Comparison of environmental and acoustic factors in occupied school classrooms for 11-16 year old students

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This paper analyses and compares environmental and acoustic measurements taken from 12 contrasting schools in England. The 203 classrooms measured ranged in age, style (open plan, semi open plan and cellular) and external noise levels. The occupied environmental measures were: CO_2 count, relative humidity, temperature and light intensity. The occupied acoustic measures taken were: L_{Aeq}, L_1, L_{10} and L_{90}. In addition, ventilation strategy, room dimensions and student numbers were also recorded. Lesson averages were compared to remove fluctuations observed in some parameters during lessons. Large variations in CO_2 levels were observed between schools with 39% exceeding recommended guidelines. Lighting levels were predominantly below the recommended level required for demanding tasks. Classrooms with mechanical ventilation had higher background noise levels than those using natural ventilation. Most environmental parameters were uncorrelated with acoustic parameters. A notable exception was the correlation between L_{Aeq} and CO_2 count; due to the relationships between these parameters, number of students and classroom floor area. A regression model was produced predicting a doubling in L_{Aeq}, with a 67% increase in student numbers.

Keywords: classroom, acoustic, CO2, occupied, ventilation, noise

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1. Introduction

This paper considers what relationship exists between indoor air quality (IAQ) and noise levels in learning environments for 11-16 year olds (secondary schools). There is increasing evidence that poor indoor air quality reduces student attention and vigilance and that noise makes it harder for children and teachers to hear and understand each other which has a detrimental effect on children's attainments. But is there a link between environmental factors and sound levels?

A relationship between CO_2 and sound levels might be assumed to exist because both are influenced by the ventilation scheme for a classroom. For instance, if ventilation is provided via windows which open onto a noisy street, then a strong relationship between CO_2 and sound levels might be anticipated. Furthermore, it might be hypothesised that raised CO_2 levels may lead to increased sound levels because of loss of concentration and attention, resulting in student distraction and noise. No published studies have investigated the relationship between acoustic and environmental factors for secondary schools.

As well as looking at the relationship between environmental factors and noise levels, this paper will also address the following questions:

1. To what extent do environmental factors vary across the schools studied?
2. Do environmental factors vary between newer and older classrooms?
3. Do environmental factors vary between open plan and cellular classrooms?
4. Does the type of classroom ventilation affect sound level?

The data was collected as part of a project to investigate the acoustic environment in secondary schools. The project includes acoustic and noise surveys of a wide range of teaching spaces in both unoccupied and occupied conditions; questionnaire surveys of students and teachers; and testing of student performance in different noise conditions.

1.1 Background

Poor indoor environmental quality (IEQ) has been related to increases in sick building symptoms [1], such as: respiratory illnesses, sick leave and losses in productivity in offices and schools [2]. The World Health Organisation reported children and young people can be more susceptible to the effects of poor air quality, both indoors and outdoors, as their lungs are still developing and they take in proportionately more air than adults [3]. The significant amount of time students spend in school makes it an important area to study. Children spend almost 12% of their time inside classrooms, more time than in any other building environment except their home [4][5].

Previous research has highlighted that IEQ is an important concern for teachers, especially in urban areas and that there has been a correlation shown between inadequate ventilation in schools and poor pupil performance [6]. The investigation provided strong evidence that low ventilation rates in classrooms significantly reduce pupils' attention and vigilance and negatively affect memory and concentration. The study also demonstrated that the attentional processes of school children were significantly slower when the level of CO_2 in studied classrooms was high.

Many previous investigations have examined the relationship between noise exposure of school children and their performance in cognitive tasks. It is widely accepted that noise has a negative effect upon the learning and attainments of 5 to 11 year old school children [7]. According to this review paper, the effects of continued noise exposure on children include: reduced attention, impaired auditory discrimination and speech perception, poorer reading ability and a reduction in school performance on national standardised tests.

Up until recently, guidance for the design of schools in England and Wales has been given via a set of building bulletins. These guidelines will be used to contextualise the findings presented. Table 1 summarises the quantitative guidance for environmental and acoustic variables from BB87 - Guidelines for Environmental Design in Schools; BB90 – Lighting Design for Schools, BB101 – Ventilation of School Buildings and BB93, Section 1 – Acoustic Design of Schools. The asterisked value in the table comes from [8], as there are no guidance for minimum humidity in the Building Bulletins.

Table 1

Minimum, recommended and maximum values for environmental & acoustic variables

	Minimum	Recommended	Maximum
CO_2 concentration (ppm)	N/A	<1500	5000
Temperature (°C)	18	24	32
Humidity (%RH)	40*	N/A	70
Light intensity (LUX @ working plane)	300	500	N/A
Indoor ambient noise level ($L_{Aeq,30\ min}$ dBA)	N/A	N/A	35

BB93 specifies acoustic performance standards to create classroom conditions that aid clear speech communication between student and teacher and provide conditions that do not interfere with study activities [9]. This uses unoccupied measurements including contributions from the following noise sources:

1. External sources including: road, rail and aircraft noise, nearby industrial and commercial premises etc.
2. Building services, e.g. ventilation systems, plant etc.

