# Application of active stack system to enhance natural ventilation in high-rise residential buildings

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## ABSTRACT
This paper is about the application of active stack system to enhance natural ventilation in public housing in Singapore. About 86% of the population is staying in high-rise public housing, known as Housing and Development Board (HDB) flats, which is designed for natural ventilation. The main objective of this work is to assess the status of natural ventilation in a typical 4-room HDB flat using scaled model in the wind tunnel, and to develop an effective active stack system to enhance natural ventilation in the flat. Four numbers of stacks with different sizes were tested at two locations in the flat. The study shows that the active stack leads to substantial increase in the air velocity at the room and thus meeting the human's thermal comfort condition. It was noted that the velocities increase along with the increase in the stack size. For smaller stacks, there is not much increase in the air velocity with the increase in fan speed.

**KEYWORDS:** Natural Ventilation, Wind Tunnel, Active Stack, Air velocity.

## 1 INTRODUCTION
The study of natural ventilation in residential buildings is of significant importance as it directly affects human health, comfort and well-being. In a hot and humid country like Singapore, natural ventilation is the most cost-effective way to minimize the physiological effect of the high humidity to achieve acceptable indoor thermal comfort condition. In residential buildings, living rooms are usually well ventilated during the day since doors and windows are open. However bedrooms are the least ventilated regions, as there is no cross ventilation with single-sided windows. In addition, the closed doors as well as the lower wind velocity during the night deter natural ventilation.

Previous works on stack ventilation is mainly based on solar chimney systems, which make use of the principle of passive stack. These include the studies done by Awbi, Bansal, Barozzi, Bouchair and Tan [1-5]. Hybrid ventilation concepts have been developed in commercial buildings in Finland [6]. However, very few similar studies for residential buildings were carried out in tropical climate. Therefore, this study aims to increase ventilation rate and achieve better indoor thermal comfort condition in public housing using active stack system.

## 2 EXPERIMENTAL WORK
### 2.1 Scale Model of Apartment with Active Stack
Figure 1 shows the plan of a typical 4-room HDB flat with a floor area of 100 square meters and height of 3 meters, which was used for this study. The scale of 1:5 is used for the model to effectively simulate the airflow in each of the individual rooms. The size of the model is 2 meter x 2.1 meter and is made of transparent plastic and plywood as shown in Figure 2. All

doors are constructed to be able to open or close. The stack is extended to a height of 4.5m. Two positions were investigated for the stack: one between bedroom1 and the master bedroom toilet; and the other between the master bedroom and bedroom1 as shown in Figure 3. Four different stack sizes as shown in Table 1 were investigated for each of these positions.

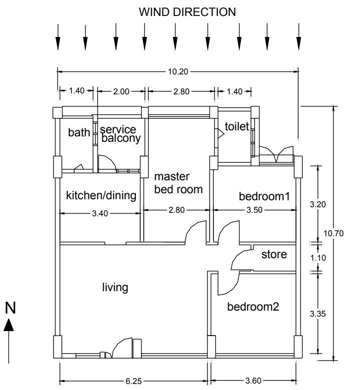


Figure1. Plan of the apartment unit

Figure 2. Apartment model for the study

Table 1. Different stack sizes used

| STACK | ABBREVIATION | SIZE OF THE STACK |
|---|---|---|
| Stack Size1 | SZ1 | 150mm X 150mm |
| Stack Size 2 | SZ2 | 200mm X 200mm |
| Stack Size 3 | SZ3 | 300mm X 300mm |
| Stack Size 4 | SZ4 | 400mm X 400mm |

The active stack aims to induce suction effect inside the rooms by installing a fan on the top of the stack as shown in Figure 4. The variation in the fan speed is controlled by a 15V DC adapter to achieve airflows, 2.7 m/s, 3.7m/s and 5.5 m/s, in the stacks.

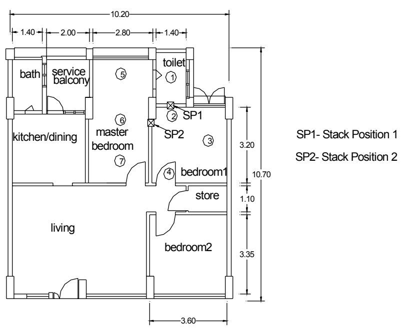


Figure 3. Stack Positions 1 & 2

Figure 4. Extract fan at the top of the stack

## 2.2 Wind Tunnel

All the experiments were conducted in an open-circuit boundary layer wind tunnel, 3.75m (W) x 17 m (L) x 1.75 m (H). The minimum requirement for the simulation of natural atmospheric boundary layer can be achieved with acceptable approximation in this short test section by insertion of various flow-conditioning devices at the test section entrance. For the length of 9.5 m upwind direction, arrayed wooden blocks have been used to create surface roughness before the movable testing table. These blocks are placed on the wind tunnel floor to simulate the ground roughness, similar to small turbulence associated with proximity on the earth surface. Airflow in the wind tunnel is generated by ten 750mm diameter fans placed at the bell-mouth end of the tunnel.

