Article

Acoustical Perceptions of Building Occupants on Indoor Environmental Quality in Naturally-Ventilated Building Façades

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ABSTRACT

Accelerated growth of urban population and motor vehicles has resulted in constant exposure to urban traffic noise that is one of the significant environmental stressors in urban environments. The aim of this research as a preliminary study is to evaluate acoustical perceptions of building occupants on their dwelling satisfaction with outdoor traffic noise through naturally-ventilated glazed building façades in the Seoul metropolitan area. This area has the highest population density among the largest countries of Organization for Economic Co-operation and Development (OECD). First, quantitative data of the A-weighted equivalent continuous sound levels (L_{Aeq}) at six sites in the Seoul metropolitan area were analyzed, showing that L_{Aeq} exceeded the thresholds of noise level standards, 65 dB(A) for day-time (06:00 AM to 10:00 PM) and 55 dB(A) for night-time (10:00 PM to 06:00 AM) respectively. Second, a questionnaire survey was conducted to find the environmental impacts of urban noise transmission on building occupants' comfort and their ventilation behaviors. It showed that approximately 87% of building occupants (n = 92) used mechanical ventilation systems rather than window ventilation methods. Eighty-two percent of participants have experienced sick building syndrome (SBS)-related symptoms such as skin irritations or coughs. Thirty-three percent of the respondents were deterred from opening windows for natural ventilation due to outdoor traffic noise transmission, and 49% of respondents complained mostly of poor task productivity. The survey outcomes propose the importance of acoustically-treated ventilation openings in naturally-ventilated glazed building façades for building occupants' indoor environmental quality in high-noise urban areas.

KEYWORDS: noise reduction; natural ventilation; acoustical comfort; naturally-ventilated building

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INTRODUCTION

According to the world urbanization prospect released by the United Nations, 55% of the world's population lives in urban areas, a proportion that is expected to increase to 68% by 2050. Among Asian regions, South Korea is experiencing a higher urban population growth compared to other Asian countries [1]. The proportion of urban population in South Korea in 2018 accounts for about 82% of its total population, surpassing by 37.5% other Asian regions and global trends. The estimated urban population growth rate in South Korea will reach about 88% in 2050 [1]. Along with rapid urbanization, the World Band Data [2] also shows that the number of motor vehicles per 1000 people in South Korea between 2000 and 2011 continually increased by about 43.9%.

The average daily traffic (ADT) represents the average number of vehicles passing on a two-way road at a specific point during 24 hours. According to the ADT data between 1998 and 2012, the volume of ADT during the intermediate seasons, such as spring and fall, was higher than that during summer and winter. The data also shows that the degree of ADT on local road traffic for day-time (06:00 AM to 07:00 PM) is higher than for night-time (07:00 PM to 06:00 AM). This study on urban traffic noise propagation in the Seoul metropolitan area states that the equivalent sound levels (L_{eq}) for day-time and night-time are higher in spring than in winter. The value of the Traffic Noise Index (TNI) is also higher during fall than winter [3]. This study indicates that the large volume of ADT and the high value of the TNI are related to natural ventilation availability in cases where building occupants prefer window ventilation methods to improve their indoor air quality during the intermediate seasons. It potentially shows that building occupants in workplaces are vulnerable to urban traffic noise transmission during their working hours (07:00 AM to 6:00 PM) when the values of ADT are high.

The European Environmental Agency (EEA) projects that the number of people exposed to high noise levels from roads, railways, and aircraft noise sources will increase from 2020 to 2030 [4]. The World Health Organization (WHO) also reports that traffic-related noise had become the most significant environmental stressor that adversely affects human health related to high blood pressure, impairment of cognitive tasks, sleep disturbance, and noise annoyance as shown in Table 1 [5–8]. Therefore, the WHO strongly recommends reducing noise levels produced by road traffic below 53 dB (L_{den}) during day-time and 45 dB (L_{night}) during night-time that are associated with adverse health effects of noise [9]. However, urban traffic noise transmission through naturally-ventilated building façades conflicts with natural ventilation performance.

Table 1. Adverse health effect of traffic noise [4,9].

Kinds of effect	Symptoms
Physical effects	Noise-induced hearing loss, hearing impairment, threshold shift
Physiological effects	Startle and defense reaction leading to a potential increase of blood pressure
Sensory effects	Aural pain, ear discomfort, tinnitus
Interference with speech communications	Reduction in the intelligibility of conversation, radio, music, television, and others
Sleep disturbance	Difficulty in falling asleep, alterations in sleep rhythm, awakening

Natural ventilation is a widely-used passive technique for improving indoor air quality, building energy-savings, and building occupants' health and comfort because a lack of ventilation rate can cause excessive humidity, overheating, and concentration of indoor pollutants [10]. A number of studies demonstrate that naturally-ventilated buildings have several advantages in reducing sick building syndrome-related symptoms such as headaches, dizziness, nausea, eye, nose or throat irritation and dry cough [11–15]. The environmental benefits from natural ventilation performance, operable windows, louvers, vents, stack ducts, wind catchers, and double skin façades have been studied based on the fundamentals of wind-driven single-sided ventilation, wind-driven cross-ventilation, buoyancy-driven stack ventilation, and combined wind- and buoyancy-driven ventilation [16].

A study on the physical and psychological health of building occupants in super tall residential buildings of South Korea indicates that indoor ventilation performance and acoustical comfort are regarded as the most critical factors, followed by other environmental requirements such as daylight, views, and indoor temperature and humidity [17]. As for naturally-ventilated building façades for natural ventilation improvement, several operable window types were investigated from a survey of 114 high-rise buildings in South Korea, as shown in Figure 1. A simulation study states that pull-down and casement-in windows improved natural ventilation performance more than project-out windows. This study concludes that window opening direction for wind-induced natural ventilation is more effective than window opening size [18]. This study places the attention how operable windows with potentially poor acoustic sound insulation can improve natural ventilation performance and noise transmission loss by acoustically-treated ventilation openings.

