. This is due to the presence of a 100 W heat load, present at the bottom of the cabin at X = -1.5, Y = -1.25, Z = -1.5 which is nearer to these planes. These loads create a low density of the air present in the cabin at the bottom region, pull the air from the window, and then it moves upward towards the chimney. Further it is seen from these two figures that the maximum velocity is high (1.07 m/s) in the XY plane located at Z= -0.875 compared to the velocity of 0.8 m/s at the XY plane located at Z = 0, due to the presence of the heat load very close to Z = - 0.875 plane which creates high potential difference and hence induces the air to the maximum velocity. At Z = 0.875 the streamlines show more recirculation at the bottom and top of the region due to the presence of stagnated air, as this plane is away from the chimney side.

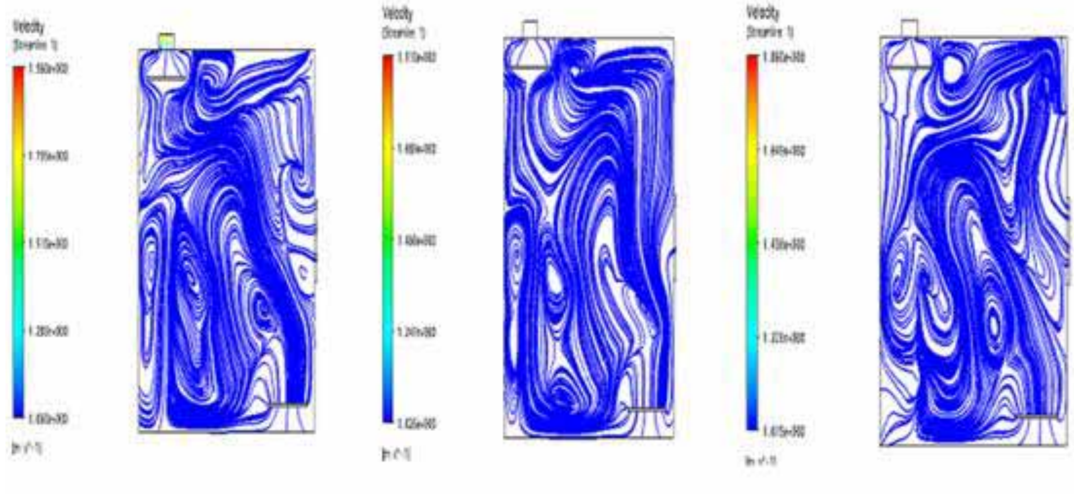
Figure 7 shows the streamlines inside the cabin for augmented ventilation for three different XY planes at the same Z locations shown for the previous case for the same inlet and initial temperature conditions along with 60°C and 24°C for the hot and cold sources respectively. The maximum velocity in all the three planes is much higher, which is approximately 1.9 m/s, and the minimum velocity is also more than 1 m/s in all the cases, which is the highest velocity present in the cabin for the case without augmented ventilation. Hence, it is construed that the presence of hot and cold sources in the augmented system increases the ventilation effect inside the cabin. There is not much variation in the airflow pattern between the three cases, since the heat load present on one side of the cabin has no significant effect compared to the effect caused by the hot and cold sources which are present at the centre of the cabin (Z = 0).

Figure 8 shows the exit velocity of the augmented ventilation system under various inlet, initial and hot and cold source temperatures. Fig. 8a shows the velocity of the air at the outlet when the inlet and the initial temperatures are maintained at 30°C and 34°C respectively, for various hot and cold source temperatures. It is seen from all the figures that for the given cold source temperature, the velocity of the air at the outlet increases with an increase in the hot source temperature. However, at a given hot source temperature, when the cold source temperature decreases the velocity of air at the outlet decreases, though the temperature difference between the hot and cold sources increases. Similar results are seen in Fig. 8b and Fig. 8c for the different inlet and initial conditions. Hence, it is concluded from the results that the temperature difference between the cold source and inlet temperature plays a major role, as the cold source temperature makes the air present in the cabin denser reducing the driving potential for the movement of air.



