# A SURVEY OF FACTORS THAT IMPACT NOISE EXPOSURE AND ACOUSTICS COMFORT IN MULTI-UNIT RESIDENTIAL BUILDINGS

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## Résumé

Les recherches sur l'exposition au bruit dans les immeubles résidentiels à logements multiples (IRLM) sont limitées, malgré les effets avérés du bruit sur la santé physique et psychologique des personnes. C'est ce qui motive l'étude actuelle qui vise à identifier les sources de bruit importantes dans les IRLM et à étudier les facteurs qui ont un impact sur le confort acoustique ainsi qu'à déterminer les différents impacts du bruit sur les occupants. Une enquête en ligne a été menée pour recueillir des évaluations subjectives de l'exposition au bruit et des effets du bruit auprès de 213 occupants. Les résultats d'une analyse de corrélation de Spearman montrent que, parmi les différentes sources de bruit extérieur, la gêne due au bruit de la circulation est celle qui présente la plus forte corrélation significative avec la gêne globale due au bruit extérieur (coefficient de corrélation = 0,64, p = 0,000). De même, la gêne causée par le bruit aérien à travers les planchers et les plafonds présente la plus forte corrélation avec la gêne causée par le bruit intérieur global (coefficient de corrélation = 0,47, p = 0,000). Les résultats montrent que l'âge du bâtiment, le niveau des étages, la proximité de constructions en cours, l'existence d'un balcon, le nombre de chambres, la proximité des ascenseurs et du vide-ordures sont des facteurs importants liés au bâtiment qui ont une incidence sur la gêne due au bruit. Les résultats montrent également que les facteurs personnels et démographiques, tels que l'âge des occupants, la durée de résidence, le statut de propriétaire, la relation avec les voisins et la volonté de payer pour de meilleures conditions acoustiques, ont une incidence significative sur les réponses subjectives. Même si les bruits intérieurs et extérieurs sont gênants, les bruits extérieurs, en particulier le bruit de la circulation, de la construction et des activités de voisinage, sont plus gênants et perturbent le sommeil que les sources de bruit intérieures.

**Mots clefs** : comfort acoustique, bruit, nuisance, résidences à logements multiples

## Abstract

There is limited research on noise exposure in multi-unit residential buildings (MURBs) despite the proven effects of noise on people's physical and psychological health. This motivates the current study which aims to identify important noise sources in MURBs and investigate factors that impact acoustic comfort as well as determine the various impacts of noise on occupants. An online survey was administered to collect subjective assessments of noise exposure and the effects of noise from 213 occupants. Results of a Spearman's correlation analyses show that, among the different outdoor noise sources, traffic noise annoyance has the strongest significant correlation with overall outdoor noise annoyance (correlation coefficient = 0.64, p = 0.000). Similarly, annoyance with airborne noise through floors/ceiling has the highest correlation with overall indoor noise annoyance (correlation coefficient = 0.47, p = 0.000). The findings show that building age, floor level, proximity to ongoing construction, existence of balcony, number of bedrooms, proximity to elevators and garbage chute are important building-related factors that impact noise annoyance. The results also show that personal and demographic factors, such as occupants' age, length of residency, ownership status, relationship with neighbors, and willingness to pay for better acoustic conditions, significantly affect subjective responses. Even though both indoor and outdoor noises cause annoyance, outdoor noises, especially noise from traffic, construction and neighborhood activities, cause more annoyance and sleep disturbance compared to indoor noise sources.

**Keywords**: acoustic comfort, noise, annoyance, multi-unit residences

## 1 Introduction

Residents of multi-unit residential buildings (MURBs) are usually located in dense urban environments and are exposed to high levels of noise from a variety of sources, including neighbors, construction and heavy traffic. Exposure to noise can have short term effects, such as annoyance and disturbance of sleep, and long term effects including mental and physical health issues [1, 2]. Studies have shown that outdoor noise levels in cities around the world exceed the recommended 55 dB noise level for daytime and 45 to 50 dB for nighttime for minimum health effects [3, 4]. For instance, a study on environmental noise exposure in the City of Toronto measured daytime (64.1 ± 6.3 dBA) and nighttime (57.5 ± 7.8 dBA) noise levels at different locations around the city [5]. They estimated that 88.7% of the city's population is exposed to equivalent daytime outdoor noise levels above 55

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dBA, which is the noise level limit set out by the World Health Organization (WHO) [6] for moderate annoyance, and 92.3% is exposed to nighttime outdoor noise levels above 45 dBA, which is the noise level limit for sleep disturbance set out by WHO for a single noise event during the nighttime. Indoor noise sources, such as neighbors and building HVAC and service systems, can also be problematic in MURBs. Mitigating actions that occupants take to decrease their acoustic discomfort, such as keeping windows closed to block outdoor noise and turning their noisy HVAC system off, can cause poor indoor air quality and increase building energy consumption [7]. It is thus important to reduce exposure to both indoor and outdoor noise and improve the acoustic performance of MURBs.

### 1.1 Factors that impact acoustic comfort

Understanding factors that impact noise exposure and comfort is an important step in improving the acoustic performance of MURBs. A number of studies have thus investigated factors that impact acoustic comfort. Such factors can generally be divided into two groups: 1) noise-related and 2) human-related [8,9].

Noise-related factors include sound pressure level, frequency of noise, noise source, time and duration of noise exposure [8]. These noise-related factors depend on building and suite characteristics. The sound insulation level of walls, windows and floors is one of the main characteristics that impact the level and frequency of noise that is transmitted between suites or from outdoors [10]. For instance, heavyweight walls attenuate more low-frequency noise compared to lightweight walls [11]. While some studies report that occupants in buildings with heavyweight walls are more satisfied with the acoustical conditions compared to lightweight walls, other studies report no significant difference between acoustic satisfaction levels in the two types of buildings [10]. Similarly, the type and location of mechanical systems, such as HVAC systems, and the sound insulation levels of their components (e.g., ducts, fans and pumps) can affect exposure levels from noise produced by the system itself, as well as transmit and increase exposure to noise from outdoors or other suites [12]. The location of suites within a building is another factor that can impact noise exposure [13]. Suites facing highways, for example, are likely to have higher noise exposure levels [14]. Similarly, suites located on lower floors are exposed to higher levels of environmental noise, such as traffic and neighborhood activity noise, compared to those located on the upper floors [14].

Another noise-related factor that affects acoustic comfort is the source of noise. Occupants are likely to be exposed to both outdoor (e.g., traffic, construction, neighborhood) and indoor (e.g., airborne and structure-borne noise from neighboring suites, and HVAC noise). Most studies that evaluate how different noise sources affect occupants' responses, however, focus only on environmental/outdoor noise sources, typically road, rail and air traffic noise [9,15]. Elmenhorst et al. [16], for example, evaluated the effects of nighttime rail and aircraft noise exposure and found that respondents were more annoyed by aircraft noise than railway noise. Similarly, a study that investigated the effects of eight outdoor noise sources found that respondents were more annoyed by traffic and aircraft noise than other noise sources such as trains and outdoor neighborhood noise [17]. Even though more focus has been given to outdoor noise sources, studies that include indoor noise sources that MURB occupants are likely to be exposed to found that indoor sources are more important than outdoor sources. In a laboratory study where subjects were exposed to the same A-weighted noise levels, Jeon et al. [18] found that occupants were more annoyed by people's conversation and drainage noise compared to traffic and floor impact noise. Similarly, Zalejska-Jonsson [19] found that airborne noise from neighboring suites has a stronger negative effect on acoustical satisfaction compared to outdoor noise. These results show that it is important to study the impacts of both outdoor and indoor noise sources when evaluating the acoustic performance of MURBs. In addition, the results also show us that the noise level alone does not determine acoustic comfort. The frequency component of the noise is as important as the sound energy level. Factors, such as expectation and duration of exposure, can also explain the differences between annoyance levels among the different noise sources [8, 9].

In addition to noise-related factors, studies show that acoustic comfort is impacted by human-related factors which include personal, societal and demographic factors [9]. Attitude towards the noise source is one important determinant of how occupants perceive and report on their acoustic environment [8, 9]. Having a positive attitude towards a noise source can result in a lower level of noise annoyance. Chan and Lam [20] found that people who use a new railway built near their residence expressed more tolerance of the noise source than those who did not use, thus did not benefit from the railway. Fear of danger from the noise source is another personal factor that can influence acoustic comfort [9]. Van den Berg et al. [21], for instance, observed a high correlation between worry due to aircraft and noise annoyance from aircraft, while the correlation between worry due to traffic and annoyance from it was lower. This can also explain why occupants report aircraft noise as the most annoying compared to other outdoor noise sources. Other factors, such as length of residency and homeownership status, are also found to affect acoustic comfort [9].

