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PROPOSED METHOD FOR MEASURING 'LIVELINESS' IN OPEN PLAN OFFICES

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ISO 3382-3 provides guidelines for measuring room acoustics in open plan offices. However, the actual behavior of people is often not considered in defining the acoustic environment of the open plan office environment. With working environments becoming more and more flexible, the varying aspects of human behavior gains importance. Inspired by the HARMONICA project (www.noiseineu.eu) a method is proposed to describe the office sound environment in an accessible way close to people's perceptions. Since sound can have both a positive and a negative influence on people's comfort and performance, the term 'Liveliness' is introduced as a relatively objective quantity. It comprises four labels, going from 'Quiet' via 'Tranquil' and 'Lively' to 'Turbulent'. Sound levels measured as equivalent levels ($L_{Aeq,5min}$) and percentile levels ($L_{A5,5min}$) are interpreted to a degree of 'Liveliness' based on an algorithm, specifically designed for office purposes. A first version of the algorithm was put together based on field measurements in five Dutch office locations. For several hours per office floor, sound levels were measured and personal scores of 'Liveliness' were listed each period of 5 minutes. The resulting algorithm was validated by two laboratory experiments with questionnaires, one for a small group of acousticians and a shorter one for a bigger group of people with mixed backgrounds. The proposed method aims for an accessible, intelligible interpretation of the sound environment in open plan offices. One possible application is to gain insight in how effectively the office lay-out is used. Another possibility is to show office workers the best spot to work that day, based on their preference for the sound environment.

Keywords: room acoustics, open plan offices, human activity, perception

1. Introduction

Noise is widely recognised as an important cause of discomfort in open plan offices. At high noise levels people tend to be less comfortable. Research has shown that productivity on the other hand is affected mostly by the degree of distraction caused by sound. Whether or not sound is distracting, depends on the type of noise and a person's type of activity. Furthermore, it appears that our personality and emotional state are important factors in perceiving sound. In short, the relation between comfort, productivity and office sound is very dependent on personal preference and the activities to be carried out. Therefore, the assessment of sound in open plan office floors requires a broad approach.

2. State of the art

The presence of noise has a significant influence on the performance of various types of office work, and in particular those involving word processing [1]. To what extent loss of performance occurs, depends on the type of work that is being performed. Venetjoki and Hongisto have summarised several studies in which this influence is quantified [2][3]. Whether this is an actual performance reduction, is not yet determined. Some sounds will not hinder but still have a negative impact on performance and vice versa. Psychological factors, e.g. an employee's state of mind, also have a significant impact in this. When someone is in a bad mood, this person is much more likely to perceive any type of sound negatively [4]. In addition, some people are more sensitive to sound than others. In 1997 Ellermeier and Zimmer found a weak relationship between increased sensitivity to noise and loss of performance [5], which was confirmed by Venetjoki et al in 2006 [3].

2.1 Sound levels

In general, dissatisfaction increases along with the sound pressure level (SPL). Research by the Technical University of Denmark (DTU) showed that there is a relationship between the SPL caused by road traffic and the number of people dissatisfied [6]. Also when the background noise level in an office (people talking, slamming doors, ringing phones, etc.) is increased from 35 dB to 55 dB, the discontent increases significantly from 4% to 68% [7].

Remarkably, during all standard tests to simulate office work, performance was only affected when it comes to performing simple calculations (3% reduction). For general office work no measurements nor surveys showed a relationship between increased noise levels and performance [7][8]. Only at very high SPL's of 70-80 dB(A) performing complex tasks is adversely affected [9]. In addition, there is a link between high SPL's and impairment of the long-term memory [10]. Short-term memory suffers from a high SPL as well, as it disrupts the *inner speech* (talking along in your head) [7]. These are long term effects however, and because of that hard to quantify. A review of 21 studies on office noise found that lowering the SPL can lead to a direct performance increase of (only) 1.7% [4].

Initially this feels counterintuitive and subjects therefore often prove to overestimate the influence of high SPL's. Thus, they often select lower noise levels as the main factor to improve their performance [10]. Nevertheless, only marginal performance effects can be proven within the reasonable limits of the office environment. Speech intelligibility appears to have a far larger impact [11].

