New Zealand Acoustics, vol. 25, no. 1, pp. 4-13, 2012

Balancing Comfortable Thermal & Acoustic Built Environments in a Sustainable Future

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A paper previously presented at ISSA 2010, 29-31 August 2010, Auckland entitled "The Challenge of Balancing the Demands for a Comfortable Thermal and Acoustic Built Environment in a Sustainable Future"

Abstract

The future demands for building ventilation are likely to have an impact on the susceptibility of buildings to the ingress of external noise. Maximizing building natural ventilation can be an attractive goal but care should be taken to consider such factors as exposure to road noise. Climate projections give information about changes that could occur over the next 90 years, this is a time scale relevant to buildings. It would seem appropriate to quantify the benefits and challenges of noise control strategies in terms of ventilation rates and energy over the life time of a building. In this research whole building ventilation and energy use during the summer months was investigated with building energy modelling. Opening characteristics were adjusted according to noise levels at the façade given by noise mapping. The effect of noise control strategies on ventilation and energy modelled with weather data representing the current day was compared with that representing the future according to the latest climate projections for UK.

INTRODUCTION

Sustainability is a wide ranging concept but at its core is a concern for the long term well being of the environment and the responsible use of natural resources. In this paper what this means for the built environment and its interrelationships with acoustics is investigated, some background to this will be introduced first.

In (Yu & Kang, 2005) a number of ways in which acoustics may affect the sustainability of the built environment are discussed. This included the consequences of higher density urban communities, natural means of noise control, building envelope design, acoustic materials and the impact of local power generation. The example presented of natural means of noise reduction is the introduction of vegetation into the urban area. Replacing geometrically reflecting boundaries with diffusely reflecting boundaries can significantly increase attenuation along a street length (Kang, 2002). In this way the strategic introduction of vegetation, particularly vegetation with dense foliage down to ground level (Attenborough, 2004) can provide noise reduction with the added benefit to aesthetic and environmental aspects.

Remedial treatments are often expensive and inefficient so simulation can be a useful tool to identify problems and optimize solutions. Noise mapping software was used to model power generation as a noise source in the case study presented in the work of (Yu & Kang, 2005). The propagation of wind turbine noise through hypothetical residential areas was modelled for a variety of land forms. It was found that various land forms can bring considerable SPL differences in terms of noise barrier effects of buildings and ground profile. The effect of turbine height was also investigated, when the height was increased from 10m to 46m, the SPL increase could be 10-20dB in far field.

Buildings and the urban area complex with many varied processes involved. Simulation can be a useful tool to deal with some of the complexity involved in for example natural ventilation. Natural ventilation strategies are difficult to implement for buildings in urban areas due to a number of reasons, such as lower wind speeds, higher temperatures due to the urban heat island effect, pollution and noise (Ghiaus et al., 2006). In their work street canyon situations were addressed with measurements of noise levels being taken outside the façade at different heights above street level. Relationships were then defined between street aspect ratio, height above street level and noise levels at which occupants might be motivated to close the windows. This demonstrated how the influence of noise on ventilation changes with position on the building façade.

The pressure differences that drive natural ventilation, wind and or buoyancy effects, are very weak, typically less than 10Pa. The easiest way to achieve the least restriction of a ventilation path is to open large areas of the façade. This can conflict with attempts to reduction noise ingress. External noise levels are often given as the reason for airconditioning buildings (Wilson & Nicol, 1994). Summertime over-heating risk could be an increasing problem for the future. Future performance analysis of case study buildings (Jentsch & Bahaj, 2008; Holmes & Hacker, 2007) suggested that with expected future temperature rises providing a comfortable summer time indoor environment without a heavy reliance on mechanical cooling will be one of the major challenges. Natural ventilation is a key part of summer time cooling strategy particular for buildings with low energy aspirations.

Various systems exist that reduce noise ingress whilst minimising the restriction of the ventilation path. Some examples of these include passive system that stagger glazing, employ absorbing liners or louvers and active systems (Kang & Zhemin, 2007; Oldham et al., 2005; Kang & Brocklesby, 2005).

The interrelationship between building envelope performance in terms of acoustics insulation and natural ventilation is focused on in (Barclay et al., 2010) noise mapping and building energy simulation was linked to quantify acoustic considerations in terms of natural ventilation and cooling energy use. As an extension to this the degree to which projected climatic changes effects these interrelationships is the subject of this investigation.

