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Sources, Effects, and Control of Noise in Indoor/Outdoor Living Environments

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Objective: To study the sources of indoor noise, its effects on human health, noise assessment and regulation through the use of standards, and techniques used to reduce noise.

Background: Noise significantly affects the living environment, and there are an increasing number of reports of its impacts on human health.

Method: We reviewed domestic and foreign data regarding environmental noise, and examined its effects and the standards used to regulate noise levels.

Results: We describe the major sources of indoor noise and suggest possible legal standards, as well as recommended criteria for the control of noise.

Conclusion: South Korea has higher legal standards of environmental noise than international standards in terms of threshold values. People in Korea are exposed to various sources of noise, and therefore the reduction of noise is urgently required.

Application: Depending on the features of indoor spaces, an appropriate degree of indoor noise can be determined and techniques to reduce excess noise are required.

Keywords: Noise, Environment, Indoor, Health effect, Regulation

1. Introduction

Noise can be defined as "undesired sound" (British Standards Institute, 1961) "unwanted sound" (American National Standards Institute, 1971) or a sound harmful to the human body, both mentally and physically. Environmental noise is considered to be unwanted harmful sound in outdoor spaces, generated by human activities and including noise from roads, railways, aircraft, and factories. Article 2 of the Noise and Vibration Control Act in Korea defines noise as "strong sound generated by the use of machines, furniture, facilities, and other objects, or by human activities from locations, including apartments" and was established by the Ordinance of the Environment Ministry. Noise is a generic term for any sound that humans do not want to hear. General noise includes loud sounds, annoying tones or impacts of sound, sounds that disturb people when listening to voices or music, sounds causing physiological impairment, sounds hindering concentration or attention at work, and sounds disturbing deep sleep or rest.

The World Health Organization (WHO) recently considered the effects of noise, and referred to it as sensation pollution, because noise is sensed through human sensory organs. The number of people complaining of hearing impairments is increasing, not only due to occupational exposure to industrial and construction site noise (e.g., blast noise, heavy construction equipment), but also due to noise in everyday life, including the operation of automobiles, subways, high speed trains, aircraft, televisions, karaoke (singing rooms), and cellphone sounds. In the United States, 9 million people are exposed to sound levels higher than 85dB, and 10 million people have a noise-induced hearing loss of 25dB or higher. In Europe, more than 28% (i.e., ¼) of all workers are exposed to sound levels of 85~90dB. About 120 to 250 million people worldwide are estimated to have some degree of hearing loss, with hearing loss now considered to be the 15th major health problem globally (Nelson et al., 2005). It is estimated that 16% of the hearing loss that develops in adults is derived from exposure to noise. In the United States, the Third National Health and Nutrition Examination Survey (NHANES III), reported that 12.5% of children aged 6~19 years (5.2 million people) have noise-induced hearing threshold shifts (NITS), based on the results of audiology tests on 5,249 children between 1988 and 1994. This suggests that they are exposed to high levels of noise (Niskar et al., 2001).

Due to the high rate of economic growth after the 1970s in Korea, national living standards have risen substantially in terms of material consumption. However, many difficulties have been experienced in maintaining a quiet living environment due to the concentration of people in cities, and an increase in noise caused by factories, construction sites, and transportation (e.g., automobiles and railways) has been a negative effect of economic development. Noise problems have emerged as an acute social problem in Korean communities, with 56,244 cases reported in 2011, an increase of 4.7% compared to 2010, and 47.4% compared to 2007. Noise problems account for 33.4% of total civil complaints in the environmental field (Kim, 2013).

The noise from industrial workplaces is not only the cause of noise-induced hearing loss, it can also result in direct damage including accidents or a decline in work efficiency. The physical, emotional, behavioral, and social functions of humans are influenced as a secondary effect of such noises. The response to noise differs, according to the strength, frequency, and complexity of the noise, as well as the exposure time and individual sensitivity to a particular noise.

Generally, occupational noise is experienced in the workplace, and many studies that have focused on auditory effects such as acoustic trauma and noise-induced hearing loss have been conducted. However, environmental noise—such as everyday noise from roads, railways, aircraft, and construction—leads to non-auditory effects, such as annoyance, disturbance of sleep, cardiovascular disease, and the impairment of the cognitive performance of children. Health effects such as these display an exposure-response relationship with the noise level. Objective disturbances to sleep can occur with a night-time indoor noise level of 50dB(A) (Stansfeld & Matheson, 2003), with a dramatic increase in disturbances reported at night-time indoor noise levels of 70dB(A) (Yoshida & Osada, 1997). The noise level due to road traffic that does not disturb hearing and produces almost no annoyance within a house is estimated to be 55~62dB. As the L_{den} of 1dB increases, it is reported that annoyance complaints increase by 12% (Klaeboe et al., 2004).

2. Indoor Noise Sources

Environmental noise has become an important everyday problem in modern living environments. Noise from roads with heavy traffic, airports, and factories is not simply a discomfort to citizens living close to these sources of noise, but it also disturbs everyday life and can cause serious health effects and diseases.

