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Noise and Vibration Sources and Mitigation in Green Buildings

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Abstract

The design of green buildings may have a detrimental effect on the acoustical amenity within the occupied spaces resulting from increased outdoor noise ingress. The desire for increased natural ventilation may reduce the acoustic performance of facades and at the same time, additional noise sources are being located on and near the facade of the building. This paper reviews noise transmission issues across facades for green buildings, identifies noise and vibration sources commonly found on tall and green buildings and discusses methods of mitigation of noise and vibration.

Keywords: façade acoustics; aero-acoustics,

Introduction

Achieving a healthy noise environment within occupied spaces is a desirable aim for all buildings. Noise control and acoustic design in buildings is well understood and has been the subject of previous presentations at CTBUH conferences (Swift, 1992). For green buildings, the acoustic performance of the facade may be reduced where there is a requirement for the provision of increased natural ventilation. Green buildings increasingly are supporting solar elements, sunshading elements, and wind powered generators external to the main structure, all of which can or may generate noise and vibration which require suitable isolation from the internal spaces. Tall buildings (see fig 1) often incorporate significant communication towers at the top of the building, again the potential source of noise and/or vibration which may affect the acoustic quality within the occupied spaces.

This paper briefly reviews approaches to achieving improved noise transmission loss performance across facades and identifying and mitigating the effects of noise and vibration sources located external to the building.

Facades and Noise Isolation

The acoustic performance of the facade controls the internal acoustic environment resulting from the ingress of external noise. Where natural ventilation is not provided across the façade, glazing is the primary noise transmission path for external noise ingress. Thermal double glazing is not necessarily a better acoustic separator than single glazing, and in some cases can be worse. (see fig 2)

The overall Rw performance of the thermal glazing is similar to 10 mm single glazing but the low frequency (traffic noise region) performance is worse.

Peter Swift

Peter Swift is presently National Technical Manager for Bassett Acoustics, a division of Bassett Consulting Engineers, an AECOM company. Peter has been employed as a consulting acoustical engineer since 1976, specialising in environmental and community noise surveys, industrial noise control, building services noise control and architectural acoustics. His qualifications are Bachelor of Engineering (Mechanical) (1969) and Doctor of Philosophy (1978) both obtained from the University of Adelaide. He is a Fellow of the Australian Acoustical Society, and a Fellow of the Institution of Engineers Australia. Peter has considerable experience in noise assessment and control in buildings including residential, commercial and public buildings. His knowledge of wind induced noise and vibration on structures coupled with his experience in structureborne noise transmission, has been used in the assessment of potential noise intrusion associated with towers and other external structures on buildings.

Matthew Stead

Matthew is a Principal of Bassett Acoustics and is the National Acoustic Manager, Australia. Matthew has worked as an acoustic consultant since 1992. He has spent time working in Adelaide, Melbourne and San Francisco. He specialises in building acoustics and has a particular interest in building vibration. His qualifications are Bachelor of Engineering (Mechanical) (1991) with 1st Class Honors from Adelaide University and a Master of Engineering Science (1999) from Monash University. Matthew has been involved with the acoustic design of numerous buildings ranging from multi-purpose theatre design, commercial and residential buildings. His experience applicable to green and tall buildings includes noise intrusion via façade system, aerodynamic noise, building services and vibration source isolation.
Noise and Vibration Sources and Mitigation in Green Buildings

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The design of green buildings may have a detrimental effect on the acoustical amenity within the occupied spaces resulting from increased outdoor noise ingress. The desire for increased natural ventilation may reduce the acoustic performance of facades and at the same time, additional noise sources are being located on and near the facade of the building. This paper reviews noise transmission issues across facades for green buildings, identifies noise and vibration sources commonly found on tall and green buildings and discusses methods of mitigation of noise and vibration.

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Introduction
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This paper briefly reviews approaches to achieving improved noise transmission loss performance across facades and identifying and mitigating the effects of noise and vibration sources located external to the building.

Facades and Noise Isolation
The acoustic performance of the facade controls the internal acoustic environment resulting from the ingress of external noise. Where natural ventilation is not provided across the façade, glazing is the primary noise transmission path for external noise ingress.

Thermal double glazing is not necessarily a better acoustic separator than single glazing, and in some cases can be worse. (see fig 2)

![Figure 1. Riparian Building Brisbane Queensland (Bassett)](image)

![Figure 2. Comparison of sound reduction performance for laminated glazing](image)

The overall $R_w$ performance of the thermal glazing is similar to 10 mm single glazing but the low frequency (traffic noise region) performance is worse.
Where increased natural ventilation is desirable, the overall acoustic performance across the façade can be compromised, given that natural ventilation openings provide little resistance to noise. Over the past few years, there has been significant investigation into the use of interactive facades and double skin facades which react to the changing solar loads, day lighting and ventilation requirements. (Selkowitz, 2003) Such smart systems will result in reduced acoustic performance if the noise transfer via the ventilation paths are not addressed. Various methods and products are being investigated and developed where some sound resistance is incorporated while still allowing for natural ventilation. These include passive attenuators such as Silencair® air vents and micro-perforated window systems (Kang, 2005) Research into active noise control at ventilation openings continues (Romeu, 2002: DeSalis, 2002) but it appears that commercially viable active noise systems are yet to become available. In general, the aim of such systems is to at least match typical façade performance achieved by single glazing. Where the external noise environment is such that greater attenuation across a façade is required, requiring wide cavity double glazing, ventilation generally needs to be provided with assistance of powered plant, either incorporated into the building air conditioning systems or using a separate balanced system with sound attenuated ducts.