Some brief background to climate change will be covered in the next sections, including its relevance to the built environment and the modelling that the projections are based on.

Climate change

Climate change is an important issue for the built environment with the built environment responsible for approximately 40% of the UK energy consumption (Commission, 2005) and possibly over 50% of the UK's carbon emissions (Department for Environment, 2008). This area is therefore of vital importance in reducing the UK's climate emissions as the built environment is seem as a sector were potential for reductions is large. An overview of the various strategies for reducing energy consumption and emissions from buildings is given by among others (Clarke & Johnstone, 2008). This included strategies for improving the efficiency of old and new buildings, Future technology and design tools such as simulation. A more specific look at thermal comfort and energy can be found in (Holmes & Hacker, 2007) which concluded that sustainable design should take into account future performance.

One of the central purposes of a building is to provide a comfortable environment regardless of external conditions. Climate change will affect how easily this is achieved. This is the case both in terms of adaptation and mitigation. There are important connections for the built environment between adaptation and mitigation. For example one of the main problems for buildings under projected climate is an increase in overheating risk (Jentsch & Bahaj, 2008; Holmes & Hacker, 2007; Hacker & Holmes, 2005). Increasing the comfort cooling could be seen as a move to adapt to the future scenario but this could be damaging to mitigation efforts if this was done by increasing energy use and carbon emissions. In addition future climatic change is particularly relevant to the built environment due to the relatively long life time of buildings and the slow turnover of the buildings stock. Climate change projections are available for the coming decades and this is a timescale relevant to the built environment.

Climate change projections

The most comprehensive information about how climate change might affect the UK is given by UKCIP02 (Hulme & Jenkins, 2002) and most recently by UKCP09 (Murphy et al., 2009). These projections are based on mathematical models of the climate system known as global climate models. These attempts to represent the many processes and interactions that affect the climate. They have been developed over time and in UKCP09 the following is represented: Firstly the movement of the atmosphere plus the physical processes that occur in it, such as the formation of clouds and precipitation, and the passage of terrestrial and solar radiation through it. Secondly the movement and exchange of heat, momentum, salt and water vapour from the oceans. Thirdly the land which affects air flow over it, and the hydrological cycle at the surface and in

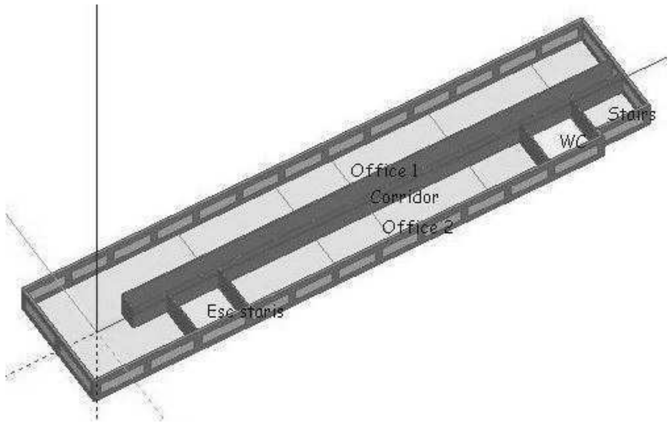

Figure 1. Floor plan of office building 1.

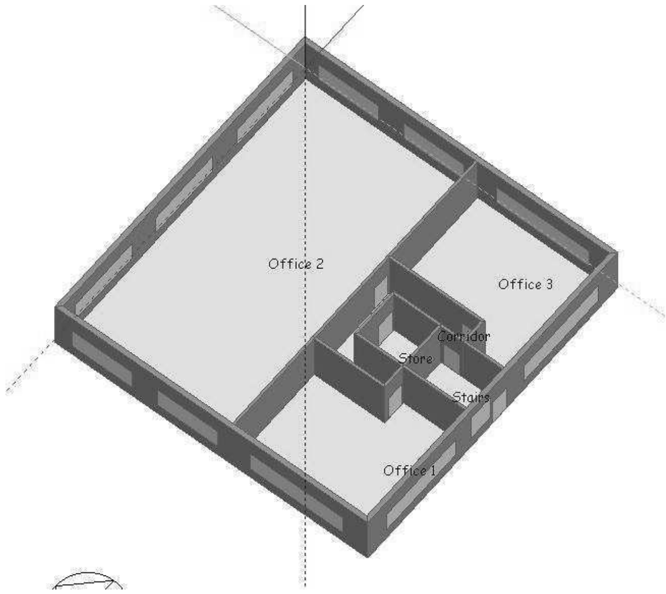

Figure 2. Floor plan of office building 2.

the soil beneath it. Lastly the cryosphere; ice on land and on sea (Murphy et al., 2009).

