DIPLOMA IN ACOUSTICS AND NOISE CONTROL

2024-2025 PROJECT REPORT[1]

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School of the Built Environment and Architecture

Institute of Acoustic Diploma Acoustics and Noise Control

Final project report

Impact of reverberation time and indoor ambient noise levels on acoustic comfort in school dining halls

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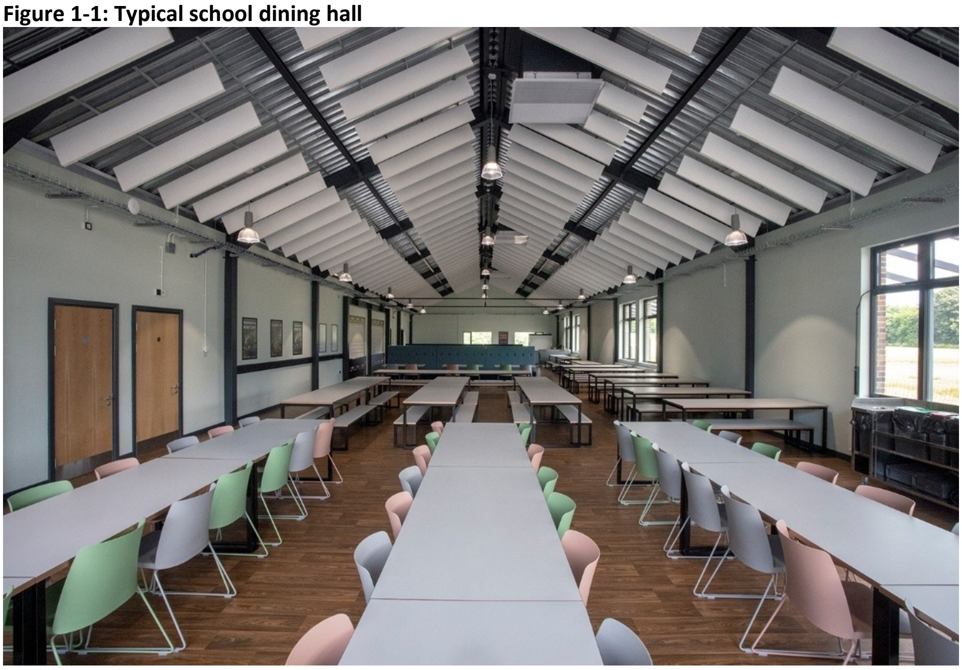
1 INTRODUCTION

Reverberation time and ambient noise levels are key metrics when considering room acoustics and can impact the perception of a space, as well as the ability of a user of the space to perform certain tasks. For example, reverberation time when poorly controlled can lead to decreased ability to comprehend and retain information (Klatte, Hellbrück, Seidel and Leistner, 2010). High ambient noise levels can also reduce speech intelligibility particularly for non-native speakers (Peng and Wang, 2019). Current research into the impact of room acoustics in schools is often focused on classrooms. Naturally, these spaces are important for student learning with good acoustic design playing a critical role in this. Students also spend a large portion of their time in these spaces and so their importance in research is undeniable.

However, dining halls are also a key space within schools for the social development of pupils and often double as multipurpose halls for sports, exams and assemblies. It is therefore important that good acoustic design is extended throughout the school building and not just limited to the classroom spaces. It shown that acoustic design can even have impact on food choices, with higher ambient noise levels being linked to unhealthier food choices (Biswas, Lund and Szocs, 2019). Therefore, where the overall health and wellbeing of the pupil is concerned, acoustics is inextricably linked.

This project then considers a relatively unresearched area of acoustics within school buildings and is expected to provide valuable insight into the experience of students within school dining halls. Furthermore, this research hopes to develop the understanding of how well current guidance documents aid in creating comfortable environments for students in school dining halls.

Figure 1-1: Typical school dining hall



1.1 Aims

This project aims to establish the current understanding of the impact of acoustics on student learning and wellbeing and relate this to relevant research on the impact of acoustics in dining establishments. This will then be used to consider the impact of reverberation time and ambient noise levels in school dining halls on the listening comfort of pupils by using several reported metrics by students. These metrics include perceived loudness and perceived annoyance due to the noise in the school dining hall as well as perceived speech intelligibility.

Furthermore, this project aims to focus on children who identify as being particularly sensitive to noise and their experience.

1.2 Objectives

- Review current literature to learn from the relevant state of the art research and knowledge to inform next objectives.
- Understand current standard of reverberation time and ambient noise level control within school dining halls through measurements in a variety of existing school dining halls.
- Understand the impact of reverberation time and ambient noise levels in school dining halls through the use of surveys completed by students and supplemented by staff observations to understand the experience of users in dining spaces and the operation and management of dining spaces to control noise.
- Compare results of surveys, reverberation time data and measured ambient noise levels with existing research and relevant guidance documents to understand the extent to which current design practices aid in achieving psychological comfort in school dining halls through acoustic design.
- Contrast and correlate the relationship between survey results with measurements of reverberation time and indoor ambient noise levels.

2 THEORETICAL REVIEW

2.1 Current standards

T_{60} reverberation time (RT) is defined as the time taken for a sound source to decrease to one millionth of its original value or equivalently decrease by 60 dB from the original noise level (Peters, Smith, and Hollins, 2012). This may not always be possible to measure due to high background noise levels or due to limitations in source noise levels. Therefore, T_{60} may be calculated by measuring either T_{20} or T_{30} , the time taken for the noise source to reduce by 20 dB or 30 dB respectively, and then multiplied by either 3 or 2 respectively to calculate the T_{60} (Peters, Smith, and Hollins, 2012).

This is a key metric when considering the acoustic properties of a room. This value is often calculated using the Sabine formula which is defined as below:

$$T = \frac{0.16V}{A}$$

Where V is the room volume in m^3 and A is the equivalent absorption where $A = S\alpha$ where S is the total surface area of the room in m^2 and α is the average absorption coefficient of the room. There are limitations on where the Sabine formula may be used, for example if one dimension of the room is significantly longer than the shortest dimension of the room, or acoustic absorption is unevenly distributed in the space, then the Sabine formula is likely to provide an inaccurate prediction of the reverberation time of the space (Peters, Smith, and Hollins, 2012).

For schools, indoor ambient noise levels (IANL) measure the equivalent noise levels from a 30 minute period in the relevant space. This includes noise ingress from external sources, building services noise, noise from ventilation in the space (including with windows open if the space is naturally ventilated), and actuator and damper noise (Daniels and Bodkin, 2015).

BB93 (Daniels and Bodkin, 2015), is the current guidance document that sets out criteria for the acoustic design of teaching and other educational spaces in the England and Wales. For dedicated dining halls, BB93 sets out a target of ≤ 1.0 s T_{mf} for new builds and ≤ 1.5 s T_{mf} for refurbishment. For multi-purpose halls, BB93 sets of a standard of 0.8-1.2 s T_{mf} for new builds and 0.8-1.5 s T_{mf} for refurbishments. T_{mf} is defined as the average reverberation time across the 500 Hz, 1 kHz and 2 kHz octave bands (Daniels and Bodkin, 2015). It is also stipulated that all measurements should be taken in finished, furnished, but unoccupied rooms.

BB93 also sets out targets for indoor ambient noise levels measured in $L_{Aeq,\ 30\ min}$ which for dedicated dining halls are 45 dB for new builds and 50 dB for refurbishments. For multipurpose halls the targets are 35 dB for new builds and 40 dB for refurbishments.

In the partner document to BB93, 'Acoustics of Schools: A design guide' (Canning et al, 2015) it is expressed how imperative it is that these spaces provide inclusive design such that all children may comfortably use the space. Following this principle, BB93 sets out more stringent criteria for classrooms which are specifically intended for use by children with special educational needs with lower indoor ambient noise level criteria and shorter reverberation time criteria. This principle is not however extended more widely across school buildings, with dining halls and multipurpose halls having the same criteria regardless of room volume, student cohort and any additional needs of the students.

Other countries such as Germany (Nocke, 2016), set out targets for absorption per volume rather than reverberation time specifically. For school dining rooms this is A/V ≥ 0.20, and an adjusted standard for inclusive listening needs in dining rooms also applies. In the Finnish standard (Finnish Standards Association, 2004), no specific reverberation time is set out for dining halls, but similar to BB93 there is improved speech intelligibility criteria set out for pupils with special education needs (SEN). Furthermore, the previous version of BB93 issued in 2003 (Daniels, Freemantle and Patel, 2003) included reverberation time requirements based on the room volume but was removed in the current version of BB93 issued in 2015 (Daniels and Bodkins, 2015).

Table 2-1 below summarises the current standards for school dining halls in England and Wales as set out by BB93 (Daniels and Bodkins, 2015).

Table 2-1: Summary of BB93 standards

BB93 Standard	Dedicated dining hall		Multi-purpose hall	
	New build	Refurbishment	New build	Refurbishment
RT (T_{mf}, s)	≤ 1.0	≤ 1.5	0.8-1.2	0.8-1.5
IANL ($L_{Aeq,\ 30\ min}$, dB)	45	50	35	40

2.2 Literature review

A study by Brännström et al. (2017) found that students reported corridors and dining halls in their school to be the spaces with the worst listening conditions. The study also indicated that children were most affected by noise when they were doing verbally demanding tasks. For example, trying to listen to a teacher rather than a classmate. The results also indicated that students with hearing sensitivities were more affected by this. The impact of poor acoustics on socialising should also not be underestimated. Therefore, considering a holistic approach to student development, it stands to reason that acoustic comfort in school dining halls should then be a high priority.

Research relating to the acoustic conditions in school dining halls specifically is limited, with a wealth of research on classroom acoustics that may be broadly extrapolated, however not specific to dining halls. Across many research papers it is demonstrated that long reverberation times and high ambient noise levels result in a more difficult listening environment for learning, particularly for non-native speakers and those with hearing sensitivities (Peng and Wang, 2019). Furthermore, research into the acoustic conditions in restaurants supports similar ideas in which well controlled ambient noise levels result in a more positive overall experience for the diners (Mistar, Sulaiman, and Che Din, 2020). The same study found that the density of diners and occupied noise levels were also key factors in determining the perceived acoustic comfort in restaurants. This concept is related to reverberation time through the concept of 'Acoustic capacity'.

'Acoustic capacity' is defined by Rindel (2012) as the maximum number of people in the space whilst maintaining reasonable conditions for conversation (assuming around 1 person is speaking for every 3-4 occupants).

This follows from the concept of the Lombard effect where multiple people speaking in a room can create a high occupancy noise level. This is due to the phenomenon when the ambient noise from the other people speaking causes others to raise their voices, leading in turn to a spiralling occupied noise level.

The following formula can then be used to estimate the acoustic capacity of a space:

$$N_{max} = \frac{V}{20T}$$

where V is the room volume in m^3, T is the reverberation time in seconds at mid frequencies (500 Hz and 1 kHz) and N_{max} is the suggested acoustic capacity for satisfactory conversation in social gatherings. If the acoustic capacity of the space is significantly exceeded it can result in an uncomfortable listening environment. This can be mitigated through means such as reducing the number of people talking in the space or using the hall at one time, or through reducing the reverberation time, or increasing the room volume. In this way, it is further demonstrated how key reverberation time is for dining spaces to control occupancy noise as well as maintain acoustic comfort.

Acoustic capacity is then linked to the occupancy noise levels by the Lombard effect. A study by Martellotta et al. (2024), investigated the occupancy noise levels during school lunch times across four schools in Italy. Averaged across the entire lunch time period, the recorded levels ranged from 81 dB up to 90 dB. These excessively high noise levels were noted as being a primary reason for children reporting short term hearing impairment, as well as feeling angry and irritated. Weekly noise exposure was also calculated and it was indicated that the adjusted limit of 75 dB for children as set out by the World Health Organisation (2018) may be exceeded in some cases.

T_{60} reverberation time is not the only metric that may be used to understand the acoustic properties of a space. Research by Chen and Kang (2004) indicates that Early Decay Time

(EDT), based on the first 10 dB of decay (Peters, Smith, and Hollins, 2012), is likely to be a better predictor of the experience of the user of a space than reverberation time. For example, they found that users of a shopping mall rated the ease of communication highest in the space with the lowest EDT despite having the longest RT of the spaces included in the survey. However, current building standards do not include EDT as a measurement parameter and have as such not been included in this research.

It is also noted that the shape as well as distribution of absorption in the school dining hall can have an impact on the reverberation time and overall experience of the space as a result. For example, Culling et al. (2020) demonstrated through the use of modelling that speech intelligibility in a restaurant style space is better where ceiling heights are higher. This is likely linked to the volume of the space increasing from higher ceilings and results in a higher acoustic capacity. Furthermore strategic placement of vertical acoustic absorption near diners was found to result in the best listening conditions.

It is also important to consider the experience of a wide variety of people within the space. For example, hearing aid users may also have difficulty due to transient noises such as plate scraping and furniture scraping which may result in discomfort due to the time lag for the gain to adjust on the hearing aid from transient noises (Mahmoud, Reichbach and Moore Brian, 2021). The impacts of acoustics are also felt by those with visual impairments. Mershon and King (1975) demonstrated that reverberation time is a key metric for those with visual impairments in understanding the size of a room, with higher reverberation times being associated with larger spaces. It has also been proposed that this feature may be used to help those with visual impairments understand virtual environments indicating the importance of room acoustics for all users (Andrade et al., 2021).

Students are also not the only users of the school dining halls. For example, a study by Kristiansen (2016) demonstrated the refurbishment of classrooms with acoustic absorption helped to reduce the reverberation time and by extension the activity noise level in the classrooms, resulting in teachers reporting less perceived exposure to noise and less disturbance by from classroom equipment noise such as projectors and smart boards. Similar studies regarding teachers' perception of noise in school dining halls could not be found.

It can therefore be seen that a variety of factors contribute to the experience of a space with reverberation time and ambient noise levels being identified as key metrics. However, importance is also placed on the individual experience, particularly for those with hearing sensitivities, hearing impairments and other additional needs. Furthermore, other factors such as placement of acoustic absorption and room height/volume, acoustic capacity and density of diners are identified as key factors for consideration of the overall experience of the hall.

3 METHODOLOGY

Following a review of current literature relating to the subjective perception of acoustic environments, such as the research conducted by Martellotta et al. (2024) and Chen and Kang (2004), a combination of objective and subjective measures were used to understand the current acoustic environment and how it is perceived.

Subjective measurements of the experience of students were collected through use of a survey and collection of objective measurements of the acoustic environment in the five schools were taken by measuring RT and IANL.

3.1 Surveys – Subjective metrics

For the subjective metrics, a questionnaire was given to students in each of the five schools. Ethical approval was sought and granted by the LSBU School of the Built Environment & Architecture Ethics Panel before schools were contacted to take part in the research.

The questionnaire asked about student sensitivity to noise, how comfortable they found the acoustic environment in their school dining hall, how easy they found it to have a conversation, the impact of the acoustics on their ability to enjoy their lunch, and how loud and how annoying they found the noise in the school dining hall. The above questions were multi-choice and on a 5-point scale with a neutral option.

At the end students were also presented with a range of statements which they were asked to tick if they felt the statement was accurate for them. These statements covered a range of positive and negative emotions such as feeling tired, irritated, annoyed, reenergised and calm due to the noise in the school dining hall. A copy of the survey can be found in Appendix A.

Where possible, questions were completed by a range of different aged students at each school in order to gain a broader understanding of the overall student experience. One secondary school was included in the surveys with the remaining four schools being primary schools.

Due to difficulties engaging schools in the surveys a variety of approaches for distributing the surveys was adopted. At schools 1, 3 and 4 the surveys were completely individually by students. At schools 2 and 5 pupils were surveyed in classrooms as a whole with each student raising their hand to indicate which answer they felt best suited them. Ideally, all surveys would have been completed in the same manner, however the effect of varying the survey method is considered small with students surveyed in classrooms encouraged to answer freely and without considering their peers responses.

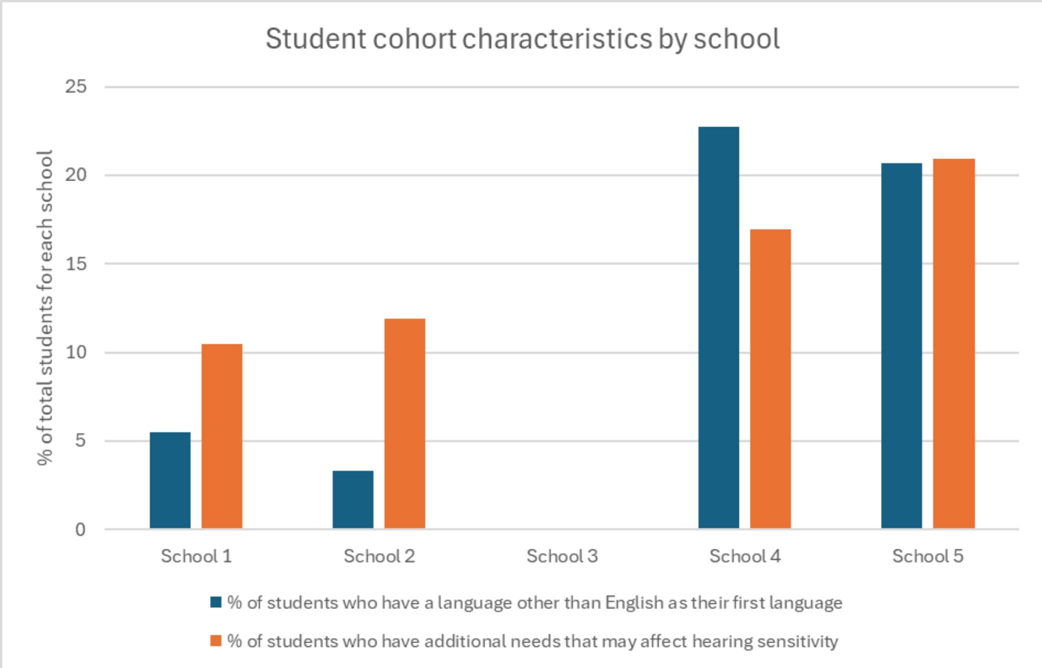
The schools involved in the surveys have been anonymised, however key metrics relating to the type of school and the age of children attending the school are presented below in Table 3-1.

Table 3-1: Basic school information summary

School no.	Age range	Type of Establishment	No. of pupils	Age of school building
1	5-11 (Primary)	Academy Converter	181	Opened in January 2025
2	5-11 (Primary)	Voluntary controlled school	151	Date unknown (but likely prior to introduction of BB93)
3	3-19 (Only junior school surveyed)	Other independent school	694	Date unknown (but likely prior to introduction of BB93)
4	11-18 (Secondary)	Voluntary aided school	2625	Exact date unknown. Dining hall built in late 1980s
5	7-11 (Primary school)	Community school	673	Refurbishment finished in January 2021

Information regarding the student cohort for each school is presented below in Figure 3-1. This information is summarised from the most recent Department for Education census (2025a and 2025b). The percentage of students who have a language other than English as their first language and SEN that may result in increased hearing sensitivities have been identified for each school. These include children with a specific learning difficulty (such as dyslexia and dyscalculia), those with social, emotional and mental health needs (SEMH, including AD/HD), those with special language and communication needs, those with hearing impairments, visual impairments and those with multi-sensory impairment and those with Autism spectrum disorder (ASD). These metrics have been considered as a whole to represent the portion of the student cohort who are most likely to experience difficulties due to poorly controlled acoustic conditions in their school, as defined by BB93 and other research (Greenland et al. ,2025).

Figure 3-1: Student cohort characteristics by school



School 3 is an independent school and as such no information was given in the DfE census data on the number of pupils who had a language other than English as their first language nor the number of pupils who received SEN support.

3.2 Objective measurements

To supplement the survey responses, RT measurements were also taken in each of the five school dining halls according to the precision method set out in BS ISO 3382-2:2008 in order to get an accurate understanding of the reverberation time in the halls (British Standards Institute, 2008). The ANC Good Practice Guide for acoustic testing in schools (2015) recommends this standard is adopted for reverberation time measurements in schools. This involved taking measurements in at least 12 independent microphone and source locations across the space.

Ambient noise level measurements were also taken in each of the school halls. These were all taken for the duration of 5 minutes. BB93 (Daniels and Bodkin, 2015) gives target indoor ambient noise level criteria based on $L_{Aeq,30\ mins}$. It is however also stated in the Good Practice Guide (2015) that if noise levels are noted to be consistent that $L_{Aeq,\ 5mins}$ levels can be considered representative of the full 30-minute period and used to determine the indoor ambient noise level of the space. In all schools, this approach was considered appropriate.

