CONFLICTS BETWEEN ACOUSTICS & SUSTAINABILITY IN SCHOOLS

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1 INTRODUCTION

Acoustic considerations have a significant influence on the design of new schools. The acoustic requirements for schools are set by Approved Document Part E (AD E)[1] of the Building Regulations by reference to Section 1 of Building Bulletin 93 "Acoustic Design of Schools" (BB93)[2]. The performance standards defined in this document are intended to give an acoustic environment which is conducive to learning and teaching. In particular, the document specifies upper limits on indoor ambient noise levels and reverberation times as well as lower limits on STI and airborne/impact sound separation between spaces.

In the context of this paper, "sustainability" is used to mean the environmental sustainability of the school as measured by the carbon dioxide (CO_2) emissions associated with the construction and running of the building. In the UK, approximately half of all CO_2 emissions are associated with buildings and schools account for roughly 15% of all public sector CO_2 emissions. In an attempt to impact climate change, the government has set a self-imposed "legally binding" target to reduce CO_2 emissions by between 26% and 32% (relative to 1990 baseline levels) by 2020. This target clearly has implications for the design of new and refurbished buildings. The requirements for CO_2 emissions in schools are set by Approved Document Part L2A (AD L2A)[3] of the Building Regulations.

In certain situations, the achievement of acoustic performance standards can influence the design in such a way as to increase the CO_2 emissions associated with the school building. As well as making compliance with AD L2A more difficult to achieve, this has an ongoing implication for the carbon emissions associated with the UK stock of school buildings.

In this paper, several situations in which there is a conflict between acoustic considerations and environmental sustainability will be discussed. The focus will be on situations which affect the emissions associated with the running of the building because these tend to be an order of magnitude greater, over the building's lifetime, than the emissions associated with construction of the building. The discussion is centered on the UK climate and regulations but many principles will universally valid.

2 PERFORMANCE REQUIREMENTS

The most important area of the school in which to achieve good acoustics are the teaching spaces. In this paper, we will focus our attention on the design of a typical secondary school classroom. The relevant performance requirements are outlined in Table 1 below.

The AD L2A requirements for CO_2 emissions are defined in terms of a relative improvement in the yearly emissions from the actual building relative to a corresponding notional building. The definitions for the notional building construction and the patterns of occupancy and plant operation are defined in the (to date unpublished) National Calculation Method (NCM)[4].

In practice, the net emissions of the buildings will need to be around 17-20kgCO_2/m^2/yr (kilograms of carbon dioxide per square metre per year) to meet AD L2A.

Document	Requirement
BB93[2]	Indoor ambient noise levels, $L_{Aeq,30min}$=35dB or under Unoccupied, unfurnished, mid-frequency reverberation time, T_{mf}=0.8s or less Airborne sound separation from adjacent classroom of $D_{nT(Tmf,max),w}$=45dB or greater Airborne sound separation of wall and glazing to corridor of Rw=40dB or greater Airborne sound separation of door to corridor of Rw=30dB or greater Element normalised level difference for ventilators to corridor of $D_{n,e,w}$-10lgN=39dB or greater Impact sound pressure level of $L'_{nT(Tmf,max),w}$=60dB or less Refer to BB93 for further details and definition of terms
BB101[5]	A minimum ventilation rate of 3 l/s/person (litres per second per person) A minimum daily average ventilation of 5 l/s/person The capability of achieving a ventilation rate of at least 8 l/s/person at any occupied time Summertime ventilation rates as necessary to avoid overheating These requirements apply for both natural ventilation and mechanical ventilation systems
BB101[5]	Indoor ambient noise levels, $L_{Aeq,30min}$=35dB or under when air is supplied at a rate of 3 l/s/person Indoor ambient noise levels, $L_{Aeq,30min}$=40dB or under when air is supplied by natural ventilation at a rate of 8 l/s/person Indoor ambient noise levels at teacher's discretion when air is supplied by natural ventilation at a rate >8 l/s/person Indoor ambient noise levels, $L_{Aeq,30min}$=35dB or under when air is supplied at any rate by mechanical ventilation
BB101[5]	No more than 120 occupied hours when air temperature rises above 28°C The air temperature should never rise above 32°C during occupied hours The internal air temperature should not be more than 5°C above external air temperature, on average during occupied hours 2 of these 3 criteria must be met to show that overheating will be avoided. The relevant occupied period is defined as 09:00 to 15:30, Monday to Friday from 1st May to 30th September
BB87[6]	Classrooms should be heated to 18°C Classrooms should d be lit to 300 lux on the working plane
BREEAM[7]	Reduction in CO_2 emissions can achieve up to 15 credits in BREEAM assessment - see Table on p2 of Energy Section