### 1.2 Measuring acoustic performance and the effects of noise

A method widely employed to evaluate the acoustic comfort in residential buildings is to measure the noise level either indoors or outdoors and compare values to those specified in national or international guidelines [4,5,22]. While this evaluation method is important to obtain an objective measure of noise levels in buildings, it is not sufficient to evaluate how and to what extent occupants are being affected by noise exposure as acoustic comfort depends on a person's perception of his or her acoustic environment [10]. Some studies have thus used other subjective and objective metrics to evaluate the effects of noise exposure. Noise annoyance level is one metric that is used to capture the subjective nature of acoustic comfort which depends on noise sensitivity, attitude towards the noise source, the importance of the noise, predictability and other demographical, personal, societal and contextual aspects [23]. Sleep disturbance is another parameter used to evaluate the effects of noise exposure [9]. Field studies typically use surveys to evaluate subjective ratings of sleep quality while laboratory studies implement a more objective evaluation by using polysomnography and actigraphs to evaluate the effects of noise on sleep disturbance and overall sleep quality. While other evaluation methods, such as health effects, activity disturbance and effects on performance [3, 24, 25], have been included in studies assessing the effects of occupational noise exposure and general effects of noise on humans, evaluating such effects is not widely implemented for acoustic comfort studies in MURBs [26].

The current study aims to assess factors that impact noise exposure and acoustic comfort of occupants which are used as indicators of the acoustic performance levels of existing MURBs in dense, urban areas. The main objectives of this study included identifying the major sources of noise in MURBs, their effects on occupants and the importance of each noise source to overall acoustic comfort. We also sought out to identify building-related, and personal and demographic factors that impact noise exposure and acoustic comfort, as well as identify any noise mitigating strategies and behavioral adaptation to noise conditions. Identifying such factors will allow us to isolate the most important areas of work required to minimize the impacts of noise on occupants as well as reduce negative impacts on building energy consumption and other indoor environmental conditions.

## 2 Methods

An online survey (Table 6 in the Appendix) with 31 questions was implemented in SurveyMonkey. The survey first asks questions on 1) demographics, 2) relationship with neighbors, 3) respondents' weekday and weekend schedule (asleep, awake at home and away from home) and subjective evaluation of the time of day (morning, afternoon, evening and night) when noise is the highest, and 4) building information and suite type. It then asks participants to rate their annoyance levels with different indoor and outdoor noise sources (listed in Table 1). The response scale ranged from "1= Not annoyed" to "5= Extremely annoyed". The survey also included questions on other effects of noise on occupants such as sleep and work disturbance, and noise mitigating strategies. In addition, the survey included open-ended questions so that respondents could report on additional factors that impacted their acoustic comfort which might not have been included in the closed-ended questions. This allowed us to identify additional noise sources and noise mitigation strategies. The survey also asked the street address of occupants' buildings, which allowed us to determine additional information about the buildings that were not covered by the survey as well as verify information provided by respondents, such as the age of the building and the total number of floors. We used a construction map of the city [27] to identify the proximity of buildings to ongoing construction during the period that the survey was administered. Only 200 responses were included in this classification as the rest of the respondents did not provide their building addresses. A building was considered to be close to ongoing construction if there was an ongoing construction within a 150 meters radius during the summer and fall of 2019 (July – October), which was when the survey was administered. In addition, we attempted to categorize buildings into those with small and large windows. A building and its suites are classified as having small windows if the window size is less than 50% of the wall area, and they are classified as having large windows if the window is more than 80% of the wall area. It should be noted that these classifications were based on visual inspections and no formal measurements of the window to wall ratios were taken. If we had doubts about whether a building fits in either category, it was left out of this classification. As such, only 187 responses were included for the window size analysis.

The survey was administered during summer and fall 2019 in the city of Toronto, Canada. To ensure that only residents of MURBs fill out the survey, we approached property managers of condominiums and apartments in the city of Toronto and asked them to distribute the online survey to all residents via email or posters that included a description of the survey along with a link to the survey and a barcode for easy access. Two-hundred and thirteen complete responses were collected from more than 30 buildings in

**Table 1:** A list of indoor and outdoor noise sources included in the survey questions.

| Outdoor sources | Indoor sources | | |
|---|---|---|---|
| | Systems and services | Neighbors | Other occupants |
| • Traffic<br>• Construction<br>• Outdoor neighborhood activities: restaurants, people on the streets, etc.<br>• Weather (e.g., wind) | • Water installations: plumbing, flushing toilet, shower, etc.<br>• Heating/cooling: heaters, air conditioning, air supply grille, etc.<br>• Service installations inside suite: laundry machine, kitchen fan, etc.<br>• Service installations outside suite: elevator, garbage chute, etc. | • Noise through walls: people talking, pets, etc.<br>• Footsteps, moving furniture and other impact noise<br>• Noise through floors/ceilings: people talking, pets, etc.<br>• Noise from balconies<br>• Noise from shared spaces: e.g., hallways and stairways | • Other occupants in the same suite: talking, other activities |

Toronto. Approximately 83% of the responses came from six buildings with total number of storeys ranging from five to 40 storeys.

A descriptive analysis of noise sources, annoyance levels, time of day when noise is highest, effects of noise on occupants and mitigation measures were presented first. Spearman's rank-order correlation analysis was used to test associations of annoyance with individual noise sources with overall acoustic annoyance in order to determine the most important noise sources that impact overall acoustic comfort. Spearman's correlation was also used to identify relationships between annoyance levels and floor level. Non-parametric tests, namely, Wilcoxon rank-sum test and Kruskal-Wallis test were used to determine whether there are statistical differences in annoyance levels among groups of suites with different characteristics, as well as among groups of respondents with different demographic and personal characteristics. Post-hoc tests (Dunn's test) were performed for significant Kruskal-Wallis test results. The analyses were conducted using R software version 3.6.1, and p-values less than 0.05 are considered significant.

# 3 Results

This section presents the results of our analysis. A descriptive summary of the results is first presented followed by the results of Spearman's correlation analysis and non-parametric hypothesis tests.

## 3.1 Summary of responses

A summary of the building-related and respondents' personal and demographic characteristics evaluated in this study are presented in Tables 2 and 3. There are relatively similar distributions between genders, ownership status and length of residency. Most of the respondents (90.6%) were between 20-49 years old. Due to the uneven distribution of sample size, the six groups of occupant age were converted to four groups as shown in Table 2. Many (69.0%) lived with other occupants, 9.4% were living with children and 16.9% had pets. When asked to describe their relationship with their neighbors, 34.4% indicated they had good relationships with other neighbors (same floor or downstairs) while only 19.4% of respondents specified that they had good relationships with their upstairs neighbors. In response to a question asking whether or not respondents are willing to pay for a suite with better noise insulation, 44.1% answered "yes", while 24.0% and 31.9% answered "no" and "not sure," respectively.

The majority of the respondents have a one-bedroom suite (52.6%) and many of the suites (57.0%) are in buildings that are 6-10 years old. The five groups of building age are converted into three groups for better distribution of sample size among groups. The majority of respondents (59.6%) indicated that their suite faces a major roadway with four or more lanes. Approximately one-third of the respondents indicated that their suites are located adjacent to or across from elevators. Using the methods described in Section 2, we estimate that, out of 187 respondents, the majority of the suites (87.2%) are located in buildings with large window areas. We also estimate that 63.0% of the suites are located in

**Table 2:** Summary of personal and demographic characteristics. Where the sample size is less than 213, the exact number of responses is indicated in brackets.

| | | | |
|---|---|---|---|
| Gender | | Age | |
| Male | 43.2% | 18-20 years | 0.9% |
| Female | 55.9% | 21-29 years | 38.5% |
| Prefer not to say | 0.9% | 30-39 years | 36.6% |
| Ownership | | 40-49 years | 15.5% |
| Rent | 45.5% | 50-59 years | 5.2% |
| Own | 53.5% | ≥60 years | 2.4% |
| Other | 1.0% | Prefer not to say | 0.9% |
| Length of residency | | Age – four groups (N=211) | |
| <6 months | 12.2% | 18-29 years | 39.8% |
| 6-12 months | 13.6% | 30-39 years | 37.0% |
| 1-3 years | 32.8% | 40-49 years | 15.6% |
| 3-5 years | 20.7% | ≥50 years | 7.6% |
| >5 years | 20.7% | Relationship with upstairs neighbors (N= 212) | |
| Living with other occupants | | | |
| Yes | 69.0% | Good | 19.4% |
| No | 31.0% | Neutral | 72.6% |
| Living with children (< 18 years old) | | Bad | 8.0% |
| Yes | 9.4% | Relationship with neighbors on the same floor or downstairs (N= 212) | |
| No | 90.6% | | |
| Have pets | | Good | 34.4% |
| Yes | 16.9% | Neutral | 62.7% |
| No | 83.1% | Bad | 2.8% |
| Willingness to pay | | | |
| Yes | 44.1% | | |
| No | 24.0% | | |
| Not sure | 31.9% | | |

