Relaxing and working from home: associations between heating, ventilation and cooling system typologies and indoor soundscape evaluation

Relaxing and working from home: associations between heating, ventilation and cooling system typologies and indoor soundscape evaluation

Simone Torresin[1,2], Rossano Albatici[1], Francesco Aletta[3], Francesco Babich[2], Tin Oberman[3], Agnieszka Elzbieta Stawinoga[4] and Jian Kang[3]

[1] Department of Civil Environmental and Mechanical Engineering, University of Trento, Italy

[2] Institute for Renewable Energy, Eurac Research, Bozen/Bolzano, Italy

[3] UCL Institute for Environmental Design and Engineering, The Bartlett, University College London, London, UK

[4] Management and Committees, Eurac Research, Bozen/Bolzano, Italy

E-mail: simone.torresin@eurac.edu

Abstract. Data from an online survey conducted in January 2021 by 464 participants living in London and working from home (WFH) after the COVID-19 outbreak were analysed, focusing on: (1) types of building services at home, (2) perceived sound dominance of building services, and (3) the perception of the indoor acoustic environment (i.e. the indoor soundscape) in relation to two main activities, i.e. WFH and relaxation. Results show that most of participants´ houses had radiators for heating and relied on window opening for ventilation and cooling. Air systems (e.g., HVAC systems) resulted in higher perceived dominance compared to other systems, but only when evaluated for WFH. Sound dominance from building services was in turn related to soundscape evaluation. Spaces with less dominant sounds from building services were more appropriate for both WFH and relaxation, and spaces with fewer dominant sounds were assessed better, but just for WFH. Participants´ evaluations generally did not differ according to building service typology. The presence of air-cooling systems was associated with better perceived sound environments, most likely due to better acoustics conditions in newly built or retrofitted dwellings, more probably equipped with air cooling systems. Preliminary findings point out the importance of carefully considering the dominance of sounds by building services, especially for air systems, in relation to traditional and new uses of residential buildings.

1. Introduction

Since the spread of the SARS-CoV-2 disease, governments have adopted unprecedented measures to prevent the virus diffusion, which included stopping non-essential productive and social activities, social distancing, and limiting movements of goods and people. Due to the shifts in living and working

patterns, dwellings are now hosting new social functions, thus becoming workplaces, spaces for physical exercise and learning activities, besides places where to rest and take care of families.

Building services feature among sound sources having an impact on acoustic comfort in residential buildings [1–3]. Being the perception of the acoustic environment (i.e., the soundscape [4]) highly context sensitive [5], the question is how the acoustic environment at home can support home activities in this changed post-pandemic context, while allowing for occupants´ wellbeing [6]. With the purpose to tackle this question, an online survey has been carried out with participants working from home in UK (London) and Italy. While surveys on indoor acoustic comfort have traditionally reflected a negative attitude towards all the acoustic stimuli (i.e. how much were you *annoyed* by these *noise* sources?), the present survey has been designed from a soundscape perspective, in order to gather information on both positive and negative effects of sounds and noises, depending on the specific task performed at home (i.e. relaxing or working at home) [7].

Preliminary results are presented, focusing on the impact of sound from building services in participants´ own dwellings on working and relaxing activities performed at home, among UK participants. The following research questions are addressed:

1. Is there a difference in the perceived dominance of sounds from heating, ventilation, and cooling systems when working and relaxing at home based on building service typology?
2. Is there a difference in the subjective evaluation of the environment for working and relaxing at home based on the perceived dominance of sounds from heating, ventilation, and cooling systems?
3. Is there a difference in the subjective evaluation of the environment for working and relaxing at home based on building service typology?

