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Methods and indicators to assess the acoustical quality of study places

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by

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This dissertation has been approved by the promotors.

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To my beloved parents:
Basel and Meisoun.

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AL	Attention level
ECG	Electrodes and electrocardiograms
EDA	Electrodermal activity
EDT	Early decay time
EEC	Electroencephalogram
EEG	Electroencephalograms
HF HRV	High-frequency heart rate variability
HR	Heart rate
IEQ	Indoor environmental quality
MRL	Mental relaxation level
PMV	Predicted mean vote
PPD	Predicted percentage of dissatisfaction
RR	Respiration rate
RT	Reverberation time
SCL	Skin conductance level
SPL	Sound pressure level
STI	Speech transmission index
VOCs	Volatile organic compounds

Summary

University students are self-directed learners who spend significant study time in study places, whether at home or in educational buildings. Studies in indoor environmental quality (IEQ) highlight the adverse effects of staying indoors for a long time due to exposure to several environmental stressors, such as unwanted sounds (i.e., noise). Acoustical quality can positively or negatively impact students' health and comfort, consequently affecting their performance. Three groups of indicators can be considered to assess the acoustical quality of study places, which are occupant-related, dose-related, and building-related indicators. Since students differ in their acoustical and psychosocial preferences for study places, it is essential to consider occupant-related indicators (e.g., individual preferences and needs). However, current acoustical guidelines for study places and educational buildings primarily focus on dose-related indicators (e.g., sound level) and building-related indicators (e.g., room geometry), while occupant-related indicators (e.g., preferences and needs) have been overlooked. Thus, the main research question of this dissertation was raised:

– **How to assess the acoustical quality of study places?**

Several methods and indicators were examined to answer the main research question and the five sub questions. These included a literature review, the 'MyStudyPlace' questionnaire that was followed by field studies, sound exposure lab experiments, and the indoor soundscape approach (comprised of semi-structured interviews).

A literature review was conducted on relevant studies in indoor acoustics and indoor soundscape to identify key indicators across the three groups as well as essential methods for their assessment. Notably, only a few studies have investigated students' acoustical preferences and needs through occupant-related indicators (both physiological and psychological), which suggested that research on students' acoustical preferences and needs in study places is required. This review thus provides a comprehensive summary of these indicators and their assessment methods, which forms a foundation for this dissertation to conduct further investigations on students' acoustical preferences and needs in study places.

Since this research started during the COVID-19 pandemic, it was important to explore where university students spend their study time and what their IEQ and psychosocial preferences of their mostly used study place. Accordingly, the 'MyStudyPlace' questionnaire was developed and completed by 451 students from the faculty of Architecture and Built Environment, which revealed that 74% of them study at home, prompting a shift in focus from study places at educational buildings to at home. As research has shown that students differ in their IEQ and psychosocial preferences, the analysis of the questionnaire aimed to provide a general overview of IEQ and psychosocial preferences of university students before investigating acoustical preferences. Students were grouped into three IEQ and three psychosocial clusters. By overlapping these clusters, nine unique student profiles were identified, with significant differences observed across several variables, including acoustical preferences. These findings underscore the importance of analysing the intersection of IEQ and psychosocial preferences to comprehensively understand profiles of students .

Consequently, these students were re-grouped based on their acoustical preferences and selected psychosocial preferences (privacy and company and the presence of others). This resulted in five clusters of students that significantly differ across several variables, including perceptions of indoor environmental quality (e.g., sounds from the outside). These five clusters are: 1) the sound concerned introvert, 2) the sound unconcerned introvert, 3) the sound partially concerned introvert, 4) the sound concerned extrovert, and 5) the sound unconcerned extrovert. Then, a field study at home study places of 23 students (from different clusters) who completed the 'MyStudyPlace' questionnaire and belong to different profiles. Each field study included interviews, building inspections, and sound pressure level measurements. Field study data revealed the aspects associated with students' acoustical preferences. For instance, building-related indicators, such as the building's location, were found to influence students' acoustical preferences.

As the literature review highlights sound, as an environmental stressor, impacts students both physiologically and perceptually. Thus, two sound exposure lab experiments (direct and indirect sound exposure) were conducted at SenseLab with 15 students (who participated in the field study). These experiments aimed to explore indicators that could explain differences in bodily responses and perceptual assessments among these students. Hearing acuity across different frequencies was assessed via audiometric tests. Bodily responses, including attention level (AL), mental relaxation level (MRL), heart rate (HR), and respiration rate (RR), were measured using wearable devices, alongside perceptual assessments of sound conditions. Correlation analysis was performed to explore relationships between bodily responses and perceptual assessments at individual and group levels.

Differences were examined to compare bodily responses and perceptual assessments between the two experiments. Results indicated that students with mild hearing loss in low-frequency experienced increases in HR in response to low-frequency sound conditions. No significant correlations were found between bodily responses and perceptual assessment during direct sound exposure. However, differences in AL responses were observed between the two experiments. The findings suggested that hearing acuity and sound type (sound frequency) are key indicators for identifying differences in bodily responses (such as HR and RR) and perceptual assessments.

The indoor soundscape approach was discussed in the literature review which tackles understanding how an individual experiences the acoustical environment in a context. It includes different methods and indicators which has been developed to gain insights into how occupants perceive and experience sounds in a specific indoor environment. In this dissertation, the indoor soundscape study at 23 home study places was studied by conducting semi-structured interviews with 23 students that belong to the different five profiles. For qualitative analysis, open coding was employed to identify sub-categories and categories based on the interview transcripts, which were then assigned to soundscape themes defined in ISO 12913-1. An affinity diagram was initially developed that comprised themes, categories, and sub-categories. Subsequently, it was then validated in two rounds of workshops with PhD students. The results indicated that students' interpretations of their sound environments, along with their responses and outcomes, differed among the students. The findings showed that the indoor soundscape approach contributes to understanding how a student experiences the sound environment at a home study place. Yet, it is mainly focused on the experience of an 'average' student rather than the different profiles of students.

To conclude, this dissertation offers future research a set of suggested methods and indicators (within three groups) to assess the acoustical quality of study places, incorporating students' acoustical preferences and needs. The five main contributions of this dissertation are as follows:

1. A comprehensive literature review identifies previous methods and indicators used to assess the acoustical quality of study places.

2. The 'MyStudyPlace' questionnaire gathers self-reported data on occupant-related and building-related indicators.

3. A mixed-methods approach combining the 'MyStudyPlace' questionnaire with field studies collects occupant-related data alongside objective data on building-related and dose-related indicators.

4 Laboratory experiments explore both objective and subjective occupant-related indicators (e.g., bodily responses and perceptual assessments) under exposure to different sound types, both direct and indirect.

5 Semi-structured interviews, based on indoor soundscape approach, collect subjective occupant-related indicators, such as sound source preferences and coping methods.

Samenvatting

Studenten aan de universiteit brengen een groot deel van hun tijd voor zelfstudie door op studieplekken, thuis of op de universiteit. Studies naar binnenmilieukwaliteit laten zien dat als gevolg van blootstelling aan verschillende binnenmilieu stressoren, zoals ongewenste geluiden (i.e. lawaai), verblijf binnen voor lange tijd tot vervelende effecten kan leiden. De akoestiek kan de gezondheid en het comfort van studenten zowel positief als negatief beïnvloeden, en dus ook hun studieprestatie. Voor het bepalen van de akoestische kwaliteit zijn drie groepen van indicatoren beschikbaar namelijk bewoner-, dosis-, en gebouw-gerelateerde indicatoren. Omdat studenten verschillende akoestische en psychosociale voorkeuren hebben voor studieplekken is het essentieel om bewoner-gerelateerde indicatoren (bijv. individuele voorkeuren en behoeften) mee te nemen. Echter, huidige richtlijnen voor akoestiek op studieplekken en universiteitsgebouwen zijn vooral gericht op dosis-gerelateerde indicatoren (bijv. geluidsdrukniveau) en gebouw-gerelateerde indicatoren (e.g. dimensies van ruimte), terwijl bewoner-gerelateerde indicatoren (bijv. voorkeuren en behoeften) over het hoofd worden gezien. Daarom is de hoofdonderzoeksvraag van dit promotieonderzoek:

– **Hoe kan de akoestische kwaliteit van studieplekken worden bepaald?**

De hoofdonderzoeksvraag werd met vijf sub-onderzoeksvragen beantwoord, waarbij verschillende methoden en indicatoren zijn toegepast. Alle groepen van indicatoren (bewoner-, gebouw-, en dosis-gerelateerde indicatoren) zijn gebruikt om de akoestische voorkeuren en behoeften van universiteitsstudenten op hun studieplekken met verschillende manieren van dataverzameling te bepalen: vragenlijsten, interviews, inspecties van studieplekken, geluidsdrukniveau metingen, workshops, en geluidsblootstelling experimenten in het lab.

Een literatuur review van relevante studies in akoestiek en ‘Soundscape’ in gebouwen werd uitgevoerd om de belangrijkste indicatoren van de drie hoofdgroepen, evenals essentiële bepalingsmethoden te identificeren. Slechts in een aantal studies zijn akoestische voorkeuren en behoeften van studenten onderzocht met bewoner-gerelateerde indicatoren (zowel fysiologisch als psychologisch). Dit suggereert dat onderzoek naar akoestische voorkeuren en behoeften van studenten op studieplekken nodig is. De review resulteerde in een uitgebreide samenvatting van de indicatoren en de bijbehorende bepalingsmethoden, en vormde de aanleiding van dit proefschrift om verder onderzoek te doen naar akoestische voorkeuren en behoeften van studenten op studieplekken.

Omdat met dit onderzoek werd gestart tijdens de COVID-19 pandemie, was het belangrijk uit te zoeken waar studenten van de universiteit hun studietijd doorbrengen en welke voorkeuren voor binnenmilieukwaliteit en psychosociale voorkeuren voor hun meest gebruikte studieplek zij hebben. De 'MyStudyPlace' vragenlijst werd samengesteld, verdeeld, en ingevuld door 451 bachelor studenten van de faculteit Bouwkunde. Omdat uit de uitkomst bleek dat 74% van de studenten thuis studeerden, werd het accent van het onderzoek verschoven van studieplekken op de universiteit naar thuis. Onderzoek heeft aangetoond dat mensen verschillen in voorkeuren voor binnenmilieukwaliteit en psychosociale voorkeuren. De analyse van de vragenlijst richtte zich daarom eerst op het geven van een algemeen overzicht van voorkeuren voor binnenmilieukwaliteit en psychosociale voorkeuren van studenten voordat hun akoestische voorkeuren werden onderzocht. Studenten werden verdeeld in drie binnenmilieukwaliteit en drie psychosociale clusters. De overlap van deze clusters resulteerde in negen unieke profielen van studenten met significante verschillen voor verschillende variabelen, waaronder akoestische voorkeuren. Deze bevindingen benadrukken hoe belangrijk het is om de combinatie van voorkeuren voor binnenmilieukwaliteit en psychosociale voorkeuren te analyseren voor het beter begrijpen van de profielen van studenten.

De studenten werden vervolgens gehergroepeerd op basis van hun akoestische voorkeuren en geselecteerde psychosociale voorkeuren (privacy en gezelschap, en de aanwezigheid van anderen). Dit resulteerde in vijf clusters van studenten die significant verschilden voor verschillende variabelen, waaronder percepties van binnenmilieukwaliteit (e.g., geluiden van buiten). Deze vijf clusters zijn: 1) de geluid bezorgde introvert, 2) de geluid onbezorgde introvert, 3) de deels geluid bezorgde introvert, 4) de geluid bezorgde extrovert, en 5) de geluid onbezorgde extrovert. Uit elk van deze clusters met verschillende profielen, werden studenten (in totaal 23) geselecteerd voor deelname aan een veldstudie op hun studieplek thuis. De veldstudie bevatte een interview, inspectie, en een geluidsdrukniveau meting. Met de uitkomst werden aspecten die geassocieerd zijn met akoestische voorkeuren van studenten bepaald. Bijvoorbeeld, verschillende gebouw-gerelateerde indicatoren, zoals de locatie van het gebouw, die de akoestische voorkeuren van studenten beïnvloeden werden gevonden.

De literatuur review toonde aan dat geluid, als binnenmilieustressor, zowel fysiologisch als mentaal effect heeft op studenten. Daarom werden twee geluidsblootstellingsexperimenten (direct en indirecte geluidsblootstelling) met 15 studenten (die ook meededen aan de veldstudie) in het SenseLab uitgevoerd. Deze experimenten waren gericht op het onderzoeken van indicatoren die verschillen in lichamelijke reacties en perceptie van deze studenten kunnen verklaren. De gehoorscherpte van elke student voor verschillende frequenties werd gemeten met een audio metrische test. Naast perceptuele beoordelingen van geluidscondities werden lichamelijke reacties (aandacht niveau (AN), mentaal ontspanningsniveau (MON), hartslag (HS), en ademhalingssnelheid (AS)) met draagbare apparaten gemeten. Correlatieanalyse werd toegepast om relaties tussen lichamelijke reacties en perceptuele beoordelingen op individueel en groepsniveau te onderzoeken. Verschillen werden onderzocht om lichamelijke reacties en perceptuele beoordelingen te vergelijken tussen de twee experimenten (directe en indirecte blootstelling). Resultaten geven aan dat studenten met mild gehoorverlies in lage frequenties een toename van HS lieten zien wanneer blootgesteld aan laagfrequente geluidscondities. Bij directe blootstelling (in oor) werden geen significante correlaties gevonden tussen lichamelijke reacties en perceptuele beoordelingen. Echter, tussen de twee experimenten werden verschillen in AN reacties gezien. Deze bevindingen suggereren dat gehoorscherpte en soort geluid (geluidsfrequentie) belangrijke indicatoren zijn voor het identificeren van verschillen in lichamelijke reacties (zoals HS en AS) en perceptuele beoordelingen.

In de literatuur review werd de Soundscape aanpak voor binnen besproken. Deze aanpak is gericht op het begrijpen hoe een individu de akoestische omgeving in een bepaalde context ervaart. Het bevat verschillende methoden en indicatoren die zijn ontwikkeld om inzicht te verkrijgen in hoe bewoners geluiden in een bepaald binnenmilieu waarnemen en ervaren. Gebaseerd op deze aanpak, zijn semigestructureerde interviews met de 23 studenten van de veldstudies op hun thuis studieplekken gehouden. Voor kwalitatieve analyse van de interview transcripten werd open codering toegepast om subcategorieën en categorieën te bepalen, die vervolgens werden toegekend aan de Soundscape thema's zoals gedefinieerd in ISO 12913-1. Een affiniteiten diagram met thema's, categorieën, en subcategorieën werd gemaakt, en vervolgens gevalideerd in twee workshops met PhD studenten van de faculteit Bouwkunde. De resultaten laten zien dat de interpretaties van geluidsomgevingen van studenten kunnen verschillen. De bevindingen bevestigen dat de Soundscape aanpak bijdraagt aan het begrijpen hoe een student de geluidsomgeving van een studieplek thuis ervaart. Echter de aanpak is vooral gericht op de ervaring van een 'gemiddeld' student en niet op de verschillende profielen van studenten.

In conclusie, dit promotieonderzoek geeft toekomstig onderzoek een set van methoden en indicatoren (in de drie groepen) mee om de akoestische kwaliteit van studieplekken te beoordelen, waarbij rekening wordt gehouden met de akoestische voorkeuren en behoeften van de student. De vijf belangrijkste bijdragen van dit onderzoek zijn:

1. Een literatuur review waarin eerder toegepast methoden en indicatoren voor het bepalen van de akoestische kwaliteit van studieplekken zijn geïdentificeerd.

2. De ‘MyStudyPlace’ vragenlijst waarmee zelf-gerapporteerde gegevens van bewoner- en gebouw-gerelateerde indicatoren zijn verzameld.

3. Een mixed-methoden aanpak die de ‘MyStudyPlace’ vragenlijst combineert met een veldstudie, voor het verzamelen van bewoner-gerelateerde gegevens en objectieve gebouw- en dosis-gerelateerde indicatoren.

4. Lab experimenten waarin objectieve en subjectieve bewoner-gerelateerde indicatoren (bijv. lichamelijke reacties en perceptuele beoordelingen) terwijl blootgesteld aan verschillende geluidsbronnen, direct en indirect, zijn onderzocht.

5. Semigestructureerde interviews gebaseerd op de Soundscape constructen waarmee subjectieve bewoner-gerelateerde indicatoren, zoals voorkeuren voor een geluidsbron en aanpassingsgedrag, zijn verzameld.

ملخص

يعتبر طلاب الجامعة طلبة تعلم ذاتي حيث يقضوا معظم أوقات الدرسة في أمكان الدراسة سواء في مباني الجامعة أو المنزل. تركز الأبحاث في مجال جودة البيئة الداخلية على أن البقاء في البيئة الداخلية لمدة طويلة يؤثر بشكل سلبي على صحة مستخدمي المباني نظرًا للتعرض للمحفزات البيئية، على سبيل المثال الأصوات الغير مرغوب فيها والتي يطلق عليها بالضوضاء. إضافةً إلى ذلك، تؤثر جودة الصوتيات بشكل ايجابي أو سلبي على صحة الطلاب وراحتهم وأداؤهم الأكاديمي. هنالك ثلاثة مستويات من المؤشرات التي يمكن أخذها بالإعتبار لتقييم جودة الصوتيات لأماكن الدراسة، وهي: المؤشرات المتعلقة بالجرعة، المؤشرات المتعلقة بشاغلي المبنى، المؤشرات المتعلقة بالمبنى. نظرًا بأن الطلاب يختلفون في تفضيلاتهم الصوتية و النفسية والاجتماعية، فإنه من المهم الأخذ بالإعتبار بالمؤشرات المتعلقة بشاغلي المبنى والتي تشمل على التفضيلات والإحتياجات الفردية. بالرغم من ذلك، لا تزال الإرشادات الصوتية للبيئات التعليمية مقتصرة على كلًا من المؤشرات المتعلقة بالجرعة و المتعلقة بالمبنى، في حين يتم تجاهل المؤشرات المتعلقة بشاغلي المبنى. لذلك، فإن هذه الأطروحة تجيب على السؤال الرئيسي:

كيف يتم تقييم جودة الصوتيات لأماكن الدراسة؟

تم الإجابة على هذا السؤال من خلال الإجابة على خمس أسئلة فرعية باستخدام طرق بحثية مختلفة والتي تشمل على مؤشرات مختلفة. تم الأخذ بالإعتبار على الثلاث مستويات من المؤشرات (المتعلقة بالجرعة وشاغلي المبنى و المبني) لتقييم التفضيلات الصوتية والنفسية والإجتماعية لطلاب الجامعة لأماكن الدراسة بتطبيق طرق بحثية متنوعة، والتي تشمل على: الإستبيانات، المقابلات، التفتيش على خصائص أماكن الدراسة، قياسات مستوى الصوت، ورش العمل، والتجارب المعملية.

تم إجراء مراجعة الأدبيات حول الدراسات السابقة ذات الصلة في مجال الجودة الصوتية والمشهد الصوتي الداخلي في البيئات التعليمية والدراسية وذلك لتلخيص المؤشرات على المستويات الثلاثة التي تم استخدامها إلى جانب طرق البجث المستخدمة لتقييم التفضيلات الصوتية للطلاب. ومن الجدير بالذكر أنه تم تقييم التفضيلات والإحتياجات (سواء الفسيولوجية أو النفسية) الصوتية للطلاب في عدد قليل من هذه الدراسات، مما يشير إلى الحاجة للمزيد من الأبحاث حول تفضيلات وإحتياجات الطلاب الصوتية في أماكن الدراسة. وقد قدمت هذه المراجعة ملخصًا شاملًا لهذه المؤشرات وطرق تقييمها والتي تُشكل الأساس لهذه الإطروحة لإجراء المزيد من التقييمات حول تفضيلات وإحتياجات الطلاب الصوتية في أماكن الدراسة.

نظرًا لأن هذا البحث قد بدأ خلال جائحة كرونا، كان من المهم استكشاف الأماكن التي يقضي فيها طلاب الجامعات أغلب وقتهم للدراسة وما هي تفضيلاتهم فيما يتعلق بجودة البيئة الداخلية والجوانب النفسية والاجتماعية في أماكن دراستهم الأكثر إستخدامًا. لذلك، تم تطوير استبيان "مكان دراستي" وتوزيعه وإستكماله من قبل 451 طالب وطالبة بكالوريوس من كلية العمارة والبيئة المبنية. أظهرت النتائج أن 74 بالمئة من الطلاب يدرسون أغلب وقتهم في المنزل، مما أدى إلى تمحور التركيز لهذه الإطروحة من أماكن الدراسة في المباني التعليمية إلى أماكن الدراسة في المنزل. وبما أن الأبحاث أظهرت أن الأفراد يختلفون في تفضيلاتهم لجودة البيئة الداخلية والجوانب النفسية والاجتماعية، فقد هدفت تحليلات الاستبيان إلى تقديم نظرة عامة على هذه التفضيلات لدى طلاب الجامعات قبل التحقيق في تفضيلاتهم الصوتية. تم تصنيف الطلاب إلى ثلاث مجموعات وفقًا لجودة البيئة الداخلية وثلاث مجموعات وفقًا للجوانب النفسية والاجتماعية.

ومن خلال تنفيذ التداخل بين هذه الست المجموعات، تم تحديد تسعة ملفات تعريفية مميزة للطلاب، حيث لُوحظت اختلافات كبيرة من ناحية عدة متغيرات، بما في ذلك التفضيلات الصوتية. تؤكد هذه النتائج على أهمية تحليل تداخل جودة البيئة الداخلية والتفضيلات النفسية والاجتماعية لفهم ملفات تعريف الطلاب بشكل شامل.

بعد ذلك، أُعيد تصنيف الطلاب بناءًا على تفضيلاتهم الصوتية وبعض التفضيلات النفسية والإجتماعية المختارة (مثل الخصوصية، ووجود الآخرين في المكان). أسفر ذلك عن تحديد خمس مجموعات من الطلاب تختلف بشكل كبير عبر عدة متغيرات، بما في ذلك تصوراتهم لجودة البيئة الداخلية (مثل الأصوات الصادرة من الخارج)، وهي: 1) الإنطوائي المُهتم بالصوت، 2) الإنطوائي الغير مُهتم بالصوت، 3) الإنطوائي المُهتم جزئيًا بالصوت، 4) المُنفتح المُهتم بالصوت، و5) المُنفتح الغير مُهتم بالصوت. تم إختيار 23 طالبًا من هذه المجموعات ذات الملفات التعريفية المختلفة لإجراء دراسة ميدانية في أماكن دراستهم من المنزل، والتي تضمنت مقابلة، وفحصًا للمبنى، وقياس مستوى ضغط الصوت. ساهمت النتائج إلى تحديد الجوانب المُرتبطة بتفضيلات الطلاب الصوتية. على سبيل المثال، تبيّن أن المؤشرات المتعلقة بالمبنى، مثل موقعه، تُؤثر على تفضيلات الطلاب الصوتية.

سلطت مراجعة الأدبيات الضوء على أن الصوت، باعتباره عامل ضغط بيئي، يُؤثر على الطلاب من الناحيتين الفسيولوجية والإدراكية. لذلك، تم إجراء تجربتين معمليتين للتعرض الصوتي (التعرض المُباشر والغير مُباشر للصوت) بمُشاركة 15 طالبًا (كانوا أيضًا جزءًا من الدراسة الميدانية) في مُختبر SenseLab. هدفت هذه التجارب إلى استكشاف المؤشرات التي يمكن أن تُفسر الفروقات في الإستجابات الجسدية والتقييمات الإدراكية بين هؤلاء الطلاب. تم قياس حِدة السمع لكل طالب عبر تردُدات مُختلفة باستخدام اختبارات قياس السمع. كما تم قياس الإستجابات الجسدية، بما في ذلك مُستوى الإنتباه، ومُستوى الإسترخاء الذهني، ومُعدل ضربات القلب، ومُعدل التنفس، بإستخدام أجهزة إستشعار قابلة للإرتداء، إلى جانب التقييمات الإدراكية لظروف الصوت. أُجري تحليل الإرتباط لإستكشاف العلاقة بين الإستجابات الجسدية والتقييمات الإدراكية على المُستوى الفردي والجماعي. كما تم فحص الفُروقات لمُقارنة الإستجابات الجسدية والتقييمات الإدراكية بين التجربتين (التعرُض المُباشر والغير مُباشر). أشارت النتائج إلى أن الطُلاب الذين يُعانون من ضعف سمعي طفيف في التردُدات المُنخفضة شُهِدوا إرتفاعًا في مُعدل ضربات القلب عند تعرُضهم لأصوات مُنخفضة التردد. لم يتم العثور على إرتباطات ذات دلالة إحصائية بين الإستجابات الجسدية والتقييمات الإدراكية أثناء التعرض المُباشر للصوت، ومع ذلك، لُوحِظت فرُوقات في إستجابات مُستوى الإنتباه بين التجربتين. وتشير هذه النتائج إلى أن حِدة السمع ونوع الصوت (تردد الصوت) هما من المؤشرات الأساسية لتحديد الفروقات في الإستجابات الجسدية (مثل مُعدل ضربات القلب ومُعدل التنفس) والتقييمات الإدراكية.

تمت مناقشة نهج المشهد الصوتي الداخلي في مراجعة الأدبيات، وهو نهج يهدف إلى فهم كيفية إدراك الأفراد للبيئة الصوتية في سياق معين. يشمل هذا النهج أساليب ومؤشرات مختلفة طُوّرت لإستكشاف حول كيفية إدراك وتصور شاغلي المبنى للأصوات وتجربتُها في بيئة داخلية مُحددة. بناءًا على هذا النهج، تم إجراء مُقابلات شبه منظمة مع 23 طالبًا خلال الدراسات الميدانية في أماكن دراستهم من المنزل. ولتحليل البيانات النوعية، تم استخدام الترميز المفتوح لتحديد الفئات الفرعية والفئات استنادًا إلى نصوص المُقابلات، ثم تم تصنيفُها ضِمن موضوعات المَشهد الصوتي المُحددة في إرشاد ISO 12913-11. تم تطوير مُخطط تقارب يتَضمن الموضوعات والفئات والفئات الفرعية مَبدئيا، ثُم جرت مُراجعته والتحقق منه في جولتين من ورش العمل مع طلاب الدكتوراه من كلية العمارة والبيئة المبنية. أظهرت النتائج أن تصورات الطلاب لبيئاتهم الصوتية، إلى جانب استجاباتهم ونتائجهم، تَختلف من طالب لآخر. كما أكدت النتائج أن نهج المشهد الصوتي الداخلي يساهم في فهم كيفية تجربة الطالب للبيئة الصوتية في مكان الدراسة من المنزل. ومع ذلك، يُركز هذا النهج بشكل أساسي على تجرُبة "الطالب المتوسط" بغض النَظر عن مُراعاته للإختلافات بين ملفات تعريف الطلاب المُختلفة.

ختامًا، تقدم هذه الإطروحة مجموعة من الأساليب والمُؤشرات (ضمن ثلاث مجموعات) لتقييم الجودة الصوتية لأماكن الدراسة، مع الأخذ في الإعتبار تفضيلات وإحتياجات الطُلاب الصوتية. تتمثل المُساهمات الخمس الرئيسية لهذا البحث في ما يلي:

1. مراجعة أدبية حددت الأساليب والمؤشرات السابقة المستخدمة في تقييم الجودة الصوتية لأماكن الدراسة.

2. استبيان "مكان دراستي"، الذي يجمع بيانات ذاتية حول المُؤشرات المتعلقة بشاغلي المكان والمُؤشرات المُرتبطة بالمبنى.

3. نهج مُتعدد الأساليب يجمع بين استبيان "مكان دراستي" والدراسة الميدانية، لجمع بيانات مُتعلقة بشاغلي المبنى وبيانات موضوعية حول المؤشرات المُرتبطة بالمبنى والتعرض الصوتي.

4. تجارب مختبرية تستكشف المُؤشرات الموضوعية والذاتية المتعلقة بشاغلي المبنى (مثل الاستجابات الجسدية والتقييمات الإدراكية) أثناء التعرض لمصادر صوتية مختلفة، بشكل مُباشر وغير مُباشر.

5. مُقابلات شبه مُنظمة تعتمد على مفاهيم المشهد الصوتي، لجمع مُؤشرات ذاتية مُتعلقة بالشاغلين، مثل تفضيلات مصادر الصوت وأساليب التكيف.

1 Introduction

1.1 Background

People spend the majority of their time, approximately 90%, indoors [1]. Research has shown that staying indoors for a long time can have adverse effects on occupants' health and comfort. This is partly because of the exposure to several environmental stimuli that are related to the four indoor environmental quality (IEQ) factors: indoor air quality, thermal quality, acoustical quality, and lighting quality. These stimuli, such as sounds, are considered physical stressors that can affect positively or negatively occupants' preferences (comfort) and needs (health) [2].

Acoustical quality plays a significant role in students' health, comfort, and performance because university students spend their self-study time at study places at home or educational buildings [3–11]. Students perform highly cognitively demanding tasks at their study places, such as memory load and numerical tasks, which can be affected negatively by background noise [7,8]. Regarding acoustical preferences (comfort), annoyance plays an important role. 38% of university students reported annoyance from background noise at open-plan study places of a university campus [5], and 87 % of primary school children were annoyed with background noise in classrooms [9]. But sounds can also have a restorative effect, as was observed in a study examining the restorative effect of different soundscapes on children performing a stressful cognitive task in a classroom [10,12]. Also, acoustical preferences have been found to be interrelated with psychosocial preferences such as privacy [11].

Regarding acoustical needs (health), ensuring healthy lives and promoting well-being for all at all ages is one of the United Nations sustainable development goals [13]. Noise, defined as unwanted sound, is a significant environmental stressor that impacts health by activating the sympathetic nervous and endocrine systems, triggering stress mechanisms that lead to adverse health outcomes, such as increased heart rate (HR) and respiration rate (RR) [14]. According to a report, published by the World Health Organization (WHO), titled: “Environmental Noise Guidelines for the European Region”, it is mentioned that noise is a significant health issue that has negative effects on people’s health and well-being [15]. Several health issues could be induced by noise exposure such as imbalanced stress hormone levels, cardiovascular diseases, and sleep disturbance [16]. Chronic exposure to moderate sound pressure levels (SPL), such as traffic and construction work, may contribute to health disorders such as central auditory processing disorder. Individuals suffering from this disorder have deficiencies in both speech perception and learning performance [17]. In contrast, a high-quality acoustical environment has positive effects on individuals’ well-being and quality of life through a restorative-promoting mechanism [18]. Moreover, students can have different preferences and needs with regard to the different IEQ factors [19]. Hence, while optimizing indoor acoustics of an educational building, it is fundamental to consider students’ acoustical preferences and needs in their educational buildings.

1.2 Problem Statement

As effects of an acoustical environment on health and comfort depend on three groups of indicators; occupant-related (e.g., acceptability of sound), dose-related (e.g., sound pressure level), and building-related indicators (e.g., presence of sound-absorbing ceiling panels) [20]. All of these three groups of indicators are needed to be considered during the assessment of the acoustical quality of a certain indoor environment. There are various standards and requirements available for assessing acoustical quality in educational buildings [21–23]. Unfortunately, these acoustical guidelines for educational buildings are mainly focused on dose-related and some building-related indicators, while occupant-related indicators are lacking. The ISO 28802 standard includes occupant-related indicators that could be assessed to examine the impact of the acoustical environment on individuals [24]. While these indicators are limited to psychological indicators (e.g., annoyance, preferences satisfaction, and acceptability), physiological indicators are not included.

Several research methods (such as questionnaires, interviews, and lab experiments) have been applied to assess occupant-related, dose-related, and building-related indicators. Previous studies [3–6,10,25–28] on students’ acoustical preferences and needs at study places or educational buildings have considered occupant-related indicators (e.g., health effects such as HR, cognitive performance, and preferences).

In the recently introduced model for the adaptive acoustical comfort in the built environment [29], individual traits, such as differences in noise sensitivity and preferences among individuals, are one of the factors (occupant-related indicators) that influence acoustical adaptation. However, the previous studies [3–6,10,25–28] have not accounted for different traits or profiles of students whose preferences and needs differ. Thus, studying profiles of occupants, based on occupant-related indicators, can contribute to understanding differences in preferences and needs of students and how they interact with the indoor environment [2]. For instance, the integrated analysis approach [2,30] facilitates the understanding of individuals' preferences and needs in an indoor environment. It considers preferences and needs (profiles) of the occupants, physical and psychosocial stressors (positive and negative) which are patterns of stressors, and the interactions of stressors at and between human and environmental levels for different scenarios (e.g. school, office, home) and different situations (e.g. sitting behind a desk, sleeping in a bed, etc.). As part of the integrated analysis approach, clustering of occupants based on their preferences and needs in an indoor environment is an effective method for profiling occupants in a certain scenario for different situations [31] based on questionnaires (could be combined with interviews). For example, Zhang et al. [19] found six profiles of primary school children based on their IEQ preferences and needs in classrooms, confirming that students differ in their preferences and needs.

The soundscape approach takes into consideration the individuals' sound perception in a certain context [32,33] which is mainly focused on acoustical comfort, and mainly within an outdoor environment. Recently, it has been addressed in the context of the indoor environment, known as indoor soundscape [12]. This approach has been studied within the context of educational buildings (e.g., classrooms) that include different methods, such as questionnaires, interviews, and lab experiments [10,25,26]. Nevertheless, the methods and indicators within this approach are mainly focused on comfort (i.e., preferences), of which acoustical needs (i.e., health) are not addressed. Babisch [14] recommended investigating the relationship between noise sources and health risk characterization, to understand better how sound levels and annoyance interrelate with health risks.

Despite the existing guidelines and despite the studies performed so far as sketched above, which indicators and methods should be used to assess the acoustical quality of study places, considering differences in students' acoustical and psychosocial preferences and needs, is still a question to be answered.

1.3 Research Aim and Questions

1.3.1 Aim and main research question

This PhD research aims to propose methods and indicators for different types of assessments (assessment of preferences and assessment of needs) that can be applied to assess university students' acoustical and psychosocial preferences of their study places. This aim is achieved through exploring the methods and indicators within three categories: occupant-related, dose-related, and building-related indicators. Hence, the main research question is:

– **How to assess the acoustical quality of study places?**

1.3.2 Sub questions

To answer the main research question, the following sub questions are stated below:

– **Q1. Which indicators and methods have been considered in previous studies to assess the acoustical quality, taking into account students' acoustical preferences and needs?**

The first sub question is fundamental to conducting a literature review of relevant studies within the domain of indoor acoustics and indoor soundscape in educational buildings. The review aims to explore the indicators and methods used in previous studies to understand students' acoustical preferences and needs in educational buildings. It summarises the indicators (occupant-related, dose-related, and building-related) and the methods that were applied in previous studies in terms of acoustical and other IEQ factors. In addition, it highlights the gaps in knowledge in the literature, concluding that studies on students' acoustical preferences and needs are required. The answer to this sub question paves the road to answering the other four sub questions. It should be noted that this literature review focused on the indicators and methods that were used in previous studies in assessing students' acoustical preferences and needs in educational buildings. Since this literature review was conducted during the COVID-19 pandemic and the majority of university students were studying from their homes [34,35], this PhD research delved into the context of study places (and specifically at home) instead of educational buildings.

- **Q2. Can university students be clustered based on their IEQ and psychosocial preferences of their study places?**
- **If yes:** What are the distinctive preferences and characteristics of each student's profile?

From the literature review, it was concluded that students differ in their preferences for both IEQ and psychosocial preferences in educational spaces. Given that this PhD research delves into the study places of university students, it is essential to first explore the overall picture of their IEQ and psychosocial preferences related to these study places. To date, the distinct profiles of university students, based on their IEQ and psychosocial preferences of their study places, have not been comprehensively investigated. Thus, to answer the second sub research question, these unique IEQ and psychosocial preferences of different profiles of students based on the 'MyStudyPlace' questionnaire are explored. With the outcome, the similarities and differences among different profiles of students can be identified. Ultimately, addressing this question contributes to a more comprehensive understanding of university students' IEQ and psychosocial preferences of their study environments.

- **Q3. Can university students be clustered based on their acoustical and psychosocial preferences of their home study places?**
- **If yes:** Can interviews with selected students from each cluster, building inspections of their home study places, and sound level measurements help to verify their acoustical preferences and their related aspects?

While the literature review showed that exploring three levels of indicators (occupant-related (e.g., preferences), dose-related (e.g., sound pressure level), and building-related (e.g., absorption materials) can lead to a deeper understanding of students' acoustical preferences and needs of their study places, the clustering of the students based on their IEQ and psychosocial preferences of their study places confirmed significant differences in university students' profiles of both acoustical and psychosocial preferences. However, the reasons behind these differences (i.e., reasons behind why there are students concerned about sounds and others are not) still need to be explored. Therefore, to answer the third sub question, clustering was performed on acoustical and psychosocial preferences of their study places. Additionally, explanations for the different preferences were explored for each profile based on interviews, inspections of their home study place, and sound level measurements (using the three types of indicators).

- Q4. **Can bodily responses be used to explain differences in preferences and/or needs for different sounds, and how can we test this?**

  The clustering of students based on self-reported acoustical and psychosocial preferences of their study places resulted in five clusters with each a distinctive profile. Besides these self-reported occupant-related indicators, the literature review identified that several bodily responses, such as heart rate, used in previous studies to examine students' acoustical preferences and needs, can also be used. However, no studies have been performed yet to monitor bodily responses as well as perceptual assessments when exposed to both preferred and non-preferred sounds, to explain differences among students. Therefore, the fourth sub question was formulated to advance knowledge on whether bodily responses can be used to explain differences in students' preferences (comfort perception) and needs (health) regarding different sounds.

- Q5. **To what extent can the soundscape approach be used to assess the acoustical quality of home study places of each student?**

  The indoor soundscape approach was used to better understand how university students experience the sound environment of their home study places. To answer the third sub question, interviews were held among several students per profile, including also questions used in the soundscape approach. In addition, SPL measurements and building characteristics (e.g., application of acoustical materials) were explored. Based on workshops held with independent researchers, the strengths and limitations of the indoor soundscape approach examining the acoustical and psychosocial preferences of university students from different profiles were studied to answer the fifth sub question.

1.4 Research Methods

In this PhD research mixed-methods were applied, resulting in mixed data (quantitative and qualitative), to explore indicators and methods that are essential to be considered for assessing students' acoustical and psychosocial preferences and needs of their study places, (see **Figure 1.1**).

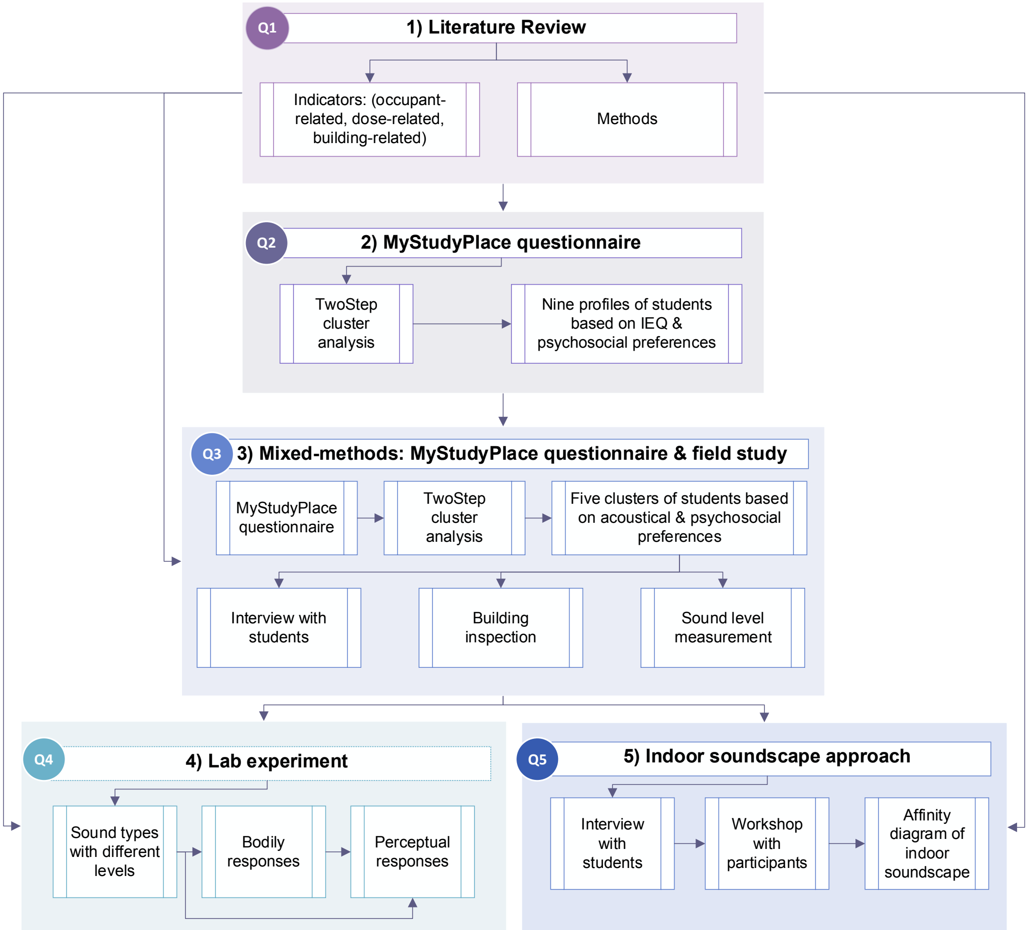

FIG. 1.1 Research methods applied to answer the related key questions.

1.4.1 Literature review

The literature review (presented in Chapter 2) as a research method, is a stepping-stone in this PhD-research. It aimed to explore the indicators (occupant-related, dose-related, and building-related) as well as the methods applied in previous studies within the field of students' acoustical preferences in educational and learning environments. The narrative synthesis of the indicators and methods contributes to selecting the indicators and methods that can be used to assess students' acoustical preferences and needs of their study places.

Publications:

- Hamida, A., Zhang, D., Ortiz, M.A., & Bluyssen, P.M. (2023). Indicators and methods for assessing acoustical preferences and needs of students in educational buildings: A review. Applied Acoustics, 202, 109187. And 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. In Healthy Buildings Europe 2021 Online Conference.

1.4.2 Questionnaire

To answer the second question, the 'MyStudyPlace' questionnaire was developed. With the outcome it was possible to empirically identify the IEQ and psychosocial preferences of university students at their study places. TwoStep cluster analysis of self-reported preferences (occupant-related indicators) of 451 participating students was performed to profile the students based on the overlap between IEQ and psychosocial preferences.

Publication:

- Hamida, A., Eijkelenboom, A., & Bluyssen, P.M. (2023). Profiling Students Based on the Overlap between IEQ and Psychosocial Preferences of Study Places. Buildings, 13(1), 231.

1.4.3 Mixed-methods: questionnaire and field studies

An explanatory study comprising of the 'MyStudyPlace' questionnaire (occupant-related indicators) followed by field studies (mixed data of the three indicators) was conducted to answer the third sub question. This mixed-methods started by clustering, using TwoStep cluster analysis, the 451 participating university students based on their self-reported acoustical and psychosocial preferences. Then, field studies were conducted at home study places of 23 students who also participated in the 'MyStudyPlace' questionnaire. The data were collected by three methods: interviews with the students, building inspections, and SPL measurements. This explanatory study was performed to better understand the aspects associated with students' acoustical and psychosocial preferences of their study places.

Publications:

- Hamida, A., Eijkelenboom, A., & Bluyssen, P.M. (2024). Profiling university students based on their acoustical and psychosocial preferences and characteristics of their home study places. Building and Environment, 111324. And Hamida, A.B., Eijkelenboom, A., & Bluyssen, P.M. (2023). Clustering students based on their acoustical-related preferences of study places. In Forum Acusticum 2023: 10th Convention of the European Acoustics Association.

1.4.4 Lab experiments

To answer the fourth sub question, two lab sound exposure experiments, with 15 students who also participated in the field studies, were conducted in the test chambers and the Experience room of the SenseLab [36]. These lab experiments involved occupant-related indicators in terms of bodily responses (HR, RR, and brain activity levels) as well as perceptual assessments (acceptability, pleasantness, and stress levels) while the students were exposed to dose-related indicators in terms of different sound types that differ in their frequencies and SPLs. Moreover, an audiometric test was performed on each student to measure hearing acuity. Because the integrated analysis approach connects patterns of environmental stressors (e.g., noise) with profiles of occupants, these lab experiment data aimed to identify which occupant-related indicator (bodily responses), dose-related indicators (physical such as sound level and frequency), and building-related indicators (data from field studies, such as existing sound sources) could help better explain each student's acoustical preferences and perceptions.

Publication:

- Hamida, A., D'Amico, A., Eijkelenboom, A., & Bluyssen, P. M. (2024). Guidance to investigate university students' bodily responses and perceptual assessments in sound exposure experiments. Indoor Environments, 100066.

1.4.5 Indoor soundscape approach

To answer question five, semi-structured interviews held with 23 university students at their home study places, including also questions used in the soundscape approach, were used. A qualitative analysis was executed to create the initial affinity diagram that substantiates the indoor soundscape of these home study places based on the soundscape themes. Then two workshops with independent researchers were facilitated to validate the initial affinity diagram.

Publication:

- Hamida, A., Eijkelenboom, A., & Bluyssen, P.M. (2024). Assessing the indoor soundscape approach among university students' home study places. In Inter. Noise 2024: 53rd International Congress & Exposition on Noise Control.

1.5 Research relevance

1.5.1 Scientific relevance

As mentioned in sub-section 1.2, there is still a lack of knowledge concerning which indicators and methods could be used to assess students' acoustical preferences and needs of their study places. Although there are several studies [19,25,25–27] in which the students' acoustical preferences and needs (accounting for occupant-related indicators) in educational buildings were considered, most of them focused on classrooms. Furthermore, while other studies shed light on the students' acoustical preferences and needs at study places (i.e. informal learning spaces) [5,11,28], they did not account for individual differences.

Therefore, this PhD research endeavours to fill these gaps in knowledge by testing indicators (of all three groups) and methods that were used in the previous studies accounting for different preferences and needs of students

1.5.2 Societal relevance

Ensuring students' health and comfort at their study places is essential for enhancing academic performance. This requires a thorough understanding of students' acoustical and psychosocial preferences and needs, which significantly impact their well-being. Thus, this PhD research contributes to society by providing more knowledge on how to assess these preferences and needs, which is the basis for defining indoor acoustical guidelines as well as creating and maintaining better study places for all students.

1.6 Dissertation outline

This dissertation (in paper-based format) consists of an introduction, five chapters answering the five sub questions, and the final chapter. The outline of this dissertation is presented in **Figure 1.2**.

Chapter 2: **Literature Review**
This chapter summarises the indicators and methods that were used in previous studies within the field of indoor acoustics and indoor soundscapes in educational buildings.

Chapter 3: **Profiles Of University Students Based on IEQ and Psychosocial Preferences**
This chapter provides an overview of the nine profiles of 451 university students who differ in both IEQ and psychosocial preferences of their study places. The profiles are based on the quantitative analysis of 'MyStudyPlace' questionnaire data.

Chapter 4: **Profiles of University Students Based on their Acoustical and Psychosocial Preferences**
This chapter describes the mixed-methods applied and the resulting mixed data that were used to profile 451 university students based on their acoustical and psychosocial preferences and needs of their study places. It includes the analysed quantitative dataset of 451 university students who completed the 'MyStudyPlace' questionnaire and data from the field studies that comprised interviews with 23 students as well as the characteristics of their home study places.

Chapter 5: **Guidance to Investigate University Students' Bodily Responses and Perceptual Assessments in Sound Exposure Experiments**
This chapter presents the two lab experiments in the SenseLab with 15 students. It includes bodily responses and perceptual assessments of these students when they were exposed to different sound types in different SPLs. The contents of Chapter 5 relate to the data of Chapter 4.

Chapter 6: **Indoor Soundscape Approach of University Students' Home Study Places**
This chapter explores the indoor soundscape approach at 23 home study places of university students. It includes substantiation of soundscape perceptual elements based on the deductive analysis of the 23 interview transcripts that were validated by two workshops with independent researchers. In this chapter, part of the indoor soundscape approach is compared with the profiling approach that is presented in Chapters 3 and 4.

Chapter 7: Conclusions and Recommendations
Finally, in this chapter, each sub question is addressed, and the main findings are highlighted. It also answers the main research question by discussing the use of different types of assessments in future studies on students' acoustical and psychosocial preferences and needs of their study places. In addition, it discusses the limitations of the thesis. Furthermore, this chapter provides recommendations for future research.

All research data supporting the findings described in this PhD research are available in 4TU.ResearchData at: 10.4121/8c1810b9-c29e-4f8b-8c11-025bd559e5c6 and 10.4121/baf5748a-5b44-4640-bea0-85ee41574bf4.

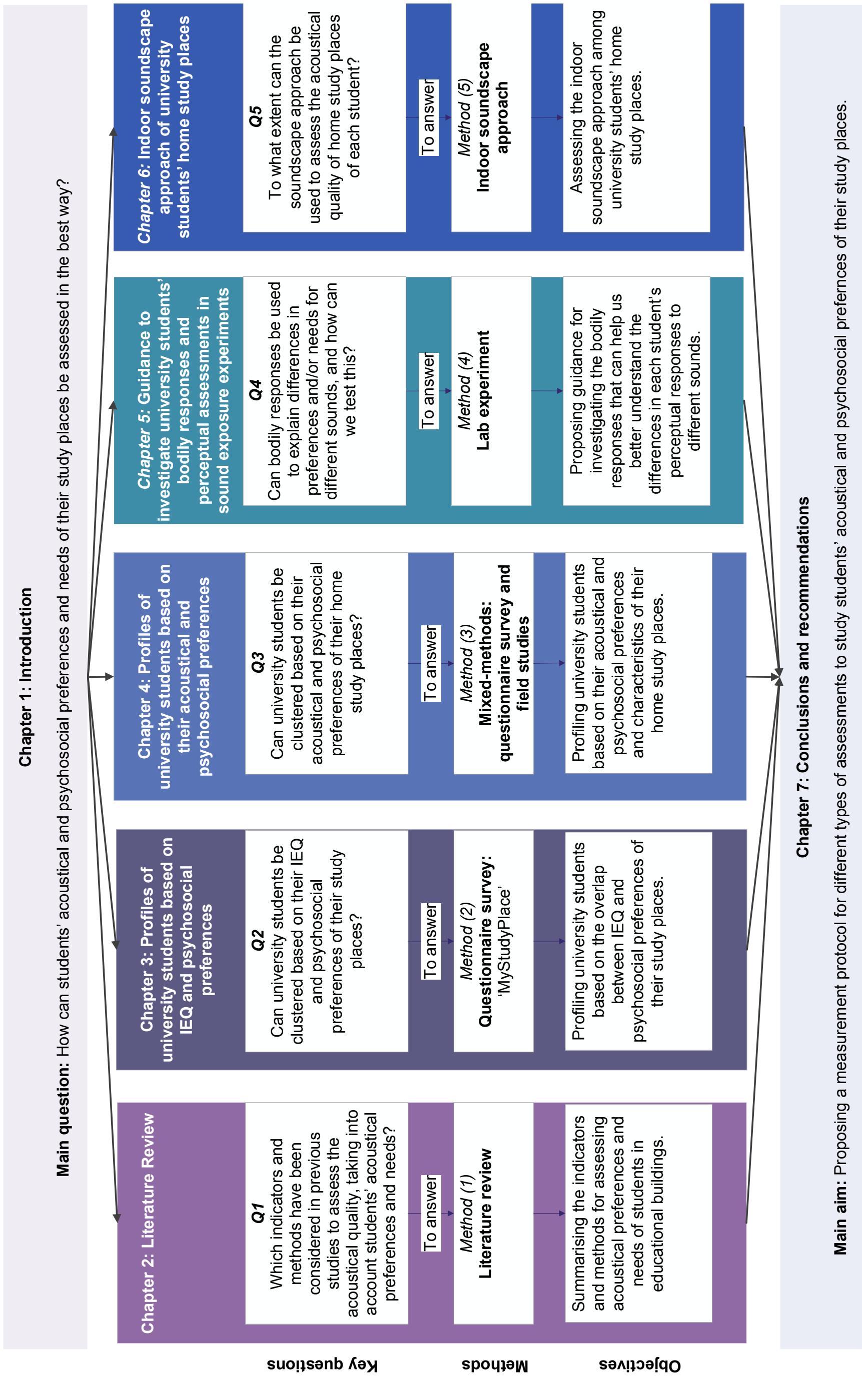

FIG. 1.2 Overview of dissertation outline.

TOC

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2 A Literature Review on Indicators and Methods for Assessing Acoustical Preferences and Needs of Students

This chapter has been published as: Hamida, A., Zhang, D., Ortiz, M. A., & Bluyssen, P. M. (2023). Indicators and methods for assessing acoustical preferences and needs of students in educational buildings: A review. Applied Acoustics, 202, 109187.

ABSTRACT Sounds (e.g., human activity, nature, building systems) are one of the indoor environmental stimuli that may have positive and/or negative effects on students' well-being and performance in educational buildings. Students in educational buildings have individual acoustical preferences and needs as portrayed by occupant-related indicators, for example perception. Acoustical guidelines for educational buildings are generally focused on acoustical performance in terms of dose-related (e.g., sound pressure level) and building-related indicators (e.g., sound absorbing walls), while occupant-related indicators (e.g., heart rate) are rarely mentioned. In contrast, previous studies such as indoor soundscape studies, do take into consideration occupant-related indicators, including physiological and psychological. Therefore, this study aimed at summarizing these indicators in a comprehensive overview that is essential for investigating the students' acoustical preferences and needs in educational buildings. A literature review of relevant studies in the domain of indoor acoustics and soundscape was carried out. A number of key indicators (occupant-related, dose-related, building-related) and methods that are fundamental to be considered were identified. Only in a few studies, students' acoustical preferences and needs were investigated by considering occupant-related indicators (both physiological and psychological). In addition, dose-related indicators of other indoor environmental quality (IEQ) factors and building-related indicators were rarely taken into account in previous studies.

KEYWORDS Occupant-related indicators; dose-related indicators; building-related indicators; acoustical preferences; acoustical needs; students.

2.1 Introduction

People spend most of their time (around 90%) in indoor environments where they are exposed to various environmental stressors that have the potential to affect individuals' health [1]. To promote individuals' well-being in indoor environments, it is therefore important to pay attention to the indoor environmental quality (IEQ) factors, comprising of thermal quality, lighting quality, acoustical quality, and air quality [2,3]. Occupants are exposed to a large number of physical stressors in indoor environments, all of which can cause annoyance and adverse effects on health [4]. It was indicated that both lighting and acoustical factors are perceived by students as factors that influence their academic performance [5]. These factors can cause annoyance and adverse effects on health, and noise was found to be the most annoying factor in schools buildings [6]. Noise, being one of these stressors, stimulates both the sympathetic nervous system and the endocrine system [7]. On the contrary, appropriate acoustical conditions in indoor environments can play a significant role in improving individuals' well-being in a positive manner [8]. The soundscape approach has been developed to consider the relationship between soundscape and individuals' well-being; individuals' sound perceptions and experience are studied [9]. According to the International Organization for Standardization (ISO) 12913-1, the term soundscape is defined as: "acoustic environment as perceived or experienced and/or understood by a person or people, in context" [10]. In educational buildings, previous studies showed that noise affected students' well-being (health and comfort) as well as performance [11–18]. In a field study, 38% of students reported to be bothered by noise, especially by speech, while performing a complex cognitive task [19]. In another study, 87% of primary school children were found to be annoyed with noise in classrooms [6].

On the contrary, positive sounds that have restorative effects (e.g., water fountain) have shown to enhance students' self-rated health as well as improve the students' short-term memory and cognitive performance [20,21]. Moreover, students can have different preferences and needs with regards to the different IEQ factors [11]. Hence, while optimizing indoor acoustics of an educational building, it is fundamental to consider students' acoustical preferences and needs in their educational buildings.

