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ARTICLE

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Augmenting natural ventilation using solar heat and free cool energy for residential buildings

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In many urban buildings ventilation is not sufficient that will increase the temperature and also create unhealthy atmosphere inside the room. In such buildings artificially induced ventilation through freely available energy promote comfort conditions by reducing the temperature by 2 to 3°C and also creating good circulation of fresh air inside the room. In the present work the concept of improving the 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 effect of improvement in natural ventilation and the results are reported. A visible reduction in temperature is observed through circulation of air from the bottom side of the room to the roof of the house using the stored hot and cool energy. A CFD analysis is also carried out using ANSYS-CFX software to simulate and evaluate the mass flow of air at the inlet and at the selected RTD location by matching the transient temperature profile of the simulated result with the experimental results at the selected RTD location.

Keywords: Energy Conservation, Free cool energy, Green building concept, Natural ventilation, Solar heating system, Computational Fluid Dynamics.

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1. Introduction : The modern comfort living conditions are achieved at the cost of vast energy resources. The increasing lifestyle in India and China in the last few years demands more energy and this may further increase in the utilization of energy resources in the world. The continuous increase in energy demand may lead to environmental damage like global warming and ozone depletion and the escalating cost of fossil fuels over the last few years.

Globally buildings are responsible for approximately 40% of the total world annual energy consumption. Most of this energy is for the provision of lighting, heating, cooling and air-conditioning. The increasing level of damage in the environment has created greater awareness in the international level which resulted in the concept of green energy building in the infrastructural sector.

In the recent years India has witnessed a tremendous growth in infrastructure development, with the construction industry recording an annual growth of 9.5%, against the global average of 5%. Green buildings are the right solution in such a situation, in which the demand for power is more. The primary role of buildings is to protect the mankind from the extremities of climates. The African termites of the Ivory Coast construct and live in well conditioned rooms in which the temperature is maintained at 29+1°C throughout the day while the external temperature varies between 10°C at night and 44°C at midday. Even our ancient traditional buildings were built with consideration to climatic conditions for keeping the inside building spaces cool in summer and warm in winter. These aspects were forgotten in the modern architecture which essentially relies on mechanical methods of heating and cooling involving large amount of energy intensive equipments. With the growing energy crisis there is a renewed interest in the building architecture to provide thermal comfort with minimum energy consumption.

Air-conditioning is commonly used to achieve thermal comfort in commercial buildings in the hot and humid climate. The use of air conditioning in residential households of urban and suburban areas is increasing continuously. Air conditioning contributes 60% of electricity consumption in a household. Hence efforts are being taken at various levels for the improvement in efficiency of an air conditioning and improvement of building envelope to reduce the load to the air-conditioning system. For residential buildings promotional schemes such as energy labeling are perceived to be more applicable and such labeling schemes do not preclude air-conditioning, but may be used to promote alternative means to achieve thermal comfort that can lead to healthier and more comfortable conditions.

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 condition inside the room. It is based on the difference in pressure, which the outside wind or the greenhouse is equipped with ventilation openings. Many researchers have studied the phenomenon of natural ventilation in houses over the last three decades.

Bansal and Mathur [1] have studied about a solar chimney assisted wind tower system for natural ventilation in buildings. The wind tower is designed to catch the wind at higher elevations and to direct it into the living space by using thermal and pressure gradients. Oca [2] developed a method for the physical simulation of natural ventilation by thermal effects in a tunnel green house (3 x 6 x 2 m) with one side opening (0.3 m) and one roof opening (0.3 m) at Barcelona, Spain. Zalewski et al. [3] explained that the solar wall and solar roofing system are both passive heating and cooling techniques, using the façade and roof of buildings as solar collector or radiator and air as the working fluid, to supply the required energy for buildings. Kang Yanbing et al. [4] developed Night Ventilation with PCM Packed Bed Storage (NVP) system and the mathematical model of NVP system is built to analyze its thermal performance and an experimental installation of NVP system used in Beijing is introduced. Sethi and Sharma [5] have studied the survey of cooling technologies for worldwide agricultural green house applications. Relevant information about the system characteristics, application and performance of the existing green house cooling technologies such as ventilation (natural and forced), shading / reflection, evaporative cooling (fan-pad, mist/ fog and roof cooling) and composite system (earth-to-air heat exchanger system and aquifer coupled cavity flow heat exchanger system) are collected.

