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Combining noise mapping and ventilation performance for non-domestic buildings in an urban area

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ABSTRACT

Maximising the natural ventilation of a building can be beneficial in terms of comfort and reduced reliance on air-conditioning. However, in urban areas this can conflict with the need to reduce the ingress of external noise. In this paper a method is presented to quantify the interaction of building noise exposure with natural ventilation potential. Finite element models of ventilation aperture sound reduction index were used to determine façade sound insulation values for naturally ventilated buildings in two locations. Road traffic noise levels at the building façade were obtained from a calculated noise map of Manchester (UK). Window openings were adjusted in the thermal simulation package and modelled with mixed mode cooling ventilation strategies (both natural and mechanical). This enabled noise considerations to be quantified in terms of building ventilation and energy use for cooling at the whole building level. For a tolerated internal road noise ingress of 34 dB(A) cooling energy consumption for the example buildings in the quieter noise locations was found to decrease by 22%–45% compared to the noisier locations. Most importantly, the introduction of noise reduction measures equal to 10 dB(A) resulted in reductions in cooling energy consumption that varied from 28% to 45% of the original cooling energy consumption. This study illustrates the importance of an integrated approach to both noise exposure and ventilation performance in urban buildings.

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1. Introduction

Natural ventilation strategies are difficult to implement for buildings in urban areas due to a number of factors, such as lower wind speeds, higher temperatures due to the urban heat island effect, pollution and noise. The pressure differences that drive natural ventilation, wind and or buoyancy effects, are very weak, typically less than 10 Pa. 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 reduce noise ingress. Ghiaus et al. [1] made noise measurements outside the façades of street canyon buildings at different heights above street level. Relationships were defined between street aspect ratio, height above street level and the noise levels at which occupants might be motivated to close the windows. External noise levels are often given as the reason for air-conditioning buildings [2]. Summertime over heating risk could be an increasing problem for the future, and performance analysis of case study buildings [3,4] suggested that, with expected future temperature rises, providing a comfortable summertime indoor environment without a heavy reliance on mechanical cooling will be a major challenge.

Various systems exist that reduce noise ingress whilst minimising the restriction of the ventilation path. Some examples of these include passive systems that stagger glazing, employ absorbing liners or louvres and active systems [5–8]. The acoustic insulation and ventilation requirements for a specific site and building are complex and so it can be difficult to quantify the benefits of different approaches. Noise mapping has become a legal requirement in Europe [9] and is therefore an existing source of information about the noise environment. This information is represented spatially taking into account the complex distribution of noise and could be from either modelled or measured information about noise levels through an urban area. Noise mapping could be a useful resource for quantifying natural ventilation potential in urban areas and, by extension, enable noise reduction measures to be quantified in terms of ventilation and energy use. In an initial study [10] natural ventilation and acoustic insulation of buildings were linked by the size and position of openings on a building

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façade; differences were detected between modelled ventilation rates and air-conditioning use in buildings with different façade noise level patterns.

In this investigation the linking of whole building noise exposure and whole building natural ventilation will be developed in more detail, with particular attention being paid to improving the description of the combined façade sound insulation. The acoustic insulation properties of a façade with ventilation apertures are dominated by the poor performance of these apertures. For this study the sound reduction index of apertures was calculated using finite element simulation. The benefit of this approach is that different aperture arrangements can be modelled in detail and then applied over whole buildings.

2. Method

Noise levels at windows in the façade of a building were calculated using noise mapping techniques (see Section 2.4 below). The opening created by an occupant's operation of a window was treated as an aperture in the façade of the building, affecting the combined sound insulation of the façade. Between the maximum and minimum levels of noise ingress, experienced when all windows are either fully opened or fully closed, a number of tolerated noise levels were sampled. Each individual window opening was adjusted in size so that noise ingress was as close to these tolerated noise levels as possible. This resulted in a range of ventilation opening sizes over the façade of the building depending on the uneven noise distribution. A separate building energy calculation was carried out for each tolerated noise level and opening regime. These calculations were run over a summer time period to establish the effectiveness of natural ventilation cooling. Cooling electricity used is presented as a graph curve against tolerated noise level.