2. Methods

Adult participants (18 – 65 years old), reporting no hearing difficulties, and working from home in London after the COVID-19 outbreak have been recruited via Prolific participant pool [8] on 18 and 19 January 2021, while the city was in a lockdown condition [9]. Upon receiving the invitation, participants completed the survey without a specific time limit. The entire survey took on average 29 minutes to complete. After excluding participants that failed attention checks, 464 participants (181 males, 282 females, 1 other; mean age: 32.2 years; SD: 9.1 years) were considered for the data analysis. The study was approved via the UCL IEDE Ethics departmental low-risk procedure on November 26th, 2020.

Participants were asked to describe the sounds and noises dominating their dwellings, report how the acoustic environment influence the different activities performed (i.e., relaxing, working, etc.) and describe the indoor soundscape that would be ideal in order to best perform those activities. The analysis presented in this paper focuses on data related to (1) the type of heating, ventilation and cooling systems present at home; (2) the perceived dominance of sounds generated by building services in the rooms employed for working and relaxing at home (*"To what extent do you hear the following types of sounds while working from home / relaxing in your…?")*; (3) the assessment of the surrounding sound environment while working and while relaxing at home; (4) the appropriateness of the surrounding sound environment for working and relaxing at home. Questions were adapted from ISO/TS 12913-2:2018 [10] and are reported in Table 1.

Statistical analyses were run in IBM SPSS Statistics 26. Firstly, frequency distributions were processed in order to explore categorical and ordinal variables. Then, non-parametric tests were used to analyze data. Mann-Whitney U tests and Kruskal-Wallis tests were run to evaluate differences respectively between two or more groups. In case of significant differences in the Kruskal-Wallis test, pairwise comparisons were performed using Dunn's procedure. A Bonferroni correction for multiple comparisons has been applied. The statistical significance threshold was set at 0.05.

Table 1. Questionnaire excerpt.

Question	Scale	Label
Now please focus on one room that is relevant for your working [relaxing] activity at home [*studio, kitchen, living room, kitchen – living room, bedroom, bathroom*] To what extent do you hear the following types of sounds while working from home [relaxing] in your [*piping*]? Sounds from building services of your house (e.g. heating, cooling, ventilation systems, toilet flushes)	Likert	Not at all (1) – Dominates completely (5), Not applicable (6)
How would you describe your present surrounding sound environment for working from [relaxing at] home?	Likert	Very good (5) – Very bad (1)
To what extent is your present surrounding sound environment appropriate to working from [relax at] home?	Likert	Not at all (1) – Perfectly (5)
How do you ventilate your house? [Select all that apply]	Multiple choice	I open the windows; I have mechanical ventilation
How do you heat your house? [Select all that apply]	Multiple choice	Radiators; Radiant floor; Electric heaters; Fireplace; Stove; Air systems
How do you cool your house? [Select all that apply]	Multiple choice	I have no cooling systems; Radiant systems (e.g. floor, ceiling, etc.); Full air systems (e.g. air conditioners); Air movement devices (e.g. ceiling or desktop fans); By opening windows

3. Results

Multiple choice questions returned several combinations of building services present in participants´ houses. For the sake of analysis, combinations have been collapsed into a limited number of exhaustive and mutually exclusive categories that will be considered in the following. A summary of heating, ventilation and cooling system typologies among the 464 participants after the coding process is shown in Figure 1.

As regards the heating systems present in participants´ houses, 65.9% reported having only radiators, 5.6% only electric heaters, 3.2% air systems (alone or in combination with other systems), 3.0% only radiant floors, and 22.3% other systems (e.g. a fireplace) or a combination of the previous ones except for the air systems (e.g. radiators and radiant floors). Ventilation is performed by opening windows (86.2 %), opening windows and using mechanical ventilation (9.7 %) or exclusively through mechanical ventilation (4.1 %). As regards the cooling systems, 68.8 % have no cooling system and/or open windows, 25.2% have air movement devices (e.g. ceiling or desktop fans) but no full-air systems, 5.6% have air systems (alone or in combination with other systems), and 0.4 % have other systems (e.g. radiant systems).

