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Assessment of personnel exposure to unfavourable acoustic environments in office space at concentration-demanding posts

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Abstract This paper presents the results of soundscape studies in office space used for work demanding high concentration. It demonstrates that acoustic pressure measurements are not the only factor influencing soundscape perception. The subjective assessment of an office space soundscape is of equal importance to objective acoustic measurements. A subjective assessment does not always overlap with measured values, while a negative soundscape contributes to diminished concentration, decreased work efficiency and more frequent mistakes among personnel. An acoustic environment can be improved not exactly by reducing noise, but rather by changing the ambient sounds to such that are more beneficial for maintaining concentration and focus.

Keywords: soundscape, office space, sound assessment, concentration.

1. Introduction

With the rising awareness regarding the influence of sound on the human body, the need to seek solutions for improving the surrounding soundscape increases as well. This has considerable significance in the case of office work that requires particular concentration. Excess sound levels are observed very rarely in office space, yet this does not entail the total lack of an unfavourable soundscape that would have a negative influence on the ability to focus at the workplace. The term "soundscape" was introduced by Murray Shafer [1]. He popularised the notion of the "acoustic environment" which, though initially rooted in music and fields of acoustic ecology studies, quickly spread to other disciplines, such as acoustics, architecture, health, environment, psychology, sociology and urban planning, calling for a holistic approach to the way humans comprehend the surrounding sounds and their perception [1]. A multi-disciplinary approach to the soundscape as well as soundscape management are becoming increasingly significant, as these methods focus on how humans actually perceive and experience the acoustic environment [2]. The definition of a soundscape is provided in detail in standard ISO 12913-1:2014 [3], according to which a "soundscape" is an international concept defining the acoustic environment as perceived and/or understood by a person or people in context. The context is understood as the relations between the person and the activity or place, in time and space.

The acoustic environment of a given location consists of sounds originating from various sources. A soundscape can include sounds among which some draw more attention than others, depending both on the physical properties of the signal (e.g. intensity) as well as its significance to the listener [4]. Results obtained by other researchers have demonstrated [5] that sounds can be divided into categories with various levels of aggregation: general categories encompass sounds originating from similar sources (slamming or closing various doors, sounds of engines) or those that serve the same functions, e.g. alarm signals. As a result of this categorisation, the assignment of specific sounds to broader groups leads to perceiving the entire groups of sounds as pleasant or unpleasant. Thus, for example, noise associated with aeroplanes, traffic or mechanical labour is generally perceived as negative, whereas the sounds of nature are acknowledged as equally positive [6]. Individuals participating in a given acoustic environment have no awareness of their own contribution to or influence on this environment [7].

Office noise is a very specific type of noise. It does not exactly entail exceeded acoustic pressure levels, but rather the occurrence of undesired, distracting sounds. Studies by other researchers [8] indicate that phone calls and group conversations are reported the most often by office personnel as sounds that distract

from work. The second most common sound source includes mechanical sounds such as produced by computer fans and printers [8]. This finds confirmation in other studies [9], which demonstrate that conversations and telephone signals constitute the most distracting sound sources. Other publications [10] also show that mental fitness at the workplace can be disturbed by various types of noise, such as the voices of other people, telephone ringtones, ventilation systems, computer fans, equipment elements and external noise.

The primary concern for managers in terms of establishing desirable organisational behaviour is to maintain the high efficiency and quality of work. Material workplace parameters such as: insufficient space, inappropriate ambient temperature, inadequate light, no ventilation, noise, flashing lights, radiation (e.g. from monitor screens) result in increased fatigue [11]. G. Lehman's classic definition states that fatigue is a "(...) temporary reduction or loss of work capability, a reversible reduction of the functioning of an organ or the entire body" [12]. In the field of interest pertaining to organisational behaviour, fatigue is a dysfunction that results in decreased work efficiency and quality. Acute and chronic fatigue, exhaustion and weariness are the most devastating to an employee's health and result in a decreased quality of the performed work [11].

The results of tests analysing the effects of sound levels in office space demonstrate that ambient levels exceeding 45 dB (A) are associated with a reduction in acoustic satisfaction [13]. According to the Polish standard PN-87/B-02151/02 [14], the adopted permissible A-weighted equivalent sound level for noise entering a room from all sources of noise combined is as follows:

- in rooms intended for mental work demanding significant concentration - 35 dB
- in rooms intended for administrative work, with no internal sources of noise - 40 dB
- in administrative rooms with internal sources of noise - 45 dB [15].

