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NOISE, VENTILATION AND OVERHEATING IN RESIDENTIAL DEVELOPMENTS

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The aim of this project is to investigate the indoor noise level from external sources that may be acceptable to occupants on a short-term basis when the alleviation of overheating is required. There is currently insufficient guidance regarding indoor ambient noise levels that should be achieved in residential developments in the situation where measures are required to control overheating. This lack of guidance is resulting in residential developments with poor indoor environmental conditions where residents are not able to achieve thermal and acoustic comfort at the same time. The problem is exacerbated by the move towards better insulated, more airtight buildings and the need, particularly in urban areas, to consider development on noisier sites. It seems very likely that this is giving rise to unnecessary sleep disturbance and adverse health effects in an increasing population of people. Therefore, there is a need to develop optimal solutions for noise and ventilation in residential developments. A starting and important step to achieve optimisation is to study the human response to, and inter-dependence of, acoustic and thermal comfort in dwellings. This can be achieved using laboratory studies on relatively small groups under closely controlled conditions. This paper will present the results of a collaborative, interdisciplinary project exploiting two unique world-class sets of expertise and experimental facilities from the University of Salford: The Acoustics Test Laboratories and the Energy House.

Keywords: Façade sound insulation, internal environmental quality, ventilation, overheating, thermal comfort

1. Introduction

Current trends in urban, residential development have been leading towards highly insulated, more airtight buildings to combat increased noise pollution and deliver more energy efficient dwellings, despite the recognition that increasing insulation from unwanted noise is often achieved at the expense of adequate ventilation [1]. Although this has been identified, it has been recognised that there is a paucity of guidance with regards to how this can adversely affect levels of thermal comfort and over-heating, resulting in poor internal environmental conditions where occupants are unable to moderate thermal and acoustic comfort at the same time [2].

There are two primary concerns this brings about, not only is there a financial impact on developers or property owners on having to retrofit property to an acceptable standard, but there are also possible health and wellbeing implications from lack of sleep and stress brought about by these discomforts. Therefore, there is clear justification to develop empirical, evidence-based guidance that can provide direction for future developments where consideration must be given to both thermal comfort, and acoustic conditions.

The initial step in developing these guidelines will be to investigate the human response to thermal and acoustic conditions in controlled, lab-based experiments. There is existing literature which de-

scribes investigations into some of the cognitive effects of heat and noise, identifying impact on cognitive performance and perceived loudness of noise stimuli due to temperature [3, 4], in addition to a range of physiological responses including metabolic rate increase and fatigue [5]. Fidget response has been identified as a stress marker for both physical [6] and psychological discomfort [7]. Due to recent advances in consumer level machine vision and applications of this technology [8], it is possible to utilise this stress marker, in conjunction with determinations of known correlates of heat and noise stress (cognitive performance, heart rate and respiratory rate), to determine the effect of heat and noise stressors which are within a stimulus range that would be realistically experienced in everyday situations to inform the development of such guidelines.

2. Methodology

2.1 Experimental design

The methodology is designed to provide pilot study data and proof-of-principle for a large externally funded project. This requires determination of three independent factors:

i. Human response will be determined using physiological measurements by techniques such as galvanic skin response, heart rate, respiratory rates and blood oxygen levels, fidgeting and salivary cortisol.
ii. Affective transfer, how the subjective rating of the noise stimulus changes due to changes in ventilation, will be determined using questionnaires and interview.
iii. Cognitive impact, the negative effect on task performance, will be investigated using a technique that measures the ability to inhibit irrelevant distractors.

An innovation proposed for development in this work is the novel application of the interactive computer periphery Microsoft Kinect. The advantages of this development are:

i. totally non-invasive for a participant (no awkward sensors or probes);
ii. provides a comprehensive selection of measurements in one application; and
iii. it allows for dynamic temporal measure (a swab or affective transfer measure is pre- and post-test).

Developer kits have recently become available that will allow software to track body and limb movement, facial emotion recognition, eye tracking, head tracking and even heart rate.