Table 1: Table of performance requirements for secondary school classrooms

3 AMBIENT NOISE LEVELS & VENTILATION

A natural ventilation and passive cooling strategy can be used to control summertime overheating in classrooms. However, this approach requires high ventilation rates and therefore large ventilation openings in the facade. This creates an obvious conflict with the need to limit noise break-in on most urban sites. Because of this, mechanical ventilation and cooling can become the default solution leading to greater energy usage and carbon emissions.

A natural ventilation and passive cooling strategy will be most effective when used in conjunction with exposed thermal mass (see Section 4) to absorb excess heat during the day and secure night-time ventilation to reject the stored heat when external air temperatures are lower.

3.1 Typical Classroom

For the purposes of this paper, a typical secondary school classroom geometry has been taken to be 8.2m (L) x 6.0m (W) x 2.8m (H) as illustrated in Figure 1. One of the longer walls is external and has a four windows measuring 1.8m (W) x 1.6m (H). The total glazed area is therefore 11.52m^2 (50% of facade area). The external wall is assumed to be oriented south. The insulation of the external wall, floor, roof and glazing all meet the AD L2 limiting standards. The classroom is assumed to have a heavy-weight construction, with plastered medium density block walls and an exposed concrete soffit. The floor is assumed to be carpet on 25mm chipboard. The calculations are based on the CIBSE[8] test reference year weather data.

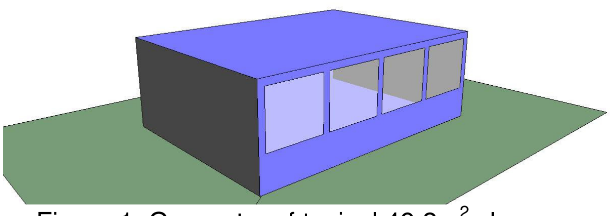

Figure 1: Geometry of typical 49.2m^2 classroom.

3.2 Thermal Gains

Classrooms have relatively high thermal gains. Typical values are shown below:

- People gains: 30 children and 1 adult ≈ 3000W
- Lighting gains: $10W/m^2$ ≈ 500W
- Computer, projector and equipment gains: $15W/m^2$ on average ≈ 750W
- Solar gains: Daily average for the room ≈ 1300W in summer and 900W in winter

Because of these relatively high gains, classrooms ventilated at a rate of 8 l/s/person do not require heating unless the external temperature is below 5°C. Heating will be required to warm up the room at the start of the school day but once at temperature, the classroom essentially has an excess amount of heat when the outdoor temperature is above 5°C which is >90% of the school year. Clearly the problem for classrooms is the control of summertime overheating. A good first step is to reduce the summertime solar gains using shading (internal or external) or solar control glazing.

To dissipate the excess heat, the classroom must either be ventilated at a high air exchange rate or alternatively be mechanically cooled.

3.3 Natural Ventilation and Noise Levels

The most straightforward method to get the ventilation rates required to control summertime overheating is to use simple opening windows. In order to keep overheating within the BB101 requirements, a ventilation rate of up to 750 litres/s (approximately 20 air changes per hour) is required. For single-sided ventilation (see Section 3.5.2) this can only be achieved if the opening window area is at least $5m^2$. In the case of the typical classroom illustrated in Figure 1, this represents roughly 43% of the total window area.

With a window opening of this size, the external wall will only give a frequency weighted level difference ($L_{P,OUT} – L_{P,IN}$) of around 10dB[9]. BB101 specifies an upper limit of $L_{Aeq,30min}$=40dB for ventilation at 8 l/s/person but does not give a requirement at higher ventilation rates. Ideally, $L_{Aeq,30min}$=40dB should not be exceeded at any ventilation rate but it is proposed here that $L_{Aeq,30min}$=45dB is acceptable given that it is under the control of the occupants to offset thermal comfort against noise levels.

It is therefore concluded that using single-sided natural ventilation through standard windows to control overheating is not feasible for facade noise levels greater than $L_{Aeq,30min}$=55dB and requires some compromise for facade noise levels greater than $L_{Aeq,30min}$=50dB. School buildings will experience a facade noise level in excess of $L_{Aeq,30min}$=50dB on most urban sites. In these cases, an alternative approach must be considered.