2.1. *Sound transmission of ventilation aperture*

An open window represents an aperture in a building's façade. For circular apertures in a wall of finite thickness and for normal incidence of the sound source, an exact mathematical solution for sound transmission has been given [11]. This exact solution is complicated and so more practically useful approximate solutions have also been developed [12,13]. These approximate solutions show good agreement with the experimental results for circular apertures up to values of $ke < 1.5$, where k is the wave number and e is the radius of the aperture. There does not appear to be an exact solution for sound transmission through slit shaped apertures, although Gomperts does suggest an approximate solution that matches the experimental results with acceptable accuracy for some cases [12]. Oldham and Zhao found that this approximation fitted the experimental results to within 1.5 dB for $kd < 2$, where d is the width of the slit aperture [14].

Some of the range of opening widths and frequency ranges that are needed to describe the octave band sound reduction index lie outside this kd condition. Numerical techniques present the possibility of investigating apertures with geometries more like those found in practice. They also give the opportunity to incorporate the noise reduction impact of absorbing materials. Finite element models are used to give values of acoustic pressure at the mesh nodes by the numerical solution of the wave equations. In this way acoustic wave propagation through the aperture was simulated. The Sound Reduction Index (SRI_A) for an aperture can then be calculated by the numerical solution of acoustic pressure from:

$$\mathrm{SRI}_A = 10\log_{10}\left(\frac{1}{r}\right)\mathrm{dB} \tag{1}$$

$$r = \frac{W_0}{W_i} \tag{2}$$

where r is the transmission coefficient, which is the ratio between energy incident on the aperture W_0 and energy transmitted through the aperture W_i. These energies can be calculated as integrals of pressure over the relevant surface:

$$W_0 = \int_{\delta\Omega} \frac{p_0^2}{2\rho c_s}dA, \quad W_i = \int_{\delta\Omega} \frac{|p|^2}{2\rho c_s}dA \tag{3}$$

When r is equal to 1, SRI_A will equal 0, indicating that all the acoustic energy incident on the aperture passes through to the receiving side. Negative values of SRI_A represent the cases where more acoustic energy passes through the aperture than is directly incident on its opening area – this was observed in the experimental results of Oldham and Zhao [14]. The frequencies at which this occurs depend on the aperture width and depth and is due to a reflected wave issuing from the aperture entrance.

As a first step to validate this numerical approach of simulating acoustic wave transmission through apertures, a circular aperture was modelled using the acoustic module of COMSOL [15] and the results compared to those given in the literature [12–14]. A circular aperture was incorporated into a continuous wall and the sound reduction index calculated from the finite element results for acoustic pressure. This was compared to the approximate solution derived by Wilson and Soroka [13]. Fig. 1 shows the comparison and also illustrates the nature of aperture sound reduction index.

There was good agreement between the finite element model and the Wilson-Soroka [13] method and this gave confidence that the numerical model could be used to describe the sound reduction index of the ventilation apertures. As well as showing the good accuracy, Fig. 1 also demonstrates how the sound reduction index varies with frequency. In this study the sound reduction index of apertures corresponding to the sliding window ventilation openings of the example buildings (see Section 2.3 below) are calculated. This is important as the combined sound insulation of the façade is dominated by the poor performance of the ventilation openings [16].

The ventilation aperture models were set up to represent a normal incident plane wave on an infinite area of wall with finite thickness. A plane wave was introduced at one side of the model with its direction incident on the wall with the aperture. The wall and internal aperture surfaces were represented in this case as

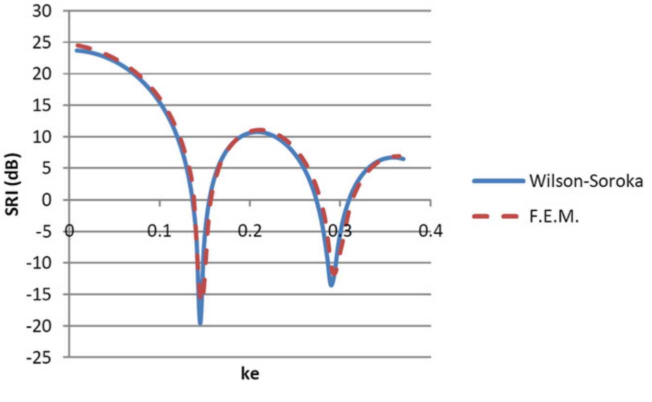

Fig. 1. Comparison of sound reduction index against *ke* for a circular aperture of radius 11 mm and depth 220 mm.

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