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ADAPTIVE COMFORT: SIMILARITIES AND DIFFERENCES BETWEEN THE ACOUSTIC AND THERMAL DOMAINS

Seda Yuksel Dicle[1]* **Francesco Aletta**[1] **Jian Kang**[1]
[1] UCL Institute for Environmental Design and Engineering, The Bartlett, University College London (UCL), UK

ABSTRACT

Adaptive responses to thermal conditions have been extensively studied through the adaptive thermal comfort model, reflected in both literature and standards. However, the application of this framework to acoustic comfort evaluations remains underexplored. This study examines the potential for an adaptive acoustic comfort model by drawing comparison with the adaptive thermal comfort model. To address this, structured interviews with 11 experts were conducted, and data were analyzed using thematic analysis. Preliminary findings reveal both similarities and differences between thermal and acoustic adaptation. Regarding the similarities with the thermal model, it was noted that outdoor conditions and adaptation influence indoor acoustic acceptability, and users exhibit adaptive acoustic behaviors to adjust to these conditions. Furthermore, this acceptability is influenced by factors such as ventilation type, control options, expectations, and personal differences. In terms of differences, the relationship between indoor acceptability and outdoor sound level in acoustic comfort is expected to be weaker than the relationship between indoor acceptability and outdoor temperature in thermal comfort in terms of the adaptive mechanism. Additionally, the dynamic nature of acoustic environments, variability in sound perception, and challenges in defining neutral or comfort level have been identified as critical considerations for developing an adaptive acoustic comfort model.

Keywords: *acoustic comfort, adaptation, soundscape, adaptive thermal comfort.*

***Corresponding author**: seda.dicle.22@ucl.ac.uk..

1. INTRODUCTION

Adaptive comfort model provides a key framework for understanding human–environment interaction and has been extensively studied in the field of thermal comfort. Unlike traditional thermal comfort model based on fixed conditions derived from heat balance principles, adaptive approaches highlight how individuals adjust their comfort through behavior, expectations, and engagement with their environment [1-3]. These approaches are grounded in the dynamic relationship between occupants and their environment, introducing adaptive setpoint temperatures as comfort thresholds [4]. This concept of environmental adaptation capability and tolerance is also applicable to other environmental conditions [5].

Acoustic comfort has traditionally been assessed through objective metrics, these assessments often overlooking the perceptual, contextual, and social dimensions of sound experience [6,7]. Recent soundscape research has demonstrated that comfort is not solely determined by decibel levels, but also by the type, meaning, and context of sounds [8,9]. Soundscape research incorporates both physical measurements and insights from human and social sciences, recognizing environmental sounds as a 'resource' rather than a 'waste', and accounting for acoustic perception [7]. It also integrates psychological, (psycho)acoustical, physiological, and social factors to understand how people perceive and experience acoustic environments [10,11]. In line with this approach, recognizing individuals as active participants who assess their environment through personal interactions and preferences, rather than as passive recipients, offers valuable insights into acoustic comfort. Within this framework, it is acknowledged that acceptable acoustic conditions may vary [12], and that individuals' tolerance levels can change in response to trade-offs between acoustic and other environmental domains [13]. Given these insights, the application of adaptive comfort principles to the acoustic domain presents a valuable conceptual opportunity. As noted by previous studies, particularly in naturally ventilated buildings, occupants may tolerate higher noise levels due to trade-offs between thermal and acoustic comfort, highlighting the need for appropriate sound environment assessment criteria [12,13]. In response to this need, recent studies have begun to explore how adaptive comfort principles can be extended to the acoustic domain. Torresin [14] examined the concept of an adaptive acoustic comfort model from a theoretical perspective, while Dicle [15] proposed a structured approach to guide the development of such a model. Building on this prior work, this research focuses on examining thermal and acoustic adaptation mechanisms, aiming to inform the development of a tailored adaptive acoustic comfort model based on the specific characteristics of acoustic perception. It highlights both the shared mechanisms and distinct features of adaptation in each domain.

2. METHODOLOGY

This study adopted a qualitative research design to explore the concept of adaptive acoustic comfort and to examine its similarities and differences with the adaptive thermal comfort model. Semi-structured expert interviews were selected as the method of data collection. The methodological framework is illustrated in Figure 1.

