COMPATIBILITY BETWEEN NOISE AND VENTILATION REQUIREMENTS IN TEACHING SPACES IN SCOTTISH SCHOOLS

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1 INTRODUCTION

Schools are critical infrastructure used by teachers and pupils, who are spending a significant amount of time in these buildings engaging in various activities including studying, doing sports, working and socializing. ASHRAE guidelines state [1] that people spend about 80–90% of their time indoors. It is recognized that it is important to ensure adequate ventilation and good indoor environment to support occupants' health and wellbeing.

According to the Department for Education [2] the number of pupils that can be accommodated in a classroom depends on several factors, including the design of the classroom (standard or open-plan), the level of schooling (primary or secondary), and national or local regulations. Studies have indicated that a range of comfort and health related effects on pupils are linked to classroom sizes, as well as the environmental comfort in the building [3-6]. Among the environmental aspects that can affect a pupil's ability to learn comfortably, the main elements are temperature, ventilation and indoor air quality, lighting, and acoustic environment in the room. The ventilation and thermal comfort are selected as the most important factors affecting cognition and ability to learn in the classrooms (i.e. [5]).

In the research article [6] relationships between acoustics, thermal performance, indoor air quality, and lighting conditions on pupils' achievements in class had been measured and analysed. One of the results of the field measurements during this research was that 91% of tested classrooms did not meet the recommended maximum background noise levels, while 15% did not meet the recommended maximum reverberation times. Additionally, 80% of those tested classrooms did not meet ASHRAE Standard ventilation rate requirements [1]. The summary of the study was that the unsatisfactory environmental conditions correlate with pupils' test scores in the regressive way.

2 DESIGN REQUIREMENTS FOR SCHOOL BUILDINGS IN SCOTLAND

The main design documents for the design of educational buildings in UK are Building Bulletins (BB): 101 [7], covering ventilation, thermal comfort and air quality aspects, and BB93 [8], covering acoustic performance and environmental noise issues. Whilst BB93 is widely used in all constituent countries in UK, BB101 is used as a mandatory document in England, but only as an advisory document in Scotland.

2.1 Survey on ventilation requirements in non-domestic buildings in Scotland

The University of Strathclyde in 2022 conducted a survey on behalf of the Scottish Government regarding evidence of where the Scottish Building Standards Section 3 (non-domestic building ventilation) is required to be updated in order to provide greater assistance in provision of adequate ventilation in new non-domestic buildings [9].

The survey has shown that CIBSE ventilation guidance was referred to and applied by most Scottish respondents when designing new non-domestic buildings, with specialist documents such as BB101 to be used where necessary. It has been highlighted in the research that whilst well-designed natural ventilation has many benefits, the indoor air quality can only be as good as the outside air quality and in some cases careful positioning of air intakes or use of filtration may be necessary. In other cases mechanical systems or systems that combine natural with mechanical (hybrid) may be the best ventilation solution for the buildings, and occupants' thermal comfort, energy demands and associated carbon emissions will also need to be considered as part of a building design strategy.

At the end of the survey the need to the complex approach to ventilation when designing new or maintaining existing non-domestic buildings is highlighted. The recommendations include CO_2 monitoring, the requirement for a building ventilation maintenance plan to support the regular inspection, cleaning and maintenance of ventilation systems in practice, and health-checks (equivalent to MOT) for non-domestic buildings.

2.2 Need for more schools to be built with Net Zero targets

In line with Net Zero Government Initiative (published in December 2023, [10]), the main aim for UK government is to reduce all direct emissions from public sector buildings by 50% and 75% by 2032 and 2037 respectively (counted against the baseline set in 2017). It had been estimated (i.e. in [11]) that the UK school buildings provide as much as 15% of all public sector buildings emission of greenhouse gases in the country.

There are over 32,000 schools currently operating in the UK [1], and the need for new educational buildings is on the grow. With the demand to reduce the carbon footprint of all public sector buildings, the approach to new and refurbished schools' design has to be altered and should take into account the environmental factor as well as all other factors associated with a school design, such as fire, ventilation, acoustics and capacity.

2.3 PassivHaus approach to school design

Passivhaus is a design standard that adopts a whole-building approach, focused on high-quality construction. Passivhaus buildings are designed to maintain a comfortable indoor temperature. Passivhaus standard sets general minimum criteria for designing an airtight envelope with minimized heat loss through any element or junction. Ventilation systems for each room or the whole building are permitted to be used, and some heat recovery system is essential. Energy-efficient appliances and lighting are typically used to further reduce energy demand. PassivHaus design ensures a high level of indoor comfort, improved indoor air quality, and reduced operating costs over the building's lifetime.