In the following, results related to the three research questions are presented.

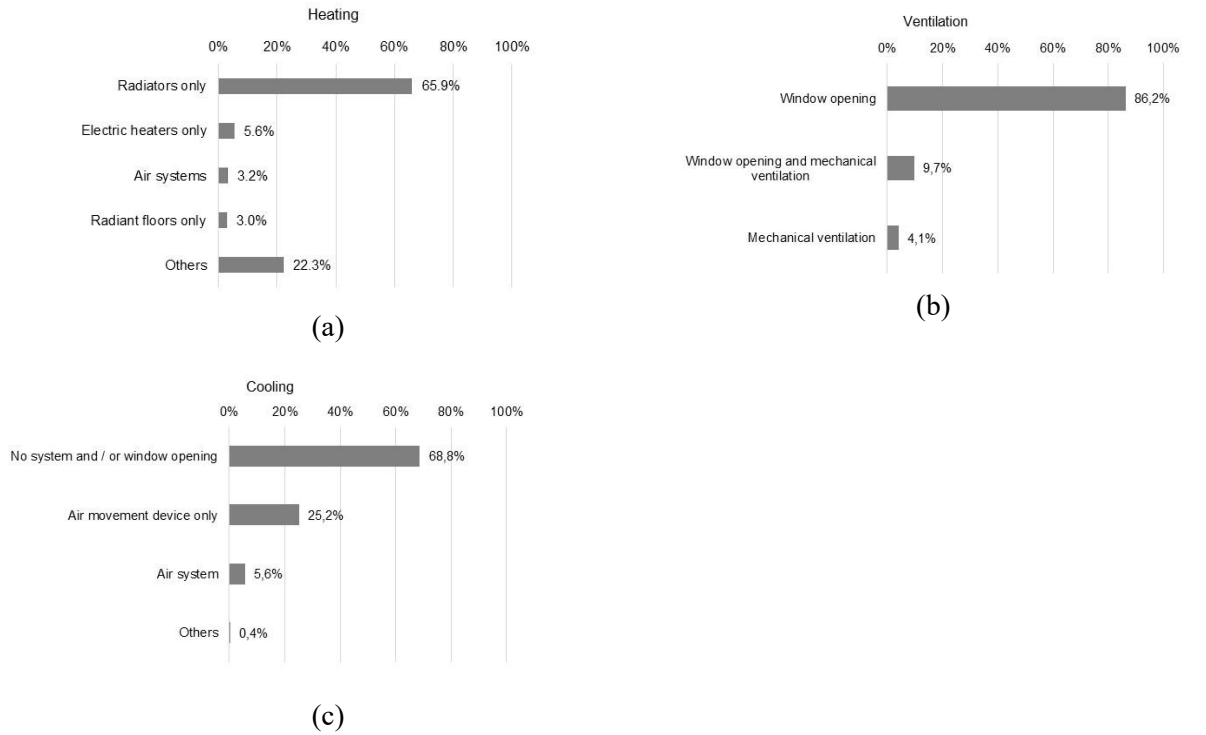

Figure 1. Percentage of building services typologies within the 464 participants´ houses for (a) heating, (b) ventilation, and (c) cooling systems.