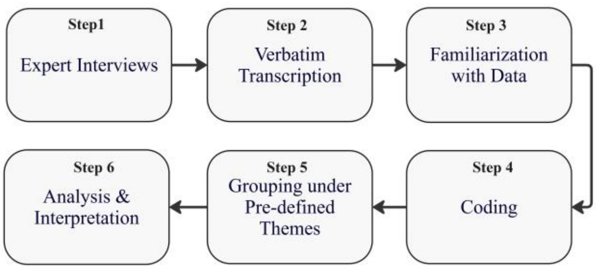

Figure 1. Methodological framework.

2.1 Participants

Interviews were conducted with 11 experts, selected through purposive sampling based on their academic publications and professional experience in relevant fields. In order to facilitate a comparative discussion of adaptive comfort from both acoustic and thermal perspectives, experts from both domains were invited, representing a mix of academia and industry to ensure a broad range of insights. The interview questions were shared with all participants in advance to support informed and reflective contributions.

2.2 Data Collection

The interviews took place either online or face-to-face, depending on the participants' preferences, and lasted approximately 50 to 60 minutes. Open-ended questions were asked to allow participants to reflect on the topics according to their specific area of expertise, and the time spent on each question varied accordingly. At the beginning of each interview, a brief explanation of the research context and the concept of adaptive comfort was provided to the participants. All interviews were audio-recorded with the participants' consent to ensure accurate documentation. The study was approved by the University College London BSEER Local Research Ethics Committee as a low-risk project.

2.3 Analysis

All interviews were transcribed verbatim and repeatedly reviewed. Following a familiarization process, an initial round of coding was conducted using NVivo software, guided by two predefined thematic categories: 'Similarities' and 'Differences'. A deductive approach was adopted, in which the initial codes were developed based on the research objectives and interview questions [16]. After the initial coding, all codes were reviewed, refined, and systematically grouped under the two predefined themes to support the thematic analysis.

3. RESULT

This study examined expert perspectives on the similarities and differences between adaptive thermal and acoustic comfort models. Thematic analysis of in-depth interviews revealed two overarching themes: (A) Similarities and (B) Differences between acoustic and thermal adaptation. The themes and selected excerpts from expert interviews are presented in this section. Themes and codes are illustrated in Figure 2.

Experts acknowledged that adaptive responses in acoustic environments are possible and conceptually comparable to those in thermal contexts. As noted: "*for the acoustic domain, this might be also possible to create such a let's say regression model" (E3)* and "*the same way that how does you find acceptable much wider range of conditions…there is a similar parallel* *with the acoustics" (E5).* It was highlighted that, similar to the thermal domain, individuals also exhibit adaptive behaviors in response to acoustic exposures: *"What I could assume that people change their behavior in order to cope with the acoustic environment" (E3), "If I have to concentrate on one thing and in my office there are other people chatting because they're in a meeting. I try to put on earplug and the classic music high volume without words" (E8).* The importance of user control was a recurring theme across both domains: *"People's perception of comfort is like their level of control over the situation" (E7) and "you have control ... you might change the state of your, you might adapt to your different acoustic environments based on your other competing comfort in other domains" (E1).* Experts also discussed cross-domain trade-offs, especially between thermal and acoustic comfort: *"you can get some adaptation there but obviously it's bit of a trade off" (E7), "everybody has a limit to that trade off" (E1). "Actions that are actually compromising multiple domains ...probably my actions would be leaded by this interaction for systems that are affecting multiple…I would I have to make a balance" (E8).* Personal and cultural differences also emerged as shared influences across thermal and acoustic adaptation: *"the capacity for adapting varies incredibly between individual, …Mediterranean countries are much noisier, so people (can) tolerate noise more than north European countries" (E9), "you get a huge response and a huge individual response" (E11)* highlighting the individual differences. Other important factors were expectations: *"if it's very noisy environment and they would often say the rated is not too bad because they expected" (E10).* Experts also indicated that in both thermal and acoustic environments, adaptive responses are shaped by factors such as function, activity type, and time of day: *"if I'm in a library I would expect very silent environment. If I'm in a shopping mall I would accept whatever" (E5) and "we decide whether the noise is annoying or not…it's not about the sound level. It's about our interpretation of that sound… the source of the sound…our activity" (E6).* Ventilation strategies and the use of personal devices were also highlighted as relevant factors: *"how important it is to people use natural ventilation more comfortably to mitigate overheating?" (E1), "(having different ventilation) affects people acceptability" (E4).* The importance of personalized systems was also emphasized: *"I would assume that this more goes towards introducing more personalized systems" (E5).* Some experts mentioned the role of coping strategies in extreme conditions: *"we can wear headphones, we can remove ourselves from the noise source and there's certainly a physiological level when we're exposed to extreme sound" (E6).*