Zhai et al. [6] validated the practical effective operation of the adsorption cooling-based air-conditioning system. Their study confirmed that the solar system contributes 70% of total energy involved in air conditioning for the average weather conditions of Shanghai. Arkar et al. [7] investigated the free cooling efficiency in a heavy weight and light weight low energy building using a mechanical ventilation system with two latent heat storage systems and it was found that the free cooling technique enables a reduction in the size of the mechanical ventilation system. Hughes and Wood [8] describe the solar energy and multi- storey residential buildings. Buildings can improve their energy security by reducing their heating demand and replacing imported energy supplies with indigenous ones. Wang Yiping et al. [9] explained the radiant panel with both heating and cooling functions used as structural materials of the building envelop, which realizes true building integrated utilization of solar energy. Ramadan Bassiouny et al. [10] carried out analytically and numerically the solar chimney concept used for improving room natural ventilation considered with geometrical parameters such as chimney inlet size and width, which are believed to have a significant effect on space ventilation. Alan and Ward [11] have investigated an internal assessment of the thermal comfort and day lighting conditions of a naturally ventilated building with an active glazed façade. It has a high thermal mass which is used to promote the use of night cooling. They reported the initial findings of an internal assessment of the thermal comfort and day lighting conditions in such a building. Khodakarami et al [12] have studied about the reducing the demands of heating and cooling in Iranian hospitals. This study examines, through modeling to range of passive building fabric techniques in two monitored case study hospitals to examine how one might best achieve this range of indoor air temperature, and reduce reliance on the heating and cooling systems.

In the present work a concept as shown in Figure (1) to improve the natural ventilation for a residential building is attempted 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 improvement in the ventilation and the cooling effect is studied by conducting an experimental investigation and the CFD simulation analysis. The solar collectors which are used in the winter season alone for hot water requirements can be utilized for this purpose during the other seasons so as to increase the utilization factor of the solar collectors installed in the residential houses. The concept of storing cool energy in PCM during the early morning hours is reported by Belen Zalba et.al [13] and Arkar et al [7]. The induced ventilation is not required during the winter season since comfort conditions can be achieved easily with the existing window openings.

2. Experimentation : The effect of improvement in natural ventilation was studied by conducting an experiment on a low energy cabin shown in Figure (2) 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. The dimensions of the hot and cool storage tanks are given in Table (1).

Table (1): Design Specification of Storage Tanks

No	Parameter	Hot Storage Tank	Cool Storage Tank
1	Material	Stainless steel	Stainless steel
2	Diameter	25 cm	14.3 cm
3	Height	31 cm	12 cm

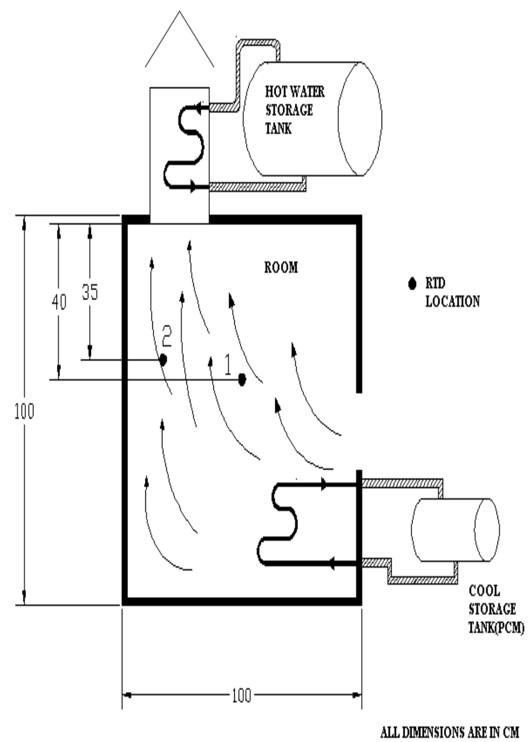

Figure (1): Concept of augmented natural ventilation using hot and cool sources

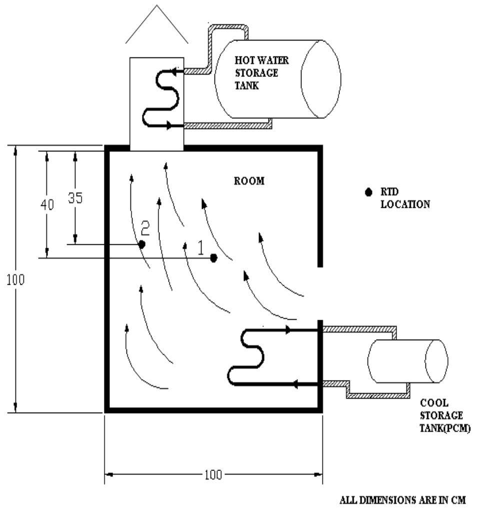

Figure (2): Experimental set-up

The storage tanks are well insulated to retain the temperature of the water in the tanks for a longer duration. The hot water from the 500 litres capacity 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 instead of storing 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 well known and available in the literature. 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 and only two locations are shown in Figure (3) where the effect of temperature reduction by induced ventilations are studied in detail and presented in this paper. During the experiments, to simulate the heating load in the cabin by electric bulbs of varying capacities 50 W, 100 W and 150 W is kept inside the cabin.

