# EXPERIMENTAL INVESTIGATION ON SINGLE-SIDED TRANSIENT NATURAL VENTILATION DRIVEN BY BUOYANCY

by

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Original scientific paper
https://doi.org/10.2298/TSCI17S2489V

*Energy consumption in building sector plays a major role in hot climate for space cooling. In this view of equipment energy consumption reduction on building space cooling, top vent and window operation-based natural ventilation model is developed in reduced scale. In this study, the performance of rectangular top vent arrangement along with window opening configuration with respect to temperature distribution and air flow pattern is investigated experimentally. The results depicted that the heat generated from the indoor element with vent and window opening configuration showed a greater influence in vertical temperature difference. For both the case of window opened and closed with vent, the time taken to attain the steady-state is shorter for larger vent compared to smaller vent. Increasing the top vent area reduces the indoor air temperature at various levels. When windows in open condition, there is significant reduction in indoor air temperature upto window level for all vent areas. Air flow pattern of the indoor air is validated through smoke visualization test.*

Key words: *thermal buoyancy, top vent, transient natural ventilation, window configuration, smoke visualization*

## Introduction

Growing energy demand has drawn the attention on energy saving aspect particularly in building sector. The natural ventilation is the technique can be used for both energy saving and air quality improvement. The prediction of air movement in single-sided natural ventilation is difficult due to bidirectional flow and strong turbulence effect [1]. The performance of different window type buoyancy-driven natural ventilation were carried out to compute the efficiency of ventilation [2, 3]. Bayoumi [4] performed a simulation with window opening grade on an office building to predict the energy efficiency in hot climate. An experimental and numerical study were conducted by Elshafei, *et al.* [5] on the impact of window parameters (window placement, window size and window shades) for a natural ventilated building. It is also reported that, due to lack of design parameters, the thermal discomfort occurs inside the space. Buoyancy-driven single opening and upper, lower opening ventilation configuration were studied with indoor heat generating elements [6, 7]. For night time cooling of a single-sided natural ventila-

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tion, commercial buildings were analyzed with a rectangular opening [8]. For better understanding of the air flow pattern an investigation was carried out through smoke visualization test [9, 10]. Even though literature shows the effective method of space cooling technique for summer climatic condition, practically renovation of the existing building is limited. Floor level bottom vent creation for all the rooms may not be possible based on the fact that the room may be small and also occupant may access or carry something till window level which may affect the air flow through the lower vent. To a larger extent, whoever may be the occupant and whatever may be the indoor access, windows can be operable. This work aimed to perform the transient buoyancy-driven natural ventilation with a rectangular top vent by operating the slider window. The indoor air temperature at various level of the room model is compared with and without opening the window on various vent areas. To confirm the air flow transportation of the arrangement, the smoke visualization test was performed.

## Experimental set-up

The prototype of natural ventilated room model is located in a hot climate test room. The front and top view of the room model is shown in figs. 1(a) and (b). The actual size of the room has dimensions of 3 × 3 × 3 m. The room model is a closed single storied and isolated. The scale down model is made with 0.016 m thick plywood, which is one-third of the actual dimensions. The single-sided natural ventilation technique is used to cool the room model indoor air in which a slider type window allows the air in and out. Only half portion of the window can be maximally opened. One-third of actual room internal heat load is resized in order to maintain the geometric ratio [11]. In this work, a point internal heat load of 100 W was considered and the location of the internal heat source (100 W bulb) was kept at center of the room model at floor level. Air is the working fluid. One set of window position arrangement and five vent cross-section area was created to perform the experiment. Rectangular vent was created above the window and just below the roof. Considering the top level of the rectangular vent and the window size, the area of the rectangular vent was increased from no vent to 0.006, 0.0132, 0.0198, and 0.0264 $m^2$. The vent area of 0.0264 $m^2$ is equal to the opening of window open area (both inlet and outlet is equal in cross-section). Resistance temperature detectors (RTD) are used to measure the indoor and test room air temperatures. The accuracy of

