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Ventilation and Sound Attenuation Potential Of Double-Skin Façades in Urban High-Rises

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"The World Health Organization has suggested that environmental noise should not exceed 55 dB(A) and 40 dB(A) for daytime and nighttime, respectively, to prevent potential psychosocial effects."

Airtight building envelopes and the indiscriminate use of heating, ventilation, and air-conditioning (HVAC) systems have historically prevented high-rise occupants from considering natural ventilation strategies. Even as a number of studies have revealed that natural ventilation can contribute to proper indoor air quality by reducing concentrations of indoor air pollutants, acoustical discomfort due to urban traffic noise transmission has become a significant factor in degrading the acoustic quality in urban environments. Specifically, the objective of this study is to suggest appropriate double-skin façade (DSF) air-cavity volume ratios, modeled by varying the thickness of vertical glass fins and the depths of air cavities, with the objective of controlling noise transmission loss and efficient heat dissipation. The scenarios of this simulation study are based on the spatial volume ratio and depth of DSF air cavities, and it shows diverse changes in air temperature, air velocity, and sound transmission loss for the two requirements.

Introduction

The International Energy Agency states that the building sector in most member countries consumed approximately 40% of global energy. Airtight building envelopes have caused an increase in HVAC system energy demand, and indoor air quality (IAQ) has become a significant factor affecting the health of building occupants in urban environments. In the United States, HVAC systems account for 50% of building energy consumption (Pérez-Lombard et al. 2008), and HVAC systems are energy intensive systems comprised of large fans, ductwork systems, and air-conditioning and heating units (Khan et al. 2008). A well-developed natural ventilation strategy could be a cost-effective method for energy-efficient building design. However, urban traffic noise transmitted via ventilation windows deters building occupants from opening windows and justifies the use of mechanical ventilation systems (Nicol & Wilson 2004). Furthermore, increased urban traffic intensity as a consequence of accelerated urban population growth has become a major constraint that degrades the acoustical quality of urban environments. The World Health Organization (WHO) has warned that high external noise levels can contribute to numerous health problems such as sleep disturbances, high blood pressure, and psycho-physiological symptoms.

Transportation as the major source of urban noise

The United Nations reports that world urban population growth is expected to increase from about 3.8 to 6.3 billion people between 2014 and 2050, and Asian regions will be experiencing the highest increase of urban population growth, by about 60.5% from 2014 to 2050. Among Asian regions, the UN stated that South Korea is experiencing a higher urban population growth compared to other Asian countries. It indicates that 82% of the nation's population was urban as of 2014, which far surpasses the 37.5% average of the rest of the Asian region.

As a result of urbanization, the number of motor vehicles has gradually been increasing in cities, and transportation noise has became the major outdoor noise source, causing adverse health effects in urban environments (Muzet 2007, Berglund et al. 1999). The US Environmental Protection Agency estimated that 19.3 million people in the United States were exposed to a daily average sound level (Ldn) greater than 65 dB from highway traffic. In China, a survey showed that in cities with more than one

Kinds of effect	Symptoms
Physical effects	Noise-induced hearing loss, hearing impairment, threshold shift
Physiological effects	Startle and defense reaction, leading to potential increase of blood pressure
Interference with speech communications	Reduction in intelligibility of conversation, radio, music, television and others
Sleep disturbance	Difficulty in falling asleep, alterations in sleep rhythm, awakening
Psychological effects	Headaches, fatigue, irritability
Performance effects	Task performance, distraction, productivity
Annoyance	Feeling of displeasure; tolerances vary enormously; noise pulses more annoying than a steady noise

Table 1. The adverse health effects of noise.

