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MEASURING AND REPRESENTING INDOOR SOUNDSCAPES: INSIGHTS FOR A METHODOLOGY FROM SOCIO-ACOUSTIC SURVEYS IN RESIDENTIAL BUILDINGS IN ENGLAND

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ABSTRACT

The soundscape framework is effective in characterising the sound environment as we perceive it. Efforts to improve the urban soundscape must be coordinated with building design to enhance the sound environment where people spend most of their time, i.e., buildings. But how to measure the indoor soundscape? And how to represent it? Building on ISO 12913 standard series, a measurement system was defined to assess the affective response to the indoor soundscape in residential buildings, indicating the perceptual constructs to be measured and the attributes to be employed in occupant surveys. The system was first applied in a monitoring campaign in residential buildings during summer 2022, involving socio-acoustic surveys in 61 dwellings in England (UK). This paper describes the methodology employed to measure the soundscape inside buildings, both through "instruments" and "people", and to collect contextual (e.g., information about the window view) and personal (e.g., noise sensitivity) features that may influence the perception of the acoustic environment. The results of the collected affective responses and their representation in the perceptual comfort-content reference system are presented. Representation methods are illustrated with reference to recent tools developed for outdoor soundscapes and their usefulness is demonstrated in the context of indoor soundscape design.

Keywords: *indoor soundscape, post occupancy evaluation, indoor environmental quality, acoustics, residential*

1. INTRODUCTION

Soundscape studies deal with the characterisation of the acoustic environment as perceived by people, in order to direct design actions towards environments of good acoustic quality. The framework on the urban soundscape has been defined by the International Organization for Standardization in the ISO 12913-1 standard [1], followed by two technical specifications (TS) on data collection [2] and analysis [3]. Recent studies have discussed the application of such a framework within buildings [4,5]. By adapting the ISO standard definition [1], indoor soundscape can be defined as the "indoor acoustic environment as perceived or experienced and/or understood by a person or people, in the context defined by the building" [6]. Indeed, the building plays a fundamental role in shaping the acoustic environment, connecting or confining the indoor from the outdoor environment and determining the needs and expectations of the occupants, depending on its intended use. The model for assessing the affective response to the outdoor soundscape is described in the part 3 of the ISO TS, based on the 8 rating scales provided in the part 2, and it has been recently redeveloped for soundscape assessment in residential (indoor) environments [7]. According to this, the affective response to indoor soundscapes can be described by a two-dimensional orthogonal system where the two main dimensions are related to how comfortable or annoying the environment is

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judged to be (i.e., the comfort dimension) or how full or empty it is, in terms of saturation with sounds and events (i.e., the content dimension). A 45 degree rotation in the same plane corresponds to two secondary axes, one relating to private and controlled vs. intrusive and out-of-control environments and the second relating to engaging vs. detached environments (see Fig. 1).

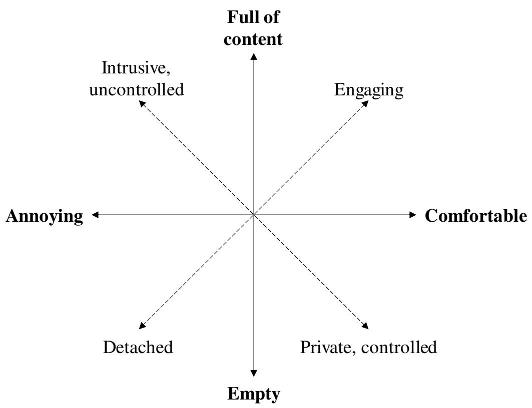

Figure 1. Model of perceived affective quality of indoor residential soundscapes. The perception of a person in an instant can be represented as a point in the scatterplot in the comfort and content coordinates. Adapted from [7].