2.2 Objectives

The objectives of the project are:

- Measure cognitive, physiological, and behavioural responses to varying *noise* levels
- Measure cognitive, physiological, and behavioural responses to varying *heat* levels
- Establish a method that can be used to measure the combined effects of *heat and noise*

2.3 Recruitment

Participants will be recruited via the participant recruitment database in Acoustics at the University of Salford. This is an online system that individuals can sign up to and view possible studies that they may wish to take part in. Information about the study will be provided together with the participant information sheet.

To ensure that informed consent is obtained they will be given the participant information sheet before making a decision to participate and will be asked to take at least 24 hours to decide if they would like to take part. Participants will be informed that they can withdraw at any time from the experiment without having to provide a reason and can withdraw their data by contacting the researcher.

2.4 Cognitive test

All participants will be asked to complete an adapted version of the Eriksen Flanker task [9]. This is a short computer-based task in which they are presented with arrows on the screen and are asked to respond to the direction of these arrows (are they pointing to the left or right). The arrows are surrounded by distractors that can be congruent, incongruent, or neutral to the central target arrow. Accuracy and response times are recorded on the basis of congruence. This task takes a maximum of 5 minutes and participants will be asked to do this 4 times; once at the start of the experiment in a separate room to provide a baseline measure, and then again at L_{pA} levels of recorded traffic noise at 35dB, 45dB, and 55dB (or 21, 24, and 27 degrees Celsius measured at the geometric centre of the test room).

2.5 Physiological tests

Whilst participants are completing the computer-based task a series of physiological measures will be taken:

i. Heart rate – this will be recorded using a device that attaches to the fingertip.
ii. Fidgeting – this is measured by way of analysis of data recorded using the Microsoft Kinect v2. This operates using a combination of infrared depth sensing and machine vision to estimate and track the positions and orientations of joints in the body.
iii. Respiratory rate – this will again be measured using the Kinect. The respiration rate is estimated by way of statistical analysis and signal processing of information recorded by the depth sensor. This signal takes the form of the time series of changes in the distance of the upper chest of the participant from the sensor.

At baseline and L_{pA} levels of 35dB, 45dB, and 55dB (or 21, 24, and 27 degrees Celsius, measured at the geometric centre of the test room) participants will also be asked to complete the Positive and Negative Affect Schedule [Appendix 1, 10]. This consists of 20 emotion words and participants are asked to rate the extent to which they are feeling each emotion at that time. Ten of the words are positive and ten are negative and the questionnaire provides a measure of positive and negative affect. The experiment will take a maximum of one hour to complete including calibration of the Kinect for each participant.

3. Results and Analysis

3.1 Data Collection and Protection

There are two parts to the study and participants can take part in one or both of these. The two parts are identical in terms of what participants are asked to do (see above). The only difference between them is that in one they will complete the tasks in the Acoustics laboratories and will be exposed to road noise of increasing loudness L_{pA} from 35dB to 55dB. In the second they will complete the tasks in the Energy House and will be exposed to room temperatures of between 21 and 27 degrees Celsius. Data collection will take place over a period of 13 weeks. Thermal comfort levels will also be measured in the experimental areas in accordance with ISO 7730:2005 [11]. This will consist of air and mean radiant temperature, humidity and airflow measurements.

3.2 Ethical issues

The research is being conducted on adults who are able to consent to participate [Appendix 2: Consent Form]. They will be given full details about the study before participating and will be able to withdraw from the study at any time. There is the possibility that participants will become uncomfortable due to the increasing noise and heat levels in the experiment however they will be warned of this before volunteering for the study. Participants will receive an inconvenience allowance for their participation and this is standard practice in psychoacoustic experiments. Individuals with hearing difficulties that are not corrected will not be able to participate in the noise condition in this study due to the fact that the researchers are investigating the effect of noise on physical and psychological

comfort. This will be explained on the information sheet and anyone who is experiencing hearing difficulties will be invited to participate in the temperature condition only.