### 2.3 Setting of Boundary Conditions

A reference wind speed of 1.3 m/s was used throughout the experiment. This average value was taken from the Singapore weather data during night hours of the whole year. The wind direction is rather constant, i.e., from north as indicated in Figure 1. Hotwire anemometer was used to monitor the wind speed and ensure that the speed is constant throughout the experiment.

### 2.4 Test Procedure

Airflow and temperature measurements were conducted using Dantec low velocity transducer 54R10 (measuring accuracy ±5%), connected to a Dantec multi channels data logger. Dantec Omni directional velocity and temperature transducers 54T21 connected to a notebook data logger were also used to measure the air velocity. The probes are placed at seven Locations, three inside each of the bedrooms and one inside the toilet as shown in Figure 3. Four conditions were evaluated as shown in Table 2. All the windows were fully open during the test. Even though Cases A, B, C and D are tested for the four stack sizes, only cases A and B and stacks SZ1 and SZ4 are discussed in this paper.

Table 2. Different boundary conditions for the measurement

| | |
|---|---|
| **Case A** | Wind Tunnel Fans off, Doors Closed |
| **Case B** | Wind Tunnel Fans on Doors Closed |
| **Case C** | Wind Tunnel Fans off, Doors Open |
| **Case D** | Wind Tunnel fans on, Doors Open |

## 3 RESULTS AND DISCUSSIONS

### 3.1 Comparison of Air Velocity with Different Stack sizes & fan speeds for position 1

#### 3.1.1 Case A (Wind tunnel fans off and doors closed)

Figure 5 shows the readings using different stacks for the three fan speeds for Case A. It is observed that the velocities increase with the increase in stack size. In general smaller stack doesn't show much increase in the air velocity with the increase in fan speed except for Location 2. The air velocity at Locations 1, 2, 3 and 4 are affected by variation of stack size and fan speed. The remaining Locations were not affected much. Location 2 is significantly affected as this is nearest to the inlet opening. The maximum velocity with SZ1 and SZ4 are 0.05m/s and 0.41m/s respectively. Even though Location 3 is directly opposite the window; the impact is not so significant. Location 1, which is inside the toilet, shows the maximum velocity of 0.082 m/s. This low value could be due to the smaller inlet and volume of space.

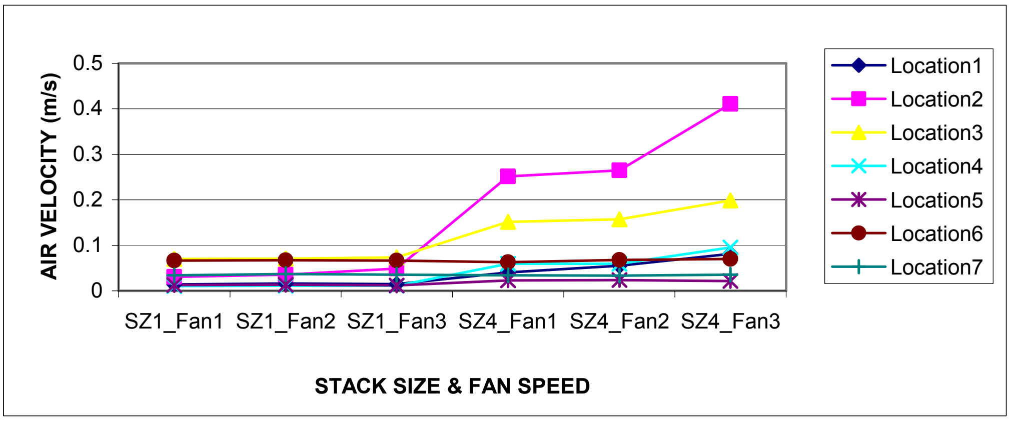


Figure 5. Air velocities with different fan speeds and stack sizes (Case A, Stack Position 1)

#### 3.1.2 Case B (Wind tunnel fans on and doors closed)

For case B, air velocities for different stack sizes and fan speeds are shown in Figure 6. It was observed that the external wind influenced the air velocity within the flat. Similar to Case A, SZ1 doesn't show much increase in the air velocity with the increase in fan speed. The velocities at Locations 1, 2, 3, 4 and 5 increase with the increase in the stack size. It is observed that for SZ1, Locations 1 and 5 show a decrease in air velocity with the increase in fan speed. Location 3 achieves a velocity of 0.67m/s with SZ4, whereas the velocity is 0.26 m/s with SZ1. This is the Location, which has the highest velocity when the doors are closed and this is highly desirable as the bed will usually be located at this position. Location 2 has a velocity of 0.59m/s with SZ4 and 0.15m/s with SZ1. Location 1 does not show high velocity even with SZ4 and the maximum velocity achieved is 0.15m/s. Location 4 shows a velocity of up to 0.23m/s with the SZ4. An increase in velocity is also observed at Location 5 with the increase in stack size, although it is located in the other bedroom. This is due to the suction effect from the toilet via the door.