Table 1 gives a classification of noise types and the major sources of noise in modern urban life. The sources of noise that cause damage in the residential indoor environment can be divided into noise generated externally and noise generated inside apartments. The largest source of outdoor noise is traffic, including aircraft, railway noise, and roads (automobiles). Noise generated inside apartments and offices includes floor impacts, sounds transmitted by air between households, plumbing equipment, home appliances, and climate control equipment (Table 1). Noise from floor impacts in the indoor environment and construction noise in the outdoor environment account for most of the civil complaints and environmental dispute mediation applications.

Table 1. Classification of noise sources

Types of noise	Noise sources
Human movement	Everyday human activities: speech, household appliances, instruments, buzzers, footsteps on stairs, children playing
Power engines	Traffic noise from automobiles and aircraft, plant machinery noise
Building equipment	Plumbing equipment
Construction/operation	Construction, workplace noise
Human gatherings	Crowd noise in schools, venues, and public facilities
Other	Sirens, alert sounds, loudspeakers, street broadcasts

According to the 2010 census of population and housing, since the late 1970s more than 60% of houses supplied in Korea have been apartments. Therefore, apartments have become a universal type of residence that cannot be excluded from residential spaces in Korea. However, in most apartments consideration of the building's environmental performance has been insufficient, with the focus being on quantitative expansion. Inter-floor noise, noise from plumbing equipment and room-to-room sound insulation have been the subject of a large number of complaints by residents (Lee et al., 2008).

Floor-impact noise caused by direct impacts on concrete surfaces is a direct cause of inter-floor noise. Floor-impact noise can be divided into light- and heavy-impact noise. Light-impact noise includes sounds such as the dragging of a dining table, pounding garlic, and the sound of a falling object. These sounds can surprise a person, but the annoyance is small because there is no reverberation. Heavy-impact noise, such as the sound of children playing, involves reverberation. Consequently, heavy impact noise can lead to severe annoyance, and serious cases can cause mental pain.

Recent trends in living environment noise can be summarized as follows. (1) An expansion of the area affected by road traffic noise and an increase in the number of citizens affected has occurred due to urbanization. (2) A rise in the number of civil complaints by the occupiers of apartments has emerged as a social issue, and design practices that consider noise and vibration from the construction stage have been adopted, with apartment certification systems in use. (3) Areas around new railways have been damaged by noise due to the opening of domestic high-speed railways. (4) An increase in civil complaints due to noise damage around airports has occurred, particularly due to the operation of Incheon Airport and the use of military aircraft in large city airports. (5) Construction site noise damage has occurred at shooting ranges and in large-scale housing development districts.

More than half of the total population of Korea are living as noise victims. The population exposed to damaging levels of noise increases annually due to construction site noise arising from an increase in the urban population, indoor noise within apartments, and noise due to leisure and recreational activities.

Many studies of environmental noise have been conducted worldwide, with a focus on the emerging issue of noise pollution due to industrialization and urbanization. In Curitiba, Brazil, with a population of 1.5 million, 93.3% of 1,000 measurement points exceeded 65dB(A) and 40.3% exceeded 75dB(A), while 80.6% of the population were reported to be exposed to noise levels of

70dB(A) or higher (Zannin et al., 2002). Caceres in Spain is a non-industrialized, small city, but Barrigon Morillas et al. (2002) reported that 90% of the city region exceeded a noise level of 65dB(A), with the main source of noise being road traffic. In Beijing, China, Zheng et al. (1996) reported that the average environmental noise exposure of citizens was 75.6dB for 24 hours, with 86% of those surveyed exposed to levels of 70dB or higher.

The biggest problem in the residential environment was noise problems, largely due to external automobile and motorcycle noise, railway noise, and noise from adjacent houses and the upper floors. In a study of one-room multiplex houses, the average noise level in almost all houses was higher than 40dB(A), with the major noise sources being external noise, indoor living noise, plumbing equipment noise, and corridor noise (Choi, 2005). As a result of measuring 10 sources of noise (external noise from traffic outside buildings, conversations, living equipment, general living activities, plumbing equipment, footsteps, falling objects, and the dragging of furniture and chairs, and internal general living noise and equipment noise caused by residents inside the housing unit) with the highest frequency of occurrence and equivalent noise levels among the sources of general living noise inside and outside apartments, the maximum level was found to exceed the legal criteria during specific time slots. Therefore, Shin et al. (2015) indicated the need for the segmentation of legal standards, centered on time slots per noise source, and for more consolidation of existing standards.

3. Effects of Noise on Health

Unlike other types of environmental pollution, environmental noise from traffic has continuously increased, and has emerged as a serious social issue in many countries.

Although it has long been known that hearing loss can result from long-term exposure to noise, the non-auditory effects of noise exposure have only recently been studied. Non-auditory effects of noise exposure are largely physiological and include effects on the cardiovascular system, the impairment of work performance and normal behavior, sleep disorders, and disturbance to conversations; i.e., effects on health and everyday life. The impairment of work performance and normal behavior is mainly a secondary effect that causes a decline in work efficiency, and difficulties in conversation due to a reduction in attention. This can lead to workplace accidents, but it is difficult to identify the risk signals leading to such events.