The performance improvement of the induced ventilation is studied by carrying out experiments initially by natural circulation and allowing the cabin to attain near steady state temperature and then the hot and cold sources are allowed to enter the cabin to induce the ventilation.

The experiments are conducted at various heat loads of 50 W, 100 W and 150 W for both natural circulation and induced ventilation conditions. In all the experiments it is assumed that the cabin is initially at the ambient conditions.

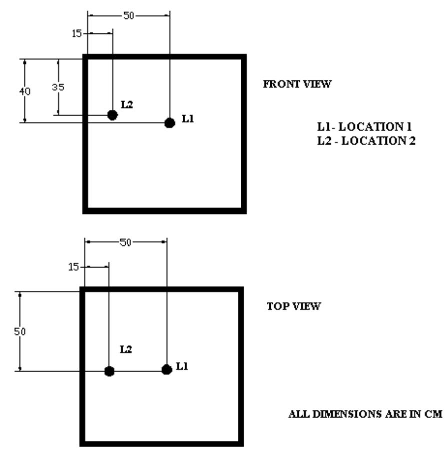

Figure (3): Location for selected RTDs for simulation

When the heater is ON the temperature of air in the cabin increases and it attains a steady state after a long duration depending on the ambient conditions and the amount of air flow through the window by natural circulation.

Similarly the experiments are also conducted with hot and cold sources connected to the cabin in operation. The required temperature of 60°C in the hot source tank is achieved by heating water using an electric immersion heater with a capacity of 1 kW and the required temperature of 28°C in the cool storage tank is achieved by keeping the frozen PCM balls (RT 27) in the tank. The experimental trails are continued until the cabin attains a near steady state temperature. The temperature variations inside the cabin with respect to time for both natural and induced ventilation are drawn and the results are discussed.

3. Computational Model : A detailed numerical model enabling the representation of the cubical room used in the experimental investigation along with the ventilation effect through hot and cold sources is implemented in the commercial CFD tool ANSYS CFX (11). The continuity, momentum and energy equation are used to calculate the 3-dimentional flow field and heat transfer.

Table (2): Boundary conditions and model selected for simulated cases

Boundary conditions			
Inlet air			
Flow direction		Normal to boundary condition	
Flow regime		Subsonic	
Mass and momentum		Mass flow rate	
Velocity		0.167 m/s	
Temperature		32°C	
Density		1.225 kg/m³	
Pressure		1 bar	
Outlet air			
Flow regime		Subsonic	
Mass and momentum		Average static pressure	
Relative pressure		0(Pa)	
Side walls			
Heat transfer		10 W/m²	
Wall influence of flow		No slip	
Wall roughness		Smooth wall	
Top wall			
Heat transfer		25 W/m²	
Wall influence of flow		No slip	
Wall roughness		Smooth wall	
Bottom wall			
Heat transfer		Adiabatic	
Wall influence of flow		No slip	
Wall roughness		Smooth wall	
Domain physics			
Name	Type	Material	Models
Room	Fluid	Air ideal gas	Heat transfer model= Thermal energy Turbulence model= k epsilon Turbulent wall function= scalable Buoyancy model= Buoyant

The geometry used in the present analysis is given in Figure (4). The imposed inlet and boundary conditions are summarized in Table. 2.

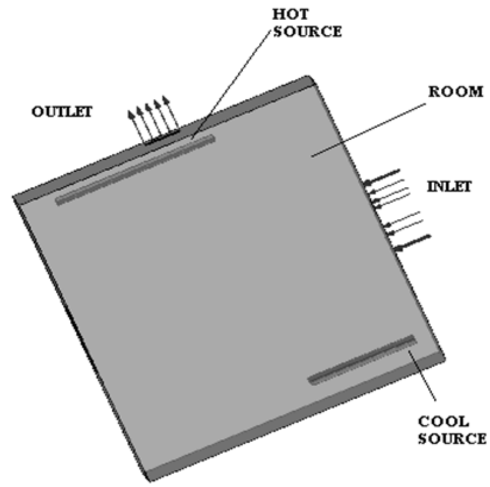

Figure (4): Physical domain

The finite control-volume method is used for the spatial discretisation of the domain. The code is based on a coupled solver for solving the differential equations using the fully implicit discretisation method and treating the hydrodynamic equations as one single system. Buoyancy is modeled using the Boussinesq approximation in which forces are modeled as source terms in the momentum equations.

Various models exist in CFX-11 code for modeling the turbulent flow. Two equation models (k-ε model) based on the eddy-viscosity concept is used for modeling the turbulence in the present analysis. Several numerical trails are conducted to match the temperature variation at the selected RTD location by varying the mass flow rate of air at the inlet. The simulation analysis is carried out for both natural and induced ventilation and the results are presented.

