# Sustainable Architecture and the Potential of Energy Conservation of Naturally Ventilated Office

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**Abstract**

The increasingly heavier dependence on air conditioning in office buildings is one of the key causes of climate change. This dependence increases our vulnerability to climate change, and reduces the ability to avoid the effects of global warming. The impact of air conditioning on electricity demand is a very significant issue in office buildings. The potentials of sustainable architecture through effective energy-saving design, and energy conservation such as efficient natural ventilation design. In order to encourage sustainable architecture the adoptions of energy-saving design strategies, the environmental design standards, the energy conservation standard and criteria, aiming to reduce the energy consumption in public buildings. Natural ventilation is an energy conservation method which may help reduce buildings energy consumption, improve the thermal comfort condition and maintain a healthy indoor environment. This paper applied physical measurement and questionnaire to determine the effect of sustainable architecture and the potential of energy conservation of naturally ventilation. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the sustainable architecture and the potential of energy conservation of naturally ventilation thus: F=65.555; p=.000. The result shows that natural ventilation can provide an acceptable indoor environmental condition without air conditioning. Recommendations were made for energy saving strategies to be applied both in the design phase of a building and when renovating existing buildings to achieve energy conservation.

**Keywords:** Climate Change, Energy Conservation, Global Warming, Natural Ventilation, and Sustainable Architecture.

## 1. INTRODUCTION

The buildings and the built environment play a major role in the natural environment. Sustainable architecture uses energy, land, water more efficiently, and produces less waste and pollution. However, the principles of sustainable building design, and how negative impacts of the buildings can be reduced or eliminated through more effective planning, design, construction, and operation is the primary benefits of sustainability in construction industry. Energy use is one of the most important environmental issues and managing its use is inevitable in any functional society. Buildings are the dominant energy consumers. Buildings consume energy and other resources at each stage of building project from design and construction through operation and final demolition (Schimschar et al., 2011). According to Lenzen and Treloar (2002), the kind and amount of energy use during the life cycle of a building material, right from the production process to handling of building materials after its end life can, for example, affect the flow of greenhouse gases (GHGs) to the atmosphere in different ways over different periods of time. Their consumption can be largely cut back through improving efficiency, which is an effective means to lessen greenhouse gas emissions and slow down depletion of non-renewable energy resources (Sasnauskaite et al., 2007). With this realization, increasing more attention is being paid to the improved energy conservation in building sector over the years, partly because the sector harbours a considerable potential of primary energy saving and reduction of emissions, having a negative impact on the environment (Dimoudi & Tompa, 2008). Energy use in a life cycle perspective includes energy needed for both operational and embodied energy. The operational energy requirements of a building can be considered as the energy that is used to maintain the environment inside that building (Dimoudi & Tompa, 2008). Thormark (2006), life cycle analysis of building shows that operational energy accounts for 85–95% of the total energy consumption and CO2 emissions of a building which comes from occupancy through heating, cooling, ventilation, and hot water use. This will include energy from electricity, gas, and the burning of fuels such as oil or coal. Use of sustainable architecture strategy such as natural ventilation, landscaping by vegetation, use of water bodies for evaporation and cooling, orientation of building, etc. can help achieve thermal and visual comfort inside the building, so that there is significant reduction in energy consumption by conventional air conditioning and artificial lightning in a building. Architects and Designers can achieve energy efficiency in buildings by studying the macro and micro climate of the site, applying solar-passive and bioclimatic design feature and taking advantage of the natural resources on site.

## 2. Literature Review

Natural ventilation can be defined as 'the movement of air through openings in a buildings fabric, due to wind or to static pressures created by the differences in temperature between the interior and exterior of the building (generally known as the
stack effect), or to a combination of these acting together' (CIBSE, 2005). Natural ventilation is subject to the variability of wind speed, wind direction, air temperature and opening configuration. Not only do these factors affect the rate of fresh air supply but also determine whether openings will act as an inlet or outlet for the air in any space within a building.

Natural ventilation can increase the heat convection between the human body and the ambient environment, so that it takes away the heat by evaporating perspiration. The average skin temperature is 32°C-34°C when people are doing light activity, and the physical evaporation rate is based on air velocity and vapour press. The increase of air velocity can speed up the evaporation rate; while the evaporation rate will be decreased merely under high vapour pressure. Providing a cooling effect by increasing air movement can be achieved as long as the air temperature is lower than skin temperature (Szokolay, 1987). Therefore, providing air movement is an important method to reduce cooling load and achieve comfort, especially in hot and humid climates, in which the evaporation is predominant (Nicol, 2004).

