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Satisfactory background noise levels in naturally ventilated buildings - challenging acoustic criteria used in the past

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ABSTRACT

This paper presents a review of acoustic criteria currently used in office buildings with the aim of determining more satisfactory indoor noise level criteria for naturally ventilated office buildings. Indoor air quality standards related to the use of natural ventilation in buildings conflict with the control of ingress of external noise through ventilation openings to meet internationally recognized background noise limits for building use. These noise standards generally assume, however, that buildings are sealed and air-conditioned, which contributes to meeting the stated recommended indoor noise levels. It is not feasible that these noise standards can be expected or are appropriate to be achieved in naturally ventilated buildings. Therefore, to account for the thermal comfort benefit of natural ventilation and the ability to locally control natural ventilation and noise levels by closing of windows, a controlled increase of the currently recommended indoor noise levels is explored, based on a review of typical conditions found in existing naturally ventilated buildings. To develop appropriate acoustic criteria for naturally ventilated buildings, consideration is given to adequate speech intelligibility of conversations and also to distraction to typical office activities.

INTRODUCTION

The use of natural ventilation in buildings is generally accepted as a sustainable design strategy because of the benefits it provides in terms of reduced energy consumption and running costs [1] and the improvement in indoor air quality it provides over mechanically ventilated buildings. The increased use of outdoor air ventilation above the minimum rates required by ASHRAE, Australian and British standards, for both mechanical ventilation and natural ventilation methods, is a general goal for sustainable building design in the US, Australia and UK respectively. The use of low-contaminant emitting materials is also a consideration.

The use of natural ventilation in buildings conflicts, however, with the control of ingress of external noise through ventilation openings. National noise standards [2, 3, 4] provide recommended guidelines for internal background noise limits for building use, and these are presented below. These standards generally assume, however, that buildings are sealed and air-conditioned, which contributes to meeting the stated recommended indoor noise levels. Therefore, in many projects, the use of natural ventilation is considered infeasible because of noise issues—either because the perceived high-noise environment cannot be controlled with practical measures to the levels recommended in national standards, or that the capital cost of noise mitigation measures outweighs the benefits of natural ventilation.

National noise standards often cannot be achieved with practical façade designs in naturally ventilated buildings due to the open areas required to allow air to enter and exit buildings.

The meaning of sustainability with respect to the acoustic environment

The application of traditional design criteria formulated for mechanically ventilated buildings, and the inability to provide practical design solutions leads to the philosophical question of what sustainability means in terms of the acoustic environment in office buildings.

The general aim of a sustainable future should include the re-evaluation of the way we live, and to challenge design restraints from the past, in the interests of conserving natural resources and living within the limits of our natural environment. This re-evaluation includes consideration of indoor environmental quality and revisiting acoustic design criteria to find more appropriate criteria applicable to naturally ventilated buildings.

Reconsideration of acoustic comfort in the context of thermal comfort and green building rating systems

Green building rating systems [5, 6, 7] include credits for high levels of thermal comfort in office buildings. Different assessment criteria are specified depending on whether the building is naturally ventilated or mechanically ventilated. For example, Greenstar [6] stipulates that for naturally ventilated buildings, the 80% and 90% acceptability limits set out in ASHRAE Standard 55-2004 [8] must be complied with to

achieve one credit and two credits respectively. The acceptability limits are calculated using an adaptive thermal comfort model derived from a global database of over 21,000 measurements taken primarily in office buildings.

For mechanically ventilated buildings, the Predicted Mean Vote (PMV) levels calculated in accordance with ISO7730-2005 [9] are used as the basis for compliance (ASHRAE Standard 55-2004 also proposes this PMV method for mechanically ventilated buildings).

The reason for using separate assesement criteria for natural ventilation and mechanical ventilation is explained in ASHRAE Standard 55-2004 by stating that occupants' in naturally ventilated spaces have "different thermal experiences, changes in clothing, availability of control, and shifts in occupant expectations".

ISO7730-2005, Section 10, also states "extended acceptable environments may be applied for occupant-controlled, naturally conditioned, spaces in warm climate regions or during warm periods, where the thermal conditions of the space are regulated primarily by the occupants through the opening and closing of windows. Field experiments have shown that occupants of such buildings could accept higher temperatures than those predicted by the PMV".

Therefore, taking the assessment methodology of thermal comfort in green building rating systems as an example, should separate acoustic design criteria be specified for naturally ventilated buildings and mechanically ventilated buildings and should acoustic criteria be further re-evaluated to more appropriately take account of the ability to control one's acoustic environment?