When studying the quality of an indoor environment, three categories of indicators can be used: occupant-related indicators (e.g., noise annoyance), dose-related/environmental-related indicators (e.g., sound pressure level), and building-related indicators (e.g., presence of sound absorbing ceiling) [4,22]. There are various standards and requirements available for assessing acoustical quality in educational buildings. For example, Building Bulletin 93 (BB93) [23,24] is an acoustical guideline for schools that provides the standards and requirements for sound performance in schools. It includes the maximum background noise level of different types of rooms, such as typical classrooms, lecture rooms (small and large), and quiet study areas (e.g., libraries and study rooms). Additionally, it sets the requirements of the noise generated from building systems, the airborne sound insulation between spaces, and the impact sound insulation of floors. According to the ANSI/ASA S12.60 (American National Standards Institute, 2010) [25], the typical classroom (in elementary and secondary schools) volume ranges between 283 and 566 m^3, while the volume of the other larger learning spaces (e.g., lecture rooms) is larger than 566 m^3. In the Netherlands, a program of requirements for fresh schools “Frisse Scholen 2021” can be applied. It covers the acoustical requirements in terms of soundproofing of the façade, building system noise, room acoustics, airborne noise insulation, and impact sound insulation [26]. Nevertheless, these acoustical guidelines for educational buildings are mainly focused on dose-related and some building-related indicators, while occupant-related indicators are lacking. However, the ISO 28802 standard includes occupant-related indicators that could be assessed to examine the impact of the acoustical environment on individuals [27]. While these indicators are limited to psychological indicators (e.g., annoyance, preferences satisfaction, and acceptability), physiological indicators are not included. Therefore, identifying comprehensive indicators is essential for understanding students' acoustical preferences and needs (e.g., preference for a certain sound type and need for a quiet or pleasant sound in a study place) for promoting their well-being and performance in their educational buildings. As part of that, occupant-related indicators (physiological and psychological), dose-related indicators, and building-related indicators are essential to be considered. Thus, this review aims to summarize the indicators and methods that have been used in previous studies for understanding students' acoustical preferences and needs in educational buildings, and developing an overview that illustrates the related results. Accordingly, the main research questions of this study are:

1 What are the indicators that have to be considered to evaluate the acoustical quality taking into account students' acoustical preferences and needs?
2 What are the methods that are used for measuring and assessing these indicators?

2.2 Materials and methods of literature review

An overview was established by summarizing main occupant-related, dose-related, and building-related indicators as well as the methods that are required for investigating the students' acoustical preferences and needs. These three main indicators are important to understand the IEQ taking into account both human and environmental levels [28]. In a recent study [29], it was observed that previous studies on indoor acoustics can be divided into studies focusing mainly on the dose-related indicators and some building-related indicators, and studies focusing on indoor soundscapes, including all three categories of indicators. Accordingly, in **Table 2.1**, the first concept (related to human level such as health) was defined to find the studies that considered occupant-related indicators, while the second concept was introduced to find both dose-related and building-related indicators linked to the acoustical environment. The third concept was included to specify the context and building occupants of the previous studies. The fourth concept focuses on the cross-modal perception was included to explore dose-related indicators of other IEQ-factors that have interaction with the acoustics. The soundscape concept was introduced during the recent review [29]. This concept was used to search for a number of relevant studies in the domain of educational buildings and other contexts (e.g., offices, hospitals) since there are limitations on indoor soundscape studies within the educational buildings context.

These five concepts with their keywords (**Table 2.1**) were expanded to find relevant studies for this scoping review: human level, acoustical environment, occupants, cross-modal perception, and soundscape were used to find the relevant studies. This table was used to find the relevant studies by creating different search queries. The concepts were combined with and/or, and the synonym of each concept was combined with another concept by using and/or. There are some terms under concept 3 that were used to find relevant studies in the domain of indoor soundscapes since it is an emerging topic. An example of search queries was ("performance" OR "perception" OR "psychological" OR "physiological") AND ("noise" OR "acoustic" OR "sound level") AND ("pupils" OR “students” OR “school children”) AND (“interaction effect” OR “cross-modal perception” OR “thermal” OR “lighting”) AND (“soundscape” OR “sound preference” OR “sounds”).

TABLE 2.1 Keywords for the literature review.

	Combined with AND				
	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Combined with OR	Physiological	Acoustical environment	University students	Cross-modal perception	Soundscape
	Human level	Background noise	Pupils	Interaction effect	Indoor soundscape
	Psychological	Noise	Students	Combined effect	Soundscape preference
	Preferences	Sound level	School children	Lighting	Sound preference
	Performance	Sound sources	Office workers*	Thermal	Sounds
	Health		Patients*		
	Well-being	Sound environment	Nurses*		
	Perception	Acoustic			

Keywords used for finding studies in indoor soundscapes due to the limited studies in the indoor soundscapes and students.

Three scientific databases were used to search the state-of-art studies, which are Scopus, Web of Science, and Google Scholar. These keywords were used to find the relevant studies in the scientific databases by different search strings of the combinations of these keywords. 916 articles were found in the databases. It can be noted that there was no time limitation for the resources set during the searching process, since this review aims at summarizing all possible indicators and methods that are used by previous studies. The resources that are considered for this review include peer-reviewed journal papers and book series. In addition, two conference proceedings were also included because they were focused on the effects of indoor soundscapes on students in educational buildings. The inclusion criteria of this scoping review were set to include studies in the domain of soundscape and acoustical environment considering occupant-related indicators in an indoor environment, acoustical environment with one or more effects (positive and/or negative) on individuals’ (and students’) physiological health, psychological health, performance, and preferences, and cross-modal perception of acoustics with other IEQ-factors. In contrast, this review excluded the studies focused on only the urban soundscape without considering indoor soundscape, or conducted only objective measurements of acoustical environment and other IEQ-factors without taking into account occupant-related indicators, or focused on the impact of acoustical environment/ indoor soundscape on subjects with hearing impairment. After screening the titles and abstracts of the resources, 44 articles (out of which 25 focused on students) were regarded as eligible and have been reviewed.

2.3 Literature review results

The synthesis of the results section is based on presenting a) the previous studies on indoor acoustics in relation to students' physiological needs, psychological needs, performance, and the cross-modal effects of the interaction between acoustics and other IEQ factors (sub-section 3.1); and b) an overview of indoor soundscape studies (sub-section 3.2).

2.3.1 Previous studies on indoor acoustics

An acoustical environment of a place, known as sound or sonic environment, refers to all sounds generated from different sound sources that an individual is able to perceive in that place [30]. Indoor acoustics in relation to students has been examined through several dimensions with relation to concept 1 and 4 in **Table 2.1** in terms of physiological needs, psychological needs, performance, and cross-modal perception. Cross-modal perception refers to the perception of the interaction between two or more environmental stimuli such as between noise and temperature. Furthermore, several studies examined the acoustical environment within the field of indoor soundscape.

2.3.1.1 Indoor acoustics and students' physiological needs

According to Maslow, the five human needs are 1) physiological needs, 2) safety, 3) love/belonging, 4) esteem, and 5) self-actualization (in descending order of importance) [31]. To ensure the well-being in any indoor environment, it is important to ensure firstly the physiological needs, which are basic needs before moving upward [32]. As concept 1 in Table 1 includes physiological and health terms, this review found that the effects of indoor acoustics on students' physiological health have been tested by various researchers [33–38]. For example, Alvarsson et al. [33] tested the effect of four sound types on stress recovery by measuring two physiological indicators of students; skin conductance level (SCL) and high-frequency heart rate variability (HF HRV). It was concluded that SCL recovery was fast during the exposure to natural sound. Furthermore, Park and Lee [39] examined the effects of floor impact sounds on individuals' physiological health by monitoring three occupant-related indicators; heart rate (HR), electrodermal activity (EDA), and respiration rate (RR). The results showed that sound pressure level (SPL) had a negative impact on both EDA and RR, while HR was not influenced by the SPL. Conversely, Abbasi et al. [36] had investigated the impacts of low-frequency sound exposure on students' physiological health, such as brain activity, by measuring electroencephalography and electrooculography. Also, mental fatigue, which is known as a mental impairment that leads to an unwillingness to perform any mental effort, was assessed by a subjective questionnaire. This questionnaire was based on the visual analogue scale of fatigue (F-VAS), which students filled out after the sound exposure. The outcomes showed that a high amount of SPL (65-75 dBA) could cause mental fatigue of students, which significantly affected their HR and working memory.

2.3.1.2 Indoor acoustics and students' psychological needs

Environmental stressors such as noise play a vital role in affecting an individual's comfort, and it is strongly dependent on the individual's psychological state [40]. The psychological responses to sound are associated with an individual's emotions, which arise from hearing a certain sound source. Individuals perceive, interpret, and prefer sounds differently with regards to sound features such as quiet, friendly, safe, calm, and distinctively clear [41]. The psychological process starts with expectations followed by the perception and may result in outcome (e.g., emotions, feelings, and thoughts) and/or behaviour-oriented action [42]. Calmness and vibrancy are two resultant emotions that could be evoked by exposure to a specific sound source [43]. Also, pleasantness (valence) and eventfulness (arousal) are the two emotional reactions that are considered valid metrics for evaluating the soundscape quality [44]. Previous studies examined the influence of indoor acoustical conditions on students' psychological needs and responses. For instance, Scannell [13] indicated that some spaces with lower background noise levels (such as airflow through ventilation systems) were perceived by students as suitable sound in informal learning spaces. These are spaces where students (usually in higher education) can perform their informal learning activities (study-related activities) such as collaborative or individual learning. These activities are usually performed outside the classroom, which could be at home or in an educational building [45]. Whereas, results from a study conducted by Wålinder et al. [46] proved that noise affected primary school children (fourth grade) negatively by increasing their stress which caused health issues such as fatigue and headache (physiological indicators). Additionally, it was found that their psychological responses in terms of emotional responses (e.g., anxiety, insecurity, and aggressiveness) were not associated with SPL.

2.3.1.3 Indoor acoustics and students' performance

Generally, indoor acoustics can influence an individuals' performance and productivity in indoor environments. For example, the effect of low-frequencies noise on individuals' cognitive performance was examined in a laboratory study [47]. It was concluded that participants had a shorter time response while they were exposed to noise, which was related to a higher stress level based on the arousal theory. Another study testified that acoustical indicators sound types such as speech noise had a significant negative effect on participants' performance and the effects were stronger by increasing the speech transmission index (STI) of the noise [48]. The impacts of indoor acoustics on students' performance were investigated in previous studies. For instance, a field study, conducted by Braat-Eggen et al. [19], in an open-plan study environment in a university measured the effects of dose-related indicators, such as reverberation time (RT), a-weighted SPL, spatial decay rate, and distraction distance, on university students' performance and disturbance. It was found that 38% of students were bothered by noise while they were performing a complex cognitive task (e.g., studying for an exam, reading, and writing). Additionally, Tristan-Hernandez et al. [15] observed the negative effect of the background noise generated inside six university facilities on changes in students' attentional processes. Furthermore, a lab study was carried out by Zhang et al. [49] with 335 primary school children (age 9 to 13) who were exposed to a series of listening tests in two test chambers (acoustically treated and untreated) with one of seven types of background sounds. The outcomes showed that there were significant interactions between the effect of the acoustical indicators; sound type and SPL on the children's performance. Whilst, the performance of students in a quiet environment was found to be not significantly better than in the other environmental scenarios which include background speech noise [12]. Prodi and Visentin [17] examined the effects of conditions in two classrooms with different RT, one quiet and one noisy (RT from 0.57 to 0.69 seconds), on the performance of school children (age 11 to 13 years old). They concluded that a longer RT affected the children's accuracy while performing a perception task.

2.3.1.4 Cross-modal effects of interactions between acoustics and other IEQ-factors

The cross-modal effects of interactions between the acoustics and other IEQ-factors had been covered by previous studies [29]. In general, Hasegawa and Lau [50] indicated in their review article that sound sources influenced the various perceptual responses such as audio, visual, cognitive, as well as emotional perceptions. Also, the visual indicators such as greenery elements and water features proved to reduce the noise annoyance perceived by individuals in an indoor environment. With regards to students' context, Chung et al. [51] found that the participants (undergraduate students) preferred sea views more than road views, since sea views attenuated the noise annoyance, while road views aggravated it. Liebl et al. [52] tested the combined effects of acoustical and visual indicators, which are speech intelligibility and lighting type, on individuals' cognitive performance and well-being. It was found that individuals perform better with the combination of low intelligibility background speech and static lighting. The speech intelligibility refers to the possibility of hearing the speaker (e.g., teacher speech) clearly in an indoor environment, which depends on the built environment characteristics in terms of RT and signal-to-noise ratio. Speech transmission index (STI) is an objective measurement for the speech intelligibility that ranges between 1.0 (perfect intelligibility) and 0.0 (no intelligibility) [53]. Furthermore, the perception of the indoor acoustical environment could be influenced by thermal conditions. Pellerin and Candas [54] mentioned that the perception of indoor acoustics might be affected by exposure to short-term and long-term thermal strains. In addition, the exposure to high noise levels contributed to thermal discomfort.

Students' perception of indoor acoustics seems to be influenced by the multisensory interactions with other IEQ-factors. For example, sound types may have an impact on the smell assessment. Bluyssen et al. [55] found that listening to the sound of primary school children talking could negatively affect the evaluation of smell. Likewise, Choi et al. [34] tested the combined effects of IEQ-factors indicators; temperature, odour, and sound type on students' stress levels. The stress level was measured by using both the paper-based test (stress examination sheet) and an electroencephalogram (EEG) to measure brain waves. The outcome indicated that individuals' stress levels increased by the exposure to the combined environment of 30oC temperature, odour irritants volatile organic compounds (VOCs), and road traffic noises. In terms of the cross-modal perception between noise level and temperature, Yang et al. [56] examined the interaction effects of room temperature and background noise on students' perception of floor impact noises in a room. A bipolar visual analogue scale subjective questionnaire was used to capture the perceptions including loudness (which is a psychological term that refers to the magnitude of the auditory sensation) and noisiness (which expressed in the sound quality). It was found that the loudness and noisiness of the floor impact noise were affected by the room temperature, background noise level, and floor impact noise levels. Dehghan et al. [35] found that both physiological indicators; systolic and diastolic pressures of students increased after exposure to different levels of noise (70, 85, and 95 dB), and the changes in both blood pressures after exposure to the combination of high temperature (40°C) and noise were subtle. These SPL are considered as high values, in which they were played in a climatic chamber by using a loudspeaker. The exposure duration was 40 minutes. Contrarily, Abbasi et al. [37] evaluated the combined effects of two dose-related indicators; noise level and air temperature on students neurophysiological responses; HR and RR. It was proved that high noise levels as well as high air temperature (30°C) could increase the mean value of neurophysiological responses of students. With regards to the cross-modal perception between the acoustics and other two or three IEQ-factors, Sun et al. [38] investigated the students perceptions and physiological reactions to the combined environment of dose-related indicators of three IEQ-factors, which are; temperature, illuminance, and sound level. It was revealed that the physiological indicators; blood pressure, HR, and skin temperature were influenced by all the three indicators of the IEQ-factors.

2.3.2 Previous studies on indoor soundscape

2.3.2.1 Soundscape

The concept of 'soundscape' was introduced by the Canadian composer R. Murray Schafer in the 1960s [57]. The soundscape is an individual's perceptual construct of an acoustical environment [30]. The main seven perceptual construct elements of soundscapes are context, sound source, acoustical environment, auditory sensation, interpretation of auditory sensation, and human responses, as presented in **Figure 2.1** [10]. The auditory sensation is one function of the neurological process that begins with receiving auditory stimuli that can be sensed by the ear receptors [10,58]. The three pillars to be considered in soundscape studies are: people, acoustical environment, and context [58,59]. The context refers to the interconnection between person, activity, and place [10,60]. Hence, the difference between the acoustical environment and soundscape is that the acoustical environment is a physical phenomenon that can be assessed by measuring dose-related indicators in terms of indoor acoustics such as SPL. On the contrary, the soundscape take into account occupant-related indicators by considering individuals' perceptual constructs (e.g., sensation, interpretation, emotional responses) of this physical phenomenon (dose-related indicators) as is illustrated in **Figure 2.2**.

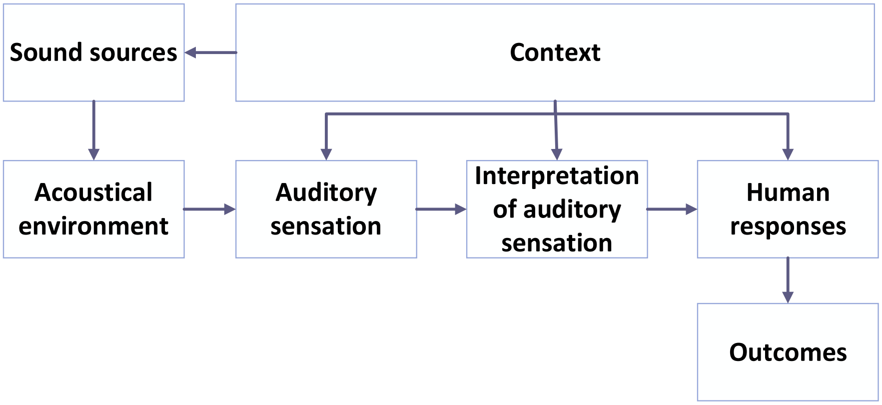

FIG. 2.1 Perceptual construct elements in a soundscape. Source: redrawn and adapted from [10].

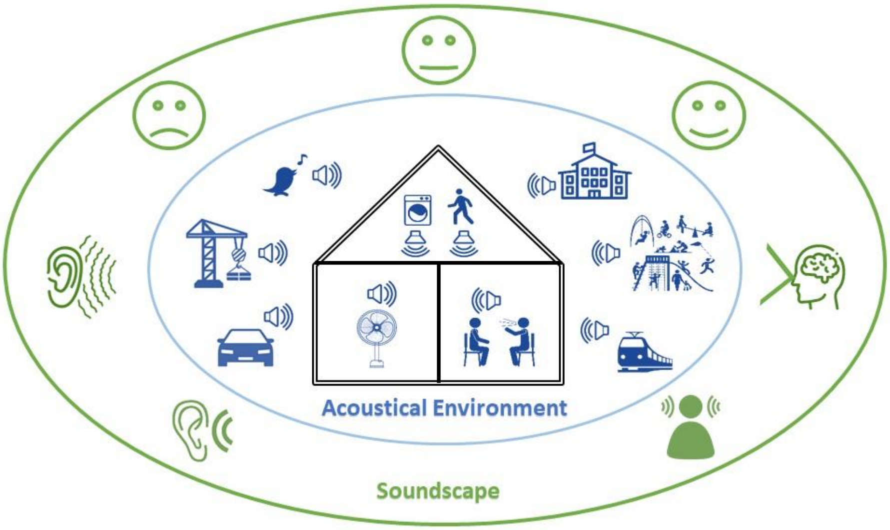

FIG. 2.2 Illustration of the difference between the acoustical environment and soundscape.

2.3.2.2 Urban soundscape vs. indoor soundscape

Urban soundscape has been studied over decades, while indoor soundscape is an emerging topic [61]. Soundscape has been recently applied to the indoor environment to explore how individuals perceive, experience, and understand indoor acoustics in different contexts, such as working and relaxing environments [62]. However, indoor soundscapes are more complex than urban soundscapes due to the complexity of the indoor acoustical environment [63]. The major factors of the indoor soundscape are classified as acoustical factors, architectural factors, and contextual factors. Among them, architectural factors, including function, architectural properties (building-related indicators), and physical environment (dose-related indicators), are the most remarkable and unique factors to the indoor soundscape. This is due to the role of the architectural factors in the way how sound propagates through the indoor environment [60]. Indoor soundscape studies have taken into account the individuals' perception of indoor acoustics by considering the human-centered approaches. Torresin et al. [62] indicated that human-centred approaches are essential to achieve positively perceived indoor acoustics. Also, Torresin et al. [64] mentioned that sound can be utilized as a biophilic design approach. The main two appraisal dimensions of the soundscape are pleasantness and eventfulness as illustrated in the soundscape circumplex model (Figure 2.3). Individuals can evaluate a particular soundscape with a combination of more than one attribute [65]. For example, Yang and Moon [66] pointed out that water sounds enhanced the participants' perceptions with regards to calmness and pleasantness. Therefore this circumplex model can be considered for investigating occupant-related indicators with regard to students' preferences and needs for certain indoor acoustics.

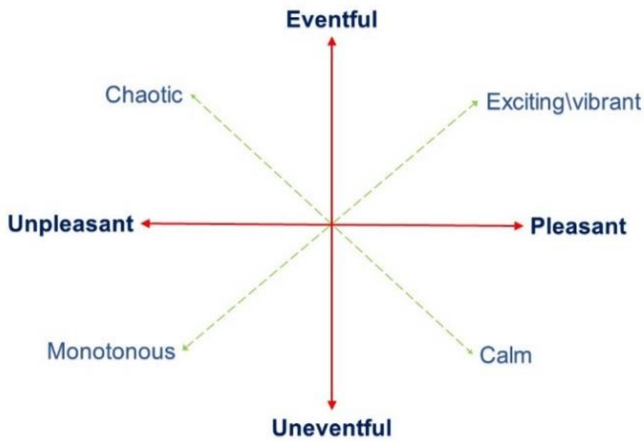

FIG. 2.3 Soundscape appraisal dimensions. Source: redrawn and adapted from [65]

2.3.2.3 Indoor soundscape studies

Only a few studies about the indoor soundscape in educational buildings (e.g., schools and university buildings) have been published. Most of them indicated that there are limited studies on indoor soundscape within context. These studies were eight and were conducted in university libraries [67–69], classrooms in higher education institutions [70], high school classrooms and computer laboratories [71,72], open study spaces in a university [73], students at home [21], and children in a classroom [20]. On the other hand, there are other studies that investigated the indoor soundscape in different contexts, in which 13 studies were found. Therefore, this study reviewed the investigations of indoor soundscapes in other types of buildings (e.g., healthcare facilities, residential buildings, offices) since the methods used in these studies and the related findings can still be seen as references.

A study conducted in healthcare facilities by Mackrill et al. [74] was one of the first studies on indoor soundscape, made use of semi-structured interviews with patients and nurses to understand the subjective responses to soundscapes in a hospital ward. The results show that patients and nurses adopted coping methods for habituating to the soundscape. Moreover, Mackrill et al. [75] carried out a lab study with participants who evaluated their emotional and cognitive responses to different hospital ward soundscapes clips. It was found that the rated emotional response as a relaxation was significantly influenced by the natural sound. Furthermore, Aletta et al. [76] examined the soundscape of the nursing homes' living rooms and found that there was a relationship between the SPL and the number of people inside the room. Indoor soundscapes have also been studied in offices. For example, the grounded theory (GT) approach was performed to investigate sound perception in an open-plan office. A user-focused soundscape survey and semi-structured interviews were used to assess the employees' sound perception. The study concluded that employees adopted strategies, such as putting on headphones, to cope with the unexpected soundscape or the sounds that were interfered with their concentration [63]. Abdalrahman and Galbrun [77] have done laboratory experiments on the potential of using water elements as sound-masking in an open-plan office. Results from these experiments proved that the water elements improved sound perception. With regards to the residential sector, Torresin, et al. [78] conducted a listening test in a laboratory to develop a soundscape model in residential buildings. The results pointed out that 1) comfort was negatively linked to loudness, 2) the content was positively connected with sound level variability, and 3) familiarity was negatively associated with sharpness. Additionally, Mohamed and Dokmeci Yorukoglu [79] indicated that cross-cultural differences and social factors affected sound perceptions. Furthermore, several previous studies carried out indoor soundscape studies in historical buildings which focused on capturing individuals' perception and/or interpretation and/

or expectations towards the acoustical environment [61,80,81]. Besides a study examined the soundscapes in a shopping mall which took into account individuals' shopping habit and their expectations towards the acoustical environment [82].

In educational buildings within the context of university buildings, Dokmeci Yorukoglu and Kang [67,68] carried out an indoor soundscape study in three university libraries by recording the sounds in three timeslots. SPL and psychoacoustic parameters (loudness, roughness, and sharpness) were measured. In addition, a subjective assessment questionnaire was used for evaluating soundscape in terms of noise annoyance and sound preferences. The questionnaire's results indicated that sounds induced by mobile phones, personal music players, and construction sites were rated as the most annoying sounds; while footsteps and page-turning sounds were the least annoying. In addition, a significant relationship was found between the objective parameters such as SPL and loudness with the subjective assessment. Xiao and Aletta [69] also conducted a soundscape study in a university library where soundwalk -a technique involving walking inside a space to listen to the surrounding environment- was performed for identifying the sound types. Also, a questionnaire survey was carried out for subjective assessments as to the frequency of hearing the sound, sounds quality, and appropriateness of sound. It was found that the soundscape quality was influenced by the space activity and the acoustical perception. Additionally, it was mentioned that space layout is a factor that can influence acoustical comfort. Furthermore, Chan et al. [70] investigated the indoor soundscape in nine classrooms of higher education institutions. This study conducted acoustical measurements including SPL. Within the context of schools, Cankaya and Yilmazer [71] developed a conceptual indoor soundscape framework of high-school environments using the GT approach to investigate the effects of soundscape on students' perception in two educational spaces: classrooms and computer laboratories. The conceptual framework demonstrated the relationships between students' expectations and sound preferences. Additionally, a series of semi-structured interviews with students were conducted to evaluate their soundscape perception. Based on their expectations, students might be annoyed by speech sounds in the classroom and by fan sounds in computer laboratories. However, speech sound was perceived as the most annoying sound source in both spaces. Cankaya Topak and Yilmazer [72] proposed guidelines for designing facilities for educational buildings (classrooms, and computer laboratories) with respect to students' perception of the acoustical environment. This was done through conducting a mixed methods approach including a questionnaire, interview, and acoustical measurements at the environmental level (including SPL, RT, and STI). The proposed design guidelines were developed using GT as an analysis method. The authors concluded that the auditory perception was linked to the space context (e.g., lecture) rather than the SPL, so it is significant to consider these perceptions while designing educational buildings.

Acun and Yilmazer [73] examined the soundscape of four open study spaces in a university through a questionnaire survey. The results showed that the sounds generated by human activities were the most disturbing and negatively affected students' concentration. During the COVID-19, Dzhambov et al. [21] carried out a study to investigate the effect of indoor soundscape on the self-rated health of university students during the pandemic. An online questionnaire was used to explore the frequency of hearing sound sources and the pleasantness of these sounds perceived by students. The outcomes of this study indicated that exposure to mechanical sounds resulted in worse self-rated health which reduced restorative quality. It was shown that positive indoor soundscapes, such as nature sounds (e.g., birdsong and flowing water), have a significant impact in improving self-rated health during social distancing times. Similarly, Puglisi et al [83] conducted an online survey during COVID-19 to capture the soundscape perception in terms of the annoyance of workers (e.g., university staff) working from home. They concluded that 25% of these workers found sounds generated by other people (e.g., walking, talking) as the most annoying sound sources. This annoyance resulted in the loss of concentration and inability to relax.

Furthermore, indoor soundscape studies can involve lab studies as a method of collecting data [20,84,85]. For instance, Shu and Ma [20] conducted a lab study where they tested the effects of classroom soundscapes on children's cognitive performance. The study revealed that among all sounds, water and fountain sounds showed the best restorative effects on children's cognitive performance. Adding to that, exposure to both fountain and stream sounds showed a better performance in short-term memory. Another study conducted by Ma and Shu [84] considered students' physiological and psychological indicators in the context of an open-plan office. This was done by measuring students' HR and blood pressure (systolic and diastolic). In addition, students' psychological experiences (e.g., fatigue, annoyance, and tension) were evaluated. It was indicated that the soundscapes that were perceived as pleasant had positive effects on fatigue restoration and reduced the annoyance level of individuals. Similarly, Medvedev et al. [85] measured the physiological indicators, including HR and SCL, of participants (students and staff) caused by different soundscapes when the participants were performing stressful tasks and resting. This study asserted that soundscapes can influence individuals' autonomic functions during both activities. Also, subjective responses were investigated through the soundscape appraisal dimensions (e.g., pleasantness, arousal, familiarity, eventfulness, and dominance).

2.4 Discussion on literature review's findings

2.4.1 Indicators for investigating indoor acoustics

There are a number of indicators concerning occupant-related, dose-related, and building-related indicators examined by the previous studies on indoor acoustics and soundscapes that were mentioned in the results section. **Appendix A** summarizes the indicators that were investigated in the 44 previous studies. The following three subsections answer the first research question: What are the indicators that have to be considered to evaluate the acoustical quality taking into account students' acoustical preferences and needs?

2.4.1.1 Occupant-related indicators

Occupant-related indicators are divided into physiological and psychological indicators, which were considered by the previous studies on indoor acoustics. With regards to physiological indicators, the authors measured the physiological indicators of individuals for investigating the individuals' acoustical needs. These indicators are HR [36], [37], [38], [39], [46], [47], [84], [85] or HF HRV [33], [36], RR [37], [39], blood pressure (diastolic/systolic) [35], [38], [46], [84], SCL [33], [85], brain activity for capturing students' stress level [34], EDA [39], salivary cortisol [46], skin temperature [38], and cerebral behaviour [15].

Regarding psychological indicators, previous studies captured students' acoustical preferences through investigating several indicators. The psychological indicators are stress levels/state [34], emotional responses (e.g., annoyance [39], [51], [67], [68], [76], [84] or assessment of disturbance [19], [46], pleasantness [21], [81], [85], calmness [76], eventfulness [76], [85], tension [84], and fatigue [84]), perception as to the acoustical environment /sound [13], [55], [63], [71], [73], [74], [79], [81], [82], [86], [87] or background noise [56], [66] or floor impact noise [56] or cross-modal perception with other IEQ-factors (e.g., draught [55], smell [55], light [55], [87], temperature/thermal sensation [55], [56], [87]) or perceptual dimensions (comfort, content, familiarity) [78], restorative effect [13], [20], [21], [74], preference in terms of acoustic/sound preferences [54], [61], [67], [68], [77], [79], [80] or view preference [51], [77] or thermal preference [54],

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noticeability [39], coping methods [63], [71], [73], [74], appropriateness of sound environment [69], acoustical comfort [54], [67], [68], soundscape expectation [61], [80], [81], and interpretation of soundscape [61], [80].

Based on the mentioned overview of occupant-related indicators, **Figure 2.4** summarizes all these indicators used to assess the effects of indoor acoustics on students' preferences and needs. In the study of students' well-being in an educational building, both categories of these indicators are essential to consider. It can be noted that the HR [33], [36], [37], [38], [39], [46], [47], [84], [85] was the most used physiological indicator in previous studies, while the perception of the acoustical environment/sound/noise [13], [55], [56], [63], [66], [74], [79], [81], [82] was the most studied psychological indicator. Measurements of physiological indicators seem to be more applicable in lab studies. Apart from that, Wålinder et al. [46] carried out a field study in a real classroom that measured several physiological indicators. Psychological indicators can thus be studied in both field and lab studies.

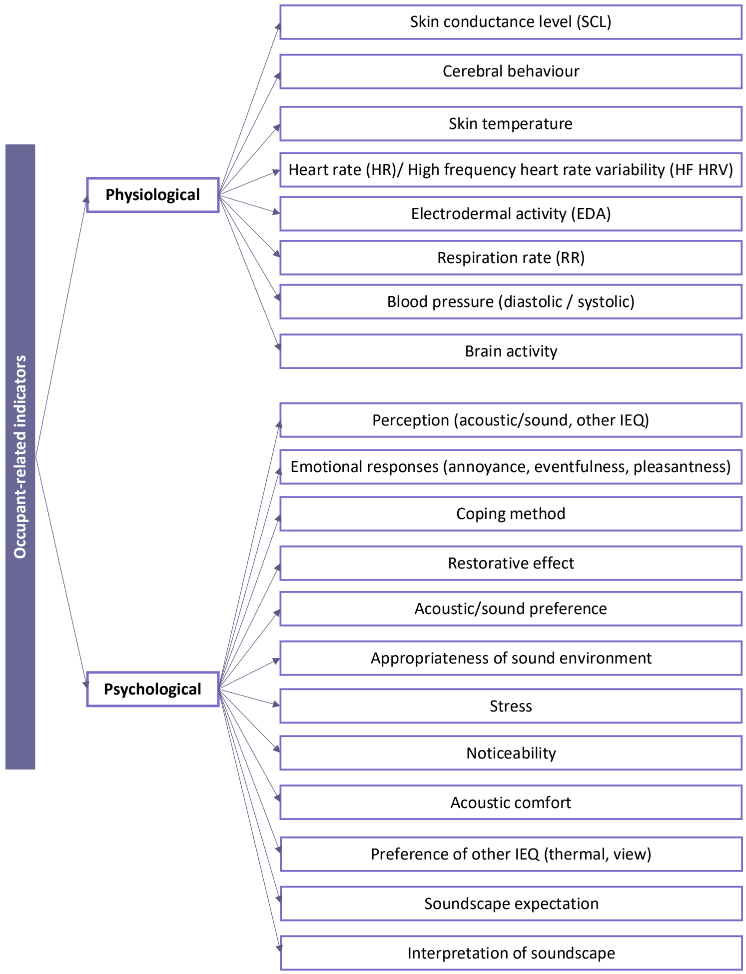

FIG. 2.4 Occupant-related indicators for measuring the effects of indoor acoustics on students.

2.4.1.2 Dose-related indicators

The reviewed 44 studies considered several dose-related indicators with regards to indoor acoustics or other IEQ-factors. Concerning the indicators of the indoor acoustics, a number of objective parameters related to room acoustics have been measured by the previous studies which are: SPL [13,19,20,33,35–39,46,48,49,51,54,56,61,63,66–69,71,73,75–78,80–82,85–87], RT [12,13,19,71,76,80,87], STI [48,71,77,80,87], speech intelligibility [52], clarity

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index (C50) [87], early decay time (EDT) [87], frequency [47], and sound source [12,15,20,21,33,34,39,48,49,51,54–56,61,63,69,71,73–82,84–86]. In addition, psychoacoustic parameters like loudness [20,67,68,76,78], fluctuation strength [20,78], roughness [20,78], and sharpness [20] were investigated. Furthermore, other indicators for other IEQ-factors are also essential to be considered because they might have interaction effects with indoor acoustics. These indicators of the other IEQ-factors were examined in the previous studies. Regarding thermal comfort, temperature [34,35,37,38,54,56,66,86,87], humidity [35,56,86,87], predicted mean vote (PMV) [87], and predicted percentage of dissatisfaction (PPD) [87] were examined. In terms of visual quality, illuminance intensity [38,86,87] was considered. Also, dose-related indicators with regard to indoor air quality such as odour irritant (e.g, VOCs) [34,55], was examined by the previous studies on indoor acoustics.

Based on this summary of dose-related indicators, **Figure 2.5** demonstrates those that can be considered in further studies on students' acoustical preferences and needs. These indicators can be measured in an existing study environment or in a laboratory (e.g., test chamber). Also, these indicators can be predicted during the design phase of the study environment such as running simulations. Among the acoustical quality indicators, SPL [13,19,20,33,35–39,46,48,49,51,54,56,61,63,66–69,71,73,75–78,80–82,86,87], and sound sources [12,15,20,21,33,34,39,48,49,51,54–56,61,63,69,71,73–82,84–86] were the two most commonly investigated dose-related indicators in the previous studies. It is worth mentioning that sound sources can have both physiological and psychological effects on students [20,33,39,84,85]. In addition, the SPL can adversely affect students' physiological needs [36,39]. Furthermore, some dose-related indicators are based on the context of a study environment [13]. For instance, speech privacy as an indicator has been applied in open-plan study environments. In accordance with the guideline [23], it is also mentioned that speech privacy is used as an indicator in open plan study/teaching spaces to provide clear communication within a student group. RT in educational buildings is found to be a fundamental indicator for the acoustical performance of classrooms and open-plan study environments [12,13,17,19,55,71]. While a higher RT proved to be important for informal learning spaces [13], a lower RT could result in a better acoustical quality. Nevertheless, the performance of students in a room with lower RT was not significantly better than in a room with a higher RT [12]. This outcome showed that improving the acoustical quality, such as reducing the RT, does not always fulfill all students' acoustical preferences and needs, in this case their performance. Thus, it is important to consider all students' preferences and needs of the acoustical environment in their educational buildings.

Regarding the indicators of other IEQ factors, temperature [34,35,37,38,54,56,66,86,87] was found to be the most measured dose-related indicator. Several studies proved that the students' physiological and psychological responses are associated with the combined effects of acoustical quality indicators (SPL and sound source) and thermal comfort indicators (temperature) [34,35,37,54,56]. Although the cross-modal perception between the acoustical quality and lighting/visual comfort [50–52] was not widely examined in previous studies, it was proven that they are associated with each other. In addition, natural visual scenes such as greenery, water elements, and sea view play a significant role in reducing the annoyance perception of the sound source. Hence, both categories of dose-related indicators (acoustical quality and other IEQ factors) are important to assess in studies on students' acoustical preferences and needs in educational buildings.

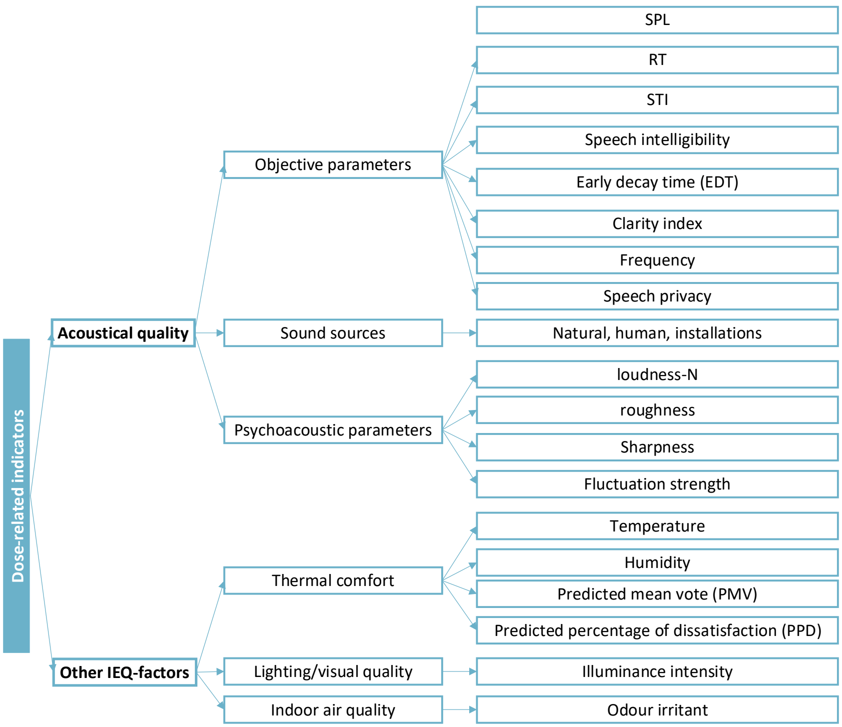

FIG. 2.5 Dose-related indicators to be considered in studies on students' acoustical preferences and needs.

2.4.1.3 Building-related indicators

Few studies considered building-related indicators. In terms of indoor acoustics, physical environment elements, such as the presence of acoustical walls and absorbing ceiling panels, can affect the acoustical quality in an indoor environment [17,49,55]. Additionally, space layout of an educational building can play a vital role in acoustical comfort [69]. As regards visual/lighting quality, lighting type [52,55,86], visual scene [51,77], and daylight access [86] were the three building-related indicators taken into account by previous studies. Regarding indoor environmental quality, ventilation system [55] was studied.

Acoustical guidelines (BB93 [24] and fresh schools "Frisse Scholen 2021" [26]) for educational buildings provide a wide range of building-related indicators. These include applying a sound-absorbing ceiling, sound-absorbing wall finishing, flooring material, space layout, and room geometry that includes both room shape and room volume. The sound-absorbing walls are applied specifically between the spaces used by the students (e.g., classrooms) and the circulation spaces (e.g., corridors). However, building-related indicators have rarely been taken into account in previous studies on students' acoustical preferences and needs. It can be noted from **Appendix A** that only four studies considered building-related indicators [17,49,55,69]. Those showed that building-related indicators interact with occupant-related and dose-related indicators. Other building-related indicators for other IEQ factors, such as lighting quality [51,52,55,77,86] and indoor air quality [55], have been considered in previous research on indoor acoustics and soundscape. Accordingly, building-related indicators (**Figure 2.6**) affect both occupant-related and dose-related indicators, and they need to be taken into account.

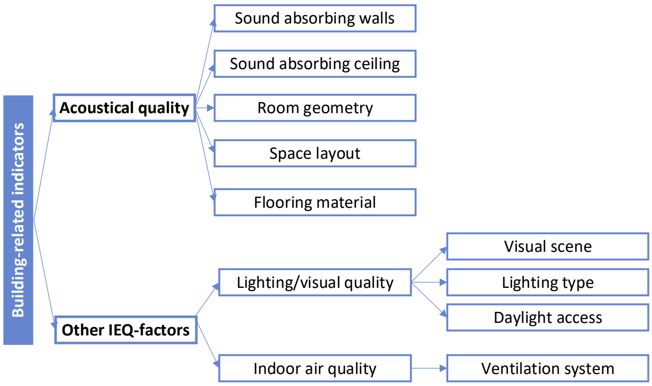

FIG. 2.6 Building-related indicators to be considered in studies on students' acoustical preferences and needs.

2.4.2 Methods for investigating acoustical quality

Several methods have been carried out to investigate the acoustical quality by measuring and assessing indicators at human level (occupant-related) and environmental-level (dose-related and building-related). The following two sub-sections answer the second research question: What are the methods that are used for measuring and assessing these indicators?

2.4.2.1 Investigations at the human level

Table 2.2 summarizes all the methods and tools that were used by previous studies to measure the occupant-related indicators. Investigations at the human level were conducted in both field and lab studies to measure occupant-related indicators. With regards to field studies, several data collection methods, which are soundwalks, questionnaires, objective measurements at the human level, and interviews were carried out. Soundwalk is a method of collecting perceptual data of an acoustical environment that is led by a moderator where expert participants follow a specified path in the space [58]. Various studies performed soundwalks for understanding human sensations, responses, and outcomes in specific indoor acoustics [69,86,88,89]. Generally, questionnaires are used for capturing individuals' perceptions, restorations, appraisals, preferences, and behaviours in an indoor environment [58]. Questionnaires were also used to identify the appropriateness of the sound [69], coping methods [73], expectation [81], and emotional responses in terms of the pleasantness of sound [21]. For example, Ricciardi and Buratti [87] used a questionnaire that included questions about students' noise perception, consequences of this perception, evaluation of the acoustical quality, and sound intelligibility. A field study carried out by Braat-Eggen et al. [19] also involved a questionnaire to obtain students' assessments of noise disturbance induced by noise sources while performing tasks. The questionnaire of this study comprised several components such as students' demographical information, noise sensitivity, and noise annoyance. Furthermore, an example of a questionnaire applied in indoor acoustical studies is the one developed by Dokmeci Yorukoglu and Kang [42], which includes psychological factors, space usage factors, and demographical factors. Demographical factors are essential in indoor acoustical studies for identifying individual characteristics of the participant group, such as gender, age, educational background, socio-cultural characteristics, and habits. Accordingly, the difference between soundwalk and the questionnaire is that soundwalk involves participants (known as experts) who might or not be the main users of the space. In addition, soundwalk requires following a certain path and listening to different acoustical environments, while it is not required in questionnaires.

Moreover, field studies could involve objective measurements of physiological indicators and students' subjective assessments. For example, Wålinder et al. [46] conducted a field study among 78 fourth-grade students for four weeks. One day of each week, a stethoscope and sphygmomanometer devices were used to measure students' blood pressure; a cotton wad was used for sampling and testing students' salivary cortisol, and a questionnaire was filled out by the students to capture their disturbance and symptoms. In addition, students were asked to draw a human figure based on Koppitz's instruction (as psychological assessments) for assessing their emotions. Often in previous studies, interviews were carried out in indoor acoustical studies [61,63,71,74,81,86,90,91]. The interview aims at in-depth understanding individuals' feelings and emotions induced by indoor acoustics [58].

Lab studies are also conducted for examining the impact of various conditions of indoor acoustics (dose-related and building-related) at the human level (occupant-related) [92,93]. Previous lab studies focused on exploring the effects of different acoustical conditions on students' physiological health [33–38,84], psychological responses [13,34,55,94], performance [12,15,48,49], and multisensory interaction/cross-modal perception [55,95]. Before conducting lab experiments, most studies screened the students based on their hearing health [33,35–37,47]. With regards to physiological measurements, several electrical devices were applied to measure physiological indicators. For instance, electrocardiograph electrodes attached to participants' right wrist and ankles were used to measure the HR. Also, a transducer belt worn around the participant's chest was applied to measure the RR [39]. Additionally, heartbeat monitoring devices were utilized to measure blood pressures (systolic and diastolic) before and after the experiment [35]. An electronic sphygmomanometer device was used for measuring the blood pressure and HR of students [38]. Furthermore, EEG, which monitor brain activity, were used to examine students' stress [34]. Also, EEG and electrodes were used to record the brain wave activity in an audiometric room [15]. On the other hand, electrodes and electrocardiograms (ECG) were applied to measure SCL, RR, and EDA [33,39,85]. In multi-sensory interaction studies, an electronic thermometer device was used to measure the participant's skin temperature [38]. In terms of psychological assessments, a designed stress examination sheet was used as a questionnaire to investigate students' stress [34]. In addition, questionnaires were also commonly used in previous lab studies. They can be used to assess students' perception of acoustical and environmental suitability [13], and cross-modal perception (acoustical, lighting, and air quality) [55]. With regards to the performance, different tasks have been applied in different studies. For example, Zhang et al. [49] used the phonological processing task to assess primary school children's performance in a lab study; Tristan-Hernandez et al. [15] used the Toulouse-Pieron test to assess the attention capacity and perception of university students and staff; Kang and Ou [48] used cognitive tasks such as serial recall, mental arithmetic reading comprehension, proofreading to assess the work performance of office workers.

TABLE 2.2 Methods and tools for investigating the occupant-related indicators.

References	Method	Indicators	Tools and equipment	Context/activity
[13,21,46,47, 63,67–69, 72,73,75–77, 79,81, 82,84–87]	Questionnaire	• Demographical information • Perception (acoustic/ sound, other IEQ) • Emotional response (pleasantness, calmness, eventfulness, annoyance) • Coping method • Restorative effect • Acoustic/sound preference • Appropriateness of sound environment • Stress • Noticeability • Acoustical comfort • Preference of other IEQ • Soundscape expectation • Interpretation of soundscape • Noise sensitivity • Satisfaction	• Subjective questionnaire	• Students at home • Students in an educational building (e.g., school/ university classroom, informal learning spaces, open-plan study environment, computer laboratory, libraries) • Lab (e.g., test chamber)
[61,63,71, 74,81,86]	Interview	• Perception • Preference • Expectation	• Structured/semi-structured questions	• Educational building (e.g., scool classroom, computer laboratory)
[15,33–39, 46,47, 84,85]	Objective measurements	• HR • Blood pressure (diastolic/ systolic) • EEC • Electrical activity of brain	• Stethoscope and sphygmomanometer • HR sensor device • Hemomanometer • Electronic thermometer	• Lab (e.g., test chamber) • School classroom
		• SCL • EDA • RR	• Electrodes and ECG	• Lab (e.g., test chamber)
		• Cerebral behaviour (brain wave)	• Electrodes and EEG	• Lab (e.g. audiometric room)
		• Salivary cortisol	• Cotton wad	• Field study in school classroom
		• Skin temperature	• Electronic sphygmomanometer (OMRON)	• Lab (e.g., test chamber)

2.4.2.2 Investigation at the environmental level

Table 2.3 summarizes all the methods and tools that were used by previous studies to measure the dose-related indicators. Investigations at the environmental level were also done in both field and lab studies by applying different methods for studying dose-related and building-related indicators. Several researchers in the field of indoor acoustics have performed field studies to assess the acoustical quality in educational buildings [19,46,72,87]. Some studies investigated the environmental level by measuring the dose-related indicators for the acoustics and other IEQ factors. For example, Ricciardi and Buratti [87] conducted a field study to evaluate three IEQ-factors (thermal, acoustical, and visual quality) in seven university classrooms. This study measured dose-related indicators with regards to indoor acoustics including the SPL of the background noise level, clarity index, STI, RT, and EDT based on the standard ISO 3382 [96]. A twelve-sided loudspeaker, as the source of the white noise, was placed at the professor's desk at a height of 1.5 meters. A precision condenser microphone, as a receiver, was placed at 4 to 6 measured points at the height of 1.1 meters as a seated student. The SPL of the background noise was measured for five minutes in the centre of each classroom by using the sound analyser. The STI and clarity index were measured in the situation of the speaker-to-listener position. Moreover, thermal indicators (e.g., temperature and humidity) were measured by using a microclimatic measurement system known as BABUC, and the measurements points were placed as a seated student (at a height of 1.1 meters). Regarding the lighting, the illuminance (lux) of each classroom was measured by a luxmeter. Also, the measurements points were based on the space index that was calculated according to the standard EN 12464-1 [97]. Other studies had only focused on the acoustical environment. For example, Braat-Eggen et al. [19] measured the acoustical indicators (such as distance disturbance, A-weighted background noise level, and RT) of five open-plan study environments according to the standard ISO 3382-3 [98]. Furthermore, Wålinder et al. [46] did a field study that included measurements of objective occupant-related indicators in three classrooms in a primary school for four weeks. SPL was measured daily (3 to 5 hours) by a sound-level meter placed at the centre of each classroom during all schooldays of the four weeks. Moreover, several studies investigated the indoor soundscape in study environments (e.g., library, classroom, open study area) [67–69,71,73]. Binaural measurements are performed for recording the acoustical environment in a space by using calibrated binaural measurement systems such as an artificial head. This recording method can be used for reproducing the acoustics of environments in laboratory experiments [58]. For instance, a binaural recording device was used to record 32 soundscapes of a hospital. These recordings were re-produced in a further experimental procedure in which individuals were exposed to them [75]. In addition, SPL, RT, and STI were measured by using a sound level meter or multi-function environment meter and omnidirectional loudspeaker [69,71,73,86]. Additionally, a building checklist can be utilized for investigating building-related indicators in field studies such as identifying ventilation systems and finishing materials of ceilings, walls, and floors [6].

Generally, lab studies can be designed with various acoustical conditions with different levels of SPL and sound recordings stimuli [92,93]. The time duration for exposing participants to acoustical stimuli was different in the previous studies due to the difference in each lab study's protocol. For instance, Choi et al. [34] exposed students to combined environmental stimuli: the sound source, temperature, and odour irritants for 15 minutes; Shu and Ma [13] exposed students to four rounds of experiments, in each round, the audio-visual soundscape was played for 3 minutes; Abbasi et al. [36] exposed students to sound stimuli for 5 minutes, including 10 minutes for adaptation before running the experiment as well as 5 minutes for rest between playing the sound stimuli. Ba and Kang [94], exposed students to a series of 9 audio stimuli continuously by playing each audio for 40 seconds, including a 10-second interval between each audio. Some studies used the loudspeakers for playing the sound stimuli [36,37,49], while others used headphones to play the sound stimuli [12,77,84].

Appendix B is a matrix that includes all the methods that were used by the selected studies in indoor acoustics. These methods are divided into methods used for investigations at the human level, and methods for investigations at the environmental level.

TABLE 2.3 Methods and tools for investigating the dose-related indicators.

References	Method	Indicators	Tools and equipment	Additions
[12,13,19,20, 33,35–39,46, 48,49,51,52, 54,56,61,63, 66–69,71–73,75–78,80–82, 86,87]	Objective measurements	• SPL • RT • STI • Clarity index (C_{50}) • Speech intelligibility • EDT	• Sound level meter • Omni-directional loudspeaker • Omni-directional microphone • Omni power sound source • 12-sided loudspeaker • Precision condenser microphone • DT8820 multi-function environment meter	• SPL measured for background speech • SPL measured in unoccupied spaces and/or occupied spaces • SPL measured the background noise at one or more than one positions • Standard: ISO 3382 • In classroom, loudspeaker positioned at 1.5 m hight (teacher postion) to measure the STIand clarity index, while the microphone positioned in a student position (1.1 m hight)
		• Psychoacoustics parameters	• Psychoacoustic analysis software	-
		• Thermal parameters (temperature, humidity, PMV, PPD)	• Microclimatic measurement set BABUC	-
		• Illuminance intensity	• Luxmeter	• Standard: EN 12464-1
[12,20,34,36, 37,49,77,84, 92–94]	Playing sound stimuli	• Sound type	• Loudspeaker • Headphone	• Different sound types (e.g., speech, music, traffic, birds)
[69,86,88,89]	Soundwalk	• Sound source identification • SPL	• Sound level meter	• Standard: ISO 12913-2
[58,75]	Binaural measurements	• Sound recordings	• Calibrated binaural measurement systems	

2.5 Conclusions and limitation

The acoustical quality can influence (positive and/or negative) students' preferences and needs, and it can affect the well-being of students in an educational building. Different students have different acoustical preferences and needs. Thus, it is important to take account of occupant-related indicators while optimizing the acoustical quality of educational buildings to understand in-depth what do students prefer and need in their educational buildings. Nonetheless, guidelines for acoustical performance of educational buildings are generally focused on dose-related and building-related indicators, while occupant-related indicators are missing. However, previous studies in indoor acoustics and soundscape proved that dose-related indicators can significantly affect occupant-related indicators in terms of physiological and psychological effects.

In this study, a narrative synthesis was employed to develop an overview of indicators and methods that can be adopted in future studies for examining students' acoustical preferences and needs in educational buildings. **Figure 2.7** illustrates an overview of the indicators and methods which includes three main processes in sequential order: inputs, methods, and outputs. In the inputs' part, three groups of indicators are included: occupant-related, dose-related, and building-related indicators. Occupant-related indicators consist of three subgroups: physiological, psychological, and demographical. Under each of these subgroups, there are a set occupant-related indicators which are essential to be considered for investigating students' acoustical preferences and needs. Dose-related indicators are divided into two subgroups that are acoustical indicators, and indicators for other IEQ-factors. The acoustical indicators are significant to be taken into account for ensuring the indoor acoustical quality, while the indicators of the other IEQs are important for studying the cross-modal perception of the interactions between the acoustics and other IEQ-factors. Building-related indicators consist of the physical environment elements and building systems in terms of acoustical and other IEQ factors. These indicators can be observed and inspected of an existing educational building, or modified in a lab study.

In the methods part, several of them can be applied after determining the intended indicators to be examined at both human and environmental levels. These methods can be conducted in lab studies or field studies. Objective measurements at the human level, soundwalk, questionnaire, and interview are methods that were used in previous studies for assessing occupant-related indicators. Besides, objective measurements at the environmental level, binaural measurements, and playing sound stimuli were the main methods for studying dose-related indicators. In addition, a building checklist or inspection can be used for identifying the building-related indicators. As it was indicated by previous studies [4,22], it is important to take into account all the three categories of indicators (occupant, environmental, and building) in order to assess the health and comfort of indoor environments. Accordingly, students' acoustical preferences and needs will be identified by determining a comprehensive set of indicators (considering the three types of indicators) as well as by selecting the appropriate methods.

The indicators and methods that are summarized in this review article (which are represented in an overview Figure 7) are limited to the 44 selected studies that are illustrated in Tables 2.2 and 2.4. This review is limited to studies on indoor acoustics and soundscape with regard to students in both schools and universities (undergraduate and graduate). It can be noted that the minimum age of the students in these studies was 8 years old, while the maximum age was 34 years old. It can also be indicated that soundwalk was only applied in one study on a study environment, which was conducted by Xiao and Aletta [69] in a public library. This library includes study areas (e.g., group study areas, and quiet study areas) that can be used by students. Almost none of these studies considered neither students' acoustical preferences nor needs in educational buildings. Thus, this review recommends examining the three main indicators to study the students' acoustical preferences and needs in future studies.

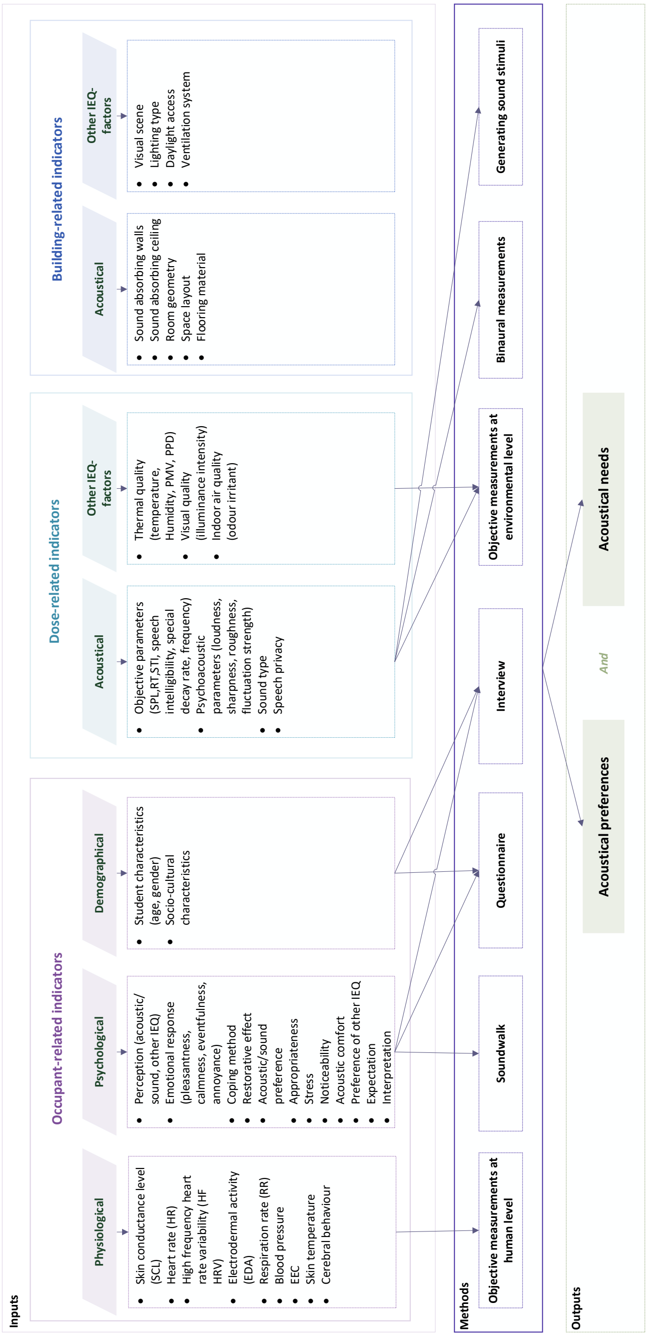

FIG. 2.7 An overview of indicators and methods that could be used for investigating students' acoustical preferences and needs in educational buildings.

