An Assessment Model for the Indoor Noise Environment of Aged Apartment Houses

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Abstract
Detached houses have been established as the traditional lifestyle of housing in Korea for thousands of years. However, apartment houses have been introduced in urban areas to meet the needs of industrialization since the 1970's. The primary consideration of these residential structures then was the rapid construction of mass housing for urbanites rather than building performance (i.e. indoor acoustic quality). Today, residents of old, first generation apartment houses are complaining of indoor noise. This study was conducted to understand the nature of occupants' complaints, and to investigate any gaps between residents' expectations concerning their indoor acoustics vis-à-vis actual performance of their apartment unit. A model for assessing the indoor acoustic environment was designed, comprising of five noise elements - floor impact noise, heavy weight floor impact noise, plumbing noise, unit-to-unit sound insulation, and traffic noise level - and their target performance levels. Measurements on five elements in actual apartment houses were performed, as well as a comparison of the results based on the residents' expectations obtained by a questionnaire survey and target levels given by the assessment model. The results have illustrated a good agreement between the measurement data and the modelled acoustic performance levels. It shows that the careful design of floor structure and plumbing systems provides a better acoustic performance for life in apartments.

Keywords: indoor noise; assessment model; apartment houses

1. Introduction
The rapid growth of Korean industries has caused a corresponding rise in urbanization. Mass housing systems such as apartment houses are the most efficient means to accommodate people living in close proximity in urban areas. Most apartments have accommodation areas of from 65 m² to 85 m², with two or three bedrooms. A row of apartments typically consists of 6 to 8 units. These apartment units are typically constructed with transverse load bearing walls, 150 mm to 200 mm thick and with longitudinal beams structurally supporting the building. The floors are usually hard-core concrete with an underfloor heating system. Occupants usually live indoors with their shoes removed, and complaints concerning noise generally include: floor impact noise generated by the bare heels of jumping children, or other sources, such as plumbing devices (e.g. washing machine and toilet flushing), airborne noise transmissions (e.g. television or hi-fi), and also noises from outdoor traffic.

When urbanization began, the primary concern was residential accommodation with mass housing, rather than the quality of living, which includes the indoor acoustic environment. With time, the requirements to provide mass housing facilities have been gradually reduced; while the demand for higher standards of living for urban residents continues to rise. The acoustic performance of recently built apartments is much better than that of first-generation apartments. There is a growing discrepancy between old and the new apartment buildings regarding the quality of the noise environment. While some old apartments have been demolished and rebuilt, and some renovated, there are still many old apartments that will need to be brought up-to-date to meet modern living standards. Demolishing and rebuilding is relatively simple as far as the acoustic environment is concerned, as these would be treated as a new building project. However, renovation is encouraged to minimize the possible damage to the urban environment. In the case of renovation, the process must be based on the current condition of the building and must meet the requirements of the Korean Building code.

To execute successful renovation of an apartment building, there are several important considerations; for instance: What are the residents' major discomforts and complaints? How low are the current acoustic elements performing? How high should the performance targets for those items be designed for, based on the Korean...
Building code or other regulations? Are these targets attainable? This study was undertaken to investigate the aforementioned questions. Surveys on the complaints of residents living in first generation apartments were carried out. An acoustic assessment model was proposed based on the survey results. Measurements and assessments were performed according to the model to illustrate the model’s validity.

2. Surveys on Residents’ Discomfort from Indoor Noise

2.1 Subjects

Two blocks of 20-year old apartment houses were investigated. The current residents, whether they are landlords or tenants, were asked to agree an interview and/or fill in a questionnaire. A total of 122 samples were collected after a full-day survey, as shown in Fig.1. Details of the apartment blocks are presented in Table 1.