Figure 1. Urban traffic intensity and airtight building envelopes in the Seoul metropolitan area. © Sanda

Type	Short-term	Long-term
Behavioral	Sleepiness, mood changes, nervousness	Depression, mania, violence
Cognitive	Impairment of function	Difficulty in learning new skills, short-term memory problems, difficulty with complex tasks
Others	Hypothermia, immune function impairment	Susceptibility to viral illness

Table 2. Consequences of sleep disturbances.

million people in population, 71.4% of the residents were exposed to noise levels above 70 dB(A) due to the accelerated growth in the number of motor vehicles. In Egypt, 73.8% of respondents in a survey complained of annoyance from road traffic noise (Ali & Tamura 2002).

Adverse health effects of noise

Environmental noise greater than the sound level of 55 dB(A) is regarded as a critical environmental problem in the European Union. Table 1 illustrates the adverse health effect of noise, and how symptoms such as physical, physiological effects and annoyance are highly related to Sound Pressure Level (SPL) in dB.

To quantify noise annoyance as subjective perception, a study regarding the relationship between SPL and noise annoyance was introduced (Kang 2007). The test group experiencing less than 55 dB(A) felt less annoyed; the test group exposed to noise between 55 dB(A) and 60 dB(A) was "somewhat" annoyed, and the test group exposed to greater than 65 dB(A) was "definitely" annoyed. It has also been discovered that nocturnal awakenings usually occur with noise levels greater than 55 dB(A) (Muzet 2007). Other studies have also demonstrated that children subjected to noisy environments have not only decreased attention spans, but also lowered task performance on cognitive assignments, compared to children in quiet environments (Hygge et al. 2003, Shield & Dockrell 2003). Ljung et al. (2009) discovered that traffic noise significantly diminishes reading and comprehension ability as well as basic mathematical performance in children. These psychological and physiological effects lead to decreased task productivity. Therefore, the WHO suggested that environmental noise should not exceed 55 dB(A) and 40 dB(A) for daytime and nighttime, respectively, to prevent potential psychosocial effects (WHO 2009). These effects of noise on the sleep process also contribute to the impairment of cognitive tasks and overall task productivity during the days following the disturbance, as seen in Table 2 (Stansfeld & Matheson 2003).

Seoul metropolitan area acoustical quality

According to the Korea Research Institute for Human Settlements (KRIHS), Seoul's population density is the highest among the largest cities of the Organization for Economic Cooperation and Development (OECD) countries (see Figure 1). The World Bank data also showed that the number of motor vehicles per 1,000 people in South Korea between 2000 and 2011 increased by 43.9%. Along with the rapid growth of urban population and urban traffic intensity in the Seoul metropolitan area, Lee et al. (2011) suggested well-being indices for the healthy environments of high-rise buildings in South Korea, and they prioritized indoor ventilation performance and acoustical satisfaction as being most highly related to physical and mental health, respectively.

According to the quantitative data collection performed as a preliminary study in the six selected sites of the Seoul metropolitan area, it was found that the traffic noise levels exceeded the threshold of the national traffic noise guidelines, which require lower than 65 dB(A) and 55 dB(A) for daytime (06:00–22:00) and nighttime (22:00–06:00) respectively, as seen in Figure 2. Noise levels during the daytime were higher than at night due to the number of moving vehicles.

Methodologies

Natural ventilation performance in buildings has been shown to be highly related to ventilation opening types. Increased wind velocity and complicated wind patterns due