**Table 3:** Summary of building-related characteristics. Where the sample size is less than 213, the exact number of responses is indicated in brackets.

| | | | |
|---|---|---|---|
| Type of apartment | | Window size (N= 187) | |
| Studio | 4.7% | Small (<50% of wall area) | 12.8% |
| One-bedroom | 52.6% | Large (>80% of wall area) | 87.2% |
| Two-bedroom | 33.3% | Located near elevators | |
| Three or more bedrooms | 9.4% | Yes | 39.9% |
| Building age (N= 205) | | No | 60.1% |
| ≤5 years | 4.0% | Located near garbage chute | |
| 6-10 years | 57.0% | Yes | 33.3% |
| 11-15 years | 18.0% | No | 66.7% |
| 16-20 years | 18.0% | Main door weather-stripped (N=211) | |
| > 20 years | 3.0% | Yes | 22.8% |
| Building age – three groups (N= 205) | | No | 33.2% |
| ≤10 years | 61.0% | I do not know | 43.1% |
| 11-15 years | 18.0% | Not applicable | 1.0% |
| >15 years | 23.0% | Balcony door weather-stripped (N=212) | |
| Facing roadway with 4 or more lanes | | Yes | 50.5% |
| Yes | 59.6% | No | 8.0% |
| No | 40.4% | I do not know | 29.7% |
| Within 150 m radius of ongoing construction (N= 200) | | Not Applicable | 11.8% |
| | | Windows weather-stripped (N=211) | |
| Yes | 63.0% | Yes | 50.7% |
| No | 37.0% | No | 11.4% |
| Have balcony | | I do not know | 36.5% |
| Yes | 84.0% | Not applicable | 1.4% |
| No | 16.0% | | |

buildings that are close to ongoing construction, thus highly exposed to construction noise. In order to determine noise insulation levels of doors and windows, and their effectiveness in reducing sound exposure, questions regarding weather-stripping were included. Approximately 50.7% of respondents have weather-stripped windows and balcony doors, while only 22.8% indicated that their main door (door to hallway) was weather-stripped.

## 3.2 Distribution of annoyance levels with noise sources

Figure 1 shows a summary of responses that indicated that they were at least slightly annoyed by individual noise sources. 79.8% of respondents were annoyed to some extent by one or more outdoor noise sources and 70.0% of respondents were annoyed with one or more sources of indoor noise. It can be seen that more respondents (> 70%) indicated annoyance with traffic noise compared to other outdoor noise sources. For indoor noise sources, the most frequently reported annoyance was with airborne noise from shared spaces followed by airborne noise through walls, and noise from heating and cooling systems. Comparing overall annoyances, the results showed that more respondents indicated annoyance with outdoor sources compared to indoor sources.

For the open-ended questions, respondents were asked to report any additional sources of noise they hear in their suites that were not included in the closed-ended questions. Respondents identified aircraft, trains, pets, renovation of neighbors' suites, emergency vehicles, occupants in short-term rentals or Airbnb guests, garbage trucks, fire/smoke alarm, outdoor noise traveling through the ventilation system, parking garage, cannons from a nearby historic site, and neighbor's AC unit as additional noise sources. While some of these fit into the indoor/outdoor categories identified in the study, we think it is important to present all noise sources reported as "additional" by the respondents. Respondents who specified short-term renters' suites as a source of noise in the open-ended questions also indicated loud and inconsistent noise coming from these suites and that short-term occupants make less effort to keep their noise levels down compared to long-term occupants.

## 3.3 Which noise sources influence overall annoyance?

The Spearman's correlation analysis was performed to identify which noise sources are important for overall noise annoyance. The results, presented in Figure 2, show that annoyance with traffic has the highest significant correlation with overall outdoor annoyance (Spearman's correlation coefficient = 0.64, $p = 0.000$). Annoyance with construction and neighborhood noise have lower levels of correlation with overall annoyance. Annoyance with weather noise, however, has no significant correlation with overall annoyance. It is also worth noting that significant correlations are observed between annoyance with traffic noise and annoyance with other noise sources For overall indoor annoyance, significant correlations are observed between annoyance with many individual noise sources and overall annoyance. Airborne noise through floors/ceilings, has the highest level of correlation (Spearman's correlation coefficient = 0.47, $p = 0.000$). Annoyance with noise from service installations have strong significant correlations. Annoyance with noise from water installations, and heating and cooling systems, showed