Finally, through comparison of the findings of the survey, the reverberation time data and indoor ambient noise levels potential correlations have been analysed. The measured acoustic data and their relation to current standards in BB93 as summarised in Table 2-1 have also been considered.

3.3 School 1

School 1 is a primary academy school. Children surveyed in this school were from the Year R class as well as Year 4 with a total of 56 respondents.

The finishes in the hall were vinyl flooring, partial coverage of ceiling tiles which were confirmed to be Class A and painted plaster walls. There is limited glazing on the walls as well as some acoustic wall panels (approximately 44 m^2 of Class A) at high level. The dimensions of the hall were 11.8 m by 15.3 m by 6.0 m high (room volume 1083 m^3). Existing finishes are illustrated in Figure 3-2.

The hall is used by the school for dining, PE, performance and assemblies.

Figure 3-2: Finishes in School 1

3.4 School 2

School 2 is a primary school. Children surveyed in this school were from Years 3 to 6 with a total of 84 respondents.

The finishes of the school hall were timber flooring with acoustic Class C ceiling tile and painted plaster walls. There was no acoustic wall panels in the hall. The dimensions of the hall are 11.5

m by 14.2 m by 4.5 m high (room volume of 735 m^3). Pictures of the existing finishes are shown in Figure 3-3.

The hall is used by the school for dining, PE, performance and assemblies.

Figure 3-3: Finishes at School 2

3.5 School 3

School 3 is an independent school with separate junior and senior school buildings, however only the junior school was involved in the survey. Children surveyed in this school were from the Year 3 to Year 6 with a total of 69 respondents.

The finishes in the hall were wooden floor with sound absorbent ceiling tiles and painted plaster walls. The long walls of the halls had significant portions of glazing with light weight blinds. The hall has dimensions 7.2 m by 12.9 m by 3.8 m high (room volume of 439 m^3). The hall also has a stage which has dimensions 7.2 m by 4.0 m by 3.0 m high (from stage floor to ceiling). Existing finishes are shown in Figure 3-4.

The hall is used by the school for dining, assemblies and musical performances.

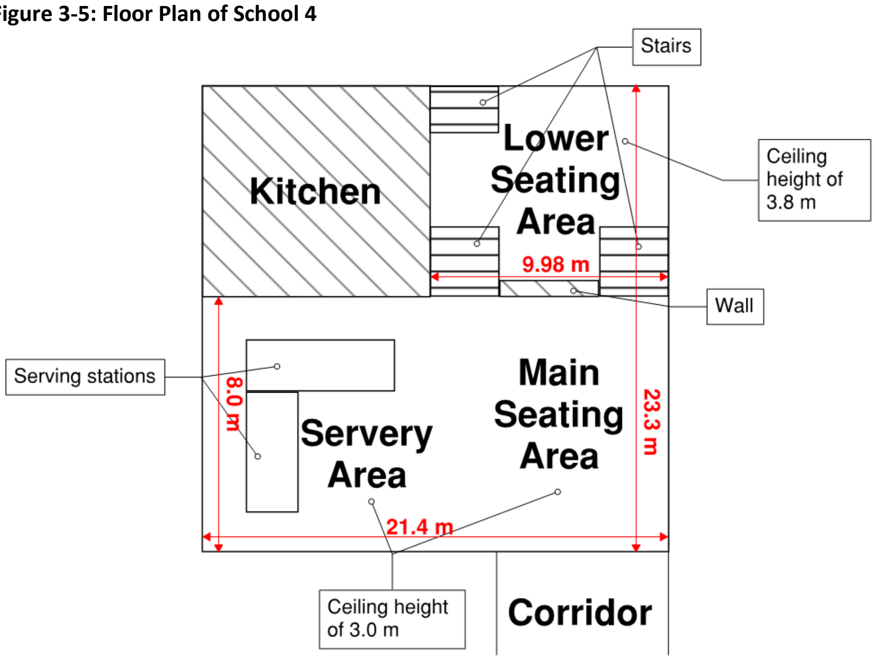
Figure 3-4: Finishes in School 3

3.6 School 4

School 4 is a secondary school. Children surveyed in this school were from Year 7 to 9 with a total of 29 respondents.

The hall had dimensions as shown below in Figure 3-5 and had a total room volume is 847 m^3.

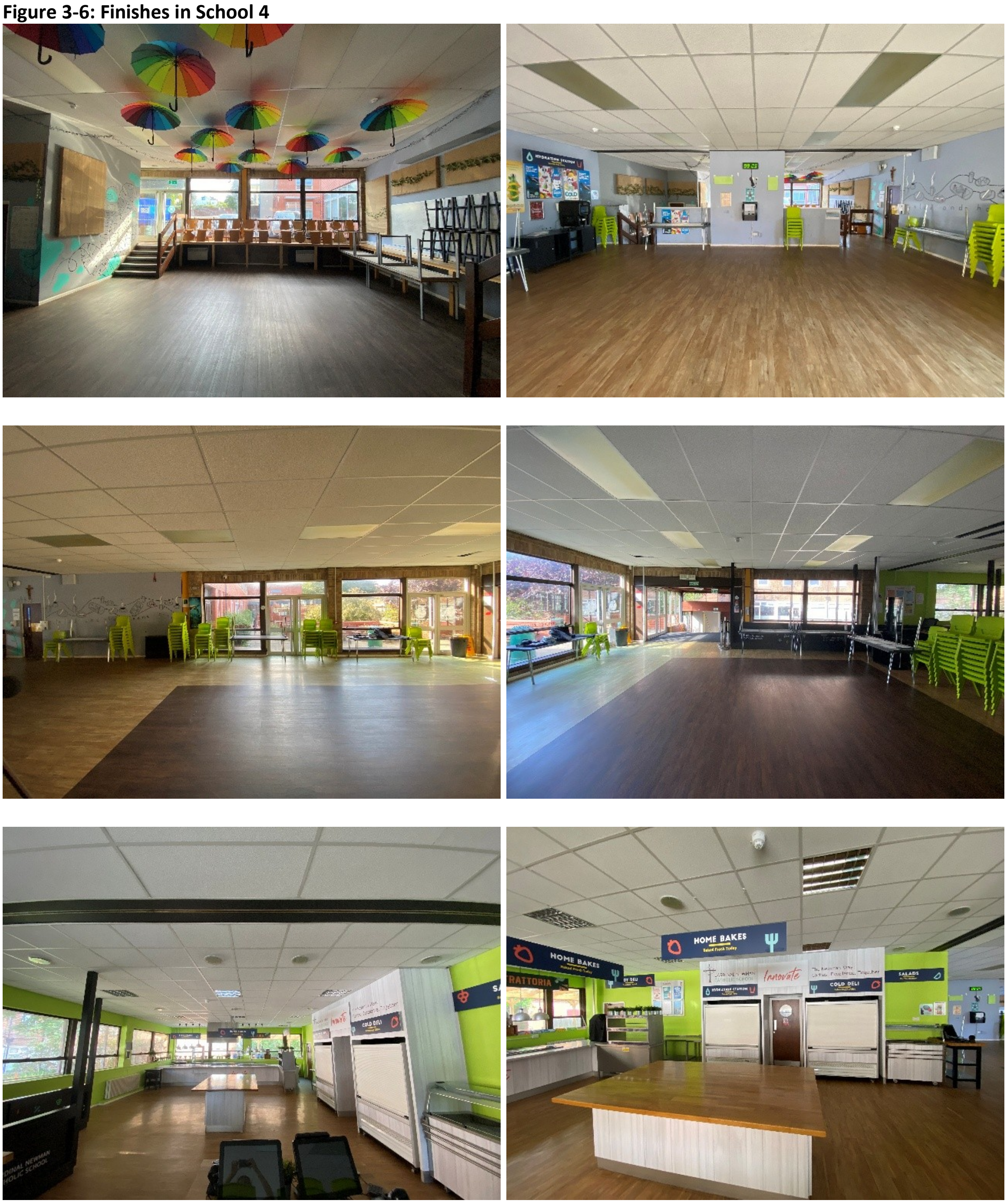
Figure 3-5: Floor Plan of School 4



The finishes in the space were vinyl floor with ceiling tiles and painted plaster walls. There was some acoustic wall panelling in place. However, it appears to be old and has been re-covered with an open weave fabric. Existing finishes are shown in Figure 3-6.

The dining hall is solely used for dining during lunch and break time, with an open plan canteen and servery in the space. It is noted that there are multiple dining spaces in this school, however this is understood to be the main space.

Figure 3-6: Finishes in School 4



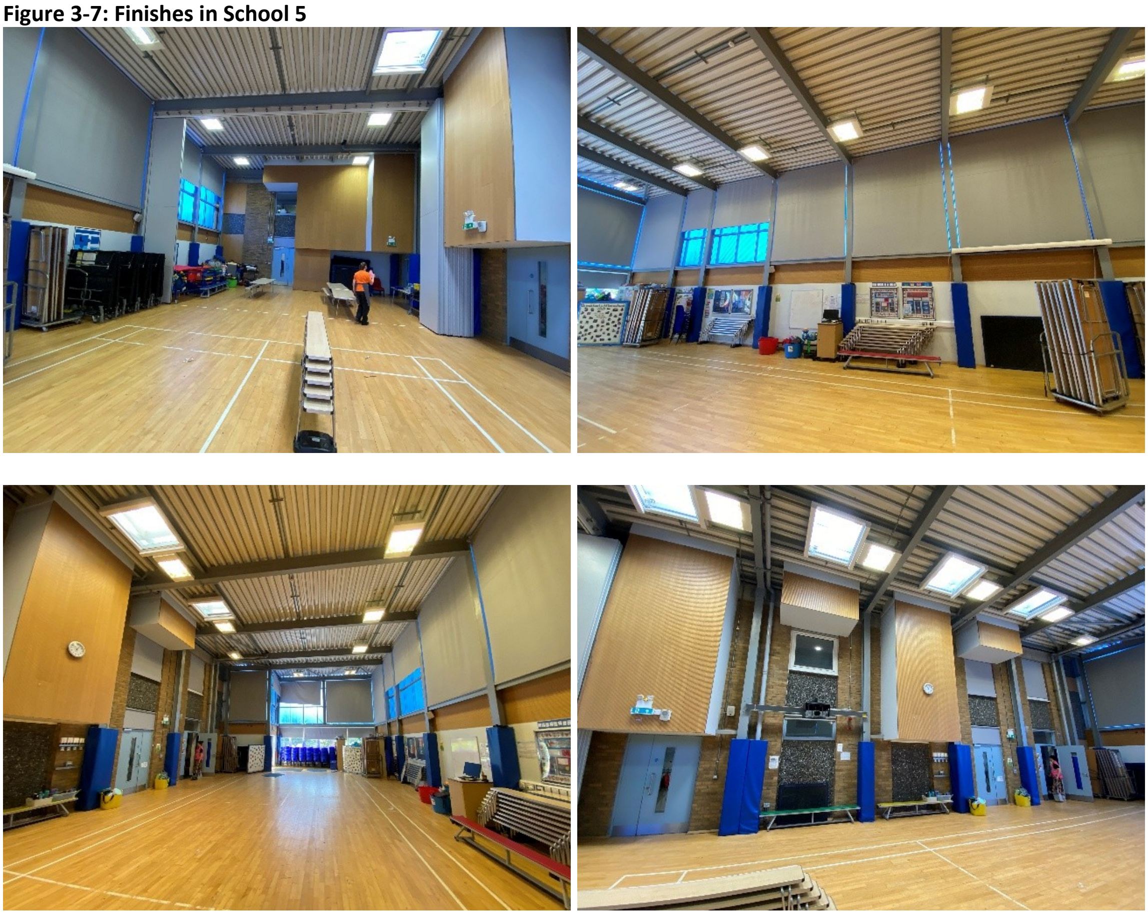
3.7 School 5

School 5 is a primary school. Children surveyed in this school were from Year 4 to 5 with a total of 75 respondents.

The hall has dimensions of 27 .0 m by 9.7 m by 6.5 m high (room volume of 1702 m^3). The finishes in the space were wooden floors with a corrugated metal roof. The hall appears to be an extension with 2 walls of the hall being mainly fair faced unpainted brick forming the original external wall. The extension external walls are painted plaster with significant portions of glazing, covered by blinds. There is also a large extent of timber battens which are presumed to offer some limited acoustic absorption. There are also some roof lanterns. Pictures of the existing finishes are shown in Figure 3-7.

The school hall is a multi-purpose hall that is as a dining room, assembly hall as well as for P.E.

Figure 3-7: Finishes in School 5



3.8 School Summary

The key characteristics of each school dining hall are displayed below in Table 3-2.

Table 3-2: School dining hall finishes

School no.	Type of hall	Volume (m^3)	Floor Finishes	Ceiling finishes	Wall finishes	Wall panels	Additional finishes
1	Multi-purpose	1083	Vinyl	Partial coverage Class A ceiling tiles	Painted plaster	44 m^2 Class A	Limited PE equipment
2	Multi-purpose	735	Wooden	Class C ceiling tiles	Painted plaster	None	Large drapes at one end of the hall with stacked dining chairs and tables
3	Multi-purpose	439	Wooden	Ceiling tiles	Painted plaster with significant portions of glazing	None	Lightweight blinds with curtains also around the stage
4	Dedicated dining hall	847	Vinyl	Ceiling tiles	Painted plaster with large extent of glazing	Limited wall panels that appear to be old and have been recover in the lower dining area	Stacked dining tables and chairs
5	Multi-purpose	1702	Wooden	Corrugated metal	Fair faced unpainted bricks and painted plaster with large extent of windows	Some timber battens	Lightweight blinds, dining tables and chairs with limited PE equipment

4 RESULTS

The overall results from both the acoustic measurements and surveys are presented below with a further break down of the results to each school given thereafter.

4.1 Acoustic Measurements

A summary of the measured reverberation time and indoor ambient noise levels are presented below in Table 4-1 below.

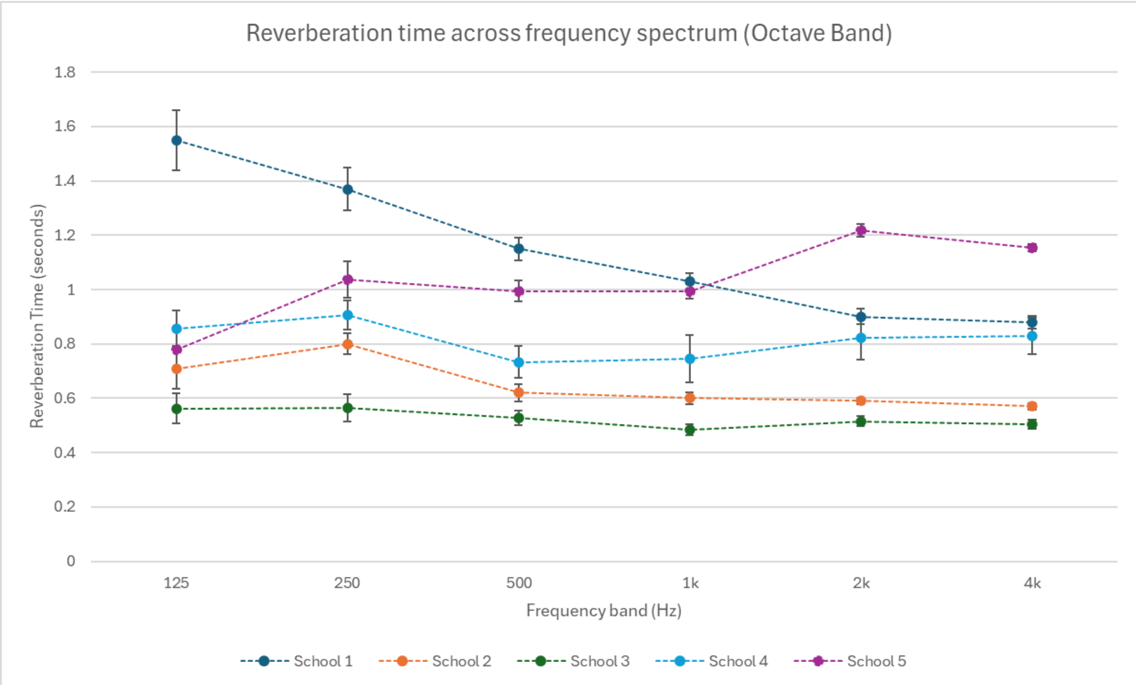
Table 4-1: Acoustic measurements summary

School no.	Volume (m^3)	Measured T_{mf} (s)	BB93 compliant?	Measured $L_{Aeq,\,5min}$, dB	BB93 compliant?
1	1083	1.03	Yes (multi-purpose hall)	35.3	Yes (rounding down to 35 dB for newbuild multi-purpose hall)
2	735	0.60	Yes (multi-purpose hall)	23.5	Yes (multi-purpose hall)
3	439	0.51	Yes (multi-purpose hall)	31.5	Yes (multi-purpose hall)
4	847	0.77	Yes (dining hall)	27.9	Yes (dining hall)
5	1702	1.07	Yes (multi-purpose hall)	36.7	Yes (refurbished multi-purpose hall)

4.2 Reverberation time measurements

The measured octave band reverberation times in each of the school dining halls are presented below in Figure 4-1. As per BS ISO 3382-2:2008, these measurements have been presented from 125 Hz to 4 kHz (British Standards Institute, 2008). Tabulated data is available in Appendix B.

Figure 4-1: Measured reverberation time for each school



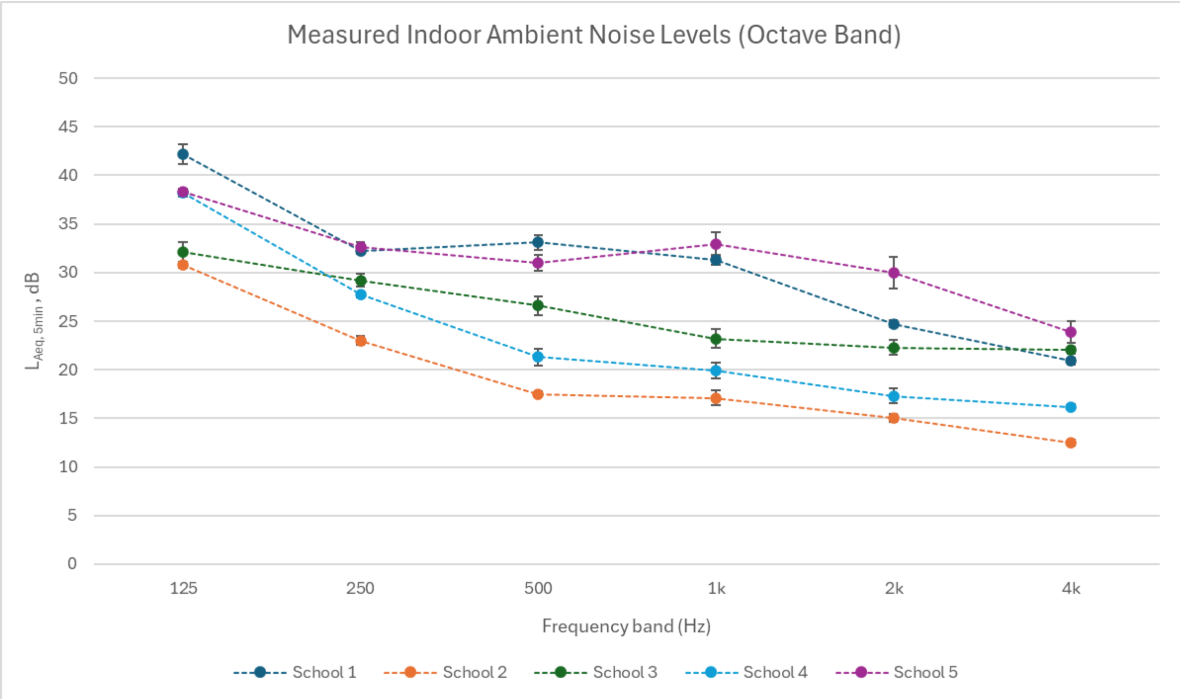
It is noted that the frequency distribution of the reverberation time measurements varies considerably across the schools. School 1 displays a significant skew towards longer reverberation times at the low frequencies, steadily decreasing as the frequencies increase. Conversely, School 5 shows the opposite, with the higher frequencies having a longer measured reverberation times high frequencies. Schools 2, 3 and 4 show comparatively flat frequency distributions with Schools 2 and 3 both exhibiting a slight peak at 250 Hz.