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3 Profiles of University Students Based on IEQ and Psychosocial Preferences

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ABSTRACT

Research has shown that students differ in their preferences of indoor environmental quality (IEQ) and psychosocial aspects of their study places. Since previous studies have mainly focused on identifying these preferences rather than investigating the different profiles of students, this study aimed at profiling students based on their IEQ and psychosocial preferences of their study places. A questionnaire was completed by 451 bachelor students of the faculty of Architecture and the Built Environment. A TwoStep cluster analysis was performed twice separately. First, to cluster the students based on their IEQ preferences, and second based on their psychosocial preferences. This resulted in three clusters under each cluster model. Then, the overlap between these two models was determined and produced nine unique profiles of students, which are: (1) the concerned perfectionist, (2) the concerned extrovert, (3) the concerned non-perfectionist, (4) the visual concerned perfectionist, (5) the visual concerned extrovert, (6) visual concerned non-perfectionist, (7) the unconcerned introvert, (8) the unconcerned extrovert, and (9) the unconcerned non-perfectionist. A number of variables was found to be significantly different among these profiles. This study's outcome indicates that studying the overlap between IEQ and psychosocial preferences is required to understand the different possible profiles of students.

KEYWORDS

IEQ preferences; psychosocial preferences; twostep cluster analysis; study place; students' profiles.

3.1 Introduction

Students in higher education spend their time carrying out study-related activities (e.g., individual studying) in indoor environments other than standard classrooms, such as informal learning/study places [1,2]. These places refer to spaces that are mainly used by students for performing such study-related activities [3]. Previous research has found that students generally conduct their study-related activities at home or in an educational building [4] and spend substantial time inside these places [5]. Therefore, understanding students' preferences of these places can help to provide indoor environments that support their academic performance and well-being [6,7]. These preferences can be related to indoor environmental aspects and psychosocial aspects [8].

Research on students' (primary, secondary, and university education) preferences is usually performed within the context of teaching-related activities (e.g., classroom setting) [9–18]. Few studies have examined university students' preferences of study places in informal learning settings (e.g., individual learning, collaborative learning outside the classroom) [19]. For example, Ramu et al. [1] explored students' preferences of informal academic study places on campus and concluded that students were generally concerned about the layout and amenities (e.g., furniture) in these places. While both indoor environmental (e.g., lighting, temperature) and psychosocial (e.g., privacy, layout) preferences were included, the study was limited to study places used for collaborative study-related activities and located in educational buildings. Beckers et al. [4] investigated the reasons behind students' choices to use a certain place (at home or educational building) for studying. These reasons were significantly correlated with students' preferences, their personal characteristics, and study-related activities. Most of the study-related activities were conducted at home, and students were found to prefer studying at home because they had the ability to control the indoor environmental quality (IEQ)-factors (e.g., indoor air, thermal, sound and lighting quality). Another study conducted by Cunningham and Walton [20] found that 52 percent of university students chose the university library as a study place because it provided a quiet environment. Furthermore, Roetzel et al. [21] revealed that students' preferences of their study places can change with the study-related activities they perform. For instance, Braat-Eggen et al. [22] indicated that university students did not prefer background sounds, such as speech, in an open-plan study environment while they were performing cognitive tasks (e.g., studying for an exam).

So far, these previous studies generalized the preferences that were identified among the student sample. However, different students have different preferences that may change over time [2,8]. For example, in a study performed by Liu and Luther [23], students showed differences in their psychosocial preferences, such as privacy and interactions. Additionally, university students from different faculties can have distinct preferences of study places, found by Wilson and Cotgrave [7]. Students of the art and design discipline scored higher important scores for room layout, the ability to adjust furniture, and controlling the environmental factors than students within the built environment and engineering faculties. This was linked to the personality traits among the students from various faculties. Therefore, it is important to understand how university students' preferences of their study places vary.

An integrated analysis approach, which takes into account the differences in preferences and needs of occupants (profiles) and the different stressors at the environmental level (pattern of stressors), was recently introduced in the field of IEQ [8,24]. The approach claims that to provide a good IEQ for all occupants, determining profiles of clusters at the human level and matching those profiles with patterns of environmental stressors (positive and negative) in a certain indoor environment could be the right way to go. In other words, to be able to determine the pattern of stressors at the environmental level, clustering occupants based on their preferences is required to first identify the profiles of clusters to better understand how they interact in an indoor environment [25]. So far, a number of studies in which groups of occupants were clustered according to their preferences and needs have shown differences among the profiles of these clusters [26,27].

Profiles of clusters have been determined for various scenarios and situations, such as home occupants [28,29], primary school children [12], office workers [26,30], and outpatient staff of hospitals [27]. In two of those studies, TwoStep cluster analysis was performed to produce profiles of clusters with regards to (1) IEQ comfort and preferences, and (2) psychosocial comfort and preferences [26,27]. The study on the outpatient staff [27] resulted in six profiles of clusters based on IEQ comfort and preferences, and three profiles of clusters based on psychosocial comfort and preferences. Similar to that, the study on office workers during COVID-19 [26] resulted in two separated models: IEQ preferences model (including four profiles of clusters) and the psychosocial preferences model (including six profiles of clusters). In the latter study, Eijkelenboom and Bluyssen [27] stated that as the overlap between IEQ preferences and psychosocial preferences models was limited, it is essential to study both in future studies.

Profiles of students based on their preferences of both IEQ and psychosocial aspects of their study places are still to be explored. Thus, in this study the question was raised whether profiles of clusters for university students based on both their IEQ, and psychosocial preferences of their study places can be determined. If so, what are the distinctive preferences and characteristics of each student's profile? Accordingly, in this study an attempt was made to cluster simultaneously students' profiles based on both IEQ and psychosocial preferences of their study places.

3.2 Material and methods for 'MyStudyPlace' questionnaire

Bachelor students of the Faculty of Architecture and the Built Environment at TU Delft were recruited for a survey in March 2021, October 2021 and March 2022. They were asked in this survey about their IEQ and psychosocial preferences of their study place. Students' names and emails were provided by the course coordinators. A brief introduction to the questionnaire was given to the students by the coordinators on the same day of sending the questionnaire. Then, each student received a unique link to the questionnaire via an invitation email. In addition, the students were informed that they had ten days to answer the questionnaire. Five days after sending the questionnaire, a reminder was sent to those students who had not submitted the questionnaire yet. Furthermore, the expected time (approximately 30 min) for answering the questionnaire was stated in the consent form (the first page of the questionnaire).

3.2.1 Questionnaire

The questionnaire, entitled "My Study Place", is based on previously validated questionnaires that were used for office workers such as the OFFICAR questionnaire [31], the preferences of office workers questionnaire [26], and the outpatient questionnaire staff [27]. The "My Study Place" questionnaire, built in the Qualtrics XM platform in both English and Dutch, consists of seven sections: personal information, psycho-social aspects, most used study place, preferences, comfort perception, lifestyle, and health. **Table 3.1** and **Appendix C** include details of the sections and sub-sections of the questionnaire. For example, the preferences section includes an IEQ preferences sub-section that comprises eight variables. This question is stated as “Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place1: not important at all; 10: extremely important-e.g., temperature”.

TABLE 3.1 MyStudyPlace questionnaire sections.

Section	Sub-section	Instrument
Personal information	Age	-
	Gender	
Psycho-social aspects	Mood	OFFICAR, select one out of nine moods (e.g., cheerful) [31,49,50].
	Recently experienced positive events (e.g., wedding) and negative events (e.g., funeral).	OFFICAR, select either yes or no [31,49,50].
	Positive and Negative Affect Schedule (PANAS)	I-PANAS-SF, including five positive affects and five negative affects, on a scale 1 to 5 (1: never, 5: always) [51].
Mostly used study place	Study place type	Select one of the three options: home, educational building, or other.
Preferences	IEQ preferences *Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place1: Not important at all; 10: Extremely important* - e.g., temperature".	Eight aspects on a scale 1 to 10 (1: not important at all, 10: extremely important) [26].
	Psychosocial preferences: "*Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place1: Not important at all; 10: Extremely important* - e.g., privacy".	Nine aspects on a scale 1 to 10 (1: not important at all, 10: extremely important) [26].
	Importance of IEQ-related items: "*Please rate on a scale from 1 to 10, the importance of each of following the items that would help you to study better; 1: Not important at all; 10: Extremely important* - e.g., lamp on my desk".	Eleven aspects on a scale 1 to 10 (1: not important at all, 10: extremely important) [26].
Comfort	IEQ perception: "*On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the past 3 months?* e.g., temperature satisfaction".	Eighteen aspects on a scale 1 to 7 (1: dissatisfied, 7: satisfied [26,27,31].
	Control over IEQ factors: "*How much control do you personally have over the following aspects of your MOST used study place?* - e.g., ventilation".	Five aspects on a scale 1 to 7 (1: not at all, 7: full control) [26].
	Psychosocial perception: *How satisfied are you with the following in your MOST used study place* - e.g., amount of privacy".	Five aspects on a scale 1 to 7 (1: unsatisfactory, 7: satisfactory) [26].
Lifestyle	Physical activity	OFFICAR, select either yes or no [31].
	Smoking	OFFICAR, select one out of four options (e.g., no never, yes former, yes incidentally, yes daily) [31].
	Alcohol	OFFICAR, select one out of three options (e.g., yes daily, yes occasionally, no) [31].
Health and medical history	Suffering from diseases: "*Have you ever been told by your doctor that you are suffering from:* e.g., asthma"	OFFICAR, includes eighteen diseases, each disease is rated one out of three options: never, yes in the last 12 months, yes but not in the last 12 months [31].

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3.2.2 Participants

The questionnaire was completed by bachelor students of the faculty of Architecture and the Built Environment in March 2021, October 2021, and March 2022. In March 2021, 409 first-year bachelor students completed the questionnaire, in which two sections—the mostly used study place and the preferences—were not included, but the questions related to time spent at home during weekdays and weekend were included. In October 2021, the questionnaire (including these two sections, but excluding the questions related to time spent at home) was sent again to these students, of which 127 completed it. Nonetheless, 127 students were not sufficient to conduct the TwoStep cluster analysis. Accordingly, the “My Study Place” questionnaire including all seven sections was sent to another 472 bachelor students in March 2022, of which 347 students completed the questionnaire. Then, all the results were combined in one dataset with 474 (347 + 127) students. Subsequently, 22 students were excluded because they did not answer the preferences questions. Additionally, one student aged 49 years was excluded from the data set. Hence, the final dataset that was used for the analysis included 451 students.

3.2.3 Ethical Aspects

The Human Research Ethics Committee (HREC) at the Delft University of Technology approved the application to conduct this study on the 31st of January 2022. A consent form was included at the beginning of the questionnaire, stating all data will be treated anonymously. This form also mentioned that students could skip any part of the questionnaire if they felt uncomfortable answering it.

3.2.4 Data Management and Analysis

The data were exported from the Qualtrics XM platform to SPSS version 26.0 software (SPSS Inc, Chicago, IL, USA) for data analysis. Descriptive statistics were performed to calculate the frequencies, percentages, maximum, minimum, and standard deviation (SD), and mean of the variables related to demographics, emotional state, IEQ comfort perception, psychosocial perception, IEQ preferences, and the importance of IEQ-related items to study better, and psychosocial preferences.

TwoStep cluster analysis is a segmentation method that enables the creation of profiles of clusters based on any form of data, including categorical data [32]. This method was also used in previous studies within the domain of IEQ to determine profiles of clusters [12,24–28]. Accordingly, TwoStep cluster analysis was performed and validated twice and separately to create two distinct cluster models. The first TwoStep cluster analysis was performed to cluster the students based on their IEQ preferences, while the second one clustered them based on their psychosocial preferences. The input variables for the IEQ preferences model comprised eight variables: ventilation and fresh air, temperature, view to the outside, sounds from the outside, sounds from the inside, smells, artificial light, and daylight. The input variables for the psychosocial preferences model comprised nine variables: storage, cleanliness, amenities, chair type, presence and company of others, size of the room, bonding or identifying with the place, ability to adapt or control the place, and privacy. The settings of the TwoStep cluster analysis were based on selecting loglikelihood, determination of the number of clusters automatically, and Akaike's information criterion (AIC). Once the cluster model was generated, four validation steps were conducted: (1) silhouette measure of the cluster model is larger than 0.2 (fair and above); (2) Chi-square tests were performed to examine the relationship between the input variables of the cluster analysis and the final cluster model, with p-value less than 0.05 considered as statistically significant; (3) the predictor importance scores of the input variables were larger than 0.02; and (4) the dataset was randomly split half (50%) to re-run the final solution model on each half to ensure that both solutions were similar to the final solution.

After the TwoStep cluster analysis, descriptive analysis was conducted to calculate the frequencies, percentages, and SD for different variables of each cluster (e.g., health, IEQ perception, IEQ preferences). To compare differences between the clusters, Chi-square and ANOVA tests were used (for nominal and continuous variables, respectively). Each student belongs to two clusters, a cluster of IEQ preferences, and a cluster of psychosocial preferences, resulting in clusters of students with the same IEQ preferences but different psychosocial preferences, and vice versa. Hence, it is important to investigate the overlap between the two models to better understand in detail the profile of students within these two models. The overlap between the two cluster models was identified using cross-tabulation. In addition, frequencies, percentages, and SD for different variables of each profile within the overlap between the two models were calculated. The significant differences between the variables among the different profiles were tested using Chi-square and ANOVA tests. Chi-square calculations with less than 5 in one cell were excluded from the analysis.

3.3 Results of 'MyStudyPlace' questionnaire

3.3.1 Students Characteristics

Table 3.2 presents several characteristics (e.g., age, gender, time spent at home, study place, and lifestyle) of the respondents in 2021 and 2022 as well as the differences between these groups (p-value). Since only the mean time spent at home was significantly different between the two groups; students in 2021 spent more time at home than students in 2022, this study mainly focused on questions related to study places and excluded the questions related to students' homes, such as building-related symptoms. The mean age of the 451 students was 20 years old. The ratio of female to male students was 1.6. Students within this study spent their studying time mostly at their homes (74%), while 26% of them stayed in educational buildings for studying. The students stayed at their homes around 17 hours per day during weekdays, and 16 hours per day during the weekend.

TABLE 3.2 Students characteristics in 2021 and 2022.

	All students	Students in 2021	Students in 2022	P-value
Invited	878	409	472	-
Respondents	474	127	374	-
Response rate (%)	54.0	31.1	79.2	-
Age - mean (SD)	19.8 (1.6)	19.6 (1.1)	19.8 (1.8)	0.61
Gender - n (%)				0.70
Male	175 (39.0)	43 (40.6)	132 (38.5)	-
Female	274 (61.0)	63 (59.4)	211 (61.5)	-
Time spent at home during weekdays - mean (SD)				-
Weekdays	16.9 (3.6)	20.4 (2.8)	15.8 (3.1)	**P<0.001**
Weekend	15.8 (4.2)	17.5 (4.2)	15.2 (4.0)	**P<0.001**
Study place - n (%)				0.26
Home	333 (73.8)	85 (79.4)	248 (72.1)	-
Educational building	116 (25.7)	22 (20.6)	94 (27.3)	-
Lifestyle - n (%)				-
Smoking	134 (29.7)	22 (20.6)	112 (32.5)	0.12
Alcohol	384 (85.1)	92 (86.0)	292 (84.9)	0.74
Physical activity	407 (90.2)	98 (91.6)	309 (89.8)	0.59

3.3.2 Students’ Preferences of Their Study Places

Figure 3.1 presents the mean and SD values of the eight IEQ preferences aspects. Daylight (8.4 ± 1.5) was the most important aspect of the whole study sample. This is followed by both view to the outside (8.2 ± 1.8) and temperature (8.2 ± 1.3). In contrast, smells (6.2 ± 2.3), artificial light (6.2 ± 2.0), and sounds from the outside (6.3 ± 2.2) were the least important IEQ aspects. **Figure 3.2** illustrates the mean and SD values of the nine psychosocial preference aspects. Amenities (8.0 ± 1.5) and cleanliness (7.6 ± 1.7) were the most important psychosocial aspects of the study place. On the other hand, students in this study reported the lowest scores on three psychosocial aspects: presence and company of others (5.3 ± 2.5), bounding or identifying with the place (5.4 ± 2.5), and size of the room (5.5 ± 2.0).

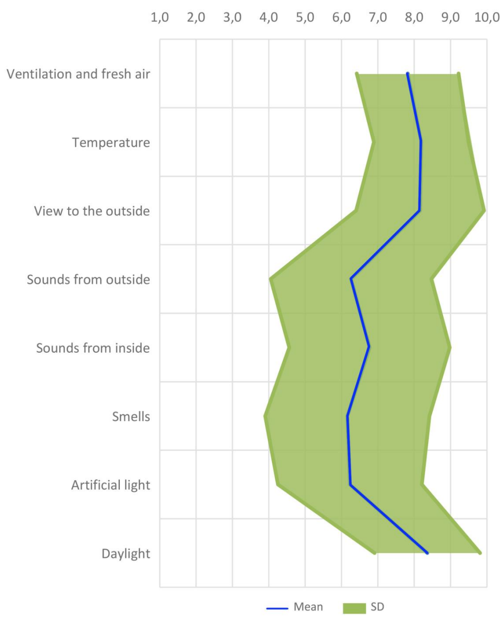

FIG. 3.1 IEQ preferences of study places.

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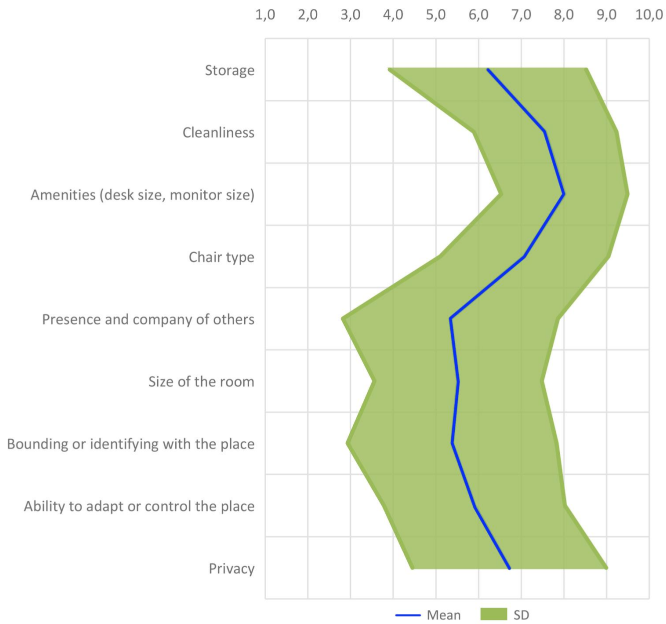

FIG. 3.2 Psychosocial preferences of study places.

3.3.3 TwoStep Cluster Analysis

TwoStep cluster analysis was carried out to categorize profiles of students based on their IEQ preferences and separate psychosocial preferences in their study places. This was carried out by using the original variables that consists of eight variables of the IEQ preferences and nine variables for the psychosocial preferences. The results of the TwoStep cluster analysis resulted in two models: the IEQ preferences model, and the psychosocial preferences model. Each of these two models comprised three distinct clusters. The Silhouette coefficient was fair for both models; 0.3 for the IEQ preferences model, and 0.2 for the psychosocial preferences model.

The predictor importance of the eight input variables for the IEQ preferences model, as well as the nine input variables for the psychosocial preferences model, was found to be strong and larger than 0.02. Additionally, after randomly splitting the dataset into two halves, only a few changes were found between the two halves and the final solution (**Table 3.3**). Furthermore, all eight IEQ preference variables were found to be statistically significant in relation to the IEQ preferences model ($p < 0.05$). Similarly, the nine psychosocial preference variables were found to be statistically significant in relation to the psychosocial preferences model.

TABLE 3.3 Predictor importance of the input variables for both models.

	Predictor importance	Final solution	First half solution	Second half solution
IEQ preferences model	0.60-1.00	Daylight (1.00) Sounds from inside (0.80) View to the outside (0.75) Smells (0.68)	Sounds from the inside (1.00) View to the outside (0.84) Daylight (0.62)	Sounds from the inside (1.00)
	0.30-0.59	Sounds from the outside (0.57) Ventilation and fresh air (0.30)	Smells (0.52) Sounds from the outside (0.42)	Daylight (0.58) View to the outside (0.44) Smells (0.40) Sounds from the outside (0.40)
	0.02-0.29	Artificial light (0.21) Temperature (0.20)	Ventilation and fresh air (0.21) Temperature (0.07) Artificial light (0.03)	Ventilation and fresh air (0.20) Artificial light (0.20) Temperature (0.06)
Psychosocial preferences model	0.60-1.00	Bonding or identifying with the place (1.00) Ability to adapt or control the place (0.91) Size of the room (0.71) Cleanliness (0.63)	Presence and company of others (1.00) Ability to adapt or control the place (0.78) Privacy (0.71)	Ability to adapt or control the place (1.00) Bonding or identifying with the place (0.82)
	0.30-0.59	Storage (0.54) Presence and company of others (0.51) Chair type (0.36) Amenities (0.33) Privacy (0.30)	Size of the room (0.56) Bonding or identifying with the place (0.54) Storage (0.53) Chair type (0.43) Amenities (0.38) Cleanliness (0.30)	Storage (0.53) Amenities (0.52) Size of the room (0.52) Presence and company of others (0.52) Chair type (0.47) Privacy (0.35)
	0.02-0.29	-	-	Cleanliness (0.22)

3.3.3.1 IEQ Preferences Model

The clusters of the IEQ preference clusters are described in **Table 3.4** and **Appendix D**. **Table 3.4** only includes the variables that were statistically different among the clusters within the IEQ preferences model ($p < 0.05$). The IEQ preferences model resulted in three clusters: IEQC1 (concerned with all IEQ aspects), IEQC2 (concerned with daylight and view to the outside), and IEQC3 (concerned with only temperature). These three clusters scored a high importance level for daylight (ranged from 7.0 to 9.0), view to the outside (ranged from 6.7 to 9.0), and temperature (ranged from 7.8 to 8.7).

TABLE 3.4 Descriptives of IEQ clusters.

	IEQC1	IEQC2	IEQC3	P-value
N (%within the total sample)	159 (35.5)	149 (33.3)	140 (31.3)	-
Gender -N (%within cluster level)				**P<0.001**
Male	42 (26.4)	63 (42.6)	68 (48.9)	-
Female	117 (73.6)	85 (57.4)	71 (51.1)	-
Study place - N (%within cluster level)				0.007
Home	103 (64.8)	117 (78.5)	110 (78.6)	-
Educational building	55 (34.6)	31 (20.8)	30 (21.4)	-
IEQ preferences - mean (SD)				
Ventilation and fresh air	8.5 (1.1)	7.7 (1.3)	7.2 (1.6)	**P<0.001**
Temperature	8.7 (1.1)	7.8 (1.3)	8.0 (1.3)	**P<0.001**
View to the outside	8.7 (1.3)	9.0 (1.1)	6.7 (1.9)	**P<0.001**
Sounds from the outside	7.6 (1.7)	4.8 (1.9)	6.3 (2.1)	**P<0.001**
Sounds from the inside	8.1 (1.4)	5.0 (2.1)	7.2 (1.8)	**P<0.001**
Smells	7.8 (1.4)	4.9 (2.0)	5.7 (2.2)	**P<0.001**
Artificial light	7.1 (1.7)	6.0 (2.0)	5.5 (1.9)	**P<0.001**
Daylight	9.0 (0.9)	9.0 (0.9)	7.0 (1.4)	**P<0.001**
Importance of IEQ-related aspects - mean (SD)				
Lamp on my desk	6.6 (2.3)	5.9 (2.4)	6.2 (2.2)	**0.026**
Personal desk ventilation and fresh air	7.6 (2.2)	7.1 (2.2)	6.4 (2.0)	**P<0.001**
Control of surrounding sounds	7.7 (1.6)	5.6 (2.2)	6.8 (1.9)	**P<0.001**
Control of shading	7.8 (1.7)	6.5 (2.2)	7.2 (1.7)	**P<0.001**
Control of room ventilation	7.8 (1.6)	6.2 (2.0)	6.5 (2.0)	**P<0.001**
Control of room temperature	7.7 (1.5)	6.7 (1.9)	6.8 (2.0)	**P<0.001**
Headphones	7.7 (2.4)	7.3 (2.6)	6.6 (2.4)	**0.004**

3.3.3.2 Psychosocial Preferences Model

Descriptions of the psychosocial preference clusters are presented in **Table 3.5** and **Appendix E**. Table 4 only illustrates the variables that were found to be statistically different among the three clusters within the psychosocial preferences model ($p < 0.05$). This model consists of three distinct clusters: PSC1 (Preference for most of psychosocial aspects), PSC2 (preference for presence and company of others), and PSC3 (preference only for amenities and cleanliness). Generally, the students within these clusters reported a high importance for two aspects, which are cleanliness (ranged from 7.1 to 9.0) and amenities (ranged from 7.5 to 8.9).

TABLE 3.5 Descriptive of psychosocial clusters.

	PSC1	PSC2	PSC3	P-value
N (%within the total sample)	110 (25.0)	186 (42.3)	144 (32.7)	-
Lifestyle - N (%within cluster level)				
Smoking	21 (19.0)	56 (26.9)	52 (36.1)	**0.025**
Alcohol	85 (77.3)	161 (86.6)	128 (88.9)	**0.021**
Study place - N (%within cluster level)				**P<0.001**
Home	98 (89.1)	117 (62.9)	110 (76.4)	-
Educational building	12 (10.9)	68 (36.6)	33 (22.9)	-
Psychosocial preferences - mean (SD)				
Storage	8.1 (1.3)	5.6 (2.1)	5.6 (2.5)	**P<0.001**
Cleanliness	9.0 (1.0)	7.1 (1.4)	7.1 (1.8)	**P<0.001**
Amenities	8.9 (1.1)	7.9 (1.2)	7.5 (1.8)	**P<0.001**
Chair type	8.0 (1.7)	7.4 (1.5)	6.0 (2.3)	**P<0.001**
Presence and company of others	5.1 (2.4)	6.6 (2.0)	4.0 (2.4)	**P<0.001**
Size of the room	6.4 (1.8)	6.2 (1.5)	4.1 (1.8)	**P<0.001**
Bonding or identifying with the place	6.6 (1.8)	6.3 (2.0)	3.3 (2.0)	**P<0.001**
Ability to adapt or control the place	7.2 (1.6)	6.4 (1.7)	4.2 (1.9)	**P<0.001**
Privacy	8.1 (1.4)	6.2 (2.2)	6.3 (2.4)	**P<0.001**

3.3.4 Overlap between the IEQ and the Psychosocial Preferences Model

The overlap between the IEQ and psychosocial preferences model resulted in nine distinct profiles that are illustrated in **Figure 3.3**. Descriptions of these profiles, presented in **Table 3.6**, are statistically significantly different between the profiles. A comprehensive description for these nine groups is illustrated in **Appendix F**. In general, all nine profiles are concerned with three IEQ preferences, which are daylight (ranged from 6.6 to 9.3), view to the outside (ranged from 6.4 to 9.1), and temperature (ranged from 7.6 to 8.9). Pertaining to the psychosocial preferences, most of the profiles scored high importance levels for two aspects: amenities (ranged from 7.4 to 8.9) and cleanliness (ranged from 6.8 to 9.0). Therefore, the description for each profile is based on highlighting which profile scored the highest and/or lowest importance level for both IEQ and psychosocial preferences among all profiles.

Each name of the nine profiles consists of two parts: the first part is related to IEQ preferences, and the second part is related to psychosocial preferences. The IEQ preferences part consists of one of three names that are; (1) concerned, which means all IEQ preferences are important, (2) visual concerned, which implies that daylight and view to the outside are important, and (3) unconcerned, which indicates that almost all IEQ preferences are not very important except for temperature. The psychosocial preferences part includes one of the four categories; (1) perfectionist, which implies high importance levels for most of the psychosocial aspects, (2) extrovert, which reflects the high importance level for the presence and company of others, (3) introvert, which means that privacy is highly important, (4) non-perfectionist, which indicates that most of the psychosocial aspects are not highly important, except amenities.

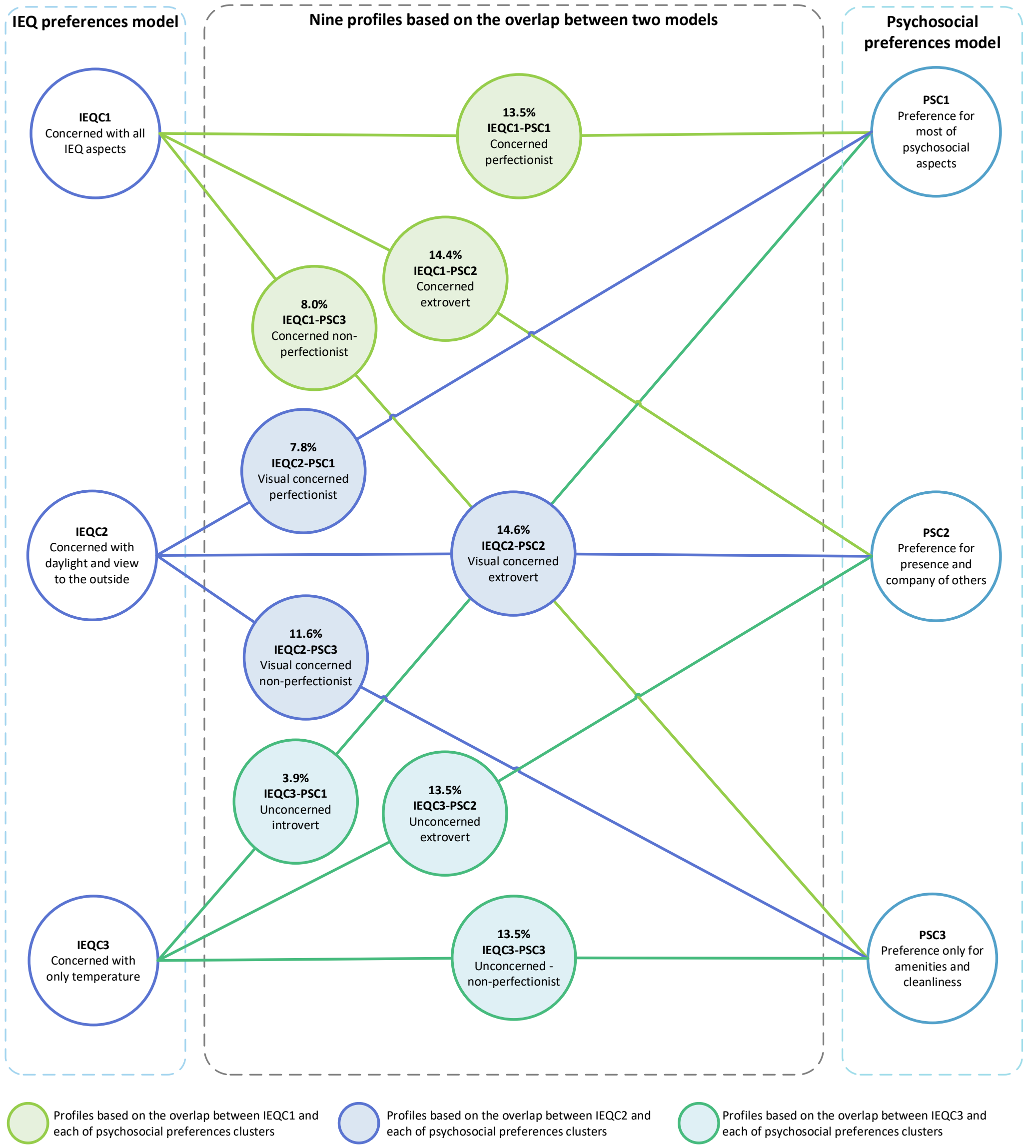

FIG. 3.3 The nine profiles of students based on the overlap between the IEQ preferences model and psychosocial preferences mode

TABLE 3.6 Description of the overlap profiles between the two clusters models.

	IEQC1-PSC1	IEQC1-PSC2	IEQC1-PSC3	IEQC2-PSC1	IEQC2-PSC2	IEQC2-PSC3	IEQC3-PSC1	IEQC3-PSC2	IEQC3-PSC3	P-value
N (%within the total sample)	59 (13.5)	63 (14.4)	35 (8.0)	34 (7.8)	64 (14.6)	48 (11.0)	17 (3.9)	59 (13.5)	59 (13.5)	-
Age										P<0.001
Mean (SD)	19.6 (1.8)	19.7 (1.9)	19.6 (1.1)	19.9 (1.2)	19.7 (1.2)	19.7 (1.5)	20.1 (0.9)	20.0 (2.1)	19.8 (1.4)	-
Maximum	29	31	24	23	24	26	22	23	23	-
Minimum	17	17	18	18	18	18	19	18	18	-
Gender – N (%within profile level)										P<0.001
Male	17 (28.8)	18 (28.6)	6 (17.1)	16 (47.1)	26 (40.6)	19 (39.6)	10 (58.8)	24 (40.7)	32 (54.2)	-
Female	42 (71.2)	45 (71.4)	29 (82.9)	18 (52.9)	38 (59.4)	28 (58.3)	7 (41.2)	34 (57.6)	27 (45.8)	-
Recently experienced events - N (%within profile level)										-
Positive events	22 (37.3)	22 (34.9)	9 (25.7)	8 (23.5)	18 (28.1)	12 (25.0)	5 (29.4)	14 (23.7)	16 (27.1)	0.012
Lifestyle - n (%within profile level)										-
Alcohol	44 (74.6)	53 (87.3)	32 (91.4)	28 (82.4)	56 (87.5)	43 (89.6)	13 (76.5)	50 (84.7)	51 (86.4)	P<0.001
Physical activity	53 (89.8)	58 (92.1)	33 (94.3)	32 (94.1)	60 (93.8)	43 (89.6)	12 (70.6)	52 (88.1)	51 (86.4)	P<0.001
PANAS - Mean (SD)										-
Positive affect	17.8 (2.7)	17.1 (2.6)	17.6 (2.2)	18.3 (2.4)	17.4 (2.5)	17.4 (2.6)	17.9 (2.4)	16.9 (2.3)	17.1 (2.9)	P<0.001
Negative affect	11.9 (3.0)	11.6 (3.1)	12.1 (3.0)	11.7 (2.7)	11.4 (2.8)	11.0 (3.1)	11.7 (3.1)	11.8 (3.0)	10.9 (3.1)	P<0.001
Health - n (%within profile level)										-
Depression	12 (20.3)	12 (19.0)	7 (20.0)	6 (17.6)	12 (17.7)	11 (22.9)	5 (29.4)	9 (15.3)	17 (28.8)	P<0.001
Anxiety	17 (28.8)	19 (30.2)	7 (20.0)	8 (23.5)	12 (18.8)	15 (31.3)	5 (29.4)	11 (18.6)	13 (22.0)	P<0.001
IEQ perception - n (%within profile level)										-
Dissatisfied with air freshness	31 (52.5)	41 (65.1)	21 (60.0)	20 (58.8)	35 (54.7)	32 (66.7)	9 (52.9)	30 (50.8)	44 (74.6)	0.011
Dissatisfied with air smell	27 (45.8)	28 (44.4)	17 (48.6)	12 (35.3)	40 (62.5)	19 (39.6)	6 (35.3)	26 (44.1)	26 (44.1)	0.003
IEQ preferences mean (SD)										-
Ventilation and fresh air	8.6 (1.1)	8.3 (1.1)	9.0 (1.1)	7.8 (1.3)	7.7 (1.4)	7.6 (1.2)	7.5 (1.5)	7.3 (1.2)	7.1 (1.9)	P<0.001
Temperature	8.7 (1.1)	8.6 (1.0)	8.9 (1.1)	8.1 (1.5)	7.8 (1.3)	7.6 (1.3)	8.4 (1.7)	7.9 (1.2)	8.1 (1.4)	P<0.001
View to the outside	8.6 (1.3)	8.8 (1.2)	8.7 (1.4)	9.1 (0.9)	8.9 (1.0)	9.2 (1.1)	7.1 (1.7)	6.9 (1.9)	6.4 (1.9)	P<0.001
Sounds from the outside	7.8 (1.4)	7.5 (1.8)	7.4 (2.1)	5.6 (1.9)	4.8 (1.7)	4.3 (1.9)	6.9 (2.0)	6.1 (2.0)	6.4 (2.1)	P<0.001
Sounds from the inside	8.2 (1.3)	7.9 (1.4)	8.2 (1.5)	4.9 (2.2)	5.1 (1.9)	5.0 (2.2)	7.4 (1.7)	7.1 (1.6)	7.2 (2.0)	P<0.001
Smells	7.9 (1.4)	7.8 (1.3)	7.5 (1.7)	5.3 (1.7)	5.1 (1.8)	4.3 (2.1)	6.5 (2.4)	5.7 (1.8)	5.6 (2.4)	P<0.001
Artificial light	7.2 (1.9)	7.0 (1.5)	6.8 (1.6)	6.6 (1.9)	5.9 (1.7)	5.5 (2.1)	6.1 (2.1)	5.5 (1.5)	5.5 (2.2)	P<0.001
Daylight	9.0 (0.9)	9.0 (0.9)	8.8 (1.0)	9.3 (0.7)	8.8 (0.9)	9.0 (1.0)	7.2 (1.3)	7.1 (1.2)	6.6 (1.6)	P<0.001

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TABLE 3.6 Description of the overlap profiles between the two clusters models.

	IEQC1-PSC1	IEQC1-PSC2	IEQC1-PSC3	IEQC2-PSC1	IEQC2-PSC2	IEQC2-PSC3	IEQC3-PSC1	IEQC3-PSC2	IEQC3-PSC3	P-value
Psychosocial preferences - mean (SD)										-
Storage	7.8 (1.3)	5.3 (2.2)	6.3 (2.6)	8.4 (1.1)	5.6 (2.1)	5.4 (2.3)	8.2 (1.3)	5.9 (1.9)	5.4 (2.5)	P<0.001
Cleanliness	9.0 (1.1)	7.4 (1.2)	7.7 (1.8)	9.0 (1.0)	7.0 (1.5)	7.0 (1.7)	9.0 (0.9)	6.8 (1.3)	6.8 (1.9)	P<0.001
Amenities	8.9 (1.2)	8.0 (1.1)	7.8 (2.0)	8.9 (0.9)	7.9 (1.3)	7.4 (1.8)	8.9 (1.0)	7.8 (1.1)	7.4 (1.5)	P<0.001
Chair type	8.1 (1.7)	7.6 (1.5)	6.5 (2.6)	7.8 (1.7)	7.3 (1.5)	5.7 (2.2)	7.9 (1.9)	7.2 (1.4)	6.1 (2.1)	P<0.001
Presence and company of others	5.3 (2.4)	6.9 (2.0)	4.8 (2.8)	4.5 (2.4)	6.5 (2.2)	3.8 (2.3)	5.4 (2.5)	6.3 (1.8)	3.6 (2.2)	P<0.001
Size of the room	6.4 (1.9)	6.4 (1.3)	4.0 (1.8)	6.1 (1.6)	6.2 (1.7)	4.1 (1.8)	6.6 (1.9)	6.0 (1.5)	4.0 (1.8)	P<0.001
Bonding or identifying with the place	6.8 (1.6)	6.5 (1.9)	3.0 (1.8)	6.3 (1.9)	6.3 (2.3)	3.2 (2.2)	6.2 (2.1)	6.3 (1.9)	3.5 (2.0)	P<0.001
Ability to adapt or control the place	7.4 (1.6)	6.4 (1.7)	3.9 (1.6)	7.0 (1.6)	6.6 (1.6)	4.3 (1.9)	7.2 (1.6)	6.3 (1.7)	4.2 (2.0)	P<0.001
Privacy	8.2 (1.4)	6.5 (2.0)	6.5 (2.7)	7.9 (1.3)	5.9 (2.5)	6.2 (2.4)	8.5 (1.6)	6.4 (2.1)	6.4 (2.4)	P<0.001
Importance of IEQ-related aspects - mean (SD)										
Chair seat heating	5.0 (2.8)	3.8 (2.3)	4.0 (3.4)	3.8 (2.7)	4.5 (2.8)	3.3 (2.6)	4.5 (2.6)	3.6 (2.3)	2.8 (2.4)	P<0.001
Chair backrest eating	4.9 (2.8)	4.0 (2.5)	3.9 (3.4)	3.7 (2.8)	4.6 (3.1)	3.1 (2.7)	4.5 (3.1)	3.7 (2.7)	2.8 (2.6)	P<0.001
Heating on my desk	4.4 (2.7)	3.6 (2.5)	3.1 (2.6)	3.8 (2.9)	4.2 (2.8)	2.7 (2.3)	3.9 (2.7)	3.6 (2.3)	2.6 (2.6)	P<0.001
Lamp on my desk	6.9 (2.2)	6.4 (2.2)	6.6 (2.8)	7.1 (2.0)	5.5 (2.1)	5.8 (2.7)	6.9 (2.2)	6.2 (2.0)	6.3 (2.3)	P<0.001
Personal desk ventilation and fresh air	8.1 (1.7)	7.0 (2.4)	7.7 (2.3)	7.3 (1.9)	7.1 (2.3)	7.1 (2.3)	6.4 (2.5)	6.2 (2.0)	6.5 (1.9)	P<0.001
Control of surrounding sounds	8.1 (1.5)	7.3 (1.5)	7.6 (1.8)	6.7 (2.2)	5.4 (1.8)	5.0 (2.2)	6.7 (2.2)	6.6 (1.7)	7.1 (1.8)	P<0.001
Control of shading	8.2 (1.6)	7.4 (1.6)	7.9 (1.9)	7.2 (2.0)	6.2 (2.1)	6.4 (2.4)	7.4 (1.8)	7.2 (1.6)	7.3 (1.7)	P<0.001
Control of room ventilation	8.2 (1.2)	7.6 (1.6)	7.4 (1.9)	7.0 (2.0)	6.1 (1.8)	6.0 (2.1)	7.3 (1.7)	7.0 (1.5)	6.0 (2.2)	P<0.001
Control of room temperature	8.3 (1.1)	7.4 (1.7)	7.3 (1.4)	7.5 (1.7)	6.3 (1.9)	6.7 (1.7)	8.3 (2.0)	6.8 (2.0)	6.7 (1.7)	P<0.001
Headphones	7.4 (2.6)	7.6 (2.3)	7.9 (2.4)	7.5 (2.4)	7.7 (1.3)	6.6 (2.9)	7.2 (2.0)	6.6 (2.2)	6.6 (2.6)	P<0.001
Presence of plants	7.0 (2.3)	5.9 (2.6)	4.8 (2.3)	7.0 (2.0)	5.7 (2.4)	5.5 (2.6)	6.9 (2.5)	5.6 (2.3)	4.0 (2.8)	P<0.001

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TABLE 3.6 Description of the overlap profiles between the two clusters models.

	IEQC1-PSC1	IEQC1-PSC2	IEQC1-PSC3	IEQC2-PSC1	IEQC2-PSC2	IEQC2-PSC3	IEQC3-PSC1	IEQC3-PSC2	IEQC3-PSC3	P-value
Personal control over the most used study place - mean (SD)										-
Temperature	4.6 (1.7)	3.8 (1.9)	4.3 (2.1)	5.3 (1.3)	4.5 (1.8)	4.4 (1.7)	4.7 (1.3)	4.3 (1.9)	4.5 (1.7)	**P<0.001**
Ventilation	5.1 (1.7)	3.9 (2.2)	4.9 (1.9)	5.5 (1.5)	4.6 (1.9)	4.6 (1.9)	5.8 (1.5)	4.4 (1.8)	4.8 (1.8)	**P<0.001**
Shading from the sun	5.2 (2.0)	4.2 (2.1)	4.6 (2.3)	5.1 (2.0)	4.3 (2.2)	4.4 (2.1)	5.4 (1.7)	5.0 (2.0)	4.5 (2.1)	**P<0.001**
Lighting	5.4 (2.0)	4.3 (2.2)	4.8 (2.2)	5.9 (1.4)	4.8 (2.1)	5.0 (1.9)	6.0 (1.0)	5.0 (2.0)	5.0 (2.1)	**P<0.001**
Noise	3.3 (1.6)	2.4 (1.1)	3.0 (1.4)	3.8 (1.8)	3.1 (1.5)	2.9 (1.4)	3.1 (1.4)	2.9 (1.5)	2.8 (1.5)	**P<0.001**

3.3.4.1 Overlap between IEQC1 with Psychosocial Clusters

The overlap between the IEQC1 and the three psychosocial clusters resulted in three profiles: IEQC1-PSC1: the concerned perfectionist; IEQC1-PSC2: the concerned extrovert; and IEQC1-PSC3: the concerned the non-perfectionist.

IEQC1-PSC1: the concerned perfectionist

The concerned perfectionist profile comprises 59 students (14%), of which 29% are male and 71% are female students. These students are the largest group that experienced positive events (37%). In terms of lifestyle, this group has the lowest number of students that consume alcohol (75%). Regarding the IEQ preferences, the concerned perfectionist students rated the highest importance for sounds from the inside (8.2), smells (7.9), sounds from the outside (7.8), and artificial light (7.2). Furthermore, they rated the highest importance (as compared to the other groups) for six IEQ-related items, which are control of room temperature (8.3), control of room ventilation (8.2), control of shading (8.2), control of surrounding sounds (8.1), personal desk ventilation and fresh air (8.1) and presence of plants (7.0). As this profile overlaps with PSC1 who are concerned with all psychosocial preferences (except presence and company of others), it is the most concerned with cleanliness (9.0), amenities (8.9), chair type (8.1), ability to adapt or control the place (7.4), and bonding or identifying with the place (6.8).

IEQC1-PSC2: the concerned extrovert

The concerned extrovert profile consists of 63 students (14%), of which the percentages of male and female students are similar as the concerned perfectionist profile (29% and 71%, respectively). This profile is the second highest group that experienced recently positive events (35%). Regarding health, students within this profile are the second highest group that suffered from anxiety (30%). It can be noted that these students are the group to have the least control over all IEQ factors in their most used study place. Pertaining to IEQ preferences, the concerned extrovert students are concerned about all IEQ aspects, especially daylight (9.0) and view to the outside (8.8). As this profile overlaps with PSC2, it is the profile that is most concerned with the presence and company of others in their study places (6.9), while they rated the lowest importance for storage (5.3).

IEQC1-PSC3: the concerned non-perfectionist

The concerned non-perfectionist profile comprises 35 students (8%), which includes the lowest percentage of male students (17%) and the highest percentage of female students (83%). Nearly half of them (45%) were feeling relaxed when they were completing the questionnaire. It can be noted that this profile rated the highest for negative affect (12.1). With regards to their lifestyle, students within this profile are the highest in terms of alcohol consumption (91%), as well as doing physical activity (94%). In terms of IEQ preferences, the concerned non-perfectionist students rated the highest importance for ventilation and fresh air (9.0), temperature (8.9) and sounds from the inside (8.2). Regarding IEQ-related items, these students rated the highest importance for headphones (7.9). As this profile overlaps with PSC3, which rated the least importance scores for most of the psychosocial preferences, it is the least concerned with bonding or identifying with the place (3.0), ability to adapt or control the place (3.9) and size of the room (4.0).

3.3.4.2 Overlap between IEQC2 with Psychosocial Clusters

The overlap between the IEQC2 and the three psychosocial clusters resulted in three profiles: IEQC2-PSC1: the visual concerned perfectionist; IEQC2-PSC2: the visual concerned extrovert; and IEQC2-PSC3: the visual concerned non-perfectionist.

IEQC2-PSC1: the visual concerned perfectionist

The visual concerned perfectionist profile is the second smallest profile size that comprises 34 students (8%), of which 47% are male students and 53% are female students. It is the profile that least experienced recently positive events (23%), while it rated the highest positive affect (18.3). Most of the students (97%) within this profile spent their studying time at their homes. Pertaining to IEQ perception, these students comprise the profile that is least dissatisfied with air smell (35%). With regards to the IEQ preferences, the visual concerned perfectionist students rated the highest importance for daylight (9.3) and view to the outside (9.1). Regarding the IEQ-related items, these students rated the highest importance for lamp on my desk (7.1), and the presence of plants (7.0). With regards to psychosocial preferences, they rated the highest importance for cleanliness (9.0), amenities (8.9) and storage (8.4). In addition, the visual concerned perfectionist students scored a high importance level for privacy (7.9).

IEQC2-PSC2: the visual concerned extrovert

The visual concerned extrovert profile is the largest profile size consisting of 64 students (15%), of which 41% of them are male students and 59% are female students. They tended to feel relaxed while they were answering the questionnaire (35%). Regarding IEQ perception, the visual concerned extrovert students are the most dissatisfied with air smell (63%) in their most used study places. However, view to the outside (8.9) and daylight (8.8) are the highest important IEQ preference aspects for these students. Pertaining to the IEQ-related items, these students are the least concerned with personal desk ventilation and fresh air (5.5). Furthermore, they rated the lowest importance scores for the IEQ related items control of shading (6.2) and control of room temperature (6.3). On the other hand, they are the second profile that scored a high importance score for headphones (7.7). In terms of psychosocial preferences, this profile is the least concerned with privacy (5.9). However, it is the second highest profile that is concerned with the presence and company of others (6.5).

IEQC2-PSC3: the visual concerned non-perfectionist

The visual concerned non-perfectionist profile comprises 48 students (11%), in which the reported percentages of male and female students (40% and 58%, respectively) are similar to the visual concerned extravert profile. The visual concerned non-perfectionist students are the highest group that suffered from anxiety (31%). With regards to IEQ preferences, they rated the lowest importance for sounds from the outside (4.3), smells (4.3), sounds from the inside (5.0), artificial light (5.5), and temperature (7.6) among the other profiles. However, these students scored high importance levels for the view to the outside (9.2) and daylight (9.0) Furthermore, they rated the lowest importance for two IEQ-related items which are control of room sounds (5.0) and control of room ventilation (6.0). However, personal desk ventilation and fresh air (7.1) is the highest important IEQ-related item for this profile. Pertaining to psychosocial preferences, this profile rated the lowest importance for chair type (5.7). Although the amenities (7.4) aspect was scored the lowest importance level by the visual concerned non-perfectionist students, it was considered the highest important psychosocial aspect.

3.3.4.3 Overlap between IEQC3 with Psychosocial Clusters

The overlap between the IEQC3 and the three psychosocial clusters resulted in three profiles: IEQC3-PSC1: the unconcerned introvert; the unconcerned extrovert; and the unconcerned non-perfectionist.

IEQC3-PSC1: the unconcerned introvert

The unconcerned introvert profile is the smallest profile size that comprises 17 students (4%), of which the percentage of male students (59%) is higher than the percentage of female students (41%). The study places for the majority of these students (94%) were located at their homes. Regarding lifestyle, the unconcerned introvert students are the second lowest group that consumes alcohol (77%), and the profile that takes part in the least physical activities (71%). On the contrary, they are the group that suffered most from depression among the other profiles (29%), as well as one of the profiles that suffered most from anxiety (29%). Pertaining to the IEQ perception, this profile reported the least dissatisfaction percentage with the air smell of their study places (35%). In terms of the IEQ-related items, this profile is the most concerned with control of temperature (8.3). In contrast, the unconcerned introvert students are the second profile that is not concerned with personal desk ventilation and fresh air (6.4). However, they do have the highest control over lighting (6.0), ventilation (5.8), and shading from the sun (5.4) in their study places. With regards to the psychosocial preferences, of the four aspects, these students rated these aspects as the highest importance: cleanliness (9.0), amenities (8.9), privacy (8.5), and size of the room (6.6).

IEQC3-PSC2: the unconcerned extrovert

The unconcerned extrovert profile is considered as a large profile size that consists of 59 students (14%), of which the female students' percentage (58%) is higher than the male students' percentage (41%). These students recorded the highest percentage of feeling neutral while they were completing the questionnaire (28%). They are the second lowest profile to experience recently positive events (24%). Furthermore, they rated the lowest positive affect (16.9). It can be noted that this profile has the least students that suffered from both depression (15%) and anxiety (19%). In terms of IEQ preferences, the unconcerned extrovert students are the least concerned with artificial light in their study places (5.5). Nonetheless, temperature (7.9) is the most important IEQ preference. With regards to IEQ perception, the unconcerned extrovert students reported the least dissatisfaction percentage with air freshness (50%). Pertaining to the IEQ-related items, these students rated both personal ventilation and fresh air the least important (6.2) and headphones (6.6). Nevertheless, control of shading (7.2) and control of room ventilation (7.0) are the most important items for them. Regarding the psychosocial preferences, this profile rated of lowest importance cleanliness (6.8) in their study places. However, the unconcerned extrovert profile is one of the profiles that rated the highest importance for the presence and company of others (6.3).

IEQC3-PSC3: the unconcerned non-perfectionist

The unconcerned non-perfectionist profile has the same profile size as the unconcerned extrovert profile, with 59 students (14%), of which the percentage of male students (54%) is higher than the percentage of female students (46%). Students within this profile rated the lowest negative affect score among other profiles (10.9). Regarding health, this profile is the second highest group that suffered from depression (29%). Pertaining to IEQ perception, this profile that is dissatisfied the most with air freshness (75%). In terms of IEQ preferences, the unconcerned non-perfectionist students are the least concerned with artificial light (5.5), view to the outside (6.4), daylight (6.6), and ventilation and fresh air (7.1). On the other hand, they are only concerned about temperature (8.1). With regards to IEQ-related items, they rated the least importance for the presence of plants (4.0), control of room ventilation (6.0) and headphones (6.6). Nonetheless, they are concerned about the control of shading (7.3) and surrounding sounds (7.0). Regarding the psychosocial preferences, this profile of students is the least concerned with the presence and company of others (3.6) and the size of the room (4.0). While amenities (7.4) and cleanliness (6.8) are the most important for these students, they are rated the least important among other profiles.

3.4 Discussion on ‘MyStudyPlace’ questionnaire’s findings

3.4.1 Comparison with Previous Studies

The majority of students (74%) within this study spent most of their studying time at their homes. A previous study indicated that a home can be considered as an off-campus informal study place, and that most students studied at home as well before the COVID-19 outbreak [33].

Students in this study were generally concerned with three IEQ preferences: daylight, view of the outside, and temperature in their study places. Furthermore, they rated high importance levels for two psychosocial aspects: amenities and cleanliness. Previous studies found similar findings with regards to these preferences. For example, temperature [34] and daylight [3,25] (which is also known as natural lighting) were found to be important criteria by university students in informal study places. Due to the development of the information and communication technologies (ICT), amenities including PCs and laptops were considered important aspects by students in informal study places [3]. In addition, the presence of windows, which also refers to the view to the outside, was also preferred by university students for their study places at the library [35]. Cleanliness has also been affirmed to be an important aspect for students in informal study places such as university libraries [36] and university campus facilities [37]. While students in the current study rated a high importance score for the view to the outside, university students in another study rated a low importance score for the window view in the university library [36]. Yet, in another two studies [38,39], university students tended to choose their study places in the campus library that is close to the window. The latter outcome is similar to the findings of the current study: students generally preferred to have a view to the outside in their study places, whether at home or on campus. A previous study concluded that window views of the natural environment outside (e.g., green spaces) have a positive psychological impact on university students in terms of recovery from attentional fatigue [40]. During COVID-19 lockdown, the poor view to the outside negatively affected the mental health of university students while they were staying at home [41]. Hence, these preferences have a significant role in fulfilling students’ preferences, as well as promoting their health.

In a study conducted by Zhang et al. [12], six profiles of primary school children based on their IEQ preferences and needs in classrooms were determined. While the most important three environmental aspects for these children were “hearing the teacher”, “fresh air”, and “air temperature”, university students from the faculty of architecture were mainly concerned with visual aspects including “daylight” and “view to the outside”. In both studies, one IEQ profile was concerned with light or visual aspects, although the primary school children were mainly concerned with artificial light and the university students with natural light. Furthermore, in both studies, one profile was concerned with all IEQ aspects, and one profile was not concerned with any of the IEQ-aspects. The difference can be seen in the additional profiles concerned with sound, thermal and air quality aspects. These differences could be associated with the population. In other words, the respondents in this study were all bachelor students of the faculty of Architecture studying to become an architect, a profession in which visual aspects are important. On the contrary, primary school children comprise pupils that are yet to choose their profession or field of study.