2.2 Distraction

Distraction is one of the main causes of loss of performance due to sound. Chanaud's 2008 research gives reason to believe that a high background noise level should not present a source of immediate distraction [12]. He discovered that habituation occurs when being exposed to a continuous background noise level, and one is no longer conscious of the sound. Distraction occurs when the SPL exceeds this continuous background noise by 10 dB or more. This is especially true if the noise source is speech, in which case the intelligibility of speech is crucial [2][3]. Therefore the *Speech to Noise ratio*, which is the difference between the speech sound level and the background noise level, is a good parameter to predict disturbance [8]. A well accepted measure of speech intelligibility is the *Speech Transmission Index* (STI) as a combination of the Speech to Noise ratio and the *Early Decay Time* (EDT). A lot of research into office noise revolves around the STI, simply because intelligible speech is both the greatest source of annoyance - and thus discomfort - and the biggest cause of performance loss [2]. Whereas performance loss is task dependent and only occurs above a certain STI value, discomfort increases consistently with ascending speech intelligibility [8]. It should also be considered that most research into performance loss by speech assumes speech to be undesirable, while in e.g. a meeting one can only be productive when high speech intelligibility is ensured.

2.3 Positive stimulation

However, both performance and comfort can also be improved by an increase in SPL. The reduced alertness which is associated with high indoor temperatures, for example, can be partly compensated by a higher background noise level. Sound is a useful stimulus in that situation. Another example demonstrating this is a test with children solving math problems. Intelligent children performed better with a higher background noise level, while less intelligent children performed best in silence. This effect is stronger in both cases if the background noise is not continuous but intermittent. Presumably, sound is an stimulus for the intelligent children to stay focused, but caused distraction for less intelligent children [7]. This experiment involved static noise, but for speech a similar phenomenon seems to take place. When a group of subjects is divided into 'above average intelligence' and 'below average intelligence', speech hardly affects intelligent people [11]. However, for the less intelligent people the performance decreased with up to 11.5%, which is a stronger effect than the 7% decrease Hongisto predicted [2].

2.4 User feedback

Due to the specific terminology used in acoustics (calculation in dB's, use of percentiles and equivalent levels etcetera), acoustical data is often incomprehensible to laymen. Therefor it is difficult for inexperienced users to see meaningful relationships between measured data and useful information about e.g. comfort. However, initiatives arise that attempt to clarify the data in such a way that it can serve as an adequate communication tool between specialist and user. The HARMONICA (Harmonised Noise Information for Citizens and Authorities) project [13] is a French example of such initiatives, which uses an intelligible colour scale to rate the nuisance caused by traffic noise, based on both its sound level and its fluctuation. Auralisation is also an upcoming way to provide insight in urban sound fields. These initiatives and the lack of a convincing equivalent for the use within buildings induced the development of a new index.

3. Investigation approach

As stated before, it is crucial to have knowledge about the information density and usefulness to the receiver(s) to determine whether sound causes loss of productivity and discomfort. Therefore it is virtually impossible to design a method to determine to what degree comfort and productivity are affected by certain sounds, without resorting to elaborate sound recognition software and general assumptions on the individuals' desire to receive the sound's potential information.

M+P has chosen a relatively neutral approach towards sound interpretation with a focus on the perceived acoustical environment. Since many open plan offices are designed to have designated zones for certain types of work, especially since the introduction of Activity Based Working (ABW), it becomes easier to make a general assumption about the acoustical quality of a certain zone. Sound levels are expected to be low and constant in zones that are meant for focused work, whereas interactive areas should facilitate exchange of information with high levels of sound and a lot of fluctuation.

In response to this, M+P coined the term *Liveliness*, subdivided into four categories: quiet, tranquil, lively and turbulent. These intelligible categories are based on a linear, numerical rating in which points are attributed for both sound level and sound fluctuation. This results in a total score for liveliness, i.e. the MACH index, ranging between one and ten points. The categories and numerical rating are introduced to overcome communication issues inherent to the use of acoustical jargon. Liveliness is intended to be an objective characteristic of an acoustic environment, that enables people to estimate its impact on their comfort and productivity.

Based on field experience from years of monitoring sound in open plan offices, a preliminary formula was devised to serve as a framework of attributing points to a certain sound level and fluctuation. A field test served to test and improve this formula, after which it was validated using two lab tests. The formulas of the algorithm serve as a framework, which can be improved continuously in the future based on our ongoing research on liveliness in practice.