6a) Z = 0   6b) Z = 0.875   6c) Z = -0.875

Figure. 6 Velocity streamlines inside the cabin for the case without augmented ventilation system



7a) Z = 0   7b) Z = 0.875   7c) Z = -0.875

Figure. 7 Velocity streamlines inside the cabin for the case with augmented ventilation system

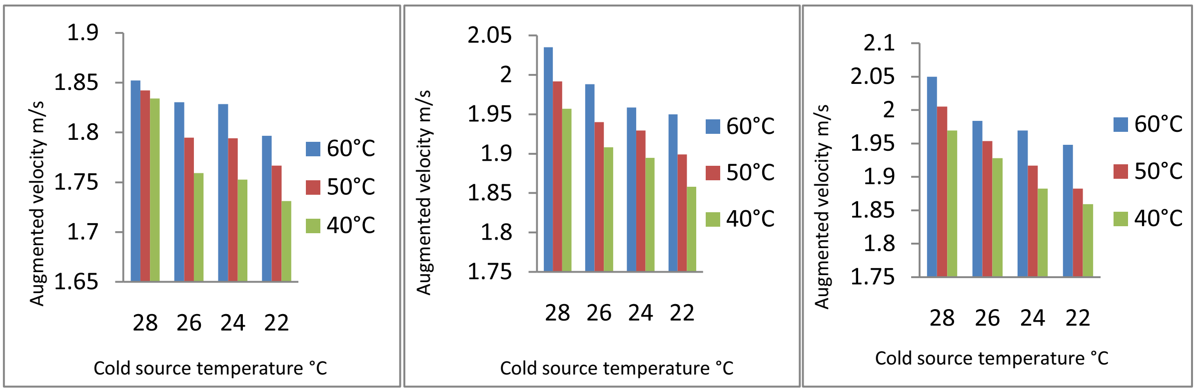


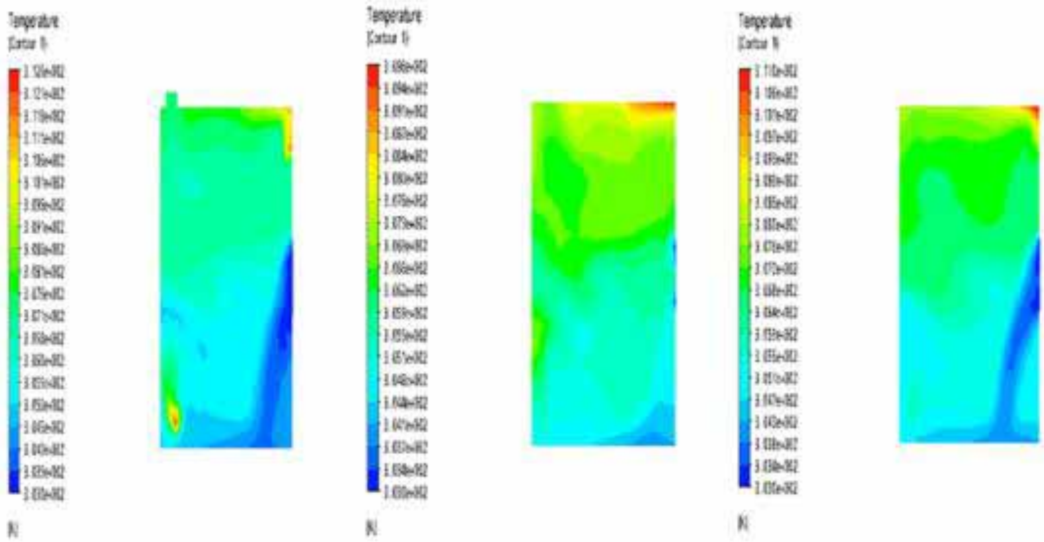
Fig. 8a Tinlet = 30°C, Tini = 34°C Fig. 8b Tinlet = 34°C, Tini = 30°C Fig. 8c Tinlet = 32°C, Tini = 32°C

Figure. 8 Variation of augmented velocity with respect to hot and cold source temperatures

Figures 9a to 9c show the temperature contours at three XY planes located at Z = 0, Z = -0.875 and Z = +0.875 when the cabin has a heat load of 100 W, 50 W at (X = -1.5, Y = -1.25, Z = -1.5) and (X = 1.5, Y = 1.25, Z = 1.5) locations respectively, and without any cold and hot sources to augment the ventilation. Fig. 9a shows the decreasing temperature from the window to the bottom of the cabin in the downward direction, which indicates the air movement in that direction; this is due to the entry air at 303 K which is denser than the internal cabin air temperature at 307 K. However, the heat load kept at the other side of the window makes the nearby air less dense and draws the air from the window side; hence, the entry air also become less dense and moves in the upward direction.