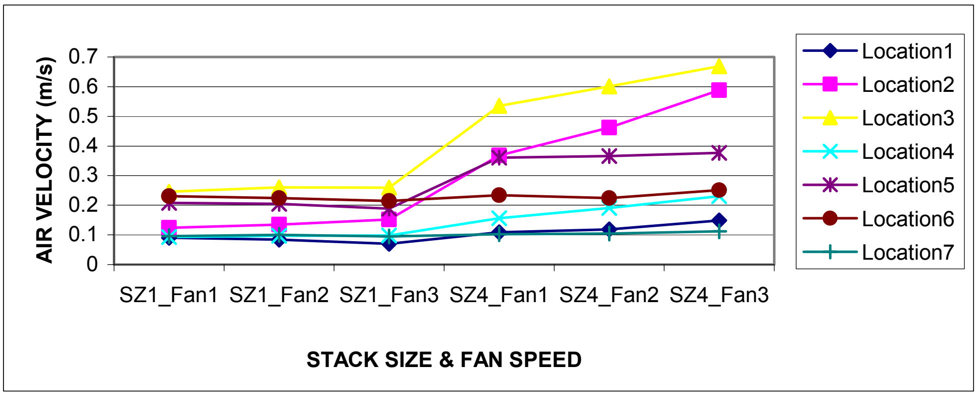


Figure 6. Air velocities with different fan speeds and stack sizes (Case B, Stack Position 1)

### 3.2 Comparison of Air Velocity with Different Stack sizes & fan speeds for position 2

#### 3.2.1 Case A (Wind tunnel fans off and doors closed)

Figure 7 shows the velocities with different stacks and fan speeds at SP2, for Case A. Locations 1, 5, 6, and 7 show higher velocities with the increase in stack size and Locations 2, 3, and 4 are not affected. For SZ1, increase in the fan speed doesn't affect the velocities at Locations 1, 5 and 6. Location 6 has the highest velocity for SZ4 as it is nearest to the inlet opening. The maximum velocity at this Location is 0.06 m/s with SZ1 and 0.39 m/s with SZ4. For Location 5, the velocity ranges from 0.02m/s to 0.21m/s and for Location 7, the velocity ranges from 0.04 m/s to 0.11 m/s. Location 1 has a velocity of up to 0.08 m/s, which is close to the value compared to SP1. Though Location 2 is closer to the inlet, it always has low velocity. This could be due to the small inlet opening on bedroom 1.

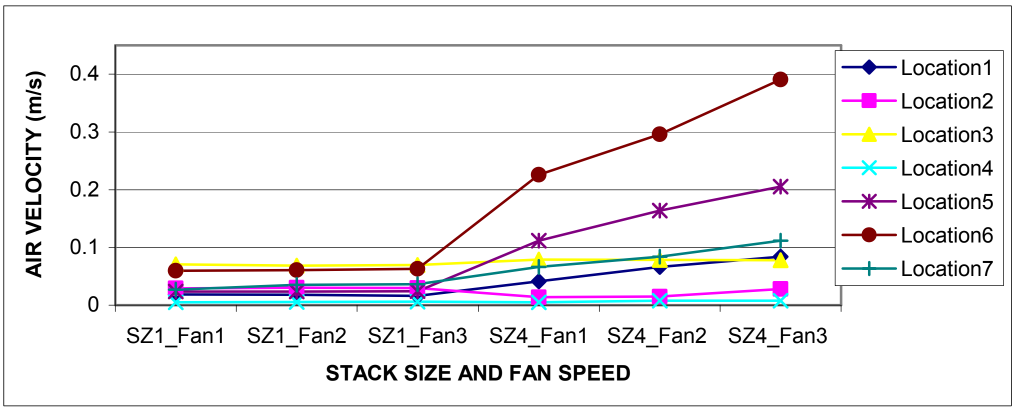


Figure 7. Air velocities with different fan speeds and stack sizes (Case A, Position 2)

### 3.2.2 Case B (Wind tunnel fans on and doors closed)

Figure 8 shows the air velocities for Case B. The Locations affected much are 5 and 6. Location 5 shows a substantial increase in air velocity with the increase in stack size, where the air velocity increases from 0.2 to 0.47 m/s. Location 6 has a maximum velocity of 0.3m/s by using SZ1 and 0.49 m/s by using SZ4. The velocities at Location 2 range from 0.07 m/s to 0.14 m/s. Location 1 has a velocity of up to 0.09 m/s, which is much lower compared to SP1.