3.4 Mechanical Ventilation and Cooling Energy Usage

The most effective way to keep out external noise is to seal the façade completely. Ventilation air must then be provided using a mechanical ventilation system with supply and extract fans. It is not practical to ventilate mechanically at the rates necessary for summertime cooling because of the associated fan power and space requirements. The standard solution would therefore be to supply ventilation air at the minimum rate required to maintain indoor air quality (daily average of 5 l/s/person) and prevent overheating by using mechanical cooling (i.e air-conditioning).

Because mechanical ventilation is more easily controlled and allows heat reclaim from outgoing air, the energy required for heating is less for a mechanically ventilated classroom than a naturally ventilated classroom. However, energy is required to run mechanical ventilation fans and for mechanical cooling. For the typical classroom described in Section 3.1, using a mechanical ventilation and cooling strategy will use additional energy equating to $95kgCO_2$/yr more emissions than a natural ventilation and passive cooling strategy.

Assuming that teaching spaces account for about 60% of the gross school area, this means that using mechanical ventilation and cooling would result in about 1.2kgCO_2/m²/yr more carbon emissions. This equates to about 6% of the overall AD L2A emissions allowance for the building.

Table 2 shows the relevant data used in the energy comparison. All calculations were made using IES<Virtual Environment> dynamic thermal simulation software tool[10].

Seasonal efficiency of boiler	89%
SSEER of mechanical cooling	2.5
Specific fan power for mechanical ventilation	1.2W per l/s
Efficiency of heat-recovery on mechanical ventilation	50%
Heating set point	18°C
Cooling set point	25°C
Natural ventilation	
Wintertime window opening	0.58m²
Summertime window opening (T>23°C)	5m²
Summertime window opening at night	0.58m²
Mechanical ventilation	
Daytime average ventilation rate	5 l/s/person
Summer night-time ventilation rate	75 l/s
Glazing assumed to be "Suncool Classic" by Pilkington - IES<VE> data	

Table 2: Data used in IES<VE>[10] energy calculation

3.5 Alternative Approaches to Natural Ventilation

It is clear from the discussion in the previous section that it is desirable to avoid the carbon emissions associated with mechanical ventilation and cooling. Some alternative strategies are discussed below by means of example.

3.5.1 Site Layout and Screening

The first step to avoiding the need for mechanical ventilation of classrooms is to consider the building layout at an early stage of the design. By orienting buildings favorably relative to sources of noise, the noise levels at classroom facades can be kept within levels that can be dealt with using a natural ventilation strategy. As discussed in the following sections, natural ventilation can still be viable up to 65dB(A) with careful design.

At Wembley Manor School[11] in London, the site is bounded to the north by a busy road. At the north of the site closest to the road, the facade levels are approximately 70dB(A). This is not atypical of an urban site. By organising the school layout so that the classrooms are shielded from the road by the two storey hall and administration block, the maximum classroom facade level can be kept below 62dB(A). Figure 2 shows a scale model of the building and Figure 3 shows a predicted noise-map of the site.

Figure 2: Scale model of Wembley Manor Primary School[11], London

To control noise break-in, the hall is mechanically ventilated and the facade facing the road is sealed. The classrooms blocks are distributed around a central open courtyard meaning that they can all be naturally cross-ventilated (refer to section 3.5.2) on both floors. This arrangement also allows the larger ventilation opening to be oriented towards the quiet central courtyard where noise levels are expected to be around 50dB(A).

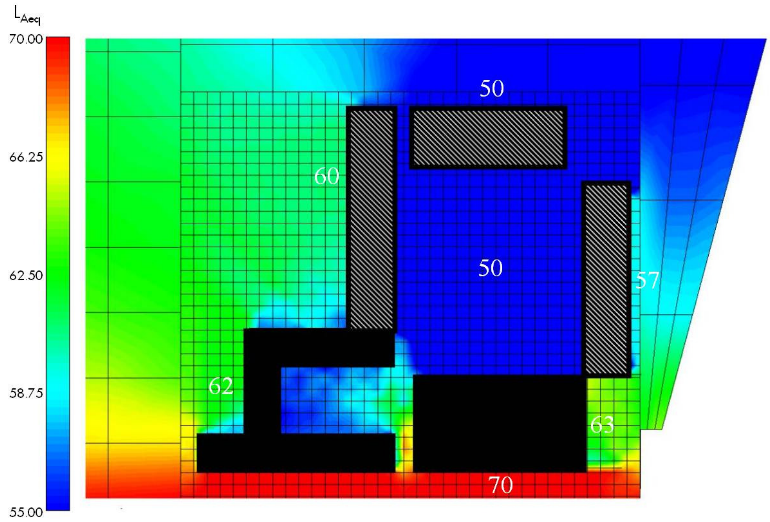

Figure 3: Noise map (plan view) of Wembley School[11] site indicating predicted $L_{Aeq,30min}$ noise levels. Values shown in white indicate the noise level at that point. The classroom blocks are shaded.