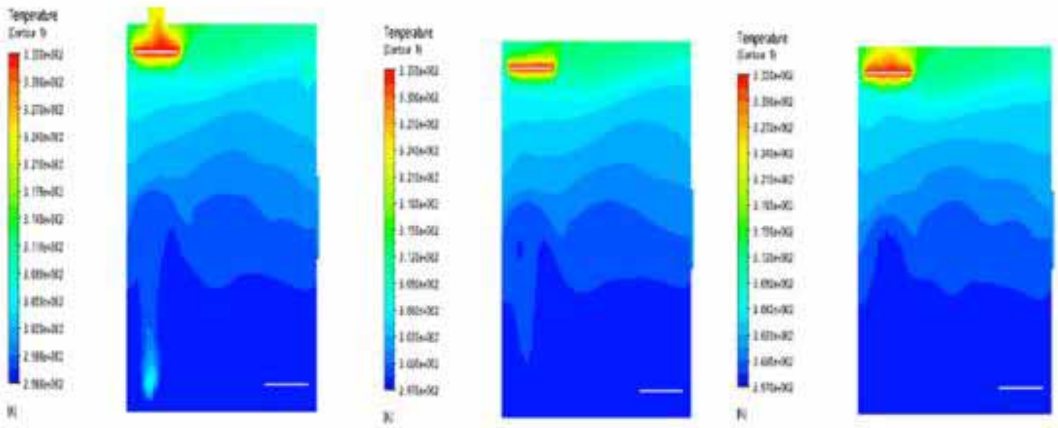
It is seen from all the figures that the temperature varies from 303 K at the bottom to 311 K at the top and at the middle of the cabin (Y = 0) in the XZ plane, an average temperature of 307 K exists; above this plane, at all Y, the temperature is above the initial temperature and at the top of the cabin the temperature is between 310 K to 312 K. Among the three planes shown in the figures the plane located at Z = 0 attains the highest temperature at the top on the other corner of the chimney, which is due to the presence of the 50 W heat load and also due to the stagnation of air near that location.

Figures 10a to 10c show the temperature contours at three XY planes located at Z = 0, Z = -0.875 and Z = +0.875 when the cabin has similar heat loads as in the case of without augmented ventilation along with hot and cold sources present at the top and bottom of the cabin respectively, to augment the ventilation. It is seen from the figures that at the middle of the cabin the temperature is slightly higher than the cold source temperature, though the air present in the top of the cabin is around 312 K and near the hot source it is 330 K. Hence, the present configuration proposed to augment the ventilation provides a cooling effect up to 3/4th of the height of the cabin, which is sufficient for the comfort in the room.



9a) Z = 0 9b) Z = 0.875 9c) Z = -0.875

Figure. 9 Temperature contours inside the cabin for the case without augmented ventilation system



10a) Z = 0 10b) Z = 0.875 10c) Z = -0.875

Figure. 10 Temperature contours inside the cabin for the case with augmented ventilation system

Figure 11 shows the variation of temperature at a particular location (X = 0, Y = 0.5, Z = 0) in the cabin with respect to the variation in the hot and cold source temperatures for three different inlet and initial conditions. It is seen from all the graphs that the steady state temperature at the selected location is predominantly the function of the cold source temperature. In all the cases the temperature at the selected location is approximately 1 to 2˚C higher than the cold source temperature. The hot source, inlet and initial temperatures have a much less influence on the steady state temperature of the cabin at the selected location, which is approximately 3/4th of the height from the cabin. This shows that the entire region below this location will be having a lower temperature than this location.