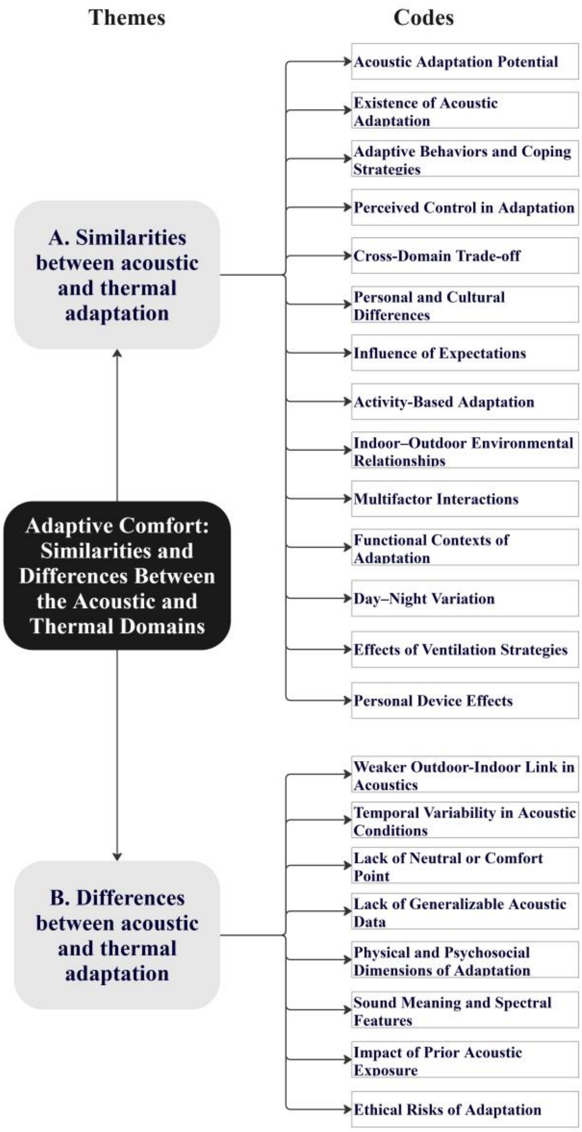

Figure 2. Thematic analysis results: themes and codes.

Despite these similarities, experts acknowledged that acoustic adaptation is possible, though generally considered weaker than in thermal contexts. As noted: *"If people who are to sleeping in quiet places in the countryside, go to a city and can't sleep because it's too noisy and people who live in cities go to the countryside and can't sleep because it's too quiet"* (*E1***)**. Similarly, *"Indoor is normally narrower, outdoor can be regarded much wider… even in acoustics you could argue similar things" (E2).* Yet others emphasized its limited strength: *"the acoustic domain this might be also possible to create such a let's say regression model… but I would assume the regression line is quite flat" (E3).* Another key distinction is variability in acoustic environments, contrasting the relative stability of thermal conditions. Noise level changes suddenly*: "all you need is a car to go by or a truck or a bus that will change the environment completely" (E2), "somebody goes into a noisy place during the day, but then comes back to a quiet place at night or vice versa… acoustic environment change quickly" (E7).* Experts also stressed the lack of a well-defined neutral point in acoustics, unlike thermal comfort: *"So if I ask what is your comfort temperature?...How should I say what is my comfort noise level?" (E3).* The lack of generalizable acoustic datasets was another concern: *"In thermal comfort we have climate data, but in the noise, we don't have this kind of data" (E4).* Experts emphasized the different adaptation mechanisms, highlighting that thermal comfort is largely physiological, whereas acoustic adaptation is more psychosocial and perception-based: "*in terms of thermal comfort, it primarily involves the balance between heat loss and how much the body can compensate for that to produce the heat and we want to have a balance…in acoustics is about perception and the quality" (E5), "Our response to sound is socially constructed… actually a kind of community reaction. It's something we share with other members of the community" (E1).* Further, the meaning and spectral features of sound were noted as critical challenges in acoustic modeling: *"The frequency characteristic of a street is particular… not the same that you get out in a garden or a park" (E4), "it's a stereo blasting from the car or the music that you listen from the radio or from a live performance, it could be completely different. So, I think absolutely the meaning is very important" (E2).* Some experts also raised ethical concerns: *"We should ask whether from the ethical point of view…if we have this connection between indoor and outdoor level and what is accepted from the ethical point of view" (E3).*