As well as increases in the number of processes represented in the models the increase in computational resources available to run these simulations has enabled finer spatial and temporal resolution of the models. This is illustrated by the improvement in horizontal resolution from 500km grid (IPCC, 1990) to 110km grid (IPCC, 2007) resolution of northern Europe.

Emission scenarios

The starting point for modelling the future behaviour of the climate is the generation of "emission scenarios" which are story lines describing possible future paths for the anthropogenic factors that affect the climate. In (Swart & Nakicenov, 2007) the IPCC Special report on emissions scenarios, six widely used key scenarios are presented. These scenarios use different assumptions about the demographic, economic and technological trends of the future to give a set of emission rates. Emission scenarios provided the radioactive forcing for the climate change predicted for the UK in UKCIP02 (Hulme & Jenkins, 2002) and in UKCP09 (Murphy et al., 2009).

Although the IPCC special report on emission scenarios does not assign probabilities to the different emission scenarios it should be noted that (Raupach et al., 2007) suggested that emission rates since 2000 have exceeded even the highest emissions scenario.

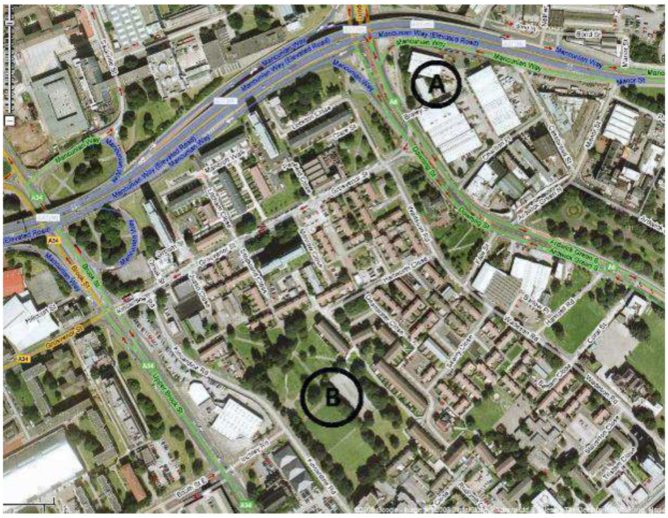

Figure 3. Area of Manchester used for noise mapping.Source: (Google maps, 2006).

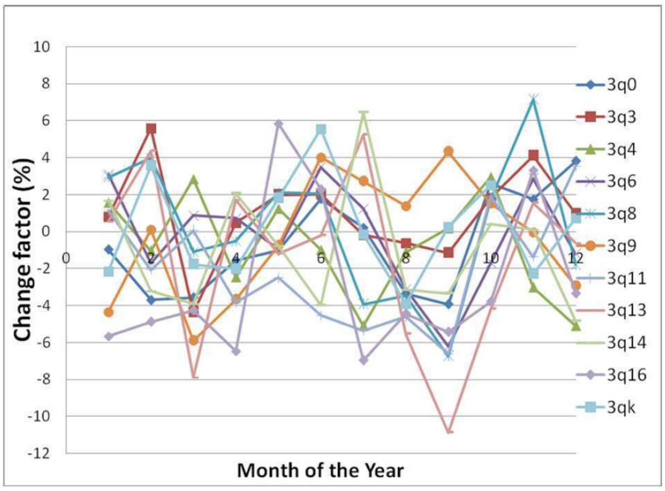

Figure 4. 2020 to 2080 change factors for Manchester wind speeds at each month of the year.

Downscaling

To get more detailed information about the climate for a particular part of the world such as the UK regional climate models (RCMs) can be used. These use the global model for the boundary conditions so that as fine a mesh as possible can be used for the region of interest. This enables better representation of the topography and importantly coastline morphology. This general approach of increasing the spatial and temporal resolution of global climate models is called downscaling.

To enable the evaluation of building performance in weather conditions expected in the future, predictions about the future need to be incorporated into weather data. Weather data used for building simulation is usually required at hourly temporal resolution. A review of methods to achieve this is given by (Guan, 2009).