It would appear that an ambient noise level (from all sources combined) exceeding 45-50 dB(A) is associated with discomfort [16].

Office workers spend a lot of time indoors, where the physical environment influences their general condition and directly impacts their work efficiency and productivity [17]. The influence of noise on the performance of monotonous activity is typically low, whereas concentration-demanding work, e.g. data gathering or analytical processes, can be disturbed by it [15]. Office noise can be particularly distracting in the case of tasks based on working memory and processes such as reading comprehension and creative thinking. Routine tasks are disturbed by ambient sounds to a minor degree. Attempts to cope with noise are reflected in risk factors concerning productivity and the general condition, such as taking extra breaks, lowering the quality of work, working overtime and applying additional effort. Results [18] demonstrate that separate rooms are better than open office space. On the other hand, individuals working in single rooms expect to have more control over the acoustic environment compared to employees who share their space with co-workers [19].

The assessment of the same sounds is dependent on the place and context in which they are heard. The acoustic comfort of individuals who are located in a given acoustic environment and familiar with it is different from how it would be evaluated by people introduced to it for the first time [20,21]. When experiencing a given soundscape for the first time, humans dedicate more attention to sounds that are new to them in such an environment. Meanwhile individuals accustomed to a particular acoustic environment ignore certain sounds. Such persons can focus more quickly on sounds that carry information. If speech occurs at the same time as ambient sounds, such sounds remain unnoticed [22].

Noise in office space may result in diminished concentration, reduced worker alertness and decreased work efficiency. Concentration-demanding mental work, data gathering or analytical processes appear particularly vulnerable to the influence of unfavourable soundscapes [23], while tasks that require intense concentration are more susceptible to noise than routine tasks [10]. On the other hand, workers are accustomed to ambient sounds, and an environment completely devoid of sound would surely turn out disturbing [24].

The purpose of these studies was to investigate the influence of individual sound sources on the soundscape assessment among employees in their workspace. Another goal was to identify the sound sources that exhibit the greatest contribution to the negative perception of soundscapes in office space and to analyse the possibilities for soundscape improvement.

2. Method and results

Sound measurements for the purpose of these studies were performed in selected office areas at the Central Mining Institute in Katowice. The tests in office space were conducted over the period of June – November 2020.

The studies encompassed two stages:

- The first stage involved acoustic measurements. The level of acoustic pressure was measured in the studied areas, with determined minimum and maximum values.
- The second stage investigated the perception of the soundscapes in the studied areas. Surveys were conducted to allow personnel to evaluate the soundscapes in their specific office areas.

Rooms intended for office work in administrative buildings were selected for the studies. Measurements were taken in a total of 15 rooms. The tests were performed continuously, with 8 hour long measurements. The determined parameters included L_{Aeq} values as well as the minimum and maximum levels of acoustic pressure. Afterwards, a survey was conducted among all the workers in a given room. Due to the COVID-19 pandemic, rooms intended for multiple people were typically staffed by single persons, working in rotation.

2.1. First stage of studies; acoustic measurements.

The first stage of studies encompassed acoustic measurements. The measurements were taken by means of the Svan945 noise meter. The instrument was placed on a 1.5 m high stand. The instrument was situated at a worker's desk. Before commencing the tests, the worker was informed that the instrument would not record conversations. The sound recording option was disregarded during the acoustic pressure level measurements. The tests were performed continuously, with 8 hour long measurements. The obtained values were averaged for the entire work day. Example courses over time are presented in Figures 1- 4.

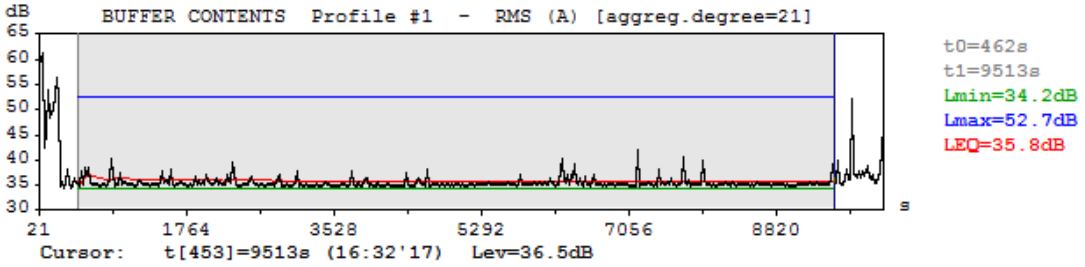

Figure 1. Course over time in a room staffed by a single person working at a computer.