The building services contributions assume that in the case of natural ventilation, windows are open as required to provide adequate ventilation. In mechanically ventilated rooms, the plant is assumed to be running at its maximum operating duty. In contrast, the environmental guidelines are all specified for occupied conditions, with no specification on plant operating duty. With the current studies dataset including both occupied and unoccupied measurements of environmental and acoustic data, interactions between these classroom factors can be investigated for the first time.

A UK study by The Office of the Deputy Prime Minister carried out indoor air quality surveys within the classrooms of eight Primary Schools in Southern England [8]. CO_2 concentration, relative humidity (%RH) and temperature levels were measured continuously throughout the day in each classroom. The majority of these classrooms fell below the recommendation of BB101: Ventilation of School Buildings [10] of 3 L/s. Whilst teachers were advised to open windows to meet these recommended air quality levels, one of the reasons some avoided doing this was due to external noise entering classrooms.

Previous research has shown that the concentration of CO_2 levels in an environment is a good indicator of indoor air quality [11]. Research by Shendell *et al.* in 2004 [12] supports CO_2 levels as an indicator of pollutant concentration, showing that a 1000ppm increase in CO_2 concentration above outdoor levels corresponded to a 10–20% increase in school absenteeism. It is argued that student absence reflects, amongst other things, communicable respiratory illnesses that are likely to proliferate in schools with poor ventilation.

Within England, there has been an intensive programme of new school construction, Building Schools for the Future (BSF), but this was stopped by the British Government in 2010. In comparing new and old schools, this paper considers new classrooms to be ones designed and constructed to adhere to the acoustic and environmental requirements set out in BB93 and BB101 after the start of the BSF scheme in 2005. To date, only a small number of studies have incorporated measurements from these more recent school constructions.

2. Measurement

The environmental variables measured were: CO_2 concentration (ppm), temperature (°C), relative humidity (%RH) and light intensity (LUX). CO_2 and temperature measurements were taken using the Duomo SenseAir, which provides a measurement range of 0-6000ppm for CO_2 concentration with an accuracy of ±3% or ±20 ppm (whichever is greater). %RH readings were logged using an Omega OM-62 with an accuracy of ±2%RH up to 90%RH. Both instruments gave temperature to an accuracy of ±0.5 °C. The data loggers gathered measurements at one minute intervals throughout the school day. CO_2 measurements were only gathered in four schools due to equipment malfunction.

Average ambient and table top light readings were logged during lessons every five minutes using a Solex Lux meter SL100. Measurements were noted uncalibrated, and then corrected using a calibrated meter after all measurements had been taken. Acoustic measurements were logged every second using a type 1 Norsonic Nor140 Sound Analyser, with an accuracy of ±0.2 dB. The L_{Aeq} measurements used in the analysis were calculated from the instantaneous measurements made during the lesson period; therefore the integration periods for each classroom differ slightly around a mean of 43.1 minutes, with standard deviation of 9.9.

All measurements were made at a location in the room chosen so as to minimise disruption to teaching (usually at the back or to one side of the room). Lesson noise levels and ambient light intensity (sensor facing front of class/teacher position) were measured at a seated head height of 1.2 – 1.3 m from the floor. The instruments measuring table top light intensity (work surface), indoor air quality (CO_2), temperature (air/ambient) and relative humidity were all placed on a table in front of the researcher (height ≈0.7 m from the floor). Although the researcher was present during the measurement process, care was taken to ensure that the researcher’s proximity to the measurement devices did not adversely affect the data recorded, and that inlet and outlet vents of the CO_2 meter were not obscured.

Estimates were made of the indoor ambient noise levels (IANL) by taking measurements while each classroom was unoccupied. The equivalent continuous noise level was measured for a period of between 1 and 5 minutes. (BB93 performance specifications require a 30 minute measurement).

Each room’s ventilation strategy was noted and is defined as:

- No ventilation (mechanical ventilation off and no windows open)
- Natural only (opened windows)
- Mechanical only (via ventilated ducting)
- Natural & mechanical (using a combination of the previous two methods)

A total of 12 schools were visited over a period of 20 months from November 2009 through to June 2011. Schools were selected to provide varied levels of school performance (in terms of student attainment and inspection scores), a range of external noise levels (ranging from 45-60 dBA) and a mixture of open plan and cellular classrooms. 26% of measurements were in autumn, 27% in winter, 41% in spring and 6% in summer.