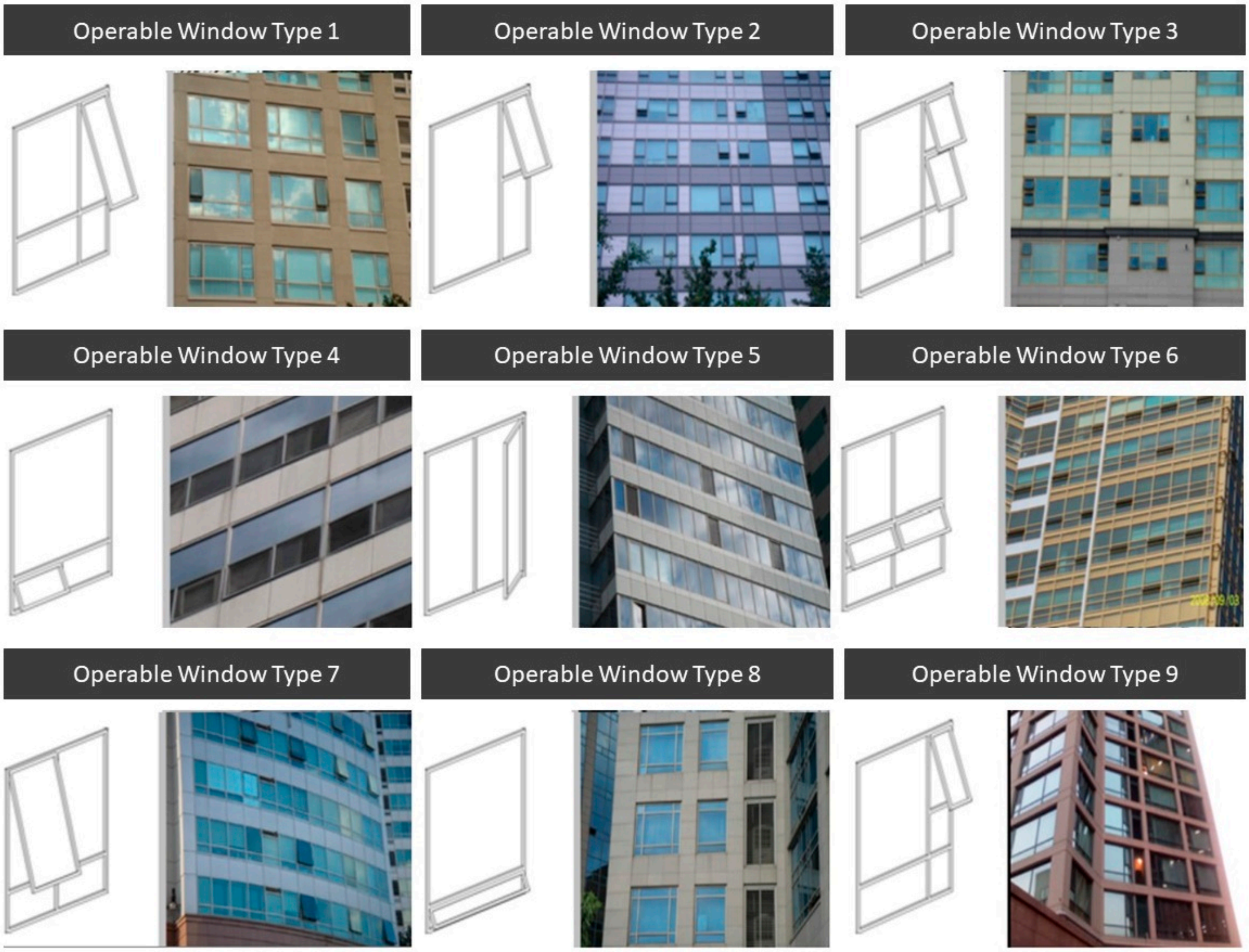

Figure 1. Operable window types of glazed building façades, South Korea [17].

For noise transmission loss through ventilation openings of high glazed building façades, airtightness of windows is a significant factor for improving acoustical insulation performance for glazed building façades. Single-paned windows improve the sound insulation performance of 2 to 4 dB, and dual-paned windows achieved sound insulation performance of 10 dB or more [19]. As ventilation opening types work with noise transmission loss, plenum window cavities, compared to conventional side-hung casement windows, significantly affect low-frequency sound transmission with the acoustical insertion loss of 7 to 9 dB [20]. Transparent micro-perforated absorbers (MPA) in a window baffle configuration and materials achieve 29 to 33 dB allowing daylight and window ventilation [21,22]. Adding micro-perforated absorbers (MPA) to the double-glazed air cavity make a sound reduction index (SRI) of 20 dB in the frequencies above 250 Hz. Its value is 10 dB higher than the case without MPA and 15 dB higher than the case with single open glazing [23].

Poor indoor environmental quality caused by a lack of the ventilation rate and traffic noise transmission in naturally-ventilated glazed façades is highly related to the building occupants health, comfort, and productivity. This study aims to understand acoustical perceptions of building occupants on outdoor traffic noise transmission in terms of their indoor air quality and acoustic quality. The findings of the research are expected to propose the importance of natural ventilation-enabling noise control devices in naturally-ventilated glazed building façades in the Seoul metropolitan area.

RESEARCH METHOD

Research Frame

The research frame employed both quantitative data collection and statistical data analysis to understand the environmental impact of urban traffic noise transmission on building occupants' ventilation behaviors in the Seoul metropolitan area. As the primary descriptor on existing indoor acoustic quality, the annual data of A-weighted equivalent continuous sound levels (L_{Aeq}) at the six sites were analyzed. In addition, a questionnaire survey was carried out to find the relationship between numerically-measured sound levels in dB(A) and acoustical perceptions of building occupants on their dwelling satisfaction.

Sites

Figure 2 shows the urban characteristics of each site including the number of traffic lanes, the width of a sidewalk, building heights, and window opening types. Sites 1 and 2 are mostly comprised of low-rise buildings (2 to 6-story buildings) adjacent to 3 traffic lanes. Site 3 is located in mid- and high-rise buildings (higher than 20 stories) with 5 traffic lanes. Sites 4, 5, and 6 consists of mixed low- and mid-rise buildings next to 3 to 4 traffic lanes. Ventilation windows (e.g., slider and/or awning) of building façades face traffic noise sources such as motor vehicles, buses, taxes, motorcycles, and pedestrians. Red circles and arrows represent the location of each sound meter and the primary direction of motor vehicles.

As for the scope of a survey, physical weather data, such as outdoor temperature, relative humidity, wind velocity, primary wind direction and geographical considerations, including urban density, traffic volume per hour, motor vehicle speed (km per hour), the volume of pedestrians, the number of traffic lights, and road surface conditions were not considered. The survey aims to mainly understand the effect of L_{Aeq} related to acoustical perceptions of building occupants on the existing indoor environmental quality.