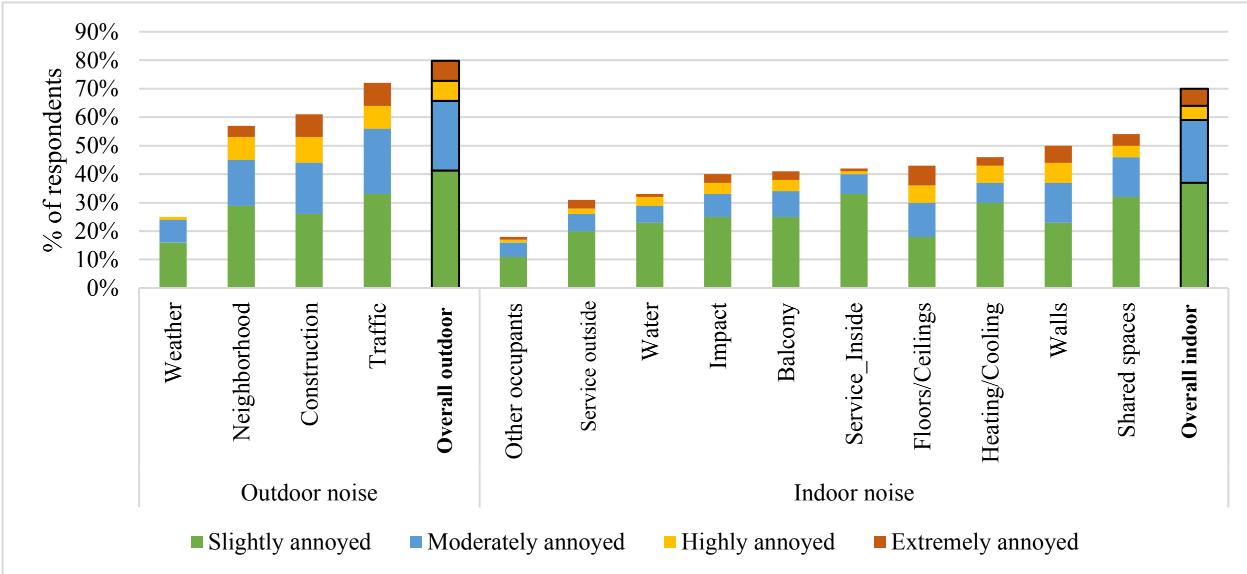


**Figure 1:** Summary of annoyance levels with indoor and outdoor noise sources.

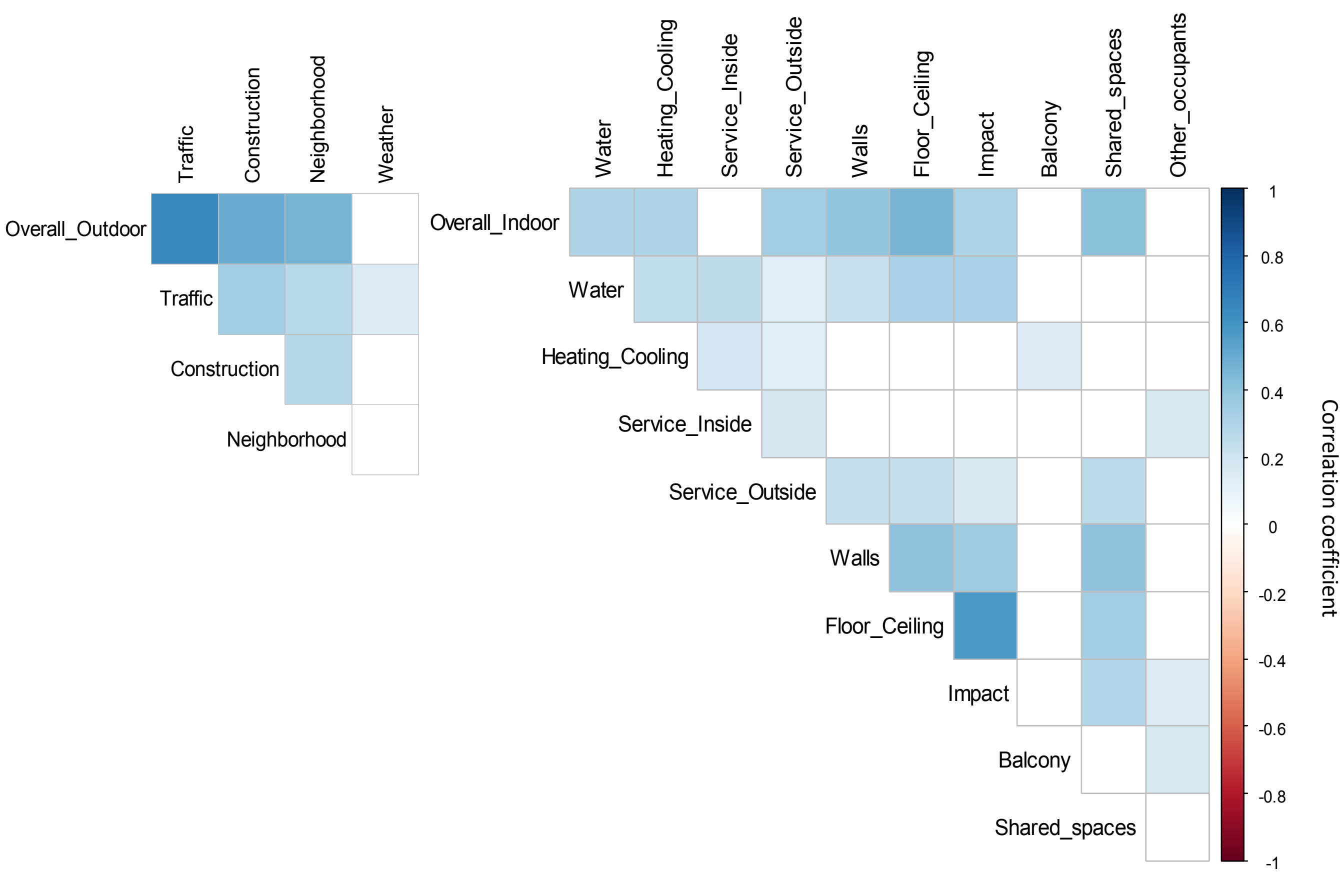


**Figure 2:** Results of correlation analysis between individual and overall outdoor noise annoyance (left) and individual and overall indoor noise annoyance (right). Empty cells indicate no significant correlation.

weaker, but still significant, correlations. Noise from service installations inside suite, neighbors' noise from balconies and noise from other occupants inside suite have no significant correlations with overall indoor noise annoyance. It can thus be concluded that indoor noises coming from sources outside one's suite are more problematic for overall annoyance with indoor noises.

Looking at individual noise sources in Figure 2, significant correlations are found in annoyance between water installations and neighbors' noise (via airborne noise through walls and floors, and impact noise), and service installations outside suite and neighbors' noise. There are also significant correlations between annoyance with other occupants in their own suite and annoyance with service installations inside suite, impact noise and noise from balconies.

### 3.4 Schedule analysis

In order to identify the time of day that the individual noise sources are the loudest, respondents were asked to report periods of the day (morning, afternoon, evening and night) that the individual noise level is typically the highest. In parallel, respondents were also asked to specify their typical weekday, and weekend schedule and indicate periods that they are typically asleep, awake at home and away from home. In addition to identifying noise trends, information regarding the schedule of respondents and perceived loud periods allowed for the identification of noise sources that cause disturbance to sleep and annoyance and disturbance to other activities when respondents are awake but at home. This information also allowed us to assess the appropriateness of having higher noise level limits set by many guidelines during daytime (7:00 – 23:00) compared to nighttime (23:00 – 7:00) based on the assumption that noise exposure during the daytime will not affect sleep. The responses are summarized in Figure 3. The bar charts show typical occupancy trends and sleep schedules of the respondents during weekdays and weekends. While many respondents reported being away during the daytime and asleep during nighttime, it is important to note that there are still a number of people that do not follow this schedule.

The bubble plot in Figure 3 shows that some noise sources are consistently loud throughout the day, while some

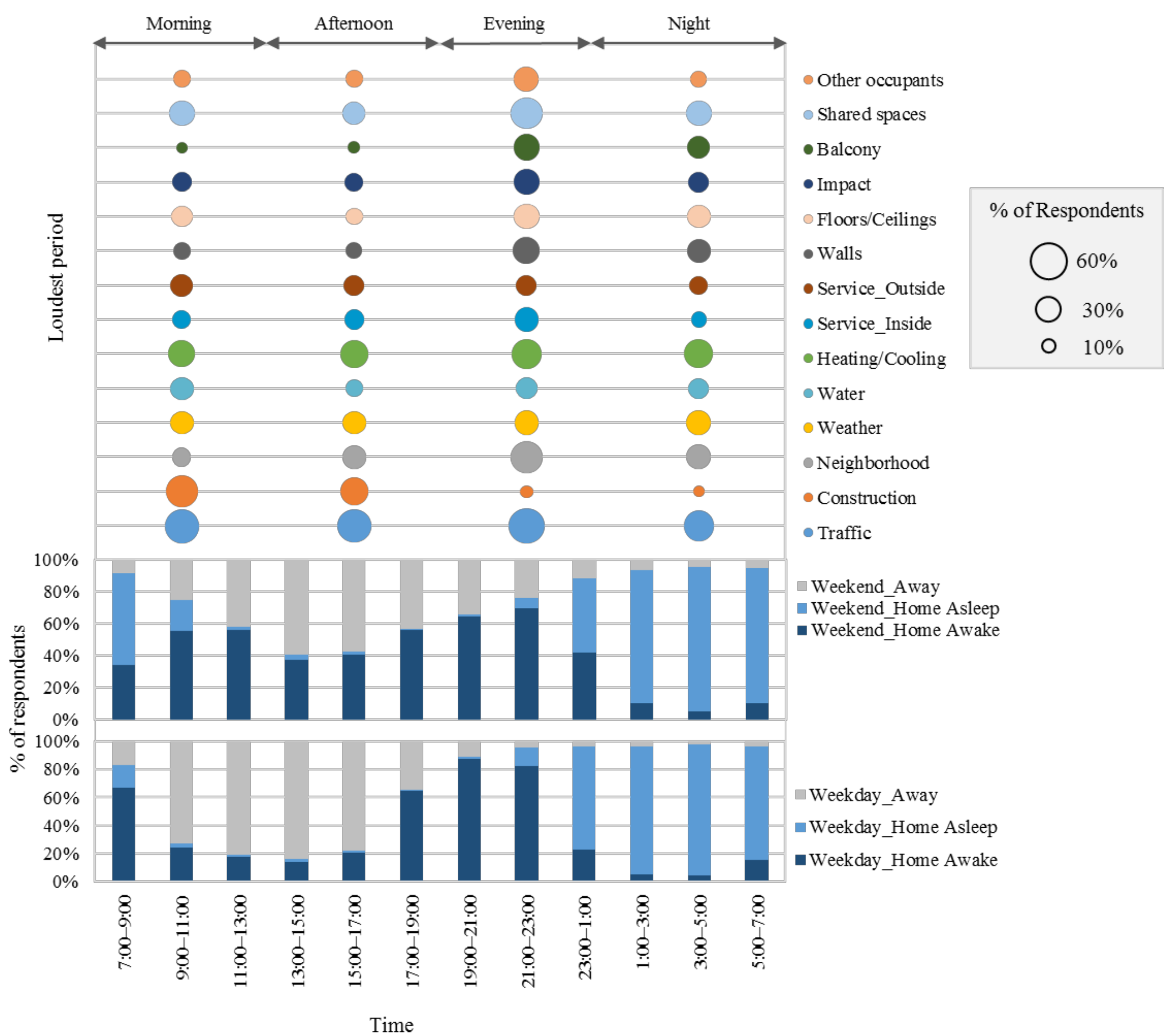


**Figure 3:** Comparison of reported loud periods and respondents' daily schedule. The area of the bubble corresponds to the number of respondents who indicated that the particular noise source is the loudest during the specific period.

other noises are loud only during specific periods. For instance, traffic, and heating and cooling system noises were reported to be consistently loud throughout the day while construction noise is reported to be loud typically during mornings and afternoons, and outdoor neighborhood noise is reported to be loud mostly during evenings and nights. In addition, except for noise from construction, outdoor neighborhood and balconies, the majority of respondents indicated that noise from most sources are equally loud during weekdays and weekends. For construction, 73.9% of respondents who hear construction noise indicated that it is louder during weekdays compared to weekends while outdoor neighborhood noise and noise from balcony were reported as the loudest during weekends by 48.3% and 50.0% of respondents respectively). This shows that most respondents are exposed to perceived loud noises from multiple indoor and outdoor sources in their suites irrespective of the time of day and day of the week.