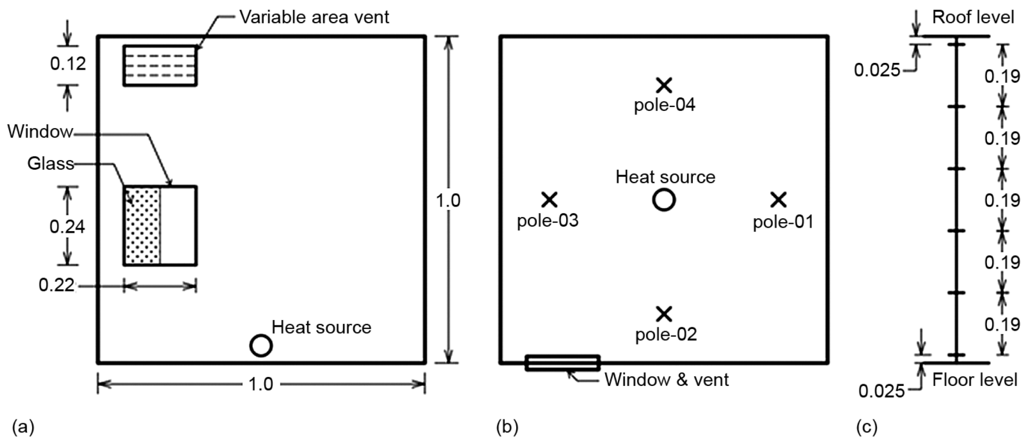


**Figure 1. Schematic illustration of the experimental set-up; (a) front view of the room model, (b) top view of the room model, (c) measuring point on a pole; all dimensions are in [m]**

the RTD is ±0.1 °C. There are four poles *viz*., pole-01, pole-02, pole-03, and pole-04, which are located 0.15 m away from the respective side walls, fig. 1(b). Figure 1(c) shows the single pole measuring point vertical location, where each measuring points are maintained with the distance of 0.19 m apart. Top and bottom level measuring points are located at 0.025 m above from the floor and roof, respectively [12]. One more RTD was placed at roof level above the heat source to measure the thermal plume temperature. The test room air temperature (environmental temperature to the room model) was also measured simultaneously.

Three cases were considered; case (a): window closed and open configuration without vent; case (b): window closed with vent, and case (c): window opened with vent. Initially, the test room was maintained at 32 °C as uniform temperature for indoor room model and test room temperatures then the respective arrangements on window and vents were made according to the case and the experiment was performed. The transient experiment was conducted for a duration of 180 minutes; the temperature of the various location was logged using data logger with one minute interval.

## Results and discussion

The buoyancy-driven ventilation on window configuration and top vent arrangement was investigated experimentally. The transient indoor air temperature distribution for the various cases results were discussed below

### *Window configuration and vent arrangements*

#### *Case (a): Window closed and open configuration without vent*

The transient vertical temperature profile of the room model without vent and window closed condition is shown in fig. 2(a). When the indoor heat source is turned ON, the indoor air temperature increases with increase in time. The floor level measuring point shows the lower temperature and roof level measuring point shows the higher temperature. The in-