The acoustic requirements of the facade are determined by assessment of the existing acoustic character of the locality plus the additional external noise sources associated with the building itself. The external vibration and noise sources that may be attached to the building can be grouped into:

- predictable and definite
- predictable and probable
- predictable and possible
- less predictable but possible

Sources – Predictable and Definite

Mechanical plant is the most common source where the vibration forces acting on the building structure and the sound power radiating from the plant is predictable and will occur. The usual major sources located on rather than within a building are cooling towers and air-cooled chillers or condensers.

With the development of green buildings generally and tall buildings in particular, the use of the building as a platform for wind powered electricity generators is increasing. The wind turbines are vertical axis or horizontal axis machines using larger numbers of small turbines and/or one or more large turbines. These mechanical plant also fall into the category of predictable and definite sources of noise and vibration which must be assessed and integrated into the structural design of the building. The predominant frequency of vibration can vary over a frequency range as a function of wind speed rather than being at a constant frequency. Major mechanical plant can be also driven by variable speed drives giving a frequency range of vibration of possible out of balance forces. In all cases, the design should be such that the driving frequencies of large plant with low rotational speed are well away from the lower modes of vibration inherent in the building structure. At higher rotational frequencies, conventional plant isolation mitigates felt vibration and audible (structure borne) vibration.

Where there are small dimension external structural, aesthetic or energy reducing or producing elements, the minimum noise and or vibration generated by vortex shedding from wind flow over the structure is predictable and definite. The frequency and acoustic power is a function of wind speed and element shape and dimensions. The noise levels and frequency rise and fall with the wind velocity, similar to wind noise in trees.

The radiated noise from the mechanical plant and smaller dimension elements exposed to wind is either known, can be measured or predicted. The noise reduction performance required for a particular façade location needs to be sufficient to suitably control the ingress of the outdoor noise environment including ambient noise, plant noise and predictable wind generated noise.

Sources – Predictable and Probable

There will almost certainly be wind speeds where the vortex shedding frequency will coincide with lower modes of vibration of the particular structural element. For repeating elements, there is also the possibility that the spacing of the elements can lead to sympathetic resonance or lock-in. In both cases, the vibration (and noise) intensity and the resulting stresses in the structural elements can be much greater than the air-acoustic noise levels with no resonant or lock-in effects, as discussed in the previous section. For both the sole structure dynamics and for the repetitive situations, the controlling factors affecting the resonant response and expected noise and vibration levels are reasonably well understood and predictable (Bachmann 1995).

The methods of mitigating the movement and forces are well understood in structural design and include the addition of elements designed to disturb the large scale air flow, preventing the production of the large scale vortices and/or accepting resonant movement will occur and incorporating damping devices to limit the amplified movement and forces.

For smaller structural elements, the resonances can be produced at higher frequencies into the audible range and have the potential to be transmitted into the building structure. The vibration energy can then propagate further into the building, and possible radiate as intrusive noise into occupied spaces, especially from lightweight walls and ceilings. The provision of visco-elastic vibration isolation at the mounting points of the structure reduces the transmission of the wind induced vibration into the building structure. The telecommunication mast on the Riparian building incorporated elastomeric bearings under the main mast and at the base of the two angled support structures. There were also isolation pads at the
horizontal braces to the building (Fig 3). The bolts connecting the mast elements to the structure across the bearing or isolation pad must themselves also be vibration isolated to prevent the higher frequency energy propagating along the bolts into the building structure.

Fig 3. Vibration isolated horizontal brace of Riparian Tower telecommunication mast