4. Field survey

A first version of the algorithm was put together based on measurements in five Dutch office locations performed by two acoustical engineers. For several hours per office floor, sound levels were measured and personal scores of *Liveliness* were listed each period of 5 minutes. The scheme presented in figure 1 shows the frame in which the algorithm was designed, where 'x' stands for equivalent sound levels $L_{A,eq}$ in classes of 3 dB and 'y' stands for the difference between the equivalent sound levels $L_{A,eq}$ and the fifth percentile values $L_{A,5}$. They add up to a total score, in which 1 represents the most tranquil environment, whereas 10 stands for the most turbulent one.

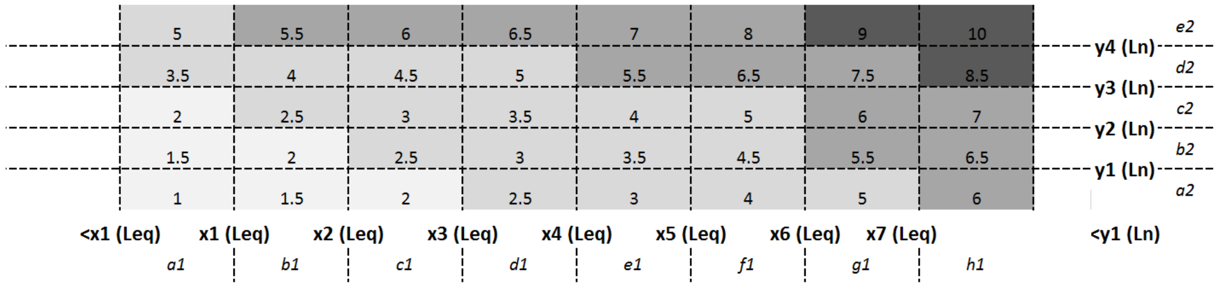

Figure 1: Frame for designing the algorithm for *Liveliness*.

During the field survey all constants were adjusted to ensure that the closest possible match was made between the perceived personal index (PI) of *Liveliness* and the calculated MACH index (MI). The average of the two individual scores made by the two acousticians, who were seated at the same desk, formed the PI. All constants (a1, b1, etc.) and parameters (x1, x,2, etc. and y1, y2, etc.) were subjected to adjustments to reach an algorithm that best fitted the data. Figure 2 shows some results of matching the graph of the PI with graph of the MI for half or full days monitoring at several office locations. The measured $L_{A,eq}$ and $L_{A,5}$ are shown for reference.

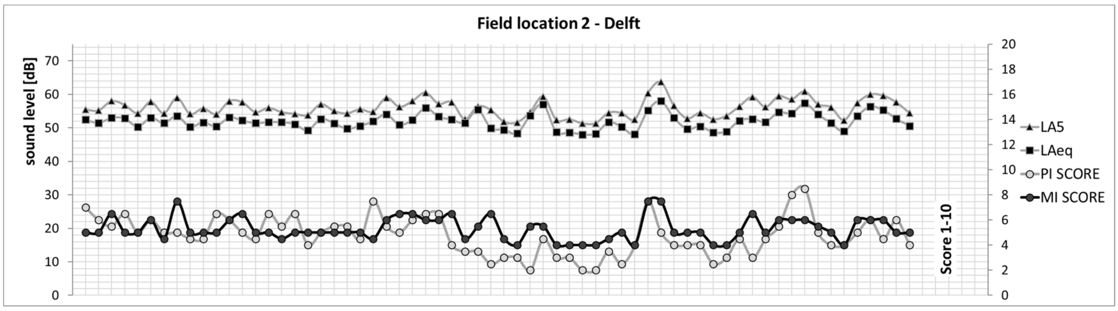

Figure 2A: Field research with 2 acousticians (second location).