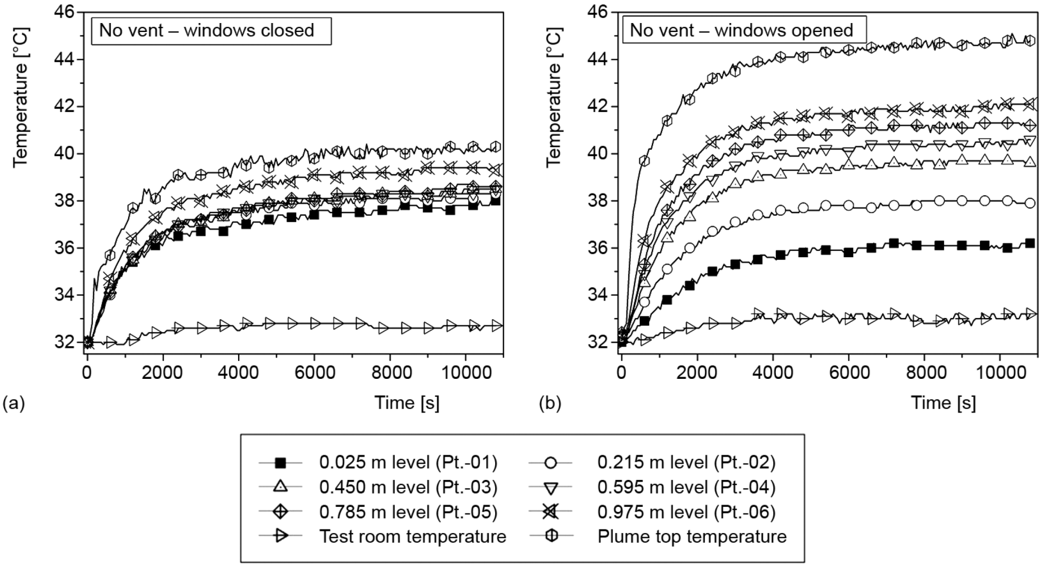


**Figure 2. The transient vertical temperature profile of the room model; (a) no vent – window closed, (b) no vent – window opened**

termediate measuring points shows the temperature within the range of lower and upper measuring point temperatures. Apart from the pole measurement, the roof level thermal plume measuring point is always higher than all the other indoor air temperature. This is due to the generation of heat source that heats up the surrounding air, which leads to reduction in density. The low density warm air moves up to the roof level as a thermal plume and the high density cold air moves down as a result of buoyancy force. Since the room is closed one, the heat and mass transfer in and out to the room model was sealed. The maximum lower level (occupant's zone) air temperature after attaining steady-state was 37.8 °C. The vertical difference in air temperature from floor level to roof level was 1.5 °C.

Figure 2(b) shows the transient vertical temperature distribution of room model with windows opened condition. With the same test room (environmental) temperature, the lower level measuring point temperature was measured as 36.2 °C. The temperature difference between two subsequent measuring point from floor level was 1.7, 1.7, 1.0, 0.9, and 0.8 °C during steady-state. The warm air from thermal plume fills the top portion of the room model initially. Due to the temperature difference between indoor air and outdoor air, the low temperature high density outdoor air flows in and warm air flows out from the model through the window. The upper and lower portion of the window is used for outflow and inflow, respectively. Hence, the resultant overall temperature difference between floor levels to roof level measuring point was 6.1 °C during steady-state.

### *Case (b): Window closed with vent*

Window closed configuration with vent arrangement transient vertical temperature distribution is shown in fig. 3 with various vent areas. When introducing a rectangular vent during window closed condition, the significant temperature difference was noted between the measuring points. This is because of the provision the vent offers for the air to flow in and out of the room. The maximum indoor air temperature also decreases with increase in the vent area. When the top vent area increases, the flow rate also enhance due to which the cold air from the outdoor may access through vent by pressure difference. So the indoor air temperature lowered down than the earlier case. The time taken to prevail the steady-state temperature is also reduced with higher vent area. During steady-state, the floor level/roof level temperatures were 36.1/42, 35.9/41, 35.8/40.6, and 35.7/40 °C for the top vent area of 0.0066, 0.0132, 0.0198, and 0.0264 $m^2$, respectively. The thermal plume temperature reduces from 44.7 to 42.4 °C.

### *Case (c): Window opened with vent*

Open window configuration with vent transient vertical temperature profile was shown in fig. 4. With the availability of internal heat source, the indoor air temperature increases. The bottom level measuring points, 0.025 and 0.215 m, shows lower temperature among all the measuring points. The difference between these measuring points was 0.5 °C. There is a markable temperature difference between below window level and above, this is due to the high density cold air that flows through the window cools the lower level of the room model. The warm air from the heat source flow up and availability of the vent provides the passage for outflow from the room. When increased in top vent area from 0.0066 to 0.0264 $m^2$, the highest temperature at the same measuring points are decreased. The continuous difference in indoor air temperature and test room temperature creates the pressure difference, which initiates the air movements [13]. During window opened steady-state condition, the floor level/roof level temperatures are 34.9/39.1, 34.5/38.3, 34.2/38.0, and 33.9/37.0 °C