### 3.5 Which building and non-building related factors affect acoustic annoyance?

To identify any correlations among building-related characteristics and suite properties, we first performed a correlation analysis on the building-related characteristics. The results of Spearman's correlation analysis are presented in Figure 4. Our results show that older buildings are low-rise, have smaller windows and are in closer proximity to ongoing construction compared to newer ones. In addition, more suites in older buildings do not have balconies, are not facing major roadways and have more bedrooms compared to suites in newer buildings. Building age does not have any correlation with weather-stripping (WS) windows/doors and proximity to elevators and garbage chutes.

Results of the correlation and statistical hypothesis test are presented in Tables 4 and 5. Note that only significant results are shown for a concise presentation of the tables. Spearman's correlation analysis shows that there is a significant negative correlation between floor level and annoyance with traffic, construction, outdoor neighborhood and overall outdoor noises. There is, however, a significantly positive correlation between floor level and annoyance with weather-induced noise. The statistical test results indicate that building-related factors, such as windows size, proximity to ongoing construction, apartment type and building age significantly affect annoyance with outdoor noises while none of the personal and demographic characteristics significantly affect annoyance with outdoor noises. Contrary to our expectation, respondents in buildings with smaller windows reported higher annoyance with outdoor noise. As shown in Figure 4, there is a negative correlation between window size and, building age. Buildings with small window are much older (average 20 years) than those with larger windows (average 10 years) (Wilcoxon rank-sum test, W = 3645.5,

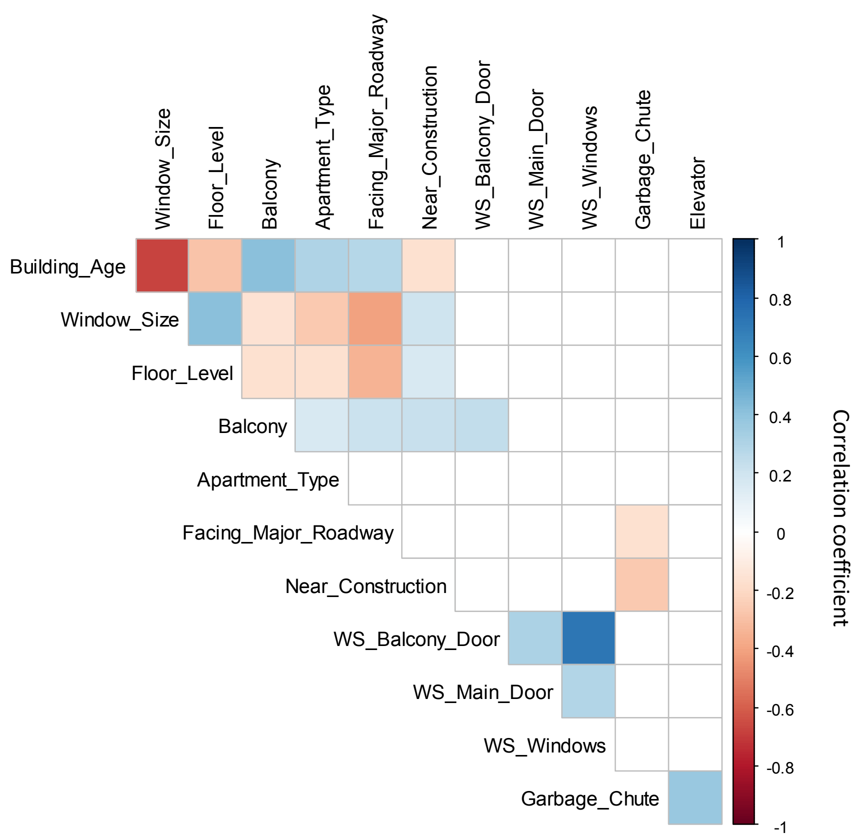


**Figure 4:** Results of correlation analysis among building characteristics and suite properties. Empty cells indicate no significant correlation.

**Table 4:** Correlation and non-parametric test results for difference in annoyance with outdoor noises (*p<0.05; **p<0.01; ***p<0.001).

| | Overall | Traffic | Construction | Neighborhood | Weather |
|---|---|---|---|---|---|
| Spearman's rank correlation test | | | | | |
| Floor level | -0.239*** | -0.160* | -0.188** | -0.265*** | 0.180** |
| Wilcoxon rank-sum test | | | | | |
| Proximity to a major roadway | 5295.5 | 6137.5 | 5065.5 | 5183.5 | 6168.0* |
| Window size | 2385.5 | 2177.5 | 3051.0*** | 2501.5* | 1610.0 |
| Proximity to ongoing construction | 4640.0 | 5414.0* | 5806.0** | 4999.0 | 3923.5* |
| Kruskal-Wallis test | | | | | |
| Apartment type | 7.9* | 7.3 | 12.3** | 6.3 | 0.4 |
| Building age | 5.8 | 5.7 | 37.6*** | 7.9* | 5.2 |
| Dunn's test | | | | | |
| Apartment type | | | | | |
| Studio & 2-bedroom | -2.5* | | -1.5 | | |
| Studio & ≥3 bedrooms | -2.0* | | -2.2* | | |
| 1 & 2-bedroom | -1.7 | | -2.4* | | |
| 1 & ≥3 bedrooms | -0.8 | | -2.9** | | |
| Building Age | | | | | |
| ≤ 10 & 11-15 yrs. | | | -4.0*** | -2.1* | |
| ≤ 10 & >15 yrs. | | | -5.5*** | -2.3* | |

$p < 0.001$). This fits well with our finding that occupants in older buildings express higher levels of annoyance compared to those in newer buildings. The post-hoc test shows that the difference is observed between respondents in buildings that are ≤10 years and ≥10 years. For apartment type, the post-hoc tests show that annoyance levels in studio and one-bedroom suites are significantly lower than suites with two or more bedrooms. This might be because respondents in suites with two or more bedrooms are mostly located in older buildings (as shown in Figure 4) where annoyance level is generally higher than newer buildings. It is important to note that having a balcony and weather-stripping balcony door/ windows have no significant effect on annoyance with outdoor noises.

For indoor noises, both building-related factors and respondents' personal and demographic characteristics significantly affect annoyance levels. Those who are living with other occupants and those who have pets are significantly less annoyed by overall indoor noise. Age, length of residency and ownership are also significant predictors of annoyance with indoor noises coming from neighbors. Older respondents and those who have lived longer in their suites showed higher annoyance levels than their counterparts. Owners also indicated higher annoyance levels than renters. Relationship with neighbors is also a significant predictor of annoyance with indoor noises. Those who expressed having good relationships with their neighbors are less annoyed with noise from neighbors and overall indoor noise than those who reported neutral or bad relationships. In addition, those who are willing to pay for better noise insulation are significantly more annoyed by neighbors' noise than those who were not willing or hesitant to pay. The results show that gender and living with children are not significant predictors of annoyance.

Examining building-related factors, respondents in older buildings showed higher annoyance with noise from water installations, and heating and cooling systems. These respondents also reported higher annoyance with noise from neighbors. Those in suites close to elevators and garbage chutes indicated higher annoyance with noise from service installation outside their suite compared to those in suites that are not close to these services. There was no significant difference in annoyance between those who weather-stripped their door to the hallway and those who did not. We found a significant negative correlation between floor level and overall indoor annoyance. In addition, those in buildings that are close to ongoing construction expressed a significantly higher annoyance with airborne and impact noise transmitted through floors compared to those that are not exposed to construction noise.

### 3.6 Effect of noise on daily activities

Figure 5 shows the reported effects of different indoor and outdoor noises. The most frequently reported effect of noise exposure is sleep disturbance. Approximately 50.2% of respondents indicated that traffic noise disturbs their sleep. Respondents also indicated that noise from construction, outdoor neighborhood, neighbors, and heating and cooling systems also affect their sleep. In addition to sleep disturbance, impacts of both outdoor and indoor noises on mental stress, mood, work/study and relaxation were also specified. Noise from neighbors and outdoor noises have the highest percentage of reported impact on mental stress and mood respectively. The highest percentage of reported impact on work/study is for construction, possibly because construction occurs during the daytime.