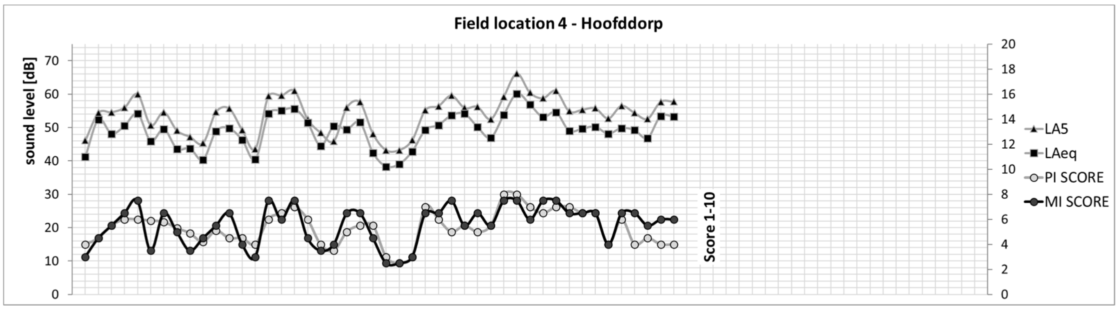

Figure 2B: Field research with 2 acousticians (fourth location).

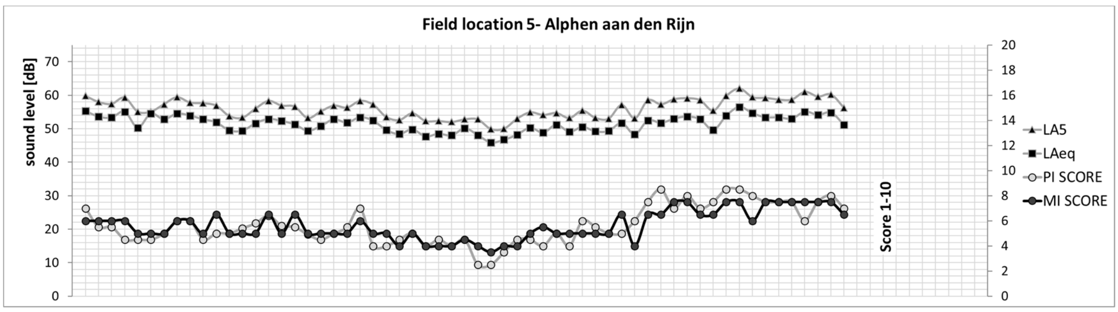

Figure 2C: Field research with 2 acousticians (fifth location).

The second location (Figure 2A) was a relatively big open plan office where some phone calls and live conversations took place, combined with other sounds like closing doors and occasionally the activity of a loud printer. Most conversations and phone calls were performed with lowered voices. The fourth location (Figure 2B) in Hoofddorp could be described as a quiet environment, where most noise was caused by some nearby conversations of a only a few people. At the last location (Figure 2C), two office environments were covered. The first working spot was chosen in large open plan office, close to a pantry where many conversations and even a meeting took place. Speech was almost always present, and non-intelligible for most of the time. The second working spot was chosen in the middle of a call centre / help desk environment.

The results of the field survey show some difference between the perception of the acousticians and the interpreted values to the MACH Index. Revaluation of the recorded 5 minute audio fragments showed that most of the fragments include other sound types than speech, like closing doors and printer activity. In composing the algorithm, the decision was made to take speech as the first and most important ingredient for the interpretation of sound levels to *Liveliness*.

5. Laboratory survey

Out of all audio fragments recorded during the on-site measurements, sixteen audio fragments were selected, each with a duration of one minute and a diversity in sound level and sound fluctuation. They were presented to two groups of people, acousticians and people with a varied background, via an online questionnaire. To the acousticians all sixteen audio fragments were offered, whereas the mixed group was presented with one of two different questionnaires with mixed fragments and with a maximum of eight audio fragments. The respondents were asked to wear headphones and turn up the sound levels to such a level that typing on the keyboard in a quiet test fragment could just be heard. The question was posed as follows:

> *Welcome to this audio fragment.*

I would rate the liveliness of this office environment as

1. *QUIET*
2. *almost quiet*
3. *more tranquil*
4. *TRANQUIL*
5. *almost tranquil*
6. *almost lively*
7. *LIVELY*
8. *more than lively*
9. *almost turbulent*
10. *TURBULENT*

Figure 3: Example how to rate *Liveliness* as part of the questionnaire

5.1 Questionnaires 10 respondents – acousticians

In figure 4A and figure 4B the results are displayed from the questionnaire among acousticians. Figure 4A shows both the personally perceived *Liveliness* (Personal Index) and the generic predicted *Liveliness* (Mach Index). The measured $L_{A,eq}$ and $L_{A,5}$ are shown for reference. For the PI the average value is projected in the bigger dots, together with the mean, minimum and maximum value and the second and third quartile (boxplots). In figure 4B the PI's are projected in one figure once more.