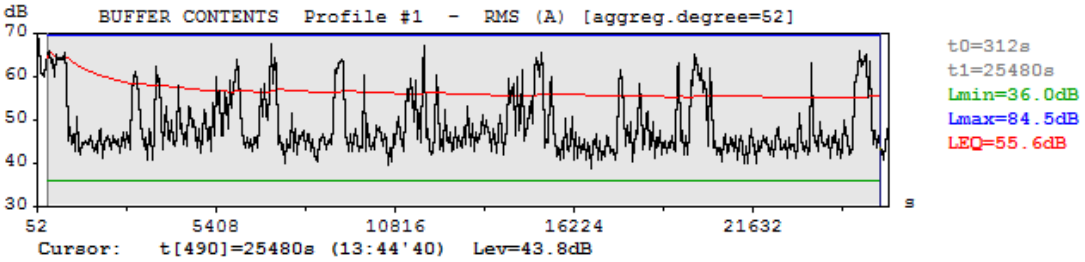

Figure 2. Course over time in a single room with frequent phone calls, conversations (numerous persons entering the room) and working office equipment.

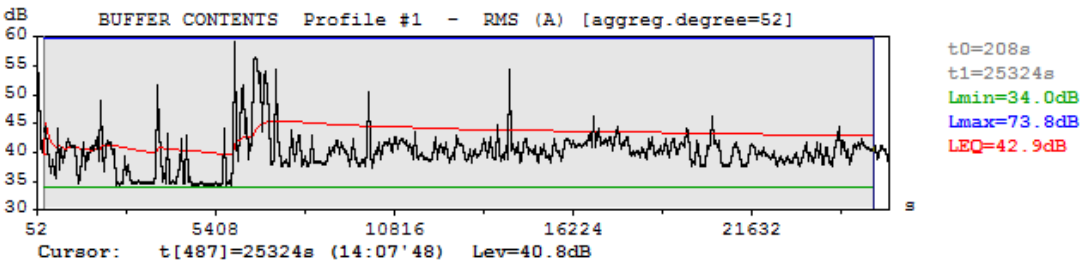

Figure 3. Course over time in an office located close to a workshop.

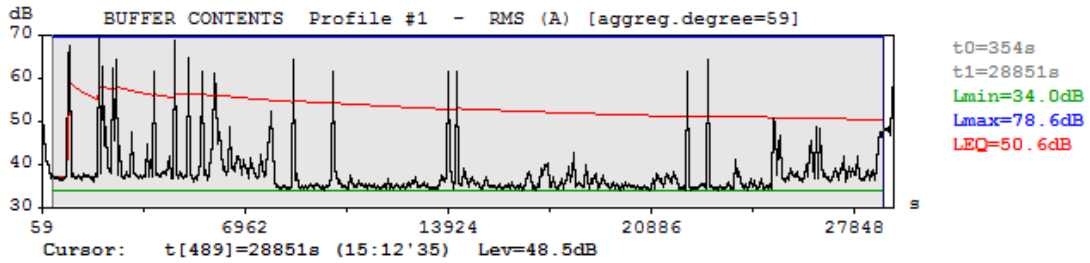

Figure 4. Course over time in a room where the employee answered numerous phone calls while working at several computers and with various office equipment.

The courses depict how the level of acoustic pressure changed over time. However, the provided minimum, maximum and L_{Aeq} values do not fully reflect the soundscape of a given room. The reason for this is the averaging of the values over time. Figure 1 presents a stable level of acoustic pressure in a room where the employee worked at a computer throughout the day. The room exhibited an uniform noise. There were no large variations in acoustic pressure. The second course (Fig. 2) depicts a completely different acoustic situation. Here, the employee also worked in a single room, but the character of the employee's work was significantly different. The employee frequently contacted co-workers by phone, while various people also entered the room from other areas. In the third case (Fig. 3), the office was located close to a workshop. During the first part of the day, the soundscape in the room was disturbed by the operation of printing equipment. The last presented course (Fig. 4) depicts work performed at an office that involved the acceptance of servicing orders. A telephone rang frequently in the room, the operation of printers and other office equipment could be heard as well.

The next part of the article presents the course of the average level of acoustic pressure for all the studied rooms.