Overall, while thermal adaptation models provide a useful starting point, acoustic adaptation requires distinct frameworks that account for perceptual, social, and contextual dynamics.

4. DISCUSSION

This study examines the role of adaptive mechanisms in the acoustic domain, drawing comparisons with the adaptive thermal comfort model. Based on expert interviews, the similarities and differences between the two domains are illustrated in Figure 3. While both domains share common features such as user–environment interaction and behavioral adjustments, expert insights revealed distinct characteristics in acoustic adaptation that necessitate domain-specific frameworks.

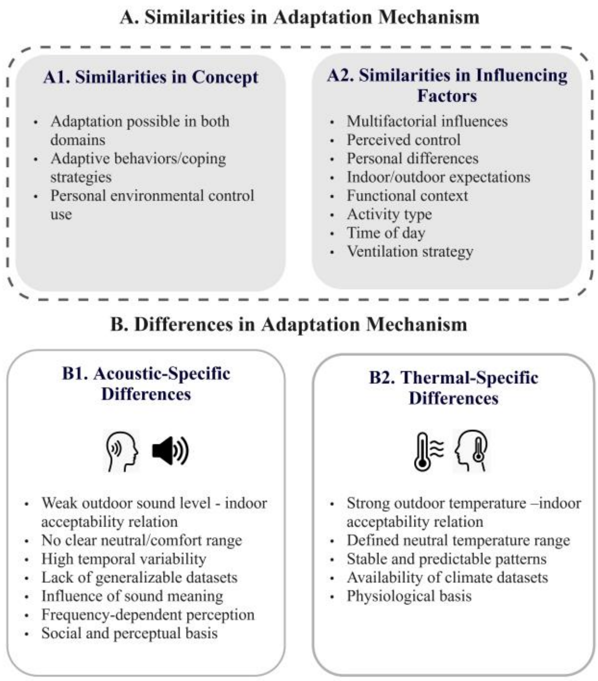

Figure 3. Comparison of Adaptive Mechanisms in Acoustic and Thermal Domains.

A key conceptual parallel between thermal and acoustic adaptation is the recognition that individuals are not passive recipients of environmental stimuli, but actively engage with their surroundings through behavioral, psychological, and contextual responses [17-19]. Soundscape studies in urban open spaces show that beyond physical sound parameters, perceptual and contextual factors strongly influence acoustic evaluations, highlighting the role of psychological adaptation [19]. Both domains exhibit shared adaptive behaviors, with participants emphasized various coping strategies, including relocating to quieter areas, using personal devices (e.g., headphones), or adjusting the duration and type of environmental exposure [20,21]. Cross-domain trade-offs were also highlighted. In naturally ventilated spaces, occupants may tolerate higher noise levels to achieve better thermal conditions by opening windows [13]. This finding underscores the need for integrated comfort models that consider multi-domain interactions rather than evaluating each environmental factor in isolation [22,23]. Perceived control emerged as a central concept in both domains. When individuals feel empowered to modify their environment their comfort thresholds tend to expand [24]. Similarly, in acoustic environments, design strategies that enhance user control and flexibility align with soundscape-based approaches, which emphasize the broader environmental experience and account for non-acoustic benefits [12,25]. In adaptive thermal comfort models, control and multifactorial influences are integrated to account for differences between naturally and mechanically ventilated environments [2,26]. Likewise, acoustic comfort may be viewed as a co-benefit of natural ventilation in specific contexts, further supporting adaptive design strategies [6,14]. Personal factors, expectations, and contextual conditions also shape adaptive responses in both domains. Cultural norms, age, prior exposure, and noise sensitivity influence how users perceive and respond to their environments [5,9]. As with thermal comfort, function, activity type, and time of day modulate acceptable acoustic conditions, what is tolerable during working hours may not be acceptable during rest or sleep [27-30]. Moreover, emerging technologies such as Personal Environmental Control Systems (PECS), which are widely applied in thermal comfort design, also play a significant role in shaping user tolerance levels [31]. Acoustic PECS, such as noise-cancelling headphones and personalized sound zones offer user-centered flexibility and address diverse comfort needs in shared environments. These solutions reinforce the shift away from one-size-fits-all design strategies, promoting individually tailored acoustic environments [21].