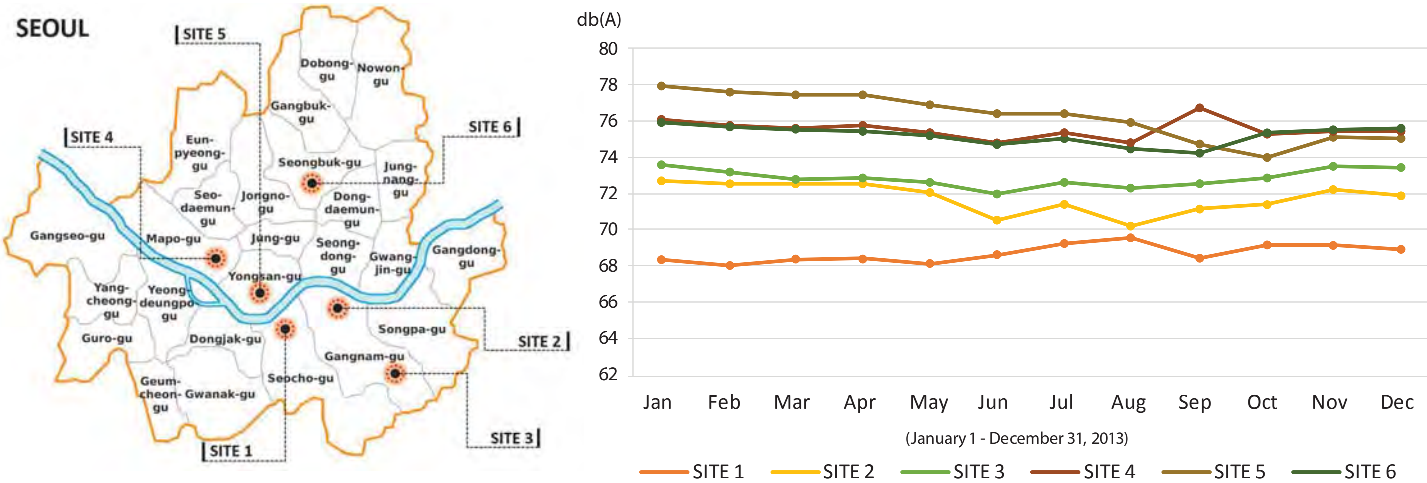


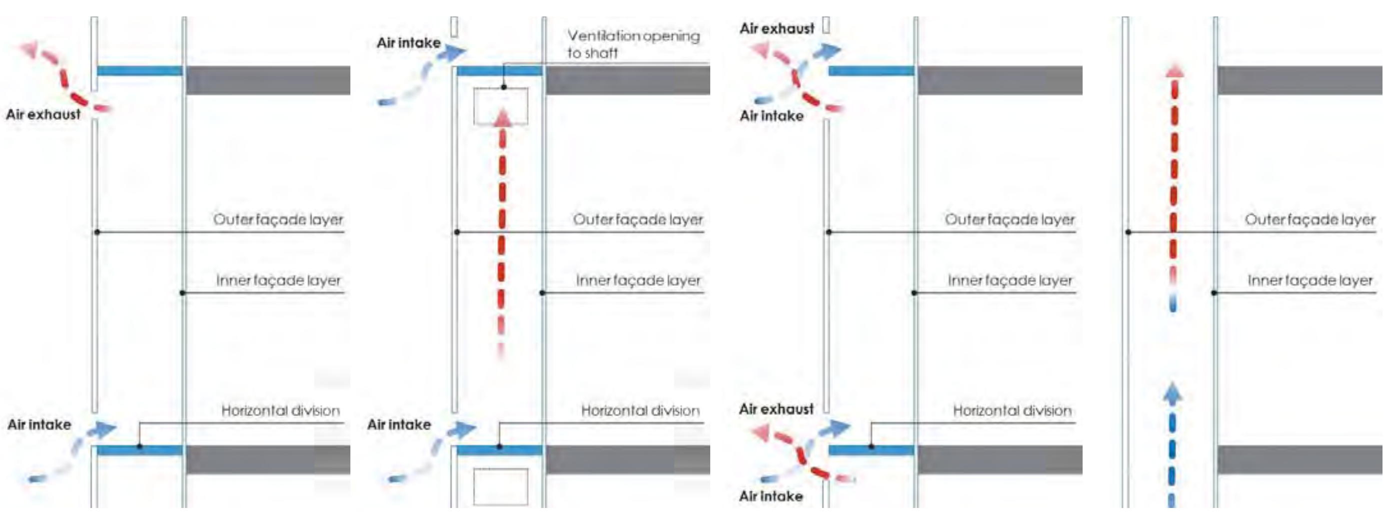
Figure 2. Annual A-weighted equivalent continuous sound levels at six locations in Seoul. Source: National Noise Information System of Korea (http://www.noiseinfo.or.kr/index.jsp).