The strategy adopted at Wembley School demonstrates that it is still possible to naturally ventilate most classrooms on an urban site next to a busy road. It is important to note that there are many other factors which should be considered when deciding on the building orientation and layout including solar shading, secure access and architectural appearance. However, keeping the acoustic considerations in mind at this stage can save money and energy down the line in terms of both building and running the school.

3.5.2 Attenuated Inlet Louvres with Cross/Stack Ventilation

The key to this approach is the use of cross or stack ventilation which is far more efficient than single sided ventilation due to the difference in wind pressures on different building facades. When the inlet and outlets are at different heights, air buoyancy also drives ventilation which is particularly useful on still days. Figure 4 shows the principal of cross and stack ventilation.

Because cross/stack ventilation is more effective than single sided window openings, the area of ventilation opening on the noisy facade can be made much smaller (thereby letting in less noise).

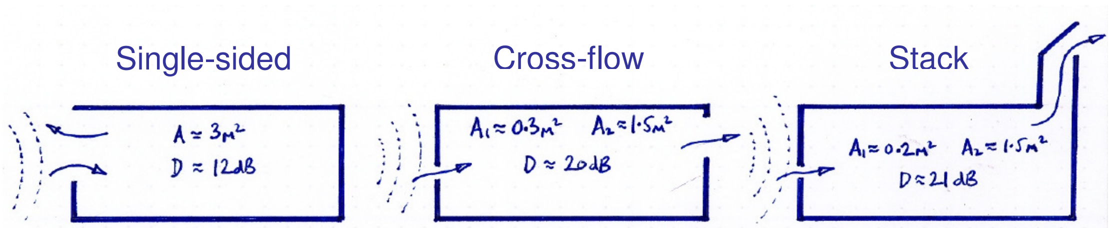

Figure 4: Modes of ventilation showing approximate open areas[12] required to give 8 l/s/person and the approximate sound reduction from the noisy facade

This approach has been used at Locking Castle Primary School & Community Centre in North Somerset[13]. The classrooms face a busy road with a measured facade level of $L_{Aeq,30min}$=58dB. Both the ground and 1st floor classrooms have roof-lights with an open area of approximately 1.5m². This means that an ventilation opening of only 0.2m² is required on the noisy facade to provide air at 8 l/s/person (the rate required to maintain indoor air quality). For summertime ventilation, this open area needs to increase to about 1m². The classrooms use an exposed concrete slab to provide thermal mass to help control summertime overheating.

To reduce noise break-in, the 0.2m² ventilation opening takes the form of a louvre with acoustically lined back-box. The design of the attenuated louvre is illustrated in Figure 5 which also shows an image of the building facade. The louvre is calculated to give a frequency weighted sound reduction of 7-10dB. With the louvre open but the windows shut, the facade will give a weighted level difference of more than 25dB. This means that the BB93/BB101 standard of $L_{Aeq,30min}$=40dB at 8 l/s/person can be achieved for facade levels of up to 65dB.

In the summertime, the windows can be opened to an area of 0.8m². With the windows and louvre open, the facade will give a weighted level difference of about 15-18dB. If, as before, we assume that $L_{Aeq,30min}$=45dB is an acceptable ambient noise level during summertime ventilation condition this strategy is satisfactory for facade noise levels of up to 60dB. If the windows are also designed to provide some acoustic attenuation, this approach can be viable up to a facade level of 65dB(A).

It is important that the louvres are designed to be secure when open, to be well sealed and thermally insulated when shut. Louvres of this type are necessarily large and must be integrated into the facade design at an early stage.