Re-evaluating acoustic criteria does not necessarily have the underlying aim of reducing noise levels in indoor environment in office buildings so that they are not noticeable. The preferred approach is to provide a "comfortable" acoustic environment while facilitating the other sustainable design elements of office buildings including:

- natural ventilation
- natural daylight
- reduced energy consumption
- increased use of recycled and renewable materials
- individual control of the working environment to enhance productivity.

The definition of "comfortable" must be carefully considered while facilitating these non-acoustic sustainable design elements. The discussion presented here focuses on a suitable acoustic environment to facilitate the use of natural ventilation in office buildings. As a compromise for the non-acoustic benefits natural ventilation provides, alternative approaches are offered to challenge noise level standards already set for sealed, air-conditioned buildings.

THE ROLE AND BENEFITS OF NATURAL VENTILATION

The role of natural ventilation in buildings can be summarized as follows:

- Improve indoor air quality by decreasing the concentration of indoor air pollutants.
- Improve thermal comfort conditions in indoor spaces.
- Decrease the energy consumption of air conditioned buildings.

As a compromise to higher noise levels due to external noise ingress, the benefits that natural ventilation provide includes lower running costs, reduced use of refrigeration and air conditioning, simpler and accessible personal environmental control, reduced space requirements for mechanical plant, and decreasing concentrations of indoor air pollutants [10]. A controlled increase in background noise levels could also have a positive acoustic benefit in terms of providing masking noise within the space. Absence of noise masking has been identified previously as a problem with the use of low noise passive cooling systems. The benefit, however, would be highly dependent on the acoustic character of the external noise being used to provide masking.

HUMAN SENSITIVITY TO NOISE LEVELS WITH NATURAL VENTILATION

The sensitivity of humans to noise in sealed air-conditioned buildings is well documented [10] and studies have been carried out to determine appropriate quantifiable measures to deal with sensitivity to noise. It is the author's opinion that when natural ventilation is used in buildings, however, a person's sensitivity to noise changes. This change in sensitivity can be attributed to the following factors:

- The expectation of a low noise level environment is lower.
- The appreciation of non-acoustic benefits that natural ventilation provides, as part of an overall sustainable design strategy, promotes occupant acknowledgment that there is the inability to control internal noise levels to the same degree as a sealed, mechanically ventilated building.
- Office layouts (open plan) in green buildings provide occupants with greater awareness and therefore tolerance of surrounding activities.
- Climate – people in countries where windows are customarily open for most of the year seem to be more tolerant of noise [11, 12].

With regards to people's general sensitivity to noise, it is the author's opinion that people generally accept a slightly higher level of variable noise from outside the building, where the source noise levels are not necessarily controllable, compared with the constant level of mechanical services noise which has had the opportunity to be engineered and controlled in the design stages and in post-occupancy use of the building. If the occupants know that all of their ventilation is achieved through openable windows, and they are free to open or close windows, then again they will accept a higher noise level than if the room is mechanically ventilated. A space which is only mechanically ventilated is considered a 'controlled' space and the occupants expect noise to be controlled to a low level. On the hottest days occupants will generally accept a slightly higher noise level in order to have additional cooling via openings.

EXISTING ACOUSTIC CRITERIA

Standards and guidelines for mechanically ventilated buildings

As a point of reference for establishing design criteria for naturally ventilated buildings, recommended background noise levels for unoccupied office spaces provided by three nationally recognised guidelines are given in Table 1.

Table 1: Recommended background noise limits for unoccupied mechanically ventilated spaces

Occupancy Type	BS8233 [4] (L_{Aeq}, dB)		AS2107 [3] (L_{Aeq}, dB)		ASHRAE [2] (NC)[1]	
	Satisfactory	Maximum	Satisfactory	Maximum	Satisfactory	Maximum
Private Office	35	40	40	50	25	35
Meeting Room	30	40	35	40	25	35
Open Plan Office	40	45	45	50	30	40

1. For comparison purposes, the NC rating is typically 5 dB below the L_{Aeq}

In summary, for open plan offices, a typical background noise limit of 40 - 45 dBL_{Aeq} is recommended and for private offices and meeting rooms, a typical background noise limit of 30 – 35 dBL_{Aeq} is recommended.

Previous research regarding acoustic quality in office buildings

There is very little research regarding reported acoustic quality specifically in naturally ventilated office buildings. Guidance for likely noise sources that affect acoustic quality, however, can be found by reviewing general occupant surveys of completed office buildings.