Aren et al (1980) indicated people's thermal sensation in the conditions of different air velocities. In his survey with the environmental condition at 50% relative humidity, 29°C indoor temperature and 1m/s air velocity, the occupants still feel comfortable when they are seated (1.3met) and wearing summer clothing (0.4clo). The comfort temperature can reach 30°C, when the air velocity rises to 2m/s. Szokolay (1985) also proposed the relationship between thermal factors and compensatory measures: the indoor air temperature would be increased by 0.6°C according to the increase of air flow by 0.005m/s, when the air velocity is above 0.15m/s. Bo (2005) found that when the temperature is above 26°C and the wind speed below 0.8m/s, thermal temperature will drop 0.55°C along with the air flow speed increasing to 0.15m/s. Givoni (1998) used a building bioclimatic chart (BBCC) to show the thermal comfort in both the developing and developed countries under the still air condition (less than 0.25m/s) and the little breeze condition (2m/s). He found that the upper temperature boundary is 3°C more in the little breeze condition. So it can be concluded that the rising of air velocity can extend people's comfort area.

Many studies proved increasing air movement is conducive for occupants to achieve comfort (Nicol et al, 1999). However, a high air flow speed indoors might cause some other problems, for example, paper might flap, which is not desirable, particularly in office buildings. EN ISO 7730 standard (1994) suggested that the air flow speed should not be over 1.5m/s in office buildings. According to Nicol and Humphreys (2010) field study, the average indoor air velocity cannot reach that higher speed in generic free-running office buildings. They pointed out that the measured indoor air velocity is from 0 to 2.1m/s and the average air speed is 0.09m/s in the SCATs (Smart Controls and Thermal Comfort) data, which was gathered from 26 European offices in France, Greece, Portugal, Sweden and the UK. In the field measurement, some subjects did use air movement to reduce the effect of high temperature, but in merely 38% of cases the air velocity is above 0.1m/s with the maximum at 0.17m/s, which means the air movement was minimal. A similar result can also be found by De Dear and Schiller (2001), that the measured average air flow speed in the building in the humid tropics climate was 0.22m/s, which was not as effective as the predicted result. Therefore, in many field studies in free-running buildings, fans are highly used by occupants to provide constant air movement so as to improve occupant thermal comfort (Sharma and Ali, 1986; Goto et al, 2007; Indraganti, 2013). In the field study in Pakistan, Nicol et al (1999) found that, when the average indoor air flow speed is about 0.45m/s with fans, the upper comfort temperature limit can increase by 2°C. In EN Standard 15251 (2007), it was suggested that in summer for those buildings without HVAC systems, the mechanical ventilation without conditioned air can be applied as a low energy method for occupants to control their environment.

**Natural ventilation strategy in office building**

Different indoor ventilation strategies will affect the indoor ventilation efficiency and air flow pattern. Three types of ventilation configuration were indicated by Baker and Steemers (2000): single-sided ventilation, cross ventilation and stack ventilation. In generic office buildings, single-sided and cross ventilation are widely used.

Single-sided ventilation is applied in a typical single room. The air enters and leaves at the same side of the room. The room can be efficiently ventilated if the depth of it is about twice than the floor height. The wind is the main driving force in summer and the thermal stack effect in winter to achieve minimum fresh air. Double opening is another form of single-sided ventilation. Due to the height difference of openings, the thermal buoyancy and wind pressure would cause the pressure difference between the two openings, and then encourage the stack effect. The double opening type will give ventilation depth for three times

floor to ceiling height (Baker and Steemers, 2000). This opening type is more efficient than the single opening. Compared with two other configurations, single-sided ventilation is the simplest and the most inexpensive but is low in efficiency.
Cross-ventilation is a relatively effective method. The ventilation openings are on both sides of the office. Air flows from one side of the opening to the other side. Wind pressure is the main driving force. The pressure difference between two opposite openings brings air flow across the entire room, and at the same time carries off the heat and pollutants from indoors. So the windward and leeward pressures are important elements for cross-ventilation. In addition, the open layout is recommended to have a maximum depth of space about four times than the height (floor to ceiling). But the indoor furnishing or partition may restrict the air flow and affect the ventilation efficiency (Baker and Steemers, 2000).
Stack ventilation is driven by the thermal buoyancy and the wind pressure. The fresh air enters the building at low level and the exhaustion at high level of the building, so the room is cross-ventilated. It is often used in buildings with a chimney or central atrium. The height of the outlet needs to be located at least half of one storage height above the top floor, in order to achieve the required air-flow rate without an enormous ventilation aperture (CIBSE AM10, 2005).