3.4.2 Students’ Profiles Based on the Overlap between the Two Cluster Models

While previous studies on office workers [26] and outpatient staff [27] conducted the cluster analysis separately based on IEQ preferences/perception and psychosocial preferences, the present study explored the overlap among the IEQ preferences and psychosocial preferences clusters. This resulted in several advantages. For instance, the number of variables that were significantly different among the profiles was higher than in the separated cluster models. In this study, health (e.g., depression) was not significantly different among both cluster models (IEQ and psychosocial preferences). However, this variable was found to be significantly different among the nine profiles resulting from the overlap. According to the study of office workers [26], the health variables such as anxiety were only significantly different among the IEQ clusters, while not found to be significantly different among the psychosocial preferences clusters. Similarly, in the study on outpatient staff [27], some variables only varied significantly among the IEQ clusters (e.g., preference for control of temperature), while it was not significantly different among the psychosocial clusters. Therefore, the overlap facilitates a more detailed understanding of the distinct characteristics among the profiles. IEQ, as well as psychosocial preferences, is also important to support comfort; combined profiles contribute to more realistic insights.

Students that had similar IEQ preferences within IEQC1, who were mainly concerned with all IEQ aspects, showed differences in various psychosocial aspects. The results showed that concerned perfectionist students were concerned with all IEQ preferences (specifically sounds and smells), as well as all the psychosocial preferences, except the presence and company of others. On the contrary, the concerned extroverts rated similar importance scores for IEQ preferences as the concerned perfectionists, but they were the most concerned cluster in terms of the presence and company of others in their study places. Additionally, the concerned extrovert students belonged to the profile that had the least personal control over IEQ aspects in their most used study places. Furthermore, both the concerned perfectionists and the concerned extroverts experienced the most recent positive events. In contrast, the concerned non-perfectionist students who were concerned with all IEQ aspects (specifically ventilation and fresh air) scored the highest negative affect compared to the other clusters. In addition, this profile scored the least importance for bonding or identifying with the place, ability to adapt or control the place, and size of the room. However, this profile rated the highest importance score for headphones as a significant IEQ-related item that helps them to study better.

Students within cluster IEQC2 that were generally concerned with daylight scored different in their psychosocial preferences. The overlap between IEQC2 and the three psychosocial preference clusters showed a significant difference in several characteristics. Visual concerned perfectionist students were the most concerned with daylight and the view to the outside. However, the students in this profile experienced the least positive events, while they scored the highest positive affect. Additionally, they were more concerned with lamp on their desks to study better than the visual concerned-extrovert students, who were the least concerned with privacy in their study places. While the visual concerned perfectionists were the most concerned with amenities, the visual concerned non-perfectionists were the least concerned with amenities. In terms of health, the visual concerned non-perfectionists suffered the most from anxiety.

IEQC3 students were the least concerned with both artificial light as well as ventilation and fresh air. They showed different characteristics in the overlap between IEQC3 and the three psychosocial preferences profiles. While both the unconcerned extroverts and unconcerned non-perfectionists suffered the most from depression, the unconcerned extroverts suffered the least from depression. In addition, the unconcerned extroverts suffered the least from anxiety. It is interesting to note that all three profiles were the least concerned with having personal desk ventilation and fresh air in their study places. However, only the unconcerned non-perfectionists reported the highest dissatisfaction with air freshness in their most used study places, while both the unconcerned introverts and the unconcerned extroverts reported the least dissatisfaction with air freshness. Additionally, the unconcerned introverts were the least dissatisfied with the smell in their most used study places. While the unconcerned introverts rated the highest importance score for control of room temperature, both the unconcerned extroverts and the unconcerned non-perfectionists rated low scores for this IEQ-related item. Additionally, the unconcerned introverts had the highest control level over IEQ aspects in their study places (specifically, ventilation, shading from the sun, and lighting). Furthermore, while the unconcerned introverts rated the highest importance for cleanliness, both the unconcerned extroverts and the unconcerned non-perfectionists were the least concerned with cleanliness. Furthermore, although the unconcerned introverts were the most concerned with privacy in their study places, both the unconcerned extroverts and the unconcerned non-perfectionists were not very concerned with privacy.

3.4.3 Differences in Preferences of Profiles in Relation to Design Implementations

In general, there were significant differences among the profiles in terms of IEQ and psychosocial preferences, which means that generalizing the preferences of the whole study sample is not appropriate. For example, while privacy was indicated as highly preferred by students in their study places [34], this study reveals that there are two opposite profiles in terms of the importance of privacy in the study places: one of them (the unconcerned introvert) was highly concerned with privacy, while the other one (the visual concerned extrovert) rated privacy in their study places as less important. This result is similar to the findings of a previous study [23] in which the outcome showed that students' characteristics (birthplace and current educational level) have an influence on students' preferences, such as privacy and interaction.

While all the nine profiles were found to be statistically different in all IEQ preference aspects, their mean importance scores were higher than the mid-scale point (5.0). Nonetheless, there were profiles for which their mean importance scores for sounds from the outside (visual concerned extroverts and visual concerned non-perfectionists), sounds from the inside (visual concerned perfectionists), and smells (visual concerned non-perfectionists) were less than the mid-point scale (5.0). This means that there are profiles of students which are not highly concerned about sounds in their study places. The current study found that three profiles are not concerned about the sounds (from the outside or the inside) at their study places. This is in line with another study, conducted by Cunningham and Walton [20], which indicated that the preferences of university students to study in a quiet environment (e.g., university library) vary. In contrast, Beckers et al. [2] found that most university students prefer studying in quiet learning spaces.

The overlap among the IEQ and psychosocial models contributed to understanding in-depth students' profiles based on their different preferences in their study places. Different approaches can be applied to fulfil the different preferences of each profile. For instance, soundscape approach considers the individual's sound preferences in a certain environment. According to ISO 12913-1 [42], the soundscape is defined as: "acoustic environment as perceived or experienced and/or understood by a person or people in a context". This approach can understand the sound preference of each profile at study places. Additionally, the soundscape is mainly focused on using the sound as a resource that fulfils the sound preference rather than focusing on quiet spaces [43]. For instance, Shu and Ma [9] concluded that natural sound sources, such as birdsongs and stream sounds, had restorative effects on classroom children after performing a cognitive task, while the quiet condition did not show an effect. In addition, a study conducted by Topak and Yılmazer [44] found that students' sound preferences differ based on the context of the space, classroom or computer laboratory. They also found that natural sounds (e.g., birdsongs) were preferred by students to hear in their learning environments. Moreover, Xiao and Aletta [45] concluded that the soundscape approach could facilitate architects and interior designers to understand the students' experiences to provide high-quality sound environments or study places, such as libraries, by identifying different types of users. Accordingly, soundscape can be accounted for during the design process to understand the sound preferences of each profile of students at their study places. Another approach that can be applied to fulfil the different preferences is the application of customized (i.e., personalized) designs. These applications can match the preferences of each profile and could provide comfort for them, such as customized and personalized shading [46], ceiling fans [47], and heating [48], which allow users to have control over the surrounding environment based on their preferences.

3.4.4 Limitations

The sample of this study is limited to bachelor university students (specifically of the faculty of Architecture and the Built environment), whose mean age was 20 years old. The questionnaire was also completed at the time of the COVID-19 outbreak, which may have influenced students' preferences during this situation. It was sent to students during the fall and spring (October and March) seasons in the Netherlands, which could have had an impact on students' responses such as whether they scored high importance for both daylight and temperature. Furthermore, the IEQ and psychosocial preferences were asked within the context of studying at study places in general, while the learning activities/styles (e.g., individual, collaborative) were not investigated in the present study. The nine profiles in this study were identified based on the preferences (IEQ and psychosocial preferences) of bachelor students at the faculty of Architecture and the Built Environment in the Netherlands. Hence, further studies could validate these nine profiles with students from other faculties, as well as other universities with a different cultural background. As this study is based on a survey (questionnaire) with 451 students who were studying either at their homes or in educational buildings, space geometry and physical measurements of IEQ factors were not included in this study.

3.5 Conclusions

In conclusion, students with similar IEQ preferences have different psychosocial preferences, and vice versa. This was affirmed by determining nine profiles of university students based on the overlap between the IEQ and psychosocial preferences. These profiles showed significant differences among them in terms of various variables, including perception, lifestyle, health, and gender. It is worthwhile to note that the number of variables that were significantly different between the profiles is higher within the overlap between the IEQ and psychosocial preferences than clustering the students based on these preferences separately. The outcome of this study provides insight into different profiles of university students, each with their own preferences of study places. For instance, the concerned perfectionists are highly concerned with sounds (from the outside and inside) of their study places, while the visual concerned non-perfectionists are not highly concerned with sounds. These findings show the need for designing study places for more than one profile and not just for the "average" student.

The novelty of this study lies in the overlap of the IEQ and psychosocial preferences models that resulted in nine profiles, which showed significant differences among a number of variables. Therefore, it is recommended for future studies to determine the profiles of occupants (e.g., students, office workers, home occupants) within different scenarios (e.g., classrooms, study places, offices, homes) by the analysis of the overlap between the two sets of clusters.

Since this study is based on a survey in which physical measurements were not considered, it is suggested for future research to investigate these study places in-depth. For instance, field studies such as exploring the soundscapes of these study places can be investigated by measuring the sound pressure level (SPL), identifying sound sources as well as space geometry, and conducting in-depth interviews with the students from different profiles.

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4 Profiles of University Students Based on their Acoustical and Psychosocial Preferences

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ABSTRACT

Understanding students' preferences of their study place, in particular acoustical and psychosocial preferences, is important to students' health and comfort. This study aimed to identify clusters of students with similar acoustical and psychosocial preferences, and to identify reasons for certain preferences of students in each cluster. A mixed-methods approach was applied, consisting of a questionnaire, which was completed by 451 bachelor students, and a field study conducted with 23 students from the same sample. The questionnaire data included among others acoustical and psychosocial preferences scores, while the field study data comprised interview transcripts, building checklists, and sound pressure level measurements. The questionnaire data were analysed using TwoStep cluster analysis to identify clusters of students based on their acoustical and psychosocial preferences. This produced five clusters of students that significantly differed in 14 variables, including preferences and perception of indoor environmental quality (e.g., noise from outside). Then, the field study data were analysed and categorised based on the five clusters of the students. The outcome explained the aspects associated with the acoustical preferences of students in each cluster. Building-related indicators such as the location of the building were found as an aspect that could affect the student's acoustical preferences. This study provides insight into the profiles of students based on their acoustical and psychosocial preferences, which are important for their health and comfort at their study places.

KEYWORDS Acoustical preferences; TwoStep cluster analysis; study places; mixed methods; university students.

4.1 Introduction

Research has shown that university students spend their studying time (except lectures) at study places (i.e., informal study places), such as places at home or in educational buildings [1–3]. University students mainly perform highly cognitive tasks at these places, such as reading, writing, and problem-solving activities [4]. However, staying indoors for a long time is not beneficial to our health. This is because people are exposed to different environmental stressors while staying indoors. These stressors are related to indoor environmental quality (IEQ) factors, including indoor air quality, thermal quality, visual quality, and acoustical quality, which play an important role in occupants' health, comfort, and performance [5–7]. In several previous studies, the indoor environment of students' homes was found to be linked to their well-being [8–10]. Acoustical quality is one of the IEQ factors that can affect students' well-being and performance while studying or learning [11–17]. For example, students' heart rate and skin conductance levels decreased after being exposed to natural sounds (e.g., fountains and birds) in a study by Alvarsson et al. [18], indicating a calming effect.

Beckers et al. [1] found that university students tend to conduct individual learning activities at home because of their ability to control the environment. During the COVID-19 pandemic, two studies showed that university students tend to spend most of their time inside their homes during the weekdays (around 18 and 20 h), even more than before the pandemic (14 and 16 h) [8,9]. Also, in another study was found that most university students (74%) spend their study time at their homes, in 2021 and 2022 [19]. Moreover, the indoor physical environment of home study places was linked to students' stress during the pandemic [10]. Hence, well-designed study places that align with students' preferences and needs are significant for promoting health, comfort, and performance [20].

Students differed in their preferences and needs (IEQ and psychosocial) of their study places [19–22]. In another study, Cunningham and Walton [4] found that almost half of university students (52%) preferred to study at the university library because of the need for quiet study places. Similarly, Roetzel et al. [22] found that the acoustical quality is one of the most important IEQ-factor that students consider when selecting their study place at a university campus. Previous studies shed light on the adverse effects of background noise on students' health, comfort, and performance [23–25]. Also, students' acoustical perception is not only dependent on dose-related indicators, such as sound pressure level, but also on students' preferences, activities, and the context of the space [20–22]. Moreover, psychosocial preferences, such as privacy and the presence of others, may differ among students [19, 26]. Harrop and Turpin [27] found a relation between students' preference for privacy and the preference for a quiet space at informal learning spaces. According to these studies, it seems that students' acoustical preferences have a relation with the psychosocial preferences, such as privacy. Nonetheless, there is a lack of knowledge of the interpersonal differences in acoustical preferences of occupants in indoor environments [28]. To better understand differences in acoustical and psycho-social preferences between individual university students, Hamida et al. [19] determined nine profiles based on the overlap between IEQ and the psychosocial preferences of study places. These profiles showed that students who have similar IEQ preferences can differ in their psychosocial preferences, and vice versa. Thus, it is important to consider both acoustical and psychosocial preferences while investigating the different clusters of students based on their preferences of study places.

To account for the individuals' differences in preferences and needs for IEQ, previous studies conducted TwoStep cluster analysis at different building contexts [19,21,29–33]. Ortiz and Bluyssen [29] revealed five clusters of home occupants based on their emotions, comfort, and locus of control at their homes. Bluyssen et al. [33] also found three clusters of university students based on their IEQ perception of their homes. Within the context of workplaces, the cluster analysis results from the study by Kim and Bluyssen [32] showed three clusters of office workers based on their IEQ comfort and self-reported health. Also, Ortiz and Bluyssen [30] found four clusters of office workers based on their IEQ preferences, and six clusters based on their psychosocial preferences during COVID-19. Furthermore, Eijkelenboom and Bluyssen [31] clustered the outpatient staff based on their IEQ comfort and preferences as well as psychosocial preferences and satisfaction at hospitals. They found six clusters based on the IEQ comfort and preferences, and three clusters based on the preferences and satisfaction of psychosocial aspects. Concerning the context of study places and learning environments, Zhang et al. [21] identified six clusters of primary school children based on their IEQ preferences in classrooms. The results from the study by Hamida et al. [19] revealed nine profiles of university students based on the overlap between IEQ and psychosocial preferences of study places. Hence, TwoStep cluster analysis shows its potential in identifying clusters of occupants based on their preferences and needs for the indoor environment. However, it does not allow for understanding the reasons behind the preferences of students in each cluster.

Ortiz and Bluyssen [29] applied a mixed-methods study design to facilitate the understanding of clusters with mixed data sources, including interview transcriptions and physical environment characteristics. Also, Hamida et al. [34] indicated that exploring the three levels of indicators (occupant-related (e.g., preferences), dose-related (e. g., sound pressure level), and building-related (e.g., absorption materials)) helps to better understand students' acoustical preferences and needs in an indoor learning environment. Therefore, this study answers the following two questions: 1) can university students be clustered based on their acoustical and psychosocial preferences of their home study places? and 2) can interviews with selected students from each cluster, building inspections of their home study places, and sound level measurements help to verify their acoustical preferences and their related aspects? It aims to explore the acoustical and psychosocial preferences of university students within different clusters based on the three levels of indicators.

4.2 Mixed-methods

4.2.1 Study design

A mixed-methods approach, as shown in **Figure 4.1**, comprising of two parts, was applied in this study: 1) a questionnaire to identify the clusters of students, and 2) a follow-up field study to profile these clusters based on the building-related, dose-related, and occupant-related aspects that relate to their preferences. According to Creswell [35], the mixed-methods study design facilitates the researcher by explaining the quantitative results supported by qualitative findings. Hence, an explanatory sequential research design was adopted in which quantitative data from the questionnaire were collected and analysed first, followed by a field study in which mixed data (qualitative and quantitative) were collected and analysed. This was done sequentially to explain the outcomes from the questionnaire data with the results from the field study data.

FIG. 4.1 Explanatory research design using a mixed-methods approach.

4.2.2 Questionnaire

The questionnaire data analysis aims at clustering the university students based on the acoustical and psychosocial preferences of their study places. As described in the previous study [19], bachelor students (n = 451) of the Faculty of Architecture and the Built Environment at Delft University of Technology completed the 'MyStudyPlace' questionnaire. The mean age of these students was 19.8 years (standard deviation (SD): 1.6 years), with 61% female and 39% male.

4.2.2.1 Questionnaire design

The 'MyStudyPlace' questionnaire (**Appendix C**) is about exploring the university students' preferences of their study places. It consists of seven sections, including the preferences section, which is divided into the IEQ preferences (e.g., artificial light), the psychosocial preferences (e.g., bonding or identifying with the place), and the importance of IEQ- related aspects (e.g., control of shading). These sections help to explain the characteristics of each cluster. For the present study, the acoustical and psychosocial preferences that belong to that section were used, focused on the acoustical-related preferences, such as sounds from outside, and psychosocial preferences, such as privacy. These preference questions were stated as: 'Please rate on a scale from 1 to 10 (1: Not important at all; 10: Extremely important), the importance of each of the following aspects for your study performance at your study place – (e.g., Sounds from outside)'.

4.2.2.2 Data management and analysis

The questionnaire data were exported to SPSS version 26.0 software (SPSS Inc, Chicago, IL, USA). TwoStep cluster analysis, which is a segmentation method [36], was performed to cluster the students based on their acoustical and psychosocial preferences of their study places. This study included five variables as input which are preferences for sounds from outside, sounds from inside, presence and company of others, ability to control or adapt to the place, and privacy. After generation of the clusters, four validation steps were performed (according to Refs. [19,37]). Once the cluster model was validated, descriptive analysis was conducted to calculate the frequencies, percentages, and SD for different variables of each cluster. Also, the normality of distribution of these variables among the whole sample was tested. Then, Chi-square and ANOVA tests (for nominal and continuous variables, respectively) were applied to test whether these variables differ significantly differences between the clusters (the p-value had to be less than 0.05 for a significant difference). Besides, Phi coefficient was calculated to measure the effect sizes of the variables that were found significantly different among the clusters.

4.2.3 Field study

In the field study, three types of data, i.e., building-related, dose- related, and occupant-related, were collected and analysed.

4.2.3.1 Participants

In the 'MyStudyplace' questionnaire, the student was asked whether he/she was willing to participate in the field study. 95 (21.1%) students answered yes. They were contacted by email to invite them to participate in the follow-up study. 23 (5.1%) students accepted to participate in the field study. The mean age of these students was 21 years (SD: 1.5 years), with 15 students (65%) were female and 8 (35%) were male. Since the majority of students who completed the questionnaire (74%) spent most of their study time at home [19], the field study was conducted at students' home study places. The study took place between November 2022 and February 2023.

4.2.3.2 Study design

The field study consisted of three parts: 1) a semi-structured interview with the student, 2) sound pressure level measurements at their home study place, and 3) an inspection of their home using a checklist.

To validate the preferences of the previously completed questionnaire, before the interview, the students were asked to answer a short questionnaire on eight preferences, identical to the question on preferences in the previously completed questionnaire (as explained in 2.2.1: ventilation, daylight, view to the outside, sounds from outside, sounds from inside, presence, and company of others, ability to adapt or control the place, and privacy).

The interview was done in English. An offline audio recorder (TASCAM DR-05X) was used to record the interview with the consent of the student. Each interview included the following questions:

1. How long have you used this study place?
2. Why did you choose this place as a study place?
3. According to the ‘MyStudyPlace’ questionnaire and the short questionnaire you completed before the follow-up study, you scored a ‘*lower/ higher*’ importance level for sounds from outside, and a ‘*lower/ higher*’ importance level for sounds from inside.
   - Why do you think sounds from outside ‘are/*became*’ ‘*important/ not important’*?
   - Why do you think sounds from inside ‘are/*became*’ ‘*important/ not important’*?
4. How should the optimal sound environment for your study place look like?
5. Which sound(s) do you prefer during your study-related activities at your study place?

The third question in the interview was personalized for each student based on their answers in both the ‘*MyStudyPlace*’ questionnaire and the short questionnaire before the interview. For example, if the student scored a high importance level for sounds from outside in both questionnaires, the researcher (interviewer) asked the student (interviewee): “*Why do you think sounds from outside are important?*”. On the other hand, if the importance of sounds from inside was scored lower than the answer in the previous questionnaire and was lower than 5, the question was stated as: “*Why do you think sounds from inside became unimportant*”?

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The sound pressure level (SPL) is one of the dose-related indicators that may have an association with student’s health and comfort in educational buildings [34,38]. Therefore, the SPL was measured at each home study place twice for 1 min with six intervals (10 s) using a sound level meter (Norsonic Nor 140). The sound level meter was placed on top of the study place desk (at a height of 120 cm, the height of a seated person’s head).

A building checklist was used to investigate the building-related indicators of the home study places that can affect the acoustical quality [39]. The checklist comprised 15 sections, such as the presence of acoustical insulation materials, windows, and the presence of mechanical ventilation (**Appendix G**).

4.2.3.3 Procedure

Each of the 23 students received an individual invitation email that indicated the day and time of the interview. Additionally, the invitation included a consent form for the study at their home study place, the short questionnaire, and the interview questions. Students were asked to send both the signed consent form and the answers to the short questionnaire back to the researcher one day before the field study.

Each home visit took 30–60 min, starting with an interview with the student (15–30 min), followed by an inspection using the checklist (5–10 min), and finally, the SPL measurements (2–3 min).

4.2.3.4 Data management and analysis

Each of the audio recording files was transcribed into a verbatim transcription and anonymized by eliminating any personal data such as the student's name (if it was included). Then these transcriptions were initially and deductively coded (open coding) using ATLAS.ti 23 software. After that, the initial codes of each question were exported into a matrix that was created in an Excel file. This matrix consists of four columns that represent the four questions of the interview, and five rows (for each cluster) that represent the clusters' initial codes for each question. Then, focused coding (i.e., aspects) for each of the initial codes was done by abstracting the initial code and assigning a positive (+), negative ( ), or neutral (/) meaning to each code, based on the student's answer. An example of the qualitative data analysis starting from initial coding to focused coding is presented in **Figure 4.2**. Finally, a data structure was developed that includes columns representing the five clusters and rows that comprise the aspects (i.e. focused codes) related to the importance of sounds from outside and inside. The SD and mean value of each SPL measurement were calculated for each home study place. Then the mean of the two measurements was calculated. After that, the median, maximum, and minimum of the SPL were calculated of each cluster. With regards to the building checklist, frequencies of several items were recorded of each cluster, such as the building type and building location. Besides, the minimum and maximum of different items were calculated, such as the study place height and gross area.

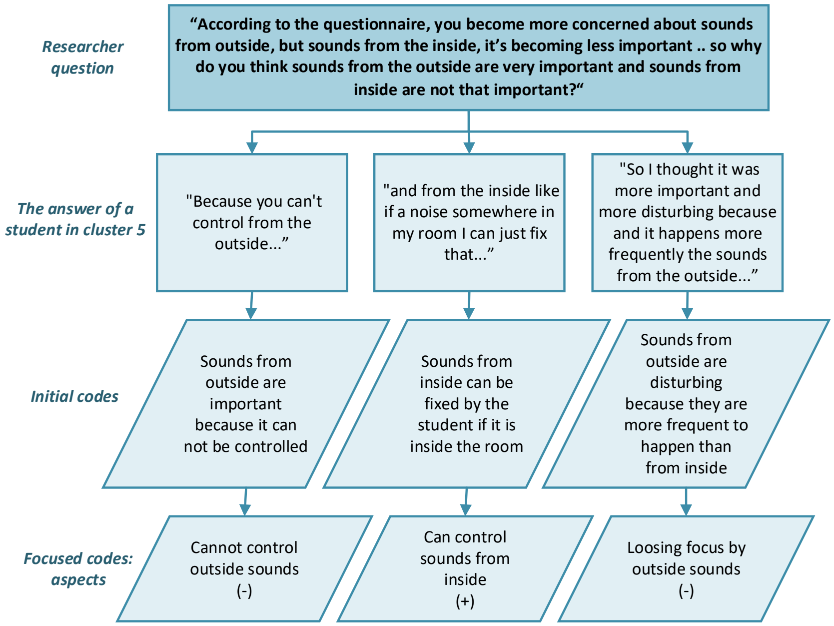

FIG. 4.2 An example of open coding of the answer to the preference question.

4.2.4 Ethical aspects

This study was approved by the Human Ethics Committee (HREC) of the Delft University of Technology on the 31st of January 2022.

4.3 Results of the mixed-methods

4.3.1 Questionnaire

TwoStep cluster analysis produced five clusters of students based on their acoustical and psychosocial preferences, as illustrated in **Figure 4.3**. Each cluster has a name that consist of two parts, which represents the acoustical and psychosocial preferences, respectively. The Silhouette measure was 0.3 and the validation results of the cluster model are presented in **Table 4.1**. Each of these clusters has its unique preferences and characteristics as shown in **Table 4.2**. These five clusters showed statistically significant differences and high effect sizes for 14 variables, including study place ($p<0.001$), sounds from outside ($p<0.001$), sounds from inside ($p<0.001$), presence, and company of others ($p<0.001$), ability to adapt or control the place ($p<0.001$), privacy ($p<0.001$), and noise from outside dissatisfaction ($p=0.017$). Other variables related to IEQ preferences, such as artificial light and smells showed also significantly differences. It was found that these variables were not normally distributed for the whole sample ($p<0.001$). Although students of the five clusters differed in their acoustical preferences, all of them scored higher importance scores for sounds from inside than sounds from outside. Cluster 1 is the cluster most concerned with sounds from outside, sounds from inside, privacy and ability to adapt or control the place. Cluster 2 is the least concerned with sounds from outside, sounds from inside, and presence and company of others.

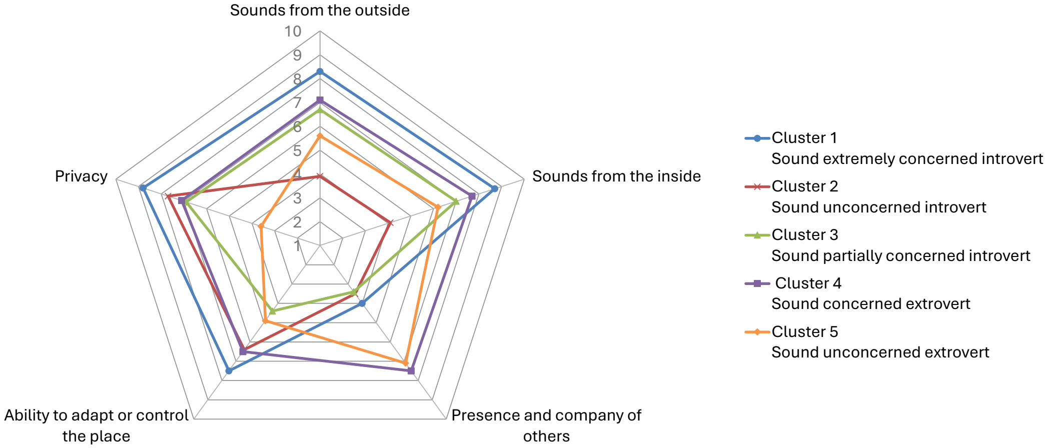

FIG. 4.3 Acoustical and psychosocial preferences of the five clusters of students.

TABLE 4.1 Predictor importance of the input variables for cluster model validation.

Predictor importance	Final solution	First half solution	Second half solution
0.60 – 1.00	Privacy (1.00) Presence and company of others (0.95) Sounds from inside (0.69) Sounds from outside (0.68)	Privacy (1.00) Sounds from outside (0.84) Sounds from inside (0.70) Presence and company of others (0.67) Ability to adapt or control the place (0.61)	Sounds from inside (1.00) Presence and company of others (0.94) Privacy (0.76) Sounds from outside (0.69)
0.30 – 0.59	Ability to adapt or control the place (0.35)	-	Ability to adapt or control the place (0.56)

TABLE 4.2 Profiles of the five clusters of students.

	Cluster 1: Sound extremely concerned introvert	Cluster 2: Sound un-concerned introvert	Cluster 3: Sound partially concerned introvert	Cluster 4: Sound concerned extrovert	Cluster 5: Sound un-concerned extrovert	p-value	Phi
Number (%)	70 (15.9)	78 (17.7)	87 (19.8)	116 (26.4)	89 (20.2)	-	-
Age mean (SD)	19.9 (1.3)	19.7 (1.1)	19.7 (1.6)	19.6 (1.5)	20.0 (2.1)	0.091	0.375
Gender N (%)						0.480	0.089
Female	44 (62.9)	42 (54.5)	50 (57.5)	76 (66.1)	57 (64.0)	-	-
Male	26 (37.1)	35 (45.5)	37 (42.5)	39 (33.9)	32 (36.0)	-	-
Study place N (%)						**P<0.001**	0.462
Home	65 (92.9)	72 (92.3)	76 (87.4)	77 (66.4)	35 (39.3)	-	-
Educational building	5 (7.1)	6 (7.7)	11 (12.6)	38 (32.8)	53 (59.6)	-	-
IEQ preferences 1: completely not important; 10: extremely important- mean (SD)							
Sounds from outside*	8.3 (1.4)	3.9 (1.9)	6.7 (1.3)	7.1 (1.4)	5.6 (2.1)	**P<0.001**	0.850
Sounds from inside*	8.7 (1.1)	4.1 (2.2)	7.0 (1.3)	7.7 (1.3)	6.2 (2.1)	**P<0.001**	0.819
Smells	7.3 (2.1)	5.0 (2.3)	6.1 (2.1)	6.7 (1.8)	5.6 (2.2)	**P<0.001**	0.448
Artificial light	6.9 (2.1)	6.0 (2.1)	6.0 (2.0)	6.5 (1.5)	5.7 (2.0)	**0.003**	0.381
Psychosocial preferences 1: not important; 10: extremely important – mean (SD)							
Presence and company of others*	4.0 (1.9)	3.5 (2.0)	3.4 (1.6)	7.5 (1.3)	7.1 (1.9)	**P<0.001**	0.829
Bonding or identifying with the place	6.2 (2.3)	5.1 (2.8)	4.5 (2.2)	5.9 (2.2)	5.2 (2.5)	**P<0.001**	0.466
Ability to adapt or control the place*	7.5 (1.5)	6.4 (2.2)	4.4 (1.8)	6.5 (1.5)	4.9 (2.1)	**P<0.001**	0.589
Privacy*	8.8 (1.2)	7.7 (2.0)	6.9 (1.5)	7.1 (1.3)	3.6 (1.4)	**P<0.001**	0.944
Importance of IEQ-related aspects 1: completely not important; 10: extremely important – mean (SD)							
Control of surrounding sounds	8.2 (1.4)	5.6 (2.5)	6.8 (1.7)	7.2 (1.5)	5.8 (2.1)	**P<0.001**	0.564
Control of shading	8.3 (1.5)	6.1 (2.5)	7.3 (1.6)	7.4 (1.5)	6.8 (1.9)	**P<0.001**	0.501
Control of room ven-tilation	8.0 (1.5)	6.2 (2.1)	6.9 (1.8)	7.0 (1.8)	6.5 (2.1)	**P<0.001**	0.411
Control of room tem-perature	8.2 (1.3)	6.9 (1.8)	6.8 (1.5)	7.5 (1.7)	6.3 (2.2)	**P<0.001**	0.427
IEQ Sound perception of study place in past 3 months - n (%within cluster level)							
Noise from outside dissatisfaction	28 (40.0)	19 (25.0)	21 (24.7)	28 (25.0)	14 (15.9)	**0.017**	0.167

*Note: *Input variable*

4.3.2 Field study

The field study was conducted with 23 students, of which four students from Cluster 1, two students from Cluster 2, eight students from Cluster 3, five students from Cluster 4, and four students from Cluster 5. The data comprised of transcriptions of the interviews, sound pressure level measurements, and the building checklist data.

4.3.2.1 Occupant-related indicators

The outcome of the interviews with the students represents the aspects associated with the importance of sounds from outside and inside, as well as the selection of the home study place's location. Tables 2 and 3 show the aspects (focused codes) assigned to the related customised interview questions.

In **Table 4.3** 'too many outside sounds' was sorted under the section 'sounds from outside are important', because it was related to the question: why do you think sounds from outside are important? Each aspect was than given a different level in terms of a neutral (/) or positive (+) or negative (-) meaning based on student's answer. Because each open question was customised based on the student's answer of each preference, there are questions that were not asked. For instance, both preferences 'sounds from outside are not important' and 'sounds from the inside are not important' were not asked to students in Cluster 1. Therefore, it is highlighted in Table 2 that these questions did not apply to that cluster, which are represented in cells with diagonal down lines.

It can be noted that 'Loud outside sounds', 'Outside sounds are annoying', and 'Losing focus by outside sounds' were most frequent explanations for high concerns about sounds from outside by Clusters 1, 3, and 4. 'People from the inside sounds' was the most frequent explanation for high concerns about sounds from inside by Clusters 1, 3, 4, and 5. 'Outside sounds are not distracting' was a neutral aspect by one student in Cluster 2 and two students in Cluster 5. This explains the low concerns of sounds from outside by these two clusters. Music and natural sounds were the most preferable (positive) sounds and considered to provide an optimal sound environment. While music is indicated as positive by 15 students among the five clusters, three students indicated it as distracting, and thus negative. Similarly, silence was indicated as a positive sound environment by six students among Clusters 1, 3, 4, and 5, while it was indicated as negative by a student in Cluster 2. It can be observed that music, silence, and people sounds were indicated positive by some students and negative by other students.

TABLE 4.3 Data structure acquired from interview analysis comprises the aspects related to acoustical preferences for each cluster.

Preferences	Aspects	Frequencies	Cluster 1 N=4	Cluster 2 N=2	Cluster 3 N=8	Cluster 4 N=5	Cluster 5 N=4
Sounds from outside are important	Too many outside sounds	4	- (1)	N/A	- (2)		- (1)
	Loud outside sounds	10	- (1)	N/A	- (3)	- (1)	
	Outside sounds are annoying	7	- (2)	N/A	- (2)	- (3)	
	Outside sounds are muted	4	+ (2)	N/A	+ (1)	/ (1)	
	Losing focus by outside sounds	7	- (2)	N/A	- (2)	- (3)	
	Hearing outside sounds when the window is open	2		N/A		- (2)	
	Facing roadside	4		N/A	- (2)	- (2)	
	People from outside sounds	6	- (1)	N/A	- (2)	- (2)	- (1)
	Need of quiet outside environment	3	+ (1)	N/A	+ (1)	+ (1)	
	Cannot control outside sounds	1		N/A			- (1)
Sounds from inside are important	People from inside sounds	10	- (2)	N/A	- (3)	+ (1) - (2) / (1)	- (1)
	Inside sounds are annoying	5	- (1)	N/A	- (3)		- (1)
	Losing focus by inside sounds	5	- (2)	N/A	- (1)	- (1)	- (1)
	Hearing inside sounds	7	- (3)	N/A		/ (3)	- (1)
	No sufficient sound insulation	3		N/A	- (1)		- (2)
	Inconstant inside sounds	2		N/A	- (2)		
	No changes in inside sounds			N/A	/ (1)	/ (1)	
	Need of quiet inside environment	2		N/A	+ (1)	+ (1)	
Sounds from outside are not important	Outside sounds are not distracting	3	N/A		/ (1)		/ (2)
	It is a quiet outside environment	1	N/A		+ (1)		
	Not hearing outside sounds	3	N/A	/ (1)	/ (1)		/ (1)
	Facing the entrance side away from the busy road	1	N/A			/ (1)	
	People sounds	2	N/A	/ (1)		+ (2)	
	Facing roadside	2	N/A			/ (1)	
	Getting used to outside sounds	2	N/A			/ (2)	
	Able to study with outside sounds	2	N/A	/ (1)			/ (1)
Sounds from inside are not important	Getting used to inside sounds	2	N/A	/ (2)		N/A	
	People from inside sounds	2	N/A	/ (2)		N/A	
	It is quiet inside environment	2	N/A		+ (1)	N/A	+ (1)
	Can control inside sounds	1	N/A			N/A	+ (1)

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TABLE 4.3 Data structure acquired from interview analysis comprises the aspects related to acoustical preferences for each cluster.

Preferences	Aspects	Frequen-cies	Cluster 1 N=4	Cluster 2 N=2	Cluster 3 N=8	Cluster 4 N=5	Cluster 5 N=4
Optimal sound environment and sound preference	Silence (totally quiet)	7	+ (2)	- (1)	+ (2)	+ (1)	+ (1)
	Music sounds (e.g., piano, classical)	18	+ (3)	+ (2)	- (1) + (5)	+ (3) - (1)	+ (2) - (1)
	Traffic (e.g., cars)	4	- (1)	- (1)	- (1)		- (1)
	Machine sounds (e.g., ventila-tion, fridge)	5	+ (1)		+ (1) - (2)	/ (1)	
	Natural sounds (e.g., birds, rain)	13	+ (2)	+ (1)	+ (6)	+ (2)	+ (2)
	People sounds (e.g., talking, working)	8	- (2)	+ (2)	- (3)	+ (1)	
	Applying sound absorption materials	5	+ (1)	+ (1)	+ (1)	+ (1)	+ (1)
	Controlling sounds	3			+ (1)	+ (1)	+ (1)
	Controlling window/door opening	4	+ (1)		+ (2)		+ (1)

Note: 1) an empty cell means a preference question was asked to students of a cluster but none of the students mentioned the aspect related to the question, 2) '+' means positive aspect, '-' means negative aspect, and '/' means neutral aspect, and 3) cells with diagonal down lines mean that the preference question was not asked to none of the students of a specific cluster.

Table 4.4 includes the 11 aspects that were associated with the selection of the location of the home study place. The three most frequently selected aspects were: '*Next to the window*', '*Room layout*' , and '*View to the outside'*. Students in all five clusters indicated that the selection of their home study place location was based on the positive rated aspect: '*Need for daylight*'. Note that '*View to outside*' varied within the same cluster; some students in Clusters 3 and 4 indicated it as positive and others as negative. Similarly, '*Facing the window*' was also varying in both Clusters 3 and 4. While one student in Cluster 3 indicated this aspect as positive, two indicated it as negative because of the other negative aspect '*Bothered by glare from the sun*'. Additionally, two students, one in Cluster 1 and one in 2, preferred studying in a private room (e.g., bedroom, private study room). This could explain the high concern for privacy of those two clusters.

TABLE 4.4 Data structure acquired from interview analysis with the aspects for selecting the location of the home study place in each cluster.

	Aspects	Frequen-cies	Cluster 1 N=4	Cluster 2 N=2	Cluster 3 N=8	Cluster 4 N=5	Cluster 5 N=4
Selection of home study place location	Preference of studying in a private room	2	+ (1)	+ (1)			
	Need of a quiet place	1	+ (1)				
	Next to the window	11	+ (1)		/ (4)	+ (3)	+ (3)
	Need for daylight	7	+ (1)	+ (1)	+ (1)	+ (2)	+ (2)
	View to outside	9	+ (1) / (1)		+ (2) - (1)	+ (2) - (1)	+ (1)
	Not close to the window	3	+ (1)		+ (2)		
	Bothered by glare from the sun	5	- (1)		- (2)	- (2)	
	Facing the window	7	+ (1)		+ (1) - (2)	+ (2) / (1)	
	Facing the wall	4	- (1)	+ (1)	- (1)	+ (1)	
	Room layout	10	/ (2)	/ (1)	/ (4)	/ (1)	/ (2)
	Limitations of the room size	7			/ (4)	/ (3)	

Note: 1) an empty cell means the question was asked to students of a cluster but none of the students mentioned the aspect related to the question, and 2) '+' means positive aspect, '-' means negative aspect, and '/' means neutral aspect.

4.3.2.2 Building-related indicators

The building checklist data of the home study places are presented per cluster in **Table 4.5**. Most of the students (n=13) live in student housing, while a few live in private housing with roommates (n=6) or parents (n=4). Most of these buildings (n=12) are situated in mixed commercial and residential areas. The number of levels of the building range from 2 to 18 floors, in which the home study place level ranges from ground level to 13 levels. Most study places are in the bedroom (n=17) of which three of them are in a studio (bedroom, kitchen, and living area). In addition, most study places (n=18) are placed close to the window. 18 of the study places have acoustical materials such as curtains or carpets inside the room. There were no acoustical materials at two home study places in Cluster 3, one home study place in Cluster 4, and two home study places in Cluster 5. All study places have a window of which only one in Cluster 5 has an unopenable window. Six home study places have mechanical ventilation, of which three of them are in Cluster 1, the others in Clusters 3, 4, and 5.

TABLE 4.5 Building and home study place characteristics of students per cluster.

		Cluster 1 N=4	Cluster 2 N=2	Cluster 3 N=8	Cluster 4 N=5	Cluster 5 N=4
Building type	Student housing (private room)	1	1	2	4	2
	Student housing (private studio)	3				
	Parents house			2	1	1
	Private apartment or house with roommate(s)		1	4		1
Location Building	Mixed residential area	1			2	
	Sub-urban with large garden			2	1	1
	Mixed commercial and residen-tial area	2	2	4	2	2
	City centre, densely packed housing	1		2		1
Building's stories number: Minimum - Maximum		4-5	3-17	2-7	3-18	2-5
Home study place's story level (0 = ground level): Minimum - Maximum		2-3	2-13	0-5	2-4	1-2
Study place height (m) Minimum - Maximum		2.5-2.6	2.6-2.8	2.0-3.7	2.3-2.5	2.3-3.2
Study place gross area (m2) Minimum - Maximum		19.2-27.2	6.8-8.2	9.9-49.1	8.3-24.5	14.2-23.2
Room type of the study place	Bedroom	1	1	5	5	2
	The living room opened to the kitchen			3		1
	Office room		1			1
	Studio (bedroom, kitchen, and living area)	3				
Study place location within the room	Close to the window and wall, at the corner	1	1	5	2	2
	Close to the wall, at the corner			1		
	Close to window and wall			1	1	1
	Close to window, wall, and door, at the corner				2	1
	Close to the window and wall, the centre of the room	1				
	Close to the wall, the centre of the room	2				
	Close to the wall and door, at the corner		1	1		

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TABLE 4.5 Building and home study place characteristics of students per cluster.

		Cluster 1 N=4	Cluster 2 N=2	Cluster 3 N=8	Cluster 4 N=5	Cluster 5 N=4
Acoustical absorption materials	Not applied			2	1	2
	Curtains	4	2	5	4	2
	Fibre tiles ceiling				2	
	Rug (part of the flooring)	1	1	1		
Wall covering	Paint	4	2	7	5	3
	Wallpaper			1		
Floor covering	Laminate flooring	3	1	7	5	3
	Synthetic smooth floor covering (vinyl)	1	1	1		1
Ceiling covering	Mineral fibre tiles				2	
	Paint	4	2	6	3	4
	Skylight (glass)			1		
	Wood			1		
Suspended ceiling: yes				1	2	
Number of windows (number can be opened); Minimum – maximum		1-2 (1-2)	1 (1-2)	1-3 (1-3)	1-2 (1-2)	1-2 (0-2)
Mechanical ventilation: yes		3		1	1	1

4.3.2.3 Dose-related indicators

Table 4.6 shows the SPL measurements results, of the 23 home study places per cluster, ranging from 25 to 49 dB(A). Clusters 1 and 2 have the lowest median (32 dB(A)), while Cluster 5 has the highest median (38 dB(A)). In addition, the interviewer investigated whether sounds from outside can be heard from inside during the interview. As a result, in 13 home study places, sounds from outside (such as birds or traffic) were heard indoors. This could mean that these home study places do not have sufficient sound insulation of windows or external walls. It can be noted that the visiting time of the 23 home study places differed due to the student's studying time at home. Out of the 23 field visits, 11 visits took place in the morning (9.00-12.00), eight visits took place in the afternoon (12.00-17.00), and four visits took place in the evening (17.00-19.00).

TABLE 4.6 Acoustical environmental characteristics and SPL of the 23 home study places per cluster.

Cluster	Student ID	Sounds from outside can be heard from outside: Yes	1st SPL LAeq (SD) [dB(A)]	2nd SPL LAeq (SD) [dB(A)]	Mean SPL LAeq [dB(A)]	Field visiting time
1	6		36 (7.1)	24 (2.8)	30	10.00-11.00
	11	X	34 (1.2)	32 (0.7)	33	9.00-10.00
	13	X	30 (2.0)	31 (1.7)	31	11.00-12.00
	23		34 (0.6)	34 (0.7)	34	16.00-17.00
	Cluster 1 Median: 32, minimum: 30, maximum: 34					
2	9	X	37 (2.2)	34 (1.2)	36	14.00-15.00
	20	X	27 (1.5)	27 (1.5)	27	17.00-18.00
	Cluster 2 Median: 32, minimum: 27, maximum: 36					
3	2		31 (1.9)	31 (2.8)	31	11.30-12.30
	3		35 (0.9)	35 (0.5)	35	16.00-17.00
	5	X	48 (5.7)	51 (5.8)	49	18.00-19.00
	7		30 (0.4)	30 (0.6)	30	13.00-14.00
	10		34 (1.3)	32 (0.4)	33	11.00-12.00
	14	X	39 (3.6)	36 (1.5)	38	17.00-18.00
	19	X	32 (2.4)	31 (1.2)	32	10.00-11.00
	21		31 (3.1)	38 (6.5)	35	10.00-11.00
	Cluster 3 Median: 34, minimum: 30, maximum: 49					
4	1	X	39 (1.3)	40 (0.2)	40	18.00-19.00
	4		33 (1.7)	32 (1.2)	33	10.00-11.00
	12		26 (2.6)	23 (0.5)	25	15.00-16.00
	16	X	29 (2.2)	31 (3.5)	30	10.00-11.00
	22	X	36 (0.3)	37 (0.8)	37	15.00-16.00
	Cluster 4 Median: 33, minimum: 25, maximum: 40					
5	8	X	40 (5.3)	41 (5.3)	41	11.00-12.00
	15	X	45 (5.8)	43 (4.6)	43	11.00-12.00
	17		30 (2.0)	29 (1.3)	30	15.00-16.00
	18	X	33 (1.4)	34 (1.7)	34	16.00-17.00
	Cluster 5 Median: 38, minimum: 30, maximum: 43					

Note: LAeq: A-weighed equivalent sound level.

4.3.3 Descriptions of the five clusters

The profile of each cluster is described below, explaining per cluster the differences in occupant-related, dose-related, and building-related indicators between students of different clusters (from the questionnaire and the field study as illustrated in Tables 1-5).

4.3.3.1 Cluster 1: sound extremely concerned introvert

Cluster 1 has the smallest cluster group size (16%). This cluster accounts for the highest percentage (93%) in terms of spending study time at home. Cluster 1 students gave the highest importance scores for sounds from inside, sounds from outside, control of surrounding sounds, the ability to adapt or control the place, and privacy. In addition, students in Cluster 1 were most concerned with other IEQ preferences (e.g., artificial light and control of shading).

These acoustical preferences aspects remained important for the four students who participated in the follow-up study (scored above 5). This means that the field study resulted in the same preferences for Cluster 1 students. The interviewed students of Cluster 1 were mainly concerned with sounds from outside because of the negative aspects, such as '*Outside sounds are annoying*' and '*Losing focus by outside sounds*'. They were also highly concerned with sounds from inside for several negative reasons, such as '*Losing focus by inside sounds*', which conveys that inside sounds have negative impacts on their focus. They preferred to study in a quiet environment, with the presence of natural sounds from outside and low-level sounds from inside, such as music or sounds caused by the ventilation system. Cluster 1 was the cluster with the highest dissatisfaction with noise from outside (40.0%). It was also found that acoustical materials, including curtains and a carpet, were applied at these study places. Three of these places had mechanical ventilation, which one of these students accept to hear the sounds generated from the mechanical ventilation system. Furthermore, the four study places were all located in a private home. This confirms their high concerns about privacy. The selection of the home study place location was based on positive aspects such as the need for a quiet and private place next to or facing the window.

Example quote from a student in Cluster 1: "*I do prefer if I don't hear too much from outside because this is really like my space, and I just want to be here in peace*".

4.3.3.2 Cluster 2: sound unconcerned introvert

Students in Cluster 2 were, similar to those in Cluster 1, more likely to spend most of their study time at their home, than students in the other clusters (92%). With regards to the acoustical preferences, students within this cluster scored the least importance level for sounds from outside and inside. Besides, Cluster 2 scored low importance levels for other IEQ preferences, such as smells and control of shading and room ventilation.

Both interviewed students from this cluster remained unconcerned with sounds from inside (scored less than 5) because of neutral aspects, such as '*Getting used to inside sounds*', which means that inside sounds did not have effect (positive nor negative) on them. This cluster is unconcerned with sounds from outside because of neutral aspects: '*People sounds*' and '*Able to study in a quiet or loud environment*', meaning that outside sound sources and their volume do not affect the student's comfort negatively nor positively. This finding could explain that students in Cluster 2 were not highly concerned with sounds and the least concerned with the presence and company of others. While the students do not prefer to study in totally quiet study places, they prefer the presence of natural sounds from outside and sounds made by people inside. Acoustical materials such as curtains were applied in both places. The two interviewees study in private home study places (a bedroom, and a private office room), of which one of them selected the study place because of the positive aspect: '*Preference of studying in a private room*'. This also could validate the finding that this cluster was the second highest cluster concerned with privacy.

Example quote from a student in Cluster 2: "*Well, because I like sounds from inside, I don't mind if people are working or cooking or we have a really loud washing machine so you can hear it, but I don't really mind that*".

4.3.3.3 Cluster 3: sound partially concerned introvert

Most of Cluster 3 students (87%) spent most of their study time at home. These students scored intermediate importance levels for sounds from inside and outside. Also, they are partially concerned with other IEQ preferences such as control of room ventilation.

The eight interviewed students within this cluster re-scored high importance levels for both sounds from outside and inside (above 5), except for one student who scored them as a 5. The students who scored above 5 were concerned about outside sounds due to negative aspects, such as '*Facing roadside*' and '*Losing focus by outside sounds*', which conveys that outside sound sources could affect student's focus negatively. Besides, they were highly concerned with inside sounds because they get annoyed and lose focus by inside sounds, such as sounds made by people. The one student who became unconcerned with outside and inside sounds, indicated that both inside and outside sounds at the current home study place were quieter compared to the previous home study place. This could convey that this student no longer belongs to Cluster 3, but this student belongs to Cluster 2. All eight interviewed students preferred quiet environments where music and sounds made by people were not present. Additionally, they prefer to have control over the sounds as well as control over opening windows and door. This could explain the finding that Cluster 3 is one of the clusters that scored a relatively high importance level for control over the surrounding sounds. Two of the home study places lack acoustical materials, while five of them have curtains, and one has a carpet. Four of the interviewed students of this cluster were staying at a private apartment/house. This could explain the finding that the students were partially concerned with privacy and least concerned with the presence and company of others.

Example quote from a student in Cluster 3: "*I think sounds just moves your concentration and it doesn't let you focus if you have too many sounds or if you have like sudden sounds, so I think that's why it's important*".

4.3.3.4 Cluster 4: sound concerned extrovert

Cluster 4 accounts for the largest cluster size (26%), in which one-third of students within this cluster spend most of their study time in an educational building. These students scored the second highest importance scores for both sounds from inside and from outside. Also, Cluster 4 is the second highest concerned with other IEQ preferences, including control of temperature and control of shading.

It can be noted that three out of the five interviewed students within this cluster became unconcerned with sounds from outside (scored 5 or 4). Lower importance of outside sounds seemed to be caused by changes in the home study place associated with building-related indicators, such as the location of the building. For instance, one of these students used to be exposed to traffic sounds, while the current home study place faced a quiet building entrance side. The two interviewed students that remained concerned with sounds from outside explained their concern because of negative aspects, such as '*Facing roadside*', and the positive aspect '*Need of quiet outside environment.*' These aspects convey that these students prefer to study in a quiet environment with the absence of traffic sounds from outside, which could have a positive effect on their comfort. Nevertheless, all five interviewed students remained concerned with sounds from inside because they need a quiet indoor environment to be able to focus. Regarding sound preference, the five interviewed students preferred to study in a quiet environment where natural sounds are present. Moreover, these students preferred to study in a place where they can control the surrounding sounds. This also supports the result that Cluster 4 was the cluster that scored the second highest importance level of control of surrounding sounds.

Four of the home study places of this cluster had acoustical materials. Four of the interviewed students were living in a student house where they shared facilities with roommates. Sharing facilities is in line with the finding that Cluster 4 students scored the highest importance level of presence and company of others.

Example quote from a student in Cluster 4: "*But also like sometimes I put rain noises and stuff because that's like a really constant sound. And I have these like podcasts of one hour that are just like people studying and then you can hear like pages being flipped and that's also a very constant sound, so that helps*".

4.3.3.5 Cluster 5: sound unconcerned extrovert

Cluster 5 has the second largest cluster size (20%), of which more than half (60%) spent most of their study time in an educational building. Students within this cluster scored the second lowest importance levels for both sounds from outside and inside. They also scored the least importance levels for other IEQ preferences, including smells and artificial light.

Two out of four interviewed students became concerned with sounds from outside, and one of these two became more concerned with sounds from inside. The two students who remained unconcerned with sounds from outside because of neutral aspects, such as '*Outside sounds are not distracting'* or '*Not hearing outside sounds*', which could mean that outside sounds did not affect the students' focus positively nor negatively. On the contrary, the other two became more concerned with sounds from outside because of the negative aspect '*Cannot control outside sounds'*, indicating the importance of control over outside sounds. Three of the interviewed students remained unconcerned with inside sounds because of the positive aspects '*Can control inside sounds*' and '*It is quiet inside environment*', which indicates that having control over inside sounds as well as studying at a quiet indoor environment fulfilled their acoustical needs, and therefore they were unconcerned with inside sounds. However, one of the interviewed students became more concerned with inside sounds because of too many inside sounds, such as noise made by people, which were not present at the previous home study place. Concerning the optimal sound environment, the four interviewed students prefer to study in a place where they can control the surrounding sounds. Also, they prefer the presence of music and natural sounds, such as rain and winds, at their study places. Besides, two of these home study places lack acoustical materials. It was observed that three of these students were living in a student house or a shared apartment where they share facilities with other roommates. This could support the fact that

Cluster 5 was the most concerned with the presence and company of others. In contrast, students in this cluster were the least concerned with privacy.

Example quote from a student in Cluster 5: "*With these sounds from outside, well, they're not really important because we have like one-sided glass. But now when I have my headphones on it doesn't really matter how much sound there is from outside, and when I put them of, I don't get distracted, so actually pretty OK with a bit of sound from outside*".

4.4 Discussion on the profiles

4.4.1 Mixed methods for understanding the sound profiles of the five clusters

The outcome of this study showed that combining the results from the questionnaire and the field study contribute to the understanding of the sound profiles of the five clusters. This is in line with the conclusions drawn by Ortiz and Bluyssen [29] who highlighted that using mixed-methods with TwoStep cluster analysis is a valuable approach to better understand the profiles of different clusters. Moreover, several studies applied a mixed-methods approach to explore occupant's experience in an indoor environment. For instance, Hong et al. [40] found a relationship between dose-related indicators of different IEQ-factors (e. g., SPL) and students' productivity in a learning environment. This indicates the importance of combining dose-related indicators with occupant-related indicators. Also, Acun and Yilmazer [41] found that measuring only the SPL is not enough to understand student's acoustical preferences of study places. This finding is similar to the results from the present study. For example, while the median SPL of the four home study places in Cluster 1 was the lowest among the five clusters, students from this cluster were the most concerned with sounds from outside and inside. On the other hand, even though the highest median SPL was measured at the four home study places of Cluster 5, students within this cluster were least concerned with outside and inside sounds at their study places. Also, they were the least dissatisfied with sounds from outside.

In a study on sounds at home study places of the same university students who participated in the questionnaire of this study [42], dominant sounds identified were sounds caused by people inside, and natural sounds (e.g., birds and rain) outside. In this study, an explanation of their preferences for sounds was determined by associating different aspects to the importance scores of the acoustical preferences as well as to which sounds students prefer to hear. These aspects can be related to sound sources (e.g., people sound), personal concentration (e.g., losing focus by sounds), perception (e.g., annoyance), building characteristics (e.g., no sufficient sound insulation), and building location (e.g., facing a roadside). Students in Clusters 1, 3, and 4 were concerned with outside sounds due to several negative aspects, such as loud outside sounds, getting annoyed by outside sounds, losing focus by outside sounds, and hearing people sounds from outside. On the contrary, students within Clusters 2 and 5 were unconcerned with outside sounds because of several neutral aspects, including being able to study in a quiet and loud environment and accepting to hear sound made by people. Also, the students within Clusters 1, 3, and 4 were highly concerned with inside sounds because of the negative aspect 'Losing focus by inside sounds', while the students within Clusters 2 and 5 were not highly concerned with inside sounds because they were able to study with the presence of inside sounds.

