A Field Survey on the Indoor Environmental Quality of the UK Primary School Classroom

The paper was originally published in British Journal of School Nursing December 2016/January 2017 Vol 11 No 10 pp492-496

Authors

Dr. Yufan Zhang*
University of Huddersfield, School of Arts Design and Architecture, Queen Street Building, Huddersfield HD1 3DH, UK
Tel: 01484 471632
Email: y.zhang2@hud.ac.uk

Professor Peter Barrett
Emeritus Professor, University of Salford, School of the Built Environment, Maxwell Building, Salford, M54WT, UK.
Tel: +44 (0)7872 176655
email: peter.x.barrett@gmail.com

Dr. Fay Davies
Associate Researcher, School of the Built Environment, University of Salford
Tel: 07443 597743
Email: faynortleydavies@gmail.com

Dr. Lucinda Barrett
Nutbox Consultancy, Whitegates, Corbar Woods Lane, Buxton, SK176RH
email: lucinda.c.barrett@gmail.com

* Corresponding author

ABSTRACT: The indoor environmental quality (thermal, visual, acoustic and air quality) of the primary school classroom has become of specific concern when it comes to the pupils' learning and well-being. A field study, conducted on random days from 2012 to 2013, was carried out in 203 classrooms from 30 primary schools in 3 areas within the UK. Physical parameters were measured at the site: illuminance, air temperature, relative humidity, CO_2 concentration and noise level. It was inferred that:(i) 30.9% classrooms did not meet the proposed standards limiting the level of CO_2 levels; (ii) light levels were found to be notably low (less than 500 lux) because the pedagogy was reliant on smart boards; (iii) high noise levels (between 40 to 80 dBA) were caused mainly from the adjacent activity areas to the classroom. Based on the findings, practical suggestions are proposed to maximize the environmental benefit to the pupils.

Keywords: classroom, indoor environmental quality, health

1. Introduction and Background

It is well established that the impact of the physical environment on pupils' health, attitude and performance is significant (Daisey et al, 2003; Heschong et al, 2002; Dijken et al, 2006; Zeiler and Boxem, 2009; Clements-Croome et al, 2008). Building and environmental regulations, recommendations and standards often address factors such as air temperature, noise level, ventilation rates etc. in an acceptable range separately. However, individual environmental factors have notable combined effects on occupants' sensation and comfort. Bluyssen et al, (2011) highlight the importance of understanding indoor environmental quality (IEQ) and suggest the individual factors, "… can cause their effects additively or through complex interactions (synergistic or antagonistic)." This is especially important to pupils in school, who are more sensitive to environmental factors than adults. Only when a comprehensive view of built environment factors is fully understood, will it be possible to improve the physical environment, to not only meet the required environmental standards, but also to achieve a positive impact on pupils' well-being. This study is an attempt to provide empirical evidence of the current situation and develop the discussion in this direction.

In this study, IEQ refers to thermal, visual, acoustic and air quality conditions, reflected by four, physical parameters: air temperature and relatively humidity (thermal), illuminance (visual) and CO_2 level (air quality). They are discussed, in turn, with reference to environmental regulation and/or recommendations published by the UK Department for Education and Skills (DfES) so far.

Light: A few studies have been published specifically on the impact of lighting design on students and/or in classrooms (Heschong et al, 2002; Tanner, 2009; Barrett et al, 2013). All of them found positive correlations between daylight and pupils' learning progress from field surveys and substantial samples. The DfES (1999) also indicated that: 'Natural lighting during daylight hours should always be the major source.' It further recommended the standard, maintained illuminance for general teaching spaces should be 300lux. For close and detailed work, the teaching spaces should be maintained at the 500lux level.

Temperature: Zeiler and Boxem (2009) have undertaken a thorough review of the effects of thermal quality in schools on the learning performance of students. They clearly showed that the thermal environment has a great influence on the students' performance. The DfES (2003a) recommended that in winter, the heating system should be capable of maintaining the air temperature at 18°C (minimum value). In summer time, overheating was defined as the internal air temperature exceeding 28°C.

Air Quality: Daisey et al. (2003) and Mendell and Heath (2005), reviewed the literature on indoor air quality, ventilation and student performance in schools. They found ventilation was inadequate in many classrooms, leading to direct and indirect connections to ill health symptoms, performance or attendance. This has all been confirmed more recently in detailed field studies (Mumovic et al, 2007; Clements-Croome et al, 2008; Grimsrud et al, 2006). The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 2004), set a guideline that the indoor CO_2 level should be below 1000ppm. The DfES (2005) specifically indicated that the concentration of carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day, should not exceed 1500ppm.

Noise: There have been many published studies of the acoustic conditions in classