

Stratum Ventilation – A Solution to Meet Challenges to Contemporary Air Distribution



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The goal of decreasing carbon emission and increasing energy conservation is a continuous process. There is no single method for achieving this goal. Should we aim to increase the amount of equipment in order to offset the negative byproducts of our existing systems? In contrast, we can try to decrease the amount of equipment we use. As long as we satisfy the performance requirements, the result will be a decrease in economic and environmental costs. Only with ongoing research and development are we able to make progress towards the correct path. This paper looks at the field of HVAC with regards to the increasing pressure from climate change. It proposes the use of a new type of air distribution system: stratum ventilation, which takes advantage of the allowance for higher indoor air velocities to offset the elevated temperatures.

Keywords: ventilation, air distribution, air jets, stratum ventilation, thermal comfort.

Current Situation

With the looming presence of worldwide climate change (Pachauri 2007), there is constant pressure to make changes to improve the situation. As a result of numerous global conferences and discussions, there is an international consensus to reduce CO₂ emission. The EU has established policies to achieve nearly zero energy buildings by 2020 (Directive 2010/31/EU 2010). A byproduct of these types of buildings, however, is the extreme insulation and airtightness they are constructed with in order to withstand the harsh climates. The result is reduced indoor air quality and thermal comfort in the summer due to the restricted evacuation of heat gains. Therefore, the role of mechanical ventilation is increased in these buildings to compensate for the increase in sanitary and cooling requirements. Alternatively, minimizing the energy consumption used by air-conditioning systems would decrease the amount of CO₂ emission. With this in mind, while revising EN ISO 7730 (Olesen n.d.), Fountain and Aren's theory was used. The theory stated

that higher air speed was required to offset increased indoor temperature (Fountain and Arens 1993).

In East Asia, the governments of the various judiciaries have recently issued guidelines and made changes in setting the indoor air temperature during the summer:

- The Hong Kong Electrical and Mechanical Services Department (EMSD) established guidelines to set the room temperature of an air-conditioned space to 25.5°C in the summer months (Electrical and Mechanical Services Department (EMSD), Government of Hong Kong S.A.R. n.d.).
- The National Development and Reform Commission of the Chinese State Council established guidelines to set the indoor temperature to 26°C in the cooling season (National Development and Reform Commission (NDRC), The State Council of China n.d.).

- Room temperature in the “Presidential Office” in Taipei has been set to 27°C after Dr. Ma Ying-jeou’s inauguration in May 2008 (NOW news 2008).
- The Ministry of Knowledge and Economy of Korea recommends room temperatures ranging from 26°C to 28°C in summer (Ministry of Knowledge and Economy 2008).
- The Ministry of Environment (MoE) of the Japanese Cabinet has encouraged its citizens to set the temperature of offices to 28°C in summer months (Ministry of the Environment (MoE) 2005).

Although these guidelines are correct from a political and environmental point of view, they are not widely implemented for two reasons. Firstly, the setting of indoor temperature is guided by the thermal comfort of the occupants and not by government regulations. Secondly, even if the room temperature is set to 26°C, only a small percentage of energy savings is obtained using conventional air distribution with a non-reheat air treatment. If a reheat air treatment is applied, even more energy would be consumed. With this in mind, it would be ideal if thermal comfort was obtainable at elevated temperatures while also achieving notable energy savings.

Allowance for increased air velocity

Air velocity is one of the major factors influencing thermal comfort along with air temperature, relative humidity, mean radiant temperature, metabolic rate, and clothing insulation. One of the implications of ASHRAE 55-2004 was that the air velocity should not be perceived by the occupants ($v < 0.35$ m/s). The introduction of ASHRAE 55-2010 allowed for elevated air movement to broadly offset the need to cool the air in warm conditions (ASHRAE 2010). This recent change allows for new opportunities to manage increased room temperatures.

Identifying suitable air distribution systems for elevated temperatures

In order to take advantage of a higher air velocity allowance, a criterion must be established to identify suitable air distribution systems for elevated temperatures. These systems should operate with temperatures and air movements comparably higher but within the range defined by ASHRAE 55-2010. There should be horizontal airflow targeting the head, neck, and chest of the occupants from the frontal or lateral directions. This criterion was based on studies that for light activities, to remove metabolic heat from the brain,

cooling should be focused upon an area superficial to the carotid arteries and jugular vein (Williams and Chambers 1971, Brown and Williams 1982, Nunneley et al. 1982, Cohen et al. 1989, Nakamura et al. 2008). Studies also showed that occupants were less sensitive to air movement from the front (Mayer 1992) and sides (Toftum, Zhou and Melikov 1997). Using this criterion, an assessment was made to determine how conventional air distribution systems match up.