The rooms tested were chosen to gather noise and environmental data from:

1. Core subject lessons (Maths, English, Science, Modern Foreign Languages and Humanities)
2. Classrooms perceived as either 'easy' or 'hard' to hear in the questionnaire survey of pupils [13].

A total of 203 classrooms were measured with an average of (16.9 ± 4) rooms in each school. Three types of classroom were sampled: (1) cellular were regular classrooms with door(s), (2) semi-open plan were cellular classrooms with open apertures (i.e. without doors), and (3) open plan where there is more than one class-base in the same room.

The classrooms varied in age: 6% were constructed in the 1950s, 29% in the 1960s, 8% in the 1970s, 30% in the 1990s and 27% in the 2000s. 85% of measurements were taken in classrooms that predated BSF. Eight different lesson types were measured: english (27%), geography (2%), history (2%), humanities (3%), maths (28%), modern foreign languages MFL (6%), music (1%) and science (30%).

3. Analysis & Discussion

3.1. Data preparation

A typical lesson period consists of a number of different activities, each with their accompanying acoustic characteristics. Some of the more common activities observed were: teacher instruction, independent work and video watching. As the environmental and acoustic data fluctuated greatly during a lesson, it was decided that means calculated over a whole lesson would be used for analysis. A quick analysis showed that comparing the relatively slow varying environmental variables with the faster varying noise levels did not serve to identify any useful trends or relationships.

The means excluded the first and last five minutes of each lesson. This was done to exclude the high sound levels produced by students settling down and packing up, as well as the drop in CO_2 concentration that occurs when the classroom doors are opened at the start and end of the lesson. Fig. 1, illustrates the A-weighted sound pressure level (L_{Af}) and CO_2 count, demonstrating the effect of the beginning and the end of the lesson and the different temporal variation in variables. Consequently, the means reflect the lesson while the students are actually learning, not when they are in transition between lessons.

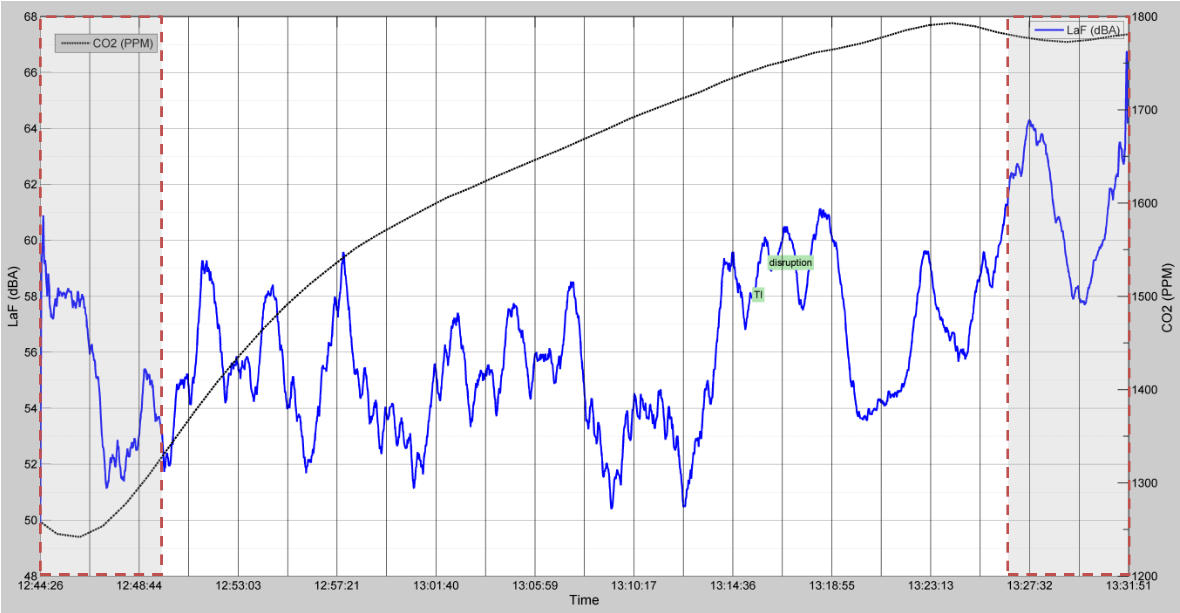

Fig. 1 Time history of L_{Af} (dBA) and CO_2 count for one lesson, only the central unshaded region was considered further in the analysis.

3.2. Summary data: school comparison

The summary data comparing each school's environmental condition will be discussed in this section. Table 2 gives a summary of the main measured continuous variables.