Morphing or time series adjustment is the term given to a popular method of imposing the climate change predictions onto a chosen weather time series representing the current weather (Hacker et al., 2009). The change to the weather variable is imposed by either a shift or a stretch or both depending on which variable. This methodology was evaluated by comparing

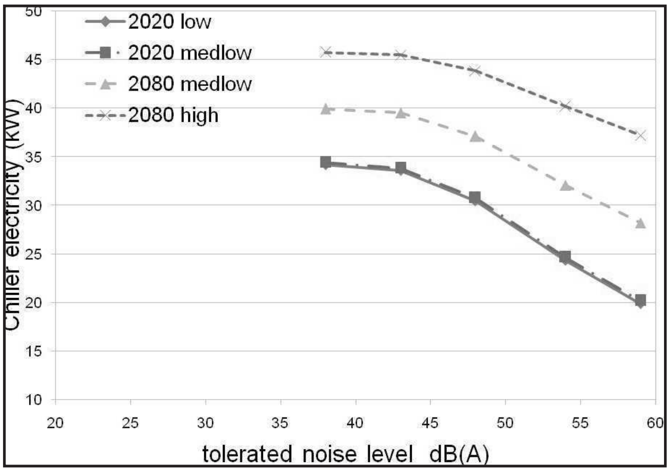

Figure 5. Building 2 in position A.

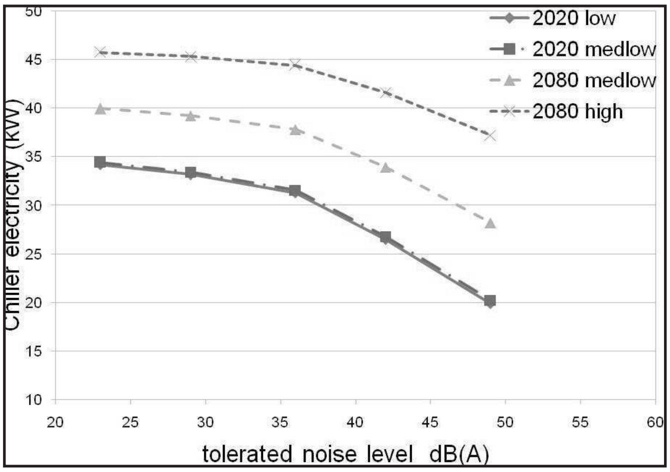

Figure 6. Building 2 in position B.

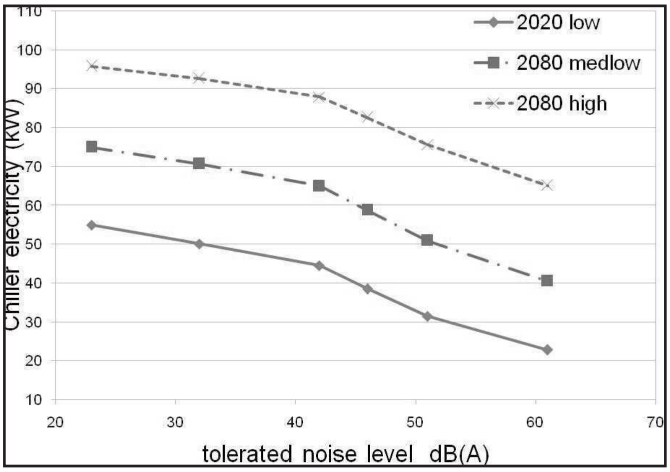

Figure 7. Building 1 in position B.

the heating degree day of morphed weather data to that given directly in UKCIP02 (Hulme & Jenkins, 2002). It was found that the heating degree days calculated corresponded well and this was thought to providing some confidence that this method was appropriate for producing future weather data (Belcher & Hacker, 2005). The method was used by the Chartered Institute of Building Services.

Engineers (CIBSE) who are the standard source of weather data for building evaluation in the UK. Climate change weather files for 14 locations in the UK are available (CIBSE, 2009) and this source of hourly weather data was used in this investigation.

METHODOLOGY

The method used here to quantify acoustic considerations in terms of ventilation rates and cooling energy use is similar to that employed previously (Barclay et al., 2010). Calculated noise levels at the façade of a building are used to determine how much the windows on that façade are opened.