The results showed a good enough resemblance between the PI scores and the predicted MI scores to offer the selected audio fragments to a bigger audience without the professional background of an acoustician. The acousticians suggested to shorten the questionnaire to a maximum of about ten minutes to minimise the threshold of participation.

Audio fragments F7, F8 and F9 were all recorded in the same office location with a measurement range set 10 dB lower than for the other audio fragments. Although this doesn't affect the measured sound levels, it lowers the volume of the recording, which turned out to be of significant effect on the personally experience liveliness. Especially the results of fragment 8 showed a big difference between the PI score and the MI score. It was decided to no longer use these fragments in this investigation.

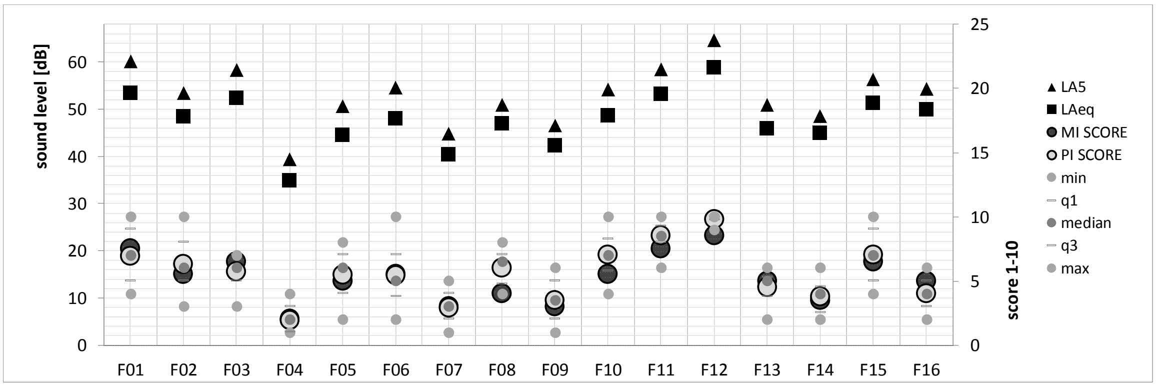

Figure 4A: Results of questionnaires with 10 acoustician respondents and 16 audio fragments.

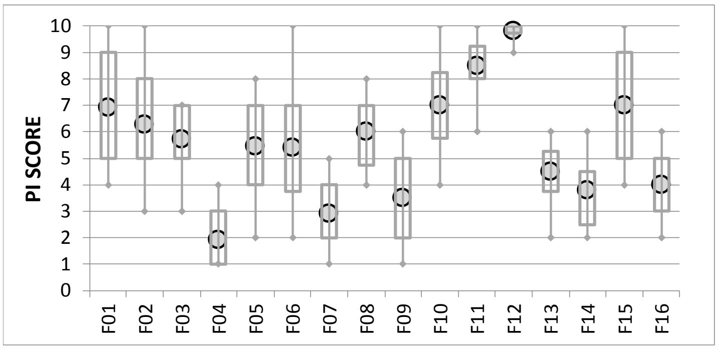

Figure 4B: Results of questionnaires with 10 acoustician respondents and 16 audio fragments. PI scores - boxplots and mean values

5.2 Questionnaires 100 respondents – random professionals

As mentioned before, the total list of audio fragments was shortened from sixteen to twelve after feedback of respondents from the first lab survey. The softly recorded fragments F7, F8 and F9 were removed from the list for further investigation. Fragment F3 was removed as well, without a specific reason. To further decrease the fill out time, two sets of audio fragments were created, each including the two audio fragments with the highest MI and the two fragments with the lowest MI. Per set four unique audio fragments with intermediate MI were added. The two sets of questionnaires together covered all twelve selected audio fragments, as used before with the acousticians. In total, almost 100 questionnaires were filled out.