Results of post occupancy surveys of a database of 142 buildings and 23,450 respondents carried out by the Center of the Built Environment (CBE) at UC Berkeley by Jenson et al. [13] indicate that people are clearly more dissatisfied with with speech privacy than overall noise level in offices.

Results further indicate that for various types of office environments, there is more tolerance to overall noise level in open plan environments compared to private offices.

Of the people who were dissatisfied with their acoustic environment in all office environments (from private offices to open plan working), 18-25% of people identified ventilation system noise as a cause of the problem. More notable was that 64-82% of people identified people talking on the telephone as a cause of the problem, and that 59-79% of people identified people talking in other office areas as a cause of the problem.

Fard [14] analysed post occupancy evaluations of LEED rated buildings compared to conventional buildings in the CBE database. Similar to the results found by Jenson et al. [13], occupants in LEED rated buildings are more dissatisfied with speech privacy than overall noise level in offices. Less than 15 % of people identified ventilation system noise as a cause of the problem.

These results imply that office activity noise is the principal cause of acoustic dissatisfaction in office spaces, rather than noise levels generated by the ventilation system.

Previous project experience by the author

A review of project work carried out by the author over the past fifteen years indicates that the criteria adopted for the break-in of external noise to office buildings is typically related to the well-established and commonly used mechanical services background noise limits that would be set for the particular occupied space.

The proposed background noise limits due to break-in of noise through natural ventilation openings have been generally set as a tolerable exceedance of the mechanical services background noise criteria. This strategy was adopted to maintain a sense of familiarity with well established mechanical noise criteria references and could be readily understood by designers familiar with these accepted criteria.

Example design criteria for internal noise limits used in façade sound insulation design work include:

- Limiting the external break-in noise level (octave-band L_{eq}) via the façade to be equivalent to the noise criterion (NC) rating if the same space was mechanically ventilated. For example, for open plan offices, a rating of NC40 is commonly selected as the background noise limit for mechanical systems. The break-in of external noise through ventilation openings used for natural ventilation would therefore also be limited to NC40, with the same tangency rating procedure applied to the octave band noise levels to determine whether the criterion method is met.
- Assessment of the external noise break-in through the naturally ventilated façade in terms of the average maximum un-weighted octave-band noise levels (L_1) in relation to an appropriate NC curve for the space. For example, using NC40 as the design criterion, octave-band L_1 noise levels would be compared to the equivalent octave-band levels making up the NC40 curve to determine whether the criterion is met. This method would better indicate the frequency components of specific or intermittent noise events causing noise annoyance.
- To take account of all noise sources in a space, another method of assessment used is in terms of overall L_{Aeq}. The use of L_{Aeq} is most suited to steady and continuous background noise as opposed to specific or intermittent noise levels. This method does not indicate the frequency dependency of annoyance from noise, but has the advantage of simplicity for carrying out the assessment and compliance measurements with sound level meters. Additionally, many national regulations [3, 4] related to recommended guidelines for background noise criteria for indoor spaces are given in terms of L_{Aeq} and comparison to these criteria is therefore straight forward.

ACOUSTIC CRITERIA USED IN GREEN BUILDING RATING SYSTEMS

Acoustic criteria used in green building rating systems generally reference national guidelines and standards intended for mechanically ventilated buildings. No specific acoustic criteria for naturally ventilated buildings are given.

The Green Building Council of Australia includes a credit in their rating system, *Greenstar – Office Design and Office As Built* [6], for meeting the recommended background noise levels given in AS2107-2000 [3] (and reproduced in Table 1 above).

The US Green Building Council's rating system LEED®-NC [5] does not currently offer a credit for limiting background noise levels in offices.

The Building Research Establishment in the UK includes a credit in their rating system, *BREEAM Offices* [7] to "ensure the acoustic performance of the building meets the appropriate standards for its purpose". The acoustic criteria referred to generally follow the recommendations of BS8233-999 [9], and are reproduced in Table 1 above.

These green building rating systems have adopted internal acoustic criteria usually applied to mechanically ventilated buildings without consideration given to natural ventilation strategies usually employed in these buildings. Obtaining the acoustic credits in the respective green building rating systems are therefore unachievable in most practical building locations due to noise ingress via the large areas of façade open areas required to achieve the natural ventilation credits.