Table 2

Descriptive statistics for main measured continuous variables

	Pupil space	No. pupils	CO_2 count	Temp	%RH	L_{Aeq}	IANL
N	198	202	75	201	203	203	203
Mean	4.4510	22.82	1547.73	21.054	50.87	64.534	36.540
Mean std. error	.27276	.994	114.741	.1343	.654	.4022	.3660
Range	31.03	87	4363	9.7	44	34.1	23.1
Std. deviation	3.83803	14.127	993.690	1.9037	9.324	5.7303	5.2150
Minimum	1.47	2	137	16.8	31	45.5	25.4
Maximum	32.50	89	4500	26.6	75	79.6	48.5

No classrooms exceed the maximum CO_2 level of 5000ppm. 39% of all measured classrooms exceeded the recommended CO_2 level of 1500ppm specified in BB101. Of the 39% exceeding the recommended CO_2 level, 93% were pre-BSF constructions (Chi-Square(1, N = 29) = 21.552, p < .001).

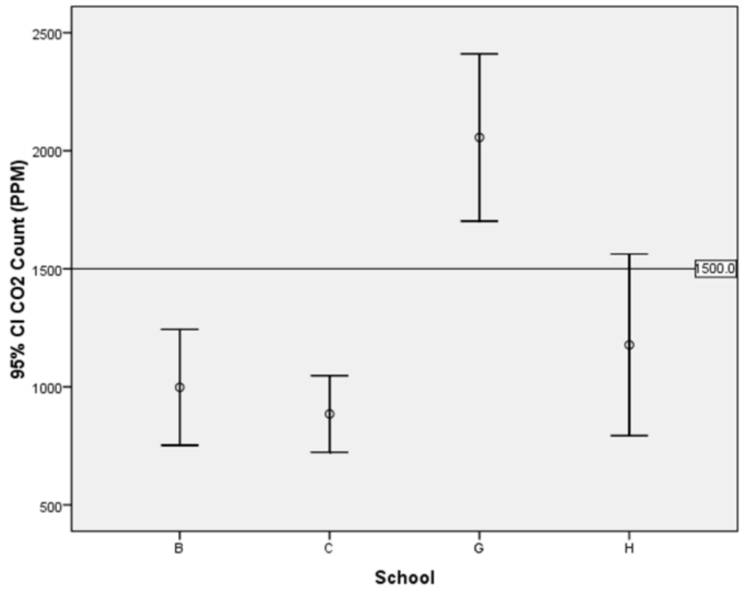

Fig. 2 Mean CO_2 counts with 95% confidence interval for each school with maximum recommended labelled

Of all the environmental variables measured CO_2 count varied the most between schools, as seen in Fig. 2. Classrooms in school G exhibited consistently higher CO_2 counts than the other three, with the majority of these classrooms exceeding the BB101 recommended daily maximum. The ventilation strategies of this school were a combination of no ventilation in use and natural ventilation only. No classrooms exceeded the stated maximum temperature of 32° C. 4.9% were below the recommended minimum temperature.

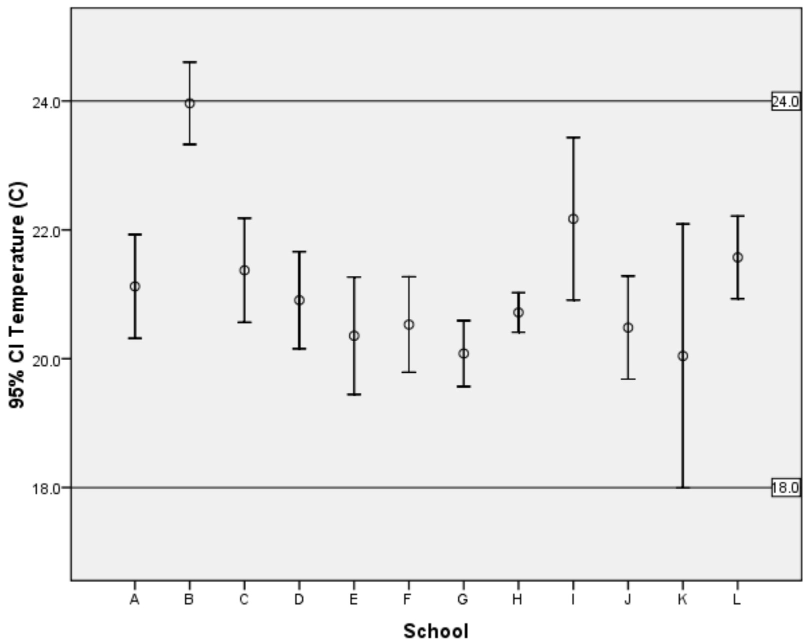

Fig. 3 Mean temperatures with 95% confidence interval for each school with minimum and recommended labelled

Average classroom temperatures were largely similar for the schools, as seen in Fig. 3, with the exception of school B showing a significantly higher mean of 24°C. Measurements of school B were done in the warmer month of mid-May; this room could only be naturally ventilated. Only 2.5% of classrooms exceeded the recommended maximum %RH level (fig. 4). 12.8% were below the recommended minimum. Low %RH can lead to drying of the eyes and throat over prolonged periods [14].