## 3. Research Methodology

The multi-purpose Air Flow Digital anemometer (AM-4812-2-2) was used to measures air velocity, air flow, and Data logger (HTC-1) air temperature & humidity. The system collected concurrent physical data: air temperature, air flow and air velocity. The instruments were placed at 0.6m, 0.9m, and 2.1m from the floor to record the thermal comfort variables simultaneously, as the subjects filled in the thermal comfort questionnaire. The measuring apparatus for field study and data documentation is shown in Table 1.

Table 1: measuring apparatus

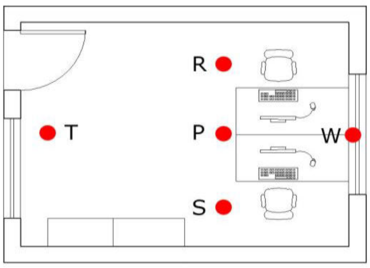
| Apparatus | Description |
|---|---|
|  | **Air Flow Digital anemometer (AM-4812-2-2):** velocity range is between 0.4m/s- 30m/s, 1.4km/h-108.0km/h, 0.8knots- 58.3knots with accuracy of ±2% +1d at 0°C-50°C and less than 90%RH. |
|  | **Data logger (HTC-1):** recording air temperature from -10°C to +50°C and relative humidity from 10% to 99%. The reading resolution for temperature and relative humidity are 0.1°C and 1%. |

## 4. Data Presentation and Analysis

The characterizations of the monitored buildings were based on the type of windows in the building which are casement and top-hanging windows. Understanding the characteristic of naturally ventilated office buildings can help to identify the natural ventilation type. The natural ventilation types in each office are also defined and the results of single-side ventilation and cross-ventilation type were compared. While the instruments recorded the surrounding environmental conditions, the researcher observed and kept track of the occupancy behavior or activities, such as the opening and closing of windows. The monitored office buildings are shown in Plate 1, Plate 2.

Plate 1: Delta State Secretariat (Morning) Plate 2: Delta State Secretariat (Afternoon)

The monitored office plan and section are shown in Figure 1 and Figure 2 respectively.



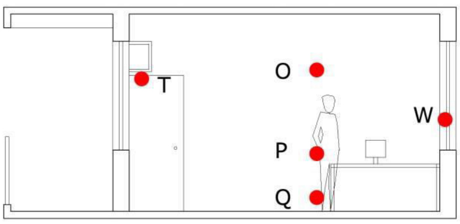
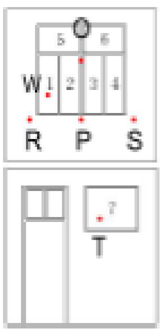




Figure 1: Plan of the office Figure 2: Section of the office

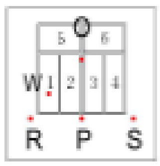
In office building (B), casement and top-hanging windows were used. Windows were separated into two parts; the two top-hanging windows were on the top and four casement windows were below them. On the corridor side there was a horizontal pivot window and a top light window which was not used. In offices B1 and B3, the author suggested using the window on the corridor side. The air flow speed measurement was taken in three offices in office building B (B1, B2 and B3). Table 1, shows the average indoor air flow speed at different points in offices B1, B2 and B3. The result showed that the indoor average air flow speed in office B2 was lower than that in offices B1 and B3. The reason was, the natural ventilation in office B2 was hybrid; when it was single-side ventilated, the indoor air flow speed was very low and it would influence the average values. In offices B1 and B3, which were cross-ventilated, it had better indoor air flow performance. When the door was closed, the opened pivot window could still make the office room cross-ventilated. But the top light window was never used. The average air flow speed on points P, R and S were very close, point O being the lowest. In office B1, point P had the highest air flow speed, and in office B3 the highest point was S. The difference may be caused by the frequency of occupants using different parts of the window.

