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Publication date
2021

Document Version
Final published version

Citation (APA)
Hamida, A. B., Zhang, D., & Bluyssen, P. M. (2021). *Interaction effects of acoustics at and between human and environmental levels: A review of the acoustics in the indoor environment*. Paper presented at Healthy Buildings Europe 2021 Online Conference, Trondheim, Norway.

Interaction effects of acoustics at and between human and environmental levels: A review of the acoustics in the indoor environment

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SUMMARY

People spend around 90% of their time indoors, where they are exposed to various physical stressors, such as unpleasant sounds, odours, temperature, and lighting, which may cause annoyance and discomfort. This literature review is focused on substantial studies that emphasize noise as a physical stressor in the indoor environment. Previous studies showed that background noise has a significant impact on human health. Adding to that, several other studies showed significant cross-modal effects between noise and other environmental stressors. However, various previous studies focused on quantifying the indicators of the indoor environmental quality (IEQ) factors rather than studying the differences of each occupant on their preferences and needs. Hence, this literature review highlights studies that take into account the interaction effects of acoustics at and between human and environmental levels. This review study aimed at identifying the key indicators to be taken into account for evaluating acoustical quality.

INTRODUCTION

People spend the majority of their time (around 90%) in the indoor environment. Staying indoors is not beneficial to human health, therefore, it is important to promote an indoor environmental quality (IEQ) that provides a healthy and comfortable environment (Bluyssen, 2020). IEQ includes four main factors (which are thermal comfort, lighting quality, acoustical quality, and air quality) that play a vital role in the human senses and wellbeing (Bluyssen, 2009). Physical stressors, such as unpleasant sounds, odours, temperature, and light, which are sensed by human sensory receptors, can contribute to annoyance and discomfort (Bluyssen, 2014). Noise was the major environmental stressor at primary schools, affecting 87% of the school children surveyed (Bluyssen et al., 2018). Noise is a physical stressor that stimulates both the sympathetic and endocrine systems. It is recommended to investigate the relation between the noise source and health risk characterization (Babisch, 2002). Noise exposure may induce changes in stress hormone levels and sleep disturbances. Besides, oxidative stress in chronic noise exposure results in noise-induced hearing loss (Bluyssen, 2014). In addition, chronic noise exposure to background noise (external and internal noise sources) can affect individuals' performance and attention (Shield & Dockrell, 2008). Thus, this study aims at identifying the key indicators at both human and environmental levels to be considered for assessing the acoustical quality.

METHODS

A literature review of scientific articles published between 2000 and 2021 was carried out.

Databases:

Various databases were browsed for finding the most recent articles, including Google Scholar, Scopus, and the TU Delft library. Relevant articles were found in journals such as Building and Environment, Applied Acoustics, and Indoor and Built Environment. Besides, conference papers were found in the domain of this study.

Keywords:

The keywords that were used for finding the relevant scientific articles are: cross-modal effect (combined effects and multisensory interaction), effects (physiological effects, comfort, and annoyance), acoustical conditions (noise exposure and noise level), indoor environmental quality, and methods (lab study, experimental study, and environmental chamber).

RESULTS & DISCUSSION

Cross-modal effects of acoustics and other IEQ-factors

Previous studies revealed that there are cross-modal effects between acoustics and the other IEQ-factors.

Acoustics and thermal comfort

Yang et al. (2018) demonstrated that psycho-acoustical parameters were affected by indoor thermal conditions, while the fan noise perceptions were found to be independent of thermal conditions (Yang et al., 2018). Also, Yang and Moon (2018) indicated that thermal conditions did not affect loudness and noise. However, the thermal comfort was decreased by increasing the noise levels (Yang & Moon, 2018).

Acoustics and visual comfort

In terms of acoustics and visual comfort/lighting, a study conducted by Liebl et al. (2012) demonstrated that individuals performed better when they were exposed to low background noise levels combined with static lighting (Liebl et al., 2012). In terms of visual factors, Hasegawa and Lau (2021) found that the greenery factor followed by water as a visual factor reduced the noise annoyance as perceived by individuals in the indoor environment (Hasegawa & Lau, 2021). Similarly, in an experimental study, it was shown that visual stimuli of sea view reduced the annoyance equivalent to a 1dB reduction in total sound pressure level (SPL) (Chau et al., 2018).

Acoustics and indoor air quality

With regards to the interaction effects of noise and odours, in a study, it was found that the effect of odour on noise perception caused neither synergism nor antagonism, but simple additivity, while noise level decreased the responses to odour (Pan et al., 2003).