**Table 5:** Correlation and non-parametric test results for difference in annoyance with indoor noises (*p<0.05; **p<0.01; ***p<0.001).

| | Overall | Water installation | Heating/ Cooling | Service_ Inside | Service_ Outside | Neighbors | | | | | Other occupants |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Walls | Floor/ Ceiling | Impact | Balcony | Shared spaces | |
| Spearman's rank correlation test | | | | | | | | | | | |
| Floor level | -0.139* | -0.048 | -0.128 | -0.081 | -0.077 | -0.023 | -0.040 | -0.015 | 0.047 | -0.029 | -0.054 |
| Wilcoxon Rank-Sum Test W | | | | | | | | | | | |
| Has other occupants | 3909.5* | 4729.0 | 4847.0 | 4873.5 | 4472.5 | 4103.5 | 3886.5* | 4197.0 | 3632.0*** | 3875.5* | 5599.5* |
| Has pets | 2482.0* | 3119.0 | 2998.0 | 2842.0 | 2706.0 | 2840.5 | 2980.5 | 3185.0 | 3645.5 | 2963.0 | 3176.0 |
| Has balcony | 2779.0 | 3365.5 | 2415.0* | 3252.0 | 2897.0 | 3295.5 | 3075.0 | 3382.5 | 4429.5*** | 3114.5 | 2454.0* |
| Neighbors have balcony | 3618.0 | 4233.5 | 3446.0 | 3631.5 | 3589.5 | 3782.0 | 3906.0 | 4192.5 | 5115.0*** | 3522.0 | 3086.5* |
| Garbage chute | 4766.5 | 4755.5 | 4746.5 | 5541.0 | 6509.5*** | 5352.5 | 5251.0 | 5205.0 | 5091.0 | 5210.5 | 5442.0 |
| Elevator | 5839.5 | 5989.0 | 5321.5 | 5777.0 | 7222.0*** | 5702.5 | 6042.0 | 5858.5 | 5743.0 | 5716.5 | 5995.5 |
| Ownership | 4669.0* | 4879.0 | 5401.0 | 5457.5 | 5665.0 | 5130.0 | 4088.5*** | 4219.5*** | 3825.0*** | 4382.0** | 5955.5 |
| Window size | 1913.5 | 2185.5 | 2263.0 | 1899.0 | 1859.0 | 2045.0 | 2132.5 | 2127.5 | 1612.5 | 1369.5* | 1951.0 |
| Proximity to ongoing construction | 5397.0 | 5227.0 | 4774.0 | 4284.5 | 4626.0 | 5224.5 | 5848.0*** | 5400.0* | 5301.0 | 5147.5 | 4703.0 |
| Kruskal-Wallis Test | | | | | | | | | | | |
| Age | 2.9 | 2.3 | 0.6 | 1.7 | 1.7 | 3.1 | 13.2** | 15.7*** | 17.5*** | 1.6 | 3.2 |
| Apartment type | 2.9 | 4.3 | 3.3 | 1.4 | 2.7 | 2.7 | 1.2 | 4.2 | 13.4** | 4.4 | 9.9* |
| Time lived in suite | 9.6* | 8.2 | 3.3 | 1.8 | 2.3 | 9.3 | 18.2*** | 13.4** | 28.4*** | 6.4 | 5.3 |
| Relationship with upstairs neighbors | 19.0*** | 6.1* | 2.2 | 2.6 | 0.2 | 4.2 | 34.8*** | 26.2*** | 10.9** | 14.5*** | 6.0* |
| Relationship with other neighbors | 14.1*** | 2.1 | 1.5 | 0.8 | 3.1 | 14.2*** | 8.3* | 1.6 | 1.9 | 9.5** | 0.4 |
| Weather-stripping | | | | | | | | | | | |
| Balcony door | 3.2 | 6.0 | 7.2 | 1.2 | 1.0 | 2.8 | 3.1 | 1.6 | 26.8*** | 2.6 | 2.9 |
| Building age | 1.5 | 9.7** | 9.1** | 4.2 | 1.9 | 1.6 | 2.6 | 6.9* | 11.6** | 11.1** | 0.4 |
| Willingness to pay | 4.0 | 1.6 | 3.2 | 0.3 | 4.8 | 6.5* | 12.5** | 8.2* | 1.9 | 6.2* | 1.5 |
| Dunn's test | | | | | | | | | | | |
| Age | | | | | | | | | | | |
| <30 & 30-39 yrs. | | | | | | | -2.1* | -2.4* | -3.1** | | |
| <30 & 40-49 yrs. | | | | | | | -3.2** | -2.8** | -3.1** | | |
| <30 & ≥50 yrs. | | | | | | | -2.3* | -3.1** | -2.9** | | |
| Apartment type | | | | | | | | | | | |
| 1 & ≥3 bedrooms | | | | | | | | | 3.3*** | | -3.1** |
| 2 & ≥3 bedrooms | | | | | | | | | 2.3* | | -2.2* |
| Length of residency | | | | | | | | | | | |
| <6 mos. & 6-12 mos. | -2.5* | | | | | | -1.7 | -0.2 | -1.0 | | |
| <6 mos. & 1-3 yrs. | -2.8** | | | | | | -2.7** | -1.7 | -2.1* | | |
| <6 mos. & 3-5 yrs. | -1.9 | | | | | | -3.0** | -2.0* | -3.4*** | | |
| <6 mos. & >5 yrs. | -2.6** | | | | | | -4.1*** | -3.1** | -4.6*** | | |
| 6-12 mos. & 3-5 yrs. | 0.9 | | | | | | -1.1 | -1.8 | -2.4* | | |
| 6-12 mos. & >5 yrs. | 0.1 | | | | | | -2.3* | -2.9** | -3.6*** | | |
| 1-3 yrs. & > 5 yrs. | 0.1 | | | | | | -2.0* | -1.9 | -3.4*** | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Relationship with upstairs neighbors | | | | | | | | | | | |
| Good & Neutral | -2.6** | -0.5 | | | | | 0.9 | 1.9 | 1.3 | 1.5 | 0.3 |
| Good & Bad | -4.3*** | -2.4* | | | | | -5.5*** | -5.1*** | -3.3*** | -3.8*** | -2.0* |
| Neutral & Bad | -3.1** | -2.3* | | | | | -5.6*** | -4.4*** | -2.8** | -3.2** | -2.5* |
| Relationship with other neighbors | | | | | | | | | | | |
| Good & Bad | -3.7*** | | | | | -3.8*** | -2.7* | | | -2.9** | |
| Neutral & Bad | -3.2** | | | | | -3.6*** | -2.9** | | | -2.4* | |
| Weather-stripping - balcony door | | | | | | | | | | | |
| Yes & Do not know | | | | | | | | | 2.5* | | |
| Building age | | | | | | | | | | | |
| ≤ 10 & 11-15 yrs. | | -3.1** | -2.2* | | | | | -2.6** | -1.1 | -0.1 | |
| ≤ 10 & >15 yrs. | | -0.5 | -2.5* | | | | | -0.4 | 2.9** | 3.2** | |
| 11-15 & >15 yrs. | | 2.2* | -0.1 | | | | | 1.9 | 3.2** | 2.6** | |
| Willingness to pay | | | | | | | | | | | |
| Yes & No | | | | | | 1.7 | 3.4*** | 2.9** | | 2.5* | |
| Yes & Not sure | | | | | | 2.4* | 2.1* | 1.2 | | 1.4 | |