Table 1. Details of the Two Apartment Blocks

| Block A | Block B |
|---------|---------|
| Date of completion | May 1986 | Oct. 1986 |
| No. of floors | 12 | 12 |
| No. of units | 384 | 192 |
| Unit area, m² | 85, 150 | 110, 180 |
| No. of floors | 15 | 15 |
| No. of units | 480 | 720 |
| Unit area, m² | 110 | 85, 110 |
| No. of units | 864 | 912 |
| Structure | Reinforced Concrete load bearing wall |
| Thickness of slab | 135mm |
| Plumbing specs. | Vertical fit, Non isolated pipe runs, toilet sewage pipe runs underneath ceiling plenum |
| Building arrangement | Linear shape, grid arrangement, located in a subcenter of a city |
| Outdoor Traffic Noise | 64dBA(5 min Leq) |

2.2 Content of the Questionnaire and Interview (Please refer to Table 2.)

The survey basically asked respondents to identify themselves, and then asked them to describe the possible sources of noises in their apartment houses e.g. floor impact noises, floor airborne noise, plumbing noise, noise from next door units, other sources such as traffic noise and so on. This survey is concentrated on the engineering aspect of the noise environment of old apartment houses. Socio-economic analyses such as the ownership and unit volume were not performed.

Table 2. Content of the Questionnaire

| Contents |
|----------|
| Address, sex, age, family status, unit type, period of residence |
| Degree of satisfaction | Current situation, reason for the discomfort, further demand |
| Floor impact noise | Floor impact noise, heavy weight floor impact noise, major noise sources, reason for the discomfort etc. |
| Floor airborne noise | Airborne noise between floors, noise from ducts, major noise sources, reason for the discomfort etc. |
| Plumbing noise | Noise from pipe runs, fixture, appliances, pumps etc. |
| Unit-to-unit airborne noise | Noise from the next door units, reason for the discomfort etc. |
| Other noise sources | Traffic noise, community noise, noise from other sources etc. |

2.3 Results

General degree of satisfaction

About a quarter of the subjects share more or less the same amount of discomfort, as shown in Fig.2. The difference in the response was partly affected by the actual noise environment, and by the individual’s threshold and sensitivity to noise. Heavy weight floor impact noise and plumbing noise are the major parameters indicated by the residents which would produce the major noise discomfort as shown in Table 3. and Fig.3. Of the 122 subjects, 41.8% complained about the heavy weight floor impact noise, and 17.2% complained about standard floor impact noise. The shallow concrete slabs used in the early 1980’s are generally poorly insulated against heavy weight impact whereas the floating structure of the floor panel heating system, of the present flooring system has good insulation against standard floor impact noise. Jeon reported that a 2dB decrease in heavy weight floor impact noise could be achieved, if the thickness of slab is increased by 30mm from 150mm to 240mm. Over 30% of respondents complained about plumbing
noise. The major sources of plumbing noise are from the water supply, water drain and toilet flushing. Water supply noise may be serious when the pipe run is connected to the building structure, whereas toilet flushing noise is generally affected by the drain system, which is installed through the ceiling plenum of the unit underneath the toilet.

Table 3. Sources of Indoor Noise Identified to Cause Discomfort Among Apartment Residents

| Parameters                            | Number of marking/122 | Rating (%) |
|---------------------------------------|-----------------------|------------|
| Heavy weight floor impact noise       | 51                    | 41.8       |
| Floor impact noise                    | 21                    | 17.2       |
| Machinery noise                       | 21                    | 17.2       |
| Airborne noise from next units        | 25                    | 20.5       |
| Floor airborne noise transmission     | 18                    | 14.8       |
| Plumbing noise                        | 42                    | 34.4       |
| Noise from other noise sources        | 27                    | 22.1       |
| Miscellaneous remarks                |                       |            |

