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A quantification model of overall dissatisfaction with indoor noise environment in residential buildings

Jin Yong Jeon, Jong Kwan Ryu *, Pyoung Jik Lee

Department of Architectural Engineering, Hanyang University, Seoul 133-791, Republic of Korea

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ABSTRACT

A quantification model concerning overall dissatisfaction from multiple noise sources in residential buildings and underlying assumptions were presented. The model was constructed by two steps; a survey and an auditory experiment. The relation between dissatisfaction with the indoor noise environment and dissatisfaction with individual noises such as floor impact, airborne, drainage, and traffic noises was first found in the survey. The annoyance from individual noises was obtained as a function of the noise level from the laboratory experiment. Then, annoyance ratings were translated into the percentage of dissatisfaction based on the relation between annoyance and dissatisfaction obtained from the survey. Finally, equations were derived for predicting the degree of dissatisfaction with the overall indoor noise environment using individual noise levels, and a classification method for the noise environment with multiple noise sources were proposed. The procedure and the quantification model can be used for the assessment of the associated overall dissatisfaction of the indoor noise environment on the basis of the level of individual sources.

1. Introduction

There are a variety of noise sources within the indoor noise environment of residential buildings. In particular, multi-storey buildings or neighboring apartment units which share wall, ceiling and floor structures provide structure-borne sound paths for the propagation of floor impact, airborne, and drainage noises. The propagation of these residential noise sources is a major cause of annoyance for apartment residents [1,2]. The percentage of multi-storey buildings has steadily increased in many major cities and most residents in this type of living situation are in a constant state of annoyance due to noise disturbances.

It is well known that subjective responses to noises, such as annoyance, depend upon the type of noise. Recent surveys [3] on indoor- and outdoor-generated noises in apartments in South Korea showed that floor impact and airborne sounds from neighboring units were selected to be the most annoying sound source occurring both during the day and night. Traffic noises coming from outside showed a relatively low selection percentage as a source of annoying noises. The indoor noise environment, taking into consideration the sound insulation of building components such as floors, walls, and windows, is an important factor in selecting a residential building. It is worthwhile to provide a guideline about the sound insulation performance or noise level for not only an individual noise source, but also the overall indoor noise environment within a dwelling. The guideline would also indicate proper measures for the sound insulation to enhance the acoustical comfort within residential buildings. Therefore, the guideline needs to be based on a comprehensive method for evaluating the overall indoor noise environment. In order to more accurately assess how an individual noise affects the indoor noise environment for a general resident, the perception of a particular noise should also be investigated.

A number of studies [4–9] predicting overall annoyance from multiple noise sources have primarily been conducted in regard to outdoor transportation noises such as road traffic, train, and aircraft. The previous studies [4–9] reported various energy summation models with and without different factors for interaction effects between each noise source upon overall annoyance. Several studies reviewed and compared the proposed models for total annoyance caused by transportation noise sources. Taylor [4] found that the simple energy summation model gave rather poor prediction in overall annoyance comparing with other models such as independent effects, energy difference, response-summation, and summation and inhabitant models. He also found that the best prediction was achieved by using independent effects and energy difference models. Izumi [5] revealed that no significant differences were found between the effectiveness of the seven models examined (i.e., the above five models, along with the pressure L_{Aeq} model and dominant source model). Ronnebaum et al. [6] found

* Corresponding author. Address: Department of Architectural Engineering, Hanyang University, 17 Haengdang-dong, Sungdong-gu, Seoul 133-791, Republic of Korea. Tel.: +82 2 2220 1795; fax: +82 2 2220 4794.
E-mail address: mr1ryu@hanmail.net (J.K. Ryu).

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that the dominant source model yields the best agreement in regards to the annoyance reaction. Recently, Miedema [9] developed an annoyance equivalent model based on the energy summation model, which led to the revision of international standards [10] for assessing annoyance caused by exposure to sound within the multi-source environment. However, it is still not clear which model provides the highest accuracy in evaluating the overall response to multiple noises, and whether the models are suitable for the evaluation of indoor residential noises. The difficulties in providing an accurate prediction for the overall response may be caused by the effect of interaction between individual noises along with the non-acoustical aspects such as noise sensitivity.

Many countries have proposed classes for determining noise levels for the proper insulation of building components indicating the acoustic performance within residential buildings [11–13]. However, the number of studies on the methodology for classifying sound isolation and noise levels is not sufficient. Several studies [1,2,14–16] used field survey measurements to investigate the relationship between the noise level or isolation performance, and the percentage of people dissatisfied (or satisfied). They proposed the percent satisfaction (or dissatisfaction) with sound insulation or the noise level as a way of evaluating and classifying the indoor noise environment. Jeon et al. [17] suggested classes of floor impact sound insulation based on subjective ratings in terms of audibility, disturbance, and amenity. However, the methods described above are not for the overall indoor noise environment, but for an individual sound or building element.