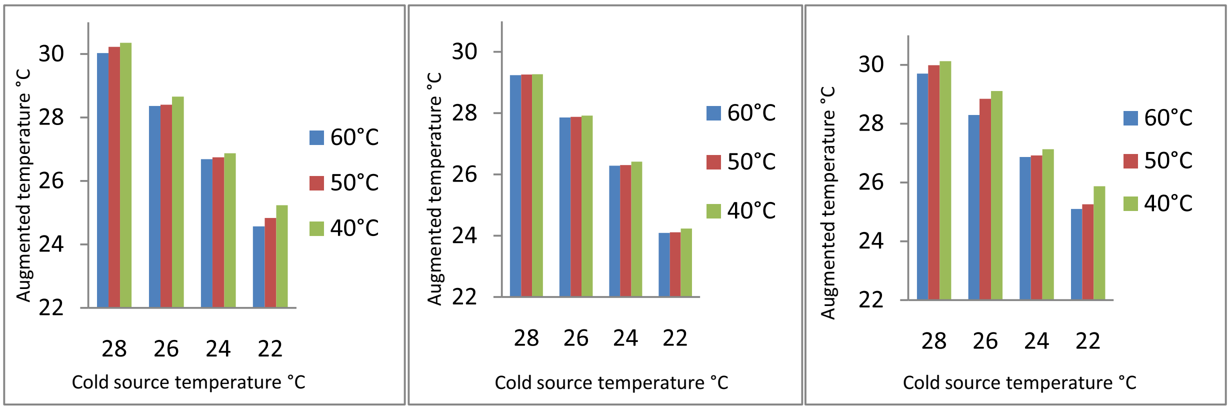


Fig. 11a T_{inlet} = 30°C, T_{ini} = 34°C Fig. 11b T_{inlet} = 34°C, T_{ini} = 30°C Fig. 11c T_{inlet} = 32°C, T_{ini} = 32°C

Figure. 11 Average temperature of the cabin for the variation in hot and cold source temperatures

Figure 12 shows the ventilation effectiveness for various hot and cold sources maintained in the augmented ventilation study for three different inlet and initial conditions. It is seen from Figure 12a that when the inlet temperature is lesser than the initial temperature (i.e. ambient temperature is lesser than the room temperature), the ventilation effectiveness varies from 2.3 to 2.5 for all values of the hot and cold source temperatures. Figure 12b shows, how, when the inlet temperature is higher than the initial temperature (i.e. ambient temperature is higher than the room temperature), the ventilation effectiveness varies from 1.12 to 1.23 for all values of the hot and cold source temperatures. Figure 12c shows that when the inlet temperature is the same as the initial temperature (i.e. ambient temperature is same as the room temperature), the values of the hot and cold source temperatures are the same. It is observed from the figure that the ventilation effectiveness is higher than in the first case where the inlet temperature is lesser than the initial temperature. The average velocity of air at the outlet without the hot and cold sources for the three cases shown in Figure12a, Figure 12b and Figure 12c respectively, are 0.74, 1.66, and 0.73. In the first case when the inlet temperature is lesser than the initial temperature, the ventilation effectiveness is high as the velocity of air at the outlet in the case without augmented ventilation is very low (0.74 m/s). Hence it is construed from the results, that it is possible to improve the ventilation by using hot and cold sources when the room temperature is higher than the ambient temperature. Since the air density of the ambient is higher than the internal air density, the air cannot move very easily, and hence, some driving potential is required to augment this ventilation. However, when the room temperature is lesser than the ambient temperature, the density of air present in the room is lesser than that of the ambient, and hence, the driving potential is created naturally for the flow of air and the velocity of air at the outlet is higher, without considering the augmented ventilation. Under these circumstances, the additional effect created by the hot and cold sources is not significant enough to improve the ventilation. In the last case, when the inlet and initial temperature are the same, the effectiveness is even higher than in the first case where the inlet temperature is lesser than the initial temperature. This is due to the fact that in the first case, when the inlet temperature is lesser than the initial temperature the entry air first flows downward in the cabin due to its higher density, and then it has to move up due to the temperature gradient between the top and the bottom. Hence, the ventilation effectiveness is higher in the last case compared to that in the first case.

Figure 13 shows the variation of the cooling efficiency for various hot and cold source temperatures at three different inlet and initial conditions. It is seen from the figure that when the inlet temperature is lesser than the initial temperature, the entry air also will aid the cooling, and hence the cooling efficiency is higher for all the cold source temperatures. In the second case, when the inlet temperature is higher than the initial temperature, the hot inlet air also has to be cooled by the cold source, and hence the cooling efficiency is comparatively less, when the temperature of the cold source is much closer to the initial temperature. It is seen from all the three cases of inlet and initial conditions, that the effect due to the hot source temperature is quite less. The hot source present at the top will not participate in the cooling/heating process, and it only aids the convective air motion in the room. Since the conductivity of the air is less, the heated air at the top cannot transmit its energy to the bottom portion.