3.1. Difference in perceived dominance of sounds from heating, ventilation, and cooling systems

A Kruskal-Wallis test was conducted to determine if there were differences in the perceived dominance of sounds generated by building services in the rooms employed for working and relaxing at home between the different typologies of heating, ventilation, and cooling systems. Perceived dominance of sounds while working from home (2 categories: not at all & a little; moderately & a lot & dominates completely, cf. Figure 2) was significantly different between the different building service typologies, both for heating, $\chi^2(4) = 11.334$, $p = .023$, ventilation, $\chi^2(2) = 7.799$, $p = .020$, and cooling systems, $\chi^2(2) = 7.152$, $p = .028$. Subsequently, pairwise comparisons were performed across the different technologies. Post hoc analysis revealed sounds from building services being significantly more dominant with air systems (mean rank = 294.07) than with radiators (mean rank = 225.30) ($p = .043$). Within ventilation systems, sounds from building services were significantly more dominant in presence of mechanical ventilation (mean rank = 283.55) than with natural ventilation (mean rank = 227.14) ($p = .025$). Within cooling systems, air systems (mean rank = 273.77) resulted in higher dominance compared to ventilators (mean rank = 221.11) ($p = .023$) or no cooling system (mean rank = 229.66) ($p = .050$). Interestingly, significant differences were detected only when sound dominance was evaluated in relation to working from home, and not for relaxing at home.

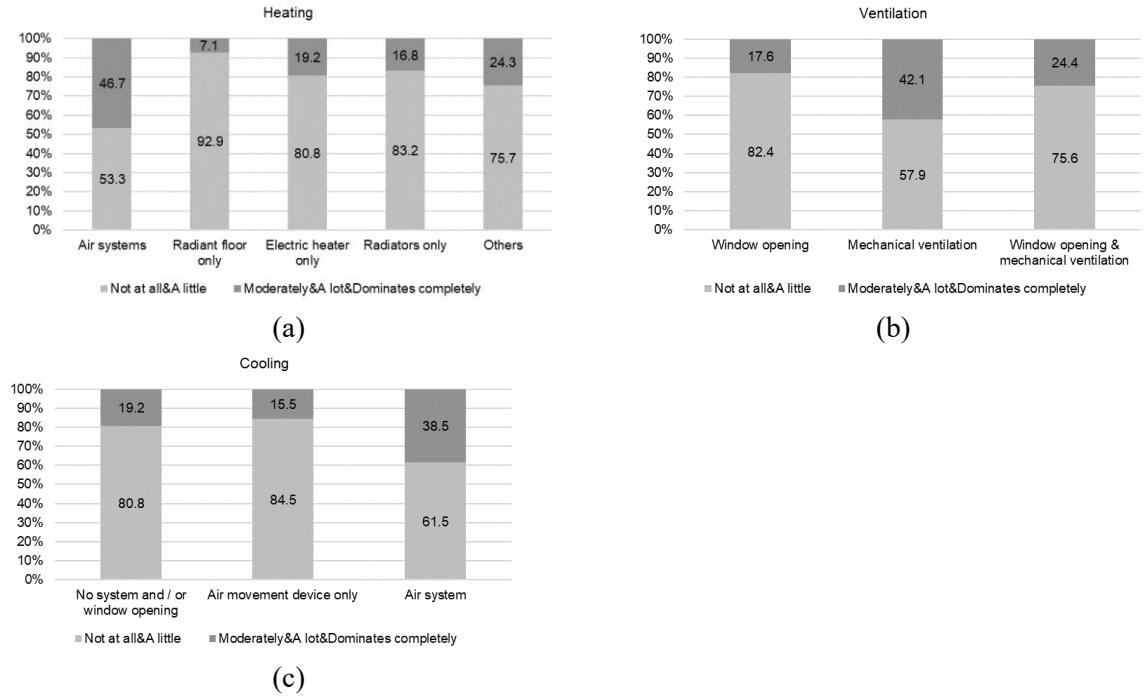

Figure 2. Percentages related to the perceived dominance of sounds from building services while working from home by building service typology: (a) heating, (b) ventilation, and (c) cooling systems.