Hearing impairment due to noise exposure is the most frequent irreversible occupational hazard worldwide, and therefore the importance of risk factors for hearing impairment due to both environmental and occupational noise, has gradually increased. There are no hearing impairment effects, if the average noise exposure level (LAeq, 8h) is less than 75dB(A), despite long-term exposure to noise (ISO, 1990). Over a 24-hour period, the environmental noise level that can cause hearing loss is reported to be 70dB (Passchier-Vermerr & Passchier, 2000).

The physiological effects of noise include effects on the cardiovascular, endocrine, nervous, and digestive systems. Noise has other physiological effects that can lead to epidermal hematocele, peripheral vasoconstriction, shaking, secretion of gastric juice, activity of gastro-intestinal tract, and bio-electrical activity in the brain, as well as having an impact on breathing, heartbeat, and skin temperature. Noise also has bio-chemical effects and can lead to changes in blood lipid, blood glucose, cortisol, epinephrine, norepinephrine, dopamine, growth hormone, magnesium (Mg), and calcium (Ca) concentrations. The response to noise is referred to as an N-response, and can cause the following. ① A response in the blood vessels with a small change of heartbeat and an increase in cerebral blood flow, characterized by peripheral vasoconstriction. ② Slow and deep breathing. ③ Changes in skin resistance following electric stimulation. ④ Changes in skeletal and muscular tension. The gastrointestinal tract causes these changes through a series of responses, and chemical changes within urine and blood can be caused by endocrine gland stimulation. A noise level of approximately 70dB can cause an N-response.

The results of studies of the cardiovascular effects of noise have shown limited-to-moderate effects on blood pressure. In general, if a person is exposed to noise, their blood pressure rises due to an increase in resistance through peripheral blood vessels via stimulation of the sympathetic nerve. Animal experiments have shown that a perpetual blood pressure increase is induced with repeated exposure to noise, until high blood pressure conditions occur due to structural changes in the peripheral blood vessels. When the noise is sufficiently loud and the exposure is unpredictable, a cardiovascular response occurs. Heartbeat and peripheral blood vessel resistance increases, and blood pressure, viscosity, and blood lipid levels change. There are also changes in electrolyte levels (Mg and Ca), and hormone levels, including epinephrine, norepinephrine, and cortisol (Ising & Gunther, 1997).

The disturbance of conversation through exposure to noise prevents understanding and the exchange of information. Mental health effects can result, such as the reduction of mental concentration, fatigue, lack of confidence, restlessness, misunderstanding, reduction of capability, problems with human relations, and various stressful responses. Individuals particularly prone to such effects include those who have hearing impairments, elderly people, children during the language learning process, and individuals who are not accustomed to a spoken language. These groups can account for a large portion of a nation's population (Lazarus, 1998). The factors that affect the understanding of the details of a conversation include the sound pressure level of the spoken words, pronunciation, distance between conversing people, characteristics of the intervening noise, characteristics of the indoor space (e.g., degree of sound reflection), and the hearing and attention capacity of the listener. For a person with normal hearing to completely understand a sentence, the signal-to-noise ratio (i.e., the difference in sound pressure level between the sound level of the conversation and the intervening noise) needs to be 15~18dB(A) (Lazarus, 1990).

Comfortable and undisturbed sleep is a prerequisite for maintaining healthy physiological and mental functions, but environmental noise is known to be an important factor in the disturbance of sleep. The primary effects of exposure to noise on sleep include difficulty in sleeping, waking up during sleep, changes in the stage or depth of sleep (especially REM: rapid eye movement), and reduction of sleep (Hobson, 1989). In addition, physiological effects during sleep include a rise in blood pressure, an increased pulse, contraction of blood vessels, change of breathing, cardiac arrhythmia, and an increase in body movement (Berglund & Lindvall, 1995). Exposure to noise at night also has secondary effects. These effects are observed during the waking period of the day following a night-time noise exposure. They include a feeling of ineffective sleep, fatigue, depression, and the reduction of work ability. People, who are sensitive to noise exposure during the night are the elderly, shift workers, individuals who are physically and mentally impaired, and individuals suffering from an existing sleep impairment.

Workers that are required to perform complex work requiring care, paying attention to various situations, and maintaining an operational memory capacity are negatively influenced by noise (Poulton, 1979). Irregular and intermittent noise is directly related to a decline in task performance (Eschenbrenner, 1971). In a study of worker's task performance at noise levels of 75~86 dB, which is the noise level of a general workplace, a reduction of conversation, numerical competence, cognitive ability, and reasoning power was identified (Kim et al., 2010). In a study targeting children, exposure to chronic aircraft noise affected learning, performance, and recollection due to the impairment of hearing. If a person has a language impairment or their learning motivation is low, these effects are more serious.