The design of a new building with use of PassivHaus standards can be authorized by receiving PassivHaus certification. For refurbished buildings some PassivHaus components can be used to achieve an extensive improvement in overall building performance, and also can be certified as EnerPHit [12].

In January 2023 the Scottish Government announced plans to introduce new minimum environmental design standards for all newbuild housing to meet a 'Scottish equivalent to the Passivhaus standard' [13]. The proposal is expected to be adopted as legislation in December 2024.

It is estimated that there are 35 Passivhaus schools currently underway or in the pipeline in Scotland. The design approach to these schools varies from the traditional route with open window ventilation, as the issues associated with plant noise have to be addressed.

3 COMPATIBILITY ISSUES BETWEEN VENTILATION AND NOISE IN SCHOOLS

In general, for a new school project, the architect combines the proposed design with the inputs of an energy specialist, a mechanical ventilation and electrical engineer, and an acoustic consultant. The inputs often come independently and are then reviewed for any compatibility clashes in each project individually

The following case studies are examples of work that had been conducted for various schools in Scotland.

3.1. Case study 1: ventilation and ambient noise compatibility

There are a range of ventilation strategies that can be adopted to meet the design requirements at the schools: from completely natural ventilation through windows and open vents, completely mechanical ventilation or hybrid systems which have the mixture of natural and mechanical ventilation options. The natural ventilation could be manual, automated, or combined option for opening windows, or just trickle vents or roof stacks. The mechanical fan driven system could be serving the whole building with supply and extracts located centrally, or have a sequence of room-based systems, where the supply and extract located in each room.

In terms of the noise from the ventilation, BB93 recommends the following levels, as shown in Table 1 below for some key teaching spaces (extract from Table 1 of [8]). These values are for rooms that are finished, furnished for normal use, but unoccupied.

Table 1. Upper limits for indoor ambient noise levels (IANLs)

Type of room	Upper limit for the indoor ambient noise level, $L_{Aeq,30min}$ (dB re 20 μPa)	
	New-build	Refurbishment
Primary school rooms, used for teaching and learning	35	40
Open plan classrooms, teaching area	40	45

Additional recommendations on the maximum permitted indoor ambient noise levels are further addressed in BB93 as shown in Table 2 below (extract from Table 2 of [8]). It should be noted that an increase of IANL rule does not apply for very noisy spaces (i.e. Sports Halls or Atria) and should be applied with care for teaching places for children with special health and educational needs.

Table 2: summary of ventilation condition, system type and associated IANL tolerance

Condition	Ventilation system	Noise level limit
Normal - ventilation for normal teaching and learning activities	Mechanical	Table 1 value
	Natural	Table 1 value + 5 dB
	Hybrid	Mechanical system noise: Table 1 value Total noise level: Table 1 value + 5 dB
Summertime - ventilation under local control of teacher to prevent overheating	Mechanical	Table 1 value + 5 dB4
	Natural or Hybrid	≤55 dB

When the type of ventilation is chosen for an application, various issues associated with noise and required air exchanges should be considered and reviewed before signing off the completed design.

3.1.1. Case study 1: design stage

The environmental noise impact assessment for a new nursery was conducted prior the design stage had commenced. The results had shown that the current background noise level is L_{Aeq} 48 dB (and L_{A90} 40 dB) outside next to the proposed building facade, which allows the open window ventilation strategy to be adopted for all nursery facades.

However, according to the exterior designer' proposal, the playground that will be used by the nursery children is located at the front of the new building. The noise from the playground will be considered as community noise firstly, to the surrounding residential receptors, and secondly – to the nursery itself. WHO99 [14] offers the following explanation on community noise: "Community noise… is defined as noise emitted from all sources except noise at the industrial workplace…. Typical neighbourhood noise comes from premises and installations related to the catering trade (restaurant, cafeterias, discotheques, etc.); from live or recorded music; sport events including motor sports; **playgrounds**; car parks…"

The regular noise levels expected from a playground are shown in Table 3 below. These data are taken from real-life measurements of a group of pre-school children involved in two types of activity: free-play and quieter shared storytelling.

Table 3. Noise Levels from Nursey Playground Activity (dB re 20 μPa)		
	$L_{Aeq,}$ (dB)	$L_{AFmax,}$ (dB)
Noise from 20 – 25 children Free play at a nominal distance of 3 m	63	84
Noise from Reading/storytelling activity at a nominal distance of 3 m	55	65

A noise assessment was required to address the breakout to the nearby residents (the barrier or closed fence is a typical solution for this situation but will be impractical for the nursery itself. Therefore the hybrid ventilation option was offered, with mechanical ventilation and windows closed during the play time at the playground, and windows open for the other times. As this hybrid ventilation is only required for a few rooms, whose windows are facing the playground, the individual units for each room with inlet and outlet on the roof/ façade wall are incorporated in this project. The project was then endorsed to adopt several other elements of PassivHaus standard (but without certification).