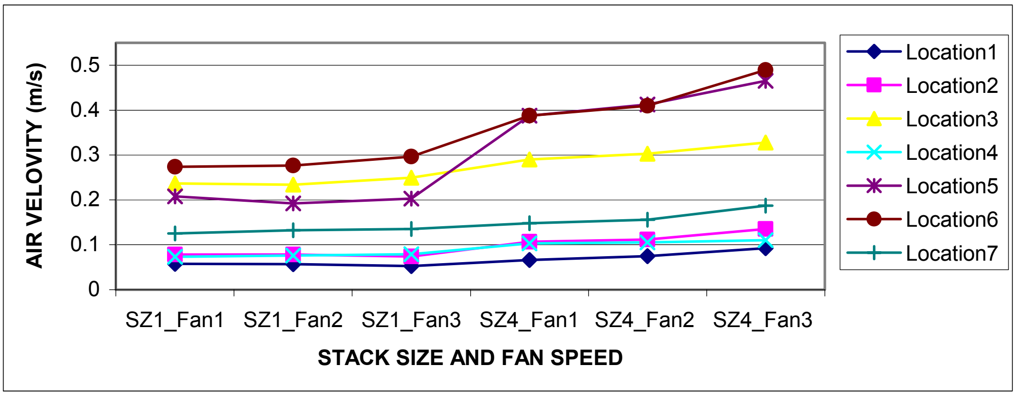


Figure 8. Air velocities with different fan speeds and stack sizes (Case B, Position 2)

### 3.3 SUMMARY

It was observed that the active stack provides substantial increase in the internal air velocities. It was noted that the velocities increase along with the increase in the fan speed as well as stack size and this increase is more prominent for the bigger stack. For SP1, the Locations near the inlet opening (Location 2) and in front of the window (Location 3) have shown significant improvement. For SP2, the Locations near the inlet opening (Location 6) and near the window (Location 5) have shown significant improvement in air velocities. When the wind tunnel fans are turned off, the percentage increase in velocity is found near the inlet openings, but when the wind tunnel fans are turned on, higher air velocities are distributed to Locations near the windows. For larger stacks, higher velocity is achieved even without any external wind.

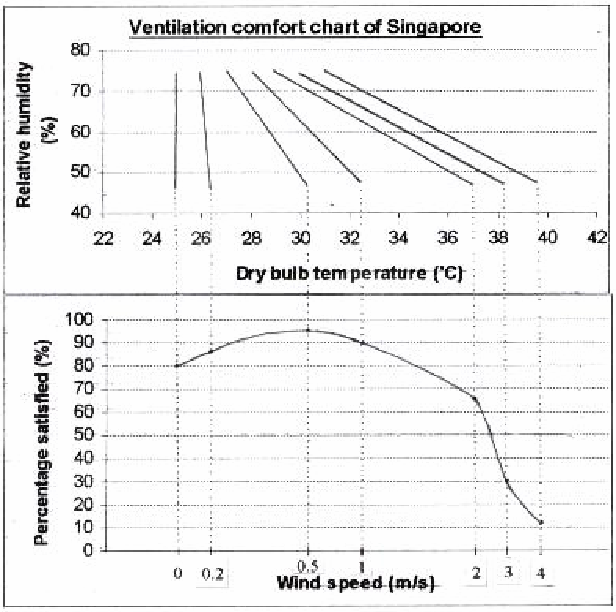


Figure 9. Singapore ventilation comfort chart

Studies [7-9] show that the increase in air velocities, especially at higher temperature enhances the thermal comfort condition. Figure 9 shows the ventilation comfort chart for Singapore derived from a chamber experiment [9]. It can be observed that velocity in the range of 0.3 m/s to 0.7 m/s can make more than 85% - 95% of the people satisfied for a range of temperature and relative humidity values as shown in the Figure. The introduction of active stack in the 4-room apartment resulted with the air velocities ranging from 0.26 m/s to 0.69 m/s. Occupants will feel comfortable in such environment

## 4 CONCLUSIONS

The present investigation has pointed out the remarkable performance of the active stack system. The percentage increase in the velocity is up to 550% and the maximum velocity achieved was 0.67 m/s. A velocity of 0.26 m/s was achieved even with the smallest stack. For larger stacks high velocities were achieved even when the wind tunnel was turned off. This indicates that on a calm evening thermal comfort could be achieved. The maximum size of the stack used is 0.4 m x 0.4 m, which is not much compared to a typical column of width 0.30 m of an HDB flat. The stacks could be placed at position 1(in between bedroom and toilet) or position 2 (in between two bedrooms). The booster fans/fan for the active stack could be powered by solar energy thus making the system more energy efficient as compared to the usage of air conditioners and rotating fans in the bed rooms.

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