The acoustical preferences of the interviewed 23 students, except for four students, were generally the same as their preferences pointed out in the 'MyStudyPlace' questionnaire. In other words, the follow-up study enabled explanation of the preferences of the five clusters, of which the preferences of 19 students did not change. However, preferences might change over time due to several factors. For example, in a study on changes in preferences of different outpatient staff profiles in hospitals during COVID-19, by Eijkelenboom et al. [43], was concluded that preferences for the indoor environment can change over time due to changes in context. In this study, four students (one in Cluster 3, two in Cluster 4, and one in Cluster 5) moved to another study place within the same building or to a new building. As a result, their preferences changed due to changes in the sound sources (from outside and/or inside) at their home study places. The two students in Cluster 4 became less concerned with outside sounds because the previously identified 'annoying' sounds (e.g. busy roads or people in the courtyard) were no longer present at the current home study place. Thus, these two students no longer belonged to Cluster 4, they could be categorised into Cluster 5. Similarly, a student in Cluster 3 became less concerned with outside sounds because the sound environment of the current home study place was quieter than the previous one. Therefore, this student could be placed into Cluster 2. In contrast, the student in Cluster 5 became more concerned with sounds from inside because of the exposure to noises made by people at the new home study place. Hence, this student could belong to Cluster 4.

Torresin et al. [44] also concluded that understanding occupants' sound preferences in a certain indoor environment is important. Therefore, in addition to scoring the preferences, it is important asking the students why they scored high or low importance scores for the acoustical preferences, and in this way determine the related aspects, another question could be which sound(s) they prefer to hear while they are in a specific indoor environment.

4.4.2 Comparison with previous studies

From the nine profiles of the same university students (who were clustered based on IEQ and psychosocial preferences) [19], three profiles were highly concerned, three profiles were partially concerned, and three profiles were unconcerned with the sounds of their study places. While the acoustical perception from that study did not show a significant difference among the nine profiles, the five clusters in the present study differ significantly concerning their perception of noises from outside. This is similar to the results by Zhang et al. [21] who also found significant differences among the six clusters of primary school children at the classroom based on perception of the four IEQ factors including noise. Furthermore, they found that Cluster 6 was the least concerned with sounds and the least dissatisfied with noise. This is similar to the results of this study, in which Cluster 5 students were not highly concerned with sounds, and the least dissatisfied with sounds from outside.

Pertaining to the psychosocial aspects, Wu et al. [45], found that in general students prefer to study in private study places. In contrast, the f ive clusters showed significant differences in terms of psychosocial preferences. This study showed that while there are clusters of students (Clusters 1 and 4) who prefer to study in quiet spaces, those in Cluster 1 were highly concerned with privacy, and those in Cluster 4 were highly concerned with the presence and company of others. Cluster 4 students some interviewed students of Cluster 4 indicated that they prefer to hear other students' activity sounds, such as paper flipping sounds. These findings align with Zhang et al. [46], who also found that students have different preferences.

4.4.3 Limitations

This study is limited to the acoustical and psychosocial preferences for study places of bachelor students from the Faculty of Architecture and the Built Environment. Also, the number of participants of the follow-up study was not equal per cluster, but at least two participants per cluster participated. Four of these students moved to other study places which affected their acoustical preferences, and thus they could be categorised into another cluster. Note that the data from the interviews with the students per cluster cannot be generalised to describe the whole cluster. Nevertheless, these data provided insight into the aspects related to the acoustical preferences of students from different clusters as well as the contextual factors, such as the building location, that may affect their preferences.

Additionally, the measured dose-related indicators in the follow-up study were limited to the SPL, for example reverberation time or other IEQ parameters were not measured. Due to time limitations during the visit of each student's home study place, involving an interview and completion of the building checklist, the SPL measurement was limited to 1 min (with six time-intervals of 10-s), and was performed twice. Although the background sound during the whole field visit of each of the home study places was not varying in general, it is recommended for future studies to measure the SPL for a longer time, at least for 15 min as suggested by Puglisi et al. [47], but preferable for 24 h to get a better idea of the SPL variation during day and night.

Furthermore, the visiting time during the day differed among these 23 home study places. The occupant-related indicators were limited to acoustical preferences and evaluation of comfort. Further studies are needed to investigate the impacts of different sounds on health [48] and performance [12,49]. Nonetheless, the data acquired in this follow-up study made it possible to better explain the acoustical preferences for study places per cluster of students.

4.5 Conclusion

A mixed-methods approach was applied consisting of a questionnaire completed by 451 bachelor students and a field study conducted with 23 students from the same sample, to answer two research questions. The f irst question ‘can university students be clustered based on their acoustical and psychosocial preferences of their study places?’ was answered by identifying five clusters of students based on two acoustical preferences and three psychosocial preferences from the questionnaire. Several aspects (including comfort perception and IEQ preferences) were found to be significantly different among these clusters, including acoustical perception. Students who were concerned with sounds, as well as those who were unconcerned with sounds, differed in their psychosocial preferences, such as privacy and presence and company of others. The second research question ‘can interviews with selected students from each cluster, building inspections of their home study places, and sound level measurements help to verify their acoustical preferences and their related aspects?’ was answered by exploring the aspects related to the acoustical preferences of students from different clusters acquired from the field study, including the investigation of the three levels of indicators. It can be concluded that the field study led to a validation of the acoustical preferences and a better understanding of the aspects associated with these preferences of the selected students from each cluster. For instance, it was revealed that Cluster 1 students are highly concerned with sounds from outside and sounds from inside because of hearing the sounds people make, were perceived as annoying. On the other hand, Cluster 2 students were not concerned with sounds from outside nor inside because they are able to study with the presence of outside and inside sounds. Also, building-related indicators (e.g. building location) were associated with student’s acoustical preferences. A mixed-methods study, including the investigation of the three types of indicators (occupant-related, building-related, and dose-related) based on a questionnaire, interviews, building checklists, and sound pressure measurements, seemed an effective approach to better understand the sound profiles of students. These profiles might help to explain the different acoustical preferences of students at home study places and might help to better design study places for students of different clusters. Moreover, it is recommended in future studies to explore the different profiles of students from different faculties and universities since this study is limited to students at the faculty of Architecture and the Built Environment at the Delft University of Technology. This study was limited to the occupant-related indicators in terms of students’ acoustical preferences and perceptions of their study places. Hence, it is recommended for future studies to test the effects of different sound sources on student’s health, including physiological measurements (e.g., heartrate).

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5 Guidance to Investigate University Students' Bodily Responses and Perceptual Assessments in Sound Exposure Experiments

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ABSTRACT

Previous studies have shown that sound influences students both physiologically and perceptually. However, most of these studies focussed on the effects of sounds at group-level, ignoring individual differences. Therefore, we investigated which indicators can be used to identify differences in bodily responses and perceptual assessments of each individual when exposed to four different sounds. First, based on an audiometric test, the hearing acuity of 15 students (from five different profiles based on their acoustical preferences and needs) was measured. Then, two sound exposure experiments were conducted in the SenseLab: direct sound exposure using earbuds in a laboratory setting, and indirect sound exposure with speakers in a real room setting. During each experiment, the attention level (AL), mental relaxation level (MRL), heart rate (HR), and respiration rate (RR) were measured with wearable devices, and students made perceptual assessments of each condition. The percentage of change normalised the four bodily response measurements among students. Based on correlation analysis and t-tests, bodily responses, and perceptual assessments across experiments were compared, at group-level and individual-level. Six students, who suffered from mild hearing loss in low-frequency sounds, showed bodily responses such as increased HR during exposure to low-frequency sound conditions. Perceptual assessments of different sound types during both lab experiments substantiated the acoustical preferences of the students from the five profiles. Bodily responses showed no strong nor significant correlations with perceptual assessments during the direct sound exposure experiments. Differences in bodily responses and perceptual assessments between the two experiments and between group-level and individual-level were observed in AL. It is concluded that hearing acuity and type of sound (sound frequencies) are key indicators for identifying differences in bodily responses (such as HR and RR) and perceptual assessment. For future research, it is crucial to consider incorporating audiometric tests, bodily responses such as HR and RR, and perceptual assessments in this type of investigations.

KEYWORDS Sound exposure; bodily responses; physiological responses; perceptual assessment; soundscape; audiometric test.

5.1 Introduction

University students spend a significant amount of time studying indoors, whether at home or in educational buildings [1–3]. Research has shown that staying indoors for a long time can affect occupants' health due to a 'bad' indoor environmental quality (IEQ) [4,5], and thus it is important to consider the IEQ of these study places and eliminate any stressors that could affect students' health negatively. The acoustical quality is one of the IEQ factors that may positively or negatively affect students' health and comfort [6,7]. Background noise is one of the IEQ stressors that can cause nonauditory effects such as prolonged stress, caused indirectly by the anti-stress mechanism that is activated when exposed to stressors such as noise [8,9]. The anti-stress mechanism increases adrenaline and nor-adrenaline levels in the short-term, possibly leading to an increase in heart rate (HR) and respiration rate (RR) [9]. Changes in physical and/or physiological responses (including HR, RR and brainwaves) as a result of exposure to a physical stressor, such as noise, are referred to as bodily responses [10,11]. Thus, a study of occupant-related indicators, including bodily responses and perceptual assessments, might contribute to a better understanding of the effects of the acoustical environment on students' preferences and needs [12].

The effects of sound as an environmental stressor have been studied using bodily responses and perceptual assessments. For instance, Alvarsson et al. [13] examined university students' bodily responses, including high-frequency HR variability, when exposed to natural sounds and environmental noises. Their findings indicated no significant changes in HR during the experiment; however, the students rated the natural sounds as the most pleasant. Abbasi et al. [14] investigated university students' bodily responses to three sound pressure levels (SPL) of low-frequency sound in a lab experiment. They recorded bodily responses, including electroencephalogram (EEG) for brain wave signals and electrocardiography for HR signals. They observed that these bodily responses significantly differed among the different SPLs, and students' mental fatigue increased when the SPL increased. Tristan-Hernandez [7] found that both beta and theta brain wave amplitudes decreased when university students were exposed to background noise, resulting in reduced attention levels while performing cognitive tasks. Furthermore, Guan et al. [15] concluded that brain wave patterns differed between the perceived comfortable sound condition (music sound at 50 dB) and the perceived uncomfortable sound condition (fan noise at 80 dB). They also observed a decline in theta wave during the uncomfortable sound condition. However, correlations between bodily responses and perceptual assessments of background noise were not tested in these studies. Park and Lee [16] measured both HR, and RR of participants and asked them to assess the noticeability and annoyance of these sounds, while being exposed to six-floor impact noise (e.g., adult walking and child running) stimuli. They found that RR was correlated significantly and positively with both perceptual assessments of the standard floor impact noise. Similarly, Hume and Ahtamad [17] concluded that RR increased during the most perceived pleasant sound clips. Thus, HR, RR, and brain waves as bodily responses could be measured to explain differences in the acoustical needs of students.

Human ears are most sensitive to high frequencies (3000 Hz-5000 Hz) and generally most annoyed by low-frequency noise (20 Hz-125 Hz), which can cause stress [18,19] and negatively impact cardiovascular responses such as HR [20]. For instance, Mu et al. [21] observed that HR slightly increased among senior adults (over 60 years old) with mild or severe hearing loss up to 55 dB(A), but remained stable above that level. Keur-Huizinga et al. [22] studied the impact of hearing acuity on HR in 125 participants aged 37 to 72, exposed to speech sound stimuli (frequencies ranged from 330 to 6300 Hz). They found no consistent changes in HR reactivity in participants with different hearing acuity, and concluded that hearing acuity might be associated with changes in the sympathetic nervous system's reactivity. Mackersie et al. [23] examined the effects of hearing loss and noise on stress-related autonomic measures in 33 participants (18 with hearing loss, 15 with normal hearing, ages 22 to 79) during sentence recognition tasks. They found that the HR of participants with hearing loss decreased at lower signal-to-noise ratios, while HR of those with normal hearing did not. They highlighted that participants with hearing loss may experience increased effort and stress during speech recognition in noisy environments, which could influence the psychophysiological responses concerning the autonomic nervous system.

The above-mentioned studies [21–23] recruited senior adults, who have a lower sensitivity to low-frequency sounds compared to young adults. Although Alimohammadi and Ebrahimi [24] tested the university students' mental performance while being exposed to both low and high-frequency sounds, they excluded the students whose hearing threshold was less than 20 dB. Hence, little is known about the relationship between hearing acuity in young adults and their bodily responses to different sound types. Furthermore, while hearing acuity measured through an audiometric test has been considered in several sound exposure experiments with human subjects [13,14,18,25,26], differences in bodily responses concerning the hearing thresholds of different students at various sound frequencies have not studied.

Most of the above-mentioned lab experiments [7,13–17] considered participants' personal traits, including demographics (e.g., age and gender) and hearing acuity or noise sensitivity. However, they mainly focused on the overall bodily responses and perceptual assessment at group-level ignoring differences in preferences and needs between individuals (profiles). Profiling occupants based on their preferences and needs of a certain indoor environment is one of the methods that take into account the differences between individuals' in the indoor environment [27]. Noting that profiling of occupants in several situations (e.g., classrooms, study places, homes, and hospitals) has been addressed in previous studies [28–31]. In connection to the sound-related preferences of students, Hamida et al. [32] identified five profiles of university students based on their acoustical and psychosocial preferences for their study places, such as sounds from the outside and privacy. These five profiles are: 1) sound concerned introvert, 2) sound unconcerned introvert, 3) sound partially concerned introvert, 4) sound concerned extrovert, and 5) sound unconcerned extrovert. Moreover, they identified aspects related to the preferences of each profile through a field study, such as both students from profiles 1, 3, and 4 were concerned with the sounds from the outside because they got annoyed and lost focus by these sounds. According to these aspects, it was concluded that the study place's context, such as building location, might affect students' acoustical preferences.

Studies on bodily responses to be measured for students from different profiles when exposed to both preferable and non-preferable sounds could not be found in the literature. Also, the hearing acuity at different sound frequencies of university students was not widely studied. In addition, to advance knowledge in this area, studies on correlations between bodily responses (e.g., HR), health aspects (e.g., hearing acuity), environmental indicators (e.g., SPL and sound frequency), perceptual assessments (e.g., pleasantness), current situation of study places (e.g., existing sound sources), and preferences of university students from different profiles, are needed. Furthermore, we still need to test which of the bodily responses (including HR, RR, and brain waves that were tested in previous studies) can be measured to explain differences in the acoustical preferences of different students. Hence, the main aim of this study is to propose guidance for investigating the bodily responses that can help us better understand the differences in each student's perceptual responses to different sounds. Therefore, the main research question of this study is: Can bodily responses be used to explain differences in preferences and/or needs for different sounds, and how can we test this?

5.2 Methods of lab experiments

5.2.1 Study design

To study which indicators can be used to identify differences in bodily responses to different sounds and sound levels, two sound exposure lab experiments were conducted on four days in November 2023 with four students per day (except for one day with three students). All of these experiments took place in the SenseLab [33]. These two sound exposure lab experiments aim to answer the four sub-questions that answer the main research question of this study, which are:

1. To what extent is an audiometric test essential for sound exposure lab experiments?
2. Can students' perceptual assessments of sound conditions substantiate their acoustical preferences from the field study?
3. Do bodily responses correlate with perceptual assessments of different sounds?
4. Do bodily responses and perceptual assessments differ significantly when students are exposed directly or indirectly to sounds?

An audiometric test was performed to test the hearing acuity of the participating students. The first lab experiment took place in two test chambers where each participant participated individually, and the second was conducted in the Experience room of the SenseLab with four students. In the first experiment, each student was exposed to different sounds and sound levels directly in both ears via earbuds where other ‘sound’ stressors were eliminated since the student sat alone in the chamber and was facing the wall. Thus, the ‘direct’ sound exposure experiment is mainly focused on the direct effect of the sound condition on both bodily responses and perceptual assessment. In contrast, the sounds in the ‘indirect’ sound exposure experiment were produced by a sound-producing system (four speakers) in the ceiling that propagated in the Experience room with the presence of other ‘sound’ stressors, such as the presence of other students. This study aims to compare whether the bodily responses and perceptual assessments of different sounds differ significantly between the direct and indirect sound exposures. In both experiments, the other factors (lighting, indoor air, and thermal conditions) were kept as constant as possible.

5.2.2 Participants of the lab experiments

Participants comprised bachelor and master students (n=15 in the test chamber with power level 1-β=0.6, and n=14 in the Experience room with power level 1-β=0.6, where β refers to beta which is type II error), from the faculty of Architecture and the Built Environment at Delft University of Technology, in the Netherlands. The power was calculated by conducting a Post hoc analysis by giving effect size=0.5, significance level=0.05, and a sample size of 15 for the first experiment, and 14 for the second experiment) using G*Power software [34]. The power level of 0.6 means that the test has a 60% probability of correctly rejecting the null hypothesis. Students were asked not to perform any physical exercise before the experiment or smoke or drink coffee, as these activities might affect their bodily responses. Seven were female students and eight were male students. Their mean age was 21 years (standard deviation: 1.5). These students all participated in a previous questionnaire and field study performed by Hamida et al. [32]. That study resulted in five profiles based on acoustical and psychosocial preferences of their study places gathered through a questionnaire. In **Figure 5.1** the acoustical and psychosocial preferences of these five profiles are presented. Two students per profile (as a minimum) participated in the lab experiments: two students from Profile 1, two students from Profile 2, three students from Profile 3, four students from Profile 4, and four students from Profile 5. Additionally, to better explain both the bodily responses and the perceptual assessments of each student, part of data gathered in that previous study [32] was used, including sound sources and building-related indicators (see **Appendix H**).

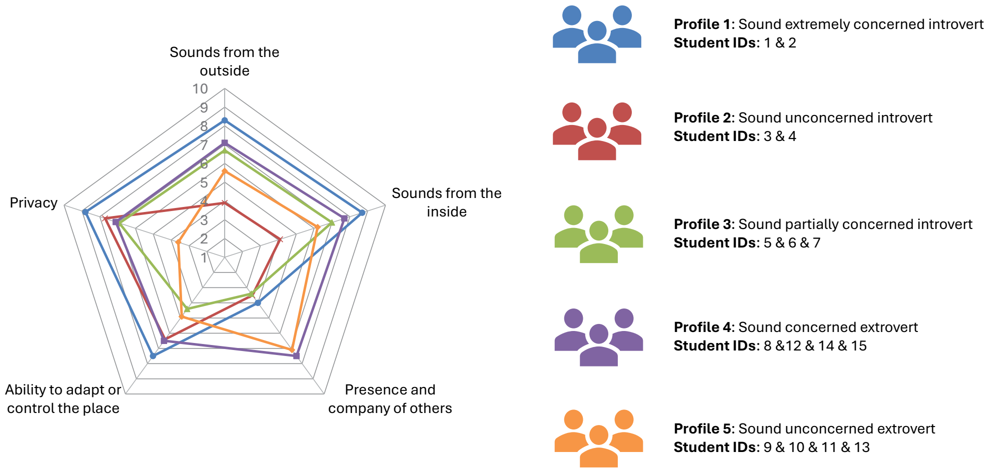


FIG. 5.1 Five profiles found in a previous study [32] and the participating student IDs.
Note: The identified legend colour for each profile was consistently used in several figures throughout the paper.

5.2.3 Bodily responses

Two wearable sensors, an EEG headband (brain activity) and a smartwatch (**Figure 5.2**), were used to measure four bodily responses: 1) attention level (AL); 2) mental relaxation level (MRL); 3) heart rate (HR); and 4) respiration rate (RR). Both HR and RR were chosen because of their possible relation with the anti-stress mechanism and their ease of measurement with smartwatches. AL was assessed to determine how certain sounds affect a student's attention, while MRL was measured to evaluate the effects of different sounds on a student's mental stress (also possibly related to the anti-stress mechanism).

The BrainLink Lite EEG headband by Macrotellect measured AL and MRL using three dry electrodes attached to the participant's forehead. EEG data were processed by the TGAM chipset from NeuroSky [35] and transmitted in real-time to a computer via Bluetooth every half-second using Python code in PyCharm 2023. The data were saved as a CSV file, including attention levels, MRLs, and various brain waves (Delta, Theta, Low-Alpha, High-Alpha, Low-Beta, High-Beta, Low-Gamma, and Mid-Gamma). Both attention and MRL were measured on a scale from 0 to 100.

The Garmin Vivosmart 5 smartwatch monitored HR and RR per minute, known to show good accuracy during low-intensity activity [36]. Since the absolute relative error of the smartwatch showed a lower error on the left wrist compared to the right wrist during a routine activity of daily living [36], students were asked to wear the smartwatch on their left wrist during the experiment. Afterward, the smartwatch was connected to a computer via USB to transfer data using Garmin Express software, and the data were manually transferred to an Excel spreadsheet.

A. BrainLink Lite EEG device.

B. Vivosmart 5 smartwatch.

FIG. 5.2 Wearable sensor devices for measuring AL, MRL, HR, and RR.

The audiometric test (**Figure 5.3**) was conducted in one of the test chambers of the SenseLab using a clinical audiometer (Otometrics MADSEN Xeta) to answer the first sub-question. A monaural audiometric test with the air conduction method was conducted by producing a sound in different SPLs (starting from 0 dB) across eight frequencies: 125, 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. The student sat in front of the examiner, holding a response stick, and clicked the response button upon hearing a sound at each frequency. The examiner recorded the hearing threshold on an audiogram. The student sat with his/her back to the examiner to avoid visual influences on the test results. The hearing threshold was calculated according to the World Health Organization's (WHO) World Report on Hearing [37]. This involved averaging the minimum SPLs that the student could hear at 500, 1000, 2000, and 4000 Hz in the better ear.

A. Audiogram sheet.
B. Response.
C. Headset.
D. Audiometer.

FIG. 5.3 The audiometric test set-up using an audiometer.

5.2.4 Perceptual assessments

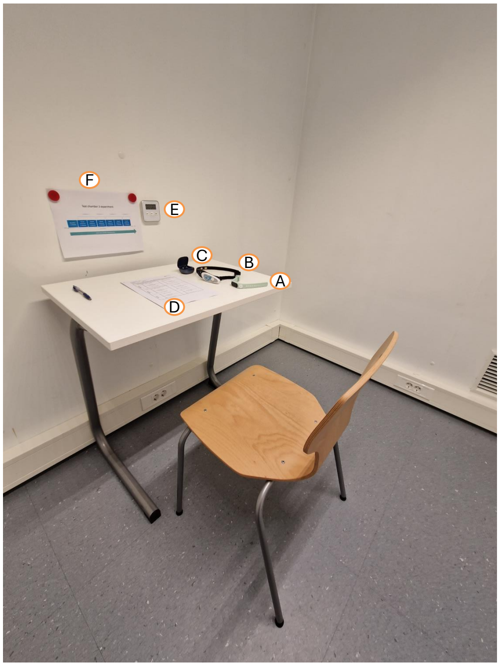
Perceptual assessments can contribute to a better understanding of an individual's acoustical preferences and needs in a certain context [38]. Therefore, questionnaires were used in the form of analogue scales that are easy and quick to be filled out by participants [39]. During the lab experiment in the test chamber, each student was asked to assess the sound conditions on a continuous scale from (-1) to (+1) based on three aspects: acceptability [40], pleasantness [17,26,41], and stress level [42] (see **Appendix I.1**). In the Experience room, students assessed the sound conditions based on two aspects: acceptability on a scale from (-1) to (+1) and noise level [40,43] (i.e., intensity [44]) on a continuous scale from (+1) to (+5) (see **Appendix I.2**).

5.2.5 Experimental setup

Previous lab experiments were carried out in a laboratory setting, such as in an audiometric room [7,16], test chamber [14,14,45], testing booth [25], or anechoic, semi-anechoic room [17,18,21,22,24] for direct sound exposure. As there is a lack of testing of the bodily responses of different sound types in real situations, this study designed two experimental setups: a laboratory setting in the test chambers (as a direct sound exposure), and a semi-real environment setting in the Experience room (as indirect sound exposure).

5.2.5.1 Test Chambers

The first sound exposure experiments were conducted in two test chambers (area 2.2*2.4 m^2) of the SenseLab. Each of these test chambers was furnished with a desk and a chair (**Figure 5.4**). A timer device was on the wall in front of the student so that the student could track the lab experiment timeline next to the timer.

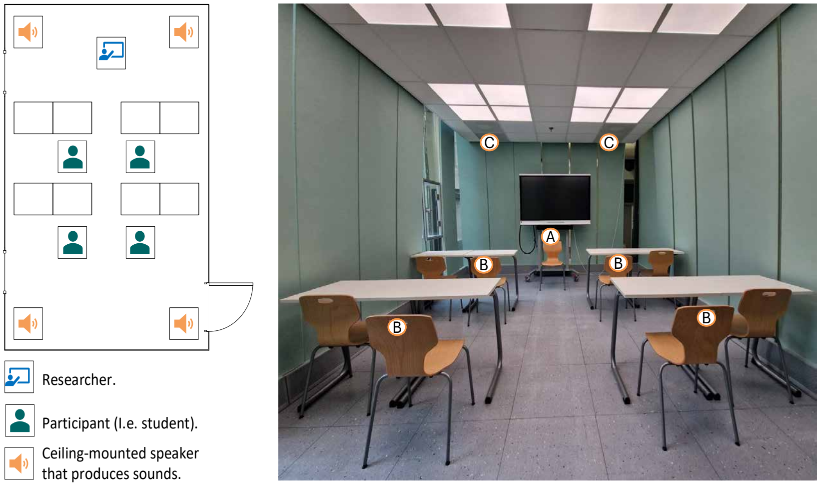


A. Vivosmart 5 smartwatch.
B. BrainLink Lite EEG device.
C. A pair of earbuds.
D. Subjective evaluation.
E. Timer.
F. Lab experiment timeline.

FIG. 5.4 Test chamber set-up as a labaratory setting.

5.2.5.2 Experience room

The second sound exposure experiment was conducted in the Experience room (area: 6.1*4.2 m^2 and height: 2.7 m) of the SenseLab. The floor is covered with smooth grey linoleum material, the ceiling consists of white acoustical panels, and the walls are made of laminated safety glass and covered with light green sound-absorbing panels. The reverberation time of the Experience room was 0.22 seconds [46]. The Experience room was furnished with eight tables (the top material is made of light wood laminate) and five chairs (**Figure 5.5**); a researcher sat in front of the students to guide them with the test procedure. Each participant sat at one of the chairs in the middle of the room, where the four participants were relatively close.



A. Researcher.
B. Participant (i.e. Student).
C. Ceiling-mounted speaker.

Floor plan of Experience room. **Visual scene of Experience room.**

FIG. 5.5 Set-up in the Experience room as a real room setting.

5.2.6 Pilot tests

Several rounds of pilot tests with participants who did not take part in the main experiments were performed in October 2023. These tests aimed to select the sound sources, define the most suitable SPLs for each sound and determine the duration of both the baseline and sound exposure times.

- The first pilot test involved three participants to compare four bodily responses during a four-minute baseline and a four-minute break between two sound types: traffic and rural area at high SPLs, as explained in Table 1.
- In the second pilot test, with four participants, differences in bodily responses within the first and second two minutes of a four-minute baseline, with a two-minute break between low and high SPLs of traffic sounds, were examined.
- In the third pilot test, five participants experienced a two-minute baseline at the beginning. Then, two sound types (rural area and traffic) were played at two SPL levels (low and high), with a two-minute break between the two SPLs of the same sound and between different sound types.

- The fourth pilot test, with three participants, was similar to the third one but the break between different SPLs of the same sound type was eliminated.

- Based on common indoor sounds at students' home study places (**Appendix H**), two additional sound sources were included: mechanical ventilation and people talking. The SPLs of all four sound types were set to 'bearable' levels (below 100 dB(A) as it is a short-term sound exposure for less than 15 minutes [47]) after discussion with two researchers.

- The fifth pilot test followed the complete experimental procedure with four participants (two participating simultaneously). This included four sound types (rural area, traffic, mechanical ventilation, and talking people sounds), each played at two SPLs, with two-minute baselines, two-minute breaks between different sound types, and a perceptual assessment form.

Based on the results of the first two pilot tests, subtle changes were observed in bodily responses between the first two and the second two minutes of a four-minute baseline and the break period. For example, in the second pilot test, the HR differences among the four participants were less than 5%, with two participants showing no differences at all. Additionally, the participants indicated that the four-minute baseline was relatively too long. Consequently, the baseline period was shortened to two minutes, as was also done in the study by Park et al. [48].

The outcome of the third pilot test showed that HR differences between the two-minute baseline and the two-minute break, within the same sound type, were minimal (0% for two participants, and 2% and 4% for the others). During the rural sound condition at high SPL with a break in the third pilot test, one participant's HR declined by only 1%. In contrast, in the fourth pilot test, the HR of participants increased by 7% during the rural area sound condition at high SPL when there was no break. Therefore, the break between the same sound type but at different SPLs was eliminated due to the observed changes in bodily responses and because participants found the number of breaks too much.

5.2.7 Sound types and levels

Four sound clips at different frequencies were selected based on the study by Hamida et al. [32] (see **Appendix H**: sounds identified at students' home study places, preferred and non-preferred sounds), and the pilot tests. Two clips represented outdoor sounds and two represented indoor sounds, covering different frequencies, were downloaded from the online database 'Freesound' [49]: 1) a quiet rural area recorded in the Netherlands (covers low-frequency ranges), 2) a city centre with high traffic recorded in the Netherlands (covers most frequency ranges), 3) mechanical ventilation (covers low frequencies), and 4) people talking in Dutch (covers moderate frequency ranges); and compiled into one file using Audacity 3.3.3 software [50]. These four sound clips were recorded monoaurally. The quiet rural area and the city centre area clips were recorded outdoors while the mechanical ventilation and the people talking clips were recorded indoors. The sound signal spectra of the four sound clips are illustrated in **Figure 5.6**.

In the test chambers, the sounds were played through noise-cancelling JBL Live Pro 2 earbuds. These were used because they are light on the participant's head since they were wearing the BrainLink Lite EEG device. Also, other researchers, such as Guo et al. [51], indicated that earbuds are true wireless stereo devices that can be connected through Bluetooth to a hardware device, such as a computer, and can provide consistent output SPLs when they receive digital audio. In the Experience room as explained by Bluyssen et al. [33], they were played through four ceiling-mounted speakers 'near-midfield studio monitors, three-way, 2*7″ woofer, ADAM Audio A77x' and 'a subwoofer 200W, 1*10″ MKII, ADAM Audio Sub10' from AMPTEC which are connected to a Behringer UMC404HD audio interface. Each sound clip was played at two different sound pressure levels (SPLs): low and high (**Table 5.1**). The SPLs for the earbuds were measured using a calibrated KEMAR dummy head with two Bruel & Kjaer microphones. In the Experience room, the SPLs were determined by using a Norsonic Nor 140 sound level meter and ensuring that the SPL did not exceed 100 dB(A).

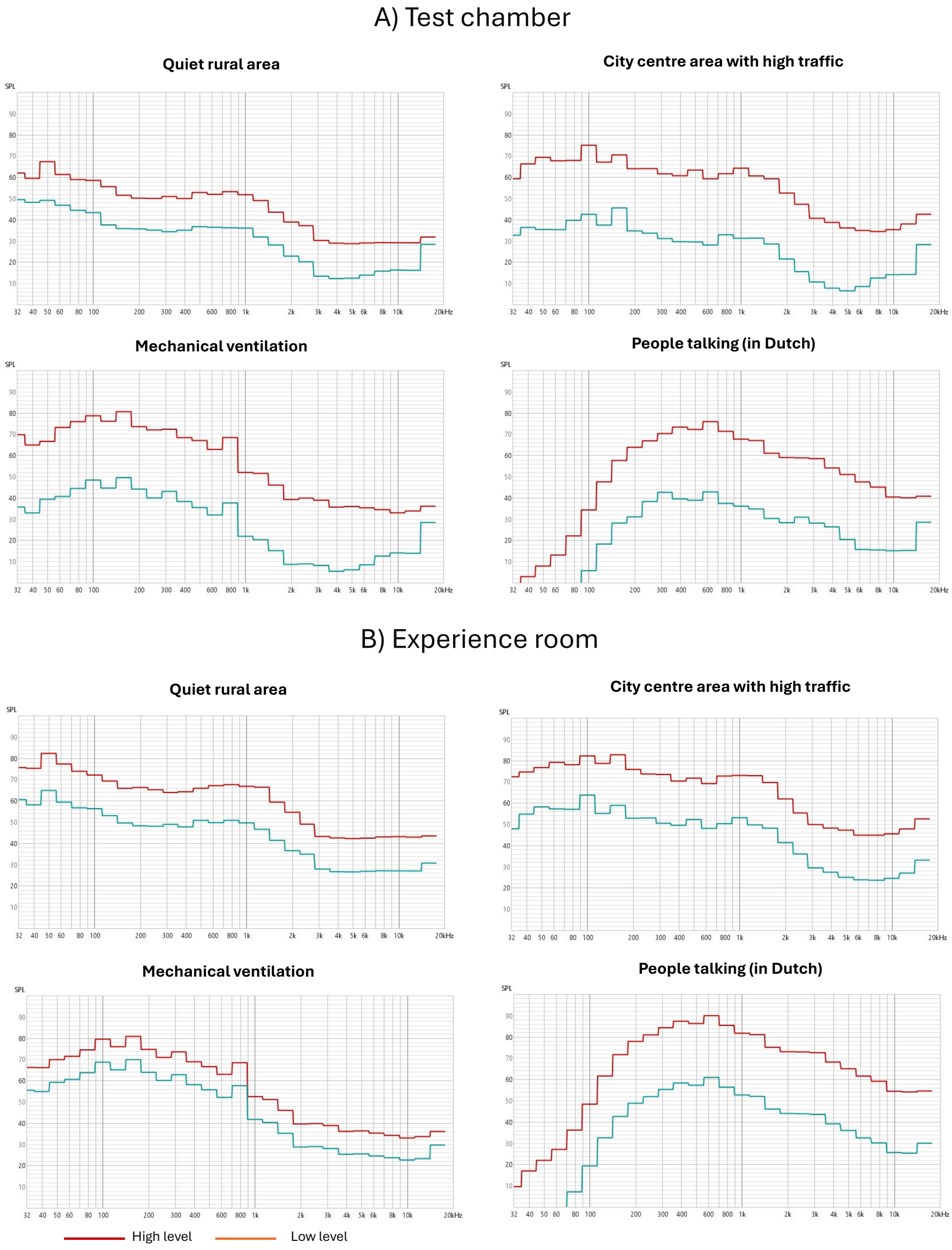


FIG. 5.6 Sound signal spectra for the four sound clips.

TABLE 5.1 Descriptions of the sounds played in both test chambers and the Experience room.

	Sound clip	Frequency (Hz)	Mean SPL (dB(A)) generated from a pair of earbuds		Mean SPL (dB(A)) generated from a the four speakers in Experience room	
			'Low' condition	'High' condition	'Low' condition	'High' condition
Outdoor sounds	Quiet rural area	20-101	22	52	33	48
	City centre area with high traffic	20-20000	38	76	43	58
Indoor sounds	Mechanical ventilation	20-721	45	56	43	53
	People talking (in Dutch)	148-940	39	53	38	58

5.2.8 Procedure

5.2.8.1 Test chambers experiments

The first experiment was divided into two parts, each with a duration of 14 minutes (**Figure 5.7**). The first part focused on the sounds from the outside while the second part focused on the sounds from the inside. Two students participated simultaneously in this experiment, each in one of the test chambers. The researcher gave an introduction to the students outside the test chambers and explained to them the procedure without informing the students about the sound sources. A researcher handed each of the students the measurement devices and the pairs of earbuds. Then each student entered the test chamber, was seated, and after two minutes heard the sentence 'this is the start of the experiment' upon which the student started the experiment by pressing the start button on the timer to track the experiment timeline. Students were asked to assess acceptability, pleasantness, and stress level during each sound condition. After the end of each part, the student heard the sentence 'This is the end of the experiment'. Once the first part was finished, the students were asked to leave the test chamber and move into the other test chamber. They had a 5-minute break in between the two parts.

In the first part of the experiment the students were exposed to four conditions: 1) sounds of a quiet rural area, which were played in two SPLs (low and then high) that each lasted for two minutes, 2) no sounds 1 that lasted for two minutes, 3) sounds of a city centre area with high traffic which was played in two SPLs (low and then high) that each lasted for two minutes, and 4) no sounds 2 that lasted for two minutes.

The second part of the experiment consisted again of four conditions, with different sounds than in the first experiment: 1) sounds of mechanical ventilation, which were played in two SPLs (low and then high) that each lasted for two minutes, 2) no sounds 3 that lasted for two minutes, 3) sounds of people talking sounds which was played in two SPLs (low and then high) that each lasted for two minutes, and 4) no sounds 4 that lasted for two minutes.

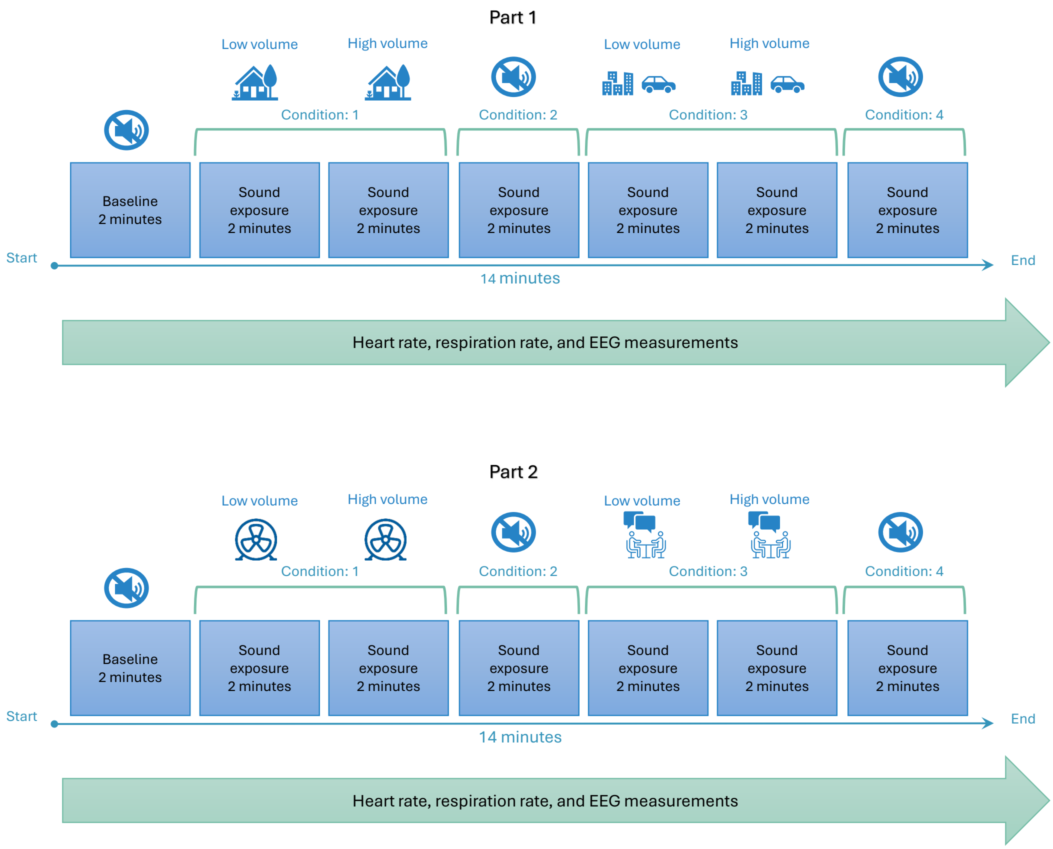


FIG. 5.7 Experimental procedure in the test chambers.

5.2.8.2 Experience room experiment

The second experiment, which was conducted in the Experience room, lasted for 24 minutes and consisted of nine conditions and three breaks (**Figure 5.8**). Four students and a researcher were seated in the Experience room. Each student wore the same wearable sensor devices as in the test chamber test.

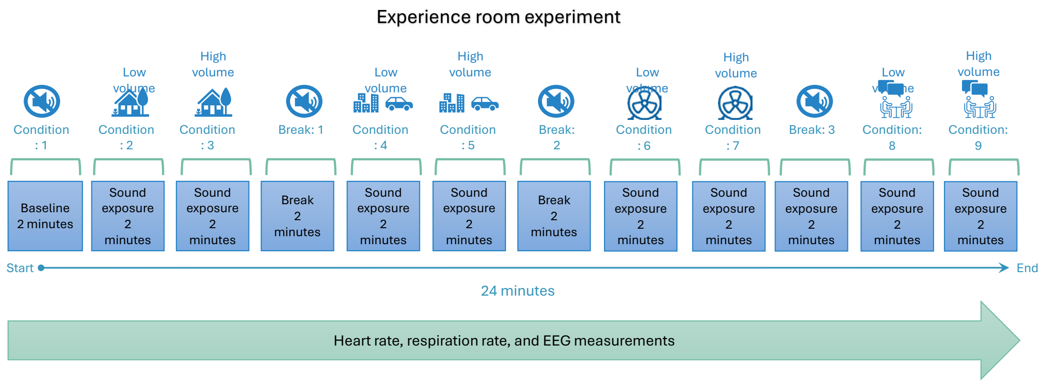


FIG. 5.8 Experimental procedure in the Experience room.

5.2.9 Data management and analysis

A dataset for the group as well as a data set for each student was created in an Excel file. Each of the datasets included the average bodily responses (heart rate, respiration rate, attention, and MRLs) of each condition in each experiment as well as the perceptual assessment of each condition. A relative change was calculated to normalise all four indicators by applying the following equation (**5.1**).

$$Relative\ change\ of\ a\ bodily\ response = \left(\frac{(C1 - C2)}{C2}\right) \times 100 \qquad (5.1)$$

Where C1= raw bodily response to a sound exposure condition;
C2= raw bodily response of a break (i.e., baseline) preceded by the sound exposure condition. **Appendix J** includes the raw data of both tests at an individual level.

The average of the perceptual assessments was calculated for the group per condition, while the individual bodily responses were recorded per condition. The continuous scale of the perceptual assessment was measured using a ruler since the scale was printed in 1:1 scale in centimetres (**Appendix I**). The standard deviation (SD) for both bodily response and perceptual assessment was calculated for the group and per individual among the conditions of each experiment. Spearman's rank-order nonparametric correlation analysis assessed the strength between the bodily response and perceptual assessment. This strength was examined by calculating both the correlation coefficient ($r>0.5$) and the probability (p-value<0.05).

A normality test (Shapiro-Wilk) was performed on the bodily responses of the group among all the conditions of both experiments. Based on that, a two-tailed t-test (for normally distributed bodily responses and perceptual assessment variables) and Wilcoxon signed-rank test(for not normally distributed bodily responses and perceptual assessment variables) were computed to test whether the bodily response and perceptual assessment differed significantly (p-value<0.05) between the two experiments in general and per condition. More specifically, these tests aim to answer the fourth sub-question by exploring whether bodily responses significantly differ when the sound was directly exposed in the student's ears as compared to indirect sound exposure. This answer explores the potential of considering bodily responses in real environmental settings (e.g., real study places).

5.2.10 Ethical aspects

This study (application ID:3555) was approved by the Human Ethics Committee (HREC) of Delft University of Technology on the 15th of November 2023.

5.3 Results of lab experiments

5.3.1 Audiometric tests

In **Figure 5.9**, the outcome of the audiometric tests is presented per student. According to the WHO test [37], all students had normal hearing in both ears, except for two (students 1 and 6) who suffered from mild hearing loss. Additionally, several students suffered from mild hearing loss in low frequencies (between 125 and 250 Hz). More specifically, the hearing threshold of students 3, 4, 6, 10, 11, and 13 of 125 Hz was higher than 25 dB, meaning that they have mild hearing loss at that low frequency sound. However, most of them could hear the highest frequency (8000 Hz) in the low SPL with at least one of their ears.

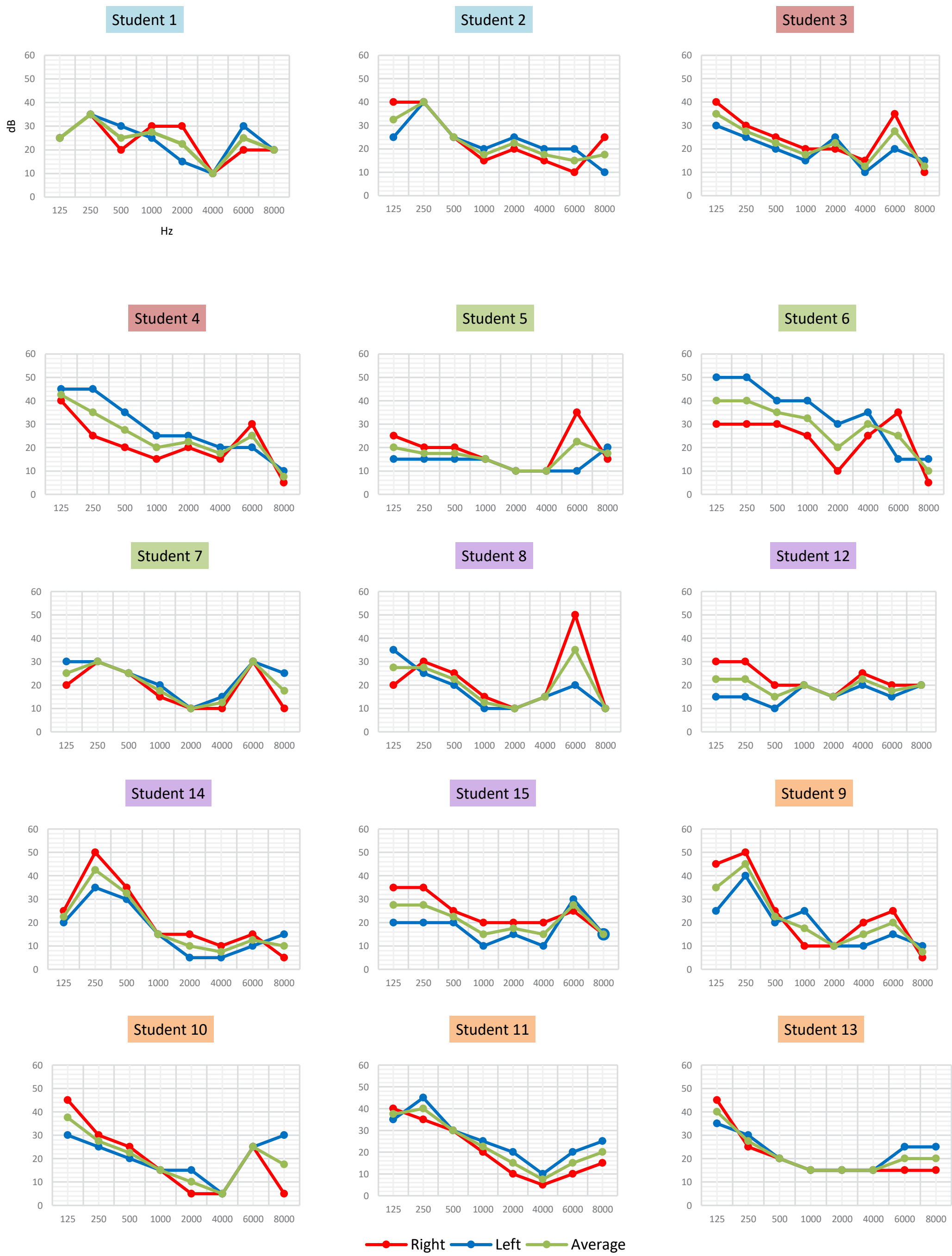


FIG. 5.9 The outcome of the audiometric test for each student.

5.3.2 Bodily responses

5.3.2.1 Bodily responses in the test chambers

The averaged responses of the 15 students to the four indicators during the eight sound conditions of the experiments in the test chambers are presented in **Figure 5.10**. In general, these four indicators fluctuated during the different sound conditions. AL increased mostly during the 'high rural' and 'high talking people' conditions by 15% and 14%, respectively. MRL increased mostly during the 'low rural' and 'low traffic' conditions by 6% and 5%, respectively. HR decreased mostly during the 'high ventilation' and 'low ventilation' conditions by 11% and 10%, respectively. RR increased mostly during the 'low traffic' condition (2%).

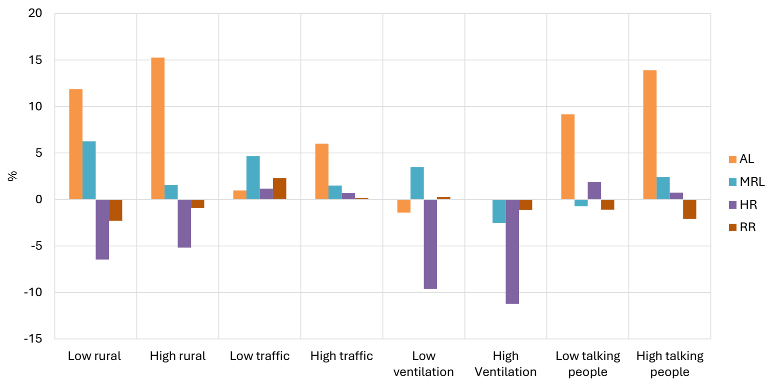


FIG. 5.10 Percentage of change in bodily responses of the group-level in the test chambers.

At individual-level, the four bodily responses differed among the 15 participants in the test chambers (see **Figure 5.11**). Also, bodily responses of several participants differed from the average of the group. Examples:

- AL decreased the most during both 'low rural' and 'high rural' conditions for students 2, 8, 10, and 12.
- MRL decreased the most for students 1, 3, 4, 8, 10, and 13 during 'low rural' and 'high rural' conditions, while for students 3, 14, and 15 MRL decreased the most during the 'high traffic' condition.
- HR increased the most during the 'high rural' condition for students 6, 9, and 15. RR increased the most during the 'high rural' condition for students 1, 6, and 7.
- RR increased the most during the 'high ventilation' condition for students 7, 8, and 14.

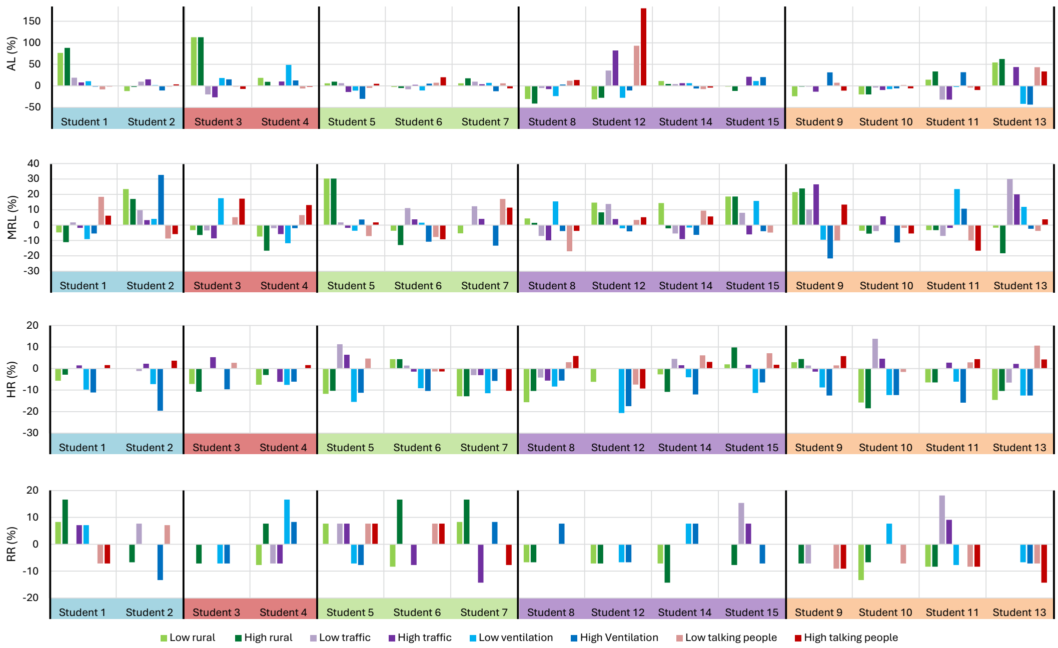


FIG. 5.11 Percentage of change in bodily responses per student in the test chambers

5.3.2.2 Bodily responses in the Experience room

Figure 5.12 shows the average percentage of change of the four bodily responses of the 14 students among the eight conditions in the Experience room. AL declined during all eight conditions, especially during the 'high traffic', 'high talking people', 'low traffic', and 'low talking people' by 14%, 11%, 11%, and 9%, respectively. In contrast, MRL increased during most of the conditions, especially during the 'high ventilation', 'high traffic', and 'low talking people' by 10%, 9%, and 9%, respectively. RR increased mostly during the 'low ventilation' and 'high ventilation' conditions, 5% and 4% respectively.

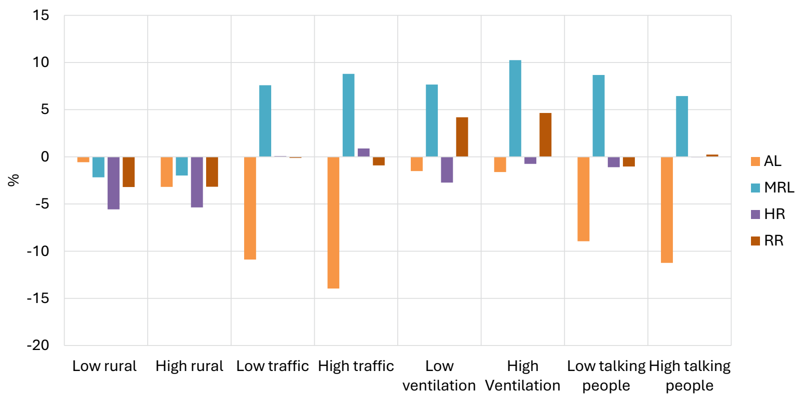


FIG. 5.12 Percentage of change in bodily responses of the group in the Experience room.

The four bodily responses differed among the 14 participants within the eight conditions in the Experience room (see **Figure 5.13**). In addition, the bodily responses of several participants differed from the average of the group. Examples:

- AL increased the most during the 'high ventilation' condition for five students (4, 11, 13, 14, and 15).
- MRL decreased the most for four students (2, 4, 11, and 14) during the 'high talking people' condition.
- HR increased the most during the 'high rural' condition for three students (3, 5, and 6).
- RR increased the most during the 'high rural' condition for four students (2, 6, 9, and 14).

FIG. 5.13 Percentage of change in bodily responses per student in the Experience room.

5.3.2.3 Differences in bodily responses between the two experiments

The normality test (Shapiro-Wilk) of the bodily responses showed that all bodily responses were normally distributed, except for MRL, which was not normally distributed in the Experience room ($p=0.01$). Therefore, a t-test was performed for all bodily responses, except for MRL of which a Wilcoxon signed-rank test was computed to test the differences between the bodily responses of the 14 students who participated in both tests, in general and per condition. The differences between the mean bodily responses showed that only AL significantly differed between the two tests ($p<0.001$), while other bodily responses: MRL ($p=0.16$), HR ($p=0.33$), and RR ($p=0.54$) showed no significant differences. **Table 5.2** shows the results of the differences between the bodily responses of the 14 students per condition between the two tests. AL significantly differed between the two experiments of three conditions: ‘low traffic’, ‘high traffic’, and ‘low talking people’ while the MRL only differed significantly among the ‘low rural’ condition. HR also differed significantly between the two experiments of three conditions: ‘low ventilation’, ‘high ventilation’, and ‘low talking people’. RR showed no significant differences between the two tests among the eight conditions.

TABLE 5.2 The probability of differences in the bodily responses between two experiments per condition at group-level.

Condition	AL	MRL	HR	RR
Low rural	0.28	**0.05**	0.95	0.56
High rural	0.19	0.31	0.76	0.57
Low traffic	**0.03**	0.73	0.90	0.26
High traffic	**0.03**	0.11	0.79	0.72
Low ventilation	0.95	0.68	**P<0.001**	0.08
High Ventilation	0.85	0.32	**P<0.001**	0.12
Low talking people	**0.02**	0.15	**0.03**	0.86
High talking people	0.10	0.93	0.65	0.40

Table 5.3 presents the differences in the bodily responses at individual-level. AL significantly differed between the two tests among seven students. MRL showed significant differences between the two tests among three students. HR significantly differed among two students only. Conversely, RR showed no significant differences between the two tests among all 14 students.