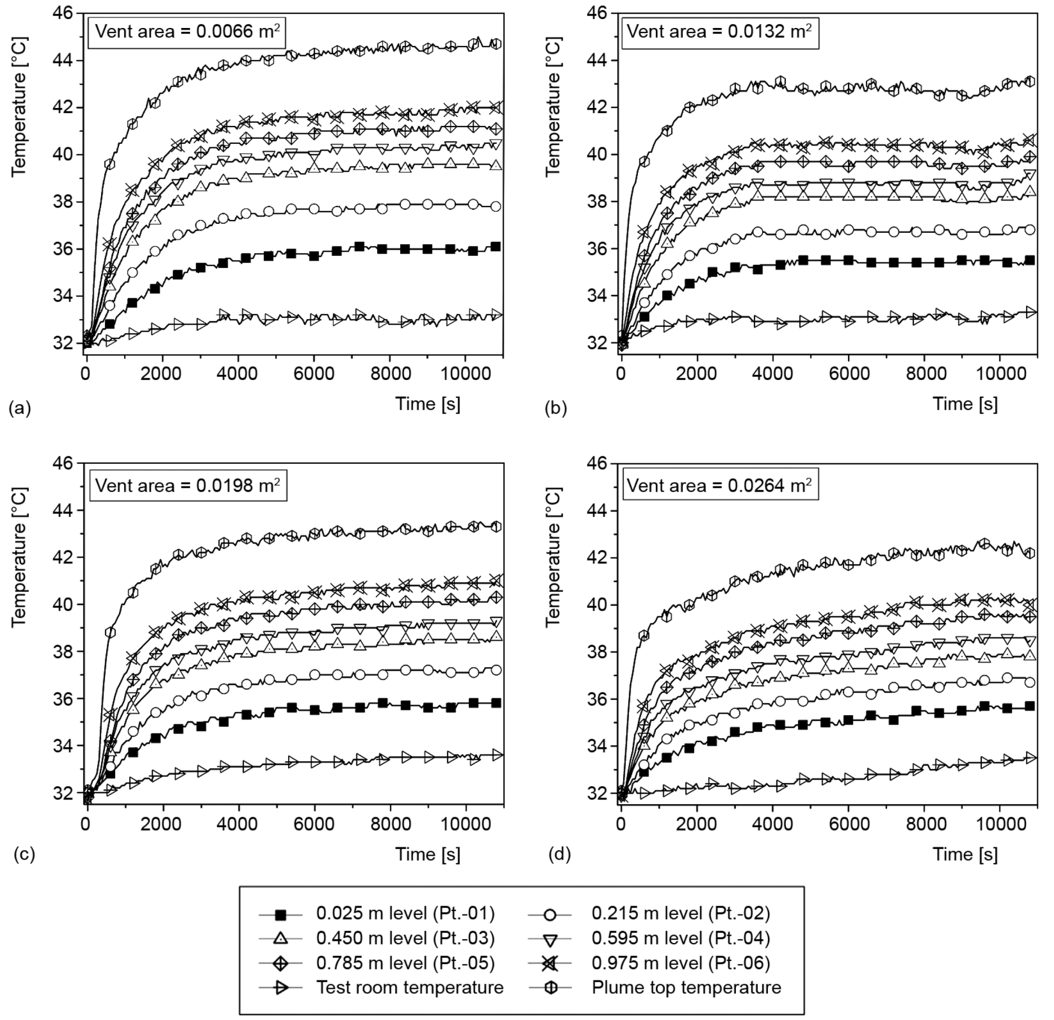


**Figure 3. The transient vertical temperature profile of window closed configuration with various top vent areas; (a) $A$ = 0.0066 m$^2$, (b) $A$ = 0.0132 m$^2$, (c) $A$ = 0.0198 m$^2$, (d) $A$ = 0.0264 m$^2$**

for the top vent area of 0.0066, 0.0132, 0.0198, and 0.0264 m$^2$, respectively. The roof level thermal plume temperature reduces from 40.6 to 37.8 °C.