4. Results and Discussion: Figures (5a) and (5b) shows the temperature variation of the air in the cabin at two RTD locations shown in the experimental set-up (Figure (2)). Initially the cabin is at 34°C which is the temperature that prevails in the ambient. It is seen from Fig. 5a that the temperature of air increases with respect to time and it reaches a steady value of 43.5°C, 47.7°C and 51.9°C for various heating loads of 50 W, 100 W and 150 W respectively. Similarly Fig. 5b shows the temperature variation at the location 2 for various heating loads of 50 W, 100 W and

150 W respectively and the temperature reaches steady values of 44.23°C, 48.29°C and 52°C after a period of approximately 160-180 minutes. It is inferred from the above results that the ventilation is not sufficient to withstand even a heat load of 50 W. Hence higher ventilation (or) cooling should be provided to maintain the cabin at the required temperature.

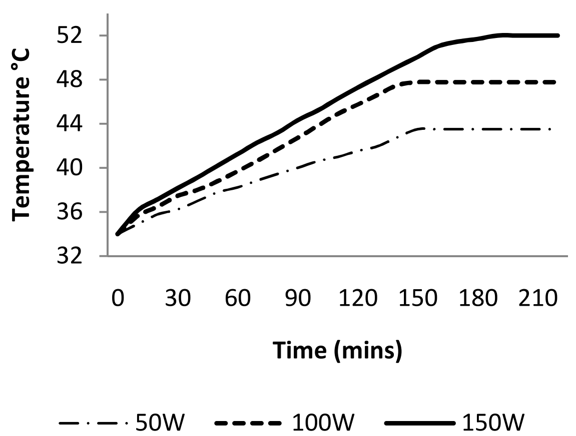

Figure (5a): Experimental Temperature variation at the selected RTD location with natural ventilation at Location 1.

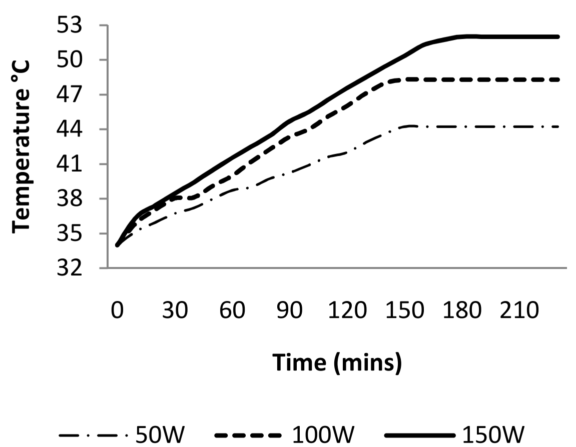

Figure (5b): Experimental Temperature variation at the selected RTD location with natural ventilation at Location 2.

Figures (6a) and (6b) shows the temperature variation of the air in the cabin at the selected RTD locations for the case of induced natural ventilation. It is also ensured that the initial temperature in the cabin and the ambient are at 34°C. It is observed from the Fig. 6a that the temperature decreases with respect to time and it reaches steady low values of 29 °C, 29.4°C and 29.8°C for the heat load of 50 W, 100 W and 150 W respectively at location 1 and the similar trend is observed in Fig. 6b for the location 2. It is seen from the results that a temperature reduction of nearly 4-5°C is achieved through induced ventilation for all the heating loads.

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.

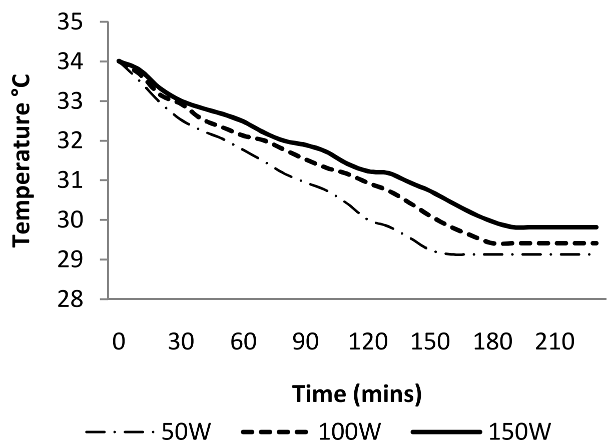

Figure (6a): Experimental Temperature variation at the selected RTD location with induced natural ventilation at Location 1.