Overall, the lowest measured reverberation time was in School 3 and the highest was in School 5.

4.3 Indoor ambient noise level measurements

The measured octave band indoor ambient noise levels in each of the school dining halls are presented below in Figure 4-2. Tabulated data is available in Appendix B.

Figure 4-2: Measured Indoor Ambient Noise Level for each school



It can be seen that generally the frequency distribution across all the measured indoor ambient levels was relatively similar with a slightly higher concentration in the lower frequencies and steadily decreasing up to the higher frequencies at 4 kHz.

It is noted that the schools had different ventilation strategies however all seemed to control ambient noise levels sufficiently. All measured indoor ambient noise levels were well below the new build standard of 45 dB for a dedicated dining hall for a new build. Most schools were also below the new build standard for a multipurpose hall of 35 dB, with only School 1 slightly exceeding at 35.3 dB and School 5 at 36.7 dB. However, all schools achieve the refurbishment standard for a multipurpose hall of 40 dB.

The lowest recorded ambient noise level was at School 2 and the highest was at School 5.

4.4 Survey Results

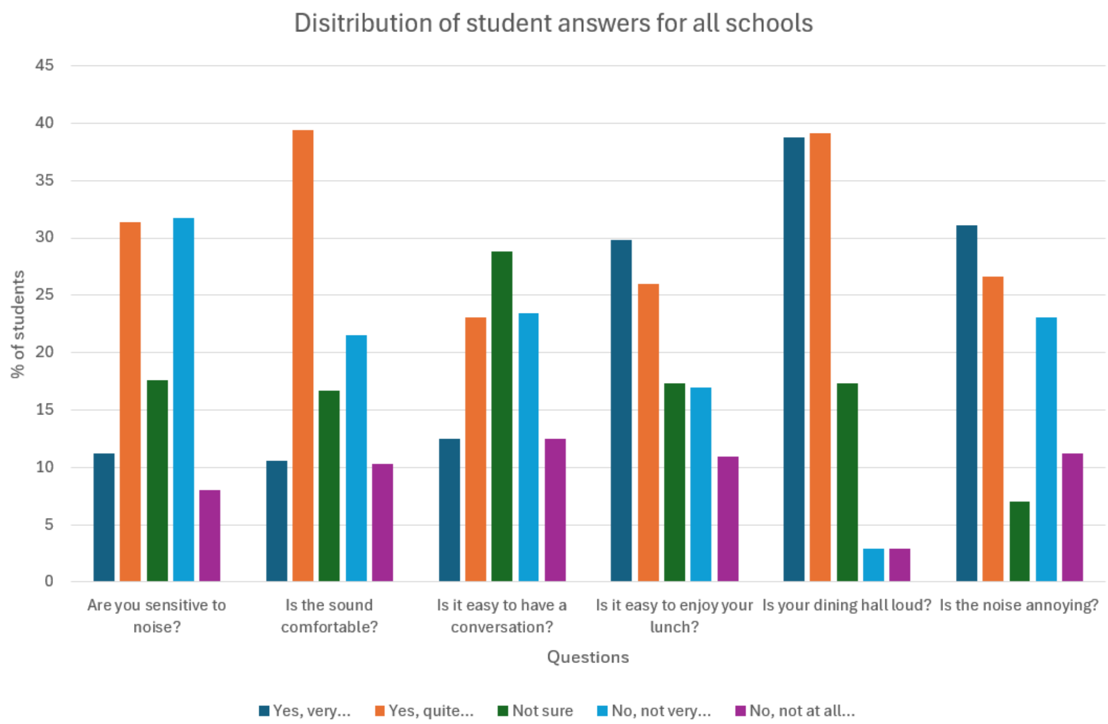
In total 313 pupils were surveyed across five schools. Overall, questions with the highest percentage of negative responses were for loudness and annoyance. With 78% of students saying they either found it “Too Loud” or “Quite Loud” and 58% of students saying they found the noise level in dining halls either “Quite Annoying” or “Very Annoying”. More students said they found the sound environment in their school dining hall to be either “Very” or “Quite comfortable” (50%) vs “Very” or “Quite uncomfortable” (36%). Equal numbers of students said they found it difficult or easy to have a conversation in their school dining hall with 36% answering either way. Over half (56%) said that the acoustics in their school dining hall had no or very little impact on their ability to enjoy their lunch.

25% of students said they found it difficult to concentrate in class after lunch due to the noise in their school dining hall. 21% and 20% respectively said that the noise in their school dining hall made them feel overwhelmed and tired. Only 6% said they felt that the noise in their school dining hall helped them to feel calm and 10% said it helped them to feel recharged.

The survey responses indicate that perceived high noise levels and annoyance as a result of this are the most prominently experienced impacts of the overall acoustics in school dining halls. Students were relatively spread over the possible responses for their general sensitivity to noise with 43% of students reporting they were either “Not at all” or “Not Very” sensitive to noise and 40% reporting they were either “Very Sensitive” or “Quite Sensitive”. The data suggests that while some students do currently enjoy the noise environment within their school dining halls, that more pupils struggle with the noise results in difficulties in coping with the rest of the school day.

Figure 4-3 below summarises the results across all schools surveyed.

Figure 4-3: Distribution of student survey answers across all schools



A further break down of the survey results and measurements from each school is presented below.

4.5 School 1 Results

The hall had a measured T_{mf} of 1.03 s which is within the target of 0.8-1.2 seconds T_{mf} for a new build multi-purpose hall.

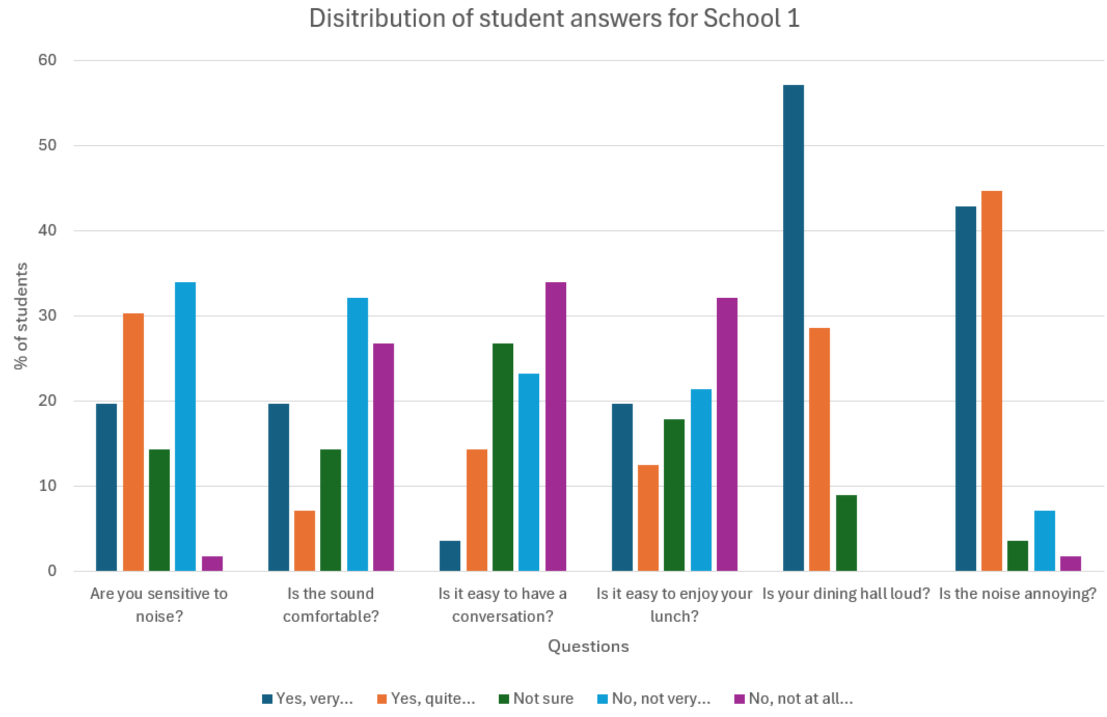
The ambient noise level was measured to be 35.3 dB $L_{Aeq,\ 5min}$ with the sound environment largely dominated by noise from the mechanical ventilation in the hall and distant traffic noise.

This school had the highest percentage of students (20%) reporting to be “Very Sensitive” to noise with the second highest overall reverberation time and highest reverberation time at low frequencies. It also had the joint highest percentage of pupils reporting that the noise in their school dining hall was “Too Loud” alongside School 2. It also had the highest number of pupils saying the noise was “Very Uncomfortable”, that it was “Very difficult to have a conversation”, that it was very difficult to enjoy their lunch and that they found the noise to be “Very Annoying”. No students in this school reported that the noise was “Too Quiet”.

The school census data indicates that 6% of pupils had a language other than English as their first language and 11% of pupils had additional needs that may result in an increased sensitivity to noise. For both metrics this is on the lower end of the spectrum for the schools included in the survey, but not the lowest.

In the free response section of the surveys, some students (5%) noted being scared by the noise in the halls. Others reported getting headaches due to the noise in the hall (3%) and that the noise levels hurt their ears (7%). Furthermore one child also reported covering their ears to try to shield themselves from the noise. Figure 4-4 summarises the survey results for School 1.

Figure 4-4: Distribution of student survey answers for School 1



4.6 School 2 Results

The hall had a measured T_{mf} of 0.60 s which is below the target range of 0.8-1.2 s T_{mf} for a new build school multipurpose hall.

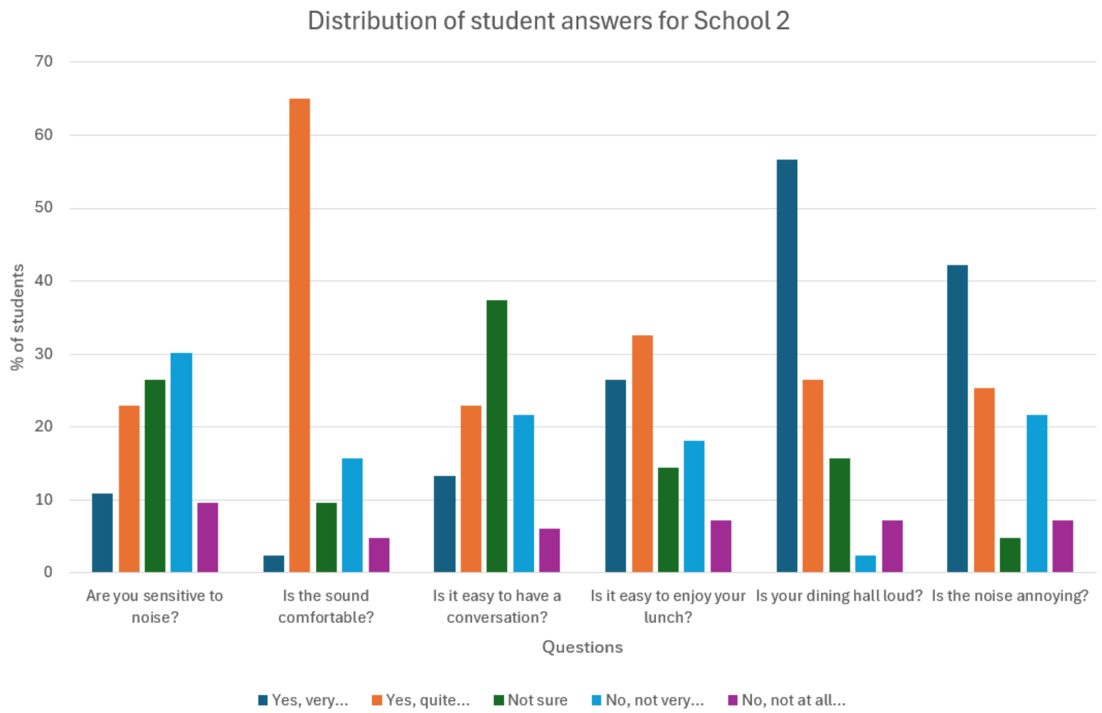
The ambient noise level was measured to be 23.5 dB $L_{Aeq, 5min}$, which is comfortably below the target of 35 dB. No dominant noise sources were identified in this hall other than the ticking of a clock.

This school was joint highest in percentage of pupils reporting the noise in the school hall as being "Too Loud" with School 1 despite having a significantly lower overall reverberation time.

The school census data indicates of the schools surveyed this school had the lowest percentage of students with English as a second language at only 3% and had 12% of students with additional needs that may result in hearing sensitivities which is the median of all schools surveyed.

No free responses were collected for surveys from this school. Figure 4-5 summarises the survey results for School 2.

Figure 4-5: Distribution of student survey answers for School 2



4.7 School 3 Results

The hall had a measured T_{mf} of 0.51 s which is below the target range of 0.8-1.2 s T_{mf} for a new build school multipurpose hall. This school had the lowest measured reverberation time of those included in the survey.

The ambient noise level was measured to be 31.5 dB $L_{Aeq, 5min}$, which is below the target of 35 dB. The sound environment was largely dominated by noise from the mechanical ventilation in the hall, distant traffic noise, and a ticking clock in the hall.

This school had the highest percentage of pupils reporting they found the acoustic environment to be "Very Comfortable" as well as the highest percentage of pupils who found it "Very easy" to have a conversation and that the noise in the school hall had no impact on their ability to enjoy their lunch. This school also had the lowest percentage of pupils reporting to be "Very sensitive" to noise at only 3% and the lowest percentage saying the noise was "Too Loud" at only 4%. They also had the lowest percentage of pupils saying they were "Very uncomfortable" with the sound in their school dining hall, the lowest percentage who found it "Very difficult" to have a conversation, "Very difficult" to enjoy their lunch and who were "Very Annoyed" by the sound in their school dining hall.

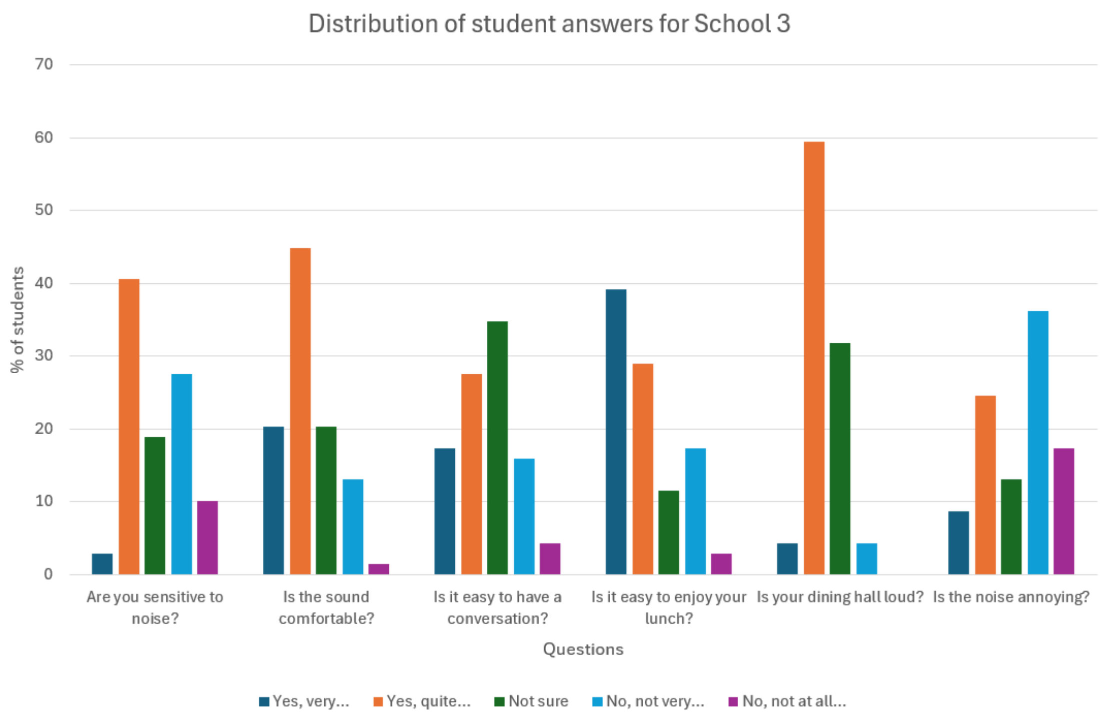
There was no census data for this school to indicate the number of students with additional needs that may make them more sensitive to noise or who had English as a foreign language.

In the free response section of the surveys from this school the majority of students reported neutral feelings about the noise in the school hall. However, one student reported covering their ears to shield themselves from the noise and being unable to eat their lunch as a result. Others reported feeling frustrated, overwhelmed and annoyed. Four students also reported frustration over being unable to communicate with friends due to the noise, or having to shout in order to do so which was reprimanded by staff. Three students also reported getting headaches due to the noise with one student reporting getting ringing in their ears due to the noise for the rest of the day. Three students reported positive emotions about the noise saying it helped them to feel alert and energised.

The negative free responses for this school were unexpected due to the low ambient noise levels and shortest measured reverberation time and overall more positive responses in the rest of the survey. Some students said they would like to eat in a quieter room so these responses may be a result of students who are particularly sensitive to noise eating in the main dining hall.

Figure 4-6 summarises the survey results for School 3.

Figure 4-6: Distribution of student survey answers for School 3



4.8 School 4 Results

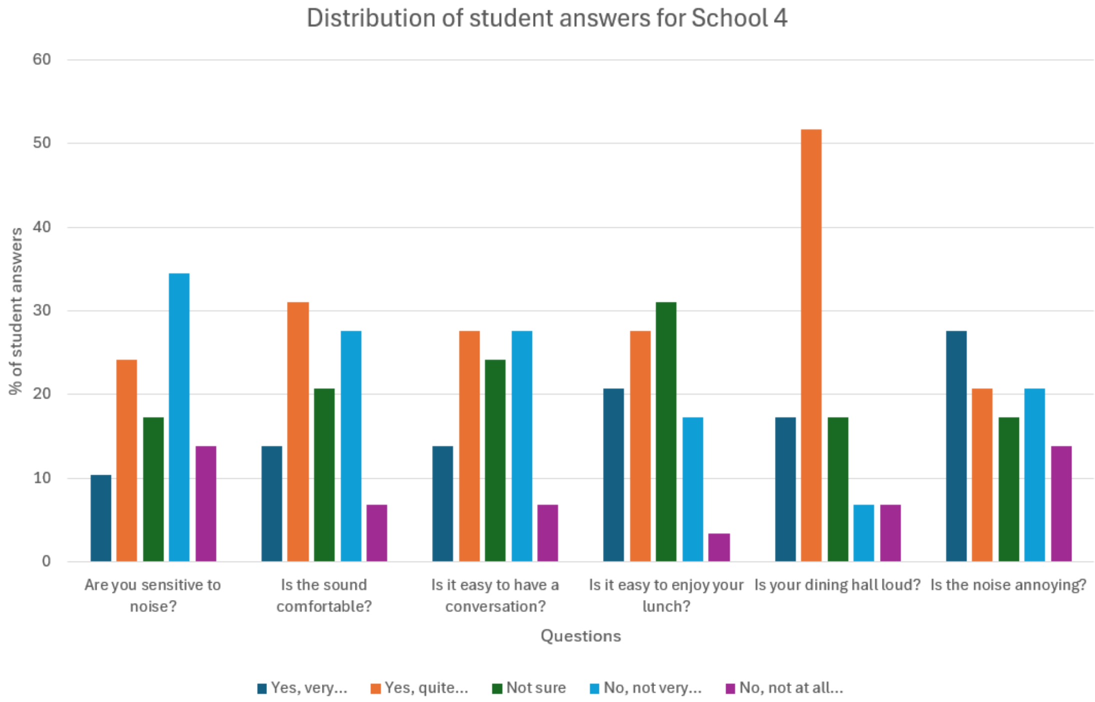
The dining hall had a measured reverberation time of 0.77 s T_{mf} which is comfortably below the target of 1.0 s T_{mf} for a new build school dining hall.

The ambient noise level was measured to be 27.9 dB $L_{Aeq,\ 5min}$, which is below the target of 35 dB. The sound environment was largely dominated by noise from the fridges in the servery area and distant traffic noise.