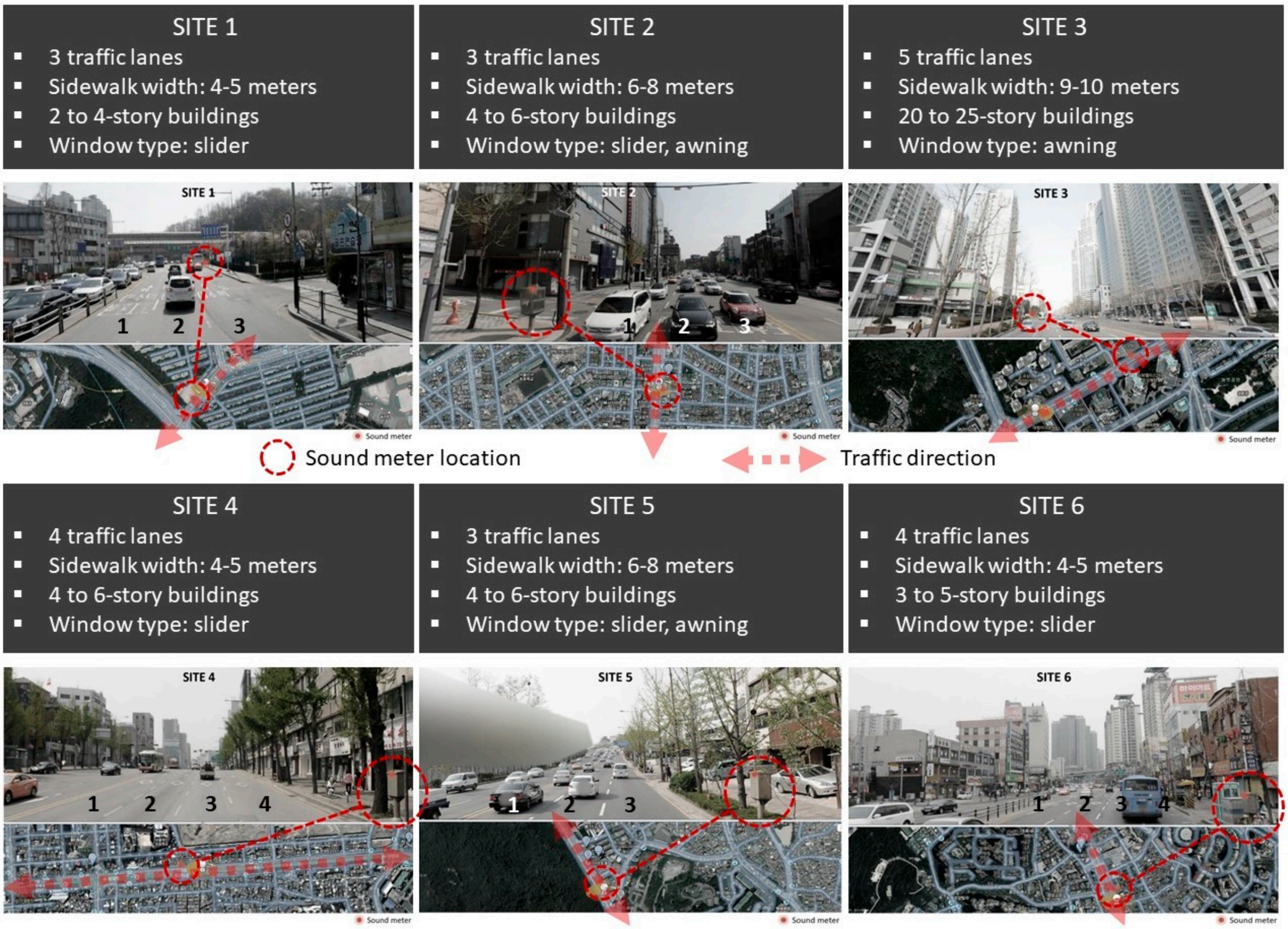

Figure 2. Urban characteristics of each site.

Data Collection

The purpose of the quantitative data collection is that L_{Aeq} is one of several significant parameters, defining the degree of noise annoyance. The study quantified the degree of noise annoyance based on sound pressure levels (SPL) in dB, showing that two variables are proportional [11]. National Noise Information System of Korea (NNISK) monitors the omnidirectional sound meters to collect the real-time data of L_{Aeq} measured at 4 meters high from the ground level without any obstacles, as shown in Figure 3. The collected real-time data of L_{Aeq} are transmitted to the main control center on a regular time cycle. The Ministry of Environment and other national environmental institutes utilize these data for environmental policymaking for the Seoul metropolitan area.

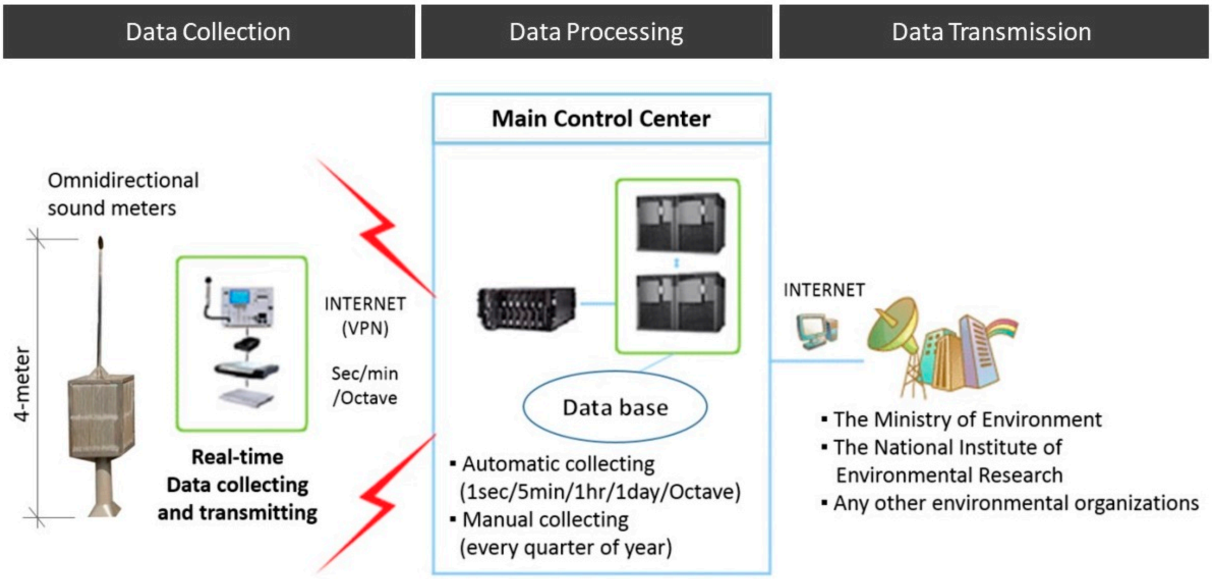

Figure 3. The flow of data collection, processing, and transmission of L_{Aeq} (Source: NNISK).