TABLE 5.3 The probability of differences of the bodily responses between two experiments at individual-level.

Profile	Student	AL	MRL	HR	RR
1	1	0.14	0.96	0.67	0.16
	2	0.77	**0.02**	0.72	0.98
2	3	**0.006**	**0.04**	0.20	0.25
	4	0.61	0.51	0.61	0.25
3	5	0.51	0.53	0.28	0.60
	6	**0.03**	**0.05**	0.15	0.59
	7	0.23	0.16	**0.004**	0.42
4	8	**P<0.001**	0.06	**0.04**	0.69
	12	0.08	0.09	0.56	1.00
	14	**P<0.001**	0.80	0.53	0.82
	15	**P<0.001**	0.08	0.36	0.67
5	9	**P<0.001**	0.58	0.15	0.91
	11	**P<0.001**	0.95	0.53	0.31
	13	0.21	0.47	0.65	0.17

5.3.3 Perceptual assessment

5.3.3.1 Perceptual assessment in test chambers

Figure 5.14 shows the average scores of three perceptual assessments for eight different conditions in the test chambers among the 15 students. It was observed that ‘low rural’, ‘low traffic’, and ‘low ventilation’ were the most acceptable conditions. Conversely, the ‘high talking people’ was perceived as the least acceptable, the least pleasant and the most stressful condition. The ‘low traffic’ condition was considered the most pleasant condition. Furthermore, ‘low rural’, ‘high rural’, ‘low traffic’, ‘low ventilation’, and ‘low talking people’ were perceived as the least stressful condition. The perceptual assessment of the eight conditions in the test chambers varied among the 15 students as shown in Figure 5.15, showing several differences among the 15 students from the different profiles.

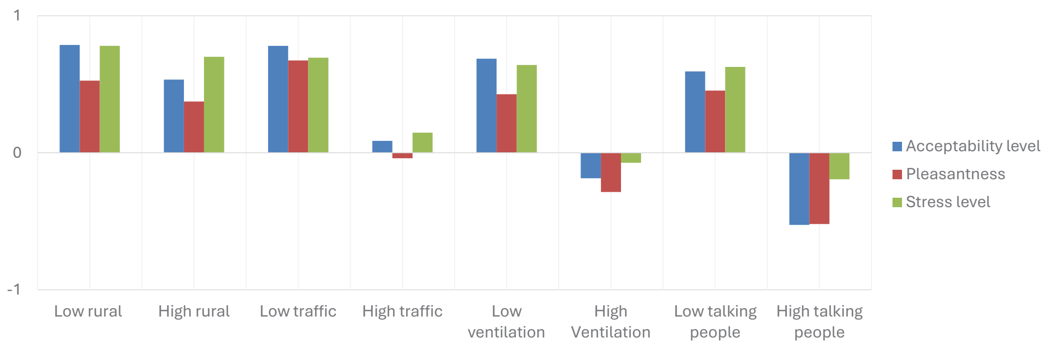


FIG. 5.14 Average perceptual assessments of the group during the eight conditions in the test chambers.

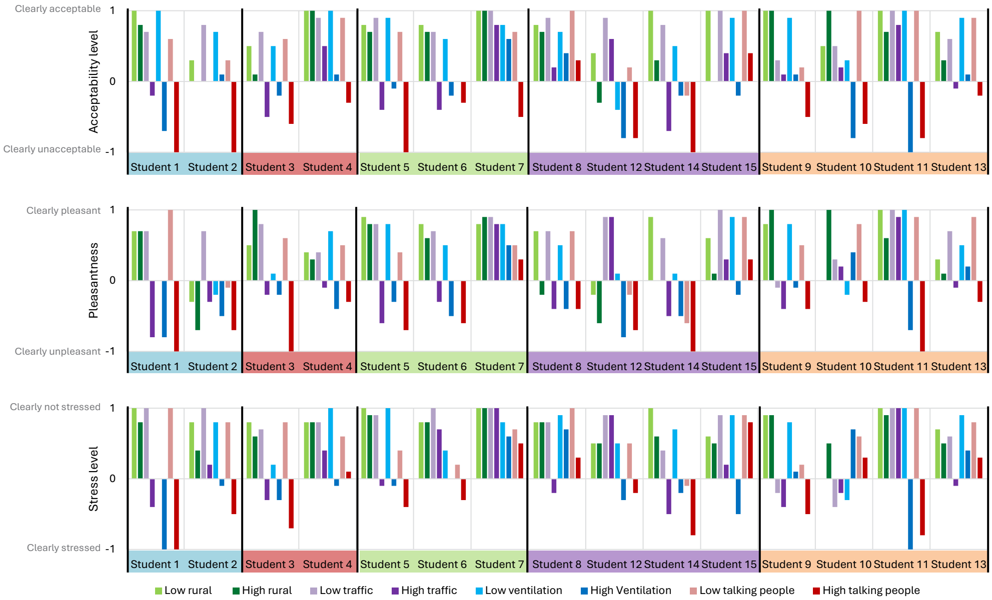


FIG. 5.15 Perceptual assessments per student in the test chambers

5.3.3.2 Perceptual assessment in the Experience room

Figure 5.16 shows the average of the two perceptual assessments of the eight conditions in the Experience room for the 14 students. ‘Low rural’, ‘low traffic’, and ‘low ventilation’ were perceived as the most acceptable and the least noisy conditions. ‘High talking people’ and ‘high ventilation’ were perceived as the least acceptable conditions; and both ‘high traffic’ and ‘high talking people’ were perceived as the noisiest conditions. Figure 17 shows the two perceptual assessments of the eight conditions in the Experience room at individual-level, showing some differences among the 14 students.

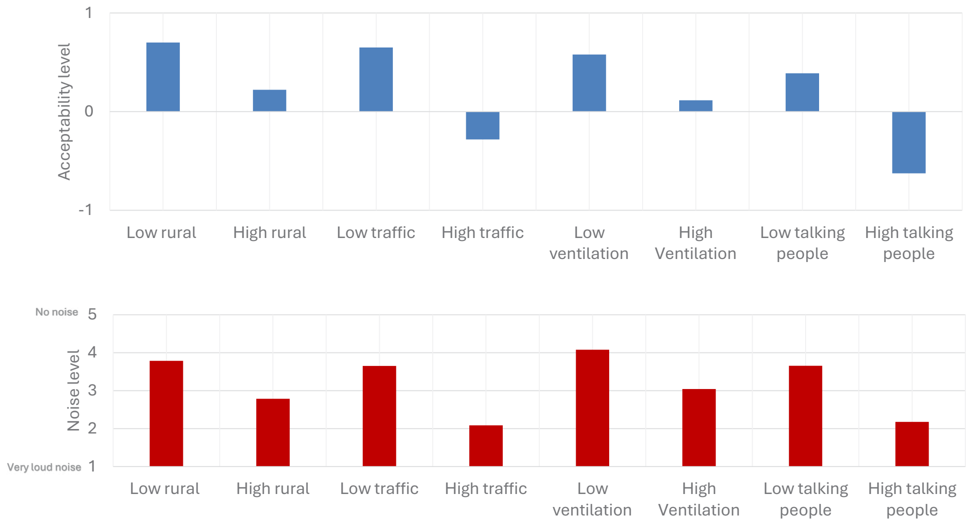


FIG. 5.16 Average perceptual assessments of the group in the Experience room.

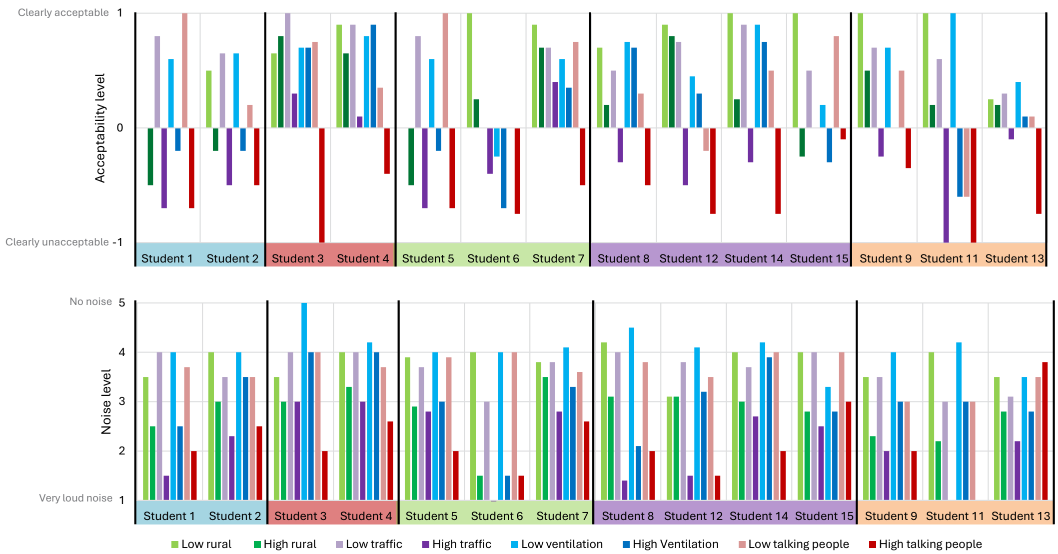


FIG. 5.17 Perceptual assessments per student in the Experience room.

5.3.3.3 Differences in the perceptual assessment

The means of the acceptability level among the eight conditions perceived by the 14 students showed no significant differences between the two experiments (p=0.12). The acceptability of 'high traffic' differed significantly between the two experiments (p=0.05). Other conditions showed no significant differences (**Table 5.4**). The mean of the acceptability levels among the eight conditions between the two experiments at individual-level (**Table 5.5**) differed significantly for seven students: student 3 (p=0.05), student 6 (p=0.03), student 7 (p=0.01), student 8 (p=0.04), student 13 (p=0.01), student 14 (p=0.03), and student 15 (p=0.01).

TABLE 5.4 Differences in perceptual assessments (acceptability) between the two experiments per condition at group level.

Condition	P-value
Low rural	**0.03**
High rural	0.12
Low traffic	0.90
Low ventilation	0.27
High ventilation	0.09
Low talking people	0.29
High talking people	0.34

TABLE 5.5 Differences in perceptual assessments (acceptability) between the two experiments per condition at individual-level.

Student	P-value
1	0.40
2	0.51
3	**0.05**
4	0.50
5	0.32
6	**0.03**
7	**0.01**
8	**0.04**
9	0.74
11	0.11
12	0.40
13	**0.01**
14	**0.03**
15	**0.01**

5.3.4 Correlations between bodily responses and perceptual assessments

5.3.4.1 Correlations between responses in the test chambers

The results of the correlations between each of the four bodily responses and three perceptual assessments at group-level are shown in **Table 5.6**. No strong nor significant correlations between the three bodily responses AL, HR, and RR and the three perceptual assessments were found. MRL showed strong and positive but not significant correlations with acceptability, pleasantness, and stress level.

TABLE 5.6 Correlations between bodily responses and perceptual assessments in the test chambers at group-level.

Bodily responses vs perceptual assessments	R	P-value
AL vs Acceptability	-0.2	0.69
AL vs Pleasantness	-0.1	0.74
AL vs Stress level	0.2	0.65
MRL vs Acceptability	**0.7**	0.06
MRL vs Pleasantness	**0.6**	0.14
MRL vs Stress level	**0.6**	0.10
HR vs Acceptability	0.0	0.91
HR vs Pleasantness	0.3	0.49
HR vs Stress level	-0.1	0.87
RR vs Acceptability	0.2	0.57
RR vs Pleasantness	0.3	0.42
RR vs Stress level	0.1	0.74

The correlations between the four bodily responses and the three perceptual assessments in the test chamber at individual-level differed among the students (see **Appendix K**).

5.3.4.2 Correlations between responses in the Experience room

Table 5.7 shows the correlations between each of the four bodily responses with the two perceptual assessments at group-level. AL was strongly, positively, and significantly correlated with both perceptual assessments: acceptability and noise level. HR showed a strong and negative as well as a significant correlation with noise level, meaning that HR increased when the condition was perceived as a loud noise. In addition, HR was strongly and negatively correlated with acceptability, although this correlation was not statistically significant. MRL and RR did not show strong nor significant correlations with the two perceptual assessments.

TABLE 5.7 Correlations between bodily responses and perceptual assessments in the Experience room at group-level.

Bodily responses vs perceptual assessments	R	P-value
AL vs Acceptability	**0.6**	**0.03**
AL vs Noise level	**0.8**	**P<0.001**
MRL vs Acceptability	-0.4	0.22
MRL vs Noise level	-0.2	0.57
HR vs Acceptability	**-0.5**	0.10
HR vs Noise level	**-0.6**	**0.04**
RR vs Acceptability	-0.4	0.25
RR vs Noise level	0.0	0.89

The correlations between the four bodily responses indicators and the two perceptual assessments differed among the 14 students (see **Appendix L**).

5.4 Discussion on lab experiments findings

5.4.1 Key findings

In the present study, it was investigated which bodily responses can be measured to explain differences in preferences and/or needs of university students from different profiles while being exposed to different sounds in two settings. Four main findings are discussed below: the audiometric test, the perceptual assessments of the different profiles, correlations between bodily responses and perceptual assessments, and direct and indirect sound exposure.

5.4.1.1 The audiometric test

Six students (3, 4, 6, 10, 11, and 13) suffered from mild hearing loss in low-frequency sounds (Figure 8). Interestingly, these students belong to the profiles who are sound partially concerned or sound unconcerned (students 3 and 4 are sound unconcerned introverts, student 6 is a sound partially concerned introvert, and students 10, 11, and 13 are sound unconcerned extroverts). Moreover, student 6's HR increased the most while being exposed to the low-frequency sound stimuli: the 'low rural' condition in the test chamber's experiment but found it most acceptable. Similarly, student 13, had the highest HR increase in the same condition in the Experience room's experiment but perceived it as slightly noisy and acceptable. These observations could mean that even though the student could not hear the sound source at a certain SPL, the body responded physiologically. Mackersie et al. [23] highlighted that participants with hearing loss may experience increased effort and stress during speech recognition in noisy environments, which could influence the psychophysiological responses concerning the autonomic nervous system. This might explain the increased HR in students 6 and 13, who likely expected to hear a sound during the 'low rural' condition but did not, leading to stress and a rise in HR. Therefore, hearing acuity seems an essential indicator to consider in sound exposure experiments that could explain a person's acoustical preferences and needs.

5.4.1.2 Perceptual assessments and the five profiles

Several differences in perceptual assessments were observed at group, individual, and profile levels. For example, in the test chamber (as illustrated in Figure 15), six students (1, 3, 5, 6, 13, and 14) deemed the 'high traffic' condition as unacceptable, noting that four of these students are from profiles 1, 3, and 4 who are sound concerned. In terms of pleasantness, students 2, 8, and 12 (from profiles 1 and 4) perceived the 'high rural' condition as unpleasant, confirming that these students are sound concerned. Conversely, five students (7, 10, 11, 12, and 15) found the 'high traffic' condition as pleasant. Interestingly, these students are exposed to traffic sounds at their home study place (**Appendix H**), which might result in the habituation of this sound type. Another example, concerning stress levels, six students (4, 7, 8, 10, 13, and 15) perceived the 'high talking people' condition as not stressful, of which four of them belong to the extrovert profiles: 4 and 5. Pertaining to the perceptual assessments in the Experience room (Figure 17), both students 1 and 2 who belong to the 'sound extremely concerned introvert' profile perceived the 'high rural' condition as unacceptable, which confirms that these two students are extremely sound concerned. Hence, these findings substantiate the conclusions of Hamida et al. [32]: students from different profiles differ in their acoustical preferences.

5.4.1.3 Correlations between bodily responses and perceptual assessments

Bodily responses did not show strong or significant correlations with perceptual assessments at the group-level in the test chamber experiment, except for MRL. Although MRL showed a strong and positive correlation with the three perceptual assessments, this correlation was not statistically significant. At the individual-level, only two students (students 6 and 12) displayed a strong and positive correlation between their MRL and acceptability. Additionally, student 6's MRL was strongly, positively, and significantly correlated with pleasantness. Conversely, student 4's MRL was strongly and significantly, but negatively, correlated with the perceptual stress level. Since MRL is not significantly correlated with perceptual assessments, it could be used as an independent bodily response alongside the other three bodily responses which did not show strong nor significant correlations, separate from perceptual assessments.

In the Experience room experiment, AL was strongly, positively, and significantly correlated with both acceptability and noise levels at group-level. It implies that when the sound condition was perceived as 'acceptable' and 'no noise', AL increased, and vice versa. Similarly, for individual students 6 and 7, AL showed strong, positive, and significant correlations with acceptability perceptual assessments. Furthermore, student 8's AL was strongly, positively, and significantly correlated with the perceived noise level. Additionally, HR was strongly, negatively, and significantly correlated with noise levels during the Experience room experiment at group-level: HR increased as the noise level was perceived as loud of which SPL was set at a high level. This finding aligns with Lorenzino et al. [52], who concluded that noise levels ranging from 30 to 55 dB(A) significantly impacted acoustical comfort, with higher noise levels correlating with increased HR and psychological discomfort. It also corroborates Abbasi et al. [14], who found that HR significantly differed among various sound levels of low-frequency noise. Moreover, Latini et al. found a strong association between pulse rate and soundscape response of which the pulse rate decreased with perceived pleasant sounds and increased with perceived unpleasant sounds [53]. Thus, HR is a significant bodily response indicator associated with the noise level and sound type (i.e., soundscape).

In summary, the four bodily responses are generally independent of the perceptual assessments. This indicates that perceptual assessments cannot be reliably predicted from bodily responses, nor can bodily responses be predicted from perceptual assessments. This also confirms the study by Erfanian et al. [54] that soundscape studies should consider both bodily responses and perceptual assessments (i.e., psychological) to understand better how and why individuals experience the sound environment in such way. However, our study shows that HR is an exception, as it can explain the perceptual assessment related to the perception of the noise level corresponding to the SPL as a physical indicator. In addition, AL is an exception that could explain both acceptability and noise level.

5.4.1.4 Direct sound exposure vs indirect sound exposure

The present study compared bodily responses and perceptual assessment between two experimental settings: direct sound exposure (laboratory setting in the test chambers) and indirect sound exposure (semi-real life setting in the Experience room). At group-level, the mean AL among the eight conditions varied significantly between the two experiments, particularly under the ‘low traffic’, ‘high traffic’, and ‘low talking people’ conditions. These significant changes were also observed at individual-level for seven students. Conversely, the acceptability assessments did not show significant differences between the two experiments. Given the significant differences in AL between the two experiments at both group and individual levels (among seven students), it appears that this bodily response might be affected by the differences in the experimental setup between the two experiments. Additionally, MRL differed significantly between the two experiments among three students and differed in the first condition ‘low rural’ at group level, which showed decreases in the second experiment. These differences might be linked to the experimental procedure. It can be also noted that the sound exposure time for both experiments lasted two minutes per condition. Thus, both AL and MRL could be more reliable bodily responses for longer sound exposure durations, such as 5 [14,51] or 10 minutes [7]. Furthermore, these two bodily responses could be measured in sound exposure experiments that involve performance tasks, such as testing mental fatigue [14] or attention based on a cognitive task [7], which could explain differences in performances. Both HR and RR showed no significant differences between the two experiments at group level. However, HR did show significant differences under ‘low ventilation’ and ‘high ventilation’ conditions with a greater decrease observed in the first experiment. This difference may be related to the fact that the student moved between chambers prior to these two conditions. Also, significant HR differences were only observed in two individual students. Moreover, HR was significantly correlated with the noise level. Therefore, HR and RR seem applicable for explaining differences in acoustical preferences and needs within short-term sound exposure experiments. These two bodily responses can be measured in real-life situations, such as a study place, since no differences were observed between the two experiments as well as they were normally distributed among students in both experiments.

5.4.2 Strengths and limitations

This study represents a first attempt to investigate university students' bodily responses and perceptual assessments, accounting for their varying acoustical and psychosocial preferences and needs, across multiple levels: group, individual, and profile levels. Through lab experiments, it enhanced the understanding of students' acoustical preferences, previously classified into five profiles [32]. Another notable strength of this study is the audiometric test conducted with 15 students, in which hearing thresholds at different frequencies (for both ears) were examined, based on the WHO guidelines [37]. Additionally in this study, bodily responses and perceptual assessments in two distinct settings were compared: a laboratory setting in test chambers and a semi-real life setting in the Experience room.

Despite the novel contributions of this study, it has some limitations. First, the sample size is relatively small, comprising 15 students (power: 1-β=0.6) from the Faculty of Architecture and the Built Environment, all of whom had participated in a previously conducted study [32]. Second, the distribution of students across the five profiles was uneven, though a minimum of two students per profile were included. Third, one student (student 10) did not participate in the Experience room experiment, reducing the sample size for the comparative analysis to 14 students. While perceptual assessments supported the acoustical preferences associated with each profile, the small sample size limits the generalisation of these findings. Fourth, the measured SPL of the same sound type differed between the earbuds (direct exposure) and the speakers (indirect exposure) which might be related to that sounds in the Experience room diffused and absorbed within the room. Fifth, the sound conditions of both experiments were not randomised among the different groups of students due to the small sample size per group (3 or 4 students) and only four groups. Finally, the bodily responses data were calculated as mean values for the two-minute exposure time rather than the real-time measurements per second due to the limitations of the Garmin smartwatch that exports the HR and RR data per two-minutes.

5.4.3 Implications and future research

The interpretation of the key findings of this study (as detailed in section 4.1) provides insights for future researchers in the design and set-up of sound exposure experiments aimed at investigating participants' bodily responses to and perceptual assessments of sounds.

First, the audiometric test is a critical procedure with the potential to elucidate participants' bodily responses and perceptual assessments when exposed to specific sound types. Second, profiling participants (e.g., students) based on their acoustical preferences could provide a clear understanding of their perceptual assessments of different sounds. Third, HR and RR are reliable and robust indicators of bodily responses that can be effectively measured using simple wearable devices, demonstrating clear reactions to short-term sound exposure. Lastly, given the lack of strong or significant correlations between bodily responses and perceptual assessments, it is imperative to consider both independently in sound exposure research.

Because of the sample size limitations as this is a follow-up study of a specific pool of students, it is recommended for future research to recruit at least 26 students per profile (of which the power level is $1-\beta=0.8$, as indicated by Park et al. [48]). This could better present the results per profile rather than per individual, such as performing the correlations between the bodily responses and perceptual assessments per profile and testing whether the profile is a significant variable. Furthermore, it is recommended for future sound exposure experiments to randomise the sound conditions to acquire comprehensive results in explaining how bodily responses can be used to explain differences in sound perceptions and preferences. Given the fact that the HR and RR showed no significant differences between the two experiments, it is encouraged to also measure them in a real-life situation, such as a real study place.

5.5 Conclusions

This study conducted two sound exposure experiments with 15 university students from five profiles who differ in their acoustical preferences of their study places. Each experiment included four bodily responses (AL, MRL, HR, and RR) and five perceptual assessments (acceptability, pleasantness, stress level, and noise level), while students were exposed to four sound types varying in frequencies and SPLs in two different settings. The key findings are summarised as follows:

1. The relationship between hearing acuity and bodily responses (such as HR) and sound perception seems to be essential for better understanding how our body responds to sound. It was observed that although students suffered from mild hearing loss in low frequency, their bodies physiologically responded when they were exposed to a low-frequency sound condition.
2. The outcomes from this study showed that the perceptual assessment in a lab experiment setting confirmed the acoustical preferences of the five profiles of university students.
3. This study found that both HR and RR were not strongly nor significantly correlated with perceptual assessments during direct sound exposure in the test chamber. HR was strongly and significantly related to the perceptual assessment of noise level in the Experience room.
4. Both HR and RR showed no significant differences between the two experiments of this study. This implies that they are reliable for explaining acoustical preferences and can be measured in real environments as well since they showed no differences between the two settings: a laboratory setting in test chambers and a semi-real-life room setting in the Experience room. In contrast, AL and MRL were affected by the experimental setting and procedure in this study, which could be more reliable for a longer sound exploration of experiments and/or involve performance tasks.

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6 Indoor Soundscape Approach of University Students’ Home Study Places

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ABSTRACT

University students spend a considerable time at study places. The acoustical quality of these study places is one of the indoor environmental qualities (IEQ) that can have an impact on student’s health, comfort, and performance. The indoor soundscape approach has been introduced to better understand occupants’ sound perception and experience of sounds in relation to the environment. This study aims to explore the indoor soundscapes of home study places of these students by conducting semi-structured interviews with 23 university students with different profiles. For qualitative analysis, open coding was used. Sub-categories, based on the codes, and categories were created and assigned to the soundscape themes that are defined in ISO 12913-1. An affinity diagram consisting of the themes, categories, and sub-categories was initially developed. Then, it was validated through two workshops with participants. The results showed that the interpretation of the sound environment, responses, and outcomes differed among the students. In a previous study, 451 students were clustered in 5 clusters with similar acoustical preferences (profiles). Therefore, it is recommended to consider making the indoor soundscape approach applicable for different profiles of occupants.

KEYWORDS

Soundscape; indoor soundscape; workshop; semi-structured interviews; home study places.

6.1 Introduction

Research has shown that university students spend their studying time in study places (i.e., informal learning spaces), such as home or educational buildings [1–3]. University students mainly perform cognitively demanding tasks in these spaces, such as reading, writing, and problem-solving activities [4]. In general, people are exposed to different environmental stimuli while staying indoors, which are related to indoor environmental quality factors (IEQ), including indoor air quality, thermal comfort, visual quality, and acoustical quality. These qualities can affect people's health and performance [5,6], and they are strongly related to students' well-being [7]. During the COVID-19 pandemic, a study showed that students stayed at home for 20 hours per weekday resulting in suffering from home-related symptoms, including headache and tiredness [8]. Hence, well-designed home study places that align with students' preferences and needs are significant for promoting both health and performance [9].

Acoustical quality is one of the four IEQ factors that influences students' well-being in study places [10,11]. Previous studies have focused on the adverse effects of background noise on students' health, comfort, and performance [12]. Little is known about the students' sound preferences of their study places [13]. The soundscape approach enables to explore in-depth how individuals experience the sound environment for a certain context [14]. It consists of several data collection methods, including questionnaire, interviews, and sound level measurements [15]. While this concept was developed for the urban environment context, it has been applied in the indoor environment context [16]. However, indoor soundscape studies within the context of educational and study places are still limited [13].

Few studies have investigated until now the indoor soundscapes in the context of learning and studying environments. For instance, Visentin et al. [17] explored the indoor soundscapes of primary school classrooms. They concluded that sounds generated by pupils were the most frequent and perceived as unpleasant sounds by them, while they prefer the presence of calm sounds such as music and natural sounds. Topak and Yılmazer [18] investigated the indoor soundscapes of classrooms and computer laboratories of a high school building. They also found that natural sounds and low music levels were evaluated positively by students. They concluded that students' sound perception was not only related to sound level but was associated with the context. However, these two studies were focused on the context of a classroom setting.

In terms of the context of study places, Acun and Yilmazer [19] assessed the indoor soundscapes of four open study places on a university campus. They explored the sound sources, students' reactions, coping methods, and their sound perceptions of these places using quantitative research methods comprising questionnaires and sound level measurements. The study revealed that students' sound perceptions did not correlate with the sound level. During the COVID-19 pandemic, Dzhambov et al [20] explored the relationship between the indoor soundscape of university students' homes and their self-reported health using a questionnaire. The questionnaire included questions related to the most frequent sounds present at home, students' sound perception concerning the pleasantness of these sounds, health, and building characteristics. They found that mechanical sounds (e.g., home appliances, construction, and sirens) were associated with low self-reported health of the students.

To date, there is still limited information about the sound experience of students at their home study places within the context of studying. Therefore, this study aims to answer the following research question: To what extent can the soundscape approach be used to assess the sound environment experience of each student at their home study place?

6.2 Methods of indoor soundscape approach

A qualitative research design, comprising a semi-structured interview and two workshops (see **Figure 6.1**), was applied to explore the sound environment experience of each student at his/her home study place. Additionally, building inspections data and sound pressure level (SPL) measurements, of which the collection is described in [21], were used.

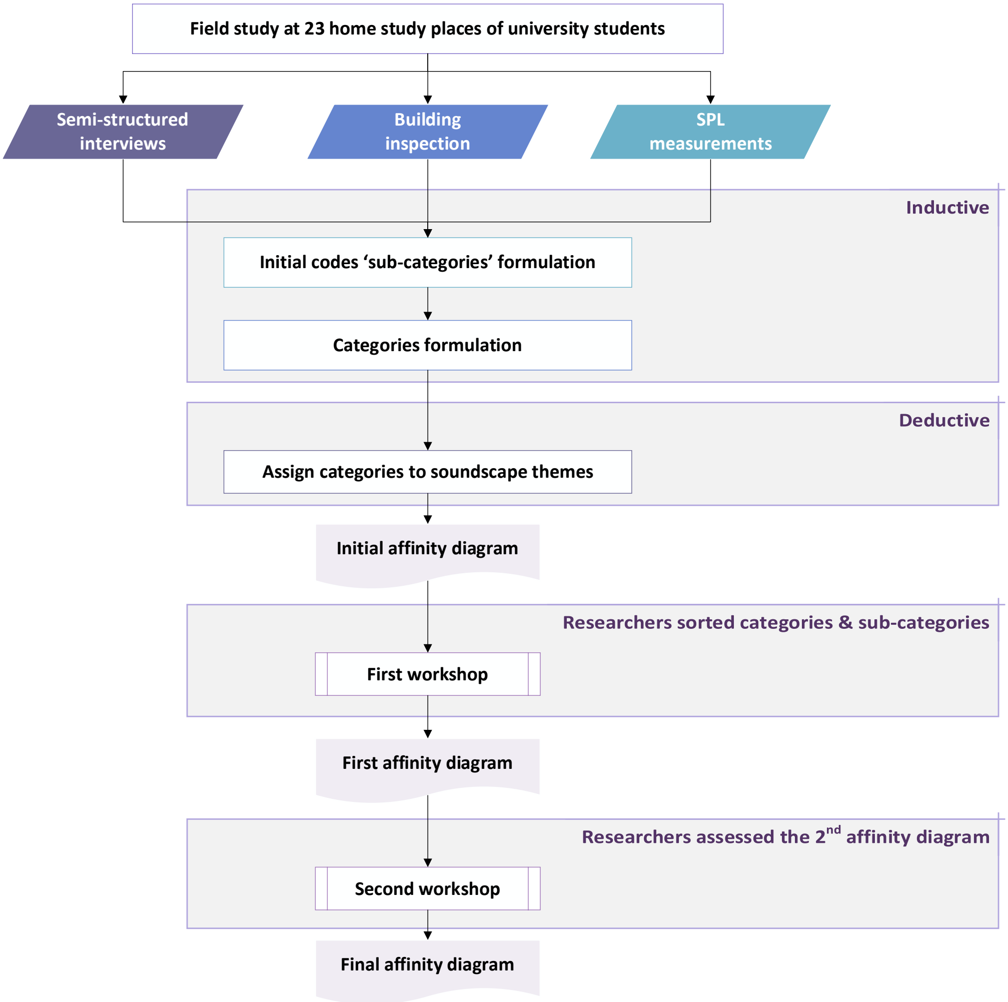

FIG. 6.1 Overview of the study design.

6.2.1 Semi-structured interviews with students

23 university students accepted to participate in this study, which took place between November 2022 and February 2023 in the Netherlands (who participated in studies of Chapters 3-5). Each of them received an invitation email, including the interview questions and a consent form which they were asked to sign [21]. An offline audio recorder device (TASCAM DR-05X) was used to record the interview

with the consent of the student. Generally, interviews lasted for 15 to 30 minutes. The interview with each student included eight sound environment-related and psychosocial aspects (e.g., privacy) questions, presented in **Table 6.1**. These questions are related to the seven elements of soundscapes that are defined in ISO 12913-1 [14], which are context, sound source, sound environment, auditory sensation, interpretation of auditory sensation, responses, and outcomes. While most of these questions were extracted from ISO 12913-2 [15], three of them were introduced by the authors (questions 4, 7, and 8).

TABLE 6.1 Interview sections and questions.

Questions	Theme
1. What are the study-related activities you often do when you are in your study place?	• Context
2. Which sounds are present at your home study place?	• Sound sources • Sound environment
3. What do you do when you are exposed to sounds you mentioned when you are at your study place? (*explained in a scenario*)	• Responses
4. In your opinion, when do you think that a specific sound is considered a noise while you are at your home study place?	• Interpretation of auditory sensation
5. Are there any sound(s) that you prefer that stimulate you during your study-related activities at your study place? [21]	• Sound sources • Outcomes
6, How do you think sound can be controlled?	• Responses
7. What do you think the optimal sound environment for your study place should look like? [21]	• Sound sources • Sound environment • Outcomes
8. How can you define the meaning of privacy in your home study place?	• Context

6.2.2 Data management and analysis

Each of the audio recording files was anonymized and transcribed into verbatim transcription. Then these transcriptions as well as the building inspections and SPLs were inductively coded (in vivo coding) using ATLAS. ti 23 software by applying the Gioia method [22]. Next, the initial codes (n=776) of the eight questions under the sound environment section were exported into an Excel file, in which these codes were organised under their related interview questions. Then, focused coding was done by assigning labels to the initial codes. Constant comparisons between these labels were done iteratively to eliminate repeated labels and reduce code numbers (n=557). After that, each label was categorised deductively under one of each of the seven pre-determined themes extracted from ISO12913-1. Finally, an axial coding was done where similar labels under each theme were grouped (n=139) and they were labelled with a category (23 categories formulation). The qualitative results including themes, categories, and sub-categories were illustrated in an initial affinity diagram.

6.2.3 Workshop

Two workshops were conducted to validate the initial affinity diagram and to avoid subjective bias. The facilitator sent an invitation email to the participants (PhD students from the Faculty of Architecture and the Built Environment at TU Delft) which included reading materials about the soundscape themes as defined in ISO12913-1. Both workshops were conducted in meeting rooms at the Faculty of Architecture and the Built Environment at TU Delft. The first workshop was conducted on the 23rd of June 2023 and the second one on the 6th of July 2023.

6.2.3.1 First workshop

The first workshop aimed to validate and assess the relevance of the categories to the themes as well as the sub-categories to the categories. This workshop was facilitated with seven participants. The facilitator organised seven empty boards (**Figure 6.2**), each representing one of the soundscape themes with its definition. The participants used three materials in three different stages within the workshop, which are yellow cards, purple cards, and black dots. A list of 23 categories was presented in a yellow card which were presented in random order. First, the facilitator asked the participants to assign collaboratively the list of 23 categories to their relevant soundscape themes. Then, the facilitator gave each participant a list of sub-categories presented in randomly organised purple cards. After that, each participant voted on the relevance of each sub-category to its assigned category using the black dots. Finally, the facilitator opened a discussion with the participants on the sub-categories that received three or less than three votes if it could be assigned to different categories.

FIG. 6.2 The first workshop setup comprised seven empty boards.

After the workshop, the affinity diagram resulted in seven themes, 22 categories, and 133 sub-categories. Additionally, two categories with in total 14 sub-categories were not assigned to any of the seven themes and received less than three votes. Next, 59 sub-categories and three categories that received less than three votes and were assessed to be not relevant to the data structure, were eliminated. It should be noted that this elimination included the whole theme ‘auditory sensation’ because of its relation to the physiological and psychological state of the ear (such as noise sensitivity [17]), which was not accounted for in this study. This resulted in the first affinity diagram comprising six themes, 19 categories, and 73 sub-categories.

6.2.3.2 Second workshop

In the second workshop, aimed to validate the first affinity diagram, six of the seven participants that participated in the first workshop, were asked to assess the relevance of each category to its assigned theme as well as each sub-category to its assigned category in the updated affinity diagram. The facilitator prepared the workshop by placing the categories and sub-categories of each theme on its corresponding board (**Figure 6.3**). Only the black dots were used by participants in this workshop. Hence, each participant was asked to vote first on the relevance of each category to its assigned theme, and then the relevance of each sub-category to its assigned category. This was followed by an open discussion on the categories and sub-categories that received less than three votes during this workshop and the first workshop. This open discussion helped to re-name the unclear categories, re-assign categories to the most relevant theme, and exclude unrelated categories from the affinity diagram. All participants agreed that the two categories with their 14 sub-categories from the first workshop could not fit into none of the themes. Then, three categories and seven sub-categories from the building inspection and the SPL measurements [21], were added to the affinity diagram.

FIG. 6.3 The second workshop setup comprised six theme boards.

6.2.4 Ethical aspects

This study was approved by the Human Ethics Committee (HREC) at Delft University of Technology on the 31st of January 2022. The participants received a voucher for their participation to the workshops.

6.3 Results of indoor soundscape

The indoor soundscapes of the home study places of university students are illustrated in an affinity diagram in **Figure 6.4**, consisting of six soundscape themes (context, sound sources, sound environment, interpretation of auditory sensation, responses, and outcomes), 22 categories, and 80 sub-categories. Each of these themes is explained further in the following sub-sections along the outcome of the interviews and the visits.

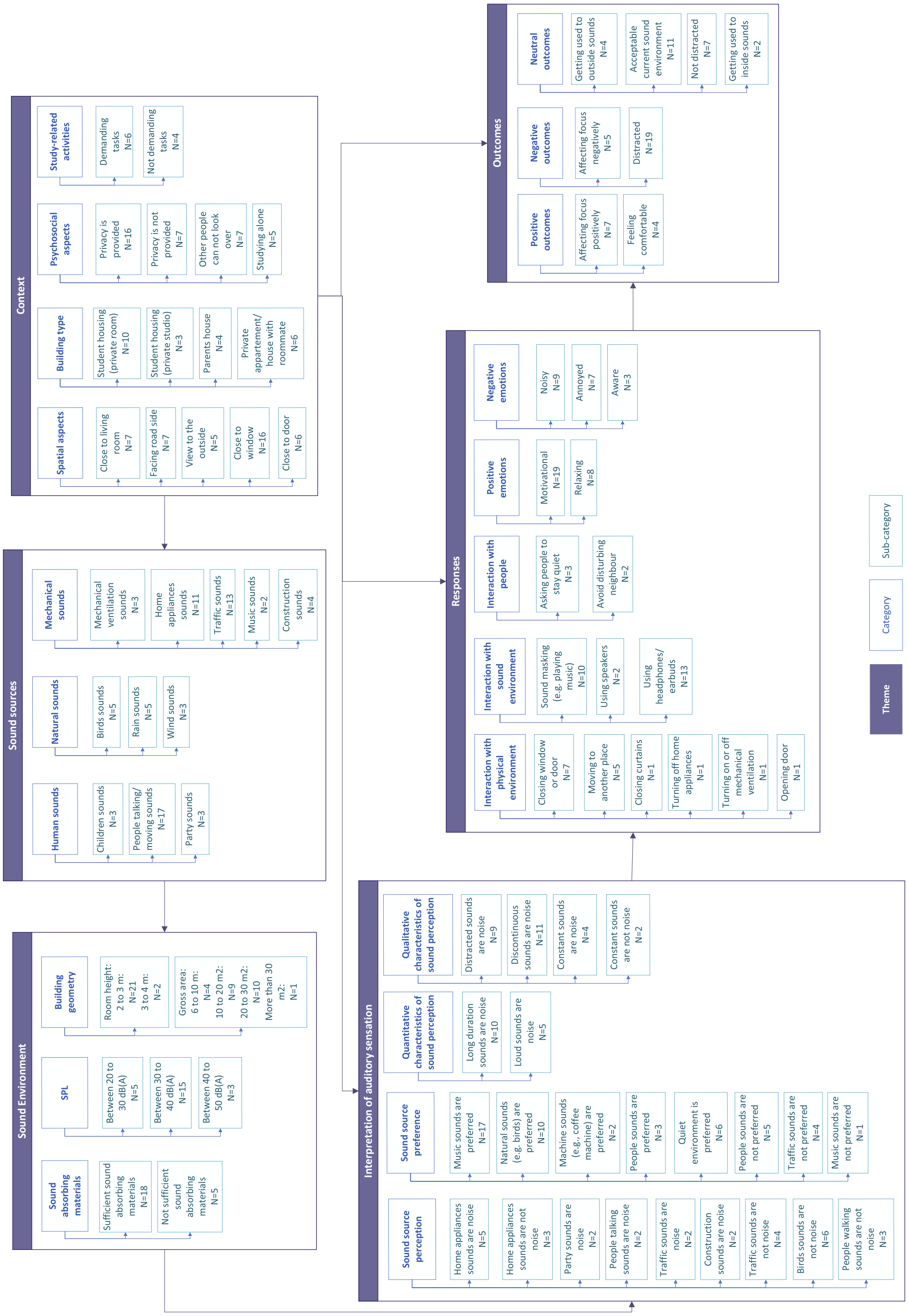

FIG. 6.4 Final affinity diagram comprises themes, categories, and sub-categories of students' experience of the sound environment at their study places.

6.3.1 Context

Context refers to the interrelationship between occupant, building, and activity. The context in home study places consists of four categories that are: 'spatial aspects', 'building type', 'psychosocial aspects', and study-related activities, which all were connected to the context of their study place. The 'spatial aspects' differed among the 23 students. More than half of the students (n=16) placed their home study place close to a window, of which five of them preferred to have a view to the outside or daylight. Seven of these home study places faced a roadside, and seven were adjacent to a living room. With regards to the 'building type', most of the interviewed students were living in student housing, studying either in a private room (n=10) or in a private studio (n=3). The majority of the interviewed students (n=16) claimed that they study at home study places where privacy, a 'psychosocial aspect' is provided. It should be noted that five of these students prefer to study alone, and seven of them did not prefer the presence of others. The 'study-related activities' were strongly connected to the context of the sound environment. Six students indicated that the sound quality of the environment is important for demanding tasks such as studying for an exam.

Student: "*My study place is adjacent to the living room. One day, I was trying to study while one of my roommates invited friends who have relatively loud and low voices. So, I could literally hear them word by word, and I could not study.*"

Student: "*So privacy is important to me when I have to do a very demanding task such as math. I also cannot listen to music while I am doing it.*"

6.3.2 Sound sources

Sound sources refer to the existing sound sources that the interviewed students were exposed to while studying at their home study places. These were attributed to three types: 'human sounds', 'natural sounds', and 'mechanical sounds'. Most of the interviewed students (n=17) were exposed to people talking or moving sounds (from outside or inside). It was found that different students were exposed to different sound sources. More than half of the interviewed students (n=13) were exposed to traffic sounds, five of the students were exposed to natural sounds such as birds, 11 students were exposed continuously to home appliances sounds such as refrigerator, and three students were exposed to mechanical ventilation sounds. Noting that sound sources are related to the context. For example, a student can be continuously exposed to traffic sounds due to the special aspect 'facing roadside'.

Student: "*From the inside, I hear sounds of people walking and sometimes making noise*."

Student: "*From the outside, I clearly hear noises from the busy road because the window has a single glazing which is not absorbing sounds from the outside*."

6.3.3 Sound environment

The sound environment refers to how a certain sound is propagated inside an indoor environment. Based on the data from [21], three categories were found to be related to the sound environment of home study places: the 'sound absorption materials', 'SPL', and 'building geometry' (e.g., room hight and gross area). While most of these home study places (n=18) had sufficient sound-absorbing materials (e.g., sound absorbing ceiling panels), five home study places did not have sufficient sound-absorbing materials. The majority of these home study places had a relatively low background sound level (less than 40 dB(A)), and in three home study places the SPL exceeded 40 dB(A).

Student (home study place's SPL is less than 40 dB(A)): "*If I am studying here and my roommate is on a phone call in the adjacent room, the wall has no sufficient sound-absorbing material, I hear everything and it is super distressing*."

6.3.4 Interpretation of auditory sensation

Interpretation of auditory sensation refers to how students experience, perceive, and prefer the sound environment within the context of their home study places. These interpretations can be categorised under four categories: 'sound source perception', 'sound source preference', 'quantitative characteristics of sound perception', and 'qualitative characteristics of sound perception'.

With regards to 'sound source perception', the perception of the same sound source differed among the 23 students. For example, while four students did not perceive traffic sounds as noise, two students perceived it as noise. For the aspect 'sound source preference', most of the students (n=17) preferred to listen to music while studying, but the types of music differed among students. More than one-third of students (n=10) preferred the presence of natural sounds while studying, such as bird songs or rain. In contrast, the preference of the same sound source can differ among students. For instance, while there were five students that did not prefer to listen to people sounds, three students preferred the presence of people sound at their home study places.

The ‘quantitative characteristics of sound perception’ were divided into two sub-categories that are ‘long duration sounds are noise’ and ‘loud sounds are noise’. 10 students considered any sound that lasts for a long time as a noise while studying.

‘Qualitative characteristics of sound perception’ can be distracted sounds, discontinuous sounds, and constant sounds. Almost half of the students (n=11) perceived the discontinuous sounds (e.g., construction sounds) as noise. In contrast, while four students perceived continuous sounds (e.g., mechanical ventilation) as noise, two students did not perceive it as noise.

Student: “*I consider a sound as a noise if it lasts for a long time. If it is for few minutes, I do not mind. But after a while, if I notice that it is lasting too long and I am not sure when it is going to stop, then it does bother me.*”

Student: “*I can study with some ventilation sounds. I do like some little noises when I’m studying, like a coffee machine. So, I do not need a completely quiet space.*”

6.3.5 Responses

Responses refers to short-term reactions and emotions. In this study, three reactions and two sub-categories for emotions were found.

Concerning reactions, students reacted differently to coping with the sound environment in terms of interaction with either the physical environment, or with the sound environment, or with people to cope with the (background) noise. More than half of the students (n=13) interacted with the sound environment by using headphones or earbuds to avoid the background noise (unwanted sound during studying). 10 of these students applied the sound masking technique by playing a sound source preference such as music. One-third of the students (n=7) interacted with the physical environment, such as closing windows or door and moving to another place (n=5). Similarly, few students interacted with people, such as asking people to stay quiet (n=3).

Pertaining to emotions, some students experienced positive emotions while others experienced negative emotions that were evoked by a certain sound environment. The majority of students (n=17) experienced motivation while studying with the presence of their sound source preference, such as music or natural sounds. In contrast, one-third of students (n=7) experienced negative emotions such as annoyance while studying with the presence of background noise (e.g., people talking or construction sounds).

Student: "*If noises from outside are not too loud, I just close the window. And if it does not work, I put headphones on. And when noises of people from inside are loud, I put my headphones on with music up loud because I do not consider music as disruptive.*"

Student: "*I can ask people here if they can be quiet. And when there is a party above here, I can go there and ask them: can you stop putting music on. I feel safe here so I can always ask that to people here.*"

6.3.6 Outcomes

The outcomes refer to the effect of the sound environment of a study place on the student's experiences. Three types of outcomes were identified in this study, which are positive, negative, and neutral outcomes. Almost half of the students (n=11) experienced a positive outcome: 'affecting focus positively' while they were studying with the presence of their sound source preference. The majority of students (n=19) experienced a negative outcome: 'distracted' when they were exposed to unwanted sounds. 11 students experienced a neutral outcome: 'acceptable current sound environment' while studying at their home study place.

Student: "*Sometimes when my roommates are talking in the living room, but I also need to socialize. So, sounds from people give a more positive experience.*"

Student: "*There has been a lot of construction work in the adjacent area. And especially at the beginning, it was so annoying, like the thudding sound. So for me, especially because I had to study at home, it was really distracting and I could not focus that well.*"

Student: "*When you are here, it is mostly the sounds of the cars moving on the road. I think these sounds are there all the time. So, after a while, I got used to it because these sounds became like a white noise that I could just filter them out.*"

6.4 Discussion on indoor soundscape

6.4.1 Advantages of the indoor soundscape approach

The soundscape approach contributes to understanding how occupants experience the sound environment in a certain context by exploring their interpretation, responses, and outcomes of sound sources in a specific sound environment. In addition, it might contribute to better design of indoor sound environment through accounting for occupants' positive experiences. In learning and study environments, the indoor soundscape approach consists of a number of data collection methods, including guided interviews with which the student's sound environment experience can be studied. Qualitative analysis methods (e.g., grounded theory) were used in previous studies to develop a conceptual framework that represents the indoor soundscape of a learning environment. For example, Topak and Yilmazer [18] found six themes of the conceptual framework of the indoor soundscape at a high school's classroom and computer laboratory: the built environment, perception, context, acoustical environment, responses, and outcomes. Five of these themes are similar to the themes that we found in the indoor soundscape assessment of the home study places. We found that the theme context such as spatial aspects (e.g., close to a window) influenced two themes: sound sources and interpretation of auditory sensation. For instance, one of the student's home study places is facing a roadside which influenced the student's sound source perception and preference. This is a similar result of the study by Topak and Yilmazer [18] who also concluded that context is an important aspect of how sound sources are interpretated.

The indoor soundscape approach enables the exploration of sound sources that students are exposed to continuously and sound sources that the students prefer to be present while studying. For instance, Visentin et al. [17] discovered that primary school children were mostly exposed to sounds generated by the children themselves of which they perceived as unpleasant sounds in the classroom. Similarly, we found that the majority of university students were exposed to sounds generated by people. However, we noticed that some students prefer this sound source to be present and others do not prefer the presence of it. Furthermore, the soundscape approach explored how students cope with the sound environment at their home study places. It was revealed that more than half of the students put on headphones/earbuds to eliminate unwanted sounds at home study place. This is also in line with the findings in the two studies (based on questionnaires) by Braat-Eggen et al.

[10] and Acun and Yilmazer [19] that more than one-third of the students used the headphones/earbuds when they were unsatisfied with the sound environment at open study places.

6.4.2 Limitations of indoor soundscape approach

Two limitations of indoor soundscape approach were found and discussed below.

6.4.2.1 Indoor soundscape for an 'average' student

In this study, the outcome of the indoor soundscape approach in the affinity diagram represents the sound experience of an 'average' student, regardless of the different characteristics among students. For example, the most dominant sound source identified was people talking/moving sounds. Acun and Yilmazer [19] also found that students frequently hear sounds generated by people while studying at study places on campus, indicating that these were perceived as the most disturbing sound source. Interestingly, in our study the perception of people sounds differed among the interviewed students: five students did not prefer the presence of people sounds, while three students preferred the presence of people sounds. In addition, students differed in their responses (i.e., coping methods) when they were exposed to an 'annoying' sound of which some of the students interact with the sound environment by using headphones/earbuds while others interact with the physical environment by closing the window or door. These findings convey that students differ in their experience (including preferences, perceptions, and coping methods) of the sound environment at study places.

Within the context of study places and learning environments, students differ in their preferences and needs. and students can be clustered based on their preferences and needs by applying Two-step cluster analysis [23] resulting in clusters with different profiles (preferences and needs). Hamida et al. [21] identified five profiles of university students based on their acoustical and psychosocial preferences, named 'sound extremely introvert', 'sound unconcerned introvert', 'sound partially concerned introvert', 'sound concerned extrovert', and 'sound unconcerned extrovert'. These profiles differed significantly in their acoustical and psychosocial preferences at study places. Two of these profiles ('sound concerned' and 'smell and sound concerned') were highly concerned with having individually controlled devices, such as headphones. The cluster analysis can be followed up with qualitative research methods such as interviews to better understand the aspects related to these preferences [21,24,25]. For instance, Hamida et al. [21] concluded that building-related indicators, such as the location of the home study place affected students' acoustical preferences. Hence, it consequently affects how the student experiences the sound environment at a study place.

6.4.2.2 Indoor soundscape mainly focused on sound

The soundscape approach is mainly focused on sound. There are other IEQ factors that interact with the sound environment. Toressin et al. [16] highlighted that the indoor soundscape approach integrated with a multisensory approach can be effective in understanding individual's perception of the sound environment in a comprehensive manner. For instance, we found in our study that several students placed their study place close to the window because they like the view to the outside. This visual aspect is associated with the sound sources from outside (e.g., traffic sounds) that could affect the student's sound experience. Also, psychosocial aspects, such as privacy, were found to be related to the sound environment. When we asked the students their meanings of privacy at their home study place for example, one student mentioned that privacy is important while performing a high demanding tasks of which the student needs also a quiet sound environment. Hence, interview questions could be developed to include questions related to both other IEQ factors and psychosocial aspects.

6.4.3 Limitations of this study

This study is limited to study plans of university students from the faculty of Architecture and the Built Environment in the Netherlands. Additionally, the workshops only included PhD students from the faculty of Architecture and the Built Environment. Moreover, this study used the pre-determined themes of the soundscape approach presented in the ISO12913-1 standard. We noticed other themes, such as psychosocial aspects and other IEQ factors, that could be added.

6.5 Conclusion

In this study, the indoor soundscape approach was applied to understand the sound environment experience of 23 university students at their home study places, using mixed data (qualitative and quantitative) of interview transcriptions, building inspections, and SPL measurements. This resulted in an affinity diagram consisting of themes, categories, and sub-categories that explain the sound experience of these students at their home study places. The affinity diagram was validated through two workshops with participants.

To answer the research question of this study, the indoor soundscape approach is indeed useful to better understand the context of the home study places in relation to sound sources, students' interpretation of these sound sources, responses, and the outcomes. However, this approach is limited to the sound environment experience of an 'average' students and does not account for the different needs (e.g., health and lifestyle) as well as preferences of these students. Moreover, the soundscape themes are limited to sound environment-related aspects. Therefore, it is recommended to consider making the indoor soundscape approach applicable for different profiles of occupants. In addition, the indoor soundscape themes could be extended to include other IEQ factors (e.g., visual comfort) and psychosocial aspects (e.g., privacy) to better understand a student's sound experience of a study place.

Note: further improvements in the affinity diagrams are proposed in **Appendix M**. These include the inclusion of two themes in the affinity diagram were proposed based on the discussion during the 53rd International Congress and Exposition on Noise Control Engineering. These are:

Note: further improvements in the affinity diagrams are proposed in Appendix K. These include the inclusion of two themes in the affinity diagram were proposed based on the discussion during the 53rd International Congress and Exposition on Noise Control Engineering. These are:

– Other indoor environmental quality factors: since this study was limited to the pre-determined themes of the soundscape approach, as defined in ISO 12913-1 standard [14], other IEQ factors can be added, such as indoor air quality, thermal quality, and lighting quality. It was observed in Chapter 6 that several students who opened the window for natural ventilation closed it when they heard sounds from the outside, such as traffic. Hence, it is important to include other IEQ factors as Dokmeci Yorukoglu and Kang [27] who suggested incorporating additional IEQ factors into the questionnaire for assessing indoor soundscapes.

- Coping methods: it was discussed that the three sub-categories ‘interaction with physical environment’, ‘interaction with sound environment’, and ‘interaction with people’ which were assigned to the theme ‘responses’, can be assigned to a new theme namely ‘coping methods. This is because the term ‘responses’ in [14] refers to short-term emotions. Also according to Topak and Yilmazer [18], the term ‘responses’ encompasses both emotional reactions and comfort, but does not include coping methods. Mackrill et al. [28] also considered the theme ‘responses’ within the sound environment experience to represent the emotional reactions (positive or negative) that an individual experiences when directly engaging with a certain sound source.

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7 Conclusions and Recommendations

7.1 Introduction

Research has shown that acoustical quality affects positively or negatively students' health, comfort, and performance while studying at study places (whether at home or educational buildings) [1–9]. Three groups of indicators: dose-related, occupant-related, and building-related indicators can be considered for assessing the acoustical quality of study places [10]. Current acoustical guidelines for the acoustical quality of educational buildings (e.g., [11–13]) are mainly focused on dose-related and some building-related indicators, with limited attention given to occupant-related indicators. Little is known about the students' acoustical preferences and needs of their study places and how this relates to their study place [14,15]. Therefore, this PhD research was carried out to answer the following research question:

- **How to assess the acoustical quality of study places?**

This research question was divided into five sub-research questions, addressed in the studies presented in Chapters 2-6 (see **Figure 7.1**).