3.2. Difference in the subjective evaluation of the environment for working and relaxing at home based on the perceived dominance of sounds from heating, ventilation, and cooling systems

A Mann-Whitney U test was run to determine if there were differences in the assessment of the quality and appropriateness of the sound environment for working and relaxing at home based on the perceived dominance of building services (2 categories: not at all & a little; moderately & a lot & dominates completely) while working or relaxing at home. Perceived sound quality for working from home was better in environments with less dominant sounds by building services (mean rank = 235.81) than in environments with more dominant sounds (mean rank = 210.89), $z = -2.048$, $p = .041$. Differently, no significant difference was found in the perceived quality of the sound environment when evaluated for relaxing at home based on the dominance of sounds from building services. As regards the appropriateness of the environment for working from home, spaces with less dominant sounds from building services (mean rank = 238.16) were judged to be more appropriate than those with more dominant sounds (mean rank = 201.08), $z = -2.657$, $p = .008$). Similarly, spaces with less dominant sounds from building services (mean rank = 237.31) were assessed as more appropriate to relax at home than those with more dominant sounds (mean rank = 201.67), $z = -2.369$, $p = .018$).

3.3. Difference in the subjective evaluation of the environment for working and relaxing at home based on building service typologies

Differences in the assessment of the quality and appropriateness of the sound environment for working and relaxing at home between the different typologies of heating, ventilation, and cooling systems were detected through Kruskal-Wallis tests. Across the different types of cooling strategies, significant differences were found on the evaluation of the quality of the acoustic environment for working from home, $\chi^2(2) = 7.702$, $p = .021$, on the appropriateness for working at home, $\chi^2(2) = 6.873$, $p = .032$ and on the overall evaluation of the space, $\chi^2(2) = 9.874$, $p = .007$. The acoustic environment was rated better for working at home in presence of air cooling systems (mean rank = 290.77) than when no cooling system was available (mean rank = 223.82) ($p = .023$), while no significant difference was detected when comparing those systems with air movement devices (mean rank = 239.26). The space

was rated more appropriate for working from home in presence of air systems (mean rank = 284.87) than when no cooling system was available (mean rank = 223.14) (p = 0.05), while no significant difference was detected between those systems and air movement devices (mean rank = 242.44). When participants were asked to provide an overall evaluation of the acoustic environment, this was rated better in presence of air systems (mean rank = 304.56) than when no cooling system was available (mean rank = 225.34) (p = .005), and better than with air movement devices (mean rank = 232.07) (p = .021).

4. Discussion

The present study investigates associations between building service typologies within heating, ventilation and cooling systems, their sound dominance and indoor soundscape evaluation in relation to relaxing and working-from-home activities. Main findings are schematically depicted in Figure 3.