The questionnaire was conducted with 92 building residents in naturally-ventilated glazed buildings for 30 days from July 1 through July 30, 2014 concerning their indoor air quality and acoustic quality. The survey respondents are building occupants adjacent to traffic noise sources including taxis, buses, motorbikes and so forth. The average distance between the buildings and traffic noise sources is about 5 to 10 meters depending on the width of a sidewalk.

Table 2 describes the list of 12 survey questions regarding the current building ventilation systems (e.g., mechanical or natural), the preference for passive ventilation (e.g., window ventilation) or active ventilation (e.g., fan-driven ventilation), reasons for natural ventilation preference, environmental obstacles to window ventilation, negative impacts of noise transmission via ventilation windows, and the daily hours affected by high traffic noise transmission to buildings.

Statistical Analysis Procedure

Descriptive statistics on acoustical perceptions of building occupants on their existing indoor environmental quality were computed for scale frequencies and response percentages. Then, the demographic data were analyzed descriptively by computing frequencies and percentages. The questionnaire was developed through the following several steps:

- Attention to environmental conflicts between indoor air quality and acoustic quality was placed based on dwelling satisfaction of building occupants in high-rise buildings in South Korea [17].
- Operable windows with poor acoustic insulation of building façades are related to high urban noise transmission [18].
- A list of 12 survey questions was asked to building occupants adjacent to urban traffic noise sources that exceed the threshold of the noise

level standards that are required to be lower than 65 dB(A) and 55 dB(A) each for day-time and night-time [24].

- The respondents were voluntary in the survey, maintaining the privacy and confidentiality of all the data.
- The percentage of responses for each question was measured on the 5-point Likert-type scale and closed questions (e.g., yes or no, single choice, multiple choice, and single word) with the help of an IBM SPSS® Statistical Package.

Table 2. Questionnaire questions and possible answers.

Q.1. Which ventilation methods are frequently used in your building?
A.1. □ Mechanical ventilation □ Natural ventilation

Q.2. Have you ever experienced any temporary illness such as sensory irritation of eyes, nose, throat and skin irritation, when you were exposed to mechanical ventilation?
A.2. □ Never □ Seldom □ Sometimes □ Often □ Always

Q.3. How much do you agree that natural ventilation (e.g., window ventilation) is more effective in indoor air quality and energy-savings?
A.3. □ Strongly agree □ Agree □ Neutral □ Disagree □ Strongly disagree

Q.4. If you prefer natural ventilation (e.g., window ventilation) to mechanical ventilation (e.g., fan-driven), what are the main reasons NOT to choose mechanical ventilation (e.g., fan-driven)? (Multiple choices)
A.4. □ Mechanical system contaminant □ Mechanical system energy use □ Mechanical system noise □ Mechanical system operation □ Other reasons

Q.5. If you prefer natural ventilation (e.g., window ventilation) to mechanical ventilation (e.g., fan-driven), how frequently do you open windows per day?
A.5. □ Never □ Seldom □ Sometimes □ Often □ Always

Q.6. When you open windows for natural ventilation (e.g., window ventilation), what are the obstacles to window ventilation? (Multiple choices)
A.6. □ Outdoor traffic noise □ Outdoor air pollutants □ Inconvenient opening ways □ Other reasons

Q.7. If you think outdoor air pollutants are the main reason for window shutdown, are you satisfied with indoor air quality?
A.7. □ Yes □ No

Q.8. If you think outdoor traffic noise is the main reason to close windows, are you satisfied with traffic noise reduction by closing windows?
A.8. □ Yes □ No

Q.9. How much do you agree that urban traffic noise negatively affects you?
A.9. □ Strongly agree □ Agree □ Neutral □ Disagree □ Strongly disagree

Q.10. What kind of adverse effects do you complain about? (Multiple choices)
A.10. □ Distracting your work □ Difficulty in communication □ Psychological stress □ Nothing

Q.11. In general, what time of a day is the highest traffic noise transmitted to a building? (Multiple choices)
A.11. □ Before noon (8 AM to 10 AM) □ Around noon (11 AM to 1 PM) □ Afternoon (2 PM to 4 PM) □ Evening (after 5 PM) □ All day long

Q.12. Do you agree that ways (or sizes) of the window opening are appropriate for adequate window ventilation?
A.12. □ Strongly agree □ Agree □ Neutral □ Disagree □ Strongly disagree

RESULTS

A-Weighted Equivalent Sound Level (L_{Aeq})

A-weighted equivalent continuous sound level is constant noise level responding to human hearing over a given period [25]. According to the measured data of L_{Aeq} at the six sites in "Ga" roadside district, which represents residential areas or areas within 50-meters from hospitals and schools, traffic noise levels exceeded the threshold of the noise level standards on the environmental policy that require them to be lower than 65 dB(A) and 55 dB(A) each, for day-time (06:00 AM to 10:00 PM) and night-time (10:00 PM to 06:00 AM) in Table 3. These values are also higher than recommended by the WHO environmental standards, as shown in Table 4, showing the level of noise annoyance based on sound pressure level (SPL). The physical and psychological impacts on building occupants' health are evident because the adverse health effects of noise are proportional to long-term exposure to urban traffic noise. According to Table 4, building occupants will experience serious noise annoyance if they are exposed to day-time SPL of 55 dB for 16 hours.

Table 3. Noise level standards for environmental policy of South Korea [24].

Category of land use	Time	Ga [1]	Na [2]	Da [3]	Ra [4]
General district	Day-time (06:00 AM to 10:00 PM)	50	55	65	70
	Night-time (10:00 PM to 06:00 AM)	40	45	55	65
Roadside district	Day-time (06:00 AM to 10:00 PM)	**<u>65</u>**		70	75
	Night-time (10:00 PM to 06:00 AM)	**<u>55</u>**		60	70

[1] Residential area, area within 50-meters from hospitals and schools; [2] Semi-residential areas; [3] Commercial areas; [4] Industrial areas.