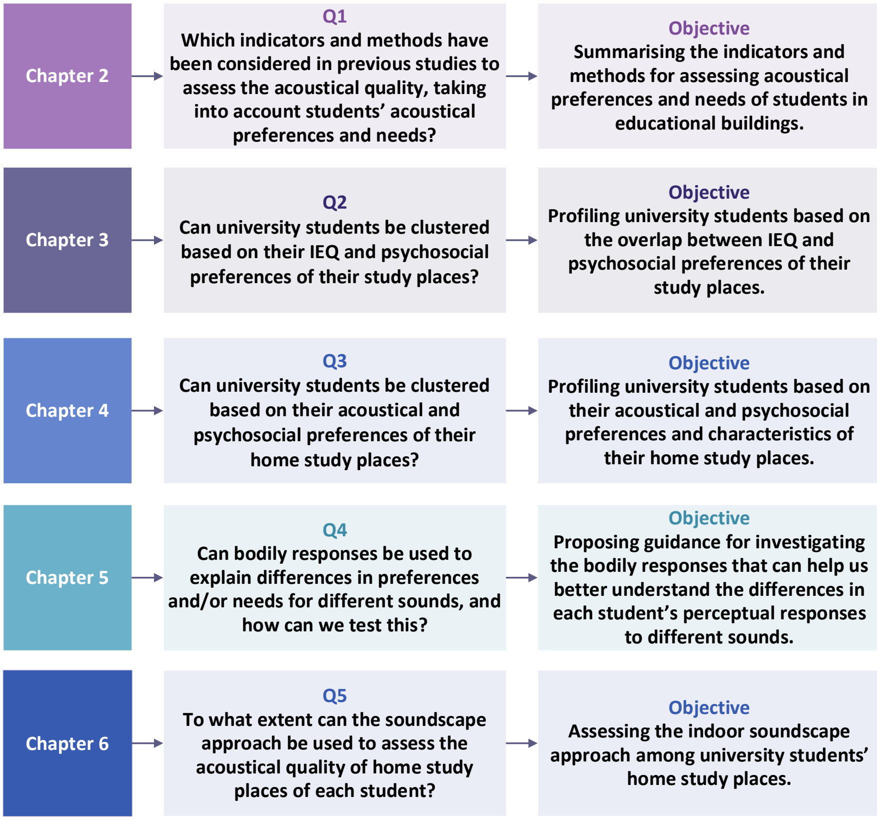

FIG. 7.1 Overview of five key questions and their objectives that were answered in Chapters 2-6.

Three groups of indicators were used to assess university students' acoustical preferences and needs at their study places (occupant-related, building-related, and dose-related indicators) through several data collection methods: questionnaires, interviews, study place inspections, sound pressure level measurements, workshops, and sound exposure lab experiments. Both quantitative (e.g., TwoStep cluster analysis) and qualitative (e.g., inductive coding) data analysis techniques were applied.

Based on the 'Home' questionnaire [16], the 'MyStudyPlace' questionnaire was developed to capture students' preferences regarding indoor environmental quality (IEQ) and psychosocial aspects of their study places. TwoStep cluster analysis was then computed to group university students based on their IEQ and psychosocial preferences. The overlap between the two cluster models resulted in nine profiles, each with significant differences in acoustical and psychosocial

TOC

preferences. Subsequently, students were re-clustered based solely on their acoustical and a selection of psychosocial preferences, resulting in five distinct profiles. 23 home study places were visited to explore the aspects related to the acoustical preferences of students from the different five profiles. These visits comprised interviews, building inspections, and sound pressure level measurements. The acquired data substantiated the acoustical preferences of the five profiles of students. Then, 15 students (of the 23 who were involved in the home study place visit) participated in a lab study, including sound exposure experiments to measure bodily responses and assess perception, and an audiometric test to measure the hearing acuity of the students at different sound frequencies. An indoor soundscape approach was performed to explore the sound environment experiences of 23 students through semi-structured interviews. The transcripts from these interviews were deductively analysed and validated through workshops with PhD students.

In Chapter 7, the main findings of each study performed are summarised to answer each of the five sub questions as well as the main research question. Then, the limitations of this PhD research are discussed and recommendations for future research are presented.

7.2 Answers to the five sub questions

— **Q1. Which indicators and methods have been considered in previous studies to assess the acoustical quality, taking into account students' acoustical preferences and needs?**

Students are exposed to several environmental stimuli while being inside educational buildings that have positive and/or negative effects on their health, comfort, and performance. Sounds are one of these environmental stimuli that are related to the acoustical quality and could affect students' well-being. Previous studies showed that students differ in their acoustical preferences and needs which are related to occupant-related indicators. However, the acoustical guidelines for educational buildings are limited to dose-related indicators (e.g., sound level) and building-related indicators (e.g., space layout). Therefore, this question was raised, and the answer to this question, presented in Chapter 2, is fundamental to this thesis, as it serves as the foundation for addressing sub questions two to five.

Chapter 2 summarises the literature review based on 44 relevant articles to identify the indicators (occupant-related, dose-related, and building-related) and their collection methods used in previous studies on students' acoustical preferences and needs in educational buildings. The review was limited to studies on indoor acoustics and soundscape, considering other IEQ factors.

The outcome of the literature review comprises an overview of comprehensive indicators of the three types of indicators (occupant-related, dose-related, and building-related) and their data collection methods, using narrative synthesis. It was found that acoustical guidelines for educational buildings are limited to dose-related and building-related indicators, while occupant-related indicators are barely included. To date, few studies examined the occupant-related indicators comprehensively, including both physiological and psychological in indoor acoustics and indoor soundscape studies. Moreover, several studies demonstrate that occupant-related indicators can be useful in investigating students' acoustical preferences and needs because different students have different preferences and needs. Occupant-related indicators can help to understand students' acoustical preferences and needs of their learning and studying environments. Hence, it was concluded that research on students' acoustical preferences and needs in educational buildings is required. Moreover, dose-related and building-related indicators of other IEQ factors were rarely suggested to be taken into account.

It should be noted that the literature review was performed during the COVID-19 pandemic. From studies performed as part of this PhD research was found that almost 74% of university students from the Faculty of Architecture and the Built Environment at Delft University of Technology spent most of their studying time at home [17,18]. Therefore, it was decided to shift the focus of the research from educational buildings to home study places.

- **Q2. Can university students be clustered based on their IEQ and psychosocial preferences of their study places?**
- **If yes:** What are the distinctive preferences and characteristics of each student's profile?

Previous studies showed that students differ in their IEQ and psychosocial preferences of their study places. Nevertheless, these studies were mainly focused on investigating the average student's preferences instead of acknowledging differences in IEQ – and psychosocial preferences between individual students. Moreover, the literature review (Chapter 2) concluded that while studying students' acoustical preferences and needs, it is important to consider other IEQ factors. Thus, this second sub question was posed. The answers to these questions are presented in Chapter 3. Based on data collected through the 'MyStudyPlace' questionnaire (**Appendix A**), which was completed by 451 university students from the Faculty of Architecture and the Built Environment at Delft University of Technology, TwoStep cluster analysis was used to cluster the students based on eight IEQ preferences and nine psychosocial preferences, separately.

The outcome of the TwoStep analysis resulted in three IEQ clusters and three psychosocial clusters. Then, the overlap between these two clusters was determined resulting in nine clusters (profiles) of university students who differed significantly in their IEQ and psychosocial preferences of their study places. In addition, several distinctive preferences and characteristics (e.g., health and lifestyle) differed significantly among the nine profiles. Interestingly, all profiles scored a high preference for daylight at their study place. On the contrary, the nine profiles showed significant differences in their preferences for both acoustical (e.g., sounds from the outside) and psychosocial preferences (e.g., privacy and presence of others), as illustrated in **Figure 7.2**.

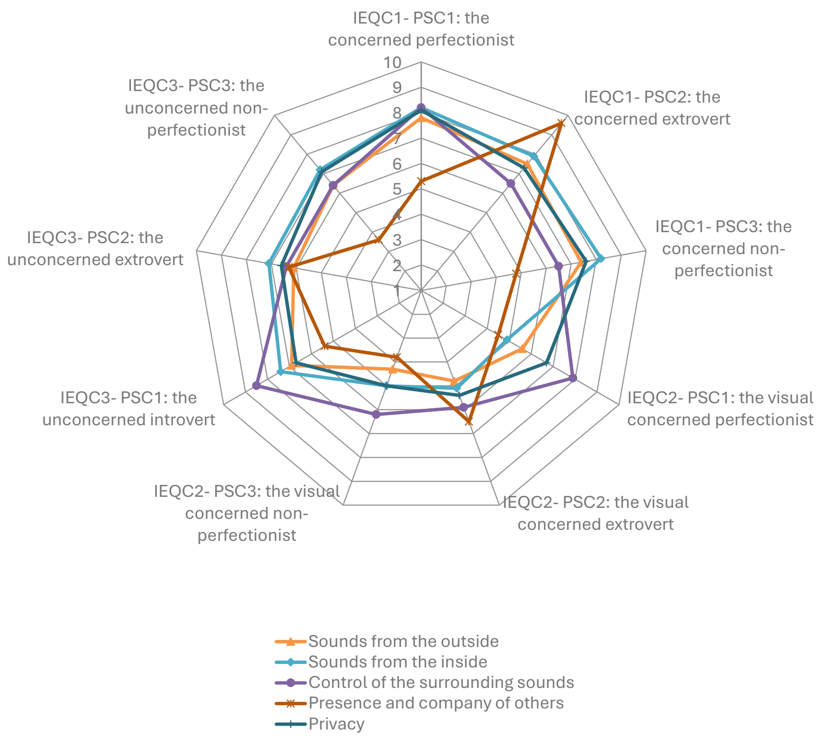

FIG. 7.2 Differences in acoustical and psychosocial preferences among the nine profiles based on their IEQ and psychosocial preferences.

For example, while the concerned perfectionists (cluster IEQC1-PSC1) and the concerned extroverts (cluster IEQC1-PSC2) are both highly concerned with both sounds from the outside and sounds from the inside, the concerned extroverts found the presence and company of others most important, while the concerned perfectionists did not. These findings shed light on the importance of studying the overlap between the IEQ and psychosocial preferences to understand the distinctive possible profiles of students. Furthermore, these findings highlight the importance of designing study places that align with the preferences of different profiles of students, rather than focusing solely on the preferences of an 'average' student.

- Q3. **Can university students be clustered based on their acoustical and psychosocial preferences of their home study places?**
- If yes: Can interviews with selected students from each cluster, building inspections of their home study places, and sound level measurements help to verify their acoustical preferences and their related aspects?

Investigating university students' acoustical and psychosocial preferences of their study places is important for their health and comfort. The nine profiles of university students (Chapter 3) showed differences in their acoustical and psychosocial preferences, including privacy and the presence of others. Because the study in Chapter 3 was limited to data collected from a questionnaire, assessments of building-related indicators (e.g., number of windows) and measurements of dose-related indicators (e.g., sound pressure level) were not carried out, an additional question was raised. The answers to both questions are presented in Chapter 4.

Using a mixed-methods approach, data from the 'MyStudyPlace' questionnaire were combined with data from a field study of 23 home study places to explore the underlying aspects determining the acoustical preferences of each profile. A TwoStep cluster analysis was conducted to re-cluster the 451 students based on their acoustical and psychosocial preferences. This resulted in five distinct clusters of university students: sound concerned introvert, sound unconcerned introvert, sound partially concerned introvert, sound concerned extrovert, and sound unconcerned extrovert. Subsequently, 23 home study places of students from the same sample were visited, with at least two students per cluster, in which the students were interviewed (semi-structured interviews), their study place was inspected, and the sound pressure level was measured.

Data from the field study helped to explain the aspects related to the acoustical and psychosocial preferences of each profile. These data, categorised into three groups of indicators (occupant-related, dose-related, and building-related indicators), provided a comprehensive description of the preferences and needs of the five profiles of university students. For instance, students from the 'sound unconcerned' profiles expressed that they could study with the presence of both sounds from the outside and inside, and therefore they are not highly concerned with the sounds. In contrast, students in the 'sound concerned' profiles were concerned with both sounds from the outside and inside, as they were easily distracted while studying with the presence of sounds. Moreover, the location of the home study place significantly influenced students' acoustical preferences.

The results of the field study confirmed the acoustical preferences of students from the five profiles. This study highlighted the importance of considering the three groups of indicators to better understand the acoustical preferences of each profile and the aspects associated with their preferences, such as 'losing focus by outside sounds.' However, the occupant-related indicators were limited to students' acoustical and psychosocial preferences. Therefore, the following sub question (Q4) was posed.

– Q4. **Can bodily responses be used to explain differences in preferences and/or needs for different sounds, and how can we test this?**

Research has shown that sounds as environmental stimuli can influence students physiologically and perceptually. Nonetheless, most previous studies focused on the effect of sounds at group level while their effects at individual level to explain the differences in their responses were overlooked. Therefore, this fourth question was posed to propose guidance to explore which bodily responses can be considered to explain the differences in each student's perceptual assessments of different sound types (Chapter 5).

To answer this question, two sound exposure lab experiments were conducted in the SenseLab with 15 university students (who also participated in the field study). Both experiments involved four bodily responses (attention level (AL), mental relaxation level (MRL), heart rate (HR), and respiration rate (RR)) and perceptual assessments during the exposure to four sound types (each played at two intensity levels).

The first lab experiment (involving 15 students) was performed in two test chambers (as a laboratory setting) where the student was exposed to the sound directly in the ear via sound-cancelling earbuds. The second lab experiment (involving 14 students) was carried out in the Experience room (as a real-life room setting) where students were exposed to the sound indirectly through speakers in the ceiling. Additionally, an audiometric test was performed to measure the hearing threshold of the 15 participants at eight frequency bands (from 125 to 8000 Hz).

Bodily responses and perceptual assessments were studied at both individual-level and group-level. Acoustical preferences of the five profiles and the building-related indicators resulting from the mixed-methods study (Chapter 4) were used to explain the differences in perceptual assessments. Hearing acuity was also considered in explaining the differences in both bodily responses and perceptual assessments at individual-level. In addition, the correlation between the bodily responses and perceptual assessments of the two experiments was tested.

One of the key outcomes is that students with mild hearing loss in low-frequency sounds showed responses in HR during exposure to low-frequency sound type (e.g., ventilation) in low sound pressure level (SPL). Therefore, it was concluded that the audiometric test is an important procedure to be considered in these types of experiments. Furthermore, it was found that lab experiments could be used to substantiate students' acoustical preferences of their study places. Moreover, both bodily responses and perceptual assessments have to be considered in these types of experiments since no strong nor significant correlations were found during the direct sound exposure experiment.

– **Q5. To what extent can the soundscape approach be used to assess the acoustical quality of each student's home study places?**

From the literature review was concluded that a soundscape is an individual's perceptual construct of an acoustical environment, which can be assessed through seven perceptual construct elements, for which an assessment approach was originally developed for the outdoor environment. Since little is known about the feasibility of applying this approach within the context of home study places, question five was formulated and the answer is presented in Chapter 6.

A qualitative research design was applied comprising semi-structured interviews with 23 university students from the Faculty of Architecture and the Built Environment (who also participated in studies presented in Chapters 3, 4, and 5). The interview comprised eight questions most of which were based on ISO 12913-2 [19], part 2 of the acoustical sounds standard, and other psychosocial questions (e.g., privacy of home study place) were included. Qualitative analysis was performed using open coding (inductive), focused coding (inductive), and themes (deductive based on the soundscape elements [20]) to create an initial affinity diagram that represents the indoor soundscape of university students. This affinity diagram was validated through two workshops with PhD students to avoid subjective bias. The final affinity diagram consists of six themes, 22 categories, and 80 sub-categories.

The response to the fifth sub question affirms that the use of the indoor soundscape approach has the potential to understand how university students experience the sound environment of their home study places. For example, the interview questions helped to explore which sound sources the student hear frequently at their study places, how they interpret these sounds, and how they deal with the sound that they consider as noise. Nevertheless, this approach is limited to how an ‘average’ student experiences the sound environment at the home study places where differences in students’ acoustical and psychosocial preferences were not accounted for in this approach. Furthermore, the seven soundscape themes [20] are limited to the sound environment-related aspects, whereas other aspects related to IEQ factors were not included.

7.3 Answer the main research question

To answer the main research question, ‘*How to assess the acoustical quality of study places?’* different methods (comprising several indicators) were applied to determine how the acoustical quality (acoustical preferences and needs of students) of study places can be assessed and which indicators can be used:

1. A literature review, identifying previous methods and indicators applied to assess the acoustical quality of the study place.
2. The ‘MyStudyPlace’ questionnaire, collecting self-reported data on occupant-related indicators and building-related indicators.
3. A mixed-methods approach combining the ‘MyStudyPlace’ questionnaire with a field study, collecting occupant-related data, and objective data on building-related indicators and dose-related indicators.
4. Laboratory experiments, studying objective and subjective occupant-related indicators (e.g. bodily responses and perceptual assessments) while being exposed to different sound sources directly and indirectly.
5. Semi-structured interviews based on the soundscape constructs collecting subjective occupant-related indicators (e.g., sound preferences and coping methods).

In **Table 7.1**, an overview is presented of the methods used, the aim, the specific indicators studied, and the main outcomes from those studies.

TABLE 7.1 Overview of methods, indicators, and the main outcomes of the four study designs that were conducted in this PhD research.

Methods	Aim	Indicators			Main outcomes
		Occupant-related	Dose-related	Building-related	
'MyStudyPlace' questionnaire (Chapter 3)	*Assessment of preferences*: profiling university students based on the overlap between IEQ and psychosocial preferences of their study places.	• Personal information. • Psychosocial aspects. • Study place's preferences (IEQ & psychosocial). • Comfort (IEQ & psychosocial perception). • Lifestyle. • Health and medical history.	-	• Mostly used study place (home or educational building).	• Three IEQ preferences clusters. • Three psychosocial preferences clusters. • Nine profiles of university students based on the overlap between the IEQ and psychosocial preferences clusters. • The number of variables that were significantly different between the nine profiles is higher within the overlap between the IEQ and psychosocial preferences than based on the clusters of preferences for IEQ and for psychosocial separately. • Nine profiles differed significantly in their acoustical preferences. • The profiles differed in self-reported health aspects.

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TABLE 7.1 Overview of methods, indicators, and the main outcomes of the four study designs that were conducted in this PhD research.

Methods	Aim	Indicators			Main outcomes
		Occupant-related	Dose-related	Building-related	
Mixed-methods: 'MyStudyPlace' questionnaire followed by field studies comprised interviews, building checklists, and sound level measurements (Chapter 4)	*Assessment of acoustical preferences:* profiling university students based on their acoustical and psychosocial preferences and characteristics of their home study places. Explanation of the profiles.	• Personal information. • Psychosocial aspects. • Study place's preferences (IEQ & psychosocial). • Aspects related to acoustical preferences. • Comfort (IEQ & psychosocial). • Lifestyle. • Health and medical history.	• SPL.	• Building type, location, storey number, & home study place's storey level. • Study place's volume, room type, & location within the room. • Acoustical absorption materials. • Wall, floor, & ceiling covering. • Number of windows. • Presence of mechanical ventilation.	• Five clusters of university students based on their acoustical and psychosocial preferences were found. • The five clusters differed significantly among 14 variables, including perception of noise. • Building location influenced students' acoustical preferences of their home study place. • To understand the acoustical preferences of each cluster, it is important to explore students' explanations and building-related aspects associated with these preferences.

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TABLE 7.1 Overview of methods, indicators, and the main outcomes of the four study designs that were conducted in this PhD research.

Methods	Aim	Indicators			Main outcomes
		Occupant-related	Dose-related	Building-related	
Two sound exposure lab experiments: direct sound exposure and indirect sound exposure. These were preceded by audiometric tests (Chapter 5)	*Assessment of needs:* examining bodily responses in a controlled sound environment to explain differences in students' perceptual responses to different sounds.	• Hearing acuity. • Bodily responses, comprising AL, MRL, HR, & RR. • Sound perception (acceptability, pleasantness, stress level, and noise level).	• SPL. • Sound frequencies.	-	• Hearing acuity is an important indicator for identifying differences in bodily responses during sound exposure experiments. • Students with mild low-frequency hearing loss showed increases in HR during the exposure to low-frequency sound conditions. • Students' acoustical preferences from field studies can be verified through sound exposure lab experiments. • During the direct sound exposure, bodily responses did not show strong correlations with perceptual assessments. • HR and RR are robust indicators for short-term sound exposure experiments and could be monitored in field studies.

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TABLE 7.1 Overview of methods, indicators, and the main outcomes of the four study designs that were conducted in this PhD research.

Methods	Aim	Indicators			Main outcomes
		Occupant-related	Dose-related	Building-related	
Interviews (based on a soundscape approach) followed by two workshops (Chapter 6)	*Assessment of preferences:* exploring students' sound environment experience of their home study places.	• Study-related activities. • Sound preference. • Sound is perceived as noise. • Coping methods.	• SPL.	• Sound sources. • Acoustical absorption materials.	• The interpretation of the sound environment, responses, coping methods, and outcomes differed among the students. • The soundscape approach is mainly focused on the sound environment's experience for an 'average' student rather than considering the experience of different profiles of students. • The soundscape approach contributes to understanding occupants' experience of a sound environment in a certain context.

Based on the outcomes of the studies performed (**Table 7.1**), the following recommendations for investigating the acoustical quality of study places can be made:

1. To explore differences among students, clustering based on both acoustical and psychosocial preferences is required. These preferences can be determined through a questionnaire.
2. Profiles of the resulting clusters can then be determined based on comparison of occupant-related indicators (acquired by the questionnaire).
3. To substantiate the resulting profiles, a visit to the study places of students from different clusters, is required. During the visit, building-related indicators can be collected with a checklist, occupant-related indicators can be explained through an interview, and dose-related indicators (such as the sound pressure level) can be monitored.
4. The questions of the interviews can be based on the constructs applied in the soundscape approach.

5 To explore more in-depth how our body responses to an acoustical environment, monitoring of bodily indicators such as heart rate and respiration rate can be applied, both in field and lab studies.

In **Appendix N**, detailed information of the applied assessment methods (for questionnaire and visit) is provided.

7.4 Limitations

This PhD research explored comprehensively the acoustical and psychosocial preferences of university students in their study places using a combination of quantitative and qualitative research methods. The sample used for these methods remained consistent throughout the study. However, several limitations of this research are outlined below:

First, the sample was restricted to undergraduate students from the Faculty of Architecture and the Built Environment at Delft University of Technology, with an average age of 20. A total of 451 students completed the 'MyStudyPlace' questionnaire. Of these, 23 students participated in the field study and semi-structured interviews, while 15 took part in the short-term sound exposure lab experiments. A key finding from Chapter 3 revealed that the nine student profiles, based on IEQ and psychosocial preferences, showed a high concern for daylight and views to the outside that may be related to their academic discipline. Consequently, it is recommended that in future studies students from a wider range of academic disciplines are recruited. The 23 students who participated in the semi-structured interviews and field studies (Chapters 4 and 6), and the 15 students who participated in the lab experiments (Chapter 5), were from the five different student profiles. However, the number of participants in each profile was unequal, with only two students representing one of the profiles. To enhance the generalisability of the findings, future research should include a larger and more balanced number of participants per profile.

Second, students' acoustical preferences were studied by considering a wide range of indicators at three levels: occupant-related, dose-related, and building-related. Nevertheless, there are some limitations to the different types of indicators. For the occupant-related indicators, this study focused solely on the acoustical preferences of university students but did not explore their study performance (i.e., productivity). Additionally, the bodily responses measured in Chapter 5 were limited to AL, MRL, HR, and RR. While AL and MRL as brain activity bodily responses did not show significant differences, they could be effective for sound exposure experiments that involve performance tasks. Other bodily responses such as skin conductance level [10], which can be used as an indicator for stress and arousal induced by sound stimuli [21,22]. Regarding dose-related indicators, only SPL was measured in students' home study places (as explained in Chapter 4).

Third, the sound exposure lab experiments (Chapter 5) were limited to short-term duration, with each sound condition lasting two minutes. This study did not include effects that could occur due to exposure to a long-term environmental stressor (e.g., chronic background noise) [23]. To measure such an effect requires a longer sound exposure time including other bodily responses (e.g., salivary cortisol), as for example in the study of Jahncke [24]: the participants were exposed to two hours of office noise, which was preceded by 15 minutes of relaxation, followed by 7 minutes of restoration after the two hours, and ended by 10 minutes of post-test. They measured the salivary cortisol after each of these four periods.

Fourth, this research focused primarily on study places (Chapter 3), particularly home study places (Chapters 4, 5, and 6). The focus on the context of home study places was made because most university students were studying at home during the COVID-19 pandemic. Other types of study places, such as those at university campuses (e.g., study places at a university library), should be considered in future studies.

7.5 Recommendations for future research

In this PhD thesis, several research methods (quantitative and qualitative) were applied to study university students' acoustical and psychosocial preferences of their study places considering the three types (or groups) of indicators. Based on the outcome, several recommendations (Chapter 7.3) and assessment methods and indicators (**Appendix N**) for studying acoustical quality in terms of preferences (comfort) and/or needs (health) were derived. Additionally, several recommendations for future research directions on study places can be made.

7.5.1 Future assessments on preferences and/or needs

The outcome of this PhD research showed that to assess students' acoustical and psychosocial preferences and needs of their study places, three types of indicators are highly recommended to be studied: occupant-related, dose-related, and building-related indicators. Both assessment of preferences and assessment of needs could be carried out for future research, as explained in the answer to the main research question. Each of these assessments can be done through several methods and indicators. Hence, the suggested assessment methods (**Appendix N**) can guide future studies on selecting the appropriate indicators and their required methods to assess students' acoustical and psychosocial preferences and/or needs of their study places tailored to a certain aim. It is important to note that profiling students based on their acoustical and psychosocial preferences for study places is a stepping stone towards understanding the differences in bodily and perceptual responses of different students. Based on the main findings from the five sub questions and the suggested two types of assessments (the answer to the main research question), a list of recommendations for future research can be made:

- Given that this study was limited to university students from the Faculty of Architecture and the Built Environment, who expressed a strong concern for both daylight and views to the outside in their study places (Chapter 3), it is recommended that future studies recruit a more diverse sample, encompassing students from different faculties.
- Other IEQ preferences should be considered in assessments of acoustical preferences and needs, as the literature review of this PhD research (Chapter 2) mentioned that these factors may interact with acoustical quality.
- Future field studies are recommended to measure other dose-related indicators, such as reverberation time and sound transmission index, to gain a more comprehensive understanding of acoustical environments since this study (Chapters 3-6) primarily used SPL as the dose-related indicator.
- Since this study involved at least two students per profile in interviews and lab experiments, the findings cannot be generalised across profiles. Increasing the number of participants to at least 26 per profile, as calculated for a power of 0.8 (Chapter 5), is necessary to improve the generalisability of results.
- Conducting audiometric tests is crucial for sound exposure lab experiments to better understand differences in bodily responses and perceptual assessments.
- HR and RR as bodily responses could be incorporated into field studies in real study places to assess students' needs by monitoring them in real situations (e.g., study place).

- Other bodily responses, such as skin conductance level in sound exposure lab experiments, as it is a robust indicator of stress or arousal [10,21,22], can be monitored.
- Future research is recommended to assess the long-term effects of sound conditions on students' bodily responses using long-duration sound exposure experiments, measuring stress-related responses such as salivary cortisol alongside HR and RR.
- Concerning the indoor soundscape approach (Chapter 6), future studies are recommended to incorporate questions about sound source preferences and coping methods in questionnaires to deepen understanding of how students experience their sound environments.

7.5.2 From research to practice

The research findings imply that comprehensive assessment of preferences can be useful to operate and manage study places, tailored to students' acoustical and psychosocial preferences. Tailored study places have the potential to enhance students' comfort and consequently their academic performance. Prediction models could be a solution to develop recommendations for tailored study places further. For instance, Jayathissa et al. [25] developed a prediction model based on comfort preferences, which required high-frequency sampling within a longitudinal data collection framework. Their findings highlighted that such data could support workplace spatial designs, allowing occupants to choose a workplace that aligns with their preferences and needs, rather than being assigned to a fixed place. This concept relates to the 'Spacematch' platform developed by Sood et al. [26]. Their study involved a one-month longitudinal data collection process. Then, the participants were clustered based on their preferences regarding noise, temperature, and light. The authors suggested that clustering occupants by preference could help to identify comfort profile types of workplaces through data-driven methods, which facilitated the development of a predictive model.

Building on the aforementioned literature and the findings of Chapter 5, the 'MyStudyPlace-Match' platform is proposed in **Appendix O** as a future research direction that has the potential to implement research findings to operate and manage real study places. Further improvements to include other IEQ preferences (e.g., daylight) and other psychosocial aspects (e.g., amenities) are suggested. This could spread awareness among students on their preferences for study places that promote both health and comfort, ultimately enhancing their academic performance.

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Appendices

APPENDIX A

Summary of indicators used in indoor acoustics studies

Note: the references belong to the references list of Chapter 2.

Ref.	Context/ Activity	Occupant-related indicators		
		Physiolog-ical	Psycholog-ical	Perfor-mance
[12]	Writing task in open-plan study environment	-	-	Writing task
[13]	Students in informal learning spaces	-	Perception	-
[15]	Students performed attention task in university facilities (lab experiment in an audiometric room)	Cerebral behaviour	-	Attention task
[19]	Students in open-plan study environment	-	Perception, assessment of distur-bance	-
[33]	Students performed stressful mental task	HF HRV, SCL	-	Mental arithmetic stress task
[34]	Students were exposed to different environmental stimuli and completed a stressful task in a test chamber	Stress level (EEC)	-	Stress examination sheet
[35]	Students were exposed to different environmental stimuli in a test chamber	Blood pressure	-	-
[36]	Students were exposed to different environmental stimuli in a test chamber	HR, HF HRV	-	-
[37]	Students performed mental task (N-back task) and were exposed to sound stimuli in a test chamber	HR, RR	-	-
[38]	Students were exposed to different environmental stimuli in a test chamber	HR, blood pressure, skin tem-perature	Perception	-
*[39]	Participants were exposed to different sound stimuli in a test chamber	HR, RR, EDA	Emotional responses, noticeability	-

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL, RT	People talking	-	-	-	-	-	-	-
	SPL, RT	-	-	-	-	-	-	-	-
	-	Classroom in exam, normal classroom, libraries, computer labs, hallways, adapted study hall	-	-	-	-	-	-	-
	SPL, RT	-	-	-	-	-	-	-	-
	SPL	Nature sound, traffic, quiet backyard	-	-	-	-	-	-	-
	-	Nature sounds, traffic sounds	-	Tempera-ture	-	With odour irritants, without odour irrians (VOCs)	-	-	-
	SPL	-	-	Tempera-ture	-	-	-	-	-
	SPL	-	-	-	-	-	-	-	-
	SPL	-	-	Tempera-ture	-	-	-	-	-
	SPL	-	-	Tempera-ture, relative humidity	Illuminance intensity	-	-	-	-
	SPL	Floor impact sounds	-	-	-	-	-	-	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiolog-ical	Psycholog-ical	Perfor-mance	
*[66]	Participants were exposed to different environmental stimuli in a laboratory	-	Perception	-	
[46]	Primary school children in classrooms	HR, blood pressure, salivary cortisol	Emotional responses	-	
*[47]	Participants were exposed to different sound stimuli in a hemi-an-echoic room, and were asked to complete a cognitive task	HR	-	Cognitive test (stroop effect)	
[48]	Students were exposed to different sound stimuli in a laboratory, and were asked to complete cognitive tasks	-	-	Cognitive tasks (serial recall, mental arithmetic, reading comprehen-sion, proof-reading)	
[49]	Students were exposed to different sound stimuli in a test chamber, and were asked to complete a listening test	-	-	Listening test	
[51]	Students were exposed to different environmental stimuli in a laboratory	-	Emotional responses, view prefer-ences	-	
[52]	Students were exposed to different environmental stimuli in mock-up offices, and performed cognitive tests	-	-	Four cognitive tests (con-centration perfor-mance test, grammatical reasoning test, serial recall task, text com-prehension task)	

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL	Water sounds, traffic sound	-	Tempera-ture	-	-	-	-	-
	SPL	-	-	-	-	-	-	-	-
	Frequency	-	-	-	-	-	-	-	-
	SPL, STI	Background noise (speech), masking sound (pink noise)	-	-	-	-	-	-	-
	SPL, RT	Traffic noise, children talking, music, no sound	-	-	-	-	Acoustically treated wall, acoustically untreated wall	-	-
	SPL	Sea sounds, road traffic sounds	-	-	-	-	-	Visual scene	-
	SPL, speech intelligibility	-	-	-	Illuminance	-	-	Lighting type	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiolog-ical	Psycholog-ical	Perfor-mance	
*[54]	Participants were exposed to different environmental stimuli in a climate chamber	-	Acoustical comfort, thermal preference	-	
[55]	Primary school children exposed to different environmental condi-tions in a lab study of a classroom set-up	-	Acoustical perception, cross-modal perception (draught, smell, light)	-	
[56]	Students were exposed to different environmental stimuli in a test chamber	-	Perception of floor impact noise, cross-modal perception (thermal conditions)	-	
[87]	University classrooms (field study)	-	Acoustical perception, lighting perception, thermal sensation	-	
[20]	Children performed a mental task after they were exposed to sound stimuli in a simulated classroom setting	-	Restorative effect	Arithme-tic task, sustained attention to response test, digit span test	
[21]	University students at home during COVID-19	-	Emotional response (pleas-antness), restorative effect	-	

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL	Quiet place, human speech, noisy workplace	-	Tempera-ture	-	-	-	-	-
	SPL, RT	No sound, traffic, children talking	-	-	-	VOCs emitted from acous-tical panels	All acousti-cal panels, fewer panels	Direct ligt, indirect light, soft light	Mixing ven-tilation, dis-placement ventilation,
	SPL	Background sounds, floor impact sounds	-	Tempera-ture	-	-	-	-	-
	SPL, RT, STI, clarity index, EDT	-	-	Tem-perature, humidity, PMV, PPD	Illuminance intensity	-	-	-	-
	SPL	Music, birdsong, fountain sound, bell rings, stream sound, ambient noise	Loudness, fluctuation strength, sharpness, roughness	-	-	-	-	-	-
	-	Traffic, indoor mechanical, outdoor mechani-cal, music, human, nature	-	-	-	-	-	-	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiolog-ical	Psycholog-ical	Perfor-mance	
*[63]	Employee working in open-plan office	-	Acoustical perception, coping methods	-	
[67, 68]	University libraries	-	Emotional response (annoy-ance), sound preference, acoustical comfort	-	
*[74]	Hospital wards	-	Acoustical perception, coping methods	-	
*[75]	Hospital wards	-	Emotional response	-	
* [76]	Living rooms in nursing homes	-	Emotional response (calmness, event-fulness, annoyance)	-	
[84]	Students performed mental tasks in simulated open-plan office	HR, blood pressure	Emotional response (annoyance, tension, fatigue)	Calculation task	

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL	Sounds generated by people, mechanical sounds, outdoor sounds, music	-	-	-	-	-	-	-
	SPL	-	Loudness, roughness, sharpness	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-
	SPL	Natural sound, hospital wards sounds	-	-	-	-	-	-	-
	SPL, RT	Installation sounds, indoor activity sounds, electronic sounds, outdoor sounds	Loudness	-	-	-	-	-	-
	-	Water sound, birdsong, footsteps, traffic noise, air condi-tioner sound	-	-	-	-	-	-	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiolog-ical	Psycholog-ical	Perfor-mance	
*[77]	Participants exposed to environmental stimuli in open-plan office	-	Sound pref-erence, view preference	-	
*[78]	Residential buildings	-	Perceptual dimension (comfort, content, familiarity)	-	
[69]	Public library	-	Appropri-ateness of sound envi-ronment	-	
[71]	High school students in two contexts: classroom and computer laboratory	-	Acoustical perception, coping methods	-	

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL, STI	Background noise (speech), sound masking (water)	-	-	-	-	-	Visual scene	-
	SPL	No sound, traffic (heavy, light), pedestrian area, garden, fan sound, music, TV	Loudness, strength, roughness	-	-	-	-	-	-
	SPL	Verbal individual sound, non-verbal individual sound, mechanical sound, traffic noise, loud music, crowds of people	-	-	-	-	Space layout	-	-
	SPL, RT	Speech, footsteps, outside traffic, birdsong, electrical equipment, installation sounds, keyboard/ key clicking mouse sounds	-	-	-	-	-	-	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiological	Psychological	Performance	
[73]	Students in open study areas in a university campus	-	Sound environment perception, coping methods	-	
[86]	University office spaces	-	Soundscape perception	-	
*[79]	Residential space with two different cultural background	-	Acoustical perception, sound preference	-	
*[80]	Historic worship space	-	Soundscape expectation, interpretation of soundscape, sound preference	-	
*[61]	Historical spaces	-	Soundscape expectation, interpretation of soundscape, sound preference	-	

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL	Computer sound, water sound, music, unintelligi-ble speech, intelligible speech, footsteps, people laughing, installations	-	-	-	-	-	-	-
	SPL	Outdoor sounds, sounds from corridors, sounds people sounds	-	Tem-perature, humidity	Illuminance intensity	-	-	Lighting type, daylight access	-
	-	Outdoor sounds, people talking, in-stallations	-	-	-	-	-	-	-
	SPL, RT, STI	-	-	-	-	-	-	-	-
	SPL	-	-	-	-	-	-	-	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiolog-ical	Psycholog-ical	Perfor-mance	
*[81]	Museum	-	Perception of sound en-vironment, soundscape expectation, emotional response (pleasant-ness)	-	
*[82]	Public shopping malls	-	Perception of sound en-vironment	-	
[85]	Students were exposed to different sound stimuli in a laboratory after they performed a stressful task	HR, SCL	Emotional responses (pleasant-ness, event-fulness,	Stressful task	
[17]	Students (302 school children) performing tasks in classroom	-	-	Speech perception, mental calcula-tion, and sentence comprehen-sion	

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL	Outdoor sounds, people sounds, installa-tions and equipment sounds, music	-	-	-	-	-	-	-
	SPL	No music, background music, foreground music	-	-	-	-	-	-	-
	SPL	Ocean sound traffic sound, silence, birdsong, construction sound	-	-	-	-	-	-	-
	RT	Classroom sounds (scraping chairs, turning pages, pencils falling). Continuous speech phrases	-	-	-	-	Sound absorbing ceiling or applying sound-ab-sorbing polyester fiber blankets	-	-

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Ref.	Context/ Activity	Occupant-related indicators			
		Physiolog-ical	Psycholog-ical	Perfor-mance	
[72]	Questionnaire: 117 students (59 in classrooms, 58 in computer laboratory) Semi-structured interview: 50 students	-	Auditory perception	-	

** Participants/context: not students/studying context*

	Dose-related indicators						Building-related indicators		
	Indoor acoustics			Other IEQ-factors			Indoor acoustics	Lighting/ visual quality	Indoor air quality
	Objective parameters	Sound sources	Psycho-acoustic parameters	Thermal comfort	Lighting/ visual quality	Indoor air quality			
	SPL, RT	Classroom: speech, footsteps, outside traffic, birds, rain, installa-tions, paper sound. Computer laboratory: Instal-lations, computer sounds, chair wheel sounds, speech, footsteps	-	-	-	-	-	-	-

APPENDIX B

Methods used in indoor acoustics studies

Note: the references belong to the references list of Chapter 2.

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Ref.	Participants	Occupant-related Indicators					Dose-related indicators			
		Ques-tionnaire	Interview	Objective measure-ments	Sound-walk	Perfor-mance task	Indoor acoustics			Other IEQ-factors
							Objective measure-ments	Playing a sound stimuli	Binaural measure-ments	Objective measure-ments
[12]	47 students (F: 18, M: 29), age 16- 27					X	X	X		
[13]	850 university students	X					X			
[15]	33 participants of university students, teachers, and other staff, (F: 16, M: 17), age 19-34			X		X	X	X		
[19]	496 university students in different five open-plan study environments					X	X			
[33]	40 university students (F: 24, M: 18), average age 27			X			X	X		
[34]	12 students (undergraduate and graduate students, F:6, M:6)	X		X			X	X		X
[35]	12 university students			X			X			X
[36]	35 university students, age 20 to 30			X			X			
[37]	35 university students, age 20 to 30 years			X			X			
[38]	35 university students (F: 8, M: 27)			X			X			X
*[39]	21 participants (F: 13, M: 8), age 18 to 42	X		X			X	X		
*[66]	54 participants (F: 29, M: 25), mean age 22	X					X	X		X
[46]	78 fourth grade children (age 10)	X		X		X	X			
*[47]	25 participants (F: 12, M: 13), age 19-29	X		X		X	X			
[48]	38 postgraduate students at university (F:20, M: 18), age 22-27					X	X	X		
[49]	335 primary school children, age 9-13	X				X	X			
*[51]	Experiment 1: 85 participants Experiment 2: 60 participants	X					X	X		X

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Ref.	Participants	Occupant-related Indicators					Dose-related indicators			
		Ques-tionnaire	Interview	Objective measure-ments	Sound-walk	Perfor-mance task	Indoor acoustics			Other IEQ-factors
							Objective measure-ments	Playing a sound stimuli	Binaural measure-ments	Objective measure-ments
*[52]	32 participants (F: 17, M: 15), age 19-31					X	X			X
*[54]	18 participants (F: 9, M: 9), mean age 23	X					X	X		X
[55]	250 primary school children, mean age 10.5	X					X	X		X
[56]	32 undergraduate and graduate students (F: 14, M: 18), age: 19 - 30	X					X	X		X
[87]	928 university students	X					X			X
[20]	Experiment 1: 46 children (aged 8-12) Experiment 2: 45 children					X	X	X		
[21]	323 students in two universities	X								
*[63]	49 employees	X					X			
*[67, 68]	30 participants in each library	X					X			
*[74]	27 participants (patients and nurses)		X							
*[75]	24 participants	X					X	X	X	
*[76]	Nursing homes	X					X			
[84]	75 graduate student	X		X				X		
*[77]	Experiment 1: 28 partici-pants (F:13, M:15) Experiment 2: 31 partici-pants (F:16, M:15)	X					X	X		X
*[78]	35 participants (F:17, M:18)	X					X	X		
[69]	12 undergraduate students participated in sound walks	X			X		X			
[71]	30 high school students in total (16 in the classroom and 14 in the computer laboratory)		X				X			
[73]	120 university students, age 18 - 26	X					X			

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Ref.	Participants	Occupant-related Indicators					Dose-related indicators			
		Ques-tionnaire	Interview	Objective measure-ments	Sound-walk	Perfor-mance task	Indoor acoustics			Other IEQ-factors
							Objective measure-ments	Playing a sound stimuli	Binaural measure-ments	Objective measure-ments
*[86]	Observation of 38 offices Interviews with 20 offices	X	X		X		X			X
*[79]	405 (two different cultural background groups)	X								
*[80]	15 participants		X				X			
*[61]	15 participants (F: 10, M: 5), age: 24-64		X				X			
*[81]	60 participants (30 in each museum)	X	X				X			
*[82]	70 participants (F: 30, M: 40)	X					X	X		X
[85]	Study 1: 45 postgraduate students, member, and staff Study 2: 30 university students and staff	X		X		X		X		
[72]	Questionnaire: 117 high school students Semi-structured interview: 50 high school students, age 14 - 18	X	X				X			
[17]	Experimental study in three classrooms with 302 school children, age 11 - 13, grade 6 to 8					X	X	X		

**Participants are not students*

APPENDIX C

MyStudyPlace questionnaire

Consent form

Hello

Our research team would like to invite you to take part in this online questionnaire.

Introduction

The indoor environmental team at the Faculty of Architecture of the Delft University of Technology greatly appreciates your participation and would like to thank you in advance for your contribution to our research by completing this questionnaire. The ultimate goal of our research is to collect data to better understand what makes study places and homes healthy and comfortable.

What is the purpose?

You will be asked to complete a questionnaire about the indoor environment in your study place and home, and the effects that this indoor environment can have on your health and comfort. The questionnaire contains questions on demographics (e.g. your age, gender), questions about your lifestyle, psychosocial aspects (mood, events), health (personal and family), questions about your preferences and needs with regards to the indoor environmental quality of your study place, and questions about some physical characteristics of your home (building characteristics, ventilation, heating system, use of materials, furniture, activities).
Completing the questionnaire will take approximately 30 minutes. Completing the questionnaire is best done while at home, because with some questions you may need to examine your home yourself. You can stop and continue at a later time, but depending on the privacy settings of your browser, the data already entered will not be saved.

Anonymity
All the data remains anonymous and is treated confidentially.

You can stop at any time
If you do not feel comfortable with a particular question, you can skip it. If you prefer to not continue answering the questionnaire, you can simply close the window. Only at the end of the questionnaire, when you click on the last arrow, your data will be saved.

How are the data used?
The collected results will only be used for research purposes and possibly be presented at conferences, and published in specialized journals. However, your data remains anonymous.

PERSONAL INFORMATION

What is your birth date? (dd / mm / yyyy) ___________________________

What is your gender?
- ☐ Male
- ☐ Female

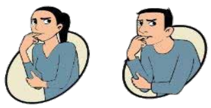
What is your marital status?
- ☐ Single
- ☐ Married / cohabiting

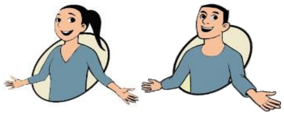
Are you interested in a follow up of this study?
- ☐ Yes
- ☐ No

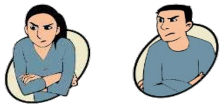
PSYCHO-PHYSICAL ASPECTS

Which of the following images best suits how you feel at this moment?

☐ 

☐ 

☐ 

☐ 

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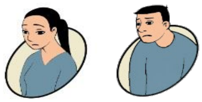
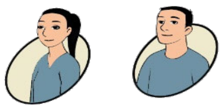
☐ 

☐ 

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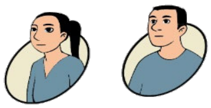
☐ 

Have you recently experienced a positive event (e.g. a birth, wedding, etc.)?

☐ Yes

☐ No

Have you recently experienced a negative event (e.g. death, accident, serious illness, etc.)?

☐ Yes

☐ No

Think about yourself and how do you normally feel, to what extent do you generally feel

	1 (never)	2	3	4	5 (always)
Upset					
Hostile					
Alert					
Embarrassed					
Inspired					
Nervous					
Determined					
Attentive					
Anxious					
Active					

YOUR MOST USED STUDY PLACE

Your MOST used study place (on campus, at home, or other) refers to the location where you spend more than 50% of your study time.

Since the coronavirus crisis started, where do you study MOST of the time?

☐ Home
☐ Educational building
☐ Other, please specify ______________________________

PREFERENCES AND NEEDS OF YOUR STUDY PLACE

Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place

1: Not important at all; 10: Extremely important.	
Ventilation and air freshness	▼ 1 ... 10
Temperature	▼ 1 ... 10
Temperature of my feet	▼ 1 ... 10
Temperature of the chair	▼ 1 ... 10
View to the outside	▼ 1 ... 10
Sounds from outside	▼ 1 ... 10
Sounds from inside	▼ 1 ... 10
Smells	▼ 1 ... 10
Artificial light	▼ 1 ... 10
Daylight	▼ 1 ... 10

Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place

1: Not important at all; 10: Extremely important.	
Storage	▼ 1 ... 10
Cleanliness	▼ 1 ... 10
Amenities (desk size, monitor size, etc)	▼ 1 ... 10
Chair type	▼ 1 ... 10
Presence and company of others	▼ 1 ... 10
Size of the room	▼ 1 ... 10
Bonding or identifying with the place	▼ 1 ... 10
Ability to adapt or control the place	▼ 1 ... 10
Privacy	▼ 1 ... 10

Please rate on a scale from 1 to 10, the importance of each of following the items that would help you to study better; 1: Not important at all; 10: Extremely important.

1: Not important at all; 10: Extremely important.	
Chair seat heating	▼ 1 ... 10
Chair backrest heating	▼ 1 ... 10
Heating on my desk	▼ 1 ... 10
Lamp on my desk	▼ 1 ... 10
Personal desk ventilation and fresh air	▼ 1 ... 10
Control of surrounding sounds	▼ 1 ... 10
Control of shading in room	▼ 1 ... 10
Control of the room ventilation	▼ 1 ... 10
Control of the room temperature	▼ 1 ... 10
Headphones	▼ 1 ... 10
Presence of plants	▼ 1 ... 10

COMFORT

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Temperature

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Temperature

- ☐ Too cold 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Too hot

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Temperature

- ☐ Varies too much 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Too stable

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Air movement

- ☐ Too little movement 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Too much draft

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Air Quality

- ☐ Too dry 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Too humid

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Air Quality

- ☐ Fresh air 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Too stuffy

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Air Quality

- ☐ Odourless 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Smelly

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Air Quality

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Daylight

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Reflection from thee sun and sky

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Artificial lights

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Lighting in general

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Noise from outside

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Noise from installations
(A/C, heating, ventilation, etc)

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Noise other than from the building installations
(eg. phone calls, people talking, footsteps, etc.)

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Noise in general

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

Vibrations

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the **past 3 months**?

General comfort

- ☐ Dissatisfied 1
- ☐ 2
- ☐ 3
- ☐ 4
- ☐ 5
- ☐ 6
- ☐ 7 Satisfied

LIFESTYLE

Do you do physical activity or work out (e.g. sports, gym, commuting by bike or on foot, etc.)?

☐ Yes
☐ No

Have you ever smoked?

☐ No never
☐ Yes, former
☐ Yes, incidentally
☐ Yes, daily

Do you drink alcoholic beverages?