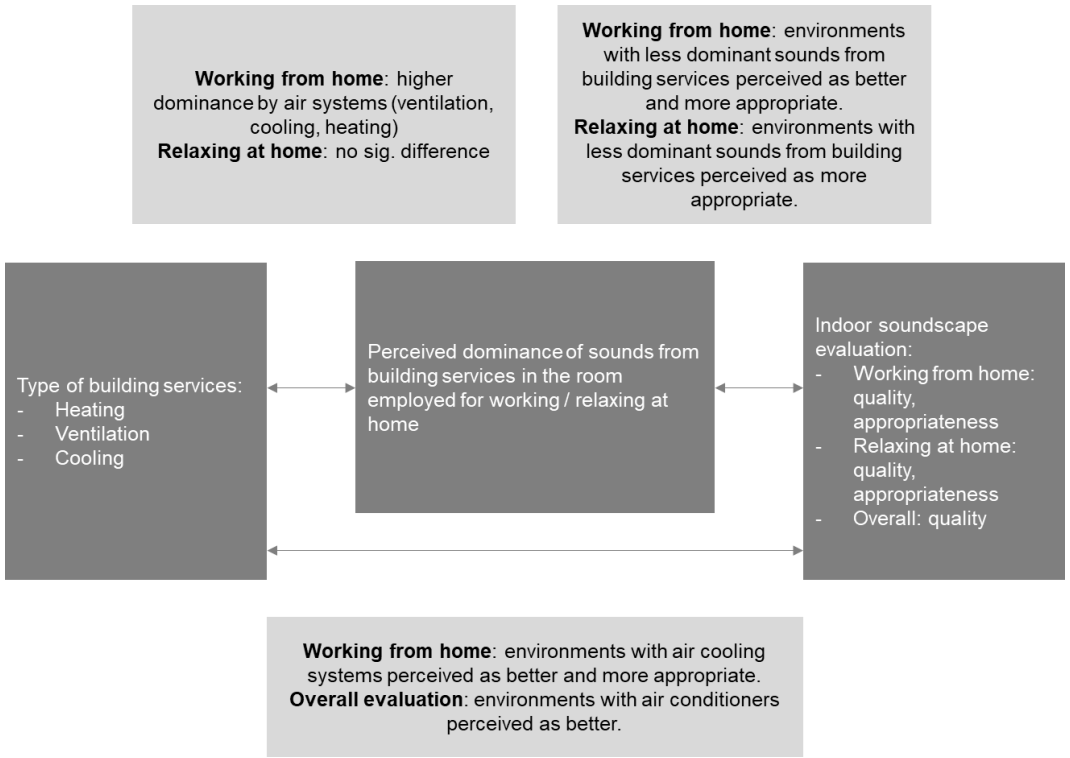

Figure 3. Graphical representation of the main results.

A different perception of the dominance of sounds by building services was observed based on their typology, when evaluated in relation to the working-from-home activity. Notably, air systems for heating, cooling and ventilation were not so commonly present among participants´ houses in London and resulted in higher perceived dominance compared to other systems. Sound dominance was in turn related to the evaluation of the environment made by participants. Spaces with less dominant sounds from building services were evaluated as more appropriate both for working and relaxing at home. As regards sound quality, spaces with fewer dominant sounds by building services were judged to be better for working from home. Differently, no significant difference in the sound quality evaluation based on sound dominance was found in relation to relaxing activities.

Participants´ evaluations were in general not significantly different on the basis of building services´ typology present at home. The only considerable differences were related to the presence of air-cooling systems (e.g. air conditioners), that were associated with better overall evaluated acoustic environments, and better evaluated and more appropriate spaces for working purposes. As the survey has been administered in the heating season (i.e., with cooling systems off), differences might be due to the fact that houses equipped with air-cooling systems are likely to be newer or retrofitted, and as such they

might provide better overall acoustic conditions. According to a survey performed in Canadian multi-unit residential buildings, effects of noise from water installations, heating and cooling systems were reported less frequently during the lockdown than before [3], probably due to a masking effect of other indoor noise sources that were perceived as louder [3], as also reported in another London case study [11]. Combined effects between the different indoor sounds, and between indoor and outdoor-generated sounds are indeed important in order to understand the perception of the indoor acoustic environment [2].

The preliminary analyses have focused on just a few of the many factors that can impact on indoor residential soundscapes. Results stress the need to carefully design, size and install building services and notably air systems, as they are related to a higher perceived dominance. This will be even more topical in the near future, as climate change and heat wave effects will lead to increasing ventilation needs to mitigate overheating risk in residential buildings. Moreover, results confirm the contextual nature of soundscape evaluation, specifically in relation to traditional and new activities that are performed at home. For instance, different building service typologies resulted in different perceived dominance of sound only when the assessment was related to the working-from-home activity, thus suggesting a higher sensitivity to the acoustic environment while working than while relaxing at home. Future analyses will complement these preliminary findings by including further factors that are reported to influence indoor residential soundscapes [5], such as person-related features (e.g. noise sensitivity, age, gender), further urban and building-related factors and contextual information derived by the qualitative analysis of open-format questions. Moreover, the analyses of data gathered from open ended questions will help evaluating differences in impacts of acoustic conditions when working in residential environments compared to when working in office settings.