Table 4. Noise annoyance level based on sound pressure level (SPL) [8,9].

Level of noise annoyance	16-hour day-time average SPL (dB)	8-hour night-time average SPL (dB)	Approximate day-night average SPL (dB)	Night-time maximum SPL (dB)
Serious annoyance	55	45	55	60
Moderateannoyance	50	40	50	60

Figure 4 shows the location of each site (Site 1: Seocho-gu, Site 2: Northern Gangnam- gu, Site 3: Southern Gangnam-gu, Site 4: Mapo-gu, Site 5: Yongsan-gu, and Site 6: Seongbuk-gu) and the annual L_{Aeq} by month for each site. Figure 5 offers annual L_{Aeq} (e.g., mean, max, min) by day-time and night-time (a) and geographical information (b) including street views, building heights, building façades, and sound meter locations in red.

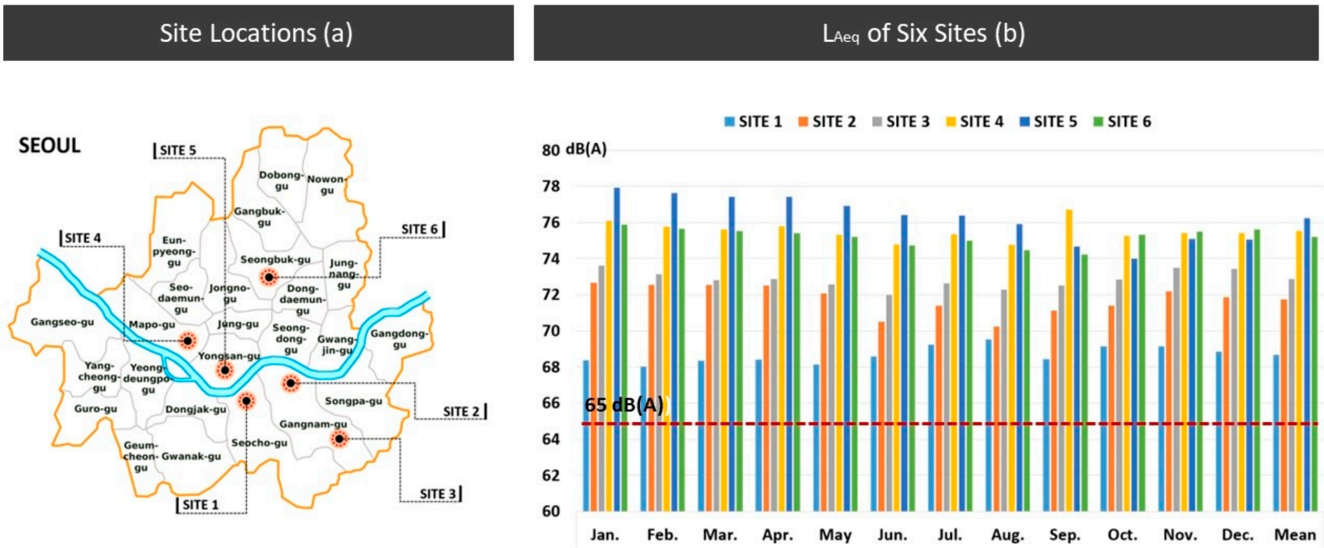

Figure 4. Site locations (**a**) and monthly L_{Aeq} of six sites (**b**).

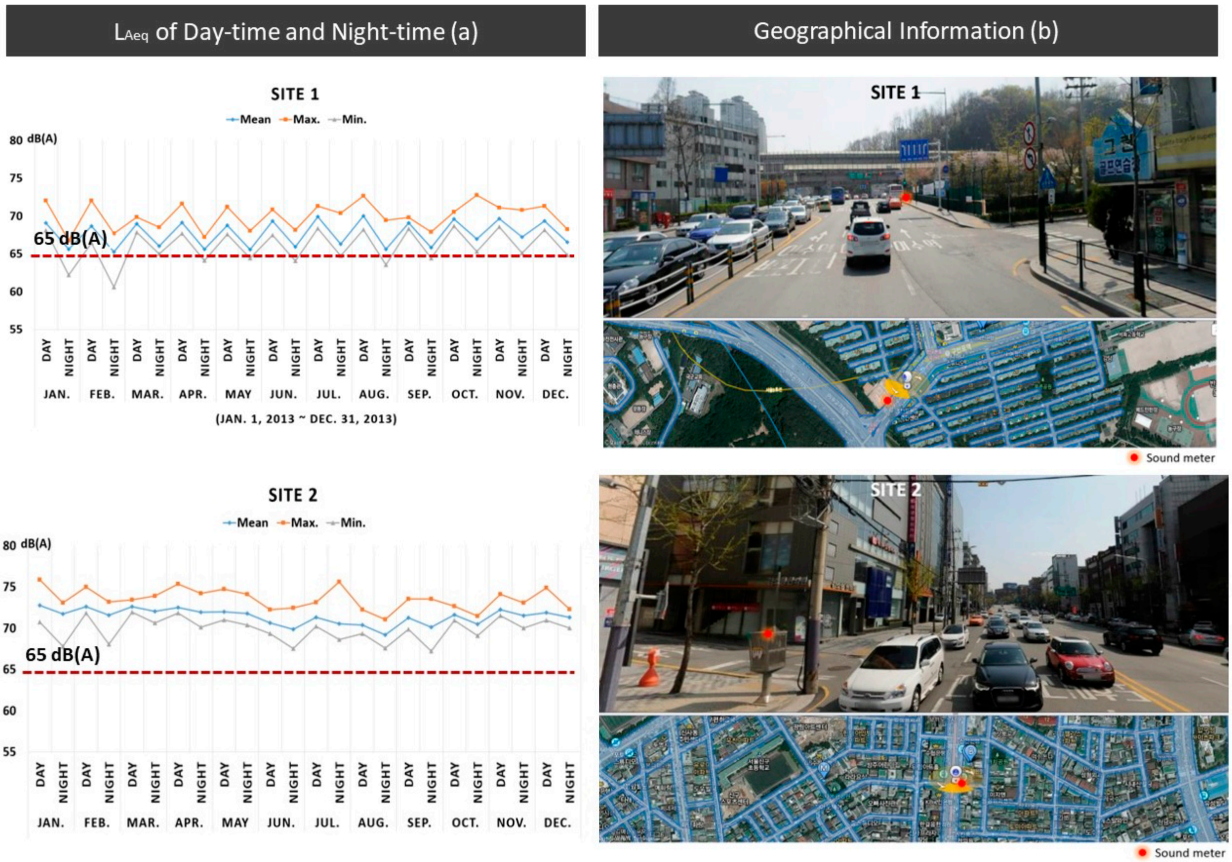

Figure 5. Annual L_{Aeq} of day-time and night-time (**a**) and geographical information (**b**).