The noise level that each window is exposed to is available from building evaluation calculations done with noise mapping software. The opening area created by the opening of a window is treated as a simple aperture in the façade of the building. Effective sound insulation of the façade is then treated as a function of the percentage of window that is opened. The approach was similar to that used in (Oldham et al., 2005; De Salis et al., 2002). This will also apply when various acoustic window arrangements are used (Kang & Zhemin, 2007; Oldham et al., 2005; Kang & Brocklesby, 2005). The accuracy of this method may be limited when openings are small and due to the assumption of frequency independence. The purpose here is to give relative relationships so these assumptions were considered initialy appropriate.

Between the maximum and minimum levels of noise ingress experienced when all windows are either opened to their maximum or fully closed, a number of tolerated noise levels are set. The window opening at all points on the façade are adjusted so that noise ingress is as close to these tolerated noise levels as possible. The intermediate tolerated noise levels correspond to levels where a mixture of different opening areas occurs over the façade of the building depending on its noise exposure. A separate building energy calculation is carried out for each tolerated noise level. These are run over a summer time period to quantify the effectiveness of natural ventilation cooling.

For this work the whole building level air flow patterns and cooling energy use was modelled for an extended summer time period. DesignBuilder/EnergyPlus software (DesignBuilder Software Ltd, 2009) was used for this. The DesignBuilder user interface uses EnergyPlus as its simulation engine. EnergyPlus is a building energy calculation tool that has been widely used and tested (Henninger & Witte, 2009). It provides a heat balance based solution to the heating and cooling loads required to maintain a building's thermal conditions. Various modules link into this core calculation to enable the representation of the building and its processes. This includes the airflow network module that is of particular importance in this work.

The approach used in this study was to use the cooling energy output from mixed mode buildings during a June to August time period. The June to August time period is represented by typical hourly weather data covering these months of the year. In mixed mode buildings internal comfort conditions are primarily maintained by natural ventilation. When this is inadequate active cooling is introduced (DesignBuilder Software Ltd, 2009). The cooling energy used by the air handling unit will therefore be used to indicate the extent to which the acoustic environment has affected the natural ventilation potential. A floor plan for the two buildings used in this work, buildings 1 and 2, are shown in Figures 1 and 2. Both buildings are representative offices buildings rather than examples of sustainable best practice.

The mapping of road traffic noise for this study was completed using the software CadnaA (DataKustik GmbH, 2004). The area mapped in Manchester is shown in Figure 3, the two positions of the example buildings are marked A and B. The building position A was next to the motorway and was in contrast to a less noisy position B. The positions were chosen due to their relatively different noise exposure and to minimise the inaccuracies due to significant reflections.

Climate change weather data

The first set of results are produced with weather data incorporating climate change projections from UKCIP02 these are weather files provided by CIBSE (CIBSE, 2009). The weather files used described typical weather conditions for Manchester with the addition of monthly climate change. Information about their use and Background are given in Hacker et al., 2009. The so called morphing method is used to produce this data and a description of the algorithm is given below. Morphing incorporates the climate change projections into a current weather data time series by one of the following three processes depending on the variable (Jentsch & Bahaj, 2008).

- 1. A 'shift' which adds the UKCIP02 predicted absolute monthly mean change (Belcher & Hacker, 2005)

$$x = x_0 + \Delta x_m \quad (1)$$

where x is the future climate variable, x_0 the original present day variable and Δx_m the absolute monthly change according to UKCIP02. This method is for atmospheric pressure.

- 2. A 'linear stretch' of hourly weather data parameter by scaling it with the UKCIP02 predicted relative monthly mean change (Belcher & Hacker, 2005)

$$x = a_m x_0 \quad (2)$$

where a_m is the fractional monthly change according to UKCIP02. This method is used for wind speed.

- 3. A combination of a 'shift' and a 'stretch'. An hourly weather data parameter is 'shifted' by adding the UKCIP02 predicted absolute monthly mean change and 'stretched' by the monthly diurnal variation of this parameter (Belcher & Hacker, 2005):

$$x = x_0 + \Delta x_m + a_m(x_0 - x_{0m}) \quad (3)$$

where x_0 is the monthly mean related to the m variable x_0, and a_m is the ratio of the monthly variances of Δx_m and x_0. This method is used for dry bulb temperature. It uses the UKCIP02 predictions for the monthly change of the diurnal mean, minimum and maximum dry bulb temperatures in order to include predicted variations of the diurnal cycle.

Weather files were available for the 2020's, 2050's and 2080's. The 2020's were assumed to represent essentially the present day as this time slice covers the 30 year time period of 2010 – 2030. Some climate change has been incorporated into this first time slice as the base weather files are drawn from the 1982 – 2004 period but these initial climate change factors are small compared to later changes. This can be seen from the results, were the low and medium low scenarios are essentially the same for the 2020's.