to urban geometry may cause difficulty in utilizing natural ventilation strategies. Even though ventilation openings in single-skin façades (SSF), such as a standard curtain wall system with operable windows could be effective in improving ventilation rate, they have limitations in urban areas exposed to very high traffic noise levels. Therefore, hypothetically designed DSFs in this study are investigated for their potential to meet ventilation and acoustical performance goals. DSFs are composed of: (i) the air cavity between the two layers, creating microclimate conditions related to cooling and heating loads; and (ii) adjustable shading devices to protect indoor space from direct solar radiation. In addition (iii), DSFs make use of the air cavity as acoustic barriers, and (iv) their curtain wall glazing systems offer occupants expansive exterior views.

Figure 3 shows airflow patterns and noise transmission are highly related to the positions of ventilation openings and the vertical divisions of DSF air cavities. Especially noteworthy, noise transmission via ventilation openings travels horizontally and vertically from room to room. Therefore, this study aims at investigating the performance of glass vertical fins inside DSF air cavities as acoustical barriers and as ventilation aids.

Simulation analysis and limitations

The hypothetical DFS model in this case consists of box windows: DSF air cavities that have vertical shading devices and vertical glass fins inside. Ventilation grills are installed at the top and bottom of the façade. The total dimensions of the DSF air cavity are 16 meters in length, four meters in height, and one meter in depth (see Figure 4). Vertical glass fins inside a DSF air cavity are situated at the distances of four, five, six, and 10 meters to create the different spatial volumes



TYPE 1
- Commonly used in situations where there are high external nose levels
- Insulation is required between adjoining rooms.
- Continuous divisions help to avoid noise transmission
- Each box window requires its own air intake and extract openings

TYPE 2
- Vertical shafts are linked with the adjoining box windows
- Requires fewer openings in the external façade layer
- Effective in limiting external noise
- Height of the stack is limited
- Most suitable for lower-rise buildings

TYPE 3
- Air cavity between the two façade layers is closed at the level of each floor
- Horizontal divisions limit noise and fire transmission, and aid ventilation
- Special care is needed to limit noise transmission from room to room

TYPE 4
- Air cavity between two façade layers is adjoined vertically and horizontally by a number of rooms.
- Ventilation openings are positioned at the top and bottom of the overall façade
- Suitable where external noise levels are very high
- Attention should be paid to noise transmission within the intermediate space.

Figure 3. Airflow diagrams based on types of DSF air cavity design. Source: Oesterle et al., 2001.

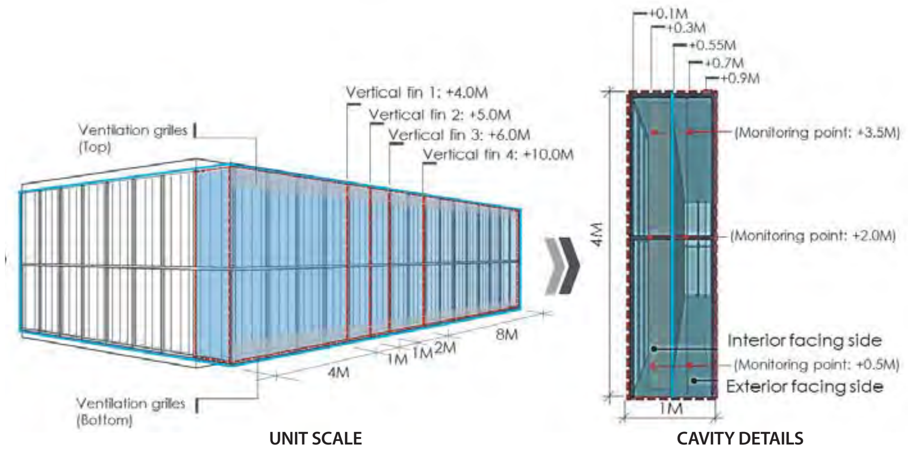


Figure 4. Unit scale and air cavity details for CFD simulation.