The purpose of this study is to suggest a quantification model for overall dissatisfaction with the indoor noise environment including multiple noise sources in residential buildings. However, it is limited to measure the residential noises in lots of houses in the field. In addition, the indoor residential noise is unlike transportation noise in outside and depend on the isolation performance of a building as well as the life style of neighbors and so on. Therefore, this study utilized the combined method of both survey and laboratory experiment. Dissatisfaction as the overall reaction to a noise environment, and dissatisfaction and annoyance for individual noises were investigated in the survey. Then, the effects of individual noise upon the evaluation of the noise environment were examined. An auditory experiment was conducted in order to investigate the level of dissatisfaction and annoyance resulting from certain individual noises as a function of noise level. From the results of both the survey and laboratory experiment, equations for predicting dissatisfaction with one's indoor noise environment were derived and a classification method for the indoor noise environment was proposed.

2. Model

In general, an annoyance has been defined as a feeling of displeasure associated with any agent or condition realized or believed by an individual or group to be adversely affecting humans [18]. However, people have various negative feelings about noises, such as anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, and exhaustion [18–20]. Although noise annoyance is seen as a major effect of noise and is a multi-faceted psychological concept, including behavioral and evaluative aspects [20], annoyance does not cover all of the negative responses to noise [18]. Job et al. [21] reported that general measures such as dissatisfaction and perceived affectedness are more valid and reliable than specific assessment of noise annoyance for the evaluation of dose-response relationships as well as for predicting the behavioral and health outcomes of exposure to noise. Uncertainty towards annoyance measurements is normally due to the lack of repeatability in individual judgments, as well as the differences between people in the reactions to the same noise [22]. Reliability of the noise dissatisfaction scale was found to be acceptable based on statistics from test-retest methods [21]. For these reasons, measures of dissatisfaction with noise or residential environment have been used for the investigation of dose-responses in many studies [1,2,14,23–25]. In the present study, dissatisfaction with the indoor noise environment was measured as a general reaction to multiple noises within the apartment unit. It was assumed that the overall dissatisfaction with the indoor noise environment integrated many kinds of responses to all noise sources occurring within the residential buildings. Dissatisfaction with individual noise was also investigated as a general reaction for each noise source.

In the present study, the independent effects model [4] (explained in Eq. (1)) was revised to predict the overall responses to multiple indoor noise sources. Our model was developed to find the structure of mental integration of the responses to separate noise sources by obtaining the standardized regression coefficient (β in Eq. (2)) from multiple regression analysis. In our model, interaction effects between responses to individual noise sources, which may exit in our daily lives, are excluded and the unique contributions of each noise source to overall response are thus considered.

$$R_{\text{overall}} = R_1 + R_2 + \cdots + R_n \tag{1}$$

$$R_{\text{overall}} = \beta_1 R_1 + \beta_2 R_2 + \cdots + \beta_n R_n \tag{2}$$

where R_{overall} is the overall response with multiple noise sources, $R_1, R_2, \ldots, R_n$ represent the responses with individual noise sources, and $\beta_1, \beta_2, \ldots, \beta_n$ are the standardized regression coefficients determined through multiple regression analysis.

The independent effects model [4] assumes that the overall response results from mental integration of the responses rather than integration of the sound energy from separate sources, and showed good predictions in several studies [4,7]. On the other hand, it was reported that the energy summation and the dominance model are not consistent with empirical data [9]. One of important elements in the models for combined exposure is a noise metric. As a major residential noise source, floor impact sound is usually evaluated with the different metric (L_{max}, maximum sound level) from that of other noise sources (L_{eq}, equivalent sound level). Therefore, it is difficult to define a noise metric of combined residential noise sources for the energy summation model. Independent effects model [4] assumes that there is no interaction effect between individual noise sources, and the contributions of separate sources to total responses are independent and additive. However, attitudes toward a certain noise sources in our daily lives affect responses to other noise sources [22,26], and thus, a response to one noise source might be correlated with responses to other noise sources. In addition, the degree of variation of the overall response can be changed by the presence of other sources [7]. Therefore, there is a need for finding the structure of a mental integration of responses to separate noise sources. The structure can be drawn by finding the unique contributions of the separate sources to the overall response.

Consequently, in the present study, original independent effects model was revised to find the independent contribution of a specific noise source to overall response. In this revision, multiple regression analysis was carried out, excluding the interaction effect between individual noise sources.

From the multiple regression analysis, the percentage of contribution for independent variables to a dependent variable can be obtained by a standardized regression coefficient, which is the estimate resulting from an analysis performed on standardized variables with a variance of one [27]. It also represents the change in the dependent variable, per standard unit change, in an indepen-