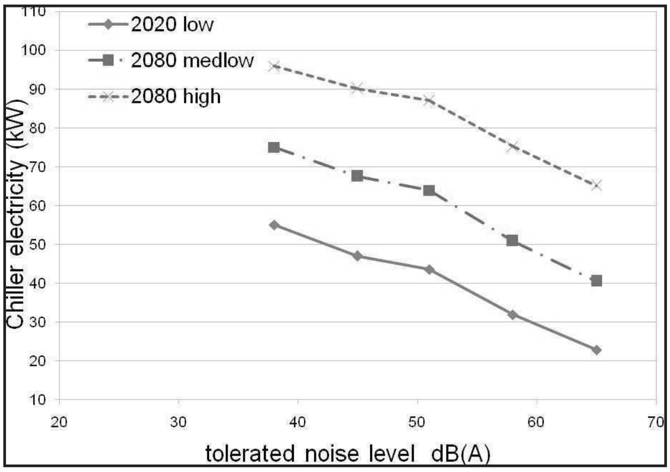

Figure 8. Building 1 in position A.

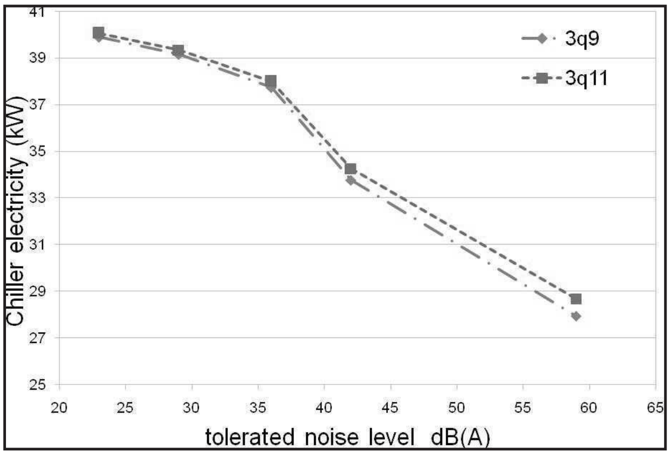

Figure 9. Building 2 in position B with 2080 medium low weather file. Two variants of the 11 member RCM used for wind speed are indicated in the legend.

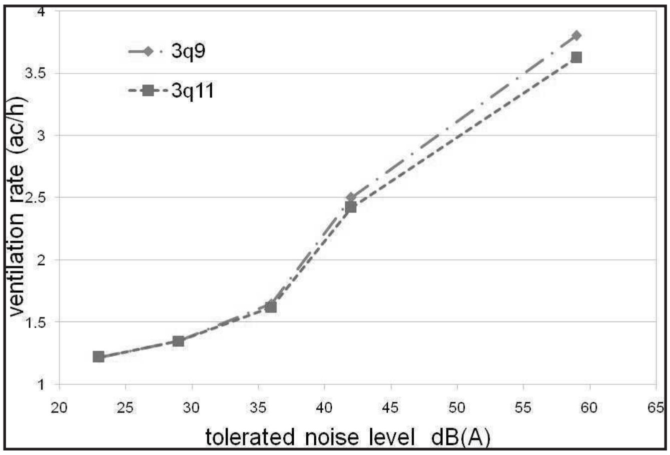

Figure 10. Building 2 in position B with 2080 medium low weather file. Two variants of the 11 member RCM used for wind speed are indicated in the legend.

UKCP09

Producing projections for something as complex as the earth's climate system is an exceptionally challenging undertaking. There are many sources of uncertainty that will affect the projections. These include structural error relating to the scheme used to represent climate processes and also the choice of value for parameters within this scheme.

In UKCP09 which is the latest climate change projections for the UK a probabilistic approach was adopted (Murphy et al., 2009). Many variant of climate models where used to sample areas of uncertainty in the representation of key physical and biogeochemical processes of the climate system. The probabilistic projections then presented the information so that the degree to which the available evidence supports a certain climate outcome can be seen.

The evidence assembled included an ensemble of climate models from the met office and also from other modelling centres from around the world. This is a similar approach to that adopted by for example the ensembles project (Hewitt & Griggs, 2004) but with a more systematic sampling of modelling uncertainties.