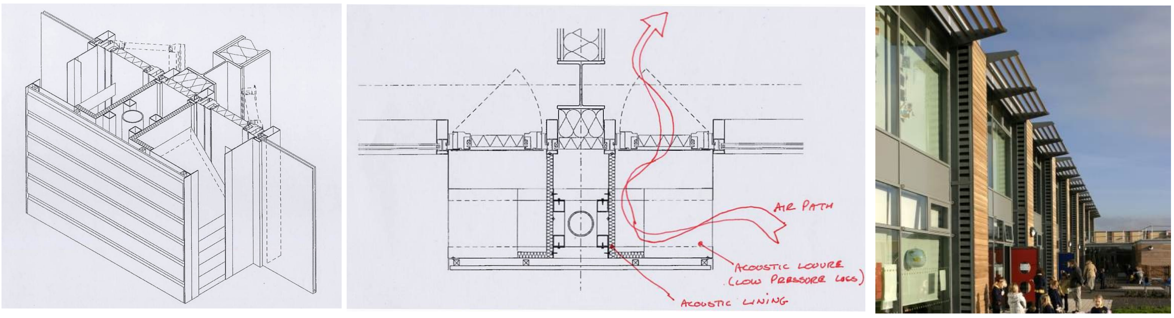

Figure 5: Acoustically attenuated louvre. Isometric (left), Plan (centre) and Photograph (right) showing the building facade at Locking Castle Primary School & Community Centre[13].

3.5.3 Stack vent via Atrium

In multi-storey schools, cross ventilation and ventilation via individual stacks to roof level may not be a possibility. As an alternative stack ventilation can be achieved via a central atrium space as illustrated in Figure 6. However, this requires a low air-resistance path between the classroom and the atrium which should also meet the BB93 minimum requirement for ventilators between circulation spaces and other spaces used by students which is given as $D_{n,e,w}$=39dB.

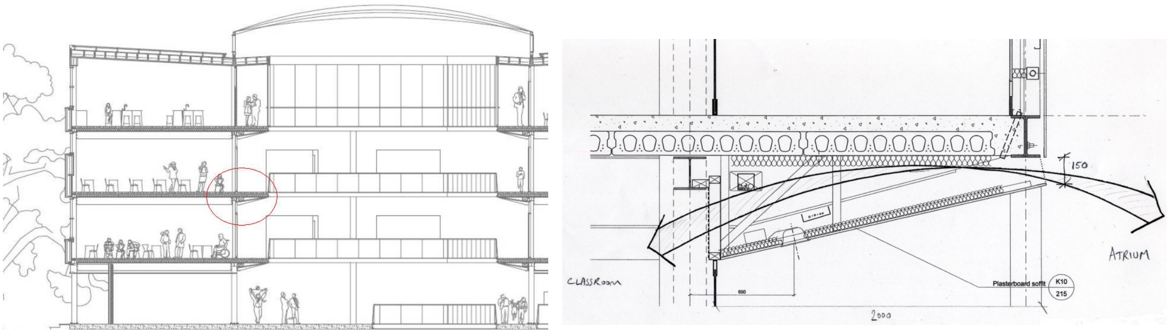

Figure 6: Stack ventilation via a central atrium at Southwark City Academy[14]. Detail (right) of attenuated ventilator between classroom and atrium.

This approach has been used at Southwark City Academy[14] in London which has four stories of classrooms around a central atrium. The classrooms are ventilated to the atrium via specially designed, attenuated ventilators also shown in Figure 6. The ventilator runs the full 7m width of the classroom, measures 150mm at the narrowest point and is 2m long. These ventilators are calculated to give a weighted normalized level difference of $D_{n,e,w}$=32-35dB. This performance is slightly less than the BB93 requirement (the building was designed before the document came into effect) but the performance of the partition between classroom and atrium as a whole is only 3dB less than it would be in the absence of the ventilator. A subsequent study by the BRE[15] shows that ventilators with higher attenuation can be constructed based on a similar principle.

By combining this strategy with that described in 3.5.2, classrooms can be naturally ventilated for facade noise levels of up to 60-65dB(A).

Figure 7: Southwark City Academy[14], Atrium (left), Close up of vent (right)

4 ACOUSTIC ABSORPTION & THERMAL MASS

Classrooms generally require some acoustic absorption to control reverberation times to BB93 values. Acoustic absorption applied to room surfaces can significantly reduce the effective “thermal mass” of the room. Spaces with low thermal mass are more at risk of summertime overheating and are more likely to result in the use of mechanical cooling leading to increased energy usage and carbon emissions.

4.1 What is “Thermal Mass”?

Thermal mass is a term which is used to describe the ability of the room surfaces to store heat over time. A building with high thermal mass can store more heat in its fabric than a building of low thermal mass. An example of a high thermal mass building is a cathedral with thick stone walls. An example of a low thermal mass building is a temporary/portable cabin office with thin, poorly insulated plywood walls.