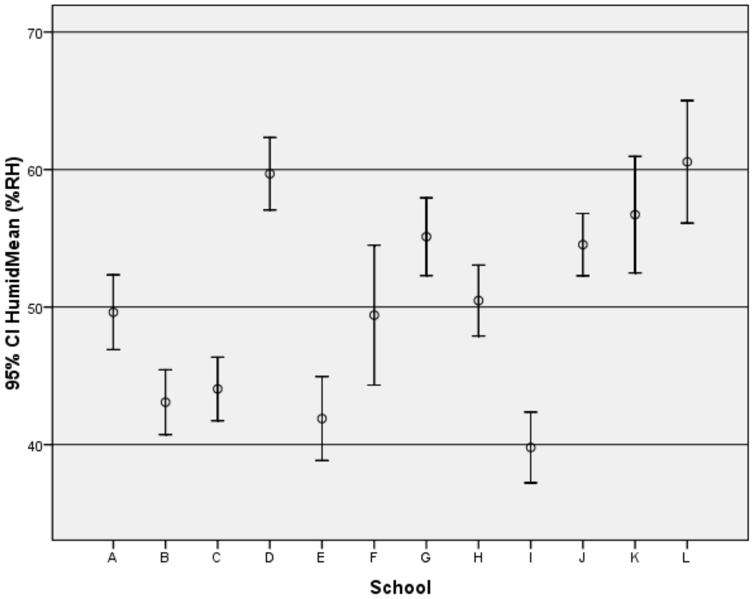

Fig. 4 Mean relative humidities with 95% confidence interval for each school with minimum and maximum recommended labelled

LUX readings were taken at table top height, in line with the advised minimum levels defined in BB90, Lighting Design for Schools [15]. 30% of classrooms fell below the minimum level of 300 LUX, with 63% falling below 500 LUX, the recommended minimum level for demanding tasks.

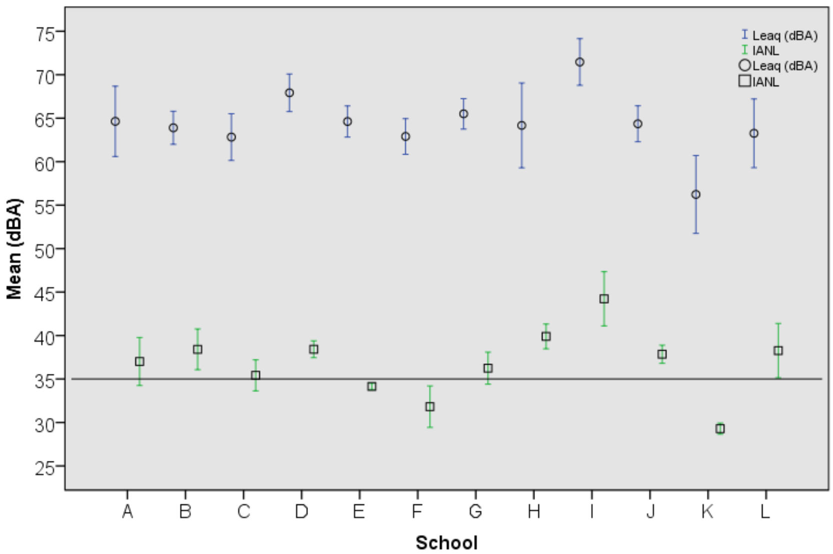

Fig. 5 Mean occupied IANL and L_{Aeq} for each school, with 95% confidence intervals with maximum IANL line (□ = unoccupied IANL, ○ = L_{Aeq})

Fig. 5 shows the mean occupied L_{Aeq} and unoccupied IANL measurements for each school. Classroom L_{Aeq} ranged from 45.5-79.6dBA, with an overall mean of 64.5dBA (std. = 5.7, N = 203).

IANL ranges were 25.4-48.5dBA, with an overall mean of 36.4dBA (std. = 5.3, N = 47). 67% of classrooms had IANL's above the BB93 standard of 35dBA (Chi-Square (11, N = 203) = 89.607, p < .001). Schools D, H, I and J did not have any rooms with an IANL below 35dBA; in fact no schools achieved 100% compliance with the BB93 acoustic standard.