Acoustics and other IEQ-factors

In a lab study on the interaction effects of acoustics with other IEQ-factors, involving primary school children in the Netherlands, it was found that the perception of smell was significantly related to draught, sound, and light perception. Smell was evaluated the worst with sound type 'children talking' (Bluyssen et al., 2019). Wu et al. (2020) conducted an experiment in a test chamber and revealed that the temperature had a crossed effect on both acoustical and visual comfort, and both sound level as well as illuminance had crossed effect on thermal comfort. The effect of acoustical satisfaction was the greatest on the overall satisfaction (Wu et al., 2020). Furthermore, Bourikas et al. (2021) assessed the cross-modal perception between thermal, acoustic, and air quality perceptions on occupants' comfort and satisfaction in university office buildings. This study used post-occupancy evaluation, a comfort survey, and concurrent environmental conditions monitoring. It was found that thermal sensation was influenced by both air quality and noise. However, the cross-modal effect of air quality and noise on the thermal sensation was not clear (Bourikas et al., 2021).

Based on the previous studies, several indicators at the environmental level are presented in **Table 1.**

Table 1. *IEQ-factors indicators at environmental level*

IEQ-factor	Indicator
Acoustics	Sound level, Sound pressure level (SPL)
	Noise/sound type
	Reverberation time
	Material absorption coefficient
	Speech transmission index (STI)
Air quality	Ventilation type
	Odour type
Thermal comfort	Temperature
	Relative humidity (RH)
	Predicted Mean Vote (PMV)
	Air velocity
Lighting/ visual comfort	Lighting type
	illuminance intensity
	Illuminance level
Lighting/ visual comfort	Correlated colour temperature (CCT)
	Sheer shades
	Electrochromic tint

Interaction effects of acoustics at the human level

The interaction effects of acoustics occur at the human level by three major health effects; physiological, psychological, and performance. In terms of physiological effects, an experimental study showed that exposure to a combination of heat and noise could cause changes in blood pressure (Dehghan et al., 2017). Abbasi et al. (2020) also found that the combined noise and air temperature affected human neurophysiological responses (heart rate and respiratory rate) significantly. It was indicated that the combined effects of both noise and air temperature were more noticeable than the effects of each of them alone on human neurophysiological responses (Abbasi et al., 2020). Additionally, Alvarsson et al. (2010) examined the effect of sound types on stress recovery in an experimental study. The results of this study showed that the skin conductance level (SCL) recovery was faster during exposure to natural sound compared to exposure to a noisy environment (Alvarsson et al., 2010). Also, laboratory experiment results showed that the noise level resulted from different floor impact sound sources had significant physiological responses. These responses represented changes that occurred in both electrodermal activity, and respiration rate that led to noise noticeability and high sound levels induced noise annoyance (Park & Lee, 2017).

Furthermore, it was observed that indoor acoustics can affect individuals' performance. For instance, in a lab study with primary school children conducted by Zhang et al. (2019), significant interactions between the effect of sound type and SPL on children's phonological processing performance were seen (Zhang et al., 2019). In terms of psychological effects, Ma and Shu (2018) concluded that soundscape elements that are considered as pleasant had a positive effect on fatigue restoration as well as mitigating the annoyance, and had a significant influence on psychological restoration (Ma & Shu, 2018). Thus, soundscapes that are perceived as pleasant and restorative by individuals play a vital role in improving the cognitive performance of students in classrooms.

In **Figure 1,** a summary of indicators at human level to assess indoor acoustical quality is presented.

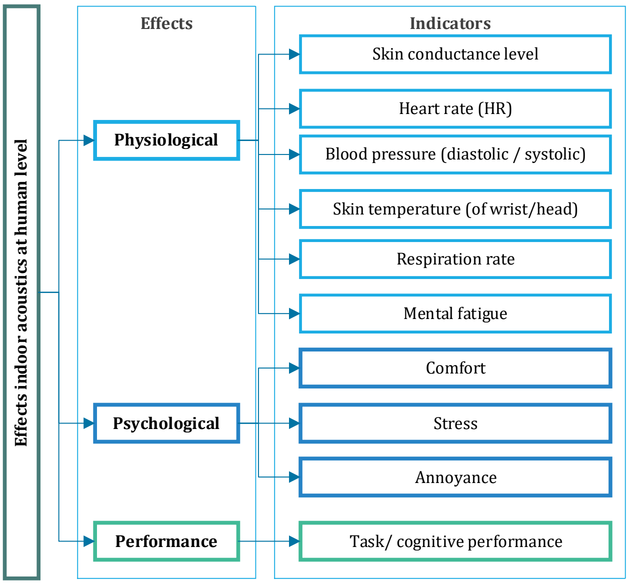

Figure 1. *Effects and indicators of acoustical conditions at human level*

CONCLUSIONS

The relevant literature on the interaction effects of acoustics with other IEQ-factors was reviewed in this paper. Previous studies showed that there are significant interaction effects between acoustics and temperature. The interaction effects of acoustics and visual comfort have also been studied. However, few studies focused on the interaction effects between acoustics and indoor air quality. Some key indicators for assessing acoustical quality at the human level were presented. To enhance the acoustical quality, it is recommended to take into account the cross-modal effects of noise/sound with other IEQ-factors and the effects (positive and negative) of the acoustical environment at the human level.

REMARK

A full version of this literature review will be published somewhere else later in a journal paper.

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