Mixing ventilation is the most common air distribution system. With its ceiling-mounted air inlets and outlets, horizontal air movement is not available. Mixing ventilation would have high fan energy consumption if the required air movement in the occupied zone is realized because of the distances between the diffusers and the occupants. It is also not applicable for heating due to the short circuiting of the warm airflows.

Displacement ventilation is thermally driven with air movement flowing upwards from the floor level. It generally provides higher air quality and better ventilation efficiency than mixing ventilation with the same airflow (Awbi 1991). Using horizontal air movement would be contradictory to the concept of displacement ventilation as it would disrupt the thermal plume around the occupants. Displacement ventilation also tends to cause overcooling of the lower zone, causing discomfort at the leg area of occupants (Wyon and Sandberg 1990). Similar to mixing ventilation, using displacement ventilation for heating would cause short circuiting of the airflow because the warm supply air is buoyant.

Using personalized/task ventilation would satisfy the established criterion. This type of air distribution supplies occupants with air from nozzles located nearby plus a background general air distribution. It uses nozzles near the occupants to distribute fresh air, providing horizontal air flow. It is very effective at providing adequate indoor air quality with good energy efficiency. However, it is often difficult and expensive to connect ducts and equip nozzles to various indoor spaces. It would also be difficult to manage in cases where the occupants require any sort of mobility and repositioning.

Stratum ventilation for small-medium rooms

The rationale behind stratum ventilation is that the indoor air quality and thermal comfort are unimportant beyond the occupied zone. In addition, the indoor air quality below the breathing zone is not important.

Stratum ventilation uses air inlets and outlets mounted on the wall(s) as shown in **Figures 1 and 2**. The air is supplied directly into the breathing zone, forming a young air layer as shown in **Figure 3**.

The occupants get the benefit of good IAQ by staying within the air supply streams and gaining more exposure to the fresh air. The age of air is younger and the CO₂ concentration is lower compared with conventional air distributions (Lin et al. 2012, Tian et al. 2010 and 2011). Unlike with mixing ventilation and displace-

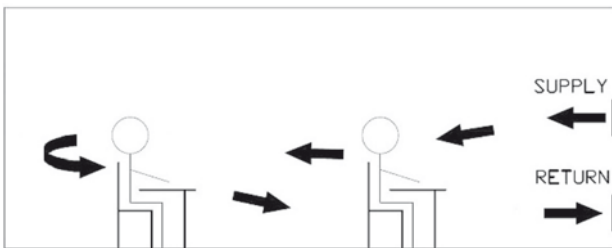


Fig 1. Conceptual design of stratum ventilation.



Fig 2. Application of stratum ventilation in a classroom.



Fig 3. Demonstration of the air supply stratum with smoke.

ment ventilation, the return air inlets mounted in the occupied zone allow for the possibility of heating, where the stratum effect is maintained.

This setup creates a modest, reverse temperature gradient (**Figure 4**) in the occupied zone, preventing the lower zone from being over-cooled. The thermal sensation of stratum ventilation was explored alongside mixing ventilation and displacement ventilation with an experimental study involving human subjects. The same subjects were subjected to varying room temperatures in a thermal sensation analysis. Using the thermal sensation votes, it was determined that mixing ventilation, displacement ventilation, and stratum ventilation had a neutral temperature of 24.6°C, 25.1°C, and 27.1°C respectively as shown in **Figure 5** (Fong et al. 2011).

This shows that stratum ventilation is more suitable at operating in elevated temperatures than conventional ventilation systems. A larger database comprising of the aforementioned data and data also for varying supply airflow rates and air diffuser types reveals that stratum ventilation can provide a uniform thermal environment (Cheng et al. 2014).

Energy savings with stratum ventilation

There are eight factors which contribute to the energy savings of stratum ventilation in comparison to conventional systems.

1. The neutral temperature of 27°C yields a higher humidity ratio for same relative humidity, lowering the latent load.
2. The higher neutral temperature means there is a smaller temperature difference between the indoor and outdoor space, resulting in smaller transmission loads.
3. The smaller enthalpy difference between the indoor air and outdoor air means there is a lower ventilation load.
4. There is a longer free cooling period because of the higher enthalpy of the indoor air.
5. The higher ventilation effectiveness means a lower ventilation load.
6. The reverse temperature gradient in the occupied zone means there is no over-cooling of the lower zone.
7. The elevated supply air temperature allows the associate chiller to have a higher evaporative temperature.
8. The lower cooling capacity permits the use of smaller pumps and fans.