This school had the highest percentage of students who reported being “Not at all sensitive” to noise (14%). It is noted that this was the only secondary school included in the surveys so the association may lie within the age range of the pupils surveyed. This school also had the highest percentage of pupils with English as a foreign language according to census data. There is no strong indication that the slightly higher proportion of students with English as a foreign language resulted in more students finding it difficult to communicate in their school dining hall.

Limited free responses were given for this school, however all indicated neutral feelings about the noise in their school dining hall. Figure 4-7 summarises the survey results for School 4.

Figure 4-7: Distribution of student survey answers for School 4



4.9 School 5 Results

The hall had a measured T_{mf} of 1.07 s which is within the target range of 0.8-1.2 s T_{mf} for a new build school multipurpose hall. This school had the longest measured reverberation time of the schools included in the survey. This school had the largest room volume of those surveyed.

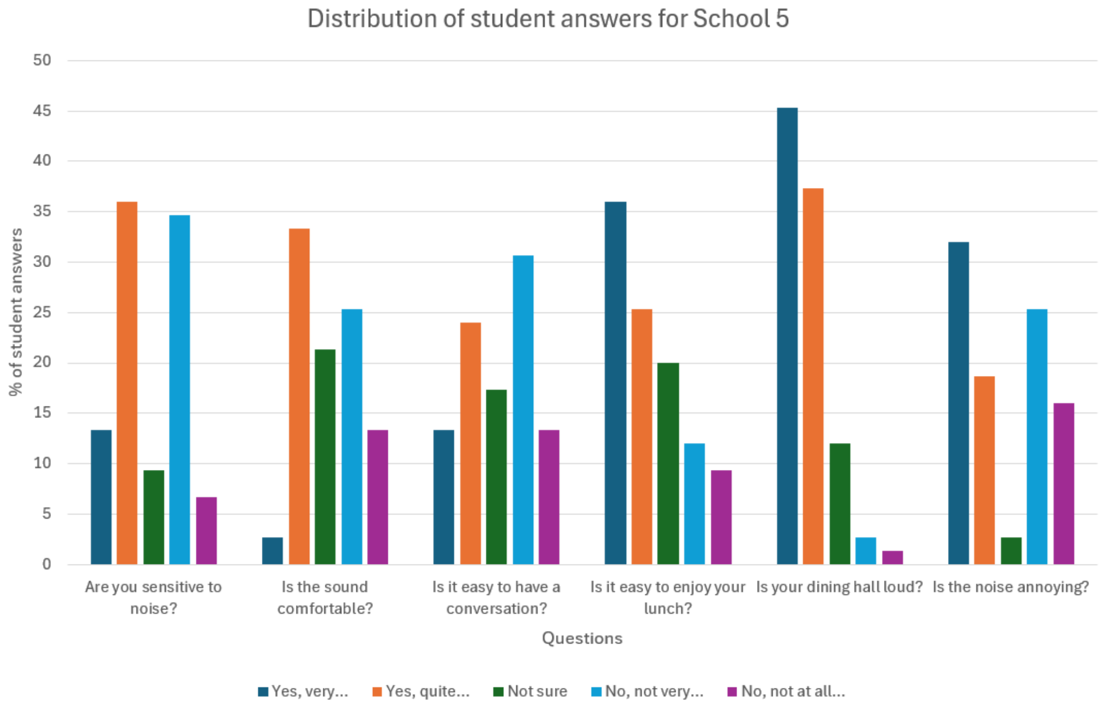
The ambient noise level was measured to be 36.7 dB $L_{Aeq,\ 5min}$, which is slightly above the target of 35 dB for a new build, but below the target of 40 dB for a refurbishment. The sound environment was largely dominated by noise from children playing in the playground directly outside the hall. It was noted that some of the roof lanterns were slightly ajar, however they could not be closed at the time of the visit. Other noise sources included distant traffic noise and occasional noise for aircraft overhead. It is therefore assumed that excluding the playground noise as required for true ambient noise measurement, that the hall would achieve the target indoor ambient noise for a new build.

This school had the highest number of pupils who reported feeling tired, irritated, overwhelmed and who found it difficult to concentrate in class after lunch due to the noise. However, this school also had the highest percentage of students who reported feeling recharged due to the sound in their school hall and who reported it helping them to enjoy their lunch. As these surveys were conducted in person, it was noted that almost all of the respondents for the latter two metrics mentioned (feeling recharged and the sound helping them to enjoy their lunch) were boys (approximately 14 in total) with very few girls (approximately 3 in total) agreeing with these statements.

School 5 had the highest percentage of pupils who had special hearing and communication needs according to the census data. This combined with a longer reverberation and higher ambient noise levels may be attributed to the high proportion of students reporting to find the noise in their school dining hall to be "Too Loud" (45%).

Figure 4-8 summarises the survey results for School 5.

Figure 4-8: Distribution of student survey answers for School 5

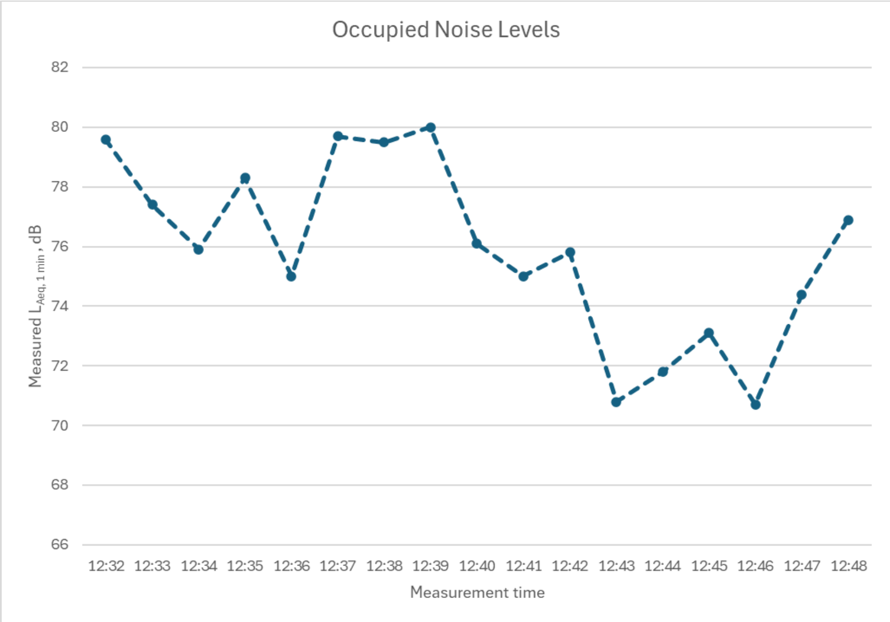


Informal feedback also indicated that teachers struggled with the occupied noise in the school dining hall.

To supplement the ambient noise level and reverberation time measurements, occupied noise levels were also taken at this school. It is noted that measurements were taken shortly before the school broke up for the summer holidays, when more pupils were opting to eat outside due to the warm weather. It is therefore understood that measured occupied noise levels may be lower than during winter months where more pupils may eat inside the hall. Measurements were taken from when lunch was underway to the end of the lunch time period as pupils left the hall to play outside. Overall, the noise environment was dominated by conversational noise from the children in the hall with some noise from plate scraping, chairs scraping on the floor and staff folding up tables as pupils emptied the hall. The highest record one minute period was at 12:39 and was 80 dB $L_{Aeq,\,1min}$. The overall occupied noise level for the entire measurement duration was 76.8 dB $L_{Aeq,\ 15min}$. Excluding the period at the end from 12:41 onwards (where a large number of children had left the hall) the typical noise level increased to 78.3 dB $L_{Aeq,\ 5min}$.

Considering measured noise levels may be lower than when the hall is fully occupied, this indicates that noise levels are very high and comparable to those measured by Martellotta et al. (2024). Furthermore, BS 8233: 2014 states that the maximum noise level for reliable communication between speakers with raised voices at 1 m is 62 dBA. It is therefore concluded that these occupied noise levels are likely to result in severe communication difficulties between pupils.

Figure 4-9: Occupied noise levels



4.10 Further Survey Results

An additional survey was also taken through the Teacher Tapp app. This research tool which sends short questions via an app push notification every day to large numbers of teachers across England (Teacher Tapp, 2024). The following question was presented with answers anonymously completed by 9,560 participants.

What measures do you adopt to help students with noise in the school dining hall? (Tick all that apply)

- Fixed sound absorption in the hall (eg wall panels or ceiling tiles)
- Ear defenders for students who are most affected
- A separate indoor room for students who are most affected
- Outdoor dining spaces
- Behavioural supervision to keep noise levels to a minimum in the hall
- We don't have any problems with noise in the dining hall
- Not applicable / can't answer

The most commonly reported solution to manage noise was staff supervision to keep noise levels in the hall to a minimum (58% of respondents, 5506 respondents).

Other more commonly reported methods were providing ear defenders for some children (43%, 4100 respondents), providing a quiet room for some children (37%, 3556 respondents) and providing outdoor eating spaces (30%, 2860 respondents).

Only 6% of teachers (529 respondents) reported having sound absorbent finishes in their hall to help with reducing the noise buildup . However, it is noted that some teachers may not be fully aware of sound absorbent finishes in the space even if they are present.

Only 9% of teachers responded saying they had no issues with noise in the school dining hall indicating the ubiquity of this problem across schools in the UK.

This was particularly true of primary schools with only 5% of primary school teachers saying they had no problem with noise, but 14% of secondary school teachers reporting the same. This indicates that primary schools are likely to be more affected by noise in dining spaces.

Results from the survey indicated similar distribution across different regions of the country. School size also had limited impact on the reported answers, with smaller schools reporting not having a problem with noise in their school dining halls (11%) only slightly more than larger schools (8%).

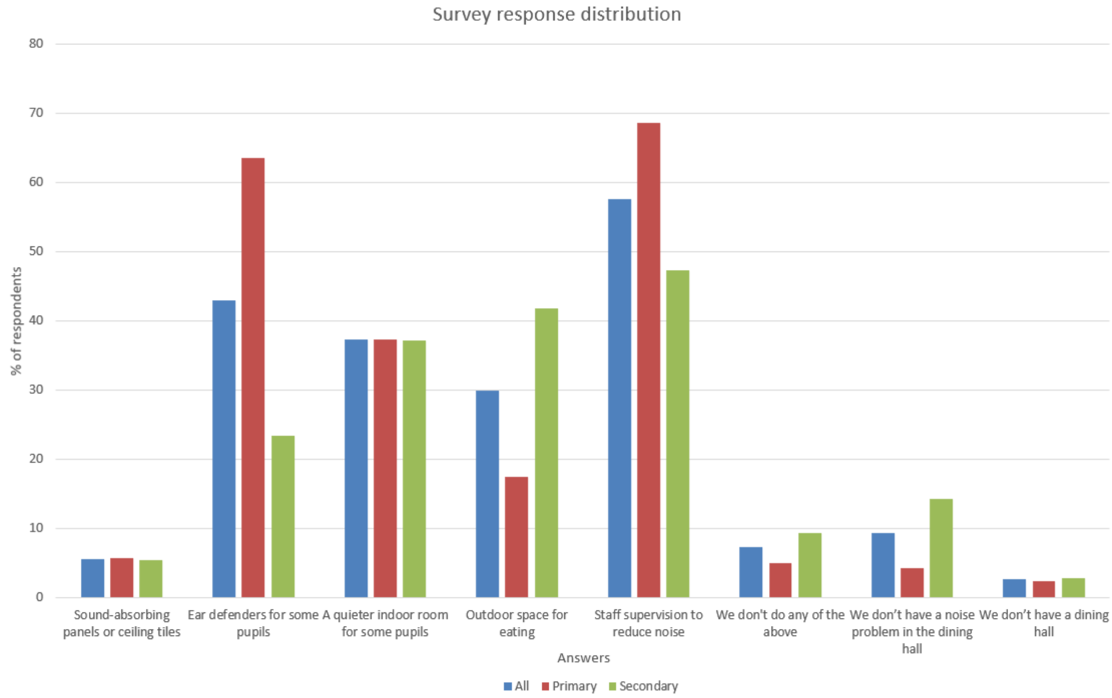
Independent schools indicated higher rates of acoustic absorption in their dining halls at 12% compared with 5% in state funded schools.

Independent schools also reported higher frequency of noise not being an issue within their school dining hall (20%) compared to only 8% of state funded schools. It is possible that due to limited resources, state funded schools may be less likely to invest in sound absorbent finishes within their school halls and are consequently more likely to have issues with noise build up.

Overall, the wider teacher survey results indicate that noise build up in school dining halls is a significant issue for the majority of schools across England, with state-funded primary schools being the most affected. Conversely, independent secondary schools are the least impacted. Results also indicate schools adopt a variety of techniques to try to mitigate noise and help pupils to cope with high noise levels, with staff supervision being the most commonly reported approach. Figure 4-10 shows a summary of the survey responses.

It is interesting to note that 70% of cited management methods (provision of ear defenders and provision of a quiet room) are not necessarily considered a suitably inclusive solution as this could exclude children from participating in conversation and social development in the main dining hall space.

Figure 4-10: Teacher Tapp survey responses (9,560 participants)



5 ANALYSIS AND DISCUSSION

5.1 Reverberation time

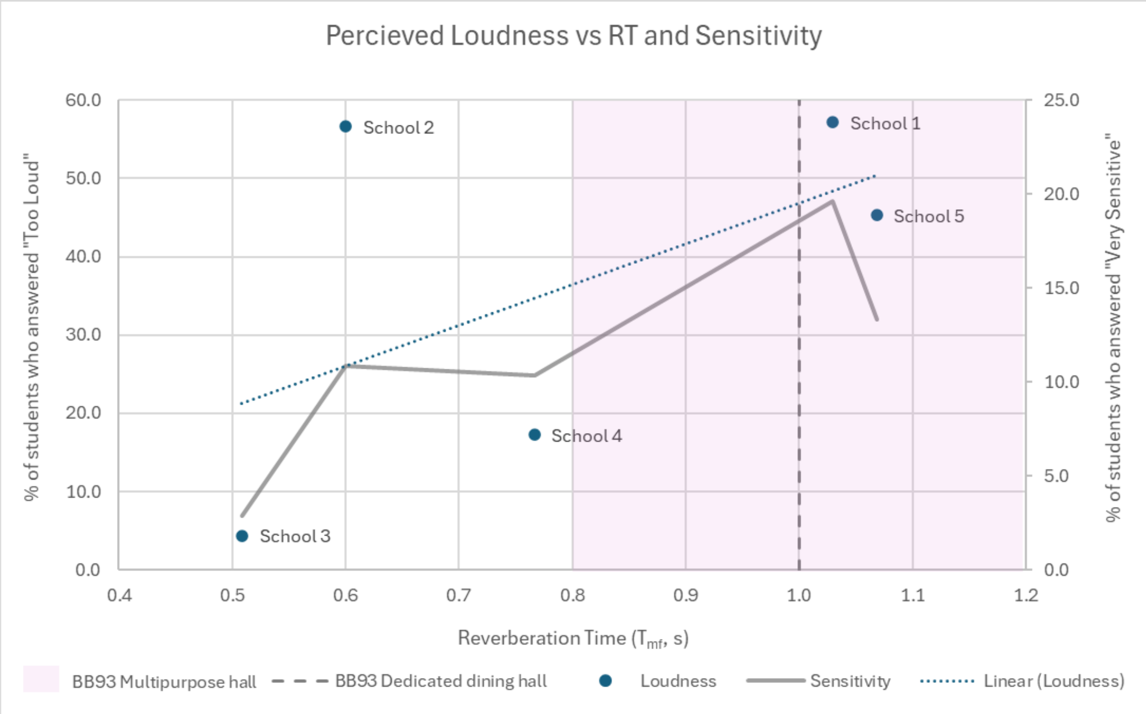
In order to understand the relationship between the RT and the experience of the students, several metrics of the overall student comfort have been compared against the measured RT within each of the respective halls. Trend lines have also been created in order to demonstrate association between the considered metrics.

For each graph, the BB93 target reverberation time ranges of 0.8-1.2 s T_{mf} for a multipurpose hall and 1.0 s T_{mf} for a dedicated dining hall have also been indicated on the graphs. The multipurpose hall range is indicated by the shaded region with the upper limit for dedicated dining halls marked by a dotted line.

Overall, the graphs indicate the general trend of increased negative overall experience as reverberation time increases. Some metrics indicate stronger trends than others with conversational difficulty plotted against reverberation time having a strong trend while perceived loudness has a slightly less conclusive result.

As established by Rindel (2012), the RT of a space is linked to the occupancy noise levels due to the Lombard effect. Figure 5-1 then shows the relationship between the students who answered "Too Loud" in the survey against the measured T_{mf} for each hall. The graph indicates that the increased T_{mf} is linked to a higher proportion of students finding the hall to be "Too Loud". School 2 is considered to be somewhat of an outlier with relatively low RT, but a high proportion of students finding the hall to be "Too Loud". Further investigation also concluded that this outlier was unlikely to be due to the student cohort being particularly sensitive to noise or having a higher percentage of pupils with additional needs that may result in an increased sensitivity to noise, nor was a correlation between room volume found. It is however noted that while a high proportion of students said it was "Too Loud", a high proportion also indicated that they found the noise to be “Quite Comfortable” in School 2 which indicates that they may not be excessively negatively impacted by the noise, but do find it to be loud.

Figure 5-1: Perceived Loudness vs reverberation time



Similarly, Figure 5-2 shows increased T_{mf} in the school dining hall is correlated with higher percentages of students reporting the noise in their school dining hall to be “Very Annoying”. Again, School 2 has a high proportion of students who report feeling very annoyed by the noise in their school dining hall, with the second lowest overall T_{mf}. As expected, Figure 5-1 and Figure 5-2 display similar overall trends with perceived loudness and annoyance of a sound being largely due to the overall sound level (Skagerstrand, Köbler and Stenfelt, 2017).

Figure 5-2: Annoyance vs reverberation time

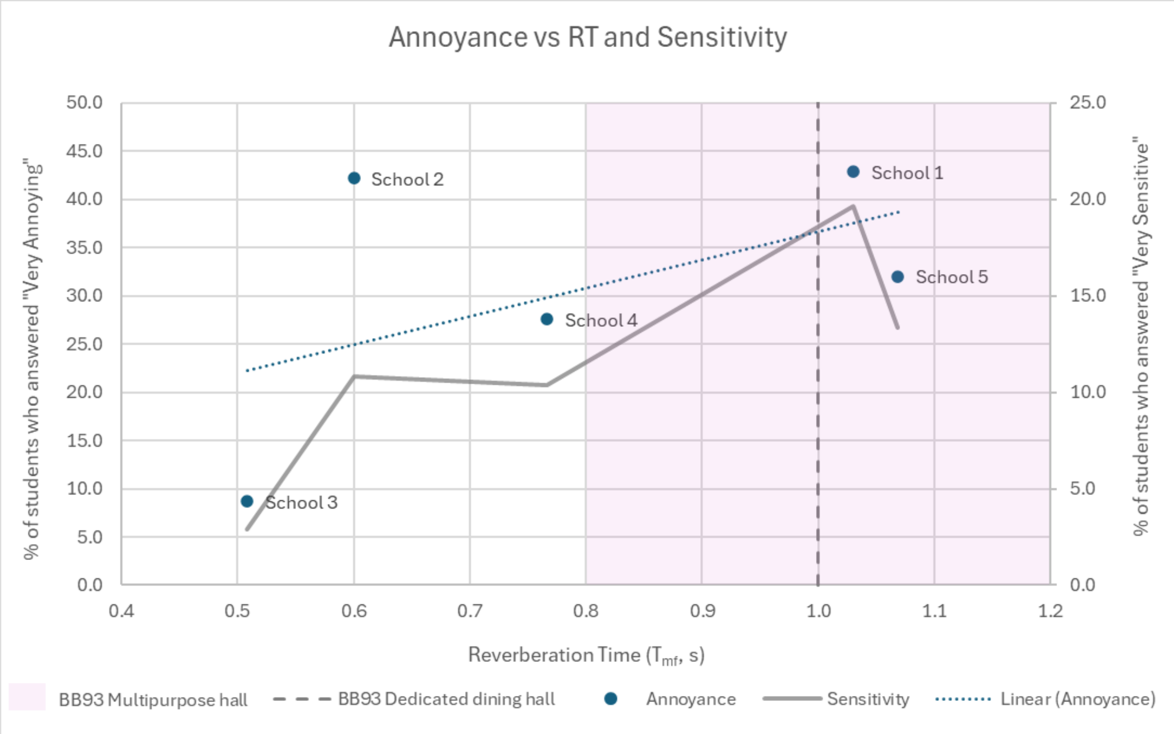


Figure 5-3 indicates a very strong trend between the RT in the school dining hall and students who reporting finding it “Quite” or “Very difficult” to have a conversation in their school dining hall. This is again expected with several classroom studies indicating the same findings amongst school aged children (Klatte, Hellbrück, Seidel and Leistner, 2010).