Annoyance is the most extensive of the negative effects of noise exposure. A feeling of annoyance is known to have a generally harmful influence on individuals and can be related to environmental factors (Koelega, 1987). People exposed to environmental noise can feel various negative emotions, including anger, disappointment, dissatisfaction, contraction, helplessness, depression, restlessness, distraction, hesitation, and exhaustion. Annoyance due to environmental noise exposure can differ according to the auditory characteristics of the noise (source, exposure), and non-auditory characteristics (social, mental, and economic status) (Fields, 1993). The factors leading to annoyance are related to the noise source, the degree of conviction that the noise will be reduced, personal sensitivity to noise, the status of the noise control response, and the importance of the economic activity being undertaken. Social demographic variables, including age, gender and socio-economic status, are not strongly related to the level of annoyance. Exposure to noise and general annoyance are more closely related at the group level than at a personal level. Annoyance resulting from exposure to environmental noise, differs in accordance with the auditory characteristics (e.g., source, exposure) and non-auditory characteristics (e.g., social, mental, and economic status) (Fields, 1993).

The mechanism of the effects of noise on mental health are yet to be fully understood. However, it is known that the secretion of cortisol and epinephrine increases, because the hypothalamic-pituitary-adrenal axis is stimulated, when sleep is disturbed or everyday life is impaired due to noise. It is widely believed that an acute stress response, continuous mental instability, depression, and physiological diseases can be caused by such endocrine system disturbances (Lundberg, 1999; Spreng, 2000; Zaharna & Guilleminault, 2010). Recent studies have shown that psychiatric symptoms including anxiety and depression are related to noise exposure. Much of the general population is exposed to environmental noise, but groups considered particularly at risk include children, females, chronic patients, and elderly people. Aircraft noise occurs irregularly and intermittently, and its occurrence is not easy to forecast. Studies of aircraft noise and mental health have focused mainly on the hospitalization rate during the initial stages of illness. Some reports have indicated that the hospitalization rate due to mental illness is high around airports (Abey-Wickrama et al., 1969; Tarnopolsky et al., 1980).

4. Indoor Noise Evaluation and Management Standards

In Korea, noise and vibration problems have emerged as important issues in many locations due to rapid industrialization, the concentration of population in cities, and life-style changes since the 1960s. An enormous increase in the number of cars and construction sites has resulted in many civil complaints, and have inconvenienced residents of urban areas. The Noise and Vibration Control Act established measures to control noise from factories, general living, traffic, and aircraft by treating noise separately from the existing Environmental Protection Act. The reason for this is that people's recognition of environmental protection is increasing, and there is a desire for a quiet environment (Figure 1) (Ministry of Environment, 2013).

For noise evaluation, the equivalent noise level, based on A-weighting, is commonly used. However, the evaluation method cannot be used to produce a standard that reflects the complex sensation responses in humans following exposure to noise. Consequently, a sound quality evaluation standard reflecting human sensitivity is needed as an environmental noise standard. Therefore, Noise Criteria (NC), Preferred Noise Criterion (PNC), Noise Rating (NR), Room Criterion (RC), Total Loudness (N), and dB(A) are widely used worldwide. As criteria to evaluate indoor noise, NC and NR values proposed by the ISO are used mainly in Europe and the United States.

The WHO Guidelines for Community Noise recommends that the average noise level (measured continuously for 5min) should not exceed 35dB in a living room, and 30dB(A) in a bed room for continuous noise, and 45dB (L_{Amax}) for intermittent sound. Outdoor living areas should not exceed 55dB(A) (45dB(A) at night) for continuous sound, and at school should not exceed 35 dB(A) during classes. A hospital ward should be 30dB(A) or lower during the night. The permissible dB level of noise differs between locations in consideration of non-auditory effects (Table 2) (WHO, 1999). Table 3 shows the NC/RC, dB(A), and dB(C) levels for indoor environments recommended by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as an indoor design target (ASHRAE, 2011).

The noise-relevant laws in Korea include the Basic Environmental Policy Act, Noise and Vibration Control Act, Housing Construction Promotion Act, Aviation Act, and Industrial Health and Safety Act, and standards have been established according to the required goals. The community noise standards in Korea were revised in 2010. The standards for community noise are applied on the basis of the areas affected by community noise. The targeted areas are divided into residential areas, green land areas, and village/ residential development/resort development zones in noise management areas, and nature preservation areas and school/ general hospital/ public library and other zones in other areas. The standards provide noise regulation criteria for the morning and