Despite these similarities, notable differences emerged. The relationship between outdoor conditions and indoor acoustic tolerance is expected that weaker in the acoustic model compared to the thermal domain. Whereas thermal models often rely on robust regression models and large scale meteorological datasets [26], acoustic environments are characterized by greater variability, sudden fluctuations, and a lack of generalizable large-scale datasets [7,30]. This complexity limits the development of predictive acoustic comfort models with similar reliability and data-driven precision. Another distinction lies in the absence of a clearly defined "neutral point" in acoustics. Unlike thermal comfort, which can be associated with a specific temperature range, acoustic comfort is shaped by the spectrum, meaning, and context of sound [11,32]. The same sound level may be perceived differently depending on its source, such as natural sounds versus mechanical noise, highlighting the crucial role of perception and psychosocial factors in acoustic adaptation [7]. Compared to the physiological basis of thermal comfort, acoustic comfort is influenced strongly by psychological and social dynamics. Perceptual and psychological adaptation processes considered interrelated and equally significant [19]. Moreover, acoustic perception is closely linked to cultural norms and social structures [33]. Participants also emphasized the role of prior exposure conditions. Individual differences in background exposure, such as those experienced at home or during commuting, are more varied and dynamic in acoustic contexts than in thermal comfort. It is noted individuals from noisier home environments may exhibit higher tolerance toward urban soundscapes [19]. These findings indicate that variability in background exposure is a critical factor influencing acoustic adaptation. Additionally, important point, raised ethical concerns about promoting tolerance to higher noise levels without adequately addressing potential health risks such as stress, sleep disturbance, or cognitive fatigue [34].

Even there are many common points, the high spatial and temporal variability of sound environments, along with differences in the meaning, frequency, and perceptual aspects of sound underscores the need for tailored conceptual models. Such variability suggests that adaptive acoustic comfort cannot simply mirror thermal models but should instead integrate the distinct perceptual and social dynamics of acoustic environments.

5. CONCLUSION

This study explores the evaluation of adaptive mechanisms in acoustic environments by drawing parallels with the adaptive thermal comfort model. The findings indicate that:

- Across both thermal and acoustic domains, behavioral strategies, perceived environmental control, expectations, and cross-domain trade-offs emerged as shared elements of adaptive comfort.
- These findings highlight the value of integrated comfort models that account for multi-sensory and multi-domain interactions, supporting occupant wellbeing in the built environment.
- Adaptive responses in both thermal and acoustic domains are also shaped by contextual variables such as function, activity type, ventilation strategy, and time of day.
- In addition, emerging user-centered technologies, such as personal acoustic control systems, offer promising avenues to enhance comfort diversity in shared spaces.

Despite these similarities, the study also identified distinct mechanisms specific to acoustic and thermal adaptation:

- Acoustic adaptation is shaped by distinct perceptual, contextual, and social mechanisms, distinguishing it from the predominantly physiological processes observed in thermal adaptation.
- The absence of a clearly defined neutral point, weaker outdoor – indoor relations, and the higher temporal and spectral variability of acoustic environments pose challenges for standardized modeling and emphasize the need for frameworks specifically tailored to sound perception.
- Moreover, individual exposure histories and cultural norms play a significant role in shaping acoustic tolerance levels, reinforcing the importance of psychological and social dimensions in comfort evaluations.

Overall, this study contributes to the conceptual foundations for adaptive acoustic comfort models and offers practical insights for future research and design strategies in environmental comfort

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