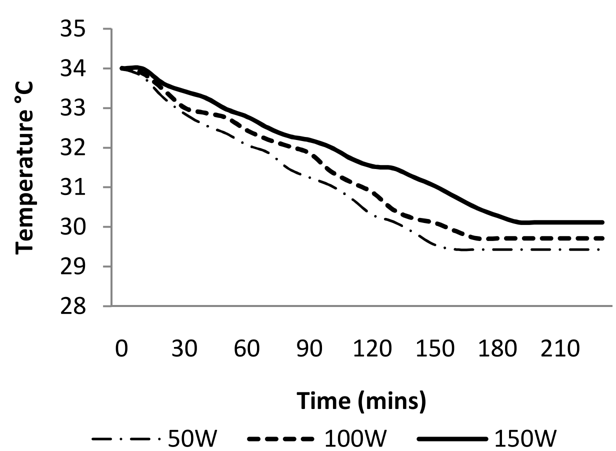

Figure (6b): Experimental Temperature variation at the selected RTD location with induced natural ventilation at Location 2.

Figure (7) shows the temperature contour obtained for the natural ventilation system after it attained steady state when a heat load of 100 W is applied in the cabin. It is seen from the Fig.7 that the temperature at the location 1 and 2 in the experimental set-up are 47.15°C and 47.88°C respectively. The temperature contour for the case with induced ventilation is shown in Figure (8). In this case the temperature is reduced to nearly 29°C at both the RTD locations after a period of 180 minutes.

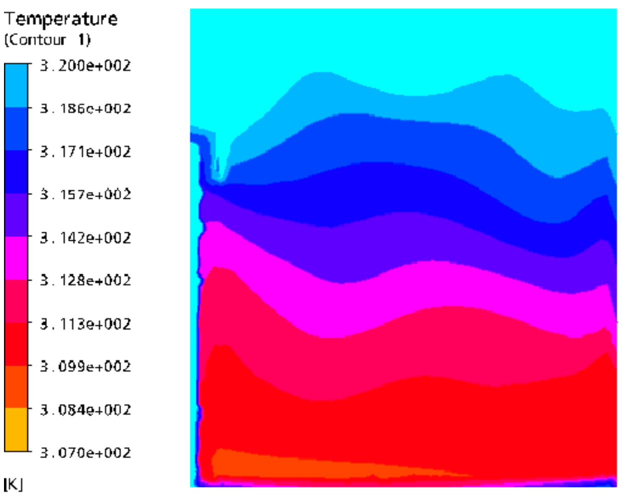

Figure (7): Temperature contour for natural ventilation system (100W heating).

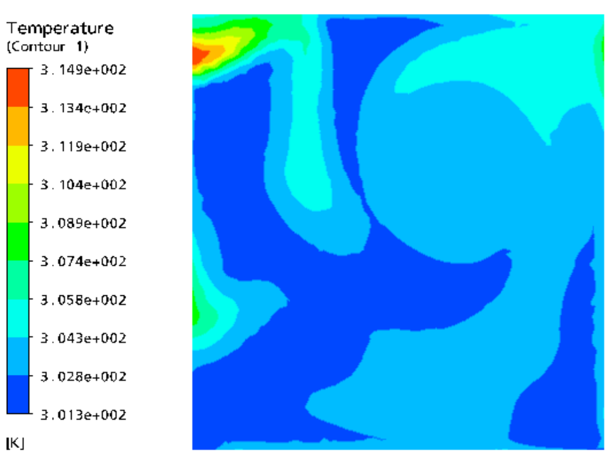

Figure (8): Temperature contour for induced natural ventilation system (100W heating).

In the CFD analysis, the transient temperature distribution simulated for both the natural ventilation and for the induced ventilation cases at all the heating loads are matched with the experimental results by varying input mass flow rate of air at inlet and evaluated the flow rate of air at the inlet and at the selected RTD locations. Figure (9) to Figure (11) show the experimental and numerical temperature variation of the air for heating loads of 50 W, 100 W and 150 W respectively. In all the cases Figure (a) and (b) show the temperature variation at the RTD locations 1 and 2 respectively. In all the above cases the simulated and experimental results are in close agreement when the inlet mass flow rate is 0.005 kg/s.

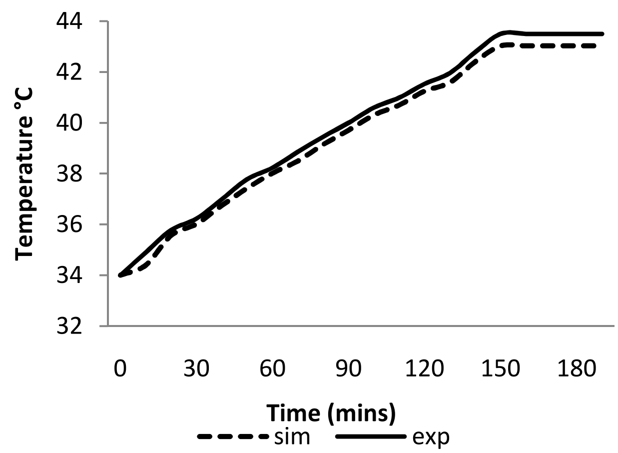

Figure (9a): Experimental and numerical Temperature variation for 50 W at selected RTD location with natural ventilation at Location 1.