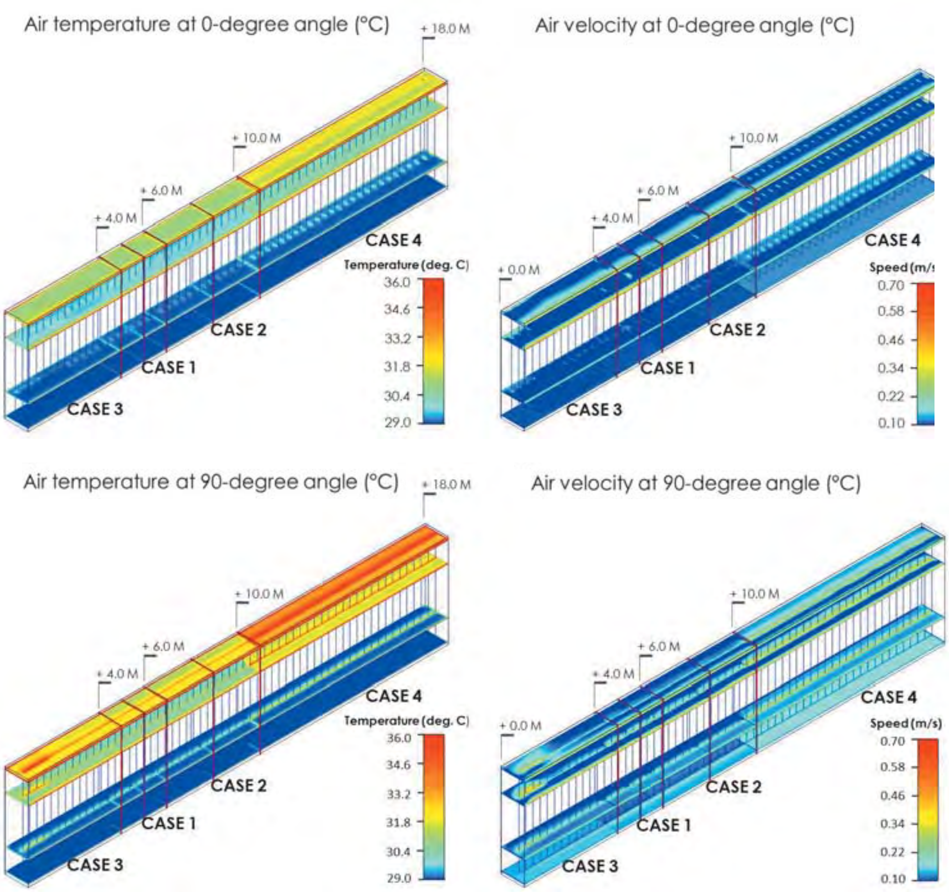


Figure 5. Air temperature and air velocity at 0- and 90-degree angles.

of DSF air cavities as seen in Figure 4. Monitoring points to measure air temperature and air velocity are designed at the height of 0.5 (P1), 2.0 (P2), and 3.5 meters (P3) inside a DSF air cavity. To examine the air temperature distribution of a DSF air cavity, Computational Fluid Dynamic (CFD) monitoring points are positioned at the distances of 0.1, 0.3, 0.55, 0.7, and 0.9 meters (see Figure 5).

The aim of the different cases (see Table 3) is to observe the changes of air temperature by changing air cavity volume ratios and sound transmission loss by changing air cavity depth and glass fin thickness. DSFs have the disadvantage of overheating inside the air cavity and transmitting noise via ventilation grills during the summer period. The CFD simulation software Mentor Graphics FloVENT 9.3 was used to simulate air temperature and air velocity inside a DSF air cavity based on CFD simulation model boundary conditions, as shown in Table 4. Due to the limitations of the acoustic simulation software for DSF, sound transmission loss was simulated by the acoustic software SoundFlow, based on the depth of the DSF air cavity and the thickness of the vertical glass fins. In the acoustic simulation study, urban geometry, building heights, surrounding buildings, and actual traffic sound sources were not considered.