Figure 5-3: Conversational difficulty vs reverberation time

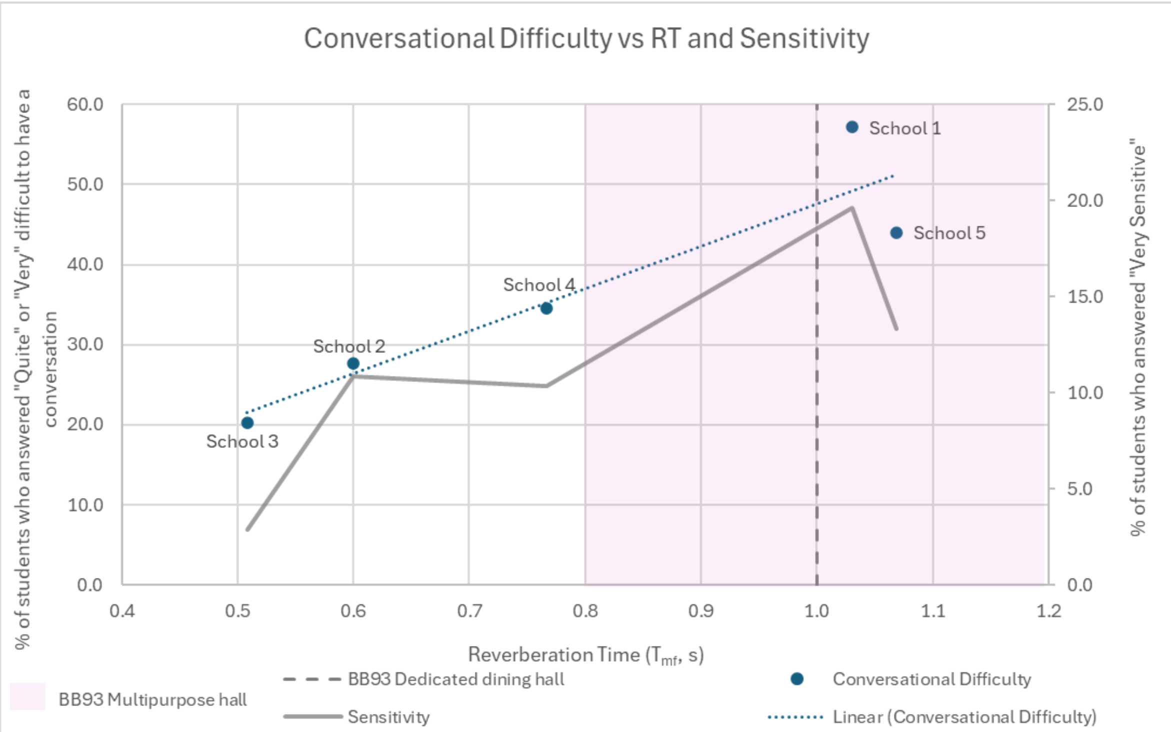
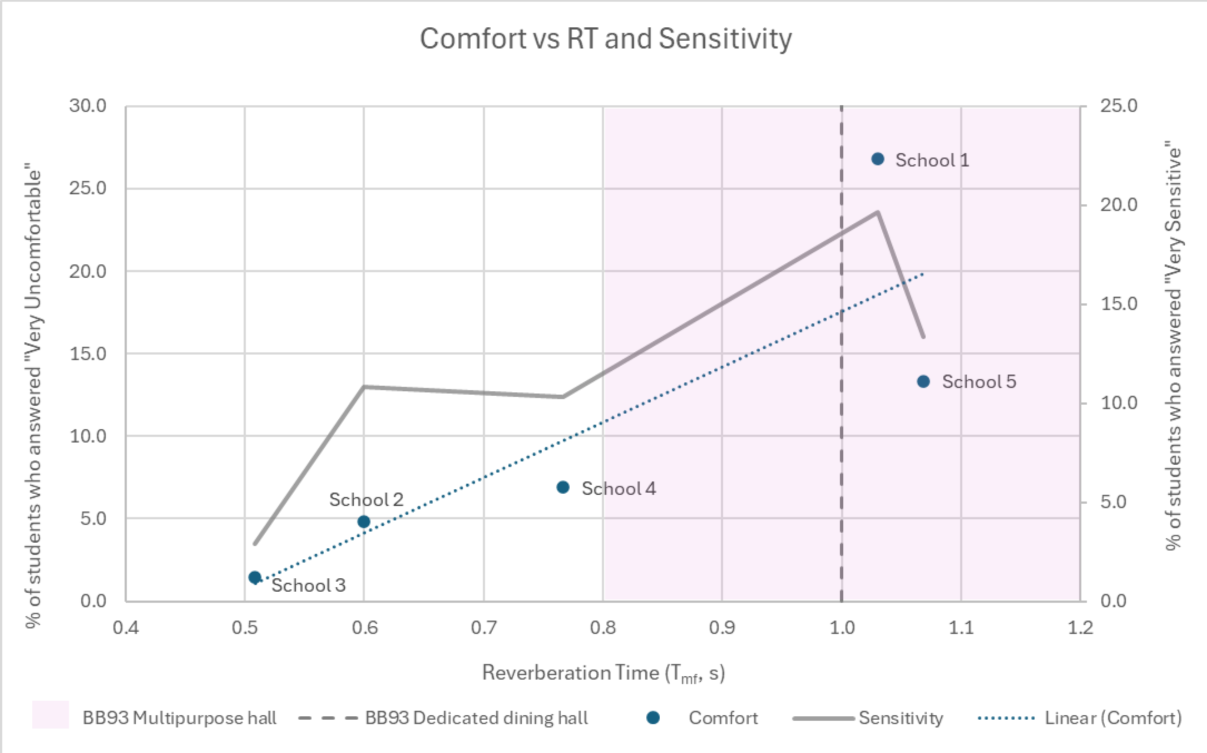


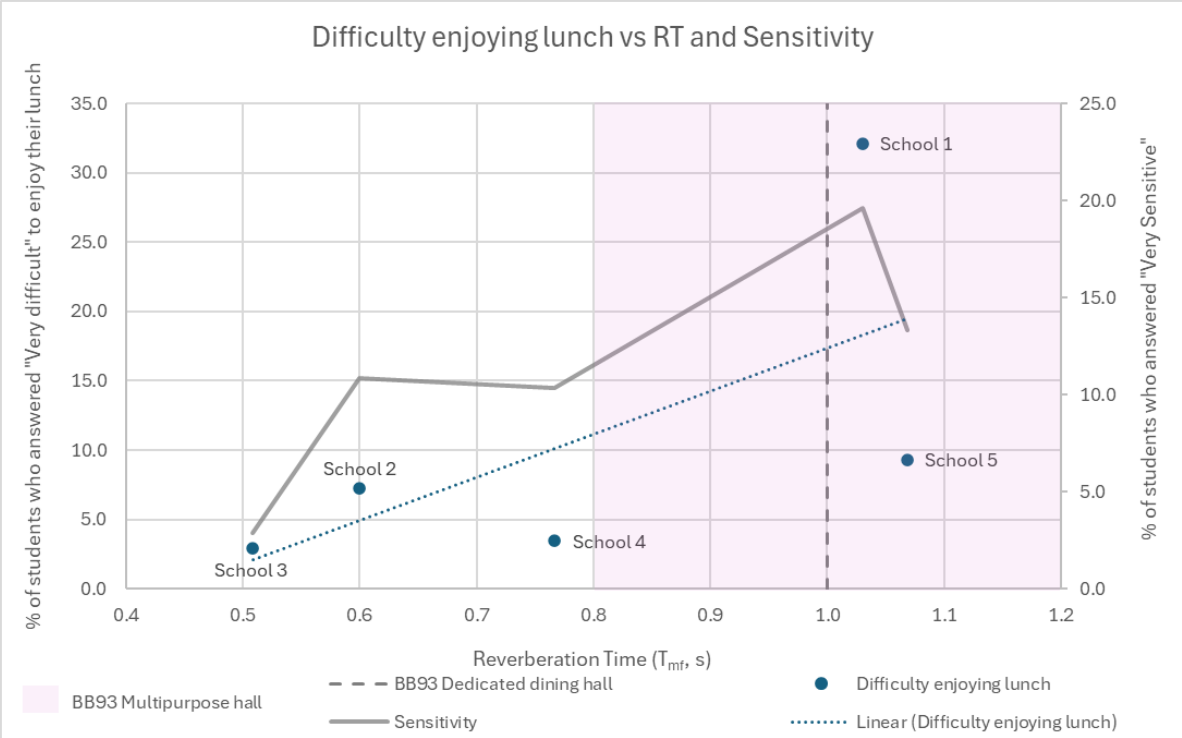
Figure 5-4 shows the RT and the percentage of students who reported feeling “Very Uncomfortable” in their school dining hall due to the noise. This graph again indicates that student comfort is strongly related to the RT in their school dining hall. Again wider research corroborates these findings, with research by Bettarello, Caniato, and Scavuzzo (2022) indicating the RT is strongly linked to the perceived acoustic comfort of a space specifically for those with hearing sensitivities.

Figure 5-4: Comfort vs reverberation time and sensitivity



Finally, Figure 5-5 shows the percentage of students who reported finding it "Very difficult" to enjoy their lunch against the measured T_{mf} in the hall. Similarly, this graph indicates a general increase in the percentage of students reporting that they find it difficult to enjoy their lunch due to noise as the reverberation time increases.

Figure 5-5: Difficulty enjoying lunch vs RT and sensitivity



Overall, across all the metrics included in the questionnaire a clear link between increased RT and increased negative responses is shown. It is also noted that within the purple shaded region (the target RT range for a multipurpose hall set out in BB93), only School 1 and School 5 sit within this region. These schools are also consistently among those with the highest proportion of pupils reporting negative responses to their experience within the hall. While schools outside this region, such as School 3 with the lowest overall RT, consistently have the lowest proportion of students reporting negative responses to the noise in their school dining hall.

This indicates that schools who fall within the target range for multipurpose halls are much more likely to have a higher proportion of students who are uncomfortable due to sound environment in their school dining – specifically as it relates to RT.

It is also noted that sensitivity to noise follows a similar trend to all the other considered metrics as plotted by the solid grey line in all graphs above. This demonstrates the expected trend that where higher percentages of the student cohort report being very sensitive to noise there is also an increased percentage of students reporting negative experiences due to the acoustic in their school dining halls.

The average response for each school was also considered by assigning numerical values to the possible responses from one to five, with five being the most negative and one being the most positive. In the case of pupils reporting their sensitivity to noise, the response “Very Sensitive” was assigned a numerical value of five and “Not at all sensitive” was assigned the value one. It is noted however that the trends observed above were much less evident when considering this averaged rating system. The responses of students who are most negatively impacted by the noise environment are considered to be most pertinent to the study and so the averaged rating graphs are presented in Appendix C for further information.

5.2 Indoor Ambient Noise Levels

Results for the IANLs were also plotted against the same metrics as shown in Figures 5-1 to 5-5. For IANLs plotted against perceived loudness and annoyance due to the noise in school dining halls no clear trend emerged. This is to be expected since ambient noise levels are measured for the unoccupied hall, and are not strongly associated with occupancy noise level, which largely depends on number of children in the space, room volume and reverberation time, provided that ambient noise level remains below the level to trigger the Lombard effect (around 45 dBA), as was the case for all schools surveyed. Indoor ambient noise levels were suitably well controlled in the surveyed schools such that it did not impact the experience of the pupils in the dining halls. The graphs for these metrics are shown in Appendix C. A dotted line on the graphs also indicates the BB93 new build standard of 35 dBA for a multipurpose dining hall (Daniels and Bodkin, 2014).

The strongest trend when considering survey results against the measured IANL was for conversational difficultly. Figure 5-6 shows the percentage of students who reported finding it "Very difficult" to have a conversation due to the noise in their school dining hall against the measured indoor ambient noise level in the hall. This trend is expected with high ambient noise levels being linked to decreased speech intelligibility and therefore more difficulty having a conversation (Peng and Wang, 2019).

Figure 5-6: Conversational difficulty vs indoor ambient noise level

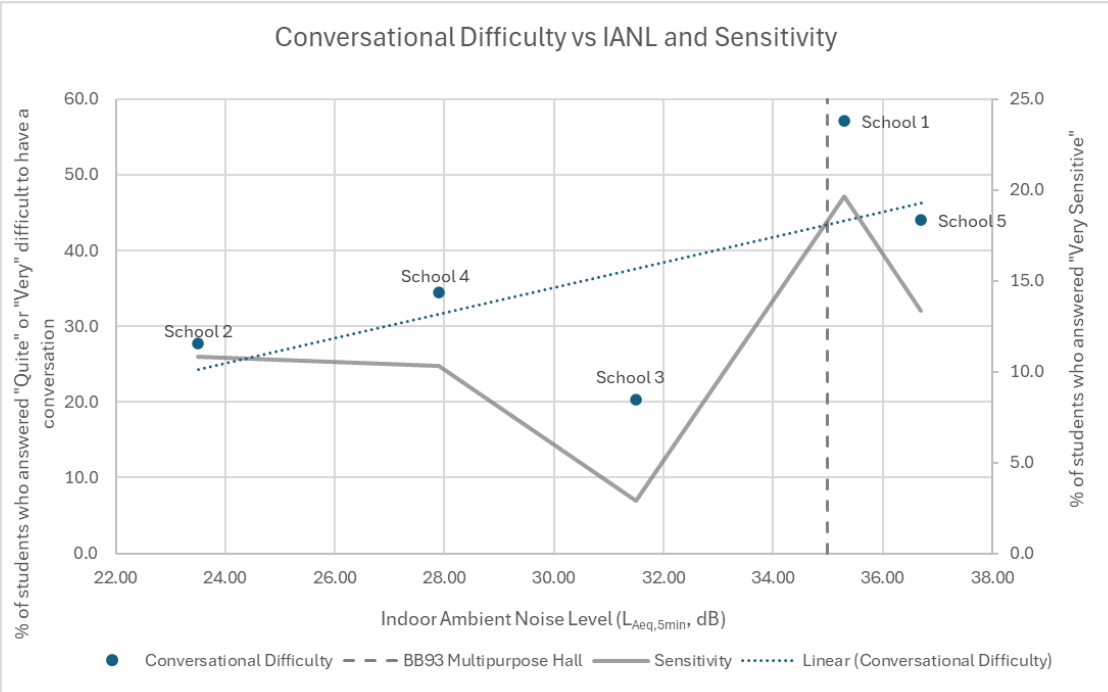


Figure 5-7 and Figure 5-8 show the measured IANL for each school plotted against students who reported finding the noise in their school dining hall to be "Very Uncomfortable" and who found the noise made it "Very difficult" to enjoy their lunch respectively. Both graphs indicate a slight upward trend indicating that higher proportions of students found the acoustic environment negatively impacted their experience as the indoor ambient noise level increased. However, these trends are considered to be somewhat less strong than considering when considered against the equivalent graphs for RT.

Overall, it is therefore concluded while some metrics indicate a trend of increased negative responses when plotted against IANL in the school dining halls, the trends were less conclusive for all metrics when compared to reverberation time. It is therefore concluded that IANLs were reasonably well controlled and in most cases fell well below the BB93 criteria for new build multipurpose halls and in some cases had limited impact on some aspects of the student experience. Where speech communication is concerned, the data indicates that lower ambient noise levels created an easier environment for students to communicate.

Figure 5-7: Comfort vs indoor ambient noise level

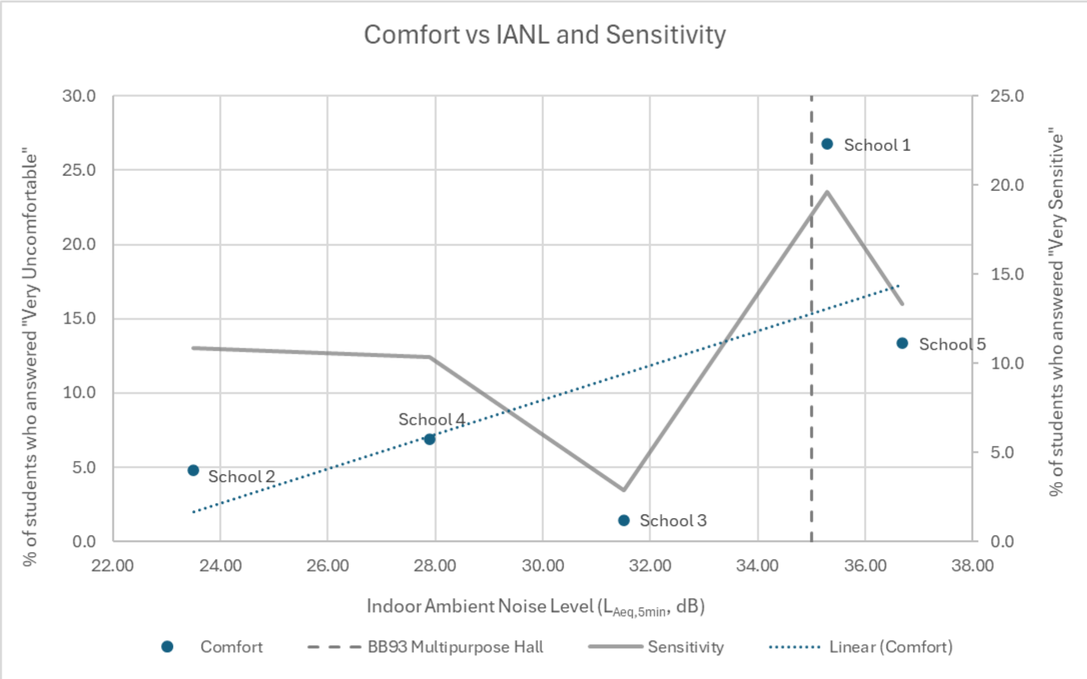
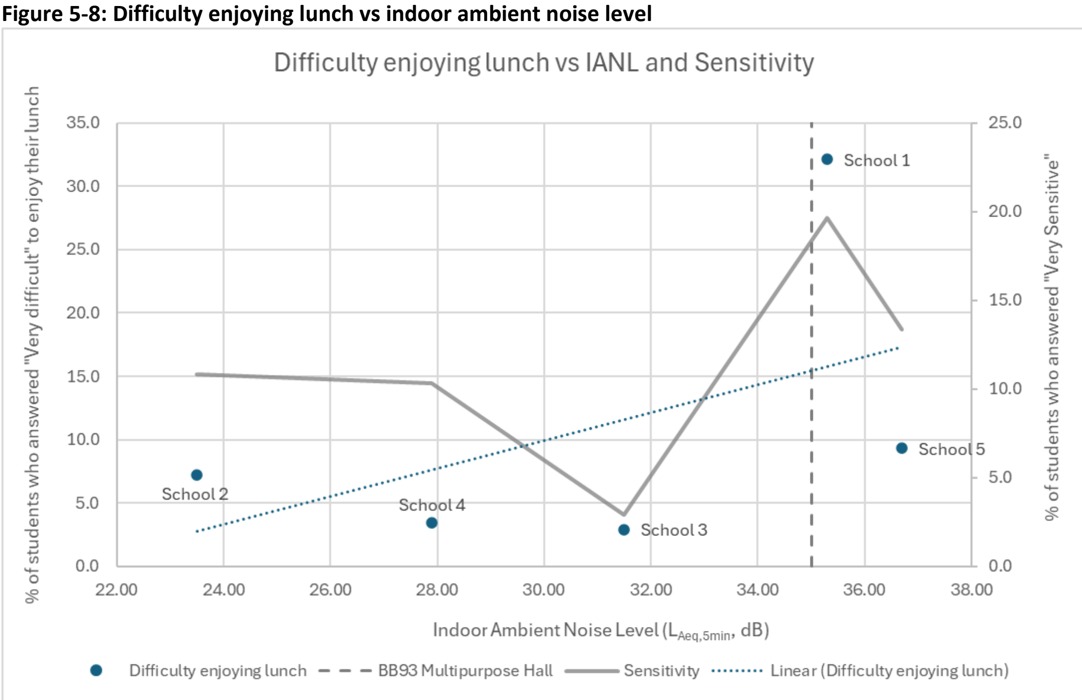


Figure 5-8: Difficulty enjoying lunch vs indoor ambient noise level



As with RT, the average response for each metric was also considered against IANLs by using a numerical rating. However, as with RT, the trends using this method indicated there was little to no correlation and so have been presented in Appendix C for further information.