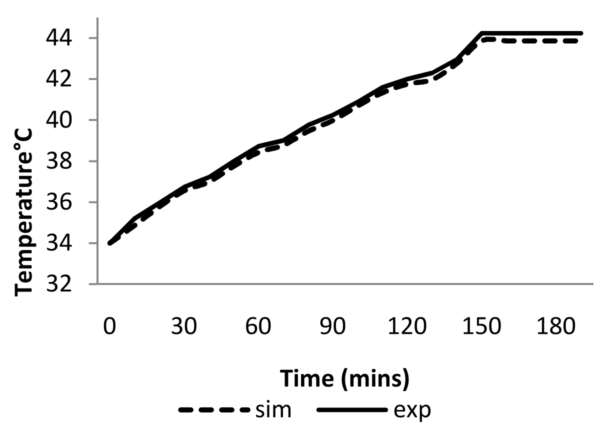

Figure (9b): Experimental and numerical Temperature variation for 50W at selected RTD location with natural ventilation at Location 2.

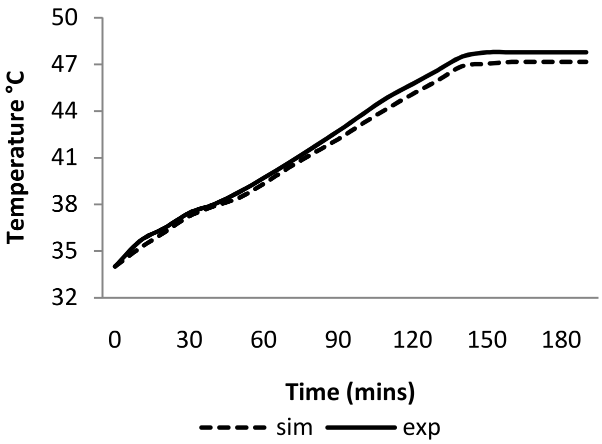

Figure (10a): Experimental and numerical Temperature variation for 100W at selected RTD location with natural ventilation at Location 1.

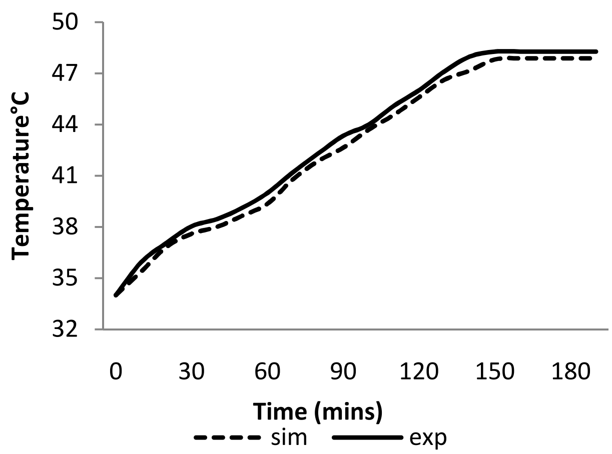

Figure (10b): Experimental and numerical Temperature variation for 100W at selected RTD location with natural ventilation at Location 2.

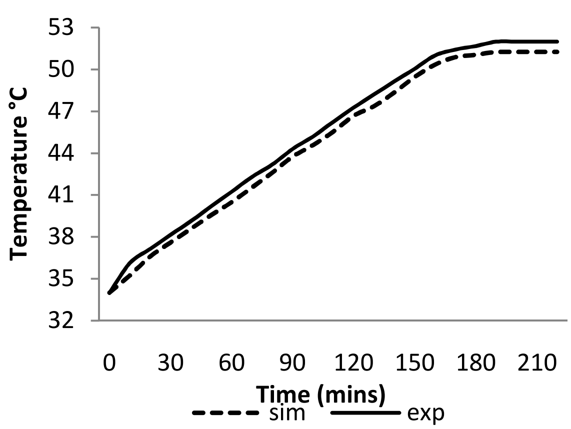

Figure (11a): Experimental and numerical Temperature variation for 150W at selected RTD location with natural ventilation at Location 1.

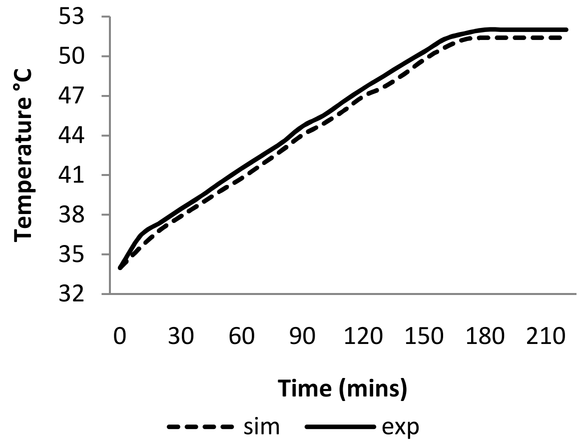

Figure (11b): Experimental and numerical Temperature variation for 150W at selected RTD location with natural ventilation at Location 2.