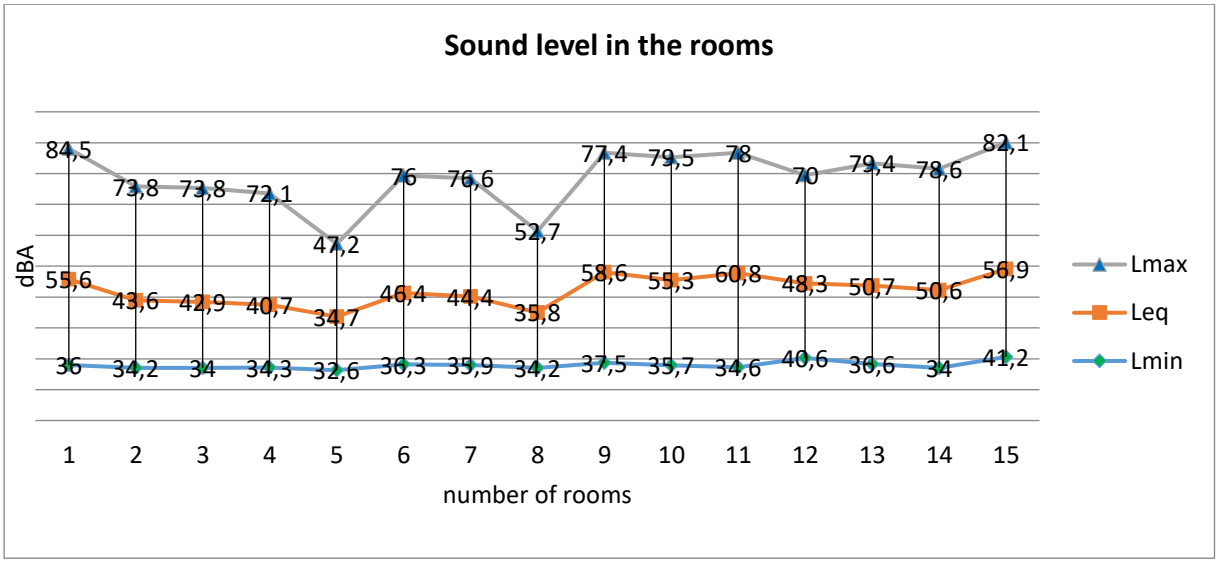

Figure 5. Minimum, maximum and average levels of acoustic pressure in the studied rooms.

Figure 5 presents a compilation of the minimum, maximum and average levels of acoustic pressure in the studied office space. The minimum acoustic pressure was similar in all the rooms and varied between 34 and 41 dBA. The average acoustic pressure levels were also comparable. Loud conversations had a minor influence on the average L_{Aeq}. However, this influence was only applicable to temporary values, and not the average value. The greatest differences concerned the temporary maximum L_{Aeq}. This was influenced by noisy telephone ringtones and loud conversations.

2.2. Second stage of studies; the survey research

The second stage of studies encompassed a subjective evaluation of the soundscape in the office space, and the way it was perceived by the workers. Surveys were conducted to allow workers to evaluate the soundscape itself as well as to identify the sources of the audible ambient sounds and to specify the workers' emotional attitude towards a given sound.

The questions concerned the volume and the adequacy of the sound in relation to the environment, and asked the employees to list the sound sources in the room as well as to assess their level of irritation, to identify distracting sounds and to share what they would like to change to improve the acoustic environment and simultaneously enhance concentration at the workplace.

Survey results

The survey began with a question concerning the general evaluation of the soundscape in a given room. All the respondents described the soundscape as positive (70%) or average (30%). No one described the soundscape as negative. The question of "how loud is it here?" was answered as "slightly" by 55% of the respondents, and "average" by 45%.

Afterwards, the employees were asked to list the sounds in the room. It was an open question, and all the workers could include any sound sources that they had noticed (Fig. 6).

The next question asked the respondents to list the pleasant and unpleasant ambient sounds.