5. Conclusion

The study reported on preliminary findings from an online survey administered to people living and working from home in London after the COVID-19 outbreak, focusing on the types of building services at home, their perceived dominance and the evaluation of the indoor acoustic environment in relation to two main activities performed, i.e. working and relaxing at home. Main conclusions are:

- Among the surveyed residential buildings in London, radiators were most commonly employed for heating, while window opening for ventilation and cooling purposes;
- The dominance of sounds generated by building services was different on the basis of the building services present at home, but just when assessed in relation to working-from-home and not for relaxing activities. In general, air systems for heating, ventilation and cooling resulted in higher perceived dominance of sounds while working from home than other building service typologies (e.g. radiators, natural ventilation);
- Spaces with less dominant sounds from building services were evaluated as more appropriate both for working and relaxing at home. As regards sound quality, less dominant sounds from building services resulted in spaces better assessed for working from home. On the other hand, while relaxing, no significant difference in the quality evaluation based on sound dominance from building services was found;
- Overall, participants´ evaluations did not vary considerably with the different building service systems. The only significant differences were related to the presence of air-based cooling systems (e.g. air conditioners), that were associated with better overall evaluated acoustic environments, and better evaluated and more appropriate spaces for working purposes. As the survey has been conducted during the winter season, this might be due to better acoustics conditions in newly built or retrofitted dwellings, that are more likely equipped with air cooling systems.

Preliminary findings point out the importance of carefully considering the acoustic implications of building services, especially for air systems, in relation to different sensitivities and needs that might occur during traditional (e.g. relaxing) and new uses (e.g. working from home) of residential buildings.

Results will be complemented by future analyses to inform actions needed to provide high-quality built environments for living and working at home, during and beyond the current COVID-19 emergency.

Acknowledgments
This work was funded by the Chartered Institution of Building Services Engineers (CIBSE) within the project 'Home as a place of rest and work: the ideal indoor soundscape during the Covid-19 pandemic and beyond'.

References
[1] Andargie M S, Touchie M and O'Brien W 2020 A survey of factors the impact noise exposure and acoustic comfort in multi-unit residential buildings *Can. Acoust.* **48** 25–41
[2] Torresin S, Albatici R, Aletta F, Babich F, Oberman T, Siboni S and Kang J 2020 Indoor soundscape assessment: A principal components model of acoustic perception in residential buildings *Build. Environ.* **182** 107152
[3] Andargie M S, Touchie M and O'Brien W 2021 Case study: A survey of perceived noise in Canadian multi-unit residential buildings to study long-term implications for widespread teleworking *Build. Acoust.* 1351010X2199374
[4] Anon 2014 ISO 12913-1:2014 - Acoustics - Soundscape Part 1: Definition and conceptual framework
[5] Torresin S, Albatici R, Aletta F, Babich F and Kang J 2019 Assessment methods and factors determining positive indoor soundscapes in residential buildings: A systematic review *Sustain.* **11** 5290
[6] Torresin S, Aletta F, Babich F and Bourdeau E 2020 Acoustics for Supportive and Healthy Buildings : Emerging Themes on Indoor sustainability *Sustain.* 6054
[7] Torresin S, Albatici R, Aletta F, Babich F, Oberman T, Elzbieta A and Kang J 2021 Indoor soundscapes at home during the COVID-19 lockdown in London – Part I : Associations between the perception of the acoustic environment, occupants´ activity and well-being *Appl. Acoust.* **183** 108305
[8] Palan S and Schitter C 2018 Prolific.ac—A subject pool for online experiments *J. Behav. Exp. Financ.* **17** 22–7
[9] Anon The Health Protection (Coronavirus, Restrictions) (No. 3) and (All Tiers) (England) (Amendment) Regulations 2021
[10] Anon 2018 ISO TS 12913-2:2018 - Acoustics - Soundscape part 2: Data collection and reporting requirements
[11] Lee P J and Jeong J H 2021 Attitudes towards outdoor and neighbour noise during the COVID-19 lockdown: A case study in London *Sustain. Cities Soc.* **67** 102768