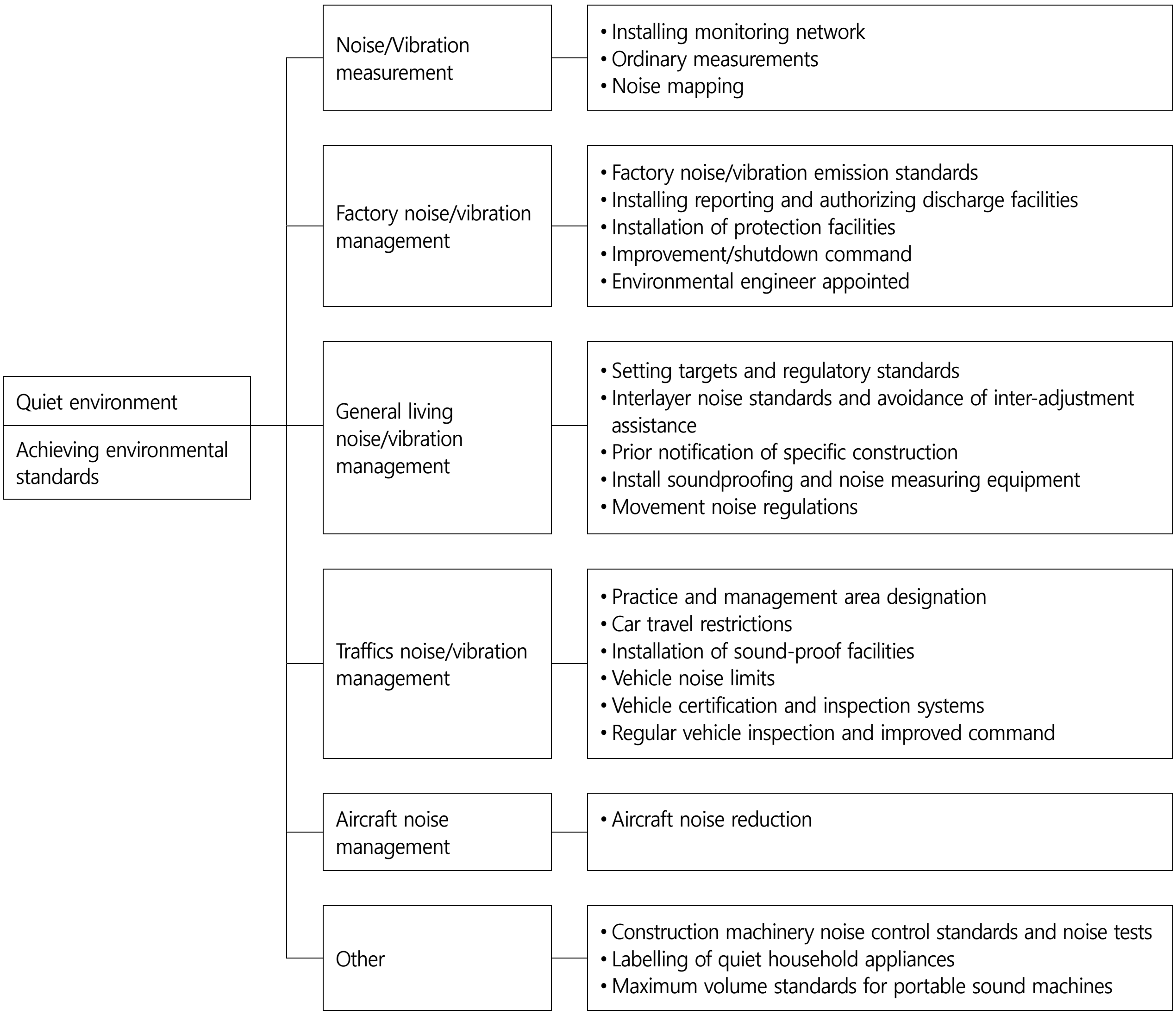

Figure 1. The system of the Noise and Vibration Control Act

Table 2. Giudeline values for community noise in specific environments (WHO, 1999)

Specific environment	Critical health effect(s)	L_{Aeq} [dB(A)]	Time base [hours]	L_{Amax} fast [dB]
Outdoor living area	Serious annoyance, daytime and evening	55	16	-
	Moderate annoyance, daytime and evening	50	16	-
Dwelling, indoors	Speech intelligibility & moderate annoyance, daytime & evening	35	16	
Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60

Table 2. Giudeline values for community noise in specific environments (WHO, 1999) (Continued)

Specific environment	Critical health effect(s)	L_{Aeq} [dB(A)]	Time base [hours]	L_{Amax} fast [dB]
School class rooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class	-
Pre-school bedrooms, indoor	Sleep disturbance	30	Sleeping-time	45
School, playground outdoor	Annoyance (external source)	55	During play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time	30	8	40
	Sleep disturbance, daytime and evenings	30	16	-
Hospital, treatment rooms, indoors	Interference with rest and recovery	#1		
Industrial, commercial shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (patrons: <5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music and other sounds through headphones/earphones	Hearing impairment (free-field value)	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults)	-	-	140 #2
	Hearing impairment (children)	-	-	120 #2
Outdoors in parkland and conservations areas	Diruption of tranquillity	#3		

#1: As low as possible
#2: Peak sound pressure (not LAF, max) measured 100mm from the ear.
#3: Existing quiet outdoor should be preserved and the ratio of intruding noise to natural background sound should be kept low.
#4: Under headphones, adapted to free-field values.