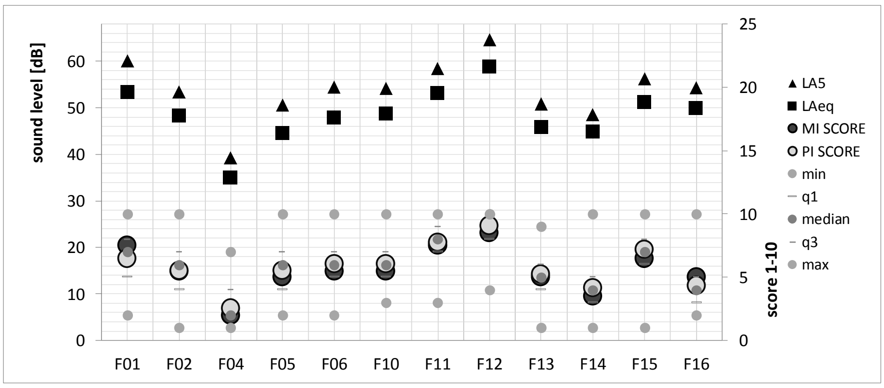

Figure 5A: Results of questionnaires with 100 respondents – random professionals and 12 audio fragments (8 fragments per set).

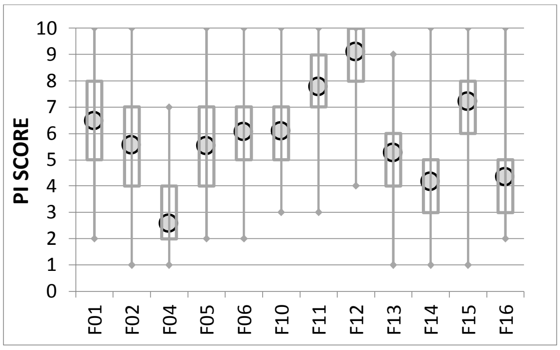

Figure 5B: Results of questionnaires with 100 respondents – random professionals and 12 audio fragments (8 fragments per set).
PI scores - boxplots and mean values

The mean results of the PI and MI show almost identical values, which gives good ground for further use of the parameter *Liveliness* in practice. Individual differences in sensitivity could be of influence on this higher rating of *Liveliness*. More sensitive people are expected to give higher scores to the same audio fragments than less sensitive people. For future investigations, it would be interesting to compare different groups of people regarding sensitivity and personal preference. Another striking outcome is a maximum score of 10 for ten out of twelve audio fragments. This result could also be attributed to sensitivity and personal preference.

6. Conclusions and applications

6.1 Method

M+P has chosen a relatively neutral approach towards sound interpretation with a focus on the perceived acoustical environment. Based on field experience from years of monitoring sound in open plan offices, a preliminary formula was devised to serve as a framework of attributing points to a certain sound level and fluctuation. A field test served to test and improve this formula, after which it was validated using two lab tests.

The result of this is a basic algorithm that serves as a framework and that can be improved using future practical experience. The algorithm calculates a MACH index (MI), ranging from 1 to 10, which rates the average perception of the acoustical environment in the monitored office, i.e. *Liveliness*. The numerical rating is also translated into one of four categories: quiet, tranquil, lively and turbulent.

6.2 Applications

Since many open plan offices are designed to have designated zones for certain types of work, especially since the introduction of Activity Based Working (ABW), it becomes easier to make a general assumption about the acoustical quality of a certain zone. Sound levels are expected to be low and constant in zones that are meant for focused work, whereas interactive areas should facilitate exchange of information with high sound levels and a lot of fluctuation. One possible application is to gain insight in how effectively the office lay-out is used. The MACH index has already been implemented in a wireless, low cost Internet of Things platform, allowing for large scale monitoring in offices.

A ten point scale and intelligible categories make the acoustical environment easier to read for laymen, which enables clearer communication and allows employees to find a zone appropriate for their tasks of that moment. The method also gives managers a tool to assess the use of the workplace.

6.3 Future research

In future research a greater diversity of audio fragments could be offered. During this research, participants were subjected to less than ten minutes of audio fragments, with a relatively large degree of variation. Real life situations are more closely resembled when the effect of adaptation to the acoustic environment is taken into account. One could think of exposing test subjects to more or longer audio fragments to investigate this effect.

Furthermore, methods of sound recognition could be developed, potentially based on self-learning systems. This would allow for a more accurate application of research performed in laboratory conditions, which often focuses on specific types of sound. As a result, a relation could be made between sound levels monitored in an office, and the predicted level of experienced *Liveliness* caused by various types of sound like speech, a door, a printer or any other type of sound.

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