Heavy weight floor impact noise

Floor impact noise, especially from heavy weight impact sources is the most frequently identified discomfort parameter. The impact is typically caused by the footsteps of children, for example, running across the living room and jumping from the sofa. A standard heavy weight impact source, the Bang Machine, has been specified by the Korea measurement standard KS F 2810-2 (Fig.4.) for testing and determination of repeatability and reproducibility of measurements. Subjects were asked to assess the degree of satisfaction in terms of the floor impact noise transmitted from upstairs, and to guess the discomfort of residents living underneath because of the heavy weight impact noise that they themselves had generated. An interesting contrast was found in their answers. As shown in Fig.3. and Fig.4., 33% of the subjects believed that they were suffering from excessive heavy weight impact noise from upstairs. In contrast, only 17% of respondents believed that the residents underneath their apartment could be feeling discomfort. This means that the noise insulation performance of first-generation apartments with shallow floor slabs is worse than they are perceived by the residents.

Fig.3. Web Diagram of Discomfort Factors (frequency)

Fig.4. Bang Machine (KS F 2810-2)

Fig.5. Degree of Satisfaction on the Noise from Upstairs
Plumbing noise

General plumbing noise is the second most frequently selected source of discomfort. A quarter of the subjects indicated this area as "unsatisfactory". Those who identified the noise to be an "extremely unsatisfactory" case were fewer than those who identified the heavy weight floor impact noise in the same category. It is widely known that toilet flushing upstairs can be annoying due to the penetrated sewage pipe that runs through the ceiling plenum and transmitting noise along the length of the piping. Water supply noise was identified to be the most uncomfortable source of plumbing noise in this survey. This was reported despite the fact that over 80% of the units have changed their fixtures as a part of the partial renovation program of the building management. Thus, there could be problems with the design, pipeline isolation and the pressure of water supply and/or duct connection, among others that still need to be resolved to reduce noise discomfort.

### 3. Building an Assessment Model and Measurement

#### 3.1 Assessment Model

As shown in the survey, there have been discomforts of residents due to indoor noise, which affected the satisfaction of the occupants of old apartment buildings. To quantify actual performance, an acoustic assessment model is proposed. The elements of the model and its target performance are shown in Table 4. There are five parameters in the evaluation model; floor impact noise, heavy weight floor impact noise, plumbing noise, unit-to-unit airborne noise transmission, and traffic noise level in units. The target levels for each of the five parameters are set up in the specified evaluation model. Heavy weight floor impact noise and plumbing noise are included as they are the most frequently marked discomfort factors from the survey. Heavy weight floor impact noise, measured in the room underneath the Bang Machine's strike, should be lower than 50dB (L'1, Fmax, AW), according to the Korean standards. Plumbing noise, particularly water supply noise, is presented as the second highest discomfort factor regarding indoor noise. In spite of the unpleasant response from the residents, there are currently no laws and regulations concerning plumbing noise. The target of 45dBA has been proposed based on the same level as the regulated indoor traffic noise level. Plumbing noise may be the only dominant noise if it exceeds 45dBA. On the other hand, there is no need for a far lower plumbing noise level than 45dBA if the outside traffic noise level measured indoors is regulated around 45dBA. This is the reason why the target level for plumbing noise was proposed as 45dBA. Unit-to-unit airborne sound insulation performance and the standard floor impact noise are included in the acoustic assessment model as they are components of the Apartment House Performance Grade Indication System and are also regulated by law. Unit-to-unit sound insulation performance should be at least 48dB (Dntw). The traffic noise level measured inside the apartment unit has been chosen to be the final part of the model. The law stipulates that the traffic noise level measured inside should not exceed 45dB.

| Parameter                  | Target Level |
|---------------------------|--------------|
| Floor impact noise        | 50dB         |
| Heavy weight floor impact | 45dBA        |
| Plumbing noise            | 45dBA        |
| Unit-to-unit airborne     | 48dB         |
| Traffic noise             | 45dB         |
3.2 Measurement According to the Model

To prove the validity of the assessment model, the model was run with the parameters given based on existing apartment units. Old apartments where residents are currently living are necessary for survey purpose, while evacuated old apartments are needed for noisy impact sound measurements and mock up experiments.