In UKCP09 probabilistic projections could not be provided for some variables, these were soil moisture, latent heat flux, snowfall rate and wind speed. Wind speed is particularly relevant to this study as it is a key driver of natural ventilation. The lack of wind in the probabilistic projections was partly due to this variable being unavailable from some climate models. Where it is available changes in wind speed show a large degree of variation and little sign of a systematic change for the future.

The extent to which the uncertainties in future wind behaviour will affect natural ventilation rates and therefore the degree to which this might translates to changes in acoustic insulation of buildings façades is looked at in this work.

11 member RCM

One source of information about the future behaviour of wind is the 11 member RCM. This made up part of the ensemble used to produce UKCP09. The aim here is to undertake an initial investigation of the sensitivity of the acoustic natural ventilation relationships to the internal modelled variability of the wind. As there are no probabilistic projections for wind speed in UKCP09 it is not possible to check where in the probability distribution each RCM projection for this variable lies. It is therefore not possible to say whether projections from one of the 11 RCM variants, is more likely than the other. In this study the sensitivity of the natural ventilation and acoustic relationship is tested to changes that represent the upper and lower bounds available from the 11 member RCM data set.

The RCM output was accessed via the LINK project (UK Meteorological Office, 2009). Figure 4 shows the variability of projections for change in wind speed. These change factors were calculated from the 11 Member RCM output which was made up of continuous daily time series from 1950 to 2099. The legend indicates the 11 variants of the HADRM3 climate model.

As can be seen there is significant variation in projection of change in wind speed. For an initial investigation of the sensitivity of natural ventilation to these variations in change in wind speed two sets of change factors were chosen that represented the upper and lower bounds of wind change factors for the months considered in the building energy simulation. These were variants 3q9 and 3q11.

As is standard practice (Hulme & Jenkins, 2002), the continuous absolute daily wind speed values were converted to relative change factors between the 30 year time periods. In this case it involved comparing the averaged wind speed for each month over the 2020's time period with that over the 2080's time period. These monthly change factors were then applied to the hourly wind time series according to the method described earlier using equation (2). This was done for the two HADRM3 variants 3q9 and 3q11 using the same initial hourly weather file

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Sound Snippets: Listening to the Brain

Eavesdroping by Brainwave

Neuroscientists may one day be able to hear the imagined speech of a patient unable to speak due to stroke or paralysis, according to researchers at the University of California, Berkeley.

The scientists have reconstructed frequency spectrograms of spoken words by two separate models based solely on recorded temporal lobe activity in a volunteer subject. The words are more or less recognizable, even though the model had never encountered these specific words before.

These scientists have succeeded in decoding electrical activity in the brain's temporal lobe – the seat of the auditory system – as a person listens to normal conversation. Based on this correlation between sound and brain activity, they then were able to predict the words the person had heard solely from the temporal lobe activity.

"This research is based on sounds a person actually hears, but to use it for reconstructing imagined conversations, these principles would have to apply to someone's internal verbalizations," cautioned first author Brian N. Pasley, a post-doctoral researcher in the center. "There is some evidence that hearing the sound and imagining the sound activate similar areas of the brain. If you can understand the relationship well enough between the brain recordings and sound, you could either synthesize the actual sound a person is thinking, or just write out the words with a type of interface device."

Pasley and his colleagues enlisted the help of people undergoing brain surgery to determine the location of intractable seizures so that the area can be removed in a second surgery. Neurosurgeons typically cut a hole in the skull and safely place electrodes on the brain surface or cortex – in this case, up to 256 electrodes covering the temporal lobe – to record activity over a period of a week to pinpoint the seizures. For this study, 15 neurosurgical patients volunteered to participate.

Pasley visited each person in the hospital to record the brain activity detected by the electrodes as they heard 5-10 minutes of conversation. Pasley used this data to reconstruct and play back the sounds the patients heard. He was able to do this because there is evidence that the brain breaks down sound into its component acoustic frequencies – for example, between a low of about 1 Hertz (cycles per second) to a high of about 8,000 Hertz –that are important for speech sounds.

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and resulted in two weather files for the 2080's. These two files were the same except for the description of wind speed. They represented the upper and lower bounds of change in wind speed taken from the 11 member RCM.

The emissions scenarios used are somewhat different in the two generations of climate models. Medium low B2 and medium high A2 were used in UKCIP02 for the middle emission scenarios. For the 11 member RCM, the emission scenario medium A1B is used. Pattern scaling factor are often used to convert changes between emission scenarios. For this case it does not seem appropriate due to the lack of a steady trend in wind speed.