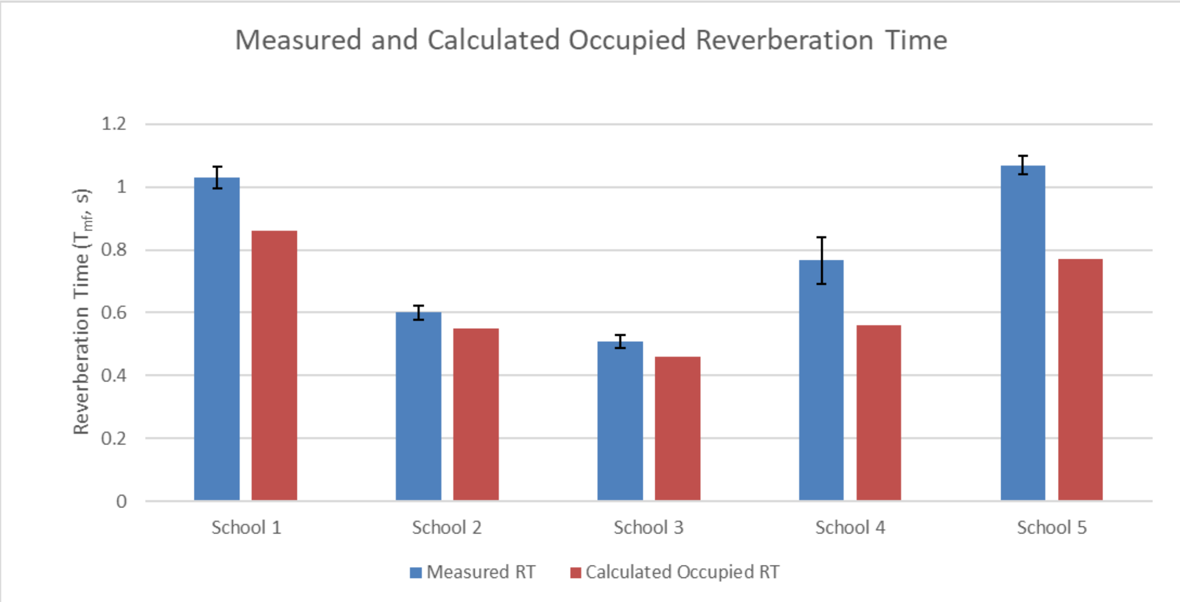
5.3 Occupied reverberation time adjustment

BB93 sets out RT targets for rooms finished as they would be for typical use, but unoccupied. However, due to the absorptive properties of occupants in the space, the occupied reverberation time of a space would be reduced in practice. This is more prominent in spaces with high occupancy numbers such as dining halls. The measured RT for each hall is presented below alongside the calculated occupied RT. The occupied RT was calculated by using a calibrated Sabine calculation based on the measurements taken in each hall and the average absorption coefficients for a child seated on a plastic or metal chair as published in Building Bulletin 51 (Department for Education, 1975).

For each hall, the occupied RT was calculated assuming the hall would be at maximum capacity of students as established in Building Bulletin 103 (Department for Education, 2014), which sets of the capacity of the hall based on the area.

As can be seen in Figure 5-9, the occupied RT for each hall is of course lower for each hall due to the increased absorption with Schools 4 and 5 seeing the biggest decrease between unoccupied and occupied reverberation time due to the higher overall capacity due to the size of the hall.

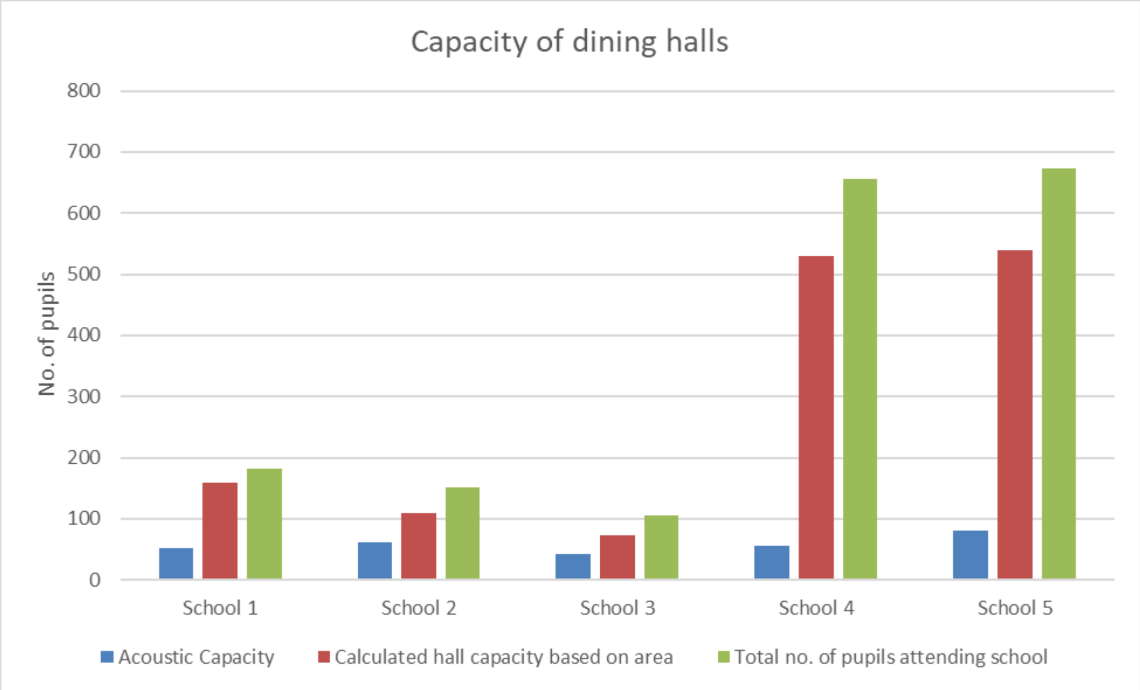
Figure 5-9: Measured and calculated occupied reverberation time



5.4 Acoustic Capacity

The acoustic capacity for each of the halls included in the survey has then also been calculated based on the formula by Rindel (2012) as described in Section 2.2. This is shown in Figure 5-10 as well as the total number of pupils who attend the school and who would be potentially use the space at any given time, as well as the capacity of the hall as calculated by the area set out in Building Bulletin 103 (Department for Education, 2014). It is noted that for School 4 the total number of pupils has been divided by 4 as it is understood that this school has 4 separate dining halls and so it is assumed that this would be roughly representative of the number of pupils using the dining hall at one time.

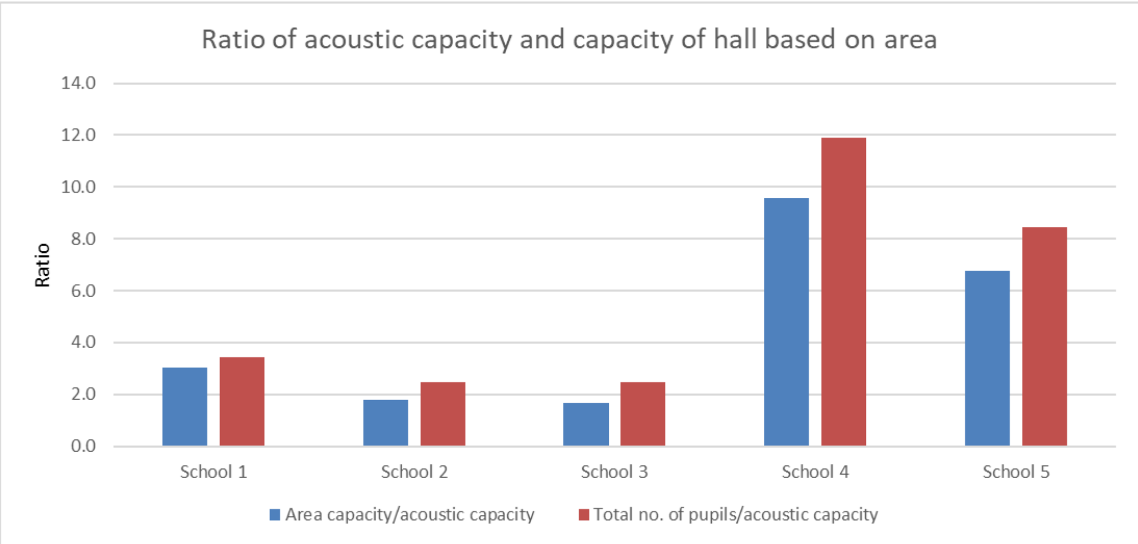
Figure 5-10: Capacity of school dining halls



In all cases it can be seen the acoustic capacity of the hall is much lower than the potential maximum capacity of the hall space and indeed the capacity based on the area of the space.

Figure 5-11 then shows the ratio of the capacity of the hall based on area and the acoustic capacity of the hall as calculated using both the measured reverberation time.

Figure 5-11: Ratio of acoustic capacity and capacity of dining halls based on area



It can be seen that the ratio of the capacity is far higher for School 4 and School 5 than for Schools 1, 2 and 3.

School 3 has the lowest ratio of area capacity/acoustic capacity at 1.7 times the acoustic capacity. This is also the school which has the lowest reverberation time and the lowest proportion of students who found the noise in their school hall to be “Very comfortable”. They also had the lowest proportion of students reporting “Very” negative experience across all questions.

Conversely of the primary schools, School 5 has the highest ratio of area capacity/acoustic capacity at 6.8 times the acoustic capacity. This school also had the highest measured reverberation time and the highest percentage of pupils who reported feeling tired, irritated, overwhelmed.

It is therefore further concluded that the increased reverberation time, which predicts a smaller acoustic capacity, combined with increased occupancy results in a worse overall experience for the pupils. School dining halls with shorter reverberation times and dining hall capacities more closely aligned with the acoustic capacity of the hall have higher rates of pupils reporting positive experiences of the sound in their school dining hall compared to those with higher reverberation times and those where the capacity of the hall is far higher than the acoustic capacity.

5.5 CATT Model

Given School 1 had the worst overall reported loudness and the highest number of pupils who reported being sensitive to noise, this school has been selected for further analysis via a CATT model. The measured reverberation time was used to calibrate the model based on knowledge of the existing finishes in the space. The overall calibrated reverberation time in the space is also presented in Figure 5-12. Figure 5-13 shows a screenshot from the model produced and Figure 5-14 shows the distribution of the modelled reverberation time across the hall at 1 kHz. The absorption coefficients used to calibrate the model are presented in Appendix D.

Figure 5-12: Measured and modelled reverberation time

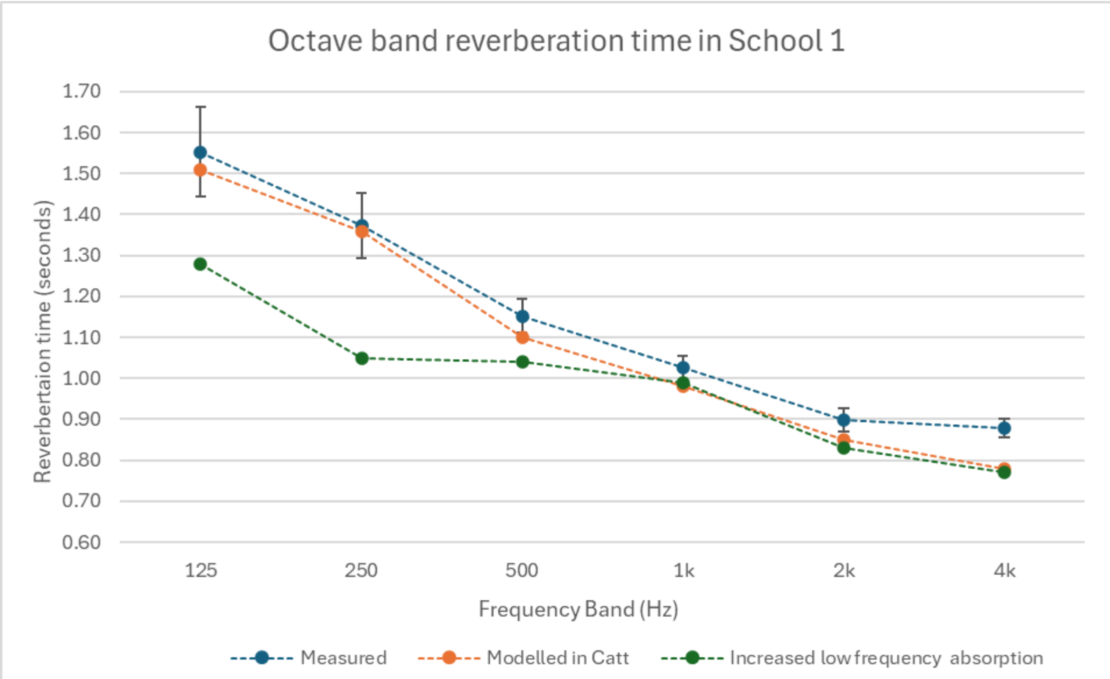


Figure 5-13: Image of Catt model of School 1 dining hall

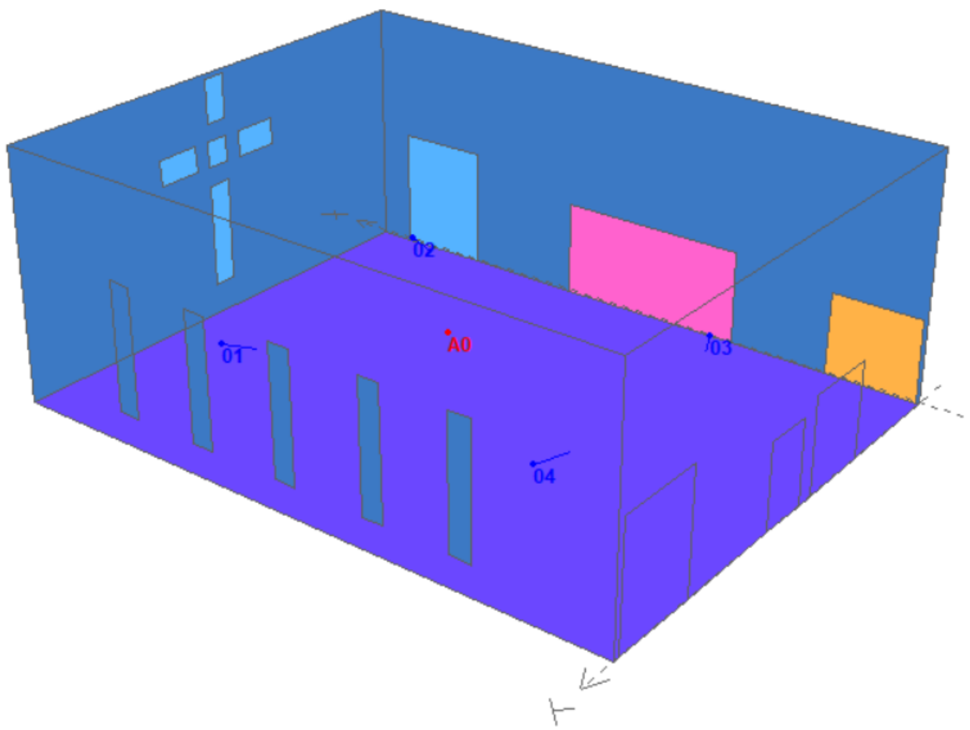
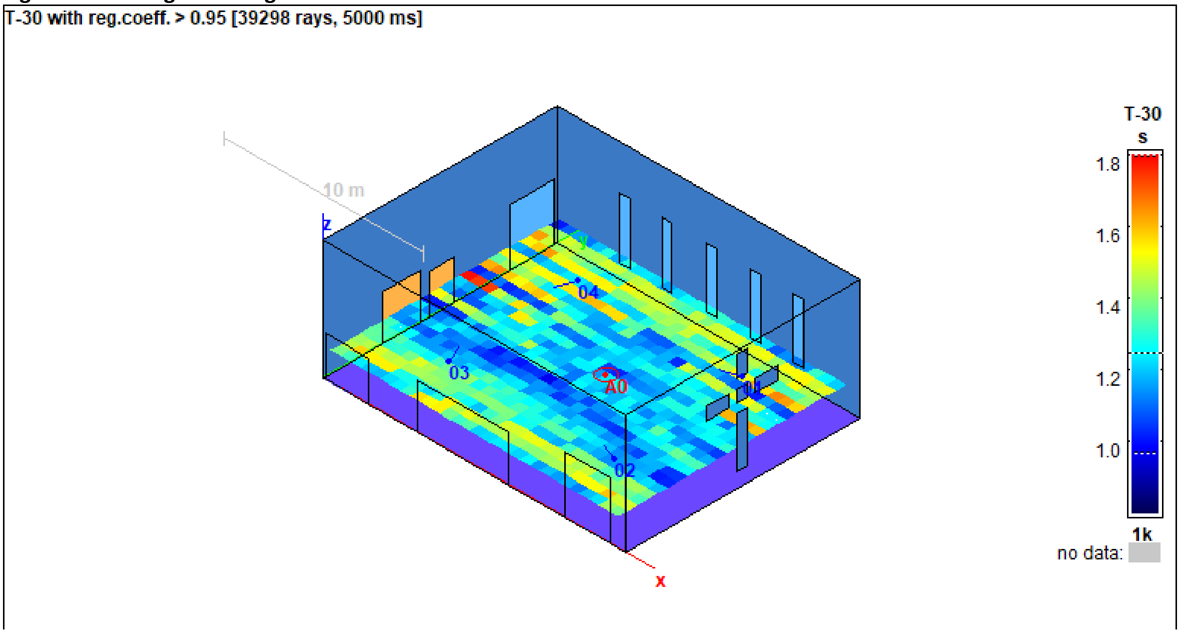
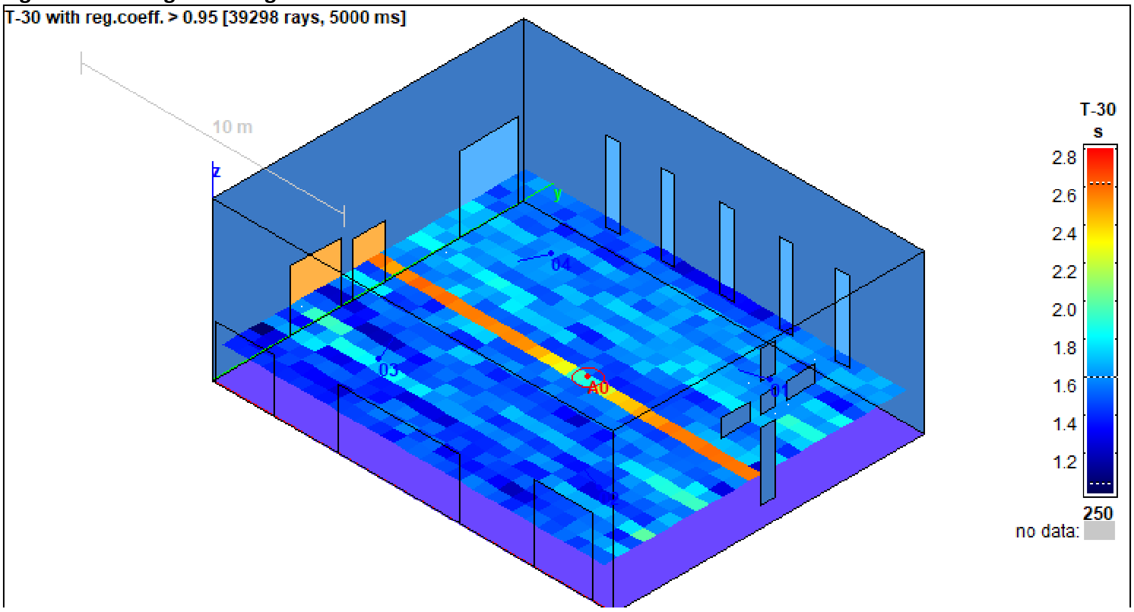


Figure 5-14: Image showing modelled reverberation time at 1 kHz in School 1



Overall, the space was relatively diffuse when modelled in CATT as shown above for 1 kHz, however there was a prominent room mode at 250 Hz as shown below in Figure 5-15.