The results of the measurements were compared with the surveyed residents' responses. The apartment units where the measurements were undertaken were built in 1979 and have never undergone any renovation nor remodeling. As shown in Fig.10., the apartments were totally evacuated for demolition and a further reconstruction project. The background noise level was very low, far below 40dBA as presented in Table 5. The measuring equipment included two types of standard impact sources, an omni-directional loudspeaker and actual plumbing fixtures as noise sources; and Oros and Svan912 as analyzers. The apartment unit plan and measurement parameters are presented in Fig.11.

3.3 Measurement Results

The overall result (Table 5.) shows that there are deficiencies in the performance of heavy weight floor impact noise and plumbing noise (Table 6.). The heavy weight floor impact noise level for both the master bedroom and the living room were calculated based on the Korean Industrial Standard KS F 2863-2. The single number levels were 51dB in the living room and 56dB in the master bedroom. Fig.11. was presented to show the difference between the two rooms based on the trends of the actual performance according to the frequency bands. The structural system of the test apartment is composed of floor slab perimeter load bearing walls instead of beams and columns as in usual apartments in Korea. The tight and wide bonding between the slabs and the load bearing walls effectively transmits noise to the rooms underneath. The bonding between the slab and four perimeter walls in the master bedroom are tighter than the living room with a relatively open layout as shown in Fig.11. This may be the major reason why the impact noise level of the master bedroom and living room are quite different. There are variations among the floor impact noise measurements. Some of them are obviously coming from the unevenly distributed microphone positions. Unit-to-unit airborne noise transmission and traffic noise level, both inside and outside, are quite satisfactory, while floor impact noise generated using a standard tapping machine was marginal. The structural system of the test apartment consists of slabs supported by load bearing walls. The unit-to-unit walls are 150 mm thick load bearing reinforced concrete walls. This is the reason why the unit-to-unit airborne noise levels are quite low. To ensure the accuracy of the current profile, details on the poor performance of the two parameters were investigated further.

4. Discussions

4.1 Possible Remediation for Heavy Weight Floor Impact Noise

The rating scheme of heavy weight floor impact noise as given in KS F 2863-2 is drawn from a comparison of the measured value with the reference curve, from 63Hz to 500Hz in the octave bands. The octave band value at 500Hz of the shifted reference curve is a single number, which allows less than 8 dB's deviation throughout the frequency bands for comparison. As seen in Fig.11., the actual performance of both rooms was deficient from the 50dB reference curve in almost
all the frequency bands. This is the reason why the residents complained about the poor performance. The value measured in the master bedroom was higher because of the floor slab’s tight conjunction with load-bearing walls, which had particularly affected the lower frequency band transmission. The levels at 500Hz were found to be almost the same, whereas they were much higher at 63Hz and 125Hz. Floating floors with resilient dampers, would increase the stiffness of the floor slabs, using damping hangers for the ceiling and placing absorbers in the ceiling plenum are some of the suggested measures to improve performance. From a later research on the factors governing heavy weight floor impact sound generated by tires, the noise environment can be improved by changing the mass and stiffness of concrete slabs, a resilient floor support system, and even the ceiling support system and its plenum.  

4.2 Remediation for Plumbing Noise

Measurements were taken according to the procedure developed by the working group, which produced the drafting of a new Korean Standard. Noise from three different noise sources should be measured at least three different positions. For all the noise sources, at almost all the microphone positions, the levels were higher than the target value, 45dBA. As predicted from the survey (Fig.9.), any kind of water supply noise would be higher than the other types of noise sources. The results are shown in Table 6. Hammering noise from the pipeline was also noted during the measurement. Lowering of water supply pressure, isolation of pipelines in the building, pipe jacketing and insulation of airborne noise through ducts and doors are possible measures to reduce noise from plumbing devices.