This method is more appropriate for other variables such as temperature. Medium low B2 and medium A1B were the closest in terms of CO_2 concentration and total radiative forcing (Swart & Nakicenov, 2007). Therefore 11 member RCM change factors for the wind were applied to the wind speeds from the CIBSE medium low weather file. This was deemed to be appropriate here as the purpose is to look at the impact of variability in change in wind speed on the natural ventilation rate.

RESULTS

The first set of results, Figures 5 to 8, compare different future time slices and emission scenarios. Results for low, medium low and high emission scenarios are plotted for the 2020's and 2080's. Average chiller electricity use by the air handling unit during occupied hours is plotted against tolerated internal noise level.

The results are displayed from minimum chiller use corresponding to the situation where all windows are opened and maximum chiller use corresponding to the situation where windows are sealed. These end points represent the limits of this investigation. The points in between sample the possible tolerated internal noise levels that represent partial opening of the façade. In a sense the tolerated noise level indicates the level of opening of the façade. Larger tolerated noise levels indicate larger opening of the building façade.

Initial changes in climate appear to be slight compared with those in the 2080's. This can be seen from the results, were the low and medium low scenarios are essentially the same for the 2020's.

Generally the results show an increase in chiller energy use as warming due to climate change is introduced. This is what would be expected. It also illustrates how maintaining summer time thermal comfort will increase with the severity of climate change. This corresponds with previous work for example (Jentsch & Bahaj, 2008).

The benefit of introducing noise mitigation measures over the whole building might be estimated by considering the natural ventilation rates equivalent to a higher noise tolerance. The relationships between tolerated noise level and cooling energy requirements are consistent with the results without climate change weather data. This can be seen in the general shape of the graphs with different climate change projections, staying relatively constant. For example with building 2 initial opening of the façade is less effective for cooling relative to a larger increase in noise ingress. This is the case for building 2 in both positions but most markedly in position A.

For building 2 as the severity of climate change increases there is a flattening of the curve representing the acoustic ventilation relationship. This indicates opening the façade becomes less effective in contributing to the cooling of the building. This could be due to the higher external air temperatures under future scenarios decreasing the cooling effect of the introduction of outside air. This effect is not so apparent for building 1.

The second set of results, Figures 9 and 10, show the impact of variability in wind speed predictions on the cooling requirements and natural ventilation rates of building 2. Both chiller electricity and ventilation rate quantities are average occupied values over the summer period investigated. The weather data used for both these sets of building simulations were CIBSE 2080's medium -low files for Manchester. The only change in the weather files used for the results below is the change in wind speed between the 2020's and 2080's, these are taken from the two variants of the 11 Member RCM, 3q9 and 3q11. The ventilation rate given in Figure 10 is the average occupied fresh air introduced into the building given in air exchanges per hour.

The different predictions in change in wind speed appear to have a relatively minor effect on ventilation rate for this building and this summer time period. The influence of the change in wind speed increases as the façade is opened.

DISCUSSION

The results suggest that providing a comfortable thermal and acoustic environment could become more strained in the future according to the projected temperature changes. Initial changes representing the 2020's are slight but these increase with varying severity for the 2080's, depending on the emission scenario.

The difference between the medium low and high scenarios during the 2080's indicates the benefits of emission reduction efforts. Also indicated in these results by the still significant increase in cooling energy for the medium low 2080's scenario is that even with emission reductions a certain level of climate change seems likely to occur in the future due to historic emissions and the climate systems thermal inertia.

Differences in the sensitivity of different buildings to climate change are indicated by more flattening of the results for building 2 than for building 1 as the severity of climate change increases.

The influence of using the two different variants of the 11 members RCM for the predictions of wind speed is relatively slight. This suggests that the uncertainty about wind speed predictions might not be a major factor for building evaluation. This could aid a more complete use of the UKCP09 projections as wind speed was not included in these projections.

While the changes in noise/sound environment in the future are not within the scope of this paper, it is certainly important to integrate such changes in future studies, for example, the effects by the development of quiet vehicles.

ACKNOWLEDGEMENTS

The authors would like to thank the Engineering and Physical

Sciences Research Council of the UK for financial support for this work. Grant number (ref. EP/F038100/1). Additional thanks go to the Chartered Institute of Building Services Engineers for the provision of future hourly weather data.

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