3.3. Influences on L_{Aeq}

With an aim to uncover how and if each variable influenced lesson L_{Aeq}, a stepwise regression [16] was carried out using L_{Aeq} as the dependent variable. With the focus on cellular classrooms, the data exhibited normality so allowing for a stepwise regression. The following predictor variables were initially submitted to the regression: pupil number, floor area, unoccupied IANL, CO_2 count, temperature and %RH. The stepping criteria used allowed variables into the model if the F statistic was significant at the 95% level, with rejection at the 90% level. A significant model emerged ($F(2,65) = 16.22$, $MSE = 375.93$, $p < .001$) , with an adjusted R^2 value of 0.312. The model consists of two variables: unoccupied IANL (standardised beta = 0.358, $p = .001$) and pupil number (standardised beta = 0.438, $p < .001$). The constituent parts of pupil space (pupil number & floor area) were used in the regression instead of pupil space itself, in a bid to uncover the influence of both elements of pupil space on L_{Aeq}.

Based on the standardized coefficients of this model, with unoccupied IANL held constant, an increase of 0.33 dB in lesson L_{Aeq} per student is predicted. The predictions made by this model should only be considered valid for class sizes within the range that has been measured in this study (2-34). Given the logarithmic nature of sound pressure level, a better model uses the decimal log of the pupil number. In this case a significant model emerges ($F(2,65) = 23.62$, $MSE = 475.22$, $p < .001$) , with a higher adjusted R^2 value of 0.403. The model consists of two variables: unoccupied IANL (standardised beta = 0.367, $p < .001$) and log pupil number (standardised beta = 0.529, $p < .001$). Based on this model, an increase in class size of 67% roughly equates to a 3dB increase in sound pressure level (if the pupils were independent noise sources, then a 200% increase would give a 3dB increase).

3.4. Pupil space

Wohlwill and van Vliet examined the effects of high density classrooms on children [17]. They concluded that high density classrooms, with too many children or too little space, can lead to excessive pupil stimulation, stress and arousal; a drain on resources available; considerable interference; reductions in desired privacy levels, and loss of control. With this in mind, a variable taking into account of floor area and number of pupils is needed in the analysis. For the purposes of this study, the term pupil space is used to describe the number of square meters per pupil. In this study pupil space ranged from 1.47 to 32.5 m^2, with a mean of (4.45 ± 0.54 m^2). The wide range of room sizes means that the pupil space data has a non-normal positive skew; therefore non-parametric statistical analysis are used below.

The importance of considering pupil space in further analysis is shown in its significant correlation with the main environmental and acoustic factors under scrutiny in this study. Pupil space shows highly significant negative correlations with CO_2 count (Spearman's rho = -.497, $p < .001$), %RH (Spearman's rho = -.227, $p = .001$) and L_{Aeq} (Spearman's rho = -.342, $p < .0001$). These correlations are understandable as more students in a smaller classroom space would inevitably lead to increases in CO_2 count and L_{Aeq}. Ventilation strategy and unoccupied indoor ambient noise level (IANL) are other measured variables which can have an effect on CO_2 count and L_{Aeq} respectively, where IANL is the average unoccupied background noise level of the classroom in dBA.

Pupil space is understandably significantly different between cellular and open plan classrooms, (Mann-Whitney U = 473, Z = -4.554, $p < .001$) as shown in Table 3.

Table 3

Mean value comparison for cellular & open plan classrooms

	Mean Value			
Room type	Floor Area (m^2)	Volume (m^3)	No. Pupils	Pupil Space (m^2)
Open Plan	285.8	728.8	50	7.58
Cellular	63.6	177	20	4.17

Due to the significant size differences between open plan and traditional cellular teaching spaces, it was decided to focus on the more common cellular classrooms in further analysis. Light intensity measurements were also left out of this stage of the analysis, due to their high fluctuation throughout the lesson period caused by lights being switched on and off for low light conditions and projector use. These instantaneous changes make the light intensity lesson average variable a skewed representation of the classrooms light intensity.

3.5. New verses old classrooms

A Mann-Whitney test is used to compare new and old classrooms. Non-parametric comparisons are used because of the non-normality of the data within each comparison group. 15% of classrooms in the study were newer BSF constructions. Average CO_2 counts differed significantly between the new and old constructions as shown in Table 4. Non-BSF classrooms averaged 1698 ppm, above the BB101 recommended daily count of 1500 ppm, with BSF classrooms averaging at 995 ppm. A significant difference in floor area, room volume and pupil space is also observed. Humidity averages show no significant differences.

Table 4

Results of Mann-Whitney test between BSF & non BSF classrooms

	Pupil space	**CO_2 Count**	**L_{Aeq}**	**Floor area**	**Room volume**
Mann-Whitney U	1578.500	278.000	2235.000	1587.500	1519.000
Z	-3.447	-2.509	-1.432	-3.421	-3.653
Asymp. Sig.	.001	.012	.152	.001	.000

Based on the significant differences observed between these room types, it can be inferred that BSF classrooms are significantly more spacious than pre-BSF rooms. Mean pupil space in pre-BSF classrooms is $4.1m^2$ per student as opposed to $6.4m^2$ per student in BSF classrooms. The significant difference in CO_2 count could be attributed to this difference in pupil space between room types.