Table 5. A Summary of the Overall Result of the Measurement of Five Major Noise Sources

| Parameters                     | Targets                  | Results                     | Remarks                  |
|--------------------------------|--------------------------|-----------------------------|--------------------------|
| Heavy weight floor impact noise | $L_{U/Fmax,AW} \leq 50$ dB | Living room 51dB, Master’s bedroom 56dB | 1dB to 6dB to be improved |
| Plumbing noise                 | SPL $\leq 45$ dBA        | Living room 47.4dB, Master’s bedroom 49.2dBA (Bath 63.2 dBA) | 2.4 dBA to 4.2dBA to be improved |
| Airborne sound insulation      | $D_{ntw} \geq 48$        | 52                          | OK                       |
| Floor impact noise             | $L_{e,AW} \leq 58$ dB    | Living room 58dB, Master’s bedroom 55dB | OK                       |
| Traffic noise level (indoor)   | $L_{eq} \leq 45$ dBA     | Far below 40                | OK                       |

Table 6. Overall Result of the Measurement of Plumbing Noise Sources

| Noise Sources | SPL in dBAs at microphone positions |
|---------------|-------------------------------------|
|               | Bath | Living room | Master's bedroom |
|----------------|------------------------------------|-------------------|
| Bath           | Supply | 68.5 | 49.9 | 48.9 |
|                | Drain | 59.0 | 44.7 | 45.7 |
| Washbowl       | Supply | 67.2 | 49.0 | 48.6 |
|                | Drain | 55.9 | 38.7 | 45.9 |
| Toilet         | Same unit: Supply | 62.4 | 44.7 | 47.2 |
|                | Flush | 63.2 | 47.4 | 49.2 |
|                | Underneath unit: Supply | 54.8 | - | 33.6 |
|                | Flush | 56.4 | - | 45.3 |

Fig.12. Comparison of the Measured Value with 50dB Reference Curve (Target)
4.3 Outdoor Traffic Noise

The outdoor noise environment is getting worse as a result of rapid urbanization in Korea. Residents living in such a deteriorating situation tend not to place much blame on it. There may be two reasons for this. Firstly, residents are well aware of the inevitable noise situation in densely urbanized residential blocks. Secondly, unlike floor impact noise and plumbing noise, there are hardly any targets on which to place blame for outdoor traffic noise.

5. Conclusion

To carry out successful acoustic remodelling of old, first-generation apartments, it is essential to assess the current performance of the indoor noise environment to identify problem areas in order to remedy major identified noise sources such as impact and plumbing noises.

A questionnaire survey was carried out to assess the complaints given by residents, who are living in old first-generation apartments. From a list of various noise sources, the noises which are causing them discomfort are identified. The most frequently marked sources were the heavy weight floor impact noise and plumbing noise. An acoustical assessment model was developed based on the survey results. The model included an assessment of standard floor impact noise, heavy weight floor impact noise, plumbing noise, airborne sound transmission from the apartment unit next door, and traffic noise.

Measurements and assessments were performed to ensure that the model was representative and could accurately reflect the current indoor noise environment. Overall, the results show that there are deficiencies in performance for heavy weight floor impact noise and plumbing noise, as illustrated in the survey. The unit-to-unit sound insulation and traffic noise level, both inside and outside, were quite satisfactory, whereas floor impact noise generated using a standard tapping machine was marginally satisfactory.

The purpose of this paper is to propose an assessment model for the indoor noise environment of aged apartment houses. Further research on the specific way of reconstruction and its effect will be followed based on this paper.

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Notes

1. The unit is the frequency in the survey, rated from 15 (floor airborne noise transmission) to 51 (heavy weight floor impact noise).
2. The 'Remarks' field in the questionnaire was not for a quantitative measure. Subjects are allowed to present any feeling and/or opinion voluntarily in that open field. Subjects who mentioned footsteps would have already marked a discomfort in (heavy weight) floor impact noise.

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