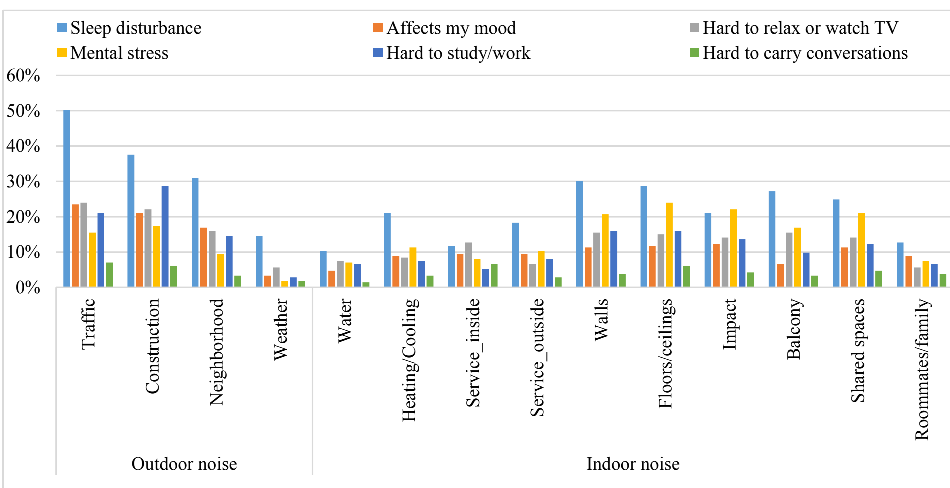


**Figure 5:** Reported effects of noise on respondents.

### 3.7 Noise mitigation measures

As shown in Figure 6, many respondents (90.1%) indicated closing their windows as an outdoor noise mitigation strategy. Other mitigation strategies were less commonly reported. It is important to note that 38.0% of the respondents specified playing music/TV loudly to mask noise. One respondent stated that they keep their balcony door open for fresh air but play loud music on their balcony to mask outdoor noise. Respondents also indicated that they leave the building (23.5%) and adjust their schedule (16.4%) to avoid noise which shows that occupants have very limited options to mitigate noise. In the open-ended question, respondents stated additional mitigation strategies. These include legal action, changing rooms or location within a room, avoid using certain spaces, such as balconies, using sound blocking curtains, installing acoustic foams and other acoustic retrofits. Some respondents specified turning off their HVAC or covering supply/return grilles, or regularly maintaining their HVAC system to reduce noise that might come from unmaintained HVAC systems, while others reported using noise from their HVAC to mask noise coming from outside their suite. A few respondents also stated that their building management is doing very little to address noise complaints. While not necessarily a mitigation strategy, more than 60% of the respondents indicated that they limit noise inducing behavior.

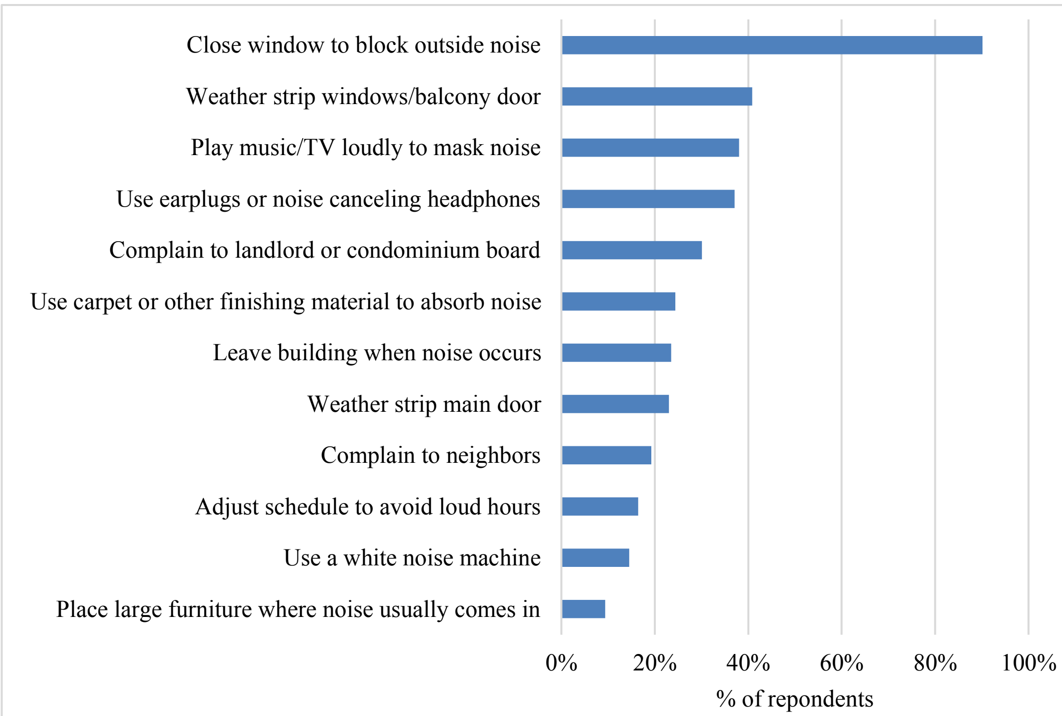


**Figure 6:** Summary of noise mitigation measures.

## 4 Discussion and recommendations

In contrast to the findings of some studies [18,19,26], the current study found that outdoor noises, specifically noise from traffic, construction and neighborhood activities, are more frequently experienced and cause more annoyance and sleep disturbance than indoor noises. We postulate that one of the reasons for this is the lack of regulation on façade sound insulation in the provincial building code [28], which gives developers little incentive to implement measures that can improve the acoustic performance of façades. The above-mentioned studies [18, 19, 26] are also conducted in Europe and Asia where there are relatively stringent energy code requirements with strict enforcement standards [29]. Better energy performance requirements, such as requirements for higher thermal insulation and improved airtightness, can contribute to the improvement of the acoustic performance of buildings [30]. The findings show that incorporating sound insulation requirements for building façades in the local building code is imperative. To reduce costs associated with noise control, requirements can be flexible for the upper floors. However, it is important to note that improving façade insulation can also decrease noise from neighboring suites' coming from inside the neighbors' suites or their balconies, thus additional measures should be taken to reduce noise coming from neighboring balconies in upper floors. Improving the acoustic performance of the façade can also improve the energy performance of the building as well as occupants' thermal comfort [30]. Similarly, a better energy efficiency standard can improve acoustic comfort.

Contrary to the results of some studies [9, 13, 31], the current study did not find any significant difference in annoyance levels with traffic and overall outdoor noise between suites that are facing a major roadway and those that are not. Bluhm et al. [32] suggest that the orientation of bedrooms is only important when there is a relatively lower traffic noise level. At high exposure levels, Bluhm et al. found that suites that are facing a major roadway and those that are not both expressed similar annoyance levels. Considering the high percentage of people who reported annoyance, and disturbance of sleep and other activities due to traffic noise, our findings indicate that respondents are exposed to high levels of traffic noise.

Our results show that the existence of balconies does not have any reduction effect on reported annoyance levels with outdoor noise, and, in fact, can increase exposure and thus annoyance to neighbors' noise from balconies. If not properly designed, balconies will not reduce outdoor noise levels, and can actually increase noise levels due to reflections from the ceiling and other hard surfaces on balconies [33]. Similarly, weather-stripping windows and balcony doors did not affect annoyance levels. Without any additional measures, especially proper selection of materials at the design stage or more rigorous retrofit measures, such as increasing insulation and adding absorptive materials, weather-stripping or sealing windows and doors alone will have minimum sound attenuation effects (typically 1 – 5 dB) [34, 35]. These results show that careful consideration of all façade components is important for better noise reduction.

While outdoor noises were found to be more problematic than indoor noises, a significant number of people still reported annoyance with indoor noises. This is likely due to the fact that, until 2020, the provincial building code did not include requirements for flanking sound transmission, and were given in terms of sound transmission class (STC) instead of apparent sound transmission class (ASTC) which takes into account flanking transmission paths [28]. Noise through walls and common building areas were thus reported more annoying than other indoor noise sources despite the minimum STC requirement of 50 for airborne sound insulation of indoor assemblies [28]. Similarly, respondents in suites close to elevators and garbage chutes expressed annoyance with the noise produced by these sources despite a minimum requirement of STC rating of 55. The building code also gives the option to show compliance to the requirements using laboratory measurements or preapproved assemblies that meet the requirements. The field performance of assemblies can, however, vary from that in laboratories and might not provide adequate sound insulation.

In addition, annoyance was reported for noise sources that are not currently regulated by the building code, including impact noise, noise from heating and cooling systems, and service installations inside suites. The current study also found that those who are exposed to high levels of outdoor noise indicate more annoyance towards indoor noises. Respondents in lower floors and those in buildings close to ongoing construction reported higher annoyance levels with indoor noises. This is in line with the Park and Lee study [36] which found that, instead of masking intermittent indoor noises, exposure to higher outdoor noise levels resulted in higher annoyance ratings and anger due to floor impact noise. These findings provide further proof for the need to carefully consider and implement both façade and indoor airborne and impact sound insulation.

This study identified disturbance of work/study as one of the important effects of noise exposure on MURB occupants. National and international noise guidelines recommend higher daytime background noise level limits for residences (typically 35 – 45 dBA) compared to enclosed offices (typically 30 – 35 dBA) based on the assumption that people do not work from their residences [37, 38]. WHO, for instance, states that the most important effects of noise in residences are sleep disturbance, annoyance and communication interference [6]. With a growing number of people working from home [39, 40], requirements for quieter residences should be implemented to limit the effects of noise on productivity. In addition, assumptions that sleep disturbance will not occur during daytime should be reviewed as our findings suggest that people have varying schedules and many people experience sleep disturbance during the daytime.