The model describes the perceptual constructs to be measured and attributes to be used in occupant surveys.
In this study, the first example of implementation of the model in the assessment of residential buildings in England is presented. Data collection takes into account the multisensory nature of the human experience of the built environment, and potential combined and cross-modal effects on acoustic perception from interaction with the thermal and visual environment and indoor air quality [8]. The aims are i) to introduce a reference methodology for future post-occupancy evaluations integrating indoor soundscape aspects from a multi-domain perspective, and ii) to show how the data collected on the affective response to the indoor soundscape can be represented and used for analysis purposes.

2. METHODS

The study refers to an occupant survey that took place in the living rooms of 61 homes (or student accommodations) in England, between 19 June and 12 October 2022, on a one-off basis. The campaign involved 34 naturally ventilated dwellings and 27 dwellings equipped with mechanical ventilation. In naturally ventilated dwellings, data collection was carried out with the windows open, while in mechanically ventilated dwellings it took place with the windows closed and the system in operation.
61 participants took part in the study (31 men [49.2%], 30 women [50.8%], M_{age}: 38.5, SD_{age}: 12.5 years), self-reporting no hearing impairment and good English level. The study was approved via the UCL IEDE Ethics departmental procedure on April 28, 2022.

3. RESULTS AND DISCUSSIONS

Crucial aspects of indoor soundscape data collection and representation are presented below. The aim is not to detail the methodology followed in the study, which answered specific research questions, but to highlight the general elements that can be integrated into post-occupancy evaluations of buildings.

3.1 Data collection

The data collection covered the characterisation of the physical and perceived acoustic environment, aspects related to the urban context, building features, situational, socio-economic, personal and environmental factors, which are known to be factors potentially affecting indoor soundscapes [9].

3.1.1 Perceived acoustic environment

The acoustic environment was characterised by adapting Method A by the ISO/TS 12913-2 [2] to address the specificities of indoor settings. This included the sound source identification, with reference to both external sources (traffic noise, other noise from outside, natural sounds, sounds from human beings), sources inside the home (other human beings, building services), or in neighbouring housing units (neighbours, building services of neighbours or common areas). However, the degree of detail of the sources to be assessed can be tailored according to the objectives of the specific study. Perceived affective quality was assessed through the evaluation of eight perceptual attributes derived from the study of Torresin et al. [7] (see labels in Fig. 1) anchored to the 5-value Likert scales described in ISO/TS 12913-2 [2]. The assessment of the surrounding acoustic environment and appropriateness of the soundscape was done by specifying the target activity of the assessment. Indeed, compared to outdoor environments which are often places of transit or relaxation, indoor environments can accommodate a variety of activities with different acoustic needs [10]. In the present study, the evaluation targeted work from home and relaxation activities.

3.1.2 Physical acoustic environment

The measurement of the physical acoustic environment was done with both mono- and binaural techniques, following the recommendations of ISO/TS 12913-2 [2]. Monoaural recordings were performed with a calibrated Class 1 NTi Audio XL2 sound level meter placed 1.15m above the floor, in close proximity to the researcher. Binaural recordings were collected with a mobile headset microphone type BHM III.3 by Head Acoustics, worn by the researcher sitting next to the participant, with the orientation according to the participant's view, and characterised by a low inherent noise (15 dBA). The 5-minute recording took place at the same time as the participant completed the questionnaire.

3.1.3 Non-acoustic environment

Aspects related to the thermal, visual and air quality environment were collected in order to be included as covariates in the indoor soundscape models and to assess potential cross-modal effects. The degree of detail and the instrumentation employed can vary according to the objectives of the study and the resources available. In the present study, the temperature was recorded using a calibrated Hobo U12 data logger. The data logger was placed on a horizontal surface close to the researcher so as not to be affected by solar radiation. The visual quality of the outdoor environment as seen from the living room was assessed both by participants in the questionnaire (*How would you describe the view from the window present in your living room? Very bad – very good)* and by taking a photo of the outdoor view from the living room. The content of the photo was then analysed following the framework proposed by Ko et al. [11]. The analysis led to the assignment of a "View content" value to each living room, ranging from 0 (insufficient) to 1 (excellent view content), depending on the available number of view layers (i.e., sky, landscape, and ground), the depth of external content, and the availability of dynamic and natural features in the window view. Perceived indoor air quality (IAQ) was assessed by questionnaire (*Overall, how would you describe the present air quality in your living room? Very bad – very good).*