More energy is required to change the temperature of a building with high thermal mass. In the winter, this can be detrimental in an intermittently occupied building because of the increased energy required to reheat after unoccupied periods. However, there is a big advantage to thermal mass in the summer because it can help lower the peak temperatures. As discussed in Section 3.2, classrooms have high thermal gains and overheating is a serious issue. The correct use of thermal mass is integral to controlling summertime overheating in a naturally ventilated classroom.

If a classroom with a high thermal mass construction is ventilated at night-time to allow it to cool down then a proportion of the heat-gains during the day will go into warming up the material of the room surfaces. This leaves less heat to warm up the air in the room and results in lower ambient temperatures. In addition, the temperature of the room surfaces stays lower in a space with high thermal mass. This has the advantage of allowing occupants to lose heat by radiation to the cooler room surfaces. This radiant cooling effect has a significant influence on occupant comfort.

The beneficial effects of thermal mass are illustrated by reference to the cathedral and temporary office examples previously sited. In a school classroom, the most convenient ways of introducing thermal mass is to have an exposed, high density concrete soffit and/or exposed medium-high density blockwork walls. An exposed concrete soffit is the more effective solution because it gives a superior radiant cooling effect.

4.2 Acoustic Absorption

The typical classroom described in Section 3.1 has an area of 49.2m² and a volume of 137.8m³. The calculations and values in this section refer to this typical classroom geometry.

For a secondary school classroom, BB93 requires an unoccupied, unfurnished, mid-frequency reverberation time of T_{mf}=0.8s or less. If the classroom floor has 5mm thick carpet tiles on a raised wood floor, then approximately 15–18m² of additional acoustic absorption are required to meet the BB93 reverberation time. This absorption area assumes a good material with a high mid-frequency absorption (absorption coefficient, α>0.95) which could be achieved using a proprietary mineral wool ceiling tile. If a less effective absorber is used, a proportionally larger area will be required.

The required acoustic absorption is normally located on the walls or ceiling. The ceiling is often the favored location because lay-in grid mineral fibre ceiling tiles are cheap and can be used to conceal a services distribution void and a poor concrete finish. Ceiling tiles are also out of reach and therefore less likely to be damaged by the students.

The disadvantage of mineral fibre ceiling tiles and other porous absorbers is that they tend to be thermally insulating because of the air voids which are essential to the way they work. For example, mineral-fibre, blown glass and plastic foam based materials are all good thermal insulators. Even a continuous air void, which forms part of many acoustically absorbent build ups, including panel type absorbers, presents a significant amount of thermal resistance. Because of this thermal insulation effect, the acoustic absorption isolates (or decouples) the room from the effect of any thermal mass which is covered by the tiles or panels. For example, if a lay-in grid tile ceiling is installed below a structural concrete slab, the thermal mass of the slab has very little effect on the room conditions. The effective room height is also reduced (refer to Section 5).

4.3 Effect of Thermal mass on Temperatures

The calculations in this section refer to the typical classroom geometry described in Section 3.1 with assumptions as given in Table 2. The classroom is naturally ventilated via opening windows with an openable area of 5m² as described in Section 3.3. Windows are left 25% open at night in the summer months to give night-time cooling. As before, the calculations are based on the CIBSE test reference year weather data.

Two different classroom constructions are considered. The “high thermal mass” construction has medium density block walls and an exposed concrete soffit. The “low thermal mass” construction has stud walls (constructed with a double layer of 12.5mm plasterboard) and acoustic ceiling tiles 100mm below the concrete soffit. In both cases, the floor is assumed to be carpet on 25mm chipboard. Figure 8 shows the air temperature, Ta, and the dry resultant temperature, Tc, in the classroom for the two cases on 11th July (CIBSE test reference year). The dry resultant temperature is an average of the air temperature and the mean radiant temperature and therefore takes account of the radiant cooling effect from the room surfaces.

It can be seen that the inclusion of an acoustic ceiling results in dry resultant temperatures which are higher by more than 2°C. Comparison of the dry resultant temperature and the air temperature shows the importance of the radiant cooling effect.

Table 3 shows the total number of occupied hours for which the air temperature exceeds specified values. These values are clearly relevant when considering a natural ventilation strategy in regard to meeting the BB101 requirements for the avoidance of summertime overheating (refer to Section 2). However, it should be noted that the BB101 does not fully account for the cooling effect from thermal mass because it uses the air temperature rather than the dry resultant temperature.