Table 3. Design guidelines for HVAC-related background sound in rooms (ASHRAE, 2011)

Room type		Octave band analysis	Approximate overall sound pressure level	
		NC/RC	dBA	dBC
Rooms with intruson from outdoor noise sources	Traffic noise	N/A	45	70
	Aircraft flyovers	N/A	45	70
Residences, apartments, condominiums	Living areas	30	35	60
	Bathrooms, kitchens, utility rooms	35	40	60
Hotels/Motels	Individual rooms or suites	30	35	60
	Meeting/banquet rooms	30	35	60

Table 3. Design guidelines for HVAC-related background sound in rooms (ASHRAE, 2011) (Continued)

Room type		Octave band analysis	Approximate overall sound pressure level	
		NC/RC	dBA	dBC
Hotels/Motels	Corridors and lobbies	40	45	65
	Service/support areas	40	45	65
Office buildings	Executive and private offices	30	35	60
	Conference rooms	30	35	60
	Teleconference rooms	25	30	55
	Open-plan offices	40	45	65
	Corridors and lobbies	40	45	65
Courtrooms	Unamplified speech	30	35	60
	Amplified speech	35	40	60
Performing art spaces	Drama theaters, concert and recital halls	20	25	50
	Music teaching studios	25	30	55
	Music practice rooms	30	35	60
Hospitals and clinics	Patient rooms	30	35	60
	Wards	35	40	60
	Operating and procedure rooms	35	40	60
	Corridors and lobbies	40	45	65
Laboratories	Testing/research with minimal speech communication	50	55	75
	Extensive phone use and speech communication	45	50	70
	Group teaching	35	40	60
Churches, mosques, synagogues	General assembly with critical music programs	25	30	55
Schools	Classrooms	30	35	60
	Large lecture rooms with speech amplication	30	35	60
	Large lecture rooms without speech amplication	25	30	55
Libraries		30	35	60
Indoor stadiums, Gymnasiums	Gymnasiums and natatoriums	45	50	70
	Large-seating-capacity spaces with speech amplication	50	55	75

evening (05:00~07:00 and 18:00~22:00, respectively), daytime (07:00~18:00), and night-time (22:00~05:00) that apply to loudspeakers, factories, workplaces, and construction sites. There is a 5~10dB compensation for noise during working hours and daytime blast noise at construction sites. The term "same building" in the standards refers to a building in which the roof, pillars, or walls are composed of one body. The community noise regulation standards for the same building apply to health clubs, gyms, martial art academies, and noise generating businesses such as music academies, karaoke bars, singing rooms, and cola tech (disco) premises (Table 4) (Ministry of Environment, 2010).

Table 4. Regulatory standards for community noise

[Unit: dB(A)]

Target areas	Noise sources		Morning, evening (05:00~07:00, 18:00~22:00)	Day (07:00~18:00)	Night (22:00~05:00)
Residential areas, green areas, administrative areas of the village district, residential and resort development zones, natural environmental conservation areas, other areas in schools, hospitals, and public libraries	Loudspeakers	Outdoor	below 60	below 65	below 60
		If the outdoor noise is generated indoors	below 50	below 55	below 45
	Factory		below 50	below 55	below 45
	Business	In the same building	below 45	below 50	below40
		Other	below 50	below 55	below 45
	Construction		below 60	below 65	below 50
Other areas	Loudspeakers	Outdoor	below 65	below 70	below 60
		If the outdoor noise is generated indoors	below 60	below 65	below 55
	Factory		below 60	below 65	below 55
	Business	In the same building	below 50	below 55	below 45
		Other	below 60	below 65	below 55
	Construction		below 65	below 70	below 50

Other countries regulate the effects of environmental noise in apartments by setting internal standards for floor impact noise, plumbing equipment noise, and external noise. Korea has criteria for measurement and evaluation of inter-floor noise and noise within apartments; However, no evaluation method and criteria for plumbing equipment noise have been established. Noise criteria in apartments in developed countries are strict. Australia's Environmental Protection Act sets an indoor noise standard for apartments at 40dB during the day and 30dB during the night. In the United States, the indoor noise target is 45dB during both day and night. Korea regulates inter-floor noise in apartments as the noise caused by the activity of residents or users, which can be divided into either direct impact noise caused by the movement of other residents or users, and airborne transmitted noise caused by sound-transmitting devices. For direct impact noise, one-minute equivalent noise levels of 43dB(A) during the day (06:00~22:00) and 38dB(A) at night (22:99~06:00) have been established, with maximum noise levels of 57 and 52dB(A), respectively. For airborne transmitted noise, 45 and 40dB(A), respectively, were established as five-minute equivalent noise levels (Ministry of Environment & Ministry of Land, Infrastructure and Transport, 2014).

The Ministry of Land, Infrastructure, and Transport has devised inter-floor noise criteria, and limit values of 58dB for light-impact noise, and 50dB for heavy-impact noise in newly built apartments. The thickness of a slab comprising the floor of the apartments was also regulated, and a target value of 201mm was set. The Interruption Structure Accreditation and Management Standards of Apartment Floor Impact Noise established four-floor impact noise performance classes and designated an accreditation agency that also considers reverse A-weighted inter-layer impact noise levels (Ministry of Land, Infrastructure, and Transport, 2013).

5. Reduction of Indoor Noise

To solve noise problems and create a quiet living environment in Korea, the Ministry of Environment established the 2nd Comprehensive Plan of Living Noise Reduction [2011-2015], launched a national noise information system (www.noiseinfo.or.kr) in October 2008, and implemented various measurement networks. In March 2012, the government launched a service for inter-floor noise in neighborhoods to solve civil grievances, due to inter-floor noise problems in apartments. To solve the noise problems at construction sites, which account for 65% of all civil noise complaints, the government introduced a noise indication system on noise-generating machinery in 2011, and conducts customized noise reduction consultations. For traffic noise management, the government produced noise maps for cities with a population of more than 250,000 in 2013. A home appliance low noise classification system has been introduced to manage inter-floor noise, and portable sound devices are used to ensure compliance with the maximum sound standard, with a particular focus on preventing hearing loss in youths (Kim, 2013).