3.1.2. Case study 1: further issues upon completion testing

Once the above project was completed, the ambient noise measurements were measured in all playrooms finished, but unfurnished, with ventilation turned on. The measurements are shown in Table 4 below.

Table 4. Ambient L_{Aeq} internal noise measurements (IANL) (dB re 20μPa)			
Test room	Measured internal ambient noise level L_{Aeq}	BB93 maximum target L_{Aeq}	Exceedance
Playroom A (with ventilation on)	35	35	N/A
Playroom B (with ventilation on)	36	35	+1 dB
Multi-use Playroom C (with ventilation on)	38	35	+3 dB

It is expected that the presence of furniture and people in the room will increase absorption (a sitting person sound absorption lies within Class C range) and provide masking noise for any sound from ventilation. However, the presence of people will also increase the internal temperature and levels of CO_2 emitted in the room, and therefore it may be required to increase the speed of the fan providing extra airflow. The change of fan rotation will adjust the noise levels, and additional measures for sound absorption will be required, such as silencers or lined ducts.

3.2 Case study 2: externally located ventilation units and environmental noise issue

In larger school projects it is expected that the mechanical ventilation will be used for some parts of the building, or for the entire school. Depending on the requirements of each project and on the number of mechanically ventilated spaces, the plant rooms, energy stores and externally located plant units can be utilised. The machinery is expected to run continuously during school operational hours in full capacity, and often during the night with reduced capacity. If multiple units are running simultaneously (i.e. ventilation units or heat recovery system during the hot weather) the noise from the plant could be audible at the nearest noise sensitive receptors (NSRs).

If the plant room is chosen, it will be located inside the building, and therefore screened from any external NSRs, and the main focus should be on the effect of the noise from the plant on the ambient noise in classrooms adjacent to the plant room (horizontally and vertically). If an energy store or energy centre is planned, it should be a purpose-designed building on the grounds of the school, and will have acoustically treated walls, ducts, louvres and roof to provide adequate sound reduction to any NSRs. In cases where a separate plant building is not practical, the roof top plant is the next available option. Roof top plants are usually not enclosed, and therefore the noise breakout issues must be addressed.

3.2.1. Case study 2: design stage assessment

A large school campus was designed and built to replace the existing schools in the area. As the school grounds were surrounded by residential buildings, the background noise level and the construction noise assessments were conducted for the proposed project. The measurements showed that the background levels L_{A90} 45 dB (worst case scenario) with slight variation from this value depending on the measurement location and time (measurements were conducted between 10am and 4pm to avoid the increased traffic noise).

At the design stage a desktop assessment was conducted to determine the maximum permitted noise levels from the combination of units and estimate the noise impact to the nearest NSRs. The results for one of the school blocks are shown in Table 5 below. The proposals included the large plant space to be sited on the roofs of this block.

Table 5. Predicted Maximum Plant Noise Levels at 3 m, L_{Aeq}, dB re 20 μPa

	Block 2
Background level, L_{A90} dB	45
Distance attenuation $20\log(r_1/r_2)$	+20
Corrections for near field reflections	-3
Audibility correction	-5
Permitted level @3 m from any side of the proposed plant	**57**

Block 2 was the closest to the residential properties, and had a clear line of sight from the roof to the top windows of the nearest residential block of flats. Total of four air handling units (AHUs) were proposed on the roof, with the potential of all of them operating simultaneously.

The selection of units was guided by the mechanical ventilation specialists, and was determined by the capacity of the proposed units, necessary air exchanges for all spaces each of the AHUs were expected to serve. Several attempts were made to mathematically assess the chosen units using manufacturer's data; however it became complicated due to the number of modifications implemented. At the later stage the design team had agreed to the proposal to introduce an acoustic barrier/ parapet around the roof edge. The proposed barrier was expected to serve not only in noise reduction, but also as a safety measure, as well as visual screening of the units from the noise sensitive receptors.

3.2.2. Case study 2: completion stage assessment

Upon completion of the installation of the roof plant, the measurements were conducted on-site to assess the real-life level of adverse impact on the NSRs by means of BS4142 assessment [15]. The noise from the measured units was broadband without significant peaks and tones. The measurement location was at the edge of the roof, with microphone being extended over and placed behind the acoustic barrier. Distance attenuation was calculated from the middle part of the barrier; the line source approach was considered. The results of the assessment are summarised in Table 6 below.