Similar graphs are drawn for the case with the induced ventilation and are shown in Figure (12) to Figure (14) for heating loads of 50 W, 100 W and 150 W respectively. Both the experimental and CFD results are in close agreement for an input mass flow rate of 0.008 kg/s. It is construed from the results that 60% improvement in ventilation effect (0.005 kg/s to 0.008 kg/s) is achieved in the induced ventilation case. In addition a considerable cooling effect is obtained which is due to the cold source present at the bottom of the cabin.

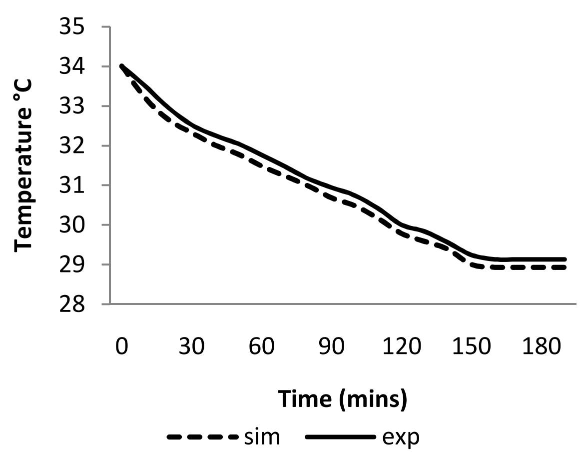

Figure (12a): Experimental and numerical Temperature variation for 50W at the selected RTD location with induced natural ventilation at Location 1.

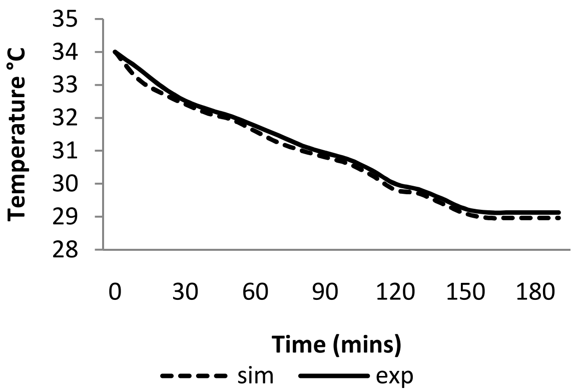

Figure (12b): Experimental and numerical Temperature variation for 50W at the selected RTD location with induced natural ventilation at Location 2.

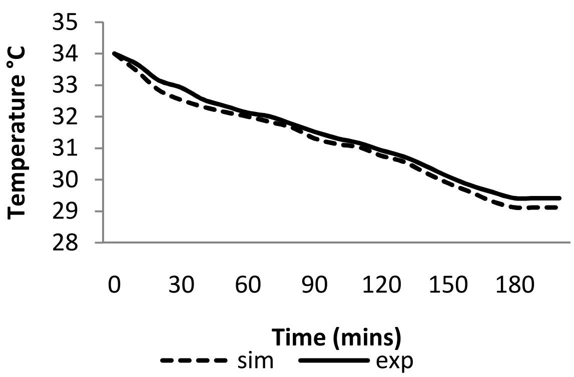

Figure (13a): Experimental and numerical Temperature variation for 100W at the selected RTD location with induced natural ventilation at Location 1.

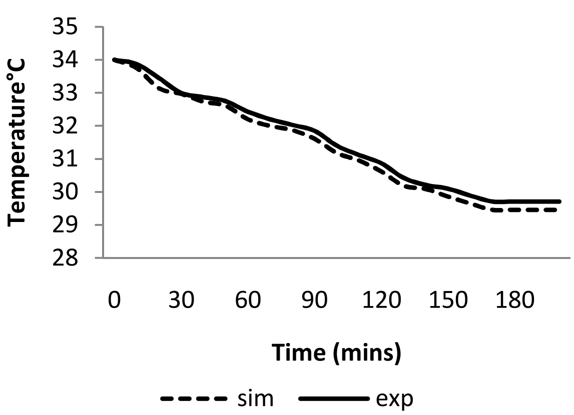

Figure (13b): Experimental and numerical Temperature variation for 100W at the selected RTD location with induced natural ventilation at Location 2.