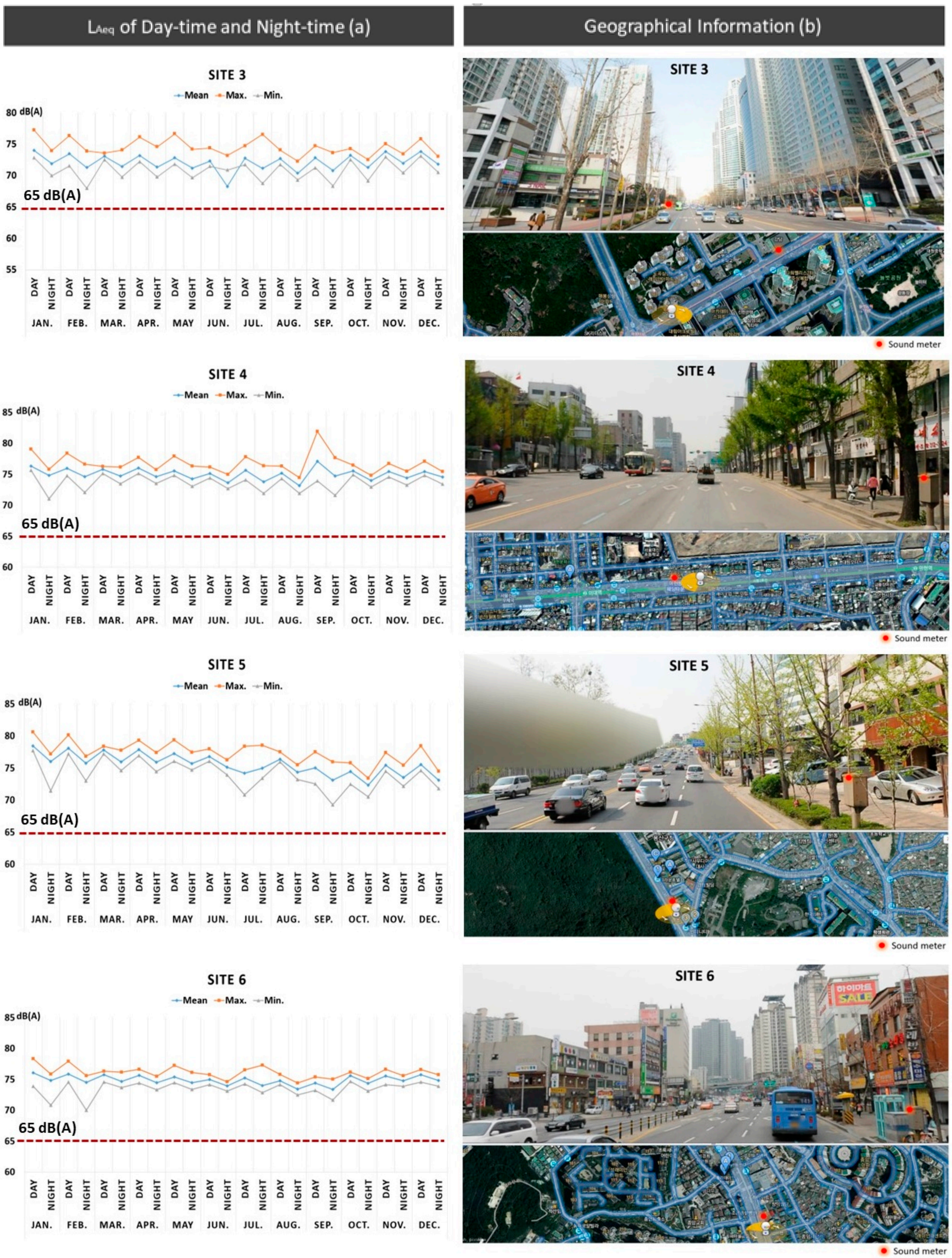

Figure 5. *Cont.*

From the analysis of the collected annual real-time data of L_{Aeq} at the six sites, the results showed that A-weighted equivalent continuous sound levels during day-time and night-time periods at six sites exceeded 65 dB(A) [24], that contain higher adverse potentials of noise annoyance based on Tables 3 and 4 [8,9,20,24]. The measured real-time data of L_{Aeq} of Sites 4, 5, and 6 were relatively higher than cases of Sites 1, 2, and 3, while assuming that the number of vehicles, speed of moving vehicles, the number of traffic lanes, the number of traffic signals, and geographical configurations of vehicle roads would affect the difference of L_{Aeq} outcomes. Under urban traffic intensity in these selected sites, it is implied that natural ventilation performance would be susceptible due to noise transmission via ventilation windows of glazed building façades.

Acoustical Perceptions Concerning Natural Ventilation

The targeted 92 subjects were randomly chosen in naturally-ventilated buildings at six sites that are adjacent to traffic lanes. The approximate distance between buildings and urban noise sources ranges from 5 meters to 10 meters depending on the width of a sidewalk. Each distribution ratio by gender is estimated 44% to 46% for females and males within an age group ranging from 26 to 65 years. It accounts for approximately 74% of the building occupants who have been residing in these locations for less than 5 years.

Table 5 summarizes the outcomes of building occupant's responses (n = 92 except for multiple choices in Questions 4, 6, 10 and 11) to their indoor air and indoor acoustic quality, as follows:

(**A.1.**) 87% (n = 80) of the respondents used mechanical ventilation and air conditioning systems.
(**A.2.**) 82% (n = 75) of respondents experienced SBS-related symptoms.
(**A.3.**) 71% (n = 65) of respondents perceived the effectiveness of natural ventilation strategy for indoor air quality and energy-saving.
(**A.4.**) 57% (n = 65) of respondents preferred natural ventilation techniques to mechanical ventilation systems due to air contaminants and noise from heating, ventilation, and air-conditioning (HVAC) systems.
(**A.5.**) 33% (n = 30) of respondents never and seldom opened their ventilation windows.
(**A.6.**) 39% (n = 54) of respondents regarded urban traffic noise as the major environmental obstacle to window ventilation.
(**A.7.**) 57% (n = 52) of respondents were dissatisfied with indoor air quality.
(**A.8.**) 63% (n = 58) of respondents were satisfied with noise transmission loss by closing windows.
(**A.9.**) 65% (n = 60) of respondents considered traffic noise as a negative factor in the built environment.
(**A.10.**) 49% (n = 60) of respondents most complained of poor task productivity.
(**A.11.**) 59% (n = 64) of respondents perceived high traffic noise levels indoors during their working hours.