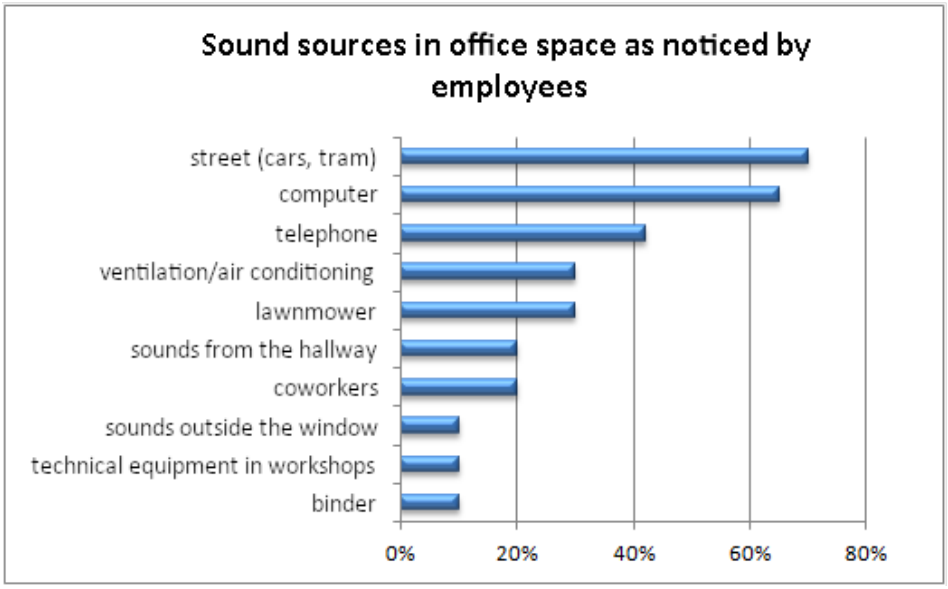

Figure 6. Sound sources in rooms as noticed by office workers.

While listing the unpleasant sound sources posed no difficulty to the workers, naming pleasant sounds turned out to be a major problem (Fig. 7). Most employees were unable to say what pleasant sounds could be heard in their offices. The pleasant sounds included only the rustling of trees outside (2 respondents), birdsong outside (2 respondents) and the radio (1 respondent).

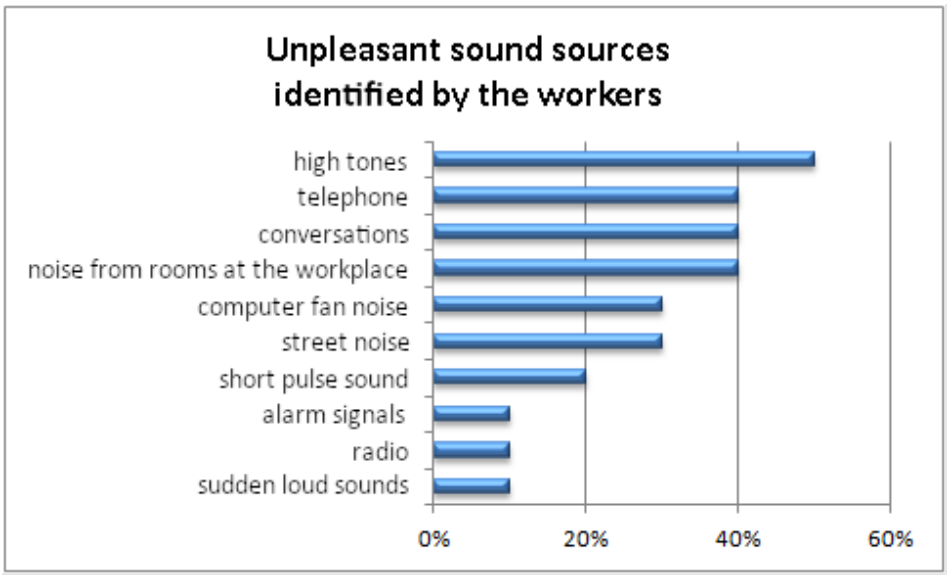

Figure 7. Unpleasant sound sources.

The next stage of the study asked the workers what solutions regarding the improvement of sounds in the office space would they consider satisfactory. The respondents mentioned:
- lowering the telephone ringtone volume
- closing the windows
- installing air conditioning that would make opening windows unnecessary
- working in a single room
- replacing the computer fan or using laptops instead of desktops

One respondent indicated that the noise is impossible to eliminate due to the nature of the performed work.

2.3. Third stage of studies

The third stage of studies involved a risk assessment using the Delphi method [25]. The Delphi method is applied to complex problems that are difficult or impossible to measure quantitatively. This approach is used for analysing natural, technical, social or economic issues. It utilises an indirect form of opinion expression by experts. Persons participating in the risk assessment create their own ranking lists by assigning a level of risk to each risk factor. The factor that involves the highest risk receives the most points. Each subsequent factor with a lower risk receives one point less. The factor with the lowest risk receives 1 point. Points assigned to individual factors by each expert are then summed.