Table 6. AHU Noise Level, Block 2 roof, dB re 20 μPa

Description	Noise levels
All AHU units (combined), 1m behind the barrier, L_{Aeq}	55
Distance attenuation $10\log(r_1/r_2)$	-15
Corrections for near field reflections at façade	+3
Combined plant noise at residential façade	43
Background noise, L_{A90}	**45**
Difference	**-2**

Whilst being onsite, the acoustician had provided some minor comments on the current barrier make-up and potential modifications to it to achieve further improvement in its performance.

3.3 Case study 3: design of teaching spaces for pupils with special hearing and communication needs

As part of additional support for learning policy run by the Department for Education [1], the inclusive educational system is utilised everywhere in UK. According to [16], the number of pupils with special educational needs (SEN) has increased by 4.7% from 2023 to 2024, and by a total of 24.9% since 2016.

In Scotland, the inclusive approach to education enables all children and young people to be part of a community, boosting their emotional wellbeing and aiding the development of social skills.

Each group of children with special hearing and communication needs is expected to be assisted at the schools with support of the specialist consultants and head teachers. There are good practices available which are used in each individual case, which may include partial refurbishment of a teaching room or part of the school. There is an ambitious target to incorporate some elements of SEN treatments into newly built schools to increase the inclusivity rates in the schools. The elements addressed by means of BB93 [8] are shown in Table 7 below.

Table 7. BB93 requirements for standard and SEN rooms

Type of room	Ambient sound upper limit, $L_{Aeq,30min}$ (dB)	Recommended Reverb. Times, T_{mf} (s)	Sound insulation requirements for walls and floors
Secondary school: teaching and learning spaces	35	≤0.8	D_{nTw} 45 dB L'_{nTw} 60 dB
Teaching space intended specifically for students with special hearing and communication needs	30	≤0.4 on average between 125 Hz and 4kHz, with ≤0.6 at any individual frequency	D_{nTw} 50 dB L'_{nTw} 55 dB

3.3.1. Case study 3: SEN for whole campus - design stage

A new high school was designed and built to be used by the existing and the new communities from the fast-growing residential development allocated nearby. The full acoustic design has been conducted by the acoustic specialists, following BB93 guidance. An environmental noise assessment was conducted and specified that an open window ventilation strategy can be adopted in most of the school, except one block. This block was designed to address pupils with SEN, and included the classrooms, atrium space and some therapy/ calming rooms.

The local authority then challenged the design team with the proposals to extend SEN use to the entire school. All consultants were asked to assess the amendments required to accommodate this change. Some key acoustics-related findings of required treatments in relation to this proposal are shown below In Table 8.

Table 8: Acoustic recommendations required, standard vs enhanced

	Arrangement to achieve BB93 standard	**Additional treatment required to achieve SEN standards**
Façade and windows	Standard façade and single glazed windows	Standard façade, windows may need changing to double glazed
Ventilation	Open window ventilation, IANL expected 33 dB Some spaces (i.e. Dining, Sports or Performance hall) have mechanical ventilation	Mechanical ventilation required in all spaces. Closed window in classrooms, max permitted IANL 30 dB
Reverberation time, classrooms	Class ‘A’ ceiling tiles / carpet / no panels RT: ≤0.8 sec	Class ‘A’ ceiling tiles / carpet / 10 m^2 wall panels RT: ≤0.4 sec
Science labs/ workshops	Class ‘A’ ceiling tiles / vinyl/ no panels RT: ≤0.8 sec	Class ‘A’ ceiling tiles / vinyl / 30 m^2 wall panels RT: 0.4 sec
SEN teaching rooms	Class ‘A’ ceiling tiles/ carpet / 4 m^2 wall panels	The same
Assembly/ Performance hall/ Sports Hall	Exposed acoustic liner tray / hard wooden floor / 130 m^2 (Class A wall panels)	With every surface in the space treated acoustically still not able to achieve SEN standard due to the space size

It had been demonstrated that the additional interior treatments and new requirement of a mechanical ventilation to serve every space of the school building will still not provide the guarantee of achieving the SEN standard in all rooms. After further assessment of the prospective expenses for all changes, the proposal was withdrawn.

4 CONCLUSIONS AND ACKNOLEDGEMENTS

It is important that in an educational building all the places for teaching are designed to be suitable environments for learning and communicating. It is also expected that all new non-domestic buildings are built with the aim to achieve Net Zero targets for emissions from public sector buildings and save/ reuse green energy. In Scotland there is a potential to introduce PassivHaus standard to schools design, but one of the biggest risks is that the other building functions can be compromised.

The compatibility challenges can be resolved by using the complex approach to the building design with a group of expert consultants working together from the earliest stage. Particular care should be taken when the schools are expected to be used by children with special educational and behavioral needs.

All examples of good practice used in this article are from author's practice as acoustic consultant at Robin Mackenzie Partnership. The author would like to thank her colleagues for providing the site testing data and invaluable advice for this work.

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