(**A.12.**) 82% (n = 75) of respondents agreed on the adequate openings ways (or sizes) of windows for improved window ventilation in spite of the negative potential for traffic noise transmission.

Table 5. Questionnaire questions and building occupants' responses.

Questions	Number of response (n = 92) and percentage
Q.1. Which ventilation methods are frequently used in your building?	□ **Mechanical ventilation: 80 (87.0%)** □ Natural ventilation: 10 (10.9%) □ No response: 2 (2.2%)
Q.2. Have you ever experienced any temporary illness such as sensory irritation of eyes, nose, throat, and skin irritation when you're exposed to mechanical ventilation?	□ Never: 17 (18.5%) □ **Seldom: 28 (30.4%)** □ **Sometimes: 33 (35.9%)** □ **Often: 10 (10.9%)** □ **Always: 4 (4.3%)**
Q.3. How much do you agree that natural ventilation (e.g., window ventilation) is more effective in indoor air quality and energy-saving?	□ **Strongly agree: 21 (22.8%)** □ **Agree: 44 (47.8%)** □ Neutral: 21 (22.8%) □ Disagree: 4 (4.3%) □ Strongly disagree: 2 (2.2%)
Q.4. If you prefer natural ventilation (e.g., window ventilation) to mechanical ventilation (e.g., fan-driven), what are the main reasons NOT to choose mechanical ventilation (e.g., fan-driven)? (multiple choices)	□ **Mechanical system's contaminant: 40 (35.1%)** □ Mechanical system's energy use: 27 (23.7%) □ **Mechanical system's noise: 25 (21.9%)** □ Mechanical system's operation and accessibility: 6 (5.3%) □ Others: 16 (14%)
Q.5. If you prefer natural ventilation (e.g., window ventilation) to mechanical ventilation (e.g., fan-driven), how frequently do you open windows per day?	□ **Never: 9 (9.8%)** □ **Seldom: 21 (22.8%)** □ Sometimes: 18 (19.6%) □ Often: 29 (31.5%) □ Always: 9 (9.8)% □ No response: 6 (6.5%)
Q.6. When you open windows for natural ventilation (e.g., window ventilation), what are the obstacles to window ventilation? (multiple choices)	□ **Outdoor traffic noise: 54 (39.4%)** □ Outdoor air pollutants: 60 (43.8%) □ Inconvenient opening ways: 15 (10.9%) □ Others: 8 (5.8%)
Q.7. If you think outdoor air pollutants are the main reason for window shutdown, are you satisfied with indoor air quality?	□ Yes: 35 (38.0%) □ **No: 52 (56.5%)** □ No response: 5 (5.4%)
Q.8. If you think outdoor traffic noise is the main reason to close windows, are you satisfied with traffic noise reduction by closing windows?	□ **Yes: 58 (63.0%)** □ No: 30 (32.6%) □ No response: 4 (4.3%)
Q.9. How much do you agree that urban traffic noise negatively affects you?	□ **Strongly agree: 13 (14.1%)** □ **Agree: 47 (51.1%)** □ Neutral: 22 (23.9)% □ Disagree: 7 (7.6)% □ Strongly disagree: 0 (0%) □ No response: 3 (3.3%)

Table 5. *Cont.*

Questions	Number of response (*n* = 92) and percentage
Q.10. What kind of adverse effects do you complain about? (Multiple choices)	☐ **Distracting your work: 60 (49.2%)** ☐ Difficulty in communication: 27 (22.1)% ☐ Psychological stress: 22 (18.0%) ☐ Nothing: 10 (8.2%) ☐ Others: 3 (2.5%)
Q.11. In general, what time of a day is the highest traffic noise transmitted to a building? (multiple choices)	☐ Before noon (8 AM to 10 AM): 16 (14.8%) ☐ **Around noon (11 AM to 1 PM): 5 (4.6%)** ☐ **Afternoon (2 PM to 4 PM): 28 (25.9%)** ☐ **Evening (after 5 PM): 31 (28.7%)** ☐ All-day long: 28 (25.9%)
Q.12. Do you agree that ways (or sizes) of the window opening are appropriate for adequate window ventilation?	☐ **Strongly agree: 16 (17.4%)** ☐ **Agree: 59 (64.1%)** ☐ Neutral: 14 (15.2%) ☐ Disagree: 3 (3.3%) ☐ Strongly disagree: 0 (0%)

Group Comparison

The effect of window ventilation related to the SBS related symptoms, indoor air quality, and indoor acoustic quality was statistically studied. Eighty-six respondents, except for the no responses (*n* = 6), were divided into three groups depending on the frequency of window ventilation: (1) Group 1 represents respondents who seldom or never open windows; (2) Group 2 are respondents who sometimes open windows; and (3) Group 3 are respondents who often or always open windows. Eighty-six respondents in Question 5, the sample size of each group was divided into 29 respondents for Group 1, 19 respondents for Group 2, and 38 respondents for Group 3, respectively.

Statistical analysis from questionnaire responses results that mechanical ventilation systems were dominantly used across three groups in Figure 6a. There was a slight percentage difference in experiencing SBS related symptoms among Groups 1, 2, and 3 in Figure 6b. Respondents in Group 1 who seldom or never open windows experienced fewer SBS related symptoms by 3 to 5% compared to Groups 2 and 3 who sometimes, often, and always open windows 1. However, it was also found that a higher percentage of respondents in Group 1 greatly experienced SBS related symptoms.

Outdoor air pollutants via ventilation windows were regarded as another reason for the degradation of indoor air quality. Building occupants perceived that window ventilation is a useful technique for improving indoor air quality in Figure 6c; however, they were not satisfied with the existing indoor air quality in Figure 6d. It showed further investigations are needed for correlations between the frequency of window ventilation opening and indoor air quality improvement. Groups 2 and 3, which sometimes, often, and always open windows, showed a higher degree of dissatisfaction with indoor acoustic quality by opening windows than Group 1 in Figure 6e. All groups responded that outdoor traffic noise has the most negative impact on their acoustical comfort and poor productivity.