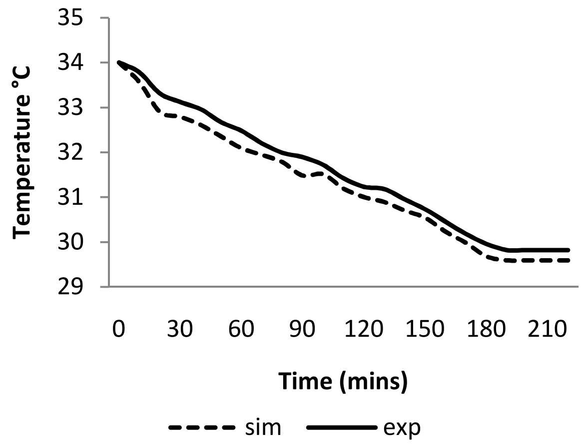

Figure (14a): Experimental and numerical Temperature variation for 150W at the selected RTD location with induced natural ventilation at Location 1.

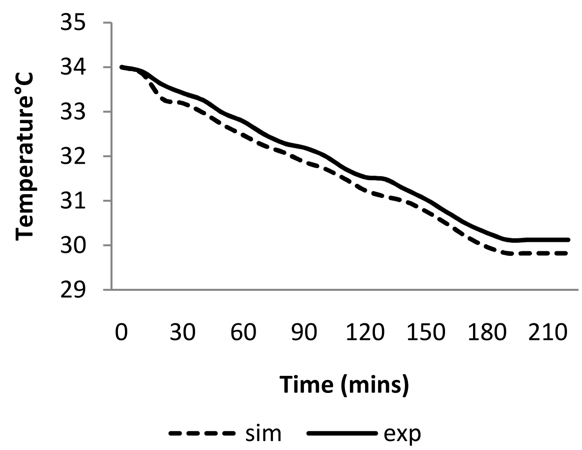

Figure (14b): Experimental and numerical Temperature variation for 150W at the selected RTD location with induced natural ventilation at Location 2.

The velocity contours obtained from the CFD results are also shown in Figure (15) and Figure (16) for the case of natural and induced ventilation respectively for a heat load of 100 W to study the velocity variation of air inside the cabin. It is seen from the Fig. 15 and Fig. 16 that the local velocity of air at RTD location 1 in natural ventilation case is 0.0103 m/s where as it is 3.33 m/s in the case of induced natural ventilation.

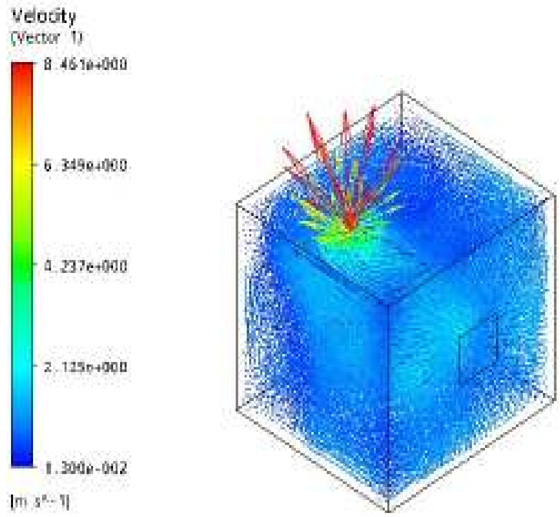

Figure (15): Velocity Streamline for natural ventilation system (100W heating).

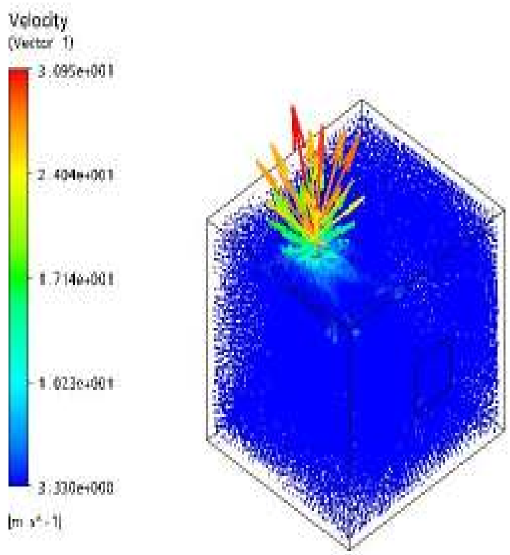

Figure (16): Velocity Streamline for induced natural ventilation system (100W heating).

It is concluded from the simulation and experimental trails that a considerable improvement in ventilation and cooling effect is achieved by the induced ventilation. However further optimization studies are required to size the capacity of the cooling and heating coil.

5. Conclusion: In the present work an experimental investigation has been carried out to analyze the thermal performance of the cabin with natural ventilation and artificially induced ventilation using natural sources. The CFD simulation is carried out to quantify the performance improvement in the induced ventilation. The result from the present study reveals that a considerable reduction in temperature and an improvement in ventilation is possible through induced ventilation. The use of solar heating systems for dual applications to induce natural ventilation along with the water heating application will increase the utilization factor which will promote the solar heating system to a larger extent.

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