Sources – Predictable and Possible

It is possible for there to be wind induced noise or infrasound produced by interaction with an element or series of elements. The vibrational energy is not related to the vortex shedding where the controlling factors are wind velocity, the cross section of the structure and modes of vibration, or the repetitive spacing of similar elements. The pressure fluctuation or noise is related to the volume of air enclosed within the geometry of a structure, that is, it can produce noise similar to the aero-acoustic relationships of wind instruments where the frequency of sound produced is related to the enclosed volume of air or the length of the column of enclosed air. This could be where the airflow over the top of an open ended tower creates a tone, similar to air blowing across the top of a bottle, or airflow across an opening on the side of a hollow tower, producing tones similar in action to a flute. The air in the enclosed volume acts like a spring-mass system, where the air in the neck of the opening represents the mass, and the air in the cavity itself represents the spring. At the right air speeds and angle of attack of the air on the opening, small eddies can form at the far side of the opening and if the frequency of eddy shedding of the air coincides with the resonant frequency of the cavity, the pressure fluctuations will be amplified and audible sound may be generated. For the Riparian mast, it was considered possible that the closed end cylinder (mast) with side opening (louvers in the access door) had a geometry similar to a flute. It appeared to be unlikely but conceptually possible that a steady wind blowing across the louvers in the access door could induce a flute type response at the fundamental resonance and odd harmonics, in this case, creating infrasound tones at approximately 1.5Hz, 4 Hz, 7 Hz, 10 Hz and 13 Hz. Locating the louvered door such that it was unlike that a steady wind could flow across it was considered to be a suitable approach to minimise the likelihood of such an occurrence.

Sources – Less Predictable but Possible

Another less obvious potential noise source is where there is a number of repetitive elements, such as parallel bars of a balustrade at a balcony or around a deck. In one case, the bars of a balustrade were 6 mm wide 125 mm deep elements with a spacing of approximately 125 mm. In certain relatively light wind conditions, the structure generated a strong noise comprising steady tones that varied in loudness but not frequency with the wind speed. (Fig 4)

The frequencies for any of the vortex shedding mechanisms of the individual elements were well below the measured tones. Winds in the order of 27 m/s would have been needed to create such tones from the smaller dimension of the elements, but the balustrade was generating noise only in light winds. The arrangement was such that lock-in frequency for repetitive similar structures was shown to be unlikely to occur and if it did, it would be at frequencies well below those experienced. A plausible explanation put forward (LeClercq, 2007) is that for a light wind at near grazing incidence, the air between the balustrade elements can become trapped and
act as if it were a series of enclosed volumes, although there is no obvious containment of the air volumes. The acoustic analogy is that the balustrade geometry acts as series of quarter wave resonators, as if there was a backing plate along one side of the balustrade. This theory predicts the tones shown on Fig 4.

We note that wind tunnel testing of full scale balustrade section was unsuccessful in generating the tones experienced in the field. It is also unlikely that scale model testing of a building in a wind tunnel would incorporate the micro detail of such a balustrade, hence it is unlikely that a potential noise problem such as this would be discovered during wind tunnel testing of the building itself. The theory presented suggests that the noise is only generated in light winds for low Reynolds numbers. At higher wind speeds where the flow becomes turbulent, the long columns of air located between the bars cease to act as a single element and the noise becomes significantly lower and more broad band.

It is not uncommon to have repetitive parallel elements on a building: sunshade elements, louvres, decorative meshes and gratings. There are many instances where buildings have significant amounts of repetitive geometry elements with no major noise issues arising, and occasionally, a wind induced noise problem does occur. It is not clear what the controlling factors are that contribute to this strong tonal noise generation in some cases and not others. The quarter wave tube analogy discussed above relates to the depth of the balustrade element, and not the specifically to the spacing between them. The wind interaction across one side of the balustrade element that induces the resonant effects may well be related to the spacing between the bars, but it is not clear at this stage what spacing enhances the effect and what spacing diminishes the effect. The effect is eliminated if the wind is turbulent, hence one method of reducing the effect is to modify the fin edge to induce turbulent flow or reduce the similarity or coherence of the airflow at all fin edges. There are other means of introducing irregular elements on the balustrade which would similarly reduce the noise by introducing disturbed flow across the balustrade edges.

**Repetition is Risky**

It appears that where there are repetitive geometric elements exposed on a building, then there is a possibility that a noise problem may occur. It is not definite that a higher noise levels will be generated but a wind condition may occur where it does.

Where a building has significant amounts of external elements exhibiting a repetitive geometry, it may not be possible to definitely state that a problem will occur, but there is risk and it is prudent to reduce that risk. Methods of reducing the likelihood of an undesirable noise generation occurring is to

- vary the spacing,
- vary the depth
- provide non-linear or irregular fin edges
- provide other elements attached to the fin edges

**Conclusion**

The methods used in improving the sustainable aspects of buildings often result in the addition of potential noise sources external to the building and at the same time, potentially reduce the acoustic properties of the façade.

The noise and vibration levels from the majority of noise source on the building can be defined and noise and vibration mitigation needs assessed. There are some potential noise sources, in particular those arising from wind effects over geometrically similar structures where it does not appear to be obvious that major noise effects will occur, but they may occur. It would be prudent for the design team to be aware of the possibility and incorporate measures in the design which would greatly reduce the potential for generating disturbing tonal noise, either by modifying the repeating elements into a more random pattern, inducing turbulence into the airflow at the element edges, or by reducing the potential for airflow to impinge at or near grazing angle across the repeating structure.

**References**