Noise that can affect indoor spaces can be divided into external noise (e.g., traffic, construction, and workplace noise) and internal building noise. For internal building noise, the living environment must be protected by structural noise prevention practices, such as the isolation of machine rooms, sound absorption and sound insulation, and the installation of silencers in the architectural planning stage. For external noise, regulations should not affect the maintenance of living requirements, or noise should be prevented from entering the living spaces by installing sound-proof walls alongside roads.

To help create a stable indoor environment and prevent noise, this study considered four aspects: elimination of noise sources, administrative actions, measures included in the architectural plan, and preventing sound from entering houses.

The methods used to eliminate noise include the control of noise from motor engines, which is the main source of urban noise, under the principle of preventing noise at its source. This could occur by the development of quieter engines through advances in technology, or the installation of noise control devices or sound absorbers. This method can be applied for factory noise and traffic engine noise.

Administrative measures to reduce noise include legislative attempts to devise noise regulations at the national level. This includes administrative actions to prevent population concentration in cities, strict zoning systems, building laws and regulations to prevent noise pollution, such as restrictions imposed on the use of automobile horns and factory machines. The potential impact of these measures is huge because they are established at the national level, in contrast to local sound-proofing measures.

Noise control measures as part of an architectural plan can efficiently prevent noise by considering noise reduction in the architectural design of a building. To reduce noise conveyance, living areas can be planned at a distance from noise sources, and efficient sound insulation can be incorporated, including sound-proof structures, double glazed windows, and the use of special noise absorbing construction materials. Noise prevention can then be achieved from an architectural aspect. Noise damage can be huge in buildings parallel to roads, because sound is reverberated, and therefore, a building needs to be built in a vertical direction or by maintaining a proper angle with respect to roads. Sound-proof walls must also be constructed alongside the road. Bricks with a rough surface can be used as a lining to prevent noise reverberation and absorb noise. In apartments, noise can be prevented by inserting sound-proofing material between each floor or wall along the internal corridors. This method can be very efficient because sound-proof measures can be established in advance when preparing the architectural plan.

When noise control measures are implemented in existing housing a much quieter environment can be enjoyed, even with slight improvements. Some simple measures to prevent noise can be implemented in actual residential spaces, such as sealing the gaps around windows and ducts to interrupt noise conveyed from the external environment, using rubber backing to reduce the metallic sound from closing doors and install materials such as curtains or carpets to absorb sound. Carpets are generally better than other floor materials at absorbing sounds, and are excellent sound-proofing materials for indoor spaces. Social measures should be adopted, such as keeping the volume of home appliances (e.g., televisions) at moderate levels, not playing musical instruments or washing at night, and generally maintaining a quiet environment by recognizing that apartments are joined spaces where multiple persons live together.

6. Conclusion

Environmental noise has many effects on humans. This study considered the concept of environmental noise and identified the main sources of noise through a literature review, and examined the seriousness of noise exposure by summarizing its effects on humans. The types of noise considered included noise due to human behavior, noise from motor engines, noise from building facilities, construction noise, working noise, and noise generated by social gatherings. Among these sources of noise, traffic was the most important in the living environment. It was identified that noise causes stressful reactions in exposed individuals, and can result in serious physical, mental, and social damage. By comparing the international legal standards and recommendations for environmental and indoor noise, it was clear that Korean standards were considerably higher than international standards in terms of the threshold values, and the actual measurement results also exceeded the international standards. Therefore, various measures to reduce noise in Korea are necessary. This may include a method to eliminate noise sources, measures against noise at an administrative action level, and measures to reduce noise as part of architectural plans, including floor-impact noise, airborne transmitted sound, and plumbing equipment noise. With regard to the existing noise problems, the quality of residential living should be improved by promoting a quiet environment, according to the specific characteristics of residential living spaces and indoor environments.

References

Abey-Wickrama, I., A'Brook, M.F., Gattoni, F.E. and Herridge, C.F., Mental hospital admissions and aircraft noise, *Lancet,* 13;2(7663), 1275-1277, 1969.

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2011 ASHRAE Handbook, Heating, Ventilating, and Air-Conditioning Applications. Atlanta, GA. 2011.

Barrigon Morillas, J.M., Gomez Escobar, V., Mendez Sierra, J.A., Vilchez Gomez, R. and Trujillo Carmona, J., An environmental noise study in the city of Caceres, Spain, *Applied Acoustics,* 63, 1061-1070, 2002.

Berglund, B. and Lindvall, T., Community noise. *Archives of the Center for Sensory Research* Vol. 2(1), Stokholm, Sweden: Stockholm Univ. and Karolinska Inst. 1995.

Choi, Y.J., Present condition of indoor noise level in one-room type multi-family housings around campus, *Korea Institute of Interior Design Journal,* 14(3), 191-198, 2005.

Eschenbrenner, A.J., Effects of intermittent noise on the perfomance of a complex psychomotor task. *Human Factors,* 13, 59-63, 1971.