3.6. *The effects of ventilation strategy*

Classrooms were grouped into ventilation types by observations made during each lesson. Ventilation type unadjusted for pupil space shows a clear change in CO_2 count as the ventilation strategy changes.

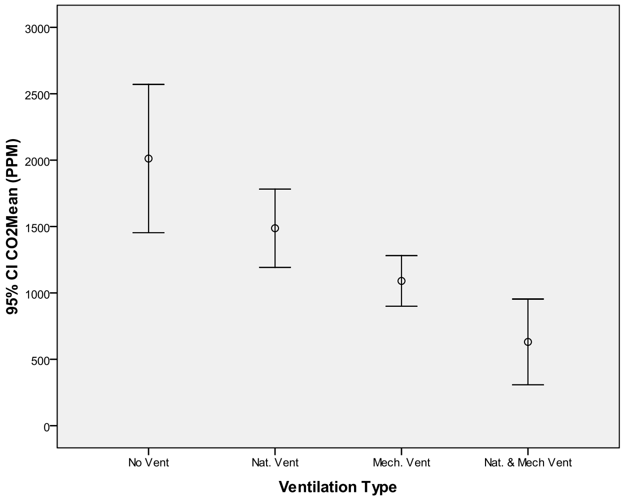

Fig. 6 Mean CO_2 count and 95% confidence interval for each ventilation type with maximum recommended labelled

The results of a Kruskal–Wallis test revealed significant differences between the environmental variables under different ventilation strategies (Table 5). Ventilation type showed no significant difference between the acoustic variables in this test.

Table 5

Results of Kruskal-Wallis test between ventilation strategies

	CO_2 Count	Temperature	%RH	L_{Aeq}	L_{A90}	L_{A1}	Pupil Space
Chi-Square	**9.066**	**22.047**	**9.993**	5.980	5.753	6.594	5.944
df	**3**	**3**	**3**	3	3	3	3
Asymp. Sig.	**.028**	**.000**	**.019**	.113	.124	.086	.114

Mann-Whitney U tests were carried out between the individual ventilation strategies employed in classrooms shown in Table 6. There were only 2 classrooms making use of both mechanical and natural ventilation so these were not included in the comparison. All differences quoted between variables in each condition are between the medians, due to the non-parametric nature of the test.

Table 6

Mann-Whitney U tests between classroom ventilation strategies

	CO_2 Count	Temperature	%RH	L_{Aeq}	L_{A90}	L_{A1}	Pupil space
No ventilation vs. natural							
Mann-Whitney U	301	**2578**	**3509**	**3412**	4010	**3347**	3888.5
Z	-1.806	**-4.561**	**-1.981**	**-2.25**	-.593	**-2.43**	-.333
Asymp. Sig.	.071	**.000**	**.048**	**.024**	.553	**.015**	.739
No ventilation vs. mechanical							
Mann-Whitney U	75	509	**518**	643	**543**	691	600
Z	-1.909	-1.820	**-2.393**	-1.389	**-2.265**	-1.004	-1.464
Asymp. Sig.	.056	.069	**.017**	.165	**.024**	.315	.143
Natural vs. mechanical							
Mann-Whitney U	191	529	613	729	**512**	688.5	588.5
Z	-1.064	-1.225	-1.174	-.165	**-2.053**	-.518	-1.388
Asymp. Sig.	.287	.221	.240	.869	**.040**	.605	.165

It is worth noting that pupil space is not seen to be significantly different between ventilation types. This suggests that pupil space does not have a strong influence on the differences in the other variables being tested. Significant differences in pupil space between strategies would be expected if it was indeed having an effect on the significantly changing variables. Interestingly, CO_2 count is also not significantly different when tested between ventilation types, contrary to what would be expected. However, there is a close to significant difference between the no ventilation and mechanical ventilation groups, suggesting that mechanical ventilation has more of an effect on CO_2 count than natural only. Temperature is seen to be significantly different when natural ventilation is used as opposed to no ventilation at all. %RH shows a smaller difference between these two conditions based on its z-value. L_{Aeq} shows a significant difference only between these conditions, suggesting that opened windows result in higher internal sound levels (+1.5 dBA). A difference in the first percentile L_{A1} is also seen (+2 dBA), which could be an indication of short term external noise entering through open windows.

When comparing between no ventilation and mechanical ventilation, %RH shows an increased difference over natural ventilation (+3.56 %RH). A significant difference in L_{A90} (an indication of background noise level) may be attributed to the noise produced by the mechanical ventilation itself (+2.8 dB), as a significant difference in this variable is also seen in the natural vs. mechanical comparison (+2.9 dB). This suggests that mechanical ventilation adds to the background noise level of a classroom more than natural ventilation.