The calculated risk is classified as one of three categories:

- $R \leq 34\%$ - low risk – no action is necessary,
- $34\% > R \leq 67\%$ - medium risk – attention should be paid to the hazards,
- $R > 67\%$ - high risk – action for limiting the risk must be taken.

Five employees of the Laboratory of Acoustics at the Central Mining Institute were selected for the risk assessment as part of the study.

Table 1 presents the assessment results for risk factors determined by means of surveys conducted among office workers. The experts evaluating the factors were not familiar with the survey results – their task was to assess the individual factors according to their expert knowledge. The persons taking part in the risk assessment were not allowed to communicate among themselves and had no knowledge of the answers given by the other experts.

Table 1. Risk factor assessment.

Risk factors	Expert					Sum of points	Risk R%	Risk category
	a	b	c	d	e			
telephone	5	5	4	7	5	26	100%	high
computer	3	5	4	5	4	21	80.8%	high
industrial equipment in workshops	5	4	3	4	4	20	76.9%	high
ventilation/air conditioning	3	2	3	2	3	13	50.0%	medium
co-workers	1	2	4	3	2	12	46.2%	medium
outside the window	2	2	1	3	2	10	38.5%	medium
street	2	1	2	2	3	10	38.5%	medium
hallway	1	1	1	2	2	7	26.9%	low
binder	1	1	1	1	2	6	23.1%	low
lawnmower	1	1	1	1	2	6	23.1%	low

Action for risk limitation was considered after the identification of high risk factors.
The experts proposed the following action:
- changing telephone ringtones to low-tone signals, lowering the volume of the signal in rooms staffed by a single worker,
- soundproofing doors to prevent sounds from the hallway and nearby workshops from entering the rooms, closing the doors to the workshop areas, changing the locations of the offices,
- changing the locations of the computers, putting sound dampening pads under the computers, replacing/cleaning the computer fans.

3. Discussion

A soundscape assessment is dependent on the function that a particular soundscape is intended to serve. In office space for conceptual work, exceeded noise levels are extremely rare. Therefore, it would seem that there are no obstacles to eliminating the disturbance that the sounds can have on the workers' concentration. However, the employees do complain about irritating sounds that distract them and prevent them from focusing.

Identifying the sounds characterised by the greatest discomfort but exhibiting values lower than the permissible limits constitutes a key task in the effort to improve soundscapes in office space. Staying in an acoustically uncomfortable environment is disruptive to work, contributes to lowered productivity and increases the risk of mistakes.

The sound sources identified in the office space included the conversations of co-workers, the movement and speech of people entering the room, noise in the hallway, computers; including computer fans and keyboards, telephones, binders and other office equipment. Some offices were equipped with air conditioning, while technical equipment from nearby workshops was audible in other rooms. A part of the rooms had windows facing Korfantego street, which is characterised by car and tram traffic. Some persons mentioned lawnmowers before the building, renovations, a few others named alarm activation.

Noises originating from various sources were the most commonly reported nuisance. The sources of the noises were computer fans, air conditioning/ventilation and cars passing in the distance. Though characterised by a low acoustic pressure, the noises provoked fatigue.
The other extreme included sounds resulting in immediate loss of focus. These were sounds with high intensity, while some persons also mentioned their high frequency. The primary source of these sounds included ringing telephones, in single cases it was also an alarm activation or the operation of equipment in workshops.

In most cases, the discomfort assessment results for sounds influencing the workers' focus at concentration-demanding posts overlapped. Employees and experts conducting the assessment identified

the following sound sources as the most distracting: telephones, workshop sounds, street noise and co-workers. On the other hand, the greatest fatigue is induced by the noise of computers and air conditioning.

As a result of the conducted studies, modifications were proposed for improving the soundscapes in office space. Improving the soundscape by eliminating noise is possible by relocating a computer (e.g. by placing it on a soft pad) or replacing the computer fans. Installing air conditioning in rooms with windows facing noisy streets as well as replacing windows with better soundproofed ones would also reduce the noise originating from busy streets (though in this case, it is recommended to consult the workers and discuss the increase in noise from the ventilation). Eliminating loud high-tone sounds is possible in the case of telephones. One of the solutions is to change the ringtone to a signal of a lower tone or reduce the telephone signal volume.

Some sounds cannot be eliminated. These are primarily conversations between co-workers. The employees assessing the soundscape are not aware that they also generate sounds themselves, thereby creating an acoustic environment in their own vicinity.

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Additional information

The author(s) declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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