### *Flow visualization test*

The opening and closing of the window configuration along with vent arrangement cases was run and the temperatures of all locations were logged. When temperature of the indoor air temperature reaches the steady-state, the smoke test was performed [14]. Smoke generator was placed nearer to the internal point heat source of the room model at mid of the room floor level. For the case of full window closed and no vent, there was no flow image. For the smoke test, the flow pattern is clear that, along the thermal plume, the smoke flows till top of the room model, when it reaches the roof level the concentration of the smoke gradually

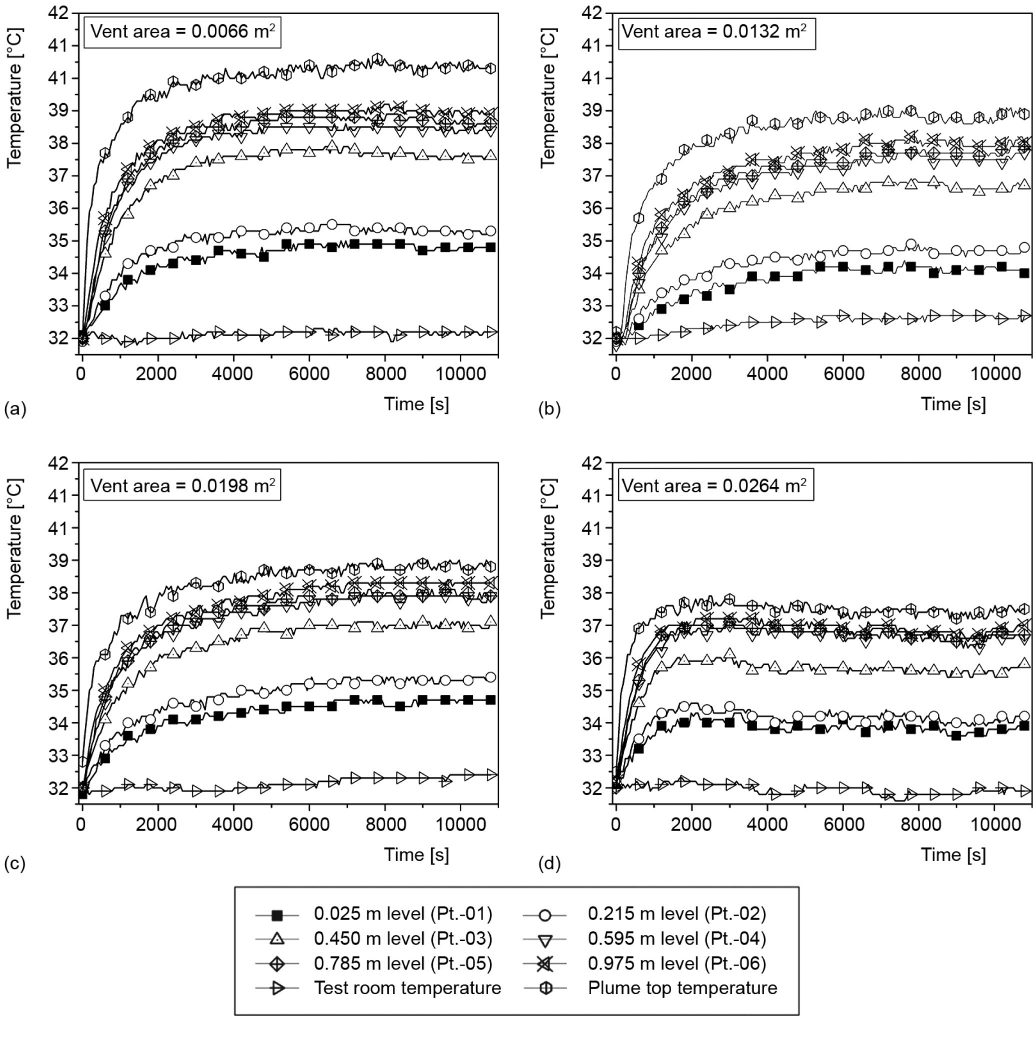


**Figure 4. The transient vertical temperature profile of window opened configuration with various top vent areas; (a) $A$ = 0.0066 m$^2$, (b) $A$ = 0.0132 m$^2$, (c) $A$ = 0.0198 m$^2$, (d) $A$ = 0.0264 m$^2$**