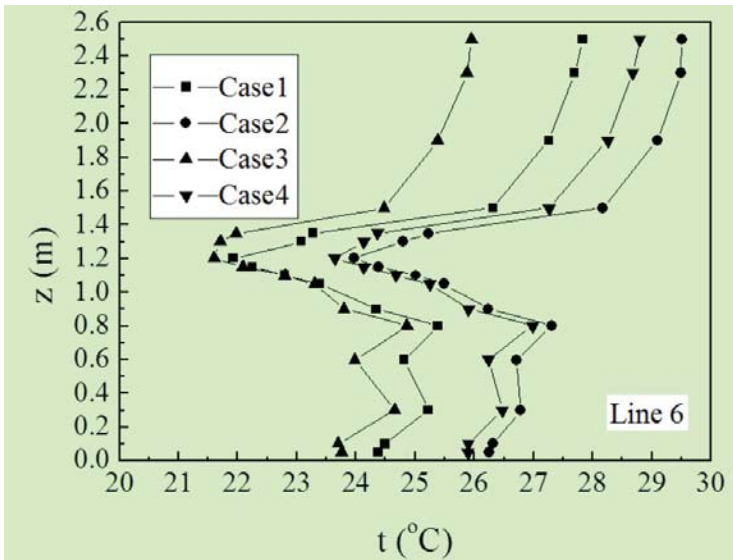


Fig 4. Vertical temperature profile of stratum ventilation.

A simulation of the year-round electric energy consumption of a typical office, a typical retail shop and a typical classroom in Hong Kong shows that stratum ventilation provides a significant amount of energy savings as seen in **Table 1** (Lin et al. 2011, Lee et al. 2013). The electrical energy consumption includes the entire air conditioning system, namely chiller and AHU (fans are inclusive), but excludes lighting, appliances in the rooms and other non-air-conditioning equipment in the rooms.

Overall, stratum ventilation is novel in that it is an innovative air distribution design concept while being old technology that requires only existing components, minimizing the risk of failure. The smaller capacity of stratum ventilation leads to smaller mechanical plants and ductwork, smaller air conditioning systems that take up less space, and substantially lower year-round

Table 1. Comparison of the year-round energy consumption between different ventilation systems.

Air distribution system	Electric energy consumption (kWh/netto-m ²)
Mixing	794
Displacement	592
Stratum	472
Energy savings	
Mixing to Displacement	25.40%
Displacement to Stratum	20.15%
Mixing to Stratum	40.43%

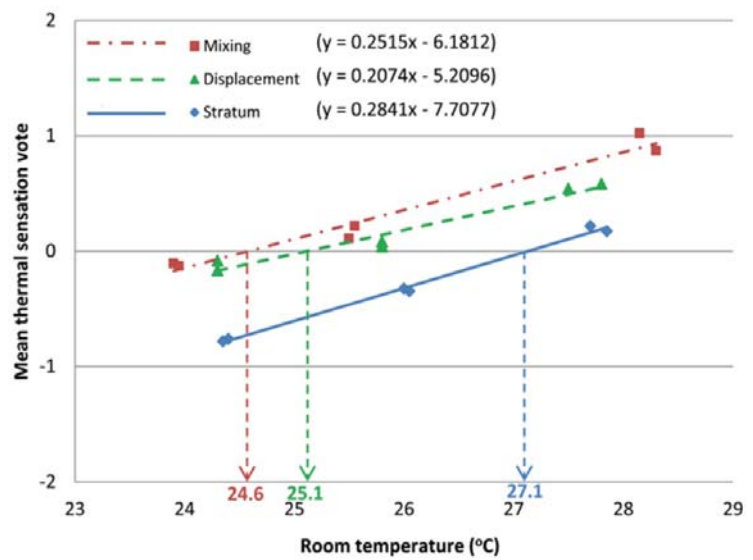


Fig 5. Thermal sensation votes of subjects.

energy consumption. These aspects yield lower initial costs, operational costs, and a smaller life-cycle carbon footprint.

Conclusion

With the presence of worldwide climate change and the corresponding governmental responses, improvements must be made upon conventional air distribution systems. With the introduction of ASHRAE 55-2010, there are new provisions for changes to conventional systems to meet the demands of elevated temperatures. Stratum ventilation has shown the potential to be a significant improvement upon conventional systems. Its use of increased air velocity allows for thermal comfort at temperatures 2.5°C higher while providing yearly energy savings of at least 20% over conventional systems. ■

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References

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