Figure 5-15: Image showing modelled reverberation time at 250 Hz in School 1

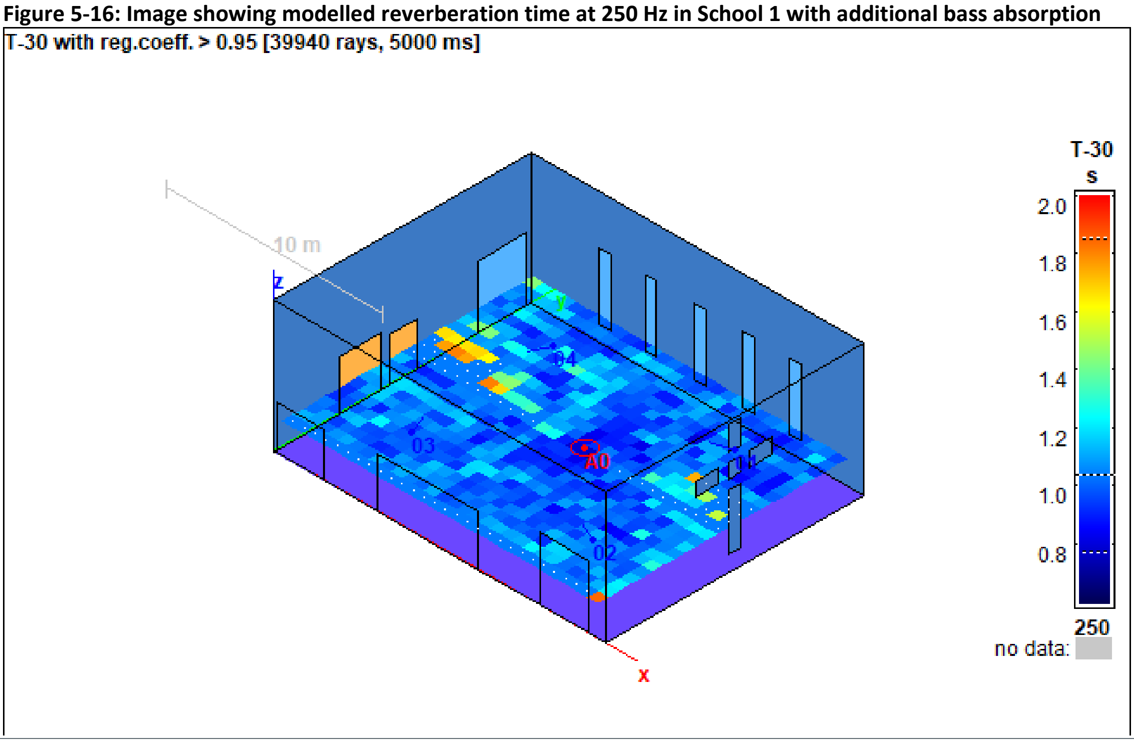


The room mode is calculated via the following formula:

$$f = \frac{c}{2}\sqrt{\left(\frac{n_1}{L}\right)^2 + \left(\frac{n_2}{W}\right)^2 + \left(\frac{n_3}{H}\right)^2} = \frac{343}{2}\sqrt{\left(\frac{8}{15.3}\right)^2 + \left(\frac{14}{11.8}\right)^2 + \left(\frac{4}{6}\right)^2} = 250 \text{ Hz}$$

By increasing the absorption of the hall at low frequencies, this room mode can be suitably well controlled as shown in Figure 5-16. The octave band data with the increased low frequency absorption is shown in Figure 5-12 in green. This was modelled by replacing the current panels in the hall with panels with bass backing pads to increase the low frequency performance. This would also help to control noise build up as excessive reverberation time at low frequencies can result in a “booming” sound quality. Higher reverberation times at low frequencies is shown to significantly reduce speech intelligibility in a space as well (Xu et al., 2021).

Figure 5-16: Image showing modelled reverberation time at 250 Hz in School 1 with additional bass absorption



The calibrated model was also auralised for a single speaker at the front of the hall. As part of further works, this space could be auralised with background conversational babble in order to simulate the lunch time sound environment. Similar to the research conducted by Yardy (2024), the experience of this simulated environment could be rated by students in order to understand the impact of changes in reverberation time to their experience using the hall. This would allow for more precise control over different variables such as sensitivity of the students surveyed as well as the reverberation time frequency distribution. Further research into the impact of the acoustic environment on children with specific additional needs could also be further investigated through this method.

6 CONCLUSIONS

Overall, the research indicates a notable relationship between increased reverberation time and increased percentages of students reporting discomfort due to the acoustic environment, excessive noise levels and difficulty having conversations.

There was a more limited correlation noted between ambient noise levels in the school dining halls and pupils reporting on the same metrics as indicated above. This is supported by the fact that the ambient noise levels were lower than 45 dBA in all surveyed schools and hence was not at a level which would trigger the Lombard Effect and an increase in occupancy noise levels. Therefore the slight increases in ambient noise level, whilst remaining below 40 dBA, had a more limited impact on the student experience compared to reverberation time.

There is also an expected correlation between higher percentages of students who report being particularly sensitive to noise and higher reported percentages of students who report being uncomfortable due to the acoustic environment, excessive noise levels and difficulty having conversations.

Results from teacher surveys also indicated that noise levels in school dining halls are generally an issue with primary school teachers reporting higher rates of problems with noise. Furthermore, current methods of noise control were most commonly report to be staff supervision followed by providing ear defenders and quiet rooms for children most impacted by the noise.

Overall the schools surveyed indicate that the current guidance within BB93 for reverberation time in school dining halls and multipurpose halls are not adequate for supporting a comfortable experience for students, particularly those with hearing sensitivities. Schools that had measured reverberation times well below the target range of 0.8-1.2 s T_{mf}, generally had the lowest rates of pupils reporting negative experiences in their school dining hall. Therefore whilst 0.8-1.2 s T_{mf}, is a minimum standard for multipurpose halls, an improved standard which takes account of those with special hearing and communication needs in dining halls would be 0.5-0.8 s T_{mf}.

This research suggests that this improved standard would help to foster an environment in which more children feel comfortable and at ease creating a more welcoming school environment.

7 LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORKS

It is noted that conclusions are based on survey results and measurements from a limited sample size across five schools.

While several secondary schools were contacted to take part in the research, only one secondary school agreed to take part in the research. It is therefore recommended that further research into the impact of reverberation time in school dining halls in secondary schools is carried out. The research indicates that they may have generally higher occupancy levels in school dining halls which would require further investigation.

Further insight could also be gained by conducting focus groups with students and teachers to further understand the impact of the acoustics in the hall on the experience of the users. This could be further supplemented by taking additional measurements such as STIPA measurements as well as more occupied noise level measurements. Particularly, this could be conducted during the winter months when more pupils would be expected to eat indoors and therefore represent a worse case scenario.

Further investigation using calibrated noise models may also allow for more precise control over variables within the student cohort such as sensitivity to noise, having English as a foreign language and student age. This would also allow for further investigation into the frequency distribution of the reverberation time and the impact on student experience.

Due to time and travel constraints all schools included in the research were located in the South East of England. To gain a fuller understanding of the wider conditions in school dining halls in the United Kingdom further research could also be conducted across a wider range of locations. However, results from TeacherTapp surveys indicate that teachers across the UK have similar experiences with the noise environment regardless of location.

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APPENDIX A

STUDENT SURVEY

Please answer as many of the questions as you want to by ticking the box in the table that you feel best answers the question for you.

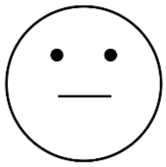
1. What year of school are you in e.g Year 1, Year 2, Year 3 etc?

____

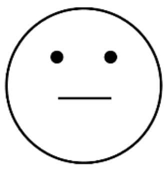
2. How sensitive do you think you are to noise generally? (Choose 1)

	Very sensitive
	A bit sensitive
	Not sure
	Not very sensitive
	Not at all sensitive

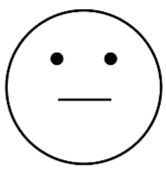
3. Think about how it sounds in your school dining space. How comfortable is the sound in your school dining space at lunch time/break time? (Choose 1)

Very comfortable	Quite comfortable	Not sure	Not very comfortable	Very uncomfortable
				

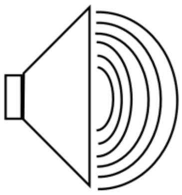
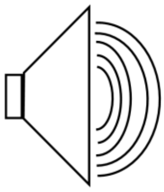
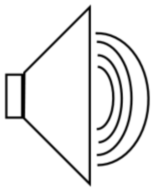
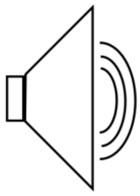
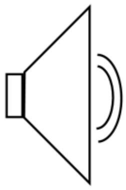
4. Think about the noise levels in your school dining space during lunch/break time. How easy is it to have a conversation? (Choose 1)

Very easy	Quite easy	Ok	Quite difficult	Very difficult
				

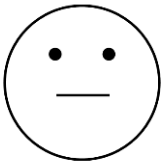
5. Does the noise level in your school dining space make it difficult for you to enjoy your lunch break? (Choose 1)

Not at all	Not really	Not sure	A little	A lot
				

6. How loud do you find your school dining space during lunch time? (Choose 1)

Too loud	Fairly loud	About right	Fairly quiet	Too quiet
				

7. How annoying do you find the noise in your school dining space during lunch? (Choose 1)

Not at all	Not very	Not sure	A little	Very
				

How do the noise levels in your school dining space make you feel? (Tick all that apply)

	I feel tired after spending time in my school dining space at lunch/break time
	I feel irritated after spending time in my school dining space at lunch/break time
	I feel overwhelmed after spending time in my school dining space at lunch/break time
	I find it difficult to concentrate in class after lunch because of the noise in the school dining space
	The sound in my school dining space helps me to feel calm
	The sound in my school dining space helps me to feel restful and recharged
	The sound in my school dining space helps me to enjoy my lunch break
	Any other feelings:

Is there anything else you'd like to mention?

____
____
____

APPENDIX B

TABULATED DATA

Table B-1 and B-2 below present the tabulated format of the measured reverberation time data and indoor ambient noise levels.

Table B-1: Measured reverberation time tabulated data

School no.	T_{mf}	125	250	500	1k	2k	4k
1	1.03	1.55	1.37	1.15	1.03	0.9	0.88
2	0.6	0.71	0.8	0.62	0.6	0.59	0.57
3	0.51	0.56	0.56	0.53	0.48	0.52	0.50
4	0.77	0.86	0.91	0.73	0.74	0.82	0.83
5	1.07	0.78	1.04	0.99	0.99	1.22	1.15

Table B-2: Measured indoor ambient noise levels tabulated data

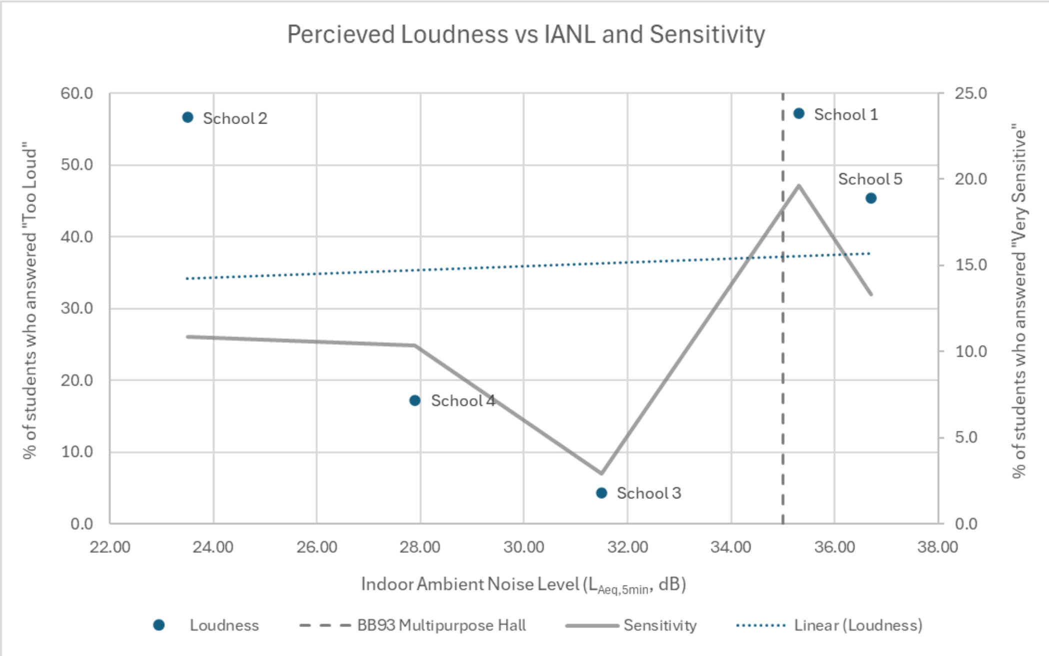
School no.	IANL ($L_{Aeq, 5min}$)	125	250	500	1k	2k	4k
1	35.3	42.2	32.2	33.1	31.3	24.7	20.9
2	23.5	30.8	23	17.5	17.1	15	12.5
3	31.5	32.1	29.2	26.6	23.2	22.3	22.0
4	27.9	38.2	27.7	21.3	19.9	17.3	16.2
5	36.7	38.3	32.6	31.0	32.9	30.0	23.9

APPENDIX C

ADDITIONAL ANALYSIS GRAPHS

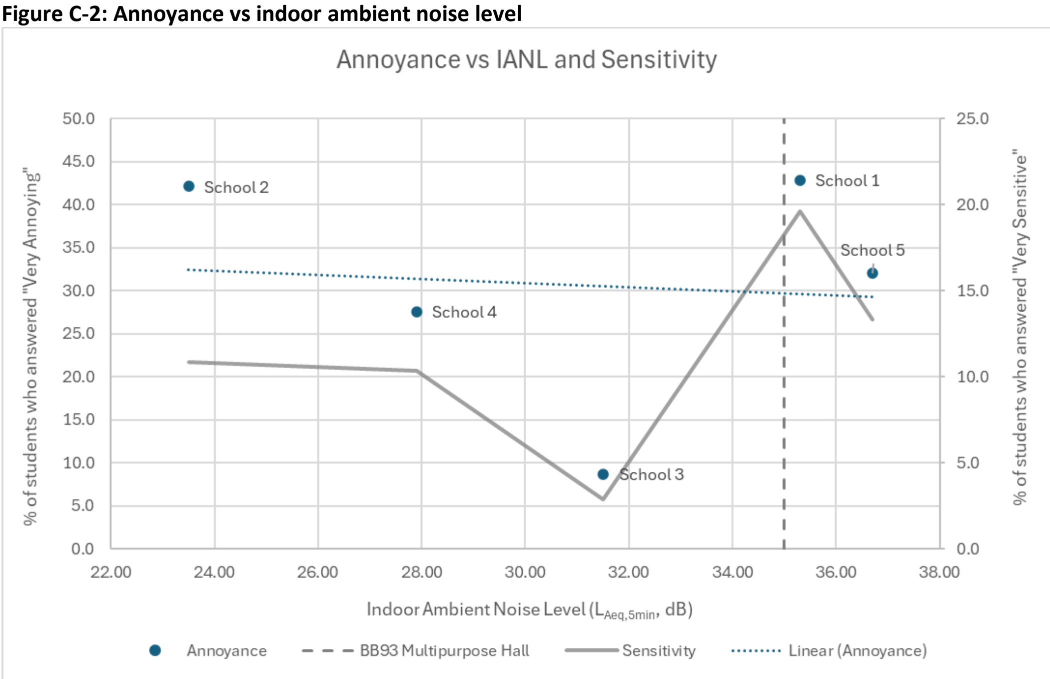
Figures C-1 below shows the measured IANL for each school plotted against the percentage of pupils who said they found the noise in their school dining hall to be "Too Loud".

Figure C-1: Perceived loudness vs indoor ambient noise level



Figures C-2 below shows the measured IANL for each school plotted against the percentage of pupils who said they found the noise in their school dining hall to be "Very Annoying".

Figure C-2: Annoyance vs indoor ambient noise level



Figures C-3 to C-7 below shows the measured RT for each school plotted against average rating given by pupils for each of the questions. Each of the possible responses was assigned a numerical value from one to five, with five being the most negative response and one being the most positive. For sensitivity "Very Sensitive" was assigned a numerical value of five and "Not at all sensitive" was given a value of one.

Figure C-3 below shows the graph for perceived loudness and RT.

Figure C-3: Average Loudness rating vs RT

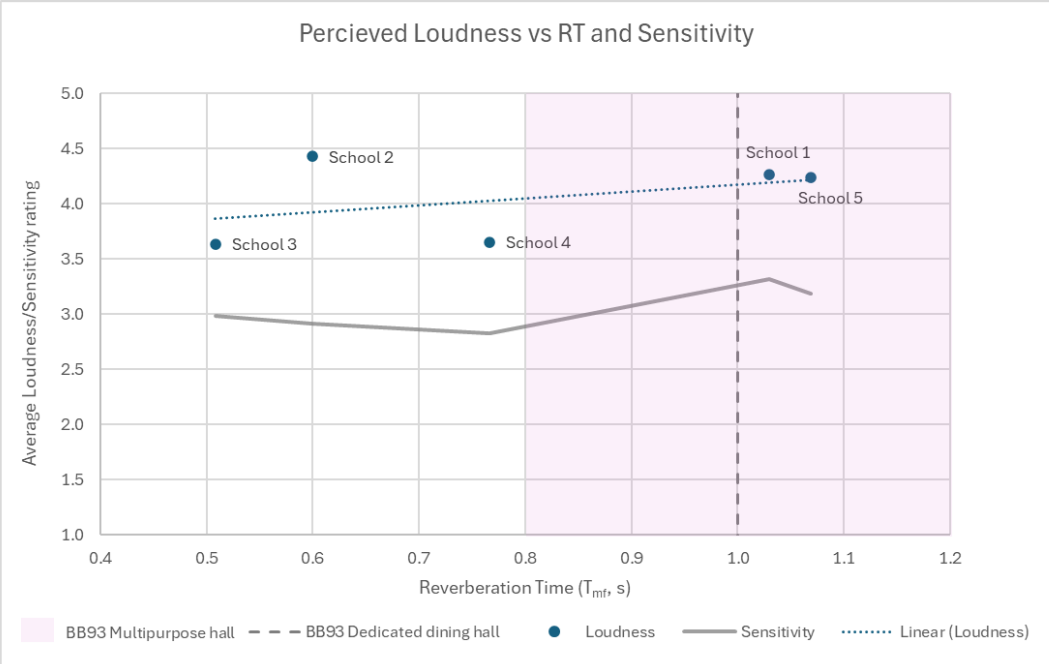


Figure C-4 below shows the graph for perceived annoyance and RT.

Figure C-4: Average Annoyance rating vs RT

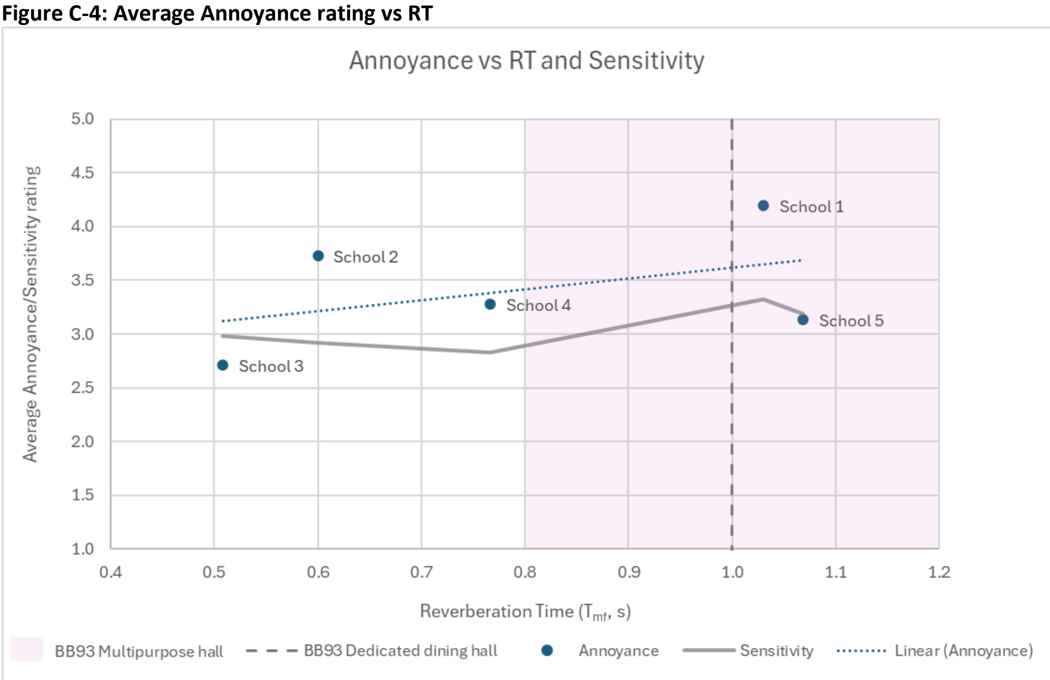


Figure C-5 below shows the graph for comfort and RT.