CHALLENGING ACOUSTIC CRITERIA USED IN THE PAST – CHOICE OF NOISE DESCRIPTOR

The criteria used previously (given above) give rise to the following considerations and challenges:

- For criteria given in relation to NC curves, by definition and intent of the use of NC curves, the noise sources should be constant and steady state, without audible tones or fluctuations in noise levels. This would most likely not be the case for external noise sources adjacent to naturally ventilated buildings.
- For criteria given in terms of L_1, this implies that for 99% of the time, the noise criterion is met. This may be considered to be a conservative target given the non-acoustic benefits that natural ventilation provides, and the human sensitivity to noise discussion above.
- For criteria given in terms of L_{Aeq}, this noise descriptor is defined as an energy-equivalent time-averaged noise level that expresses the time-varying sound level for the specified period as though it were a constant sound level with the same total sound energy as the time-varying level. This implies that the criteria represent a time averaged noise level, and the instantaneous noise level at any one time has the 50% probability of being higher or lower than the resulting L_{Aeq} and would not accurately reflect the perceived noise disturbance. The advantages, however, of being a common statistical noise measure used in design criteria around the world and ease of measurement in the field make this method attractive for use. In addition, with consideration to natural ventilation purposes—where noise is just one of many considerations for sustainable building design, and the character of the noise sources causing annoyance in naturally ventilated buildings can be varied—the use of L_{Aeq} could be considered acceptable as a noise parameter for acoustic design criteria for naturally ventilated buildings.

The choice of an appropriate statistical noise descriptor for assessment of noise break-in via naturally ventilated building facades warrants a standalone subjective assessment of effect on speech intelligibility and distraction to work activities.

THE WAY FORWARD FOR SETTING REVISED CRITERIA

Subjective testing using auralisations in a controlled environment

A subjective assessment regarding the effect on speech intelligibility by various levels of traffic noise was carried out in a controlled environment called the Arup SoundLab [15]. The aim of the assessment was to use subjective word tests to ascertain the level of impairment of speech intelligibility in the presence of external background noise entering office buildings via natural ventilation openings. Background noise levels were varied in 3 dB increments to determine the sound pressure level at which the level of speech intelligibility in offices would be unsatisfactory.

The results demonstrated that the allowable level of external traffic noise break-in (L_{Aeq}) to naturally ventilated buildings could be set over 10 dB higher than currently recommended for sealed and mechanically ventilated buildings, while still maintaining a good level of speech intelligibility within office spaces. The results of this work provide the first indications that traditional criteria can be revised and that there are opportunities for introducing practical and less stringent noise mitigation measures, if necessary, for naturally ventilated buildings at a reasonable cost in the context of the building construction budget. Further research work is currently being undertaken to assess the disturbance to typical work activities by various levels of traffic noise ingress.

Revised noise criterion curves for naturally ventilated buildings

Noise Criterion (NC) curves are widely used to evaluate noise conditions in occupied spaces and are based on achieving satisfactory speech intelligibility or acoustic comfort in occupied office spaces with mechanical ventilation. The curves were derived by Beranek from personnel surveys and noise surveys in occupied office spaces of a US aircraft base in 1956 [16]. The survey included 190 participants, working in 17 difference spaces with various background noise environments. A follow-up study in 1957 [17] provided further data from other occupied office buildings to substantiate the results from the initial study and provide a revision to the initially proposed criteria. A total of 300 participants took part in the combined study. The same questionnaire was used for both studies, and focused on interference to speech and ability to accomplish tasks without loss of performance. Analysis of the subjective assessment with the background noise measurements carried out led to the derivation of the NC curves still used as the basis for mechanical noise control specifications today.

It would therefore be a reasonable approach to undertake a similar study in existing naturally ventilated buildings to derive suitable background noise criteria in occupied office spaces. The end goal would be a modified set of NC curves ("NV-NC" curves) suitable for applying to the design of naturally ventilated office spaces.

Subjective testing in an existing naturally ventilated building

To substantiate the results obtained from subjective testing in a controlled environment [15], the same subjective testing methodology could be applied in a real building environment, where natural ventilation is the principal ventilation strategy.

By carrying out the testing in an existing naturally ventilated building, the thermal benefits of natural ventilation (improved indoor air quality and connection to the outdoor environment) would be inherently captured in the results.

Using a similar methodology to that used for the Arup SoundLab assessment, the noise source used in testing would be calibrated at the internal listening location and varied in 3 dB increments to determine the effect on speech intelligibility and task distraction.

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