Table 1: The average indoor air flow speed on different measurement points in offices B1 (CV), B2 (SSV/CV)) and B3 (CV) (point W was located at the opened window).

| | Windows in the office | Opening window/door | Point W | Point O | Point P | Point R | Point S | Point T Window | Point T Door |
|---|---|---|---|---|---|---|---|---|---|
| Office in Building B |  | 1,Door | 1 | 0.46 | 0.73 | 0.81 | 0.22 | 0 | 0.66 |
| | | 4,Door | 1 | 0.49 | 0.71 | 0.20 | 0.84 | 0 | 0.64 |
| | | 1,4,Door | 1 | 0.51 | 0.74 | 0.79 | 0.82 | 0 | 0.70 |
| | | 1,4,7,Door | 1 | 0.61 | 0.77 | 0.83 | 0.85 | 0.80 | 0.79 |
| | | 1,7 | 1 | 0.59 | 0.62 | 0.81 | 0.19 | 0.93 | 0 |
| | | 4,7 | 1 | 0.60 | 0.63 | 0.20 | 0.78 | 0.90 | 0 |
| | | 1,4,7 | 1 | 0.63 | 0.64 | 0.80 | 0.78 | 0.95 | 0 |

In office building B, except for the top light window, the top-hanging window on the south-facing window was not used as well. According to occupant use of window condition, only windows 1 and 4 were used. Detailed data are shown in Table 2.

Table 2: The proportion of measured internal air flow speed in office building B (point W was located at the opened window).

| Windows in the office | Office | Point W (m/s) | Point O (m/s) | Point P (m/s) | Point R (m/s) | Point S (m/s) |
|---|---|---|---|---|---|---|
|   | B1 | 1.10 | 0.53 | 0.87 | 0.80 | 0.74 |
| | B2 | 0.59 | 0.30 | 0.53 | 0.45 | 0.45 |
| | B3 | 1.12 | 0.54 | 0.76 | 0.82 | 0.85 |

When window 1 and the door were opened (Figure 3), the largest point was R; point P was slightly lower than point R. Point S was the lowest one. Therefore, open window 1 had more impact on points R and P, the air flow mainly passing through points R and P in the office. When window 4 and the door were opened, the situation was the opposite; point S had a larger average air flow speed than point P, while point R was the lowest. In these two conditions, at point O it was very similar. Open windows 1 and 4 had the same influence on indoor air flow at point O. Besides, the figure for point O was lower than point P, which just below point O; the incoming air flow in the office had more impact on the lower part of the room than the upper area.

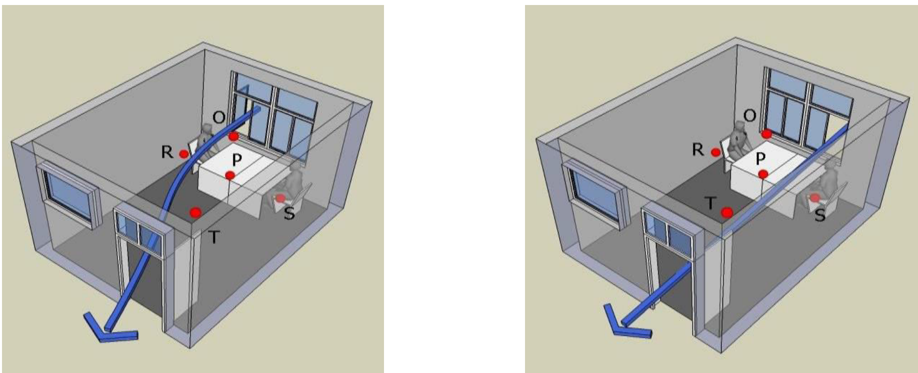
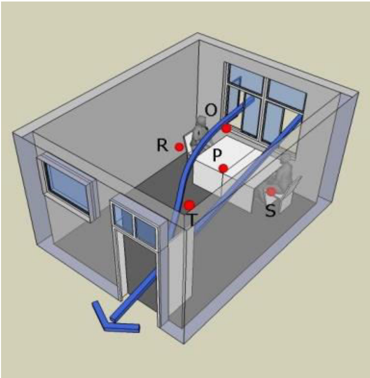



Figure 3: Possible air flow path in the office when window 1 and the door were opened (Left), and when window 4 and the door were opened (Right).