3.1.4 Other features

Data on environmental conditions are complemented by information on building characteristics (e.g., type of dwelling, dwelling size, type of windows and building services), situational factors (e.g., presence of other people at home), socio-economic factors (e.g., home ownership status), and personal data (e.g., age, gender, noise sensitivity, psychological well-being). The type of data collected can be adjusted depending on the research questions addressed.

3.2 Data representation

The 8 values obtained from the evaluation of the perceptual attributes can be reduced to a pair of coordinates according to the trigonometric transformation given in Part 3 of ISO 12913 and then plotted on the Comfort-Content circumplex (Fig. 2).

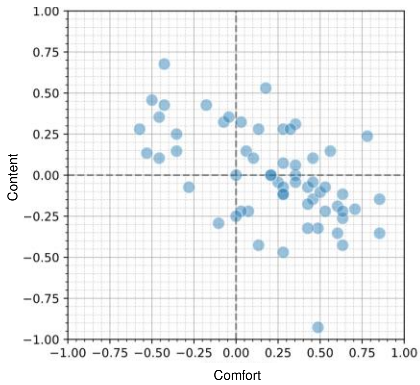

Figure 2. Scatterplot of indoor soundscape perception

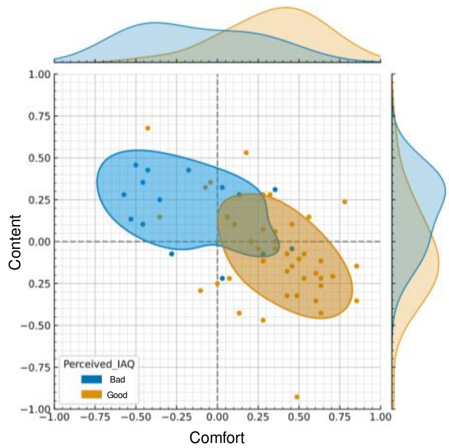

Figure 3. Comparison of indoor soundscape perception as a function of perceived IAQ

Once individual responses are plotted, following the method introduced by Mitchell et al. [12], we can superimpose the graphs of the marginal distribution on the

two dimensions and compare groups of responses on the basis of, for example, the 50th percentile contour, i.e. the contour containing 50% of the points (see Fig. 3).
This allows to observe i) the distribution of responses on comfort and content, including aspects related to central tendency, dispersion and possible skewness of the response, ii) the general shape of the indoor soundscape within the perceptual space, iii) the degree of agreement on the perception of the soundscape among the sample.
For instance, an interesting cross-modal effect can be observed in Fig. 3: in homes where the air quality is perceived to be better, the contour of the indoor soundscape is located in the positive comfort region and is lower in content compared to those with worse perceived IAQ.
The same type of comparisons can be made for other variables, such as thresholds of specific acoustic parameters.

4. CONCLUSIONS

The present study outlines a method for collecting data on the physical and perceived acoustic environment and representing the affective response to the sound environment on the indoor soundscape circumplex. The collection of data on factors inherent to other environmental factors, and relating to the building, urban, situational and personal context acquires detailed information on the person – acoustic environment relationship and highlights any cross-modal effects. Finally, the representation on the soundscape circumplex is effective in that it allows to analyse the impacts of variables not only in terms of annoyance but in broader perceptual terms. Reading the outcomes on the comfort-content space provides information for designing more comfortable and supportive environments for the activities carried out in buildings, beyond annoyance reduction.

5. FUNDING

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