3.3 Data Analysis

Performance on the cognitive task (accuracy and response times), heart rate, level of movement (fidgeting), respiratory rate, positive affect, and negative affect will be compared across the 4 noise conditions and across the 4 temperature conditions using a within-participants ANOVA. Planned contrasts will be used to compare the measures at each condition with that at baseline.

4. Discussion

New buildings are designed to be air tight, yet the ventilation systems used in these buildings can be noisy and distracting to residents. In addition, overheating is common and this may cause individuals to open windows and doors. This will negate any energy efficiency credentials of the building, but it will also allow external noise into the building. Studies show that noise can have an adverse effect on human performance yet currently there are no agreed best-practice guidelines for the level of noise suitable in homes.

There is currently insufficient guidance regarding indoor ambient noise levels that should be achieved in residential developments in the situation where measures are required to control overheating. This lack of guidance is resulting in residential developments with poor indoor environmental conditions where residents are not able to achieve thermal and acoustic comfort at the same time. The problem is exacerbated by the move towards better insulated, more airtight buildings and the need, particularly in urban areas, to consider development on noisier sites. It seems very likely that this is giving rise to unnecessary sleep disturbance and adverse health effects in an increasing population of people.

Therefore, there is a need to develop optimal solutions for noise and ventilation in residential developments. An important step to achieve optimisation is to study the human response to and interdependence of acoustic and thermal comfort in dwellings. This can be achieved using lab studies on relatively small groups under closely controlled conditions. The investigations above are a first step in response to an identified urgent need to provide guidance on acoustic conditions and design when considering both the provision of ventilation and prevention of overheating.

5. Conclusions

This study will be an initial pilot to investigate the effects of heat and noise on human perception, behaviour, and performance. The aim is to test a methodology that will effectively measure aspects of behaviour under varying noise and heat conditions, which can then be used to explore the interaction between heat and noise under different conditions. These preliminary results will be presented at the conference together with recommendations for further work and methods for ensuring industrial impact of the findings.

6. Acknowledgements

This project is funded by the University of Salford. The Association of Noise Consultants (ANC), the trade association for acoustic, noise and vibration industry are the key Industry Partner on this project. Their role is to provide help: forming a steering group, designing the project objectives, reviewing progress on the project, ensure industrial impact, and promoting and publishing the findings.

7. Appendices

7.1 Appendix 1: Positive and Negative Affect Schedule

This scale consists of a number of words that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word.
Indicate to what extent you feel this way right now, that is, at the present moment.

Use the following scale to record your answers:

1	2	3	4	5
very slightly or not at all	*a little*	*moderately*	*quite a bit*	*extremely*

_____	interested
_____	distressed
_____	excited
_____	upset
_____	strong
_____	guilty
_____	scared
_____	hostile
_____	enthusiastic
_____	proud
_____	irritable
_____	alert
_____	ashamed
_____	inspired
_____	nervous
_____	determined
_____	attentive
_____	jittery
_____	active
_____	afraid

7.2 Appendix 2: Consent Form

CONSENT FORM

NOVOHEAT - Noise, Ventilation and Overheating in Residential Developments

Name of Researcher:

Please tick box and sign.

1. I have read and understand the information sheet (version XX date XXXXXX) for the above study.	☐
2. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.	☐
3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.	☐
4. I understand that if I do withdraw from the study, then all the data relating to me will be destroyed.	☐
5. I understand that my test results may be used in publications, reports, web pages, and other research outputs but my name will not be used.	☐
6. I understand that my anonymised test results will be held in the University of Salford Research Data Management systems and will be made publicly available for the foreseeable future.	☐
7. I understand that some things I say to the researcher may be quoted anonymously in the project findings. I give permission for anonymous quotes to be used.	☐
8. I understand that one year after the research has ended the NovoHeat project will delete my name and contact details but will retain my anonymous test results for the foreseeable future.	☐
9. I agree to take part in the above study.	☐

Name of Participant	Date	Signature

Name of Researcher	Date	Signature

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