When windows 1 and 4 and the door were open together (Figure 4), the average air flow speed on points R and S were very close to each other, with the figures at 0.79 and 0.82. Point P was slightly lower than points R and S. Compared to the last two cases, the air flow speeds were very similar. In those situations, the air flow speed at point P was quite steady. When window 7 was open as well, it increased the indoor air flow speed to a certain extent; the air flow speed at each point had slightly increased. Point S had the largest air flow speed, which was 0.85, then point R (0.83), both points reaching their largest average air flow speed compared with other situations, as well as point P.



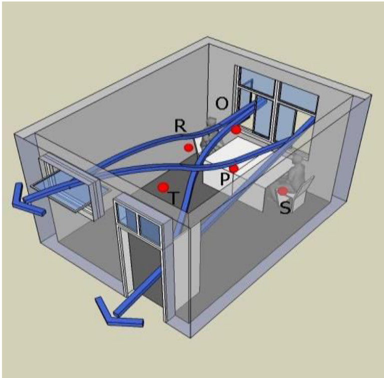




Figure 4: Possible air flow path in the office when windows 1 and 4 and the door were opened (Left), and when windows 1, 4, 7 and the door were opened (Right).

Point T (when the door was open) also had the highest air flow speed. The opened window 7 helped to increase the air flow speed on an opened door. It can be understood that when only window 1 or 4 was open, the lower air flow speed on the door side was related to a small opening area between indoor and outdoor which would limit the indoor air flow rate. When both windows 1 and 4 were opened, the air flow speed on an opened door should be higher than that when window 7 was opened, because extending the effective opening area would reduce the air flow speed when the volume flow rate was still. However, the measured result is the opposite. This may be because opening window 7 increased the effective opening areas on the partition wall and the air flow could pass through the office much easier; this could help raise the indoor air volume flow rate and air flow speed. Alternatively, if the air flow was coming from both directions, a stream of air flow would pass through the open door to the other side, and the air flow from the other side of the room would pass through window 7. Although the air flow speed at point O was larger than previous conditions, it was still the lowest air flow speed in the room. As the air flow speed increased at point P was related to open window 7, the air flow would pass through the upper part of the room.

When the door was closed, windows 1 and 7 were opened (Figure 5). The air flow speed on window 7 was close to window 1. In the office room, the largest air flow was at point R which was close to opening window 1, and in the middle of the air flow path. The air flow speed at points P and O were close, and point P was slightly higher than point O. The small air flow speed occurs at point S which was far away from a possible air flow path. When windows 4 and 7 were opened the situation was opposite at point R and S. At points P and O, the situation was the same as the previous one but the air flow speed was slightly higher; this may be because opening window 4 has more influence on points P and O. Window 7 was on the diagonally opposite side of window 4; the air flow would pass through the room diagonally.

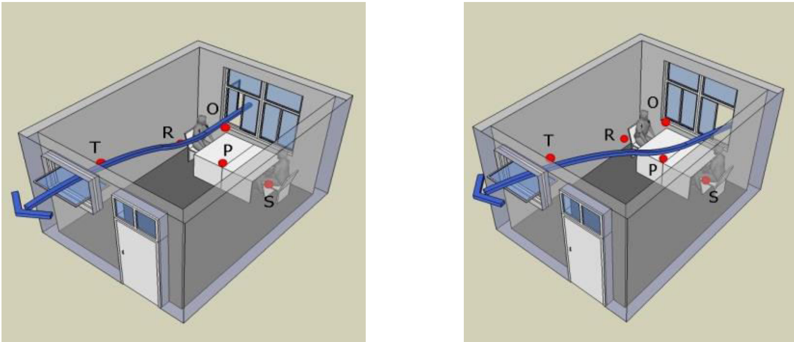



Figure 5: Possible air flow path in the office when windows 1 and 7 were opened (Left),
and when windows 4 and 7 were opened (Right).