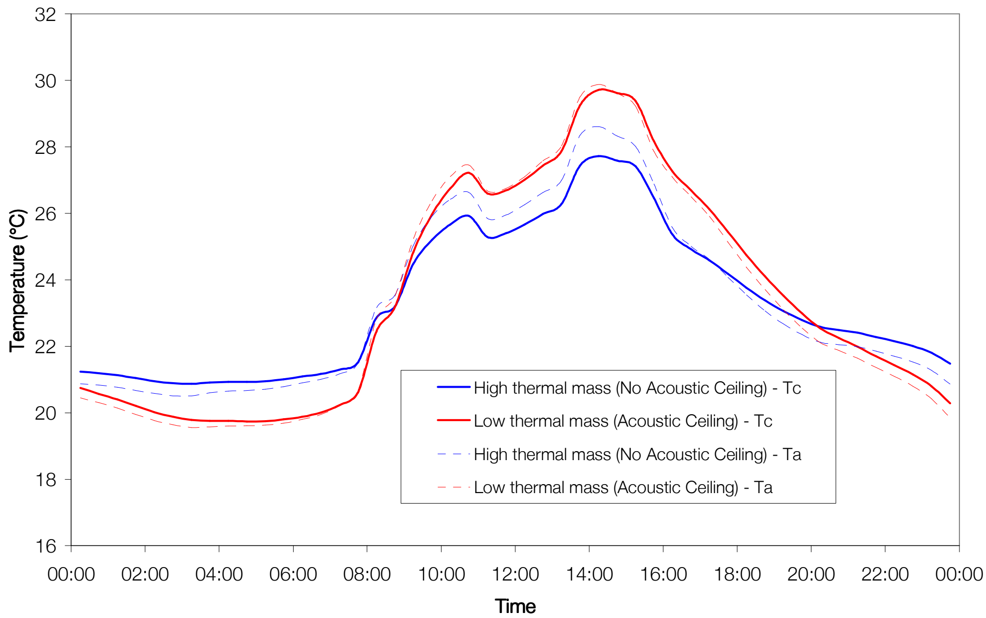

Figure 8: Indoor air temperatures in high and low thermal mass classrooms

	Occupied hours above temperature			
	> 26°C	> 28°C	> 30°C	> 32°C
Low thermal mass	48	16.5	4.5	2
High thermal mass	29.5	9	2.5	0

Table 3: Number of occupied hours for which stated air temperatures are exceeded

4.4 Combining Absorption and Thermal Mass

The use of thermal mass is integral to controlling summertime overheating in naturally ventilated classrooms. However, as discussed in the previous sections, indiscriminately applying acoustic absorption to the room surfaces can significantly reduce the effect of any available thermal mass.

One alternative is to use helmholtz absorbers which do not rely on a porous material or on an air gap and therefore do not necessarily have the same problem of being thermally insulating. For example, concrete blocks are available with slots connected to an internal cavity to give a helmholtz damped resonator effect. It is reported[16] that these blocks can give mid-frequency absorption coefficients in excess of α=0.6. Blocks of this type could give a good acoustic performance without compromising thermal mass.

Figure 9: Example of acoustic absorption suspended within the space

Another approach is to use porous acoustic absorbers but to suspend them within the space so as not to completely cover and thermally isolate the walls or ceiling. An example might be to suspend small panels of absorption below the soffit, possibly as part of a light fitting, by a distance which allows air flow behind the panel Alternatively, baffles or other absorbent items could suspended in the space. Some examples of this approach are shown in Figure 9. This approach has the additional advantage that all sides of the acoustic absorber are exposed, increasing the effective absorption area and reducing the amount of absorption material required. If panels are suspended below the soffit, it should always be taken into account that restricting the view of the soffit reduces the radiant cooling effect which, as discussed earlier, is just as important as maintaining airflow past the soffit.

5 REVERBERATION TIMES & ROOM HEIGHT

High floor to ceiling heights in classrooms give a series of benefits including more effective natural ventilation and better daylight penetration into the room. More daylight means less usage of electric lighting and therefore less energy use and carbon emissions. However, higher rooms lead to longer reverberation times making BB93 requirements harder to comply with.

5.1 Reverberation time

According to standard Sabine statistical acoustics, the reverberation time is proportional to volume and therefore, for a constant room area, to room height. Table 4 shows the approximate area of additional acoustic absorption which is required to meet the BB93 requirement of T_{mf}=0.8s in a 49.2m² classroom (as in Section 3.1) of various heights (using the same assumptions as in Section 4.2). High floor to ceiling heights are clearly not desirable from an acoustics point of view.