Fields, J.M., Effects of personal and situational variables on noise annoyance in residential areas, *The Journal of Acoustical Society of America,* 93, 2753-2763, 1993.

Hobson, J.A., Sleep, *Scientific American Library,* New York, NY: W.H. Freeman & Co., 1989.

Ising, H. and Gunther, T., Interaction between noise-induced stress and magnesium losses: relevance for long-term health effects. In: Augustinovicz F, editor. Inter Noise 97, Help Quiet the World for a Higher Quality Life, Vol. 2. Poughkeepsie, NY: *Noise Control Foundation,* p.1099-1104, 1997.

International Organization for Standardization, ISO 1999, Acoustics - Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment. Geneva, Switzerland, ISO, 1990.

Kim, B.J., The main policy directions for promoting living environment management*, Bulletin of Korea Environmental Preservation Association,* 408, pp.9-11, 2013.

Kim, S.C., Park, K.S. and Kim, K.W., The Study on Affecting Subject Accomplishment by Noise*, Journal of the Ergonomics Society of Korea,* 29(1), 121-128, 2010.

Klaeboe, R., Amundsen, A.H., Fyhri, A. and Solberg, S., Road traffic noise - the relationship between noise exposure and noise annoyance in Norway, *Applied Acoustics,* 65, 893-912, 2004.

Koelega, H.S., Environmental Annoyance: Characterization, Measurement, and Control. Amsterdam, Netherlands: *Elseivier Science Ltd.,* 1987.

Lazarus, H., New methods for describing and assessing direct speech communication under disturbing conditions, *Environment International,* 16, 373-392, 1990.

Lazarus, H., Noise and communication: the present state. In: Carter NL, Job RFS, editors. Noise as a Public Health Problem (Noise Effects '98). Sydney, Australia: *Noise Effects '98 PTY Ltd.*, Vol. 1, p.157-162, 1998.

Lee, T.G., Ko, K.P., Kim, H., Song, G.G. and Kim, S.W., An experimental study on the subjective response for water supply and drain installations in apartment batgroom, *Transactions of the Korean Society for Noise and Vibration Engineering,* 18(6), 663-673, 2008.

Lundberg, U., Coping with stress: Neuroendocrine reactions and implications for health, *Noise and Health,* 1(4), 67-74, 1999.

Ministry of Environment (Korea), *Law No. 11669*, Noise and Vibration Control Act, 2013.

Ministry of Environment (Korea), *Environmental Enforcement Ordinance No. 587,* Regulation of standards for community noise, 2010.

Ministry of Environment and Ministry of Land, Infrastructure and Transport (Korea). *Environmental Enforcement Ordinance No. 559*, Regulation of standards and scope of noise between floors on residential building, 2014.

Ministry of Land, Infrastructure and Transport (Korea), *MOLIT Notice 2013-611*, Regulation of standards for housing construction, 2013.

Nelson, D.I., Nelson, R.Y., Concha-Barrientos, M. and Fingerhut, M., The global burden of occupational noise-induced hearing loss, *American Journal of Industrial Medicine,* 48(6), 446-458, 2005.

Niskar, A.S., Kieszak, S.M., Holmes, A.E., Esteban, E., Rubin, C. and Brody, D.J., Estimated prevalence of noise-induced hearing threshold shifts among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey, 1988-1994, United States, *Pediatrics,* 108(1), 40-43, 2001.

Passchier-Vermerr, W. and Passchier, W.F., Noise exposure and public health, *Environmental Health Perspectives,* 108(1), 123-131, 2000.

Poulton, E.C., Composite model for human perfomance in continuous noise, *Psychological Review,* 86(4), 361-375, 1979.

Shin, J., Song, H. and Shin, Y., Analysis of the characteristic of living noise in residential buildings, *Journal of the Korea Institute of Building Construction,* 15(1), 123-131, 2015.

Spreng, M., Possible health effects of noise induced cortisol increase, *Noise and Health,* 2(7), 59-64, 2000.

Stansfeld, S.A. and Matheson, M.P., Noise pollution: non-auditory effects on health, *British Medical Bulletin,* 68, 243-257, 2003.

Tarnopolsky, A., Watkins, G. and Hand, D.J., Aircraft noise and mental health: I. Prevalence of individual symptoms, *Psychological Medicine,* 10(4), 683-698, 1980.

World Health Organization, *Guidelines for community noise,* WHO, London, United Kingdom, 1999.

Yoshida, T. and Osada, Y., Effects of road traffic noise on inhabitant of Tokyo, *Journal of Sound and Vibration,* 205(4), 517-522, 1997.

Zaharna, M. and Guilleminault, C., Sleep, noise & health: Review, *Noise and Health,* 12(47), 64-69, 2010.

Zannin, P.H.T., Diniz, F.B. and Barbosa, W.A., Environmental noise pollution in the city of Curitiba, Brazil, *Applied Acoustics,* 63, 351-358, 2002.

Zheng, D., Cai, X., Song, H. and Chen, T., Study on personal noise exposure in China, *Applied Acoustics,* 48, 59-70, 1996.

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