When windows 1, 4 and 7 were opened, point R had the largest air flow speed, and then the second one was at point S. Points P and O were very close, compared to the previous situations when point O had the largest air flow speed. It can be found on Table 1 that, when window 7 was opened, the air flow speed at point O was larger than when the window was closed. Changing the opening position could influence the indoor air flow path and the air flow speed at different parts of the room. Opening window 7 raises the indoor air flow path and increases the air flow speed on the upper part of the room. Oppositely, the air flow speed at point P was reduced by closing the door and opening window 7. Because point P was lower than point O, opening window 7 would reduce the impact of air flow on the lower part of the office. Although points R, S and P were at the same height, changing opening height seemed to have a very limited effect on points R and S. The reason probably was that points R and S were close to the opening windows 1 and 4. To sum up, in office building B, only windows 1 and 4 were used by occupants on the window side. And points R and S were mainly influenced by those two windows. The air flow speed on points P and O were more related to window 7 and the door on the partition wall. Closing window 7 and opening the door could raise the air flow speed at point P and reduce the air flow speed at point O; if opening window 7 and closing the door, the situation is the opposite.

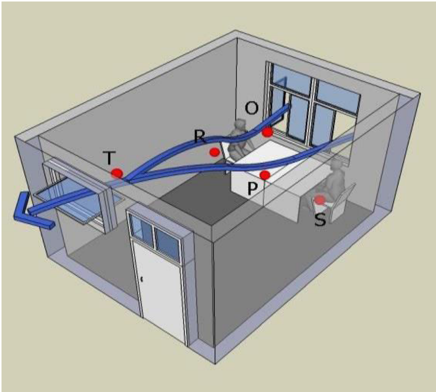



Figure 6: Possible air flow path in the office when windows 1, 4 and 7 were opened.

When window 7 and the door were both opened, the indoor measurement point could achieve its largest speed. Opening the door had more influence on points R, P and S. And air flow seemed to go downwards when it moved into the office. In the situation when window 7 and the door were both open, the air flow speed at point P was the largest and the air flow speed at point O was lower than when the door was closed and window 7 was opened. So, changing the location of the opening area can adjust indoor air flow patterns and air flow speed. Also, increasing the opening area on the partition wall and reducing the baffle in the office can raise the indoor air flow speed as well.

## 5. Discussion of results

According to measured results in the office, the indoor air temperatures varied in the comfort range in most of working hours. It seemed that the indoor conditions were acceptable. And in the cross-ventilated office, as the indoor air flow speed was positive, occupants used windows to control indoor air flow pattern and air flow speed which may improve their comfort perception. There were more opening options in the office; on the south-facing window, opening the lower part of the window could have more impact on the working area than the window on the higher part. Closing the door and opening the higher part of the window on the other side of the office could keep the air flow passing through the upper part of the office and just above the occupants when they were sitting near the table. When the door was open, it would pull the air flow downwards and influence the low part of the office. Only two windows were used on the south-facing window. By controlling the window on the corridor side and the door, it could adjust the indoor air flow patterns and speed. When the door was opened, it had more impact on air flow at the low part of the offices, and when opening the corridor side window the situation was the opposite. If both were opened, the air flow was inclined to move downwards. This may because the door‘s opening area was much larger than the window and less resistance. Perhaps, the door‘s discharge coefficient may larger than the window‘s, the air flow can path through the opening door much easier than window.

## 6. Conclusions

Natural ventilation is the process of replacing air in any space to provide high indoor quality without the use of mechanical means. Ventilation conditions inside a space have a direct influence on the health, comfort and well-being of the occupants. Natural ventilation has become an important strategy in sustainable architecture. It can be used to supply outside air, reduce odours and pollutants, and remove heat from spaces, people and mass. Designing for natural ventilation also has potential to reduce construction and operational costs associated with the purchase and use of mechanical equipment, and the increased productivity of building occupants due to improvements in the indoor environment and connection with the outdoors. The climate suitability, window orientation and operable windows are the key factors for natural ventilation.

Being able to open a window and to have contact with nature appears to be a key characteristic in sustainable building design. Therefore, the opening location, opening size and window types had great impact on indoor air flow patterns and the air flow speed on different parts of the office. According to different natural ventilation strategies and requirements of indoor air flow patterns, different windows should be selected to achieve the demand and help occupants to adapt to the indoor environment and adjust personal comfort. Thereby reducing the need for air-condition and conserving energy (electrical) requirement for mechanical ventilation system.

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