The results also suggest that poor indoor acoustic conditions in MURBs can result in occupants' actions that can negatively impact the indoor environmental conditions of their buildings as well as energy-adverse actions. Reduction in indoor air quality is one consequence of noise mitigating actions, such as turning off HVAC, covering supply/return grilles, or closing windows. Other actions, such as keeping the windows closed or keeping the HVAC on to mask other noise, can increase the heating and cooling demand of buildings. More importantly, some actions, such as playing loud music to mask noise, can exacerbate the acoustic condition in buildings which shows the importance of noise control in MURBs.

Despite existing evidence suggesting that people can adapt to noise [9, 41, 42], our findings show that length of residency does not have an effect on annoyance with outdoor noise. Weinstein [43] suggests that people tend to form opinions about the noise conditions in the first few days or few weeks and tend to stick to their initial opinion even if the actual effect of noise on the disturbance of their daily activity decreases. The current study also found that annoyance with indoor noise, particularly from neighbors, increased with increasing length of residency. One explanation for this is that, as a number of respondents indicated, short-term occupants have a temporary mindset and make less effort to reduce the noise they make, and thus are less likely to be disturbed by noise from others. Another explanation is the expectations of future noise levels. Residents who have been exposed to growing noise levels over past periods fear that the noise will keep increasing in the future [8,44]. With limited or no options to mitigate noise, occupants thus express more annoyance in anticipation of the noise increase.

## 5 Conclusions

This paper describes general acoustic comfort levels in MURBs, identifies important sources of noise in MURBs and presents factors that impact occupants' annoyance with noise and other effects of noise on occupants. Our findings indicate that many occupants are experiencing acoustic discomfort with both indoor and outdoor noises. Among the studied building-related factors, building age, type of apartment, floor level and proximity to ongoing construction were found to impact annoyance with outdoor noise. Proximity to a major roadway, existence of balcony, and weather-stripping had no influence on annoyance with outdoor noise. For indoor noise annoyance, the existence of balcony, apartment type, proximity to elevators and garbage chute had an impact. While age, ownership, Length of residency and willingness to pay for better acoustic conditions had negative impacts on annoyance with indoor noises, living with other occupants, having pets and better relationships with neighbors reduced annoyance levels. We found that traffic, construction and noise from outdoor neighborhood activities, cause more annoyance and sleep disturbance compared to indoor noises. For indoor noise, airborne noise from neighbors, and noise from heating and cooling systems were identified as more annoying than other sources. Our findings also show that lack of proper noise control options can lead to some noise mitigating behaviors which can have negative effects on indoor air quality and building energy consumption, as well as worsen the overall acoustic condition in buildings. While the current study identifies important factors that impact acoustic comfort, it is based on subjective assessment only. Future research can combine field acoustic measurements with subjective assessments to identify the relationship between building features, indoor noise levels and occupant comfort.

## Acknowledgments

The authors would like to thank the Natural Sciences and Engineering Research Council of Canada, the Ontario Ministry of Research and Innovation Early Researcher Award, and HGC Engineering for providing grants and financial support. The authors benefited from participating in the IEA EBC Annex 79 meetings.

## Appendix

**Table 6:** Survey questions and response options.

| | Questions | Response options |
|---|---|---|
| 1. | Gender | Male; Female; Prefer not to say |
| 2. | Age | 18 – 20 ; 21 – 29; 30 – 39; 40 – 49; 50 – 59; 60 or older; prefer not to say |
| 3. | For how long have you lived in your current apartment? | < 6 months; 6 – 12 months; 1 – 3 years ; 3 – 5 years ; > 5 years |
| 4. | What is your apartment ownership status: | I am renting; I own the apartment; Other (please specify):________ |
| 5. | Please indicate your typical schedule during weekdays.<br>• 7am – 9am; 9am – 11am; … | Home – asleep; Home – awake; Away |
| 6. | Please indicate your typical schedule during weekends.<br>• 7am – 9am; 9am – 11am; … | Home – asleep; Home – awake; Away |
| 7. | Please enter your street address. | __________________________ |
| 8. | What is your apartment type | Studio; One-bedroom; Two-bedroom; Three or more bedrooms |
| 9. | How many floors does your building have? | __________________________ |
| 10. | Which floor is your unit located on? (Ground floor = 1) | __________________________ |
| 11. | Is your apartment located near (adjacent to or across from the hall) an elevator? | Yes; No |
| 12. | Is your apartment unit located near (adjacent to or across from the hall) a garbage chute? | Yes; No |
| 13. | Does your apartment unit have a balcony? | Yes; No |
| 14. | Do any of the apartment units adjacent to your unit have balconies? | Yes; No |
| 15. | Is your apartment unit adjacent a roadway with 4 or more lanes (2 lanes each way)? | Yes; No |
| 16. | Please indicate if doors windows are weather-stripped.<br>• Door to hallway<br>• Windows<br>• Balcony door | Yes; No |
| 17. | Do you have dog(s), bird(s) or other noisy pets in your apartment unit? | Yes; No |
| 18. | Are you currently living with anyone else? | Yes; No |
| 19. | Please specify the number of full-time occupants in your unit.<br>• Adults (18 years or older); 11 – 17 years old; 6 – 10 years old; 1 – 5 years old; 1 year old or younger | (Specify number for each age group) |
| 20. | How would you describe your relationship with your upstairs neighbors? | Good; Neutral; Bad |

| | | |
|---|---|---|
| 21. | How would you describe your relationship with your neighbors on your floor or downstairs neighbors? | Good; Neutral; Bad |
| 22. | Thinking about the last 12 months in your apartment, how much were you bothered or annoyed by these outdoor noise sources?<br>• Traffic<br>• Construction<br>• Outdoor neighborhood activities: restaurants, people on the street, etc.<br>• Weather (e.g., wind)<br>• Other (please specify): | Not annoyed; Slightly annoyed; Moderately annoyed; Highly annoyed; Extremely annoyed; Not applicable |
| 23. | Thinking about the last 12 months in your apartment, how much were you bothered or annoyed by overall outdoor noise? | Same as above |
| 24. | Thinking about the last 12 months in your apartment, how much were you bothered or annoyed by these Indoor noise sources?<br>• Water installations: plumbing, flushing toilet, shower, etc.<br>• Heating/cooling: heaters, air conditioning, air supply grille, etc.<br>• Service installations inside unit: laundry machine, kitchen fan, etc.<br>• Service installations outside unit: elevator, garbage chute, etc.<br>• Noise through walls: people talking, pets, etc.<br>• Footsteps, moving furniture and other impact noise<br>• Noise through floors/ceilings: people talking, pets, etc.<br>• Noise from balconies<br>• Noise from shared spaces: e.g., hallways and stairways.<br>• Other occupants in the same unit: talking, other activities<br>• Other (please specify): | Same as above |
| 25. | Thinking about the last 12 months in your apartment, how much were you bothered or annoyed by overall indoor noise? | Same as above |
| 26. | Please indicate the time(s) of day when the following noise is the highest. Please select all that apply. (Same outdoor and indoor noise source options as question #22 and #24) | Continuous; 7am– 12pm; 12pm–7pm; 7pm–11 pm; 11pm–7am; Not applicable |
| 27. | Please indicate the day(s) when the following noise is the highest. (Same outdoor and indoor noise source options as question #22 and #24) | Weekday; Weekend; Both; Not applicable |
| 28. | Please indicate any effects each noise source might have on your daily activities. Please select all that apply. (Same outdoor and indoor noise source options as question #22 and #24) | Sleep disturbance; Hard to work/study; Hard to relax or watch TV; Hard to carry conversations; Affects my mood; Mental stress; No effect; Not applicable |
| 29. | Do you use any of the following noise mitigation measures in your unit?<br>• Close the window to block outside noise<br>• Weather strip windows or balcony door<br>• Weather strip main door<br>• Complain to neighbor about the noise<br>• Complain to landlord or board about the noise<br>• Use carpet or other finishing material to absorb noise<br>• Place large furniture where noise usually comes in<br>• Leave building when the noise occurs<br>• Adjust schedule to avoid loud hours<br>• Use a white noise machine<br>• Use earplugs or noise-canceling headphones<br>• Play music/TV loudly to mask the noise<br>• I/We limit noise inducing behavior (decrease music/TV volume, don't use vacuum cleaner at night, etc.)<br>• Other (please specify): _________ | Yes ; No |
| 30. | Is there anything you would like to add regarding the acoustic comfort in your unit? | _________________________ |
| 31. | Would you pay more for a unit with better noise insulation? | Yes; No; Not sure |

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