Room height [m]	2.2	2.8	3.4	4.0
Area of absorption [m²]	9	17	24	32
Area of absorption [%floor area]	18%	34%	49%	65%

Table 4: Area of acoustic absorption required to meet T_{mf}=0.8s for various room heights

5.2 Daylight

Daylight penetration to the back of the room is better for a high floor to ceiling height. Based on the typical secondary school classroom geometry described in Section 3.1, a computer simulation of daylight penetration has been carried out for four different floor to ceiling heights. The window sill is 1m above the ground in each case and the window head is 0.2m below the soffit. The modelling has been carried out using Radiance for IES<VE>[10]. All results correspond to a standard CIE (Commission Internationale de l'Eclairage) overcast sky i.e. diffuse light only, no direct sunlight.

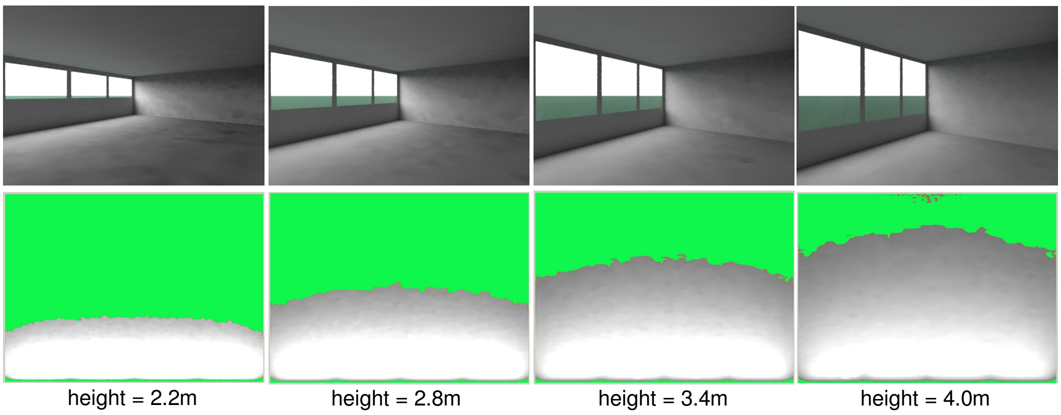

Figure 10: Daylight in classroom for various room heights. The top images show a rendering of surface luminances, the bottom images show a plan view of the working plane. The green area is that for which daylight is unacceptable for working and must be supplemented by electric lights.

It is clear from the results shown in Figure 10 that energy use for electric lighting will be higher for a low floor to ceiling height. Based on the data given in Figure 3 of the DfES BB87 spreadsheet[17], increasing the floor to ceiling height from 2.2m to 3.4m saves roughly 25kgCO_2/yr for the typical classroom. This amounts to roughly 0.3kgCO_2/m²/yr for the school as a whole or 1.5% of the overall AD L2A allowance.

5.3 Ventilation and Stratification

Having higher floor to ceiling heights improves the effectiveness of natural ventilation. For example, in single sided ventilation, increasing the height of a window from 1.6m to 2.2m reduces the size of the ventilation opening required to get 8l/s/person from $3m^2$ to $2.25m^2$.

Higher rooms also mean a greater potential for thermal stratification of air. Air at the top of the room is hotter than at occupancy level. Allowing more height above occupants for the warmer air means that air around occupants is cooler for a given average air temperature, improving comfort.

6 CONCLUSIONS

The examples presented in this paper illustrate that acoustic requirements for school classrooms can be at odds with achieving a low energy design. However, most of the problems presented can be “designed out” provided that the acoustic design input starts at a suitably early stage and is properly integrated with the design of the building as a whole.

All school buildings, and all individual classrooms are different and must be approached on a case-by-case basis. The discussions presented here are for a typical school classroom and cannot necessarily be applied universally. The aim for the acoustic consultant is to analyse and anticipate the types of issues highlighted. The aim of the rest of the design team is to take account of acoustic considerations at an early stage so that design conflicts can be avoided further down the line.

The focus in this paper has been the reduction of CO_2 emissions but the motivation for the development of a passive design can also be measured in terms of whole-life-costs. A low-energy, passive design results in low fuel bills, low maintenance costs and gives more robust and reliable operation over the life of the building. All measures taken to reduce CO_2 emissions are a step towards producing carbon neutral schools.

7 REFERENCES

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