3.7. Open plan / cellular classroom comparison

To investigate the difference between a true open plan teaching space and a traditional cellular classroom, room type 2 (semi-open plan) was excluded from the analysis. 85.7% of all classrooms were classed as cellular with 8.5% classed as open plan and the remaining 5.9% as semi-open plan, which were excluded in the following analysis. Table 7 shows the Mann-Whitney U tests between the two room types. Non-parametric tests are used because the data does not satisfy the assumption of normality.

Table 7

Mann-Whitney U tests between open plan and cellular classrooms

	CO_2 Count	Temperature	%RH	L_{Aeq}	L_{A90}	L_{A1}	Pupil space
Mann-Whitney U	**79**	1197	**953**	1224	**925**	**1036.5**	**473**
Z	**-2.896**	-1.232	**-2.418**	-1.172	**-2.547**	**-2.034**	**-4.554**
Asymp. Sig.	**.004**	.218	**.016**	.241	**.011**	**.042**	**.000**

Based on these results it would seem that these room types have similar L_{Aeq} values. The significance of the background sound level L_{90} difference may be due to the difference in pupil space observed, as could the short term sound level L_1 difference. The significant differences seen in CO_2 count and %RH suggest that these rooms exhibit a distinction in their environmental conditions. With open plan spaces being much larger and generally containing more students during a lesson period, these room type comparisons require these factors to be considered. With the high z-value of pupil space, this suggests that this may be a confounding factor in the comparisons of other variables between room types.

3.8. Correlation analysis

When calculating a Spearman's rho correlation between the main variables in the study without considering pupil space, moderate correlations are seen between CO_2 count and acoustic variables as shown in Table 8.

Table 8

Spearman's Rho correlations between main variables (NS=not significant)

	Acoustic (Spearman's Rho)			
Environmental (Spearman's Rho)	L_{Aeq}	L_1	L_{10}	L_{90}
CO_2 Count	.315***	.284**	.340***	.216*
Temperature (°C)	NS	NS	NS	NS
Humidity (%RH)	NS	NS	NS	NS

** = p < 0.1* ***= p < 0.05* ****=p < 0.01*

To test the assumption that the correlation observed between the acoustic and environmental variables hides a more complex relationship, a partial correlation analysis was carried out, controlling for pupil space. No significant correlations were observed. This shows that the observed relationship between CO_2 count and acoustic measures are predominantly due to the number of students present in the class and its floor area.

4. Conclusions

The present study has examined the relationship between environmental and acoustic variables within classroom spaces for 11-16 year olds. No causal relationship have been observed between the acoustic and environmental variables, any significant correlations observed appear to be due to changes in pupil numbers and floor area. The more modern BSF classrooms have shown improvements in IEQ over their pre-BSF counterparts. Somewhat surprisingly, the effectiveness of the different ventilation strategies employed, revealed that CO_2 concentrations were not significantly affected by utilizing mechanical or purely natural ventilation as opposed to rooms using no ventilation during measurements. The opening of windows seemed to provide an improved temperature reduction over mechanical ventilation, although mechanically ventilation classrooms showed reduced %RH amounts over naturally ventilated classrooms. A side effect of window opening was seen in the increase in L_{Aeq} and L_1 values, suggesting that external noise levels were having an effect on the internal classroom sound environment. The raised ambient sound level measure L_{90} seemed to be indicative of a background noise increase caused by the use of mechanical ventilation.

It was apparent that pupil space played an important role in determining classroom situations in terms of both their environmental and acoustic characteristics. When comparing open plan with cellular classrooms, differences between variables were confounded by this influential factor. It may seem an obvious conclusion that the more students present in a smaller space would lead to an increase in L_{Aeq} and CO_2 concentration, but with more research, this could lead to improved design guidelines that factor in proposed pupil space with optimal environmental and acoustic thresholds.

5. Acknowledgements

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Figure captions

Fig. 2 Time history of L_{Af} (dBA) and CO_2 count for one lesson, only the central unshaded region was considered further in the analysis.

Fig. 2 Mean CO_2 counts with 95% confidence interval for each school with maximum recommended labelled

Fig. 3 Mean temperatures with 95% confidence interval for each school with minimum and recommended labelled

Fig. 4 Mean relative humidities with 95% confidence interval for each school with minimum and maximum recommended labelled

Fig. 5 Mean occupied IANL and L_{Aeq} for each school, with 95% confidence intervals with maximum IANL line (□ = unoccupied IANL, ○ = L_{Aeq})

Fig. 6 Mean CO2 count and 95% confidence interval for each ventilation type with maximum recommended labelled

Fig. 1 = Full page width

Fig. 2-4 = Small column size

Fig. 5 = Full page width

Fig. 6 = Small column size