☐ Yes, daily
☐ Yes, occasionally
☐ No

HEALTH AND MEDICAL HISTORY

Personal medical history

Have you ever been told by your doctor that you are suffering from:

	Never	Yes, in the last 12 months	Yes, but not in the last 12 months
Asthma			
Bronchitis / pneumonia			
Noise / wheezing noise of the chest			
Other chest conditions			
Hay fever			
Allergic rhinitis (runny nose / itchy nose, tearing / itchy eyes, frequent sneezing / coughing)			
Eczema			
Dermatitis			
Other skin conditions			
High percentage of fat in the blood (cholesterol, triglycerides)			
Diabetes			

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	Never	Yes, in the last 12 months	Yes, but not in the last 12 months
High blood pressure			
Heart disorders			
Migraine			
Depression			
Anxiety			
Mental health problems			
Other disorders/diseases			

APPENDIX D

IEQ preferences clusters

	IEQC1	IEQC2	IEQC3	P-value
n (%within the total sample)	159 (35.5)	149 (33.3)	140 (31.3)	-
Age				0.325
Mean (SD)	19.6 (1.7)	19.7 (1.3)	19.9 (1.7)	-
Maximum	31	26	29	-
Minimum	17	18	18	-
Mood - n (%within cluster level)				0.375
Cheerful	12 (7.5)	14 (9.4)	10 (7.1)	-
Relaxed	42 (26.4)	43 (28.9)	39 (27.9)	-
Calm	31 (19.5)	20 (13.4)	15 (10.7)	-
Neutral	31 (19.5)	28 (18.8)	33 (23.6)	-
Sad	10 (6.3)	8 (5.4)	17 (12.1)	-
Bored	21 (13.2)	23 (15.4)	17 (12.1)	-
Recently experienced events - n (%within cluster level)				
Positive events	45 (34.0)	40 (26.8)	36 (25.7)	0.226
Negative events	56 (35.2)	44 (29.5)	50 (35.7)	0.455
Lifestyle - n (%)				
Smoking	42 (26.4)	46 (30.9)	46 (32.8)	0.380
Alcohol	133 (83.7)	129 (86.6)	119 (85.0)	0.502
Physical activity	146 (91.8)	138 (92.6)	120 (85.7)	0.098
PANAS - Mean (SD)				
Positive affect	17.5 (2.6)	17.6 (2.5)	17.1 (2.7)	0.122
Negative affect	11.8 (3.0)	11.3 (2.9)	11.4 (3.0)	0.617
Health - n (%within cluster level)				
Hay fever	35 (22.2)	30 (20.1)	33 (23.6)	0.205
Rhinitis	52 (32.9)	51 (34.2)	43 (30.2)	0.074
Eczema	18 (6.3)	25 (16.8)	22 (15.7)	0.517
Other skin conditions	12 (7.6)	15 (10.1)	18 (12.9)	0.590

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	IEQC1	IEQC2	IEQC3	P-value
Migraine	24 (15.2)	23 (15.5)	21 (15.0)	0.314
Depression	31 (19.5)	29 (19.5)	32 (22.9)	0.477
Anxiety	44 (27.8)	31 (20.8)	30 (21.4)	0.126
Mental health problems	32 (20.3)	23 (15.5)	23 (16.4)	0.677
IEQ perception of study - n (%within cluster level)				
Temperature in general dissatisfaction	31 (19.5)	27 (18.1)	38 (28.4)	0.084
Temperature not stable	42 (26.4)	36 (24.2)	43 (30.7)	0.588
Dissatisfied with air freshness	93 (58.5)	88 (59.1)	84 (60.0)	0.730
Dissatisfied with air smell	72 (45.3)	71 (47.7)	58 (41.4)	0.393
Air quality in general dissatisfaction	23 (14.5)	18 (12.1)	18 (12.9)	0.521
Daylight dissatisfaction	22 (13.8)	15 (10.1)	15 (10.7)	0.928
Reflection from the sun dissatisfaction	27 (17.0)	25 (16.8)	12 (8.6)	0.167
Artificial light dissatisfaction	24 (15.1)	33 (22.1)	25 (17.9)	0.182
Lighting in general dissatisfaction	13 (8.2)	16 (10.7)	9 (6.4)	0.867
Noise from outside dissatisfaction	36 (22.6)	37 (24.8)	36 (25.7)	0.391
Noise from installations dissatisfaction	19 (11.9)	23 (15.4)	20 (14.3)	0.907
Noise other than installations dissatisfaction	38 (23.9)	29 (19.5)	29 (20.7)	0.745
Noise in general dissatisfaction	28 (17.6)	30 (20.1)	20 (14.3)	0.921
Vibration dissatisfaction	21 (13.2)	16 (10.7)	16 (11.4)	0.836
Psychosocial perception of study place- n (%within cluster level)				
Amount of privacy dissatisfaction	14 (8.8)	10 (6.7)	12 (8.6)	0.754
Layout dissatisfaction	12 (7.5)	10 (6.7)	6 (4.7)	0.498
Decoration dissatisfaction	8 (5.0)	10 (6.7)	13 (9.3)	0.337
Cleanliness dissatisfaction	22 (13.8)	21 (14.1)	19 (13.6)	0.993
View to the outside dissatisfaction	16 (10.1)	20 (13.4)	18 (12.9)	0.611
Psychosocial preferences - mean (SD)				
Storage	6.5 (2.3)	6.2 (2.3)	6.0 (2.3)	0.503
Amenities	8.3 (1.5)	8.0 (1.5)	7.8 (1.4)	0.064

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TOC

	IEQC1	IEQC2	IEQC3	P-value
Presence and company of others	5.8 (2.5)	5.1 (2.6)	5.0 (2.6)	0.308
Size of the room	5.9 (1.9)	5.4 (2.0)	5.2 (2.0)	0.133
Bonding or identifying with the place	5.8 (2.3)	5.3 (2.6)	5.1 (2.4)	0.090
Ability to adapt or control the place	6.2 (2.1)	5.9 (2.1)	5.1 (2.6)	0.249
Importance of IEQ-related aspects - mean (SD)				
Chair seat heating	4.3 (2.8)	4.0 (2.8)	3.4 (2.5)	0.106
Chair backrest eating	4.4 (2.9)	3.9 (3.0)	3.5 (2.8)	0.095
Heating on my desk	3.9 (2.7)	3.6 (2.7)	3.2 (2.5)	0.141
Presence of plants	6.1 (2.5)	5.9 (2.5)	5.1 (2.7)	0.62
Personal control over the most used study place - mean (SD)				
Temperature	4.2 (1.9)	4.7 (1.7)	4.4 (1.8)	0.206
Ventilation	4.6 (2.0)	4.8 (1.8)	4.6 (1.8)	0.311
Shading from the sun	4.7 (2.2)	4.5 (2.1)	4.8 (2.0)	0.772
Lighting	4.8 (2.2)	5.1 (1.9)	5.1 (1.9)	0.377
Noise	2.9 (1.4)	3.2 (1.6)	2.9 (1.5)	0.168

APPENDIX E

Psychosocial preferences clusters

	PSC1	PSC2	PSC3	P-value
n (%within total sample)	110 (25.0)	186 (42.3)	144 (32.7)	-
Age				0.084
Mean (SD)	19.7 (1.5)	19.8 (1.8)	19.7 (1.3)	-
Maximum	29	31	26	-
Minimum	17	17	18	-
Gender -n (%within cluster level)				0.776
Male	43 (39.1)	68 (36.6)	58 (40.3)	-
Female	67 (60.9)	117 (62.9)	85 (59.0)	-
Mood - n (%)				0.262
Cheerful	9 (8.1)	20 (10.8)	7 (4.9)	-
Relaxed	26 (23.7)	48 (25.8)	50 (34.7)	-
Calm	18 (16.4)	29 (15.6)	19 (13.2)	-
Neutral	23 (20.9)	42 (22.6)	23 (16.0)	-
Sad	10 (9.1)	14 (7.5)	9 (6.3)	-
Bored	20 (18.2)	18 (9.7)	21 (14.6)	-
Recently experienced events - n (%within cluster level)				
Positive events	35 (31.8)	54 (29.0)	37 (25.7)	0.557
Negative events	34 (30.9)	64 (34.4)	47 (32.6)	0.822
Lifestyle - n (%)				
Physical activity	97 (88.2)	170 (91.4)	129 (89.6)	0.658
PANAS - Mean (SD)				
Positive affect	18.0 (2.5)	17.1 (2.5)	17.3 (2.6)	0.168
Negative affect	11.8 (2.9)	11.6 (2.9)	11.2 (3.1)	0.301
Health - n (%within cluster level)				

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	PSC1	PSC2	PSC3	P-value
Asthma	4 (3.6)	9 (8.0)	4 (2.8)	0.204
Hay fever	21 (19.1)	45 (24.2)	31 (21.5)	0.796
Rhinitis	26 (23.6)	70 (37.7)	48 (33.3)	0.194
Eczema	16 (7.3)	26 (14.0)	23 (16.0)	0.984
Other skin conditions	6 (5.4)	22 (11.8)	17 (11.8)	0.262
Migraine	16 (14.5)	30 (16.2)	22 (15.3)	0.697
Depression	23 (20.9)	33 (17.8)	35 (24.3)	0.923
Anxiety	30 (27.3)	42 (22.6)	35 (24.3)	0.181
Mental health problems	21 (19.1)	23 (16.7)	24 (16.7)	0.701
IEQ perception of study - n (%within cluster level)				
Temperature in general dissatisfaction	23 (20.9)	43 (23.1)	29 (20.1)	0.832
Temperature not stable	32 (29.1)	48 (25.8)	41 (28.5)	0.744
Dissatisfied with air smell	45 (40.9)	94 (50.5)	63 (43.8)	0.261
Air quality in general dissatisfaction	18 (16.4)	20 (10.8)	21 (14.6)	0.324
Daylight dissatisfaction	9 (8.2)	24 (12.9)	18 (12.5)	0.434
Reflection from the sun dissatisfaction	11 (10.0)	28 (15.1)	26 (18.1)	0.188
Artificial light dissatisfaction	14 (12.7)	37 (19.9)	29 (20.1)	0.227
Lighting in general dissatisfaction	7 (6.4)	18 (9.7)	12 (8.3)	0.623
Noise from outside dissatisfaction	30 (27.3)	50 (26.9)	30 (20.8)	0.399
Noise from installations dissatisfaction	16 (14.5)	24 (12.9)	20 (13.9)	0.902
Noise other than installations dissatisfaction	26 (23.6)	39 (21.0)	32 (22.2)	0.842
Noise in general dissatisfaction	20 (18.2)	32 (17.2)	26 (18.1)	0.953
Vibration dissatisfaction	16 (14.5)	24 (12.9)	13 (9.0)	0.385
Psychosocial perception of study place- n (%within cluster level)				
Cleanliness dissatisfaction	10 (9.1)	28 (15.1)	24 (16.7)	0.193
View to the outside dissatisfaction	11 (10.0)	25 (13.4)	18 (12.5)	0.676
IEQ preferences - mean (SD)				
Ventilation and fresh air	8.2 (1.3)	7.8 (1.3)	7.7 (1.7)	0.065
View to the outside	8.5 (1.4)	8.2 (1.7)	7.9 (2.0)	0.075
Sounds from the inside	7.1 (2.2)	6.7 (2.0)	6.7 (2.4)	0.154

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TOC

	PSC1	PSC2	PSC3	P-value
Importance of IEQ-related aspects - mean (SD)				
Personal desk ventilation and fresh air	7.6 (2.0)	6.7 (2.3)	7.0 (2.2)	0.138
Headphones	7.4 (2.4)	7.3 (2.3)	6.9 (2.7)	0.734
Personal control over the most used study place - mean (SD)				
Temperature	4.8 (1.6)	4.2 (1.9)	4.4 (1.8)	0.087
Shading from the sun	5.2 (2.0)	4.5 (2.1)	4.5 (2.1)	0.051
Lighting	5.7 (1.7)	4.7 (2.1)	5.0 (2.0)	0.065
Noise	3.4 (1.6)	2.8 (1.4)	2.9 (1.4)	0.069

APPENDIX F

Descriptive of the overlap nine profiles

	IEQC1-PSC1	IEQC1-PSC2	IEQC1-PSC3	IEQC2-PSC1	IEQC2-PSC2	IEQC2-PSC3	IEQC3-PSC1	IEQC3-PSC2	IEQC3-PSC3	P-value
n (%within the total sample)	59 (13.5)	63 (14.4)	35 (8.0)	34 (7.8)	64 (14.6)	48 (11.0)	17 (3.9)	59 (13.5)	59 (13.5)	-
Mood - N (%)										
Cheerful*	5 (8.5)	5 (7.9)	2 (5.7)	3 (8.8)	9 (14.1)	2 (4.2)	1 (5.9)	6 (10.2)	3 (5.1)	-
Relaxed*	14 (23.7)	12 (19.0)	16 (45.7)	4 (11.8)	23 (35.9)	8 (16.7)	4 (23.5)	13 (22.0)	9 (15.3)	-
Calm*	11 (18.6)	14 (22.2)	6 (17.1)	6 (17.6)	7 (10.9)	7 (14.6)	1 (5.9)	8 (13.6)	6 (10.2)	-
Neutral*	13 (22.0)	14 (22.2)	3 (8.6)	7 (20.6)	11 (17.2)	8 (16.7)	3 (17.6)	17 (28.8)	12 (20.3)	-
Sad*	3 (5.1)	4 (6.3)	1 (8.6)	1 (2.9)	2 (3.1)	4 (8.3)	2 (11.8)	8 (13.6)	5 (8.5)	-
Bored*	9 (15.3)	8 (12.7)	3 (8.6)	6 (17.6)	7 (10.9)	10 (20.8)	5 (29.4)	3 (5.1)	8 (13.6)	-
Recently experienced events - n (%within profile level)										
Negative events	20 (33.9)	22 (34.9)	13 (37.1)	8 (23.5)	20 (31.3)	15 (31.3)	6 (35.3)	22 (37.3)	19 (32.2)	0.054
Lifestyle - n (%within profile level)										
Smoking *	8 (13.6)	22 (34.9)	12 (34.3)	10 (29.4)	19 (29.7)	15 (31.2)	3 (17.7)	15 (25.4)	21 (35.6)	-
Study place - N (%within profile level)										
Home	49 (83.1)	31 (49.2)	22 (62.9)	33 (97.1)	43 (67.2)	40 (83.3)	16 (94.1)	43 (72.9)	46 (78.0)	-
Educational building*	10 (16.9)	31 (49.2)	13 (37.1)	1 (2.9)	21 (32.8)	7 (14.6)	1 (5.9)	16 (27.1)	13 (22.0)	-
Health - n (%within profile level)										
Hay fever*	9 (15.3)	18 (28.6)	8 (22.9)	8 (23.5)	11 (17.2)	10 (20.9)	4 (23.5)	16 (27.1)	13 (22.0)	-
Rhinitis*	14 (23.7)	28 (44.5)	10 (28.6)	8 (23.5)	24 (37.5)	17 (35.4)	4 (23.5)	18 (30.5)	21 (35.6)	-
Eczema*	6 (10.2)	7 (11.1)	5 (14.3)	7 (20.5)	11 (17.2)	7 (14.6)	3 (17.6)	8 (13.6)	11 (18.6)	-
Other skin conditions*	2 (3.4)	8 (12.7)	2 (5.7)	3 (8.8)	6 (9.4)	5 (10.4)	1 (5.9)	7 (11.9)	10 (17.0)	-
Migraine*	6 (10.2)	11 (17.5)	7 (20.0)	8 (23.5)	10 (15.6)	5 (10.4)	2 (11.8)	9 (15.3)	10 (16.9)	-
Mental health problems*	11 (18.6)	14 (22.2)	6 (17.1)	8 (23.5)	8 (12.5)	7 (14.6)	2 (11.8)	9 (15.3)	11 (18.6)	-

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	IEQC1-PSC1	IEQC1-PSC2	IEQC1-PSC3	IEQC2-PSC1	IEQC2-PSC2	IEQC2-PSC3	IEQC3-PSC1	IEQC3-PSC2	IEQC3-PSC3	P-value
IEQ perception of study place - n (% level)										
Temperature in general dissatisfaction*	13 (22.0)	13 (20.6)	5 (14.3)	4 (11.8)	14 (21.9)	8 (16.7)	6 (35.3)	16 (27.1)	16 (27.1)	-
Temperature not stable	14 (23.7)	20 (31.7)	8 (22.9)	11 (32.4)	12 (18.8)	13 (27.1)	7 (41.2)	16 (27.1)	19 (32.2)	0.093
Air quality in general dissatisfaction*	8 (13.6)	10 (15.9)	5 (14.3)	5 (14.7)	5 (7.8)	8 (16.7)	5 (29.4)	5 (8.5)	8 (13.6)	-
Daylight dissatisfaction*	6 (10.2)	11 (17.5)	5 (14.3)	2 (5.9)	8 (12.5)	4 (8.3)	1 (5.9)	5 (8.5)	9 (15.3)	-
Reflection from the sun dissatisfaction*	6 (10.2)	15 (23.8)	6 (17.1)	4 (11.8)	11 (17.2)	10 (20.8)	1 (5.9)	2 (3.4)	9 (15.3)	-
Artificial light dissatisfaction*	8 (13.6)	13 (20.6)	3 (8.6)	6 (17.6)	12 (18.8)	14 (29.2)	-	12 (20.3)	12 (20.3)	-
Lighting in general dissatisfaction*	3 (5.1)	8 (12.7)	2 (5.7)	4 (11.8)	9 (14.1)	2 (4.2)	-	1 (1.7)	8 (13.6)	-
Noise from outside dissatisfaction*	17 (28.8)	15 (23.8)	4 (11.4)	9 (26.5)	18 (28.1)	10 (20.8)	4 (23.5)	17 (28.8)	15 (25.4)	-
Noise from installations dissatisfaction*	8 (13.6)	7 (11.1)	4 (11.4)	4 (11.8)	8 (12.5)	10 (20.8)	4 (23.5)	9 (15.3)	6 (10.2)	-
Noise other than installations dissatisfaction*	14 (23.7)	14 (22.2)	10 (28.6)	8 (23.5)	11 (17.2)	10 (20.8)	4 (23.5)	14 (23.7)	11 (18.6)	-
Noise in general dissatisfaction*	10 (16.9)	10 (15.9)	8 (22.9)	7 (20.6)	14 (21.9)	9 (18.8)	3 (17.6)	8 (13.6)	9 (15.3)	-
Vibration dissatisfaction*	7 (11.9)	10 (15.9)	4 (11.3)	6 (17.6)	7 (10.9)	3 (6.3)	3 (17.6)	7 (11.9)	6 (10.2)	-
Psychosocial perception of study place- n (%within profile level)										
Amount of privacy dissatisfaction*	1 (1.7)	12 (19.0)	1 (2.9)	1 (2.9)	2 (3.1)	7 (14.6)	-	6 (10.2)	6 (10.2)	-
Layout dissatisfaction*	3 (5.1)	7 (11.1)	2 (5.7)	-	5 (7.8)	5 (10.4)	-	2 (3.4)	4 (6.8)	-
Decoration dissatisfaction*	2 (3.4)	6 (9.5)	-	-	6 (9.4)	4 (8.3)	-	3 (5.1)	10 (16.9)	-
Cleanliness dissatisfaction*	6 (10.2)	12 (19.0)	4 (11.4)	3 (8.8)	9 (14.1)	9 (18.8)	1 (5.9)	7 (11.9)	11 (18.6)	-
View to the outside dissatisfaction*	4 (6.8)	10 (15.9)	2 (5.7)	3 (8.8)	11 (17.2)	6 (12.5)	4 (23.5)	4 (6.8)	10 (16.9)	-

** N<5, thus chi-squared test not performed*

APPENDIX G

Building checklist used during the field study

1. Building information	
Number of storeys of the building	(_____)
Storey number of where the study place is located	(_____)
Is the above story occupied by people?	Yes No
Ceiling height of the study place room	(_____)m
The floor area of the study place rooms	(_____)m^2
In which room does the study place is located?	Bedroom Living room Kitchen Other:_______________
Where is the study place located?	Close to window Close to wall Centre of the room Close to the entrance At the corner
2. Where is the building situated?	
Industrial area	
Mixed industrial/residential area	
Commercial area	
Mixed commercial/residential area	
City centre, densely packed housing	
Town, with or without small gardens	
Suburban, with large gardens	
Village in a rural area	
Rural area with no or few other homes nearby	

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3. Are there any nearby (within 100 meters) noise sources outside the building that might influence the indoor environment?	
None	
Car parking with a minimum of 50 places close to the building	
Busy road (at least part of the day)	
Highway	
Railway or station	
Subway	
Tram way	
Air traffic (up to 3 km)	
Water traffic	
Other entertainment or leisure	
School building	
Community buildings (halls, churches, etc.)	
Workshops	
Construction works	
4. Can you hear outside noise inside the study place?	Yes No
5. Are there any major indoor noise sources found inside the study place?	
No indoor noise sources	
Other occupants inside the same space	
Neighbours	
Machines (printers, computers, dryer/washing machines)	
Vibrations (fans, ducts)	
Elevators	
Other:______________________	
Sound pressure level at home study place (for one minute)	____________
6. Is there any acoustical insulation applied?	Yes: curtain, soft materials No
7. Wall covering of the study place	
Wallpaper	
Enamel/gloss paint	
Dispersion/emulsion paint	
Wood/sealed cork	
Porous fabrics including textiles	
Stone/tiles	
Exposed concrete/plaster	
Other:______________________	

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8. The floor covering of the study place	
Carpet	
Wood	
Synthetic smooth floor covering (e.g., rubber, vinyl)	
Exposed concrete	
Tiles (e.g., stone, ceramic)	
Other:______________________	
9. Ceiling covering of the study place	
Wallpaper	
Paint	
Synthetic material	
Mineral fibre tiles	
Wood/cork fibre tiles	
Gypsum/plaster	
Exposed concrete	
Other:______________________	
10. Is there a suspended ceiling?	Yes No
11. Number of windows in the study place	Number: (_____) Window-to-wall ratio: (____)
Can they be open?	Yes, number: (_____) No
12. Is there mechanical ventilation in the study place?	Yes No
13. Study place furniture	Chair: (arm, armless) Desk Cabinet Desk lamp Other: _____________
14. Study place technologies	Computer or laptop Printer Headphones Other: ____________

APPENDIX H

Home study place characteristics of the participated students in the lab experiments

Student (profile)	Building type			Home study place location				Sound sources at home study place		Sound is noise	Sound source preference
	Student housing	Private housing with roommate(s)	Private housing with parents	Private studio	Private bedroom	Private office room	Shared living room	From outside	From inside		
1(1)	X			X				• Construction • Truck loading	• Mechanical ventilation	• Continuous sounds	• Silence • People studying at the library • Music
2(1)	X			X				• Doorbell from the other building • Truck loading	• Footsteps from neighbours upstairs • Refrigerator	• Distracting sounds • Not constant sounds • Loud sounds	• Music • Winds sounds • Rain sounds

>>>

Student (profile)	Building type			Home study place location				Sound sources at home study place		Sound is noise	Sound source preference
	Student housing	Private housing with roommate(s)	Private housing with parents	Private studio	Private bedroom	Private office room	Shared living room	From outside	From inside		
3(2)	X				X			• Nearby school in the morning • Winds	• People talking in the living room	• Distracting sounds • Noticeable sounds • Not normal sounds • Vacuum sounds • Loud sounds	• Music • people walking sounds
4(2)		X				X		• Traffic (cars)	• Radio • People talking in the living room	• Louds sounds (e.g., washing machine)	• Music
5(3)			X		X			• Birds • Traffic sounds in previous home study place	• People talking in the living room • TV • Washing and dry-ing machines	• Louds sounds (e.g., vacuum machine)	• Quiet sound envi-ronment • Rain sounds
6(3)			X		X			• Birds • People playing at the soccer field (when the window is opened) • Neighbour sounds from the garden (only during summer when the window is opened)	• People talking in the living room	• People sounds	• Quiet sound envi-ronment
7(3)		X			X			• Café' • Birds • Electric saw • Traffic (cars,tram) • Sirens	• Neighbours talking	• Continuous sounds (too long sound duration) • Neighbours talking • Electric saw sounds	• Music (piano) • Listening to podcast

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TOC

Student (profile)	Building type			Home study place location				Sound sources at home study place		Sound is noise	Sound source preference
	Student housing	Private housing with roommate(s)	Private housing with parents	Private studio	Private bedroom	Private office room	Shared living room	From outside	From inside		
8(4)			X		X			• Winds and rain when the window is opened • Traffic (cars) when the window is opened • Children playing outside when the window is opened	• People talking in the same house • Washing and drying machines • Parot talking	• When student's mood is negative, all sounds are considered noise • Inconstant sounds	• Music (piano and with known lyrics)
9(5)	X				X			• People working in the garden • Birds • Rains	• Music sounds from neighbour upstairs (not often. happens once or twice a month) • It is a quiet home study place in general	• Continuous sounds (too long sound duration) • Loud sounds	• Different types of music (classical. pop. soul) in a low level as a background
10(5)	X						X	• Traffic (cars)	• People talking in the same apartment • Washing machine • Footsteps from neighbours upstairs	• Inconstant sounds • Distracting sounds	• Quiet sound environment
11(5)		X			X			• People walking • Traffic (cars and tram)	• Plumbing system • People walking and talking from the same apartment	• All sounds are noise • People walking sounds are not noise. it is a pleasant sound	• Music (e.g.. rock. hip-hop. electronic).

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TOC

Student (profile)	Building type			Home study place location				Sound sources at home study place		Sound is noise	Sound source preference
	Student housing	Private housing with roommate(s)	Private housing with parents	Private studio	Private bedroom	Private office room	Shared living room	From outside	From inside		
12(4)	X				X			• Goose • Sirens from police and ambulance stations (the student get used to these sounds)	• Music played by other students in the same apartment	• Inconstant sounds • Loud sounds	• Music without lyrics • People studying sounds (e.g.. paper-flipping sounds) • Constant sounds such as rain
13(5)			X			X		• Winds and rain • Traffic (cars, trains but not often, and planes)	• Door tapping sounds when it is a windy day • It is a quiet home study place from the inside	• Loud sounds • Unusual sounds • Scooter sounds	• Wind sounds • Birds sounds
14(4)	X			X				• It is a quiet home study place from the outside • Truck loading sounds	• It is a quiet home study place from the inside • Ventilation in the bathroom (when the door is open)	• Loud sounds • Irregular sounds • Any sounds that cannot be filtered out	• Depends on studying task • Music • Rainfall sounds
15(4)	X				X			• People talking • Traffic sounds in previous home study place	• People talking • Mechanical ventilation	• Continuous sounds • Party sounds	• Quiet study place while studying • Listening to music during drawing

Profile 1: Sound extremely concerned introvert, profile 2: sound unconcerned introvert, profile 3: sound partially concerned introvert, profile 4: sound concerned extrovert, profile 5: sound unconcerned extrovert

APPENDIX I

Perceptual assessment form of the lab experiments

APP. I.1 Test in the test chamber

Student ID: **Condition:**

Imagine you have to study under these sound conditions. Please mark on the following scales:

	During the first 2 minutes of this condition	**During the second 2 minutes of this condition**
	How acceptable is this sound environment?	
Acceptability	Clearly acceptable Just acceptable - - - - - - - - - - Just unacceptable Clearly unacceptable	Clearly acceptable Just acceptable - - - - - - - - - - Just unacceptable Clearly unacceptable
	How do you feel about this sound environment?	
Pleasantness	Clearly pleasant Just pleasant - - - - - - - - - - Just unpleasant Clearly unpleasant	Clearly pleasant Just pleasant - - - - - - - - - - Just unpleasant Clearly unpleasant
Stress level	Clearly not stressed Just not stressed - - - - - - - - - - Just stressed Clearly stressed	Clearly not stressed Just not stressed - - - - - - - - - - Just stressed Clearly stressed

APP. I.2. Test in the Experience room

Student ID: **Condition:**

	Imagine you have to study under these conditions, how do you feel about the following? **Please mark on the following scales:**	
Sound	Clearly acceptable Just acceptable Just unacceptable Clearly unacceptable	No noise Slight noise Moderate noise Loud noise Very loud noise

APPENDIX J

Raw data of the bodily responses during the lab experiments

	AL in test chamber														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Baseline 1	17	42	23	43	50	40	51	66	54	55	42	58	24	45	59
Low rural	30	37	49	51	53	39	54	46	41	44	48	40	37	50	58
High rural	32	41	49	47	55	38	60	39	53	44	56	42	39	47	52
Baseline 2	37	40	60	39	49	39	51	41	52	53	50	28	32	48	52
Low traffic	44	44	48	39	52	36	56	39	51	51	34	38	32	50	52
High traffic	40	46	44	43	42	40	53	38	45	48	34	51	46	51	63
Baseline 3	55	56	33	39	63	37	57	63	48	54	38	47	55	49	44
Low ventilation	61	57	39	58	56	33	61	48	48	50	37	34	32	52	49
High Ventilation	54	50	38	44	44	39	50	65	63	51	50	42	31	46	53
Baseline 4	61	60	55	49	42	40	52	58	55	52	52	15	30	53	58
Low talking people	56	59	54	46	40	43	55	65	59	53	50	29	43	49	58
High talking people	60	62	51	48	44	48	49	66	49	49	47	42	40	51	58

	MRL in test chamber														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Baseline 1	63	47	62	54	43	54	56	69	42	54	61	48	60	49	43
Low rural	60	58	60	50	56	52	53	72	51	52	59	55	59	56	51
High rural	56	55	58	45	56	47	56	70	52	51	59	52	49	48	51
Baseline 2	55	62	58	51	56	54	49	71	49	52	57	51	40	55	50
Low traffic	56	68	56	50	57	60	55	66	54	50	53	58	52	52	54
High traffic	54	64	53	48	55	56	51	64	62	55	56	53	48	50	47
Baseline 3	55	49	57	51	55	65	60	52	74	62	47	49	42	63	43
Low ventilation	50	51	67	45	53	66	60	60	67	62	58	48	47	62	51
High Ventilation	52	65	57	50	57	58	52	50	58	55	52	47	41	59	59
Baseline 4	49	69	58	46	56	65	53	53	60	55	60	59	53	53	49
Low talking people	58	63	61	49	52	60	62	44	54	54	54	61	51	58	41
High talking people	52	65	68	52	57	59	59	51	68	52	50	62	55	56	39

AL in Experience room													
1	2	3	4	5	6	7	8	9	11	12	13	14	15
71	42	45	58	61	46	58	39	50	48	49	42	45	54
63	43	35	51	48	56	58	39	58	52	43	38	44	56
57	45	26	51	38	40	57	49	47	53	50	43	46	58
57	47	32	59	42	60	55	55	49	68	49	47	44	59
47	53	26	59	41	56	60	60	44	34	40	31	38	52
43	56	30	56	41	55	54	36	40	36	31	47	37	51
40	60	60	45	41	63	53	42	54	40	45	34	45	50
44	54	38	44	49	51	48	45	51	62	22	37	47	54
45	62	36	57	39	26	50	40	39	64	34	40	52	54
45	61	51	51	58	61	51	70	49	66	40	51	51	52
48	56	27	44	51	53	54	57	46	60	47	42	50	48
60	53	23	59	42	45	47	49	48	61	33	44	50	50

MRL in Experience room													
1	2	3	4	5	6	7	8	9	11	12	13	14	15
63	43	58	51	57	51	34	56	82	48	67	56	47	51
54	45	59	45	61	45	41	62	70	46	59	60	41	53
56	48	57	52	65	47	36	52	69	52	61	49	43	56
51	49	58	48	60	44	37	45	45	48	61	48	47	65
55	51	65	49	50	57	37	50	56	56	58	50	53	67
58	49	64	50	55	54	40	53	62	57	48	49	58	61
57	55	46	49	53	40	42	53	50	61	47	56	57	56
53	48	55	56	50	44	48	59	66	50	71	55	56	57
51	52	51	58	51	65	46	54	71	55	71	54	53	49
48	66	54	59	54	31	51	38	54	52	65	47	57	53
54	55	68	58	56	43	57	54	57	50	61	48	58	56
53	59	59	53	63	43	58	57	55	46	60	53	47	50

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	HR in test chamber														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Baseline 1	71	89	84	67	68	69	70	77	68	76	78	49	48	74	51
Low rural	67	89	78	62	60	72	61	65	70	64	73	46	41	72	52
High rural	69	89	75	65	61	72	61	69	71	62	73	49	43	66	56
Baseline 2	67	90	76	65	62	72	65	72	72	65	73	50	46	66	56
Low traffic	67	89	76	65	69	73	63	69	73	74	73	50	43	69	56
High traffic	68	92	80	61	66	71	63	68	71	68	75	50	47	67	57
Baseline 3	72	97	83	66	71	77	70	72	80	73	82	63	56	75	62
Low ventilation	65	90	83	61	60	70	62	66	73	64	77	50	49	72	55
High Ventilation	64	78	75	62	63	69	66	68	70	64	69	52	49	66	58
Baseline 4	62	82	74	61	64	73	68	68	69	64	69	54	47	65	56
Low talking people	62	82	76	61	67	72	68	70	70	63	71	50	52	69	60
High talking people	63	85	74	62	64	72	61	72	73	64	72	49	49	67	57

	RR in test chamber														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Baseline 1	12	15	14	13	13	12	12	15	14	15	12	14	14	14	13
Low rural	13	15	14	12	14	11	13	14	14	13	11	13	14	13	13
High rural	14	14	13	14	13	14	14	14	13	14	11	13	14	12	12
Baseline 2	14	13	13	14	13	13	14	13	14	14	11	13	14	13	13
Low traffic	14	14	13	13	14	13	14	13	13	14	13	13	14	13	15
High traffic	15	13	13	13	14	12	12	13	14	14	12	13	14	13	14
Baseline 3	14	13	14	12	14	13	13	13	11	13	13	15	15	13	14
Low ventilation	15	13	13	14	13	13	13	13	11	14	12	14	14	14	14
High Ventilation	14	13	13	13	12	13	13	14	11	13	13	14	13	14	13
Baseline 4	14	14	13	13	13	13	13	13	11	14	12	14	14	13	13
Low talking people	13	15	13	13	14	14	13	13	10	13	11	14	13	13	13
High talking people	13	14	13	13	14	14	12	13	10	14	11	14	12	13	13

	HR in Experience room													
	1	2	3	4	5	6	7	8	9	11	12	13	14	15
	66	68	62	76	57	67	53	72	64	73	55	56	69	67
	56	69	63	61	60	68	52	68	63	67	45	60	57	55
	58	69	66	62	63	71	54	65	66	63	44	55	55	54
	60	68	66	63	62	69	56	68	66	62	45	72	56	53
	61	68	65	62	62	71	55	71	63	62	46	70	54	56
	59	69	65	60	66	74	56	70	66	65	46	63	55	58
	59	73	65	61	64	72	60	72	67	67	48	54	55	56
	57	71	67	63	61	70	59	68	60	68	48	46	56	55
	60	76	67	60	62	72	59	70	62	66	51	48	57	56
	58	79	68	63	62	70	57	67	67	69	50	47	59	60
	58	73	69	64	60	70	58	69	63	69	47	50	59	56
	59	72	68	62	62	71	60	70	68	69	49	49	58	57

	RR in Experience room													
	1	2	3	4	5	6	7	8	9	11	12	13	14	15
	15	13	13	14	12	13	14	13	13	13	14	14	13	13
	14	13	13	13	10	14	13	12	13	13	13	13	13	13
	13	15	13	12	9	14	13	12	14	12	13	13	14	13
	14	14	14	12	9	15	13	13	14	11	13	13	14	13
	13	14	14	13	10	14	13	13	13	11	13	13	14	13
	13	13	13	13	11	14	13	13	12	10	13	14	13	14
	13	14	12	13	9	14	13	14	11	10	13	13	13	13
	14	13	12	15	10	14	13	14	10	11	13	14	14	15
	13	14	13	15	11	14	13	13	10	12	13	13	13	15
	13	14	12	14	11	14	14	13	10	13	13	13	13	14
	13	13	12	14	11	13	14	14	10	13	13	14	12	13
	13	13	12	15	13	13	13	14	11	13	12	15	13	13

APPENDIX K

Correlations between bodily responses and perceptual assessments at individual-level –

Tests in test chambers

Physiological vs perceptual	R														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
AL vs Acceptability	**0.7**	0.0	0.2	0.4	0.4	**-0.8**	**0.8**	-0.1	-0.1	-0.1	-0.3	-0.1	0.0	0.4	-0.3
AL vs Pleasantness	0.2	0.3	0.4	0.1	0.5	**-0.7**	**0.9**	-0.2	0.2	0.2	-0.2	-0.1	-0.2	**0.7**	-0.1
AL vs Stress level	0.4	0.0	0.4	0.4	0.4	0.4	**0.7**	-0.2	0.1	0.1	-0.5	0.0	-0.1	0.5	-0.3
MRL vs Acceptability	-0.5	0.2	0.0	**-0.8**	0.0	**0.8**	-0.1	-0.1	0.2	0.2	0.0	**0.6**	-0.1	0.3	0.1
MRL vs Pleasantness	0.1	-0.2	-0.4	-0.3	0.4	**0.9**	-0.1	0.0	0.0	-0.3	0.3	0.3	0.0	0.1	0.1
MRL vs Stress level	0.2	0.0	-0.1	**-0.7**	0.2	0.4	-0.1	0.1	0.0	-0.5	0.0	0.4	-0.1	0.4	0.2
HR vs Acceptability	-0.5	**-0.7**	0.0	**-0.6**	-0.3	0.4	-0.4	0.0	0.1	-0.3	0.2	**0.8**	-0.2	-0.1	0.1
HR vs Pleasantness	-0.2	-0.4	-0.3	-0.3	-0.4	0.5	-0.3	-0.2	0.1	-0.3	-0.1	0.5	0.0	-0.2	-0.2
HR vs Stress level	0.0	-0.4	0.0	-0.4	-0.5	0.1	-0.2	-0.1	0.1	-0.5	0.3	**0.7**	-0.3	-0.3	-0.1
RR vs Acceptability	**0.7**	**0.6**	0.1	0.0	-0.2	-0.2	0.4	-0.3	0.2	**-0.6**	0.0	0.2	0.1	-0.2	**0.6**
RR vs Pleasantness	0.2	**0.8**	-0.1	0.0	-0.1	-0.5	0.4	-0.4	0.1	-0.4	0.3	0.4	0.1	-0.2	**0.7**
RR vs Stress level	0.2	**0.7**	0.2	0.0	-0.1	**-0.8**	0.2	-0.2	0.3	-0.4	0.2	0.3	0.0	-0.3	0.4

	P-value														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0.06	0.88	0.64	0.27	0.19	0.07	P<0.001	0.82	0.71	0.82	0.34	0.87	0.93	0.15	0.38
	0.56	0.36	0.23	0.78	0.07	0.02	P<0.001	0.48	0.55	0.63	0.50	0.89	0.57	**0.02**	0.76
	0.35	1.00	0.22	0.37	0.20	0.04	**0.01**	0.60	0.71	0.66	0.13	0.95	0.78	0.10	0.43
	0.20	0.63	0.88	**0.02**	0.90	0.33	0.75	0.77	0.50	0.63	0.89	0.14	0.73	0.34	0.70
	0.86	0.45	0.25	0.46	0.25	**0.02**	0.86	0.94	0.97	0.29	0.39	0.53	1.00	0.80	0.82
	0.68	0.94	0.71	0.07	0.63	P<0.001	0.86	0.65	0.97	0.07	0.90	0.28	0.74	0.16	0.62
	0.23	**0.02**	0.88	0.15	0.43	0.38	0.24	0.91	0.68	0.38	0.59	**0.02**	0.58	0.68	0.73
	0.68	0.25	0.35	0.46	0.21	0.29	0.41	0.58	0.71	0.41	0.67	0.26	0.91	0.45	0.62
	0.93	0.23	0.88	0.27	0.12	0.25	0.52	0.65	0.85	0.14	0.41	**0.04**	0.51	0.41	0.79
	0.06	0.06	0.73	0.98	0.61	0.76	0.16	0.40	0.44	**0.04**	0.90	0.60	0.73	0.47	**0.03**
	0.68	P<0.001	0.73	0.99	0.80	0.57	0.26	0.18	0.69	0.16	0.35	0.39	0.83	0.47	**0.01**
	0.63	**0.02**	0.48	0.98	0.67	0.17	0.53	0.48	0.39	0.18	0.56	0.49	0.95	0.38	0.16

APPENDIX L

Correlations between bodily responses and perceptual assessments at individual-level –

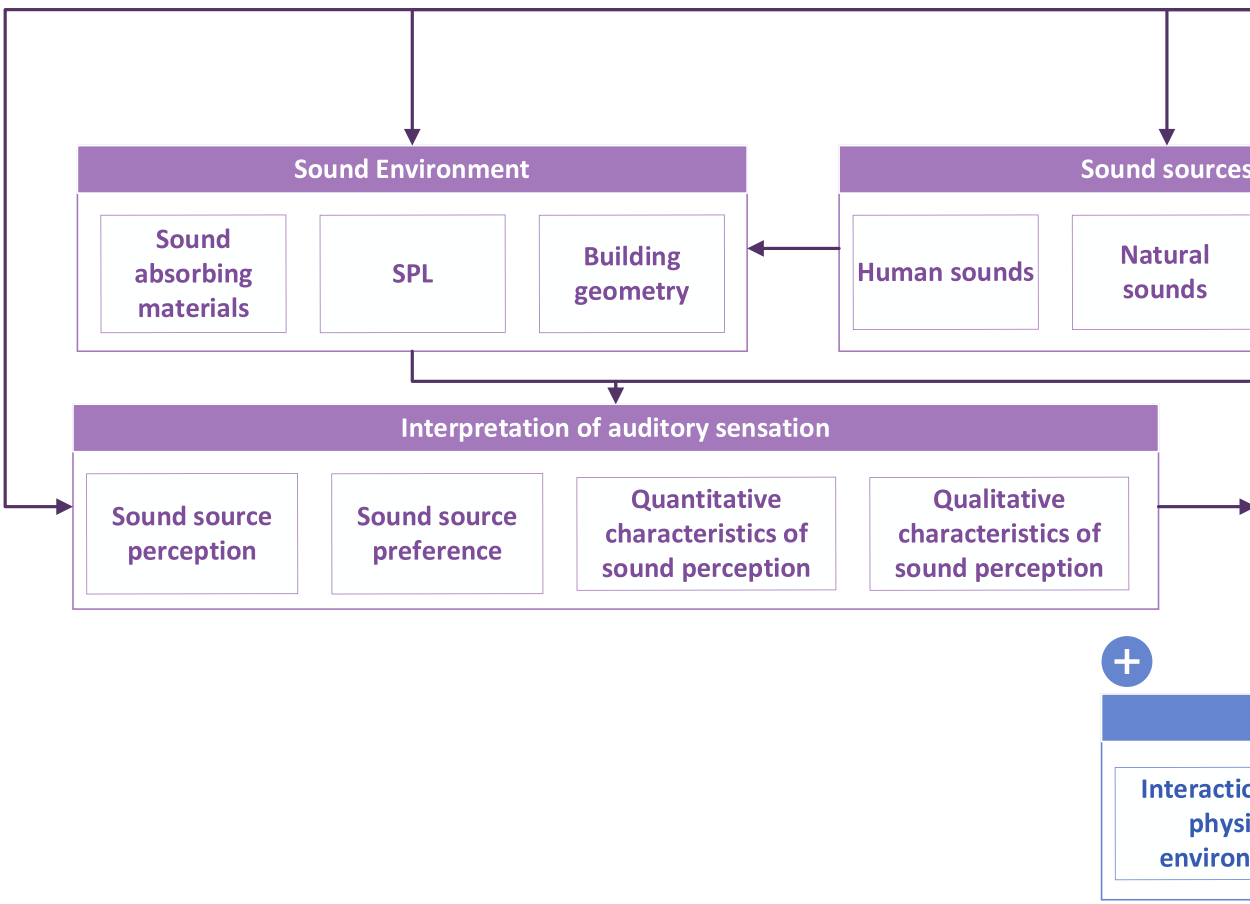
Tests in the Experience room

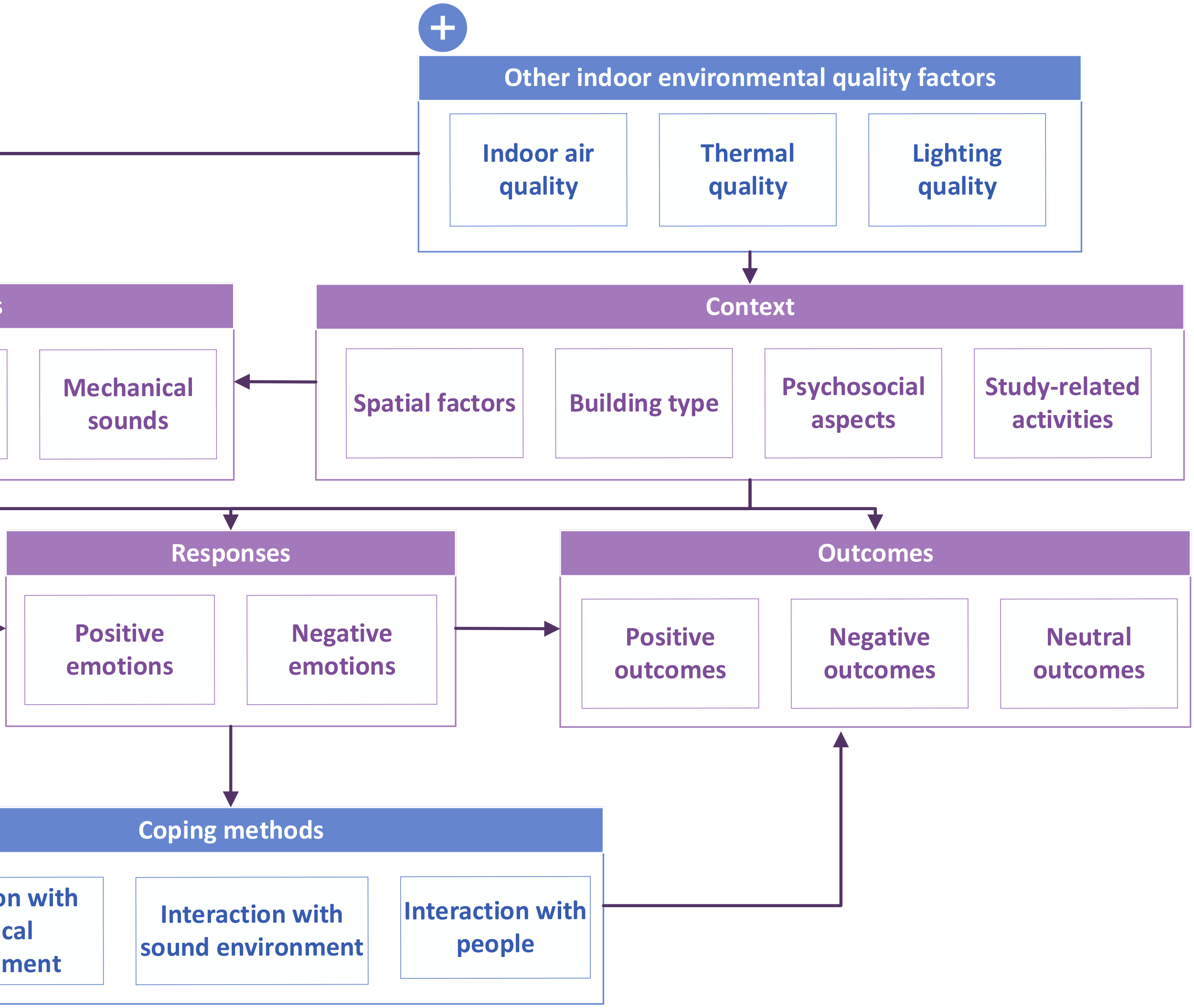
Physiological vs perceptual	R													
	1	2	3	4	5	6	7	8	9	11	12	13	14	15
AL vs Acceptability	0.1	-0.1	0.1	0.5	0.3	**0.8**	**0.7**	0.5	0.4	0.3	0.2	0.1	0.1	-0.4
AL vs Noise level	0.1	-0.3	0.2	0.1	0.4	0.2	0.3	**0.6**	0.2	0.4	-0.2	-0.4	0.4	-0.1
MRL vs Acceptability	-0.1	0.0	0.3	0.2	-0.4	**-0.7**	0.1	-0.4	-0.3	-0.2	0.0	-0.2	0.0	0.5
MRL vs Noise level	-0.2	-0.1	**0.8**	0.4	-0.3	-0.3	0.2	-0.2	0.1	-0.4	**0.8**	**0.7**	0.1	0.5
HR vs Acceptability	-0.1	-0.1	0.2	-0.2	**-0.6**	0.3	-0.4	-0.5	-0.4	-0.3	-0.4	-0.2	0.0	-0.1
HR vs Noise level	-0.2	0.0	0.2	0.3	**-0.6**	**-0.6**	**-0.7**	-0.4	**-0.7**	-0.1	0.2	0.5	0.3	-0.3
RR vs Acceptability	0.3	0.2	0.3	0.3	-0.1	**0.6**	**-0.6**	-0.4	0.0	0.3	-0.1	-0.3	0.2	-0.3
RR vs Noise level	0.3	0.2	0.4	0.5	-0.1	0.1	-0.2	-0.2	-0.2	**0.6**	0.6	0.1	0.1	-0.4

	P-value													
	1	2	3	4	5	6	7	8	9	11	12	13	14	15
	0.89	0.80	0.86	0.20	0.30	**0.03**	**0.01**	0.15	0.27	0.41	0.61	0.87	0.83	0.24
	0.82	0.30	0.54	0.75	0.18	0.63	0.43	**0.03**	0.54	0.23	0.69	0.34	0.27	0.79
	0.87	0.94	0.39	0.60	0.28	**0.04**	0.75	0.17	0.43	0.50	0.98	0.63	0.89	0.16
	0.57	0.75	**0.01**	0.31	0.37	0.55	0.50	0.48	0.80	0.17	**0.02**	0.07	0.78	0.11
	0.78	0.77	0.50	0.64	**0.05**	0.54	0.17	0.14	0.27	0.37	0.32	0.65	0.94	0.68
	0.65	0.91	0.52	0.54	**0.05**	0.11	**0.02**	0.26	**0.01**	0.74	0.66	0.22	0.31	0.40
	0.51	0.53	0.41	0.53	0.83	0.14	0.07	0.23	0.89	0.30	0.82	0.44	0.47	0.30
	0.48	0.59	0.23	0.24	0.82	0.81	0.58	0.51	0.48	**0.03**	0.11	0.72	0.69	0.18

APPENDIX M

Proposed themes and categories to better explain students’ sound environment experience at home study places


Sound Environment
Sound absorbing materials
SPL
Building geometry
Sound sources
Human sounds
Natural sounds
Interpretation of auditory sensation
Sound source perception
Sound source preference
Quantitative characteristics of sound perception
Qualitative characteristics of sound perception
+
Interactio
physi
environ



Other indoor environmental quality factors
Indoor air quality
Thermal quality
Lighting quality
Context
Spatial factors
Building type
Psychosocial aspects
Study-related activities
s
Mechanical sounds
Responses
Positive emotions
Negative emotions
Outcomes
Positive outcomes
Negative outcomes
Neutral outcomes
Coping methods
on with
cal
ment
Interaction with sound environment
Interaction with people

APPENDIX N

Assessment methods

Questionnaire

Aim: To cluster and profile students based on the acoustical and psychosocial preferences of their study places. Guidelines:

1. Develop a questionnaire (see for example the questionnaire **Appendix C**).
2. Distribute the questionnaire to a large sample size, at least 70 times the number of variables [1], of (university) students (preferably from several faculties).
3. Include a question about the aspects related to acoustical preferences (e.g., losing focus by outside sounds, as detailed in Chapter 4) that are recommended to be added to better understand the reason beyond why students are or are not concerned with the sounds in study places. For example, students can select from the list of aspects associated with acoustical preference 'sounds from outside are important', such as those explored in Chapter 4: 'losing focus by outside sound' and/or 'losing focus by outside sounds'. Moreover, students can also choose the option 'other' and type their reasons behind their acoustical preferences.
4. Include questions based on the soundscape approach, such as sound sources present at the study place, sound preference for performing an activity, and coping methods while being exposed to noise (e.g., closing window).
5. Perform a TwoStep cluster analysis and validate it to cluster the students based on their acoustical and psychosocial preferences.
6. Test with ANOVA and Chi-square which variables differ significantly between clusters to describe the unique characteristics of each cluster.

Visit

Aim: To substantiate the profiles, the study places of students from different clusters will be visited based on mixed-methods. During the visit, building-related indicators can be collected with a checklist, occupant-related indicators can be explained through an interview, and dose-related indicators (such as the sound pressure level) can be monitored. Guidelines:

1. Develop a building checklist (see for example **Appendix G**).
2. Create questions for a semi-structured interview (see for example **Table 6.1**).
3. Determine measurement protocol for dose-related indicators.
4. Install devices for monitoring of dose-related indicators.
5. Complete the building checklist to collect the building-related indicators, such as building location and the presence of acoustical materials.
6. Conduct the interview.
7. Analyse the data for a holistic overview of the characteristics of each cluster.

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APPENDIX O

‘MyStudyPlace Match’ platform

This online platform (**Figure. O.1**) could be managed by university campus facility managers which aims to assist students in selecting a study place that best aligns with their acoustical and psychosocial preferences. Additionally, it seeks to raise awareness among students about the importance of choosing a suitable study place that promotes their health and comfort according to their preferences. The ‘MyStudyPlace-Match’ proposed platform serves as a managing tool for study places that align with different individual preferences. The implementation of such a platform would involve architects designing diverse study places on a university campus that match different acoustical and psychosocial profiles. Then, the ‘MyStudyPlace-Match’ platform can be developed by researchers and administrated by facility managers, which would feature a predictive questionnaire for students to rate the importance level of their acoustical and psychosocial preferences. Based on students’ responses, they would be assigned to a preference profile. The platform would subsequently recommend study places that best match the identified profile. Nevertheless, the successful implementation of such a platform requires a larger and more diverse sample of students from various faculties. Additionally, it is crucial to validate the proposed profiles to ensure their accuracy and reliability.

The 'MyStudyPlace-Match' platform could be developed by the following stepwise phases, which is recommended to be conducted and validated in future research since it is a proposal for now:

1. Organize the dataset by compiling the data from the 'MyStudyPlace' questionnaire (explained in Section 7.2.1), and ensuring it includes sufficient responses to support a robust prediction model. The dataset should incorporate acoustical preferences, psychosocial preferences, and clusters (i.e., profiles). Other IEQ preferences, such as daylight, can be included. The following are examples of adequate datasets from previous studies:
   - 4,743 responses with 67 features from 38 participants over six months [1].
   - 1,182 responses from 25 participants over 30 days [2].
   - 1,080 responses from 20 participants over 180 days [3].
2. Develop a predictive model by creating a predictive model using machine learning algorithms. Train the model on the historical dataset from the questionnaire, such as the prediction model developed by Kim et al. [1] based on thermal preferences.
3. Define variables by using acoustical and psychosocial preferences (e.g., sounds from the outside, sounds from the inside, the ability to control or adapt the place, privacy, and presence and company of others) as input variables for the model. In addition, other input variables that were found to be significantly differ among the clusters could be considered.
4. Define the cluster type (i.e., profile) as the model's output.
5. Validate the predictive model by splitting the data into training and testing sets to evaluate its performance and accuracy, as demonstrated by Kim et al. [1].
6. Develop the online platform by creating the 'MyStudyPlace-Match' platform (Figure 7.5) and integrate it into the university's common platform.
7. Manage the platform by operating and administering the platform to ensure its functionality and accessibility.
8. Conduct a follow-up questionnaire to collect feedback on the comfort and effectiveness of the frequently used study place which is recommended by the platform.

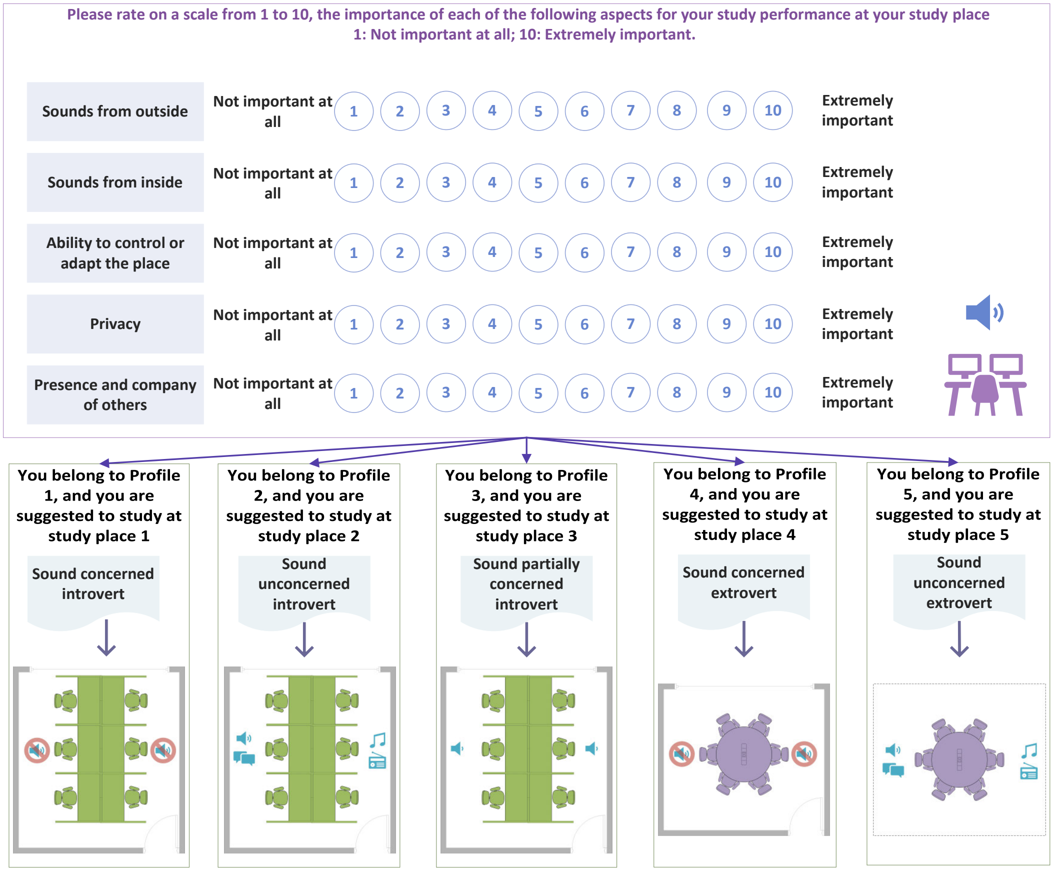

FIG. APP. O.1 The proposed 'MyStudyPlace-Match' platform based on practical-related guidelines for administrating study places at a university campus.

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Curriculum Vitæ

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Education

2020-2025 **PhD**
Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, the Netherlands.
Thesis title: Acoustical preferences and needs of students: Methods and indicators to assess the acoustical quality of study places

2018-2020 **Master in Architecture**
College of Architecture and Planning, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia.
Thesis title: Environmental Impact Cost Assessment Model for a Residential Building in Saudi Arabia

2011-2016 **Bachelor in Interior Design**- *First class honors*
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Professional experience

2017-2018 **Interior Designer (Freelancer)**
Designed projects: cafes, a private resort, an exhibition booth, a conference hall, a coffee & nuts store, and a research agency office in Saudi Arabia.

2016-2017 **Interior Designer**
Al-Fraihi Consultant Architecture and Planning, Al-Khobar, Saudi Arabia. Designed projects: a hospital's inpatient room, residential units, commercial buildings, offices, community care centre, and hotels in Saudi Arabia.

Academic experience

2024 Assisted a tutor in conducting a workshop on the research conducted in the indoor environmental quality at the SenseLab in the course: Climate Design (2024) offered to master students in the Building Technology track.

2023 Assisted a tutor in conducting a workshop on smells of indoor material in the course: Climate Design (2023) offered to master students in the Building Technology track.

A tutor in the course: Technoledge Health and Comfort (2023) master course in Building Technology track. Tasks: giving a presentation on how questionnaire can be used as a research method for understanding the indoor environment and supervising the group that worked on the indoor air quality for use in a meeting space.

2022 Assisted a tutor in conducting the workshop on smells of indoor material in the course: Climate Design (2022) for master students in the Building Technology track and gave a short lecture about the home questionnaire.

Extracurricular activities

- 4th – 8th November 2024, Autumn School Series in Acoustics: Building and Room Acoustics, Eindhoven University of Technology, Eindhoven, the Netherlands (*Participant*).
- 25th – 29th August 2024, Inter-Noise 2024: 53rd International Congress & Exposition on Noise Control Engineering, Nantes, France (*Presenter*).
- 11th – 15th September 2023, Forum Acusticum 2023: 10th Convention of the European Acoustics Association, Turin, Italy (*Presenter and reviewer*).
- 11th – 14th June 2023, 18th Healthy Buildings Europe Conference 2023, Aachen, Germany (*Presenter, session co-chair, and reviewer*).
- 22nd – 25th May 2022, CLIMA22, Rotterdam, the Netherlands (*Presenter and reviewer*).
- 21st – 23rd June 2021, Healthy Buildings Europe 2021,Norway (*Presenter*).

Reviewer for scientific international journals

- Building and Environment.
- Building Simulation.
- Engineering, Construction and Architectural Management. Facilities.
- International Journal of Building Pathology and Adaptation.

Languages

- Arabic (Native language).
- English (Advanced).
- Dutch (Basic: A2 level).

List of Publications

Scientific journals

Hamida, A., D'Amico, A., Eijkelenboom, A., & Bluyssen, P. M. (2024). Guidance to investigate university students' bodily responses and perceptual assessments in sound exposure experiments. Indoor Environments, 100066.

Hamida, A., Eijkelenboom, A., & Bluyssen, P. M. (2024). Profiling university students based on their acoustical and psychosocial preferences and characteristics of their home study places. Building and Environment, 111324.

Hamida, A., Eijkelenboom, A., & Bluyssen, P. M. (2023). Profiling Students Based on the Overlap between IEQ and Psychosocial Preferences of Study Places. Buildings, 13(1), 231.

Hamida, A., Zhang, D., Ortiz, M. A., & Bluyssen, P. M. (2023). Indicators and methods for assessing acoustical preferences and needs of students in educational buildings: A review. Applied Acoustics, 202, 109187.

Ding, E., Zhang, D., **Hamida, A.**, García-Sánchez, C., Jonker, L., de Boer, A. R., ... & Bluyssen, P. M. (2022). Ventilation and thermal conditions in secondary schools in the Netherlands: Effects of COVID-19 pandemic control and prevention measures. Building and Environment, 109922.

International conferences

Hamida, A., Eijkelenboom, A., & Bluyssen, P. M. (2024). Assessing the indoor soundscape approach among university students' home study places. In Inter-Noise 2024: 53rd International Congress & Exposition on Noise Control Engineering.

Hamida, A., Eijkelenboom, A., & Bluyssen, P. M. (2023). Clustering students based on their acoustical-related preferences of study places. In Forum Acusticum 2023: 10th Convention of the European Acoustics Association.

Hamida, A. B., Eijkelenboom, A. M., & Bluyssen, P. M. (2023). University students' perception of the sound environment at their home study places. In 18th Healthy Buildings Europe Conference 2023.

Hamida, A., Zhang, D., Ortiz, M. A., & Bluyssen, P. M. (2022, May). Students' self-reported health and psychosocial status at home before and during COVID-19. In CLIMA 2022 conference.

Hamida, A., 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. Healthy Buildings Europe Conference 20201.

25#11

Acoustical preferences and needs of students

Methods and indicators to assess the acoustical quality of study places

Amneh Basel Hamida

University students are self-directed learners who dedicate considerable time to studying in study places. Research on indoor environmental quality (IEQ) highlights the adverse effects of prolonged indoor exposure to environmental stressors, including noise. Acoustical quality can significantly influence students' health and comfort. To evaluate the acoustical quality of study places, three groups of indicators can be considered: occupant-related, dose-related, and building-related indicators. Given that students have different acoustical and psychosocial preferences for study places, it is crucial to consider occupant-related indicators. However, existing acoustical guidelines for study places and educational buildings primarily focus on dose-related and building-related indicators, while occupant-related indicators have been overlooked. Therefore, the main research question of this dissertation was posed:

How to assess the acoustical quality of study places?
This question was answered through several research methods. First, a literature review identified indicators and methods used to study students' acoustical preferences and needs. Then, 'MyStudyPlace' questionnaire was completed by university students who were clustered based on their IEQ and psychosocial preferences, resulting in nine profiles. Subsequently, students were re-clustered based on acoustical and selected psychosocial preferences, resulting in five profiles. To further explore these profiles, 23 home study places were visited, incorporating interviews, building inspections, and sound pressure level measurements. After that, 15 of these students participated in sound exposure lab experiments, which involved bodily responses, audiometric tests, and perceptual assessments. Furthermore, an indoor soundscape approach using semi-structured interviews with the 23 students examined their sound environment experiences of their home study places. This dissertation offers future research a set of suggested methods and indicators to assess the acoustical quality of study places.

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