increasing from top level to the bottom level. For the case of no vent, the smoke fills till the window and starts flowing out from the room model through window opening which is shown in fig. 5. Without window opening with vent of small area, 0.0066 m$^2$, shows that the flow of smoke towards up; when increasing the vent area, the out flow angle varies. This forced flow shows the more amount of air change occurring through the vents. It is also clear from the image that the upper portion of the vent allows the warm air (smoke) out from the room model and the bottom portion of the vent allows the cold air in to the room model. In case of window open position, the flow of smoke is almost perpendicular to the side walls and the smoke flow covers full vent area irrespective of the range of vent size. The open portion of the window allows the high density air in and top vent allows the warm air out. It is also noted from the window opened case 0.0066 m$^2$ vent area (25% of window opening) arrangement smoke flow occupies full area of vent and some more smoke flow occurs at top portion of the window. This indicates the insufficient top vent area to drain the warm air through it with this amount of internal heat source. Further increase in the vent area to 0.0132 $m^2$ (50% of window opening) smoke drains through top vent only. This shows the rate at which the warm air generation plays the major roll in vent area.

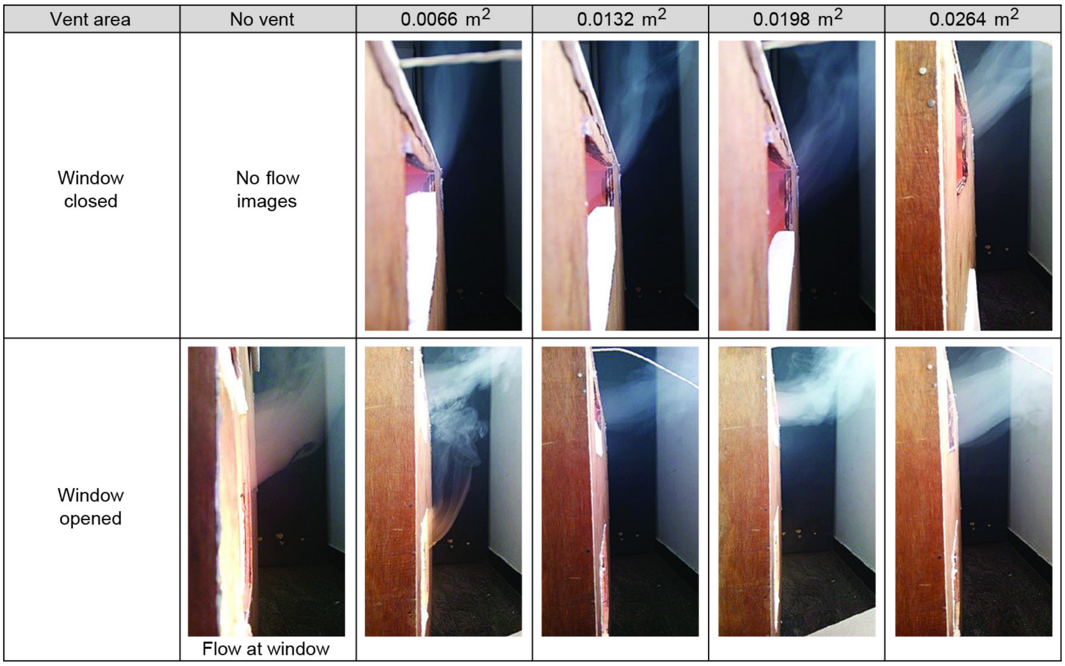


**Figure 5. Smoke visualization test on various window position with various top vent area**

## Conclusion

The performance of various top vent area arrangement with window open/closed configuration were performed on a single-sided ventilated room model. Generally, opening of the window shows the air flow in/out of the room. It can be concluded that from the vertical temperature profile, the opening of the window supplies the fresh air from outdoor to the indoor. The top vent enhances the air flow out and it reduces the accumulation of warm air inside the building. With the availability of the vent, the indoor air temperature reduces, the temperature reduction depends on top vent area along window opening. Window opening with vent further reduces the lower level air temperature. So in the view of renovation of an existing building with vent may produce significant effect on indoor air temperature. The smoke visualization test confirms that the flow pattern of the air and it shows that the internal heat generation plays an important roll on generation of warm air.

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Paper submitted: May 16, 2017
Paper revised: July 7, 2017
Paper accepted: August 1, 2017

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