Figure C-5: Average comfort rating vs RT

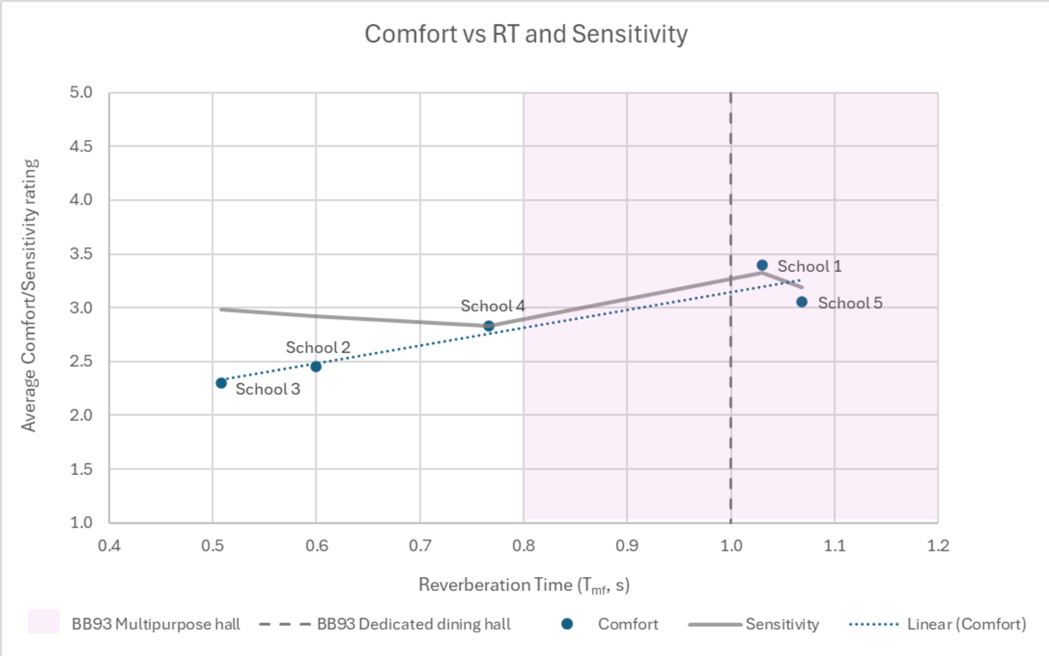


Figure C-6 below shows the graph for conversational difficulty and RT.

Figure C-6: Average conversational difficulty rating vs RT

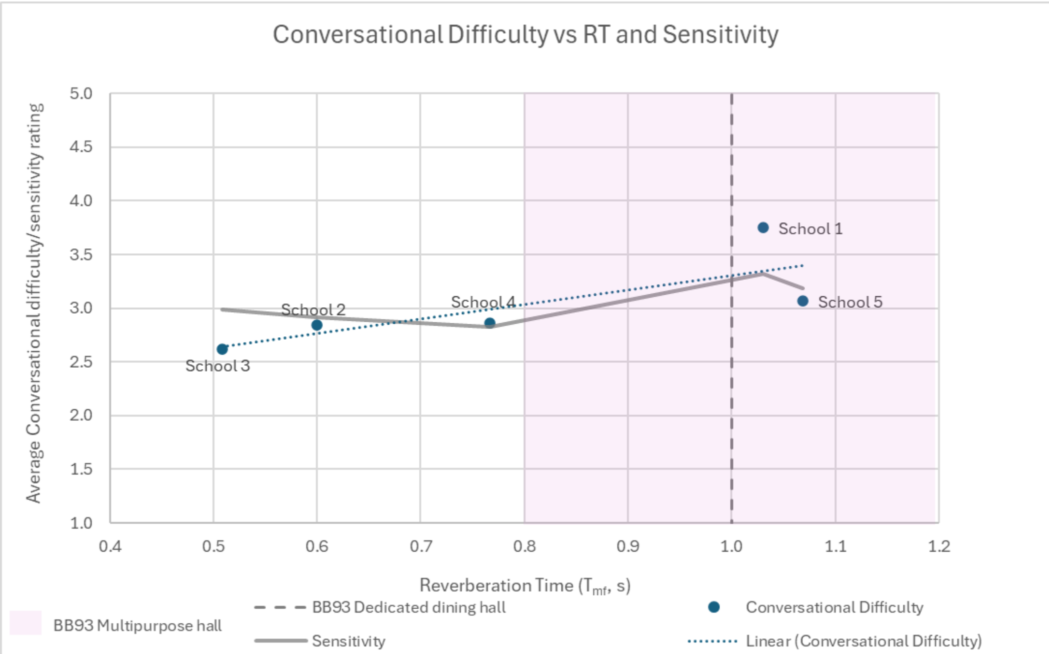
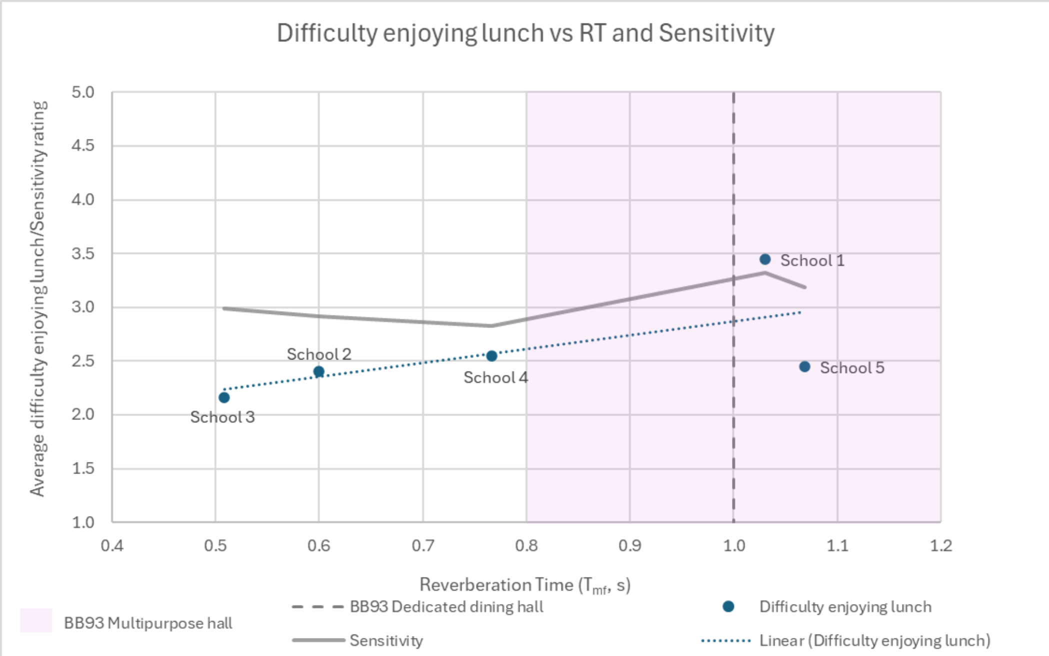


Figure C-7 below shows the graph for difficulty enjoying lunch and RT.

Figure C-7: Average difficulty enjoying lunch rating vs RT



Figures C-8 to C-12 below shows the measured IANL for each school plotted against average rating given by pupils for each of the questions. The numerical ratings for each response were assigned as described above for the equivalent RT graphs.

Figure C-8 below shows the graph for perceived loudness and IANL.

Figure C-8: Average Loudness rating vs IANL

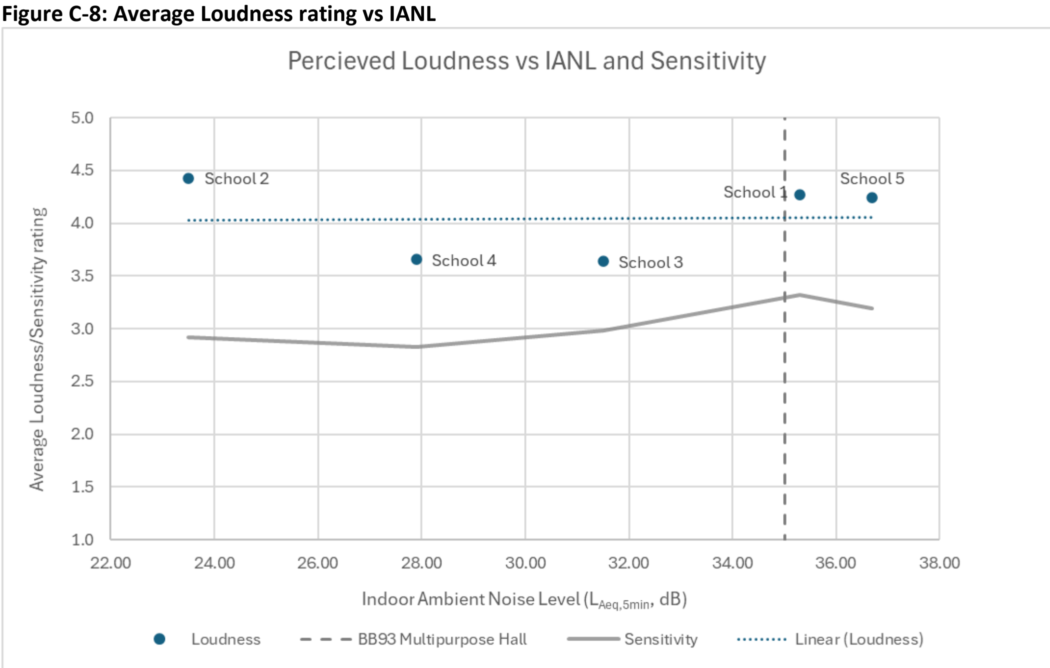


Figure C-9 below shows the graph for perceived annoyance and IANL.

Figure C-9: Average Annoyance rating vs IANL

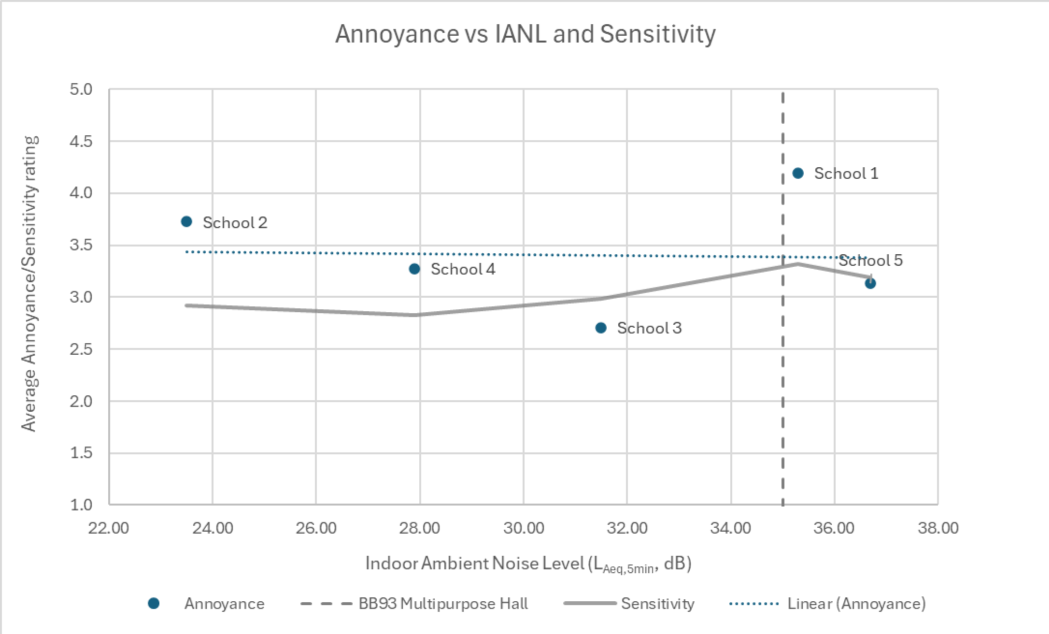


Figure C-10 below shows the graph for comfort and IANL.

Figure C-10: Average comfort rating vs IANL

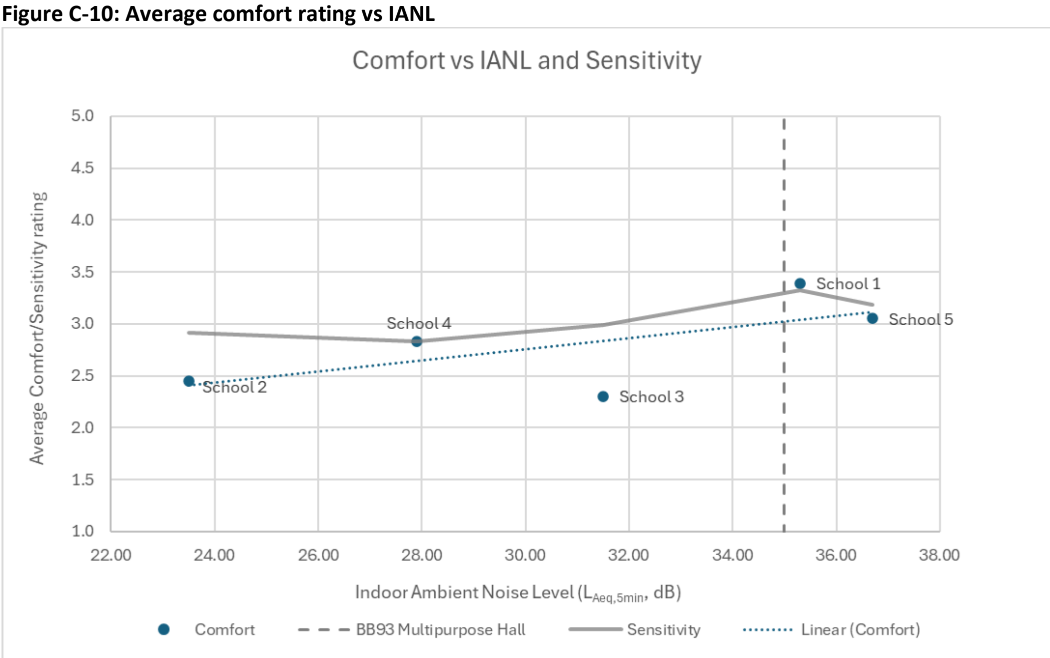


Figure C-11 below shows the graph for conversational difficulty and IANL.

Figure C-11: Average conversational difficulty rating vs IANL

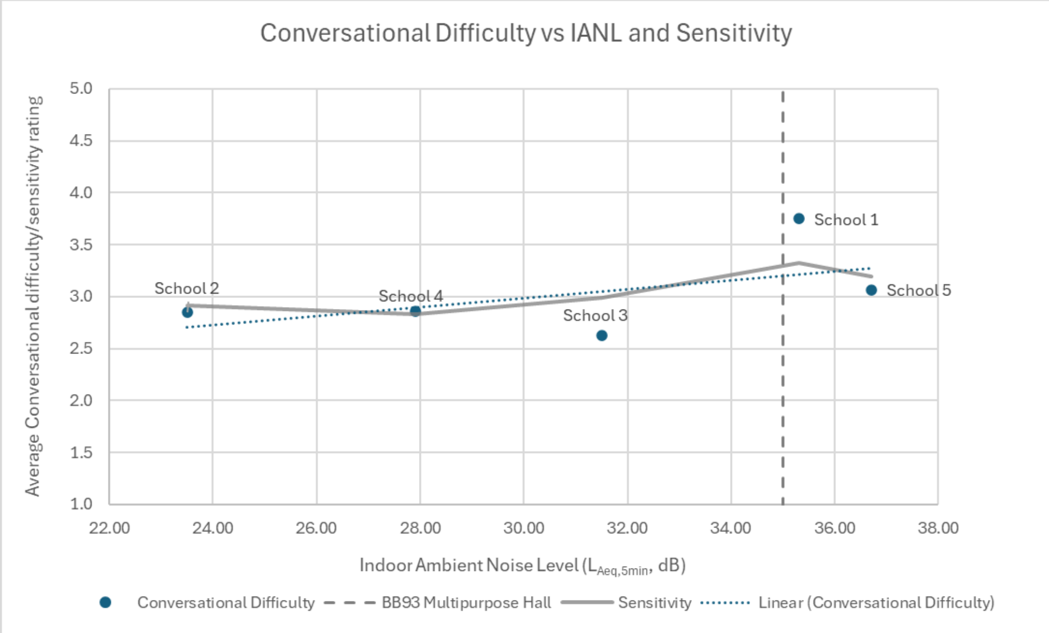
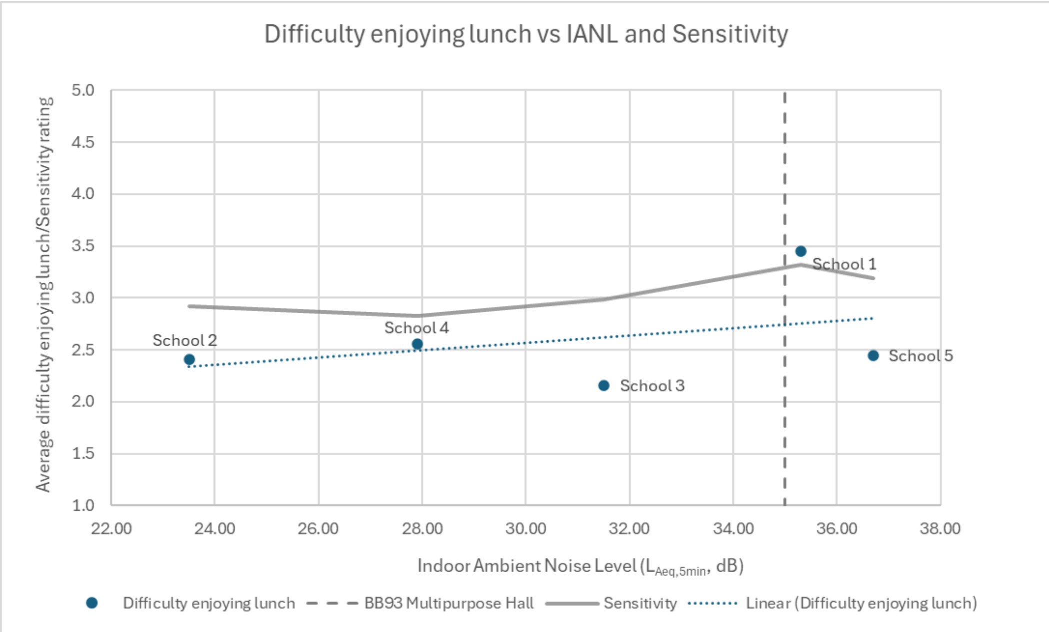


Figure C-12 below shows the graph for difficulty enjoying lunch and IANL.

Figure C-12: Average difficulty enjoying lunch rating vs IANL



APPENDIX D

CATT MODEL COEFFICIENTS

Table D-1 below shows the absorption coefficients used in the calibrated CATT model of School 1.

Table D-1: Absorption coefficients for School 1 CATT model

Surface	125	250	500	1k	2k	4k
Curtain	0.20	0.30	0.50	0.70	0.90	0.90
Vinyl floor	0.03	0.03	0.04	0.05	0.05	0.06
Glazing	0.10	0.07	0.06	0.03	0.02	0.02
Timber doors	0.14	0.10	0.06	0.08	0.10	0.10
Class A ceiling tiles	0.40	0.85	1.00	0.90	1.00	1.00
Walls*	0.16	0.15	0.17	0.20	0.21	0.19
*Note a composite calculation for the total absorption of the walls with 44m^2 of panel coverage was used.						