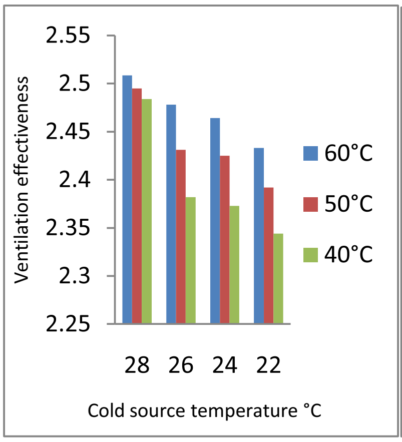


Fig. 12a Inlet 30°C Initial 34°C

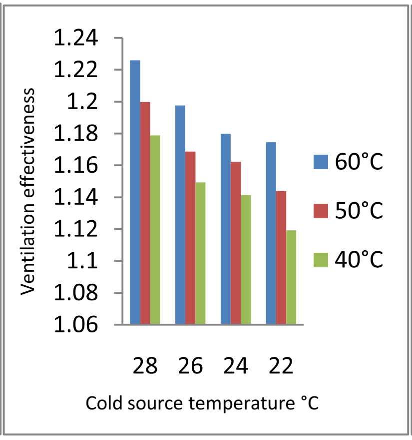


Fig. 12b Inlet 34°C Initial 30°C

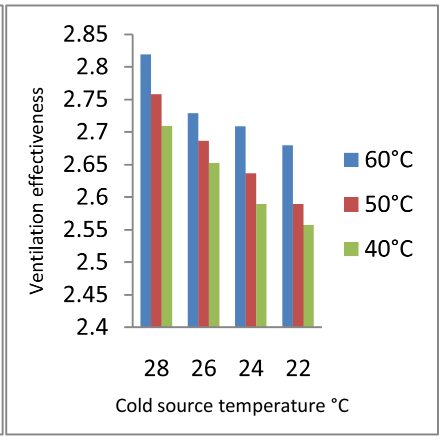


Fig. 12c Inlet 32°C Initial 32°C

Fig. 12 Variation of ventilation effectiveness with respect to hot and cold source temperatures

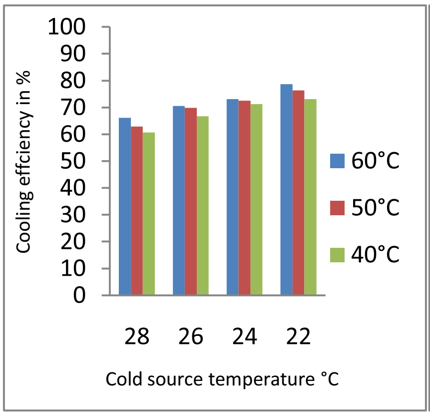


Fig. 13a Inlet 30°C Initial 34°C

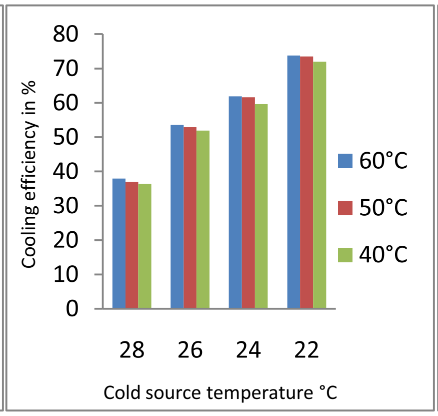


Fig. 13b Inlet 34°C Initial 30°C

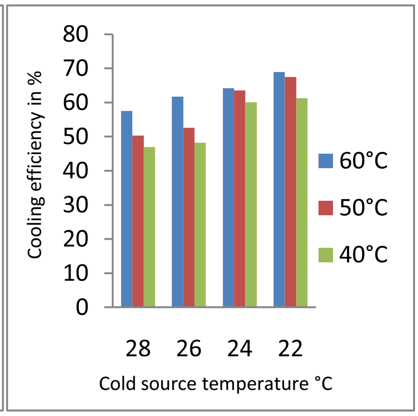


Fig. 13c Inlet 32°C Initial 32°C

Figure. 13 Variation of cooling efficiency with respect to hot and cold source temperatures

5. Conclusion

In the present work a novel concept of augmenting the ventilation and cooling effect for a cabin using a hot and cold source is studied, by conducting an experimental investigation. A CFD simulation analysis is also carried out and the results obtained for various parameters of interest are presented in detail. During the summer period the utilization of a solar hot water system is reduced in residential buildings, as the requirement for hot water is less. This hot energy collected using the hot water system may be utilized to augment the ventilation effect. In summer, usually the room temperature after sunset is higher than the ambient temperature, and hence, the natural ventilation effect will be less and uncomfortable for the residents. The energy stored from the hot water storage system can be used to augment the ventilation during this period to draw cool air from the surroundings. In the same way the cool energy can also be stored by supplying the cool air available during the early morning hours in a storage medium, and this cool source can be utilized to provide cool energy during the day time. The results from the present study reveal that a considerable reduction in temperature and an improvement in ventilation is possible through augmented ventilation. This concept and the results presented in this paper will be very useful for the engineers, designers and also the policy makers involved in the construction of Green buildings.

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