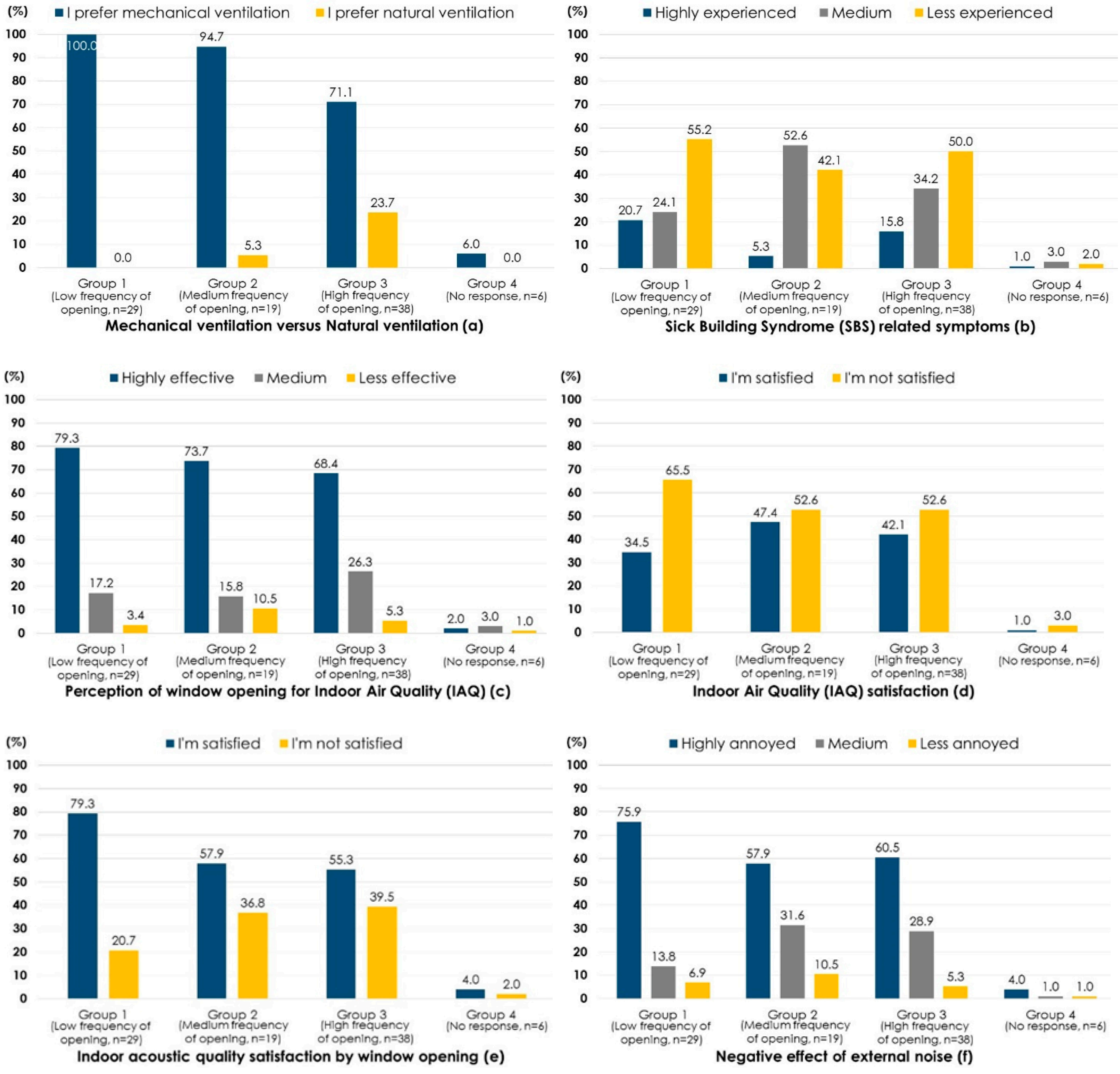

Figure 6. Group comparisons by frequency of window ventilation.

DISCUSSION AND CONCLUSIONS

The A-weighted equivalent continuous sound levels (L_{Aeq}) collected from the omnidirectional sound meters at six sites of the Seoul metropolitan area exceeded the noise thresholds that could potentially cause noise annoyance and sleep disturbance during day-time and night-time. The measured annual L_{Aeq} was higher than environmental noise level standards to be lower than 65 dB(A) and 55 dB(A) for each day-time (06:00 AM to 10:00 PM) and night-time (10:00 PM to 06:00 AM) period. This numerical data implies that building occupants have been consciously and unconsciously exposed to unacceptable noise levels for a long-term period that potentially causes adverse health effects due to noise.

In spite of statistical limitations, 92 building occupants adjacent to the urban traffic noise sources responded that 82% of them experienced SBS symptoms among all participants. Fifty-seven percent of respondents preferred natural ventilation techniques to mechanical ventilation systems due to air contaminants and noise from heating, ventilation, and air-conditioning (HVAC) systems. However, 33% of respondents seldom opened their ventilation windows, and 39% of respondents regarded urban traffic noise as the major environmental obstacle to window ventilation. The major adverse effects of noise for building occupants were related to a decrease in task productivity, difficulty in communication, and psychological stress.

Even if there was a slight difference in experiencing the SBS symptoms based on the frequency of window ventilation, the three groups responded dissatisfaction with their indoor air quality. All groups perceived that window ventilation is the potential natural ventilation technique for improved indoor air quality. The degree of dissatisfaction with their indoor acoustic quality by window ventilation was higher in Groups 2 and 3 than Group 1, implying that building occupants reduced outdoor traffic noise transmission by closing windows. Overall, all groups responded that they were affected negatively by outdoor traffic noise.

From the research findings, the development of acoustically-treated ventilation openings as ventilation-enabling noise control devices is necessary for both indoor air quality improvement and noise transmission loss in Seoul metropolitan areas that are exposed to high traffic noise sources. The environmental conflicts between natural ventilation and noise transmission in naturally-ventilated glazed façades are a crucial issue that is highly related to the comfort and health of urban building occupants. Further investigations are needed for the integrative development of acoustically-treated air vents and applications of active noise control electronics to ventilation openings as noise barriers and air channels.

CONFLICTS OF INTEREST

The author declares that there is no conflict of interest.

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