Results and Discussion

Air temperature and air velocity

Compared to other cases, higher air temperatures were observed in Case 4, with 90-degree angled shading device slats parallel to the glazing. Besides, the thermal performance by heat dissipation inside a DSF air cavity was better in Case 1 and Case 2,

Classification		Cases			
FloVENT 9.3 (Air temp, air velocity)	DSF air cavity volume ratio length : depth	CASE 1	CASE 2	CASE 3	CASE 4
		1:1	2:1	4:1	8:1
SoundFlow (Sound transmission loss)	DSF air cavity depth (mm)	CASE 5	CASE 6	CASE 7	CASE 8
		250	500	750	1000
	Glass fin thickness (mm)	CASE 9	CASE 10	CASE 11	CASE 12
		5	10	15	20

Table 3. CFD and acoustic simulation cases.

Classification	Parameters (unit)	FloVENT 9.3	SoundFlow
Ambient outdoor conditions	Air temperature (°C, °F)	29 (84)	29 (84)
	Relative humidity (%)	50	50
Size and materials	External glazing thickness (mm)	10	10
	Internal glazing thickness (mm)	10	10
	DSF air cavity depth (mm)	1,000	See Table 3
	Glass fin thickness (mm)	10	See Table 3

Table 4. CFD and acoustic simulation model boundary conditions.

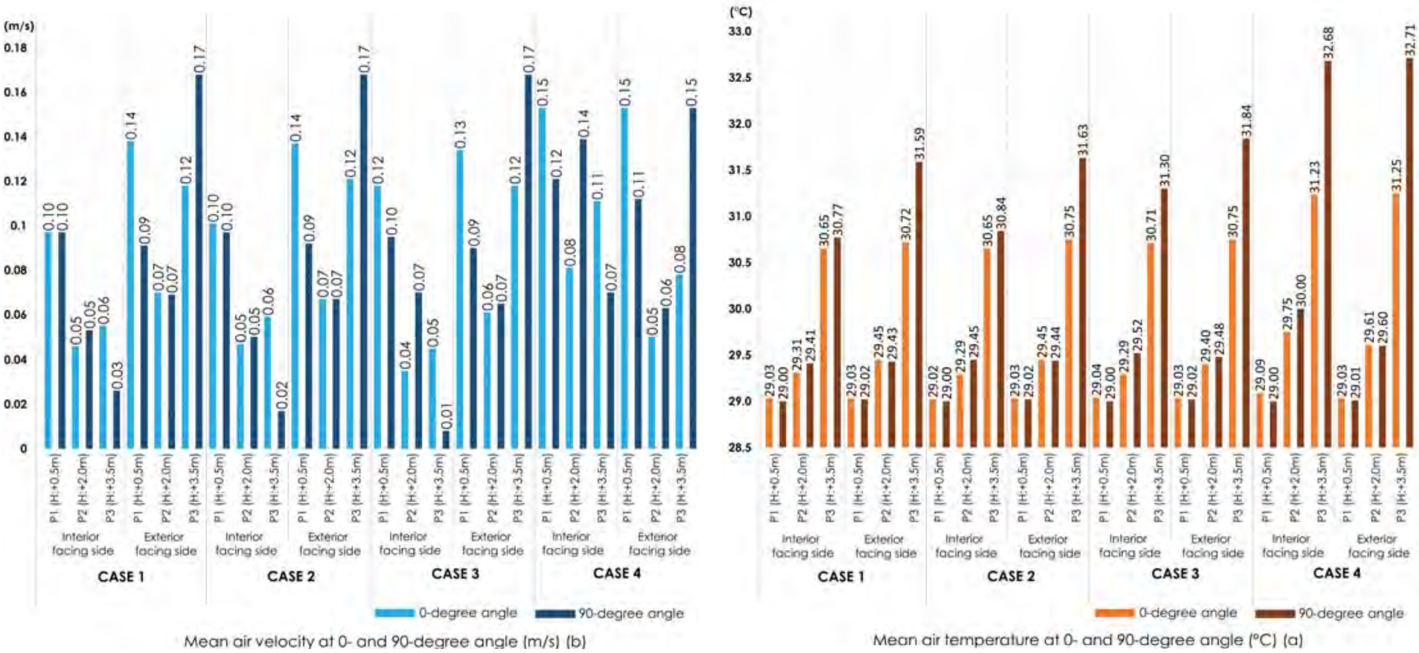


Figure 6. Mean air temperature and mean air velocity at 0- and 90-degree angle.

when shading device slats are oriented at a 0-degree angle perpendicular to glazing, than in Case 4. It was discovered that Case 4 has a higher potential of overheating inside a DSF air cavity during the summer period.

Figure 5 also shows that higher air temperature was discovered in Case 4, when shading device slats were oriented at a 90-degree angle (parallel to glazing). The recommended ratio of length to depth of a DSF air cavity for efficient heat dissipation by the stack effect during summer period is recommended as one meter in length to one meter in depth for Case 1, when the shading device slats are perpendicular to glazing; and two meters in length to one meter in depth for Case 2. For Case 4, the recommended ratio is eight meter's length to one meter's depth.

In the case of the 0-degree angled shading device slats, the mean air temperature of Case 4 at the highest monitoring points P3 (H: +3.5 meters) in air cavities, was greater by 0.5 to 0.9ºC than that of other cases (see Figures 6). Comparing the mean air temperature between 0- (perpendicular to glazing) and 90-degree (parallel to glazing) angled shading device slats at the highest monitoring point P3 (H: +3.5 meters) in air cavities, cases with 90-degree angled shading device slats recorded higher air temperatures by 1.1 to 1.5ºC than that of cases with 0-degree angled shading device slats.

The mean air velocity of the 90-degree angled shading device slats at the lowest monitoring point P1 (H: +0.5 meters) in air cavities was higher in both the interior- and exterior-facing side's air cavities. The highest mean air velocity of the 0-degree angled shading device slats at the highest monitoring point, P3 (H: +3.5 meters) was observed in the exterior-facing side's air cavities. Case 4 (with the highest length-to-depth ratio) is indicative of the potential of an overheating problem inside a DSF air cavity during the summer period – a key disadvantage of DSFs, especially those which, in a high-rise condition, would be tall and flush to the perimeter of a building.

Sound transmission loss (STL) and sound transmission class (STC)

Due to the limitations in representing shading-device orientations in acoustics simulation software, SoundFlow was simply used to simulate STL values based on DSF air cavity depth and glass fin thickness. SoundFlow is an acoustic software for calculating the absorption, reflection, and transmission of sound by multi-layered structures. STL is a single-number rating for interior building partitions that represents noise from speech, television, radio, and office equipment over the frequency range of 125 Hz to 4000 Hz. The STC of a panel is the STL value at 500 Hz on the STC contour, which consists of the three straight-line parts with different scopes over the frequency range of 125 Hz to 4000 Hz. Higher values in STL or STC indicate better acoustic performance against noise transmission. However, STC has limited capability to measure indoor noise situations beyond the upper frequency range (such as traffic noise), to which STC is not fully applicable. Also, Transmission Loss (TL) panel ratings do not necessarily equate to STC values. Table 5 shows subjective perception measurement based on STC values.

From the initial simulation results of the acoustic properties of the DSF assembly (see Figure 7), it was found that Case 7 (air cavity spacing = 750 mm) showed higher STC values than Case 8 (air cavity spacing = 1,000 mm) because the TL value at 500 Hz on the STC contour of Case 8 was lower than that of Case 7. Increased air-cavity depth showed better effectiveness in sound transmission loss across the entire frequency range. In Cases 7 and 8, sound transmission loss in a low frequency range showed lower values compared to other cases designed with narrower air cavity depth.

STC	Subjective description
30	Most sentences clearly understood
40	Speech can be heard with some effort. Individual words and occasional phrases heard.
50	Loud speech can be heard with some effort. Music easily heard.
60	Loud speech essentially inaudible. Music heard faintly; bass not disturbing.
70	Loud music heard faintly, which could be a problem if the adjoining space is highly sensitive to sound intrusion, such as recording studio or concert hall.
75 & above	Most noises effectively blocked

Table 5. Subjective perception of STC values.

Conclusions

Differing spatial configurations of DSF air cavities, achieved by varying the vertical glass fin and air cavity depth, affected air temperature, air velocity, and sound transmission loss inside the air cavity. It was found that air temperature in Case 4, with an 8:1 length-to-depth ratio in its DSF air cavity, showed higher potential of overheating problems during summer periods. It also means that Case 4 has higher potential cooling energy loads and thermal discomfort. Case 1 and Case 2 showed relatively lower mean air temperatures inside DSF air cavities through proper heat dissipation by the stack effect. With respect to sound transmission, Case 7 (air cavity spacing = 750 mm) obtained higher STC values than other cases (Cases 5 to 8) designed with different air-cavity depth. And Case 12 (glass fin thickness = 20 mm) achieved higher STC values when compared to other cases (Cases 9 to 11) designed with thinner glass fins.

“Overheating is a key disadvantage of double-skin façades, especially those which, in a high-rise condition, would be tall and flush to the perimeter of a building.”

Therefore, CFD simulation results imply that box-windowed DSF air cavities with 1:1 or 2:1 (length to depth) ratios are appropriate for achieving efficient natural ventilation through the stack effect during the summer period. Acoustic simulation results show that DSF air cavity depths with 750 mm and thicker glass fins achieve higher STC values, thus having the potential to decrease noise transmission to indoor spaces via ventilation openings in urban areas with high traffic noise levels. ■

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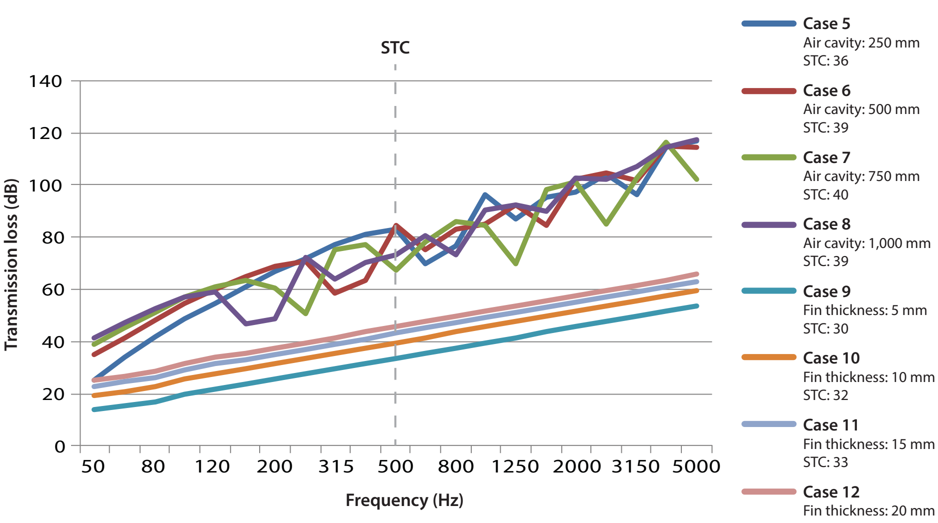

Figure 7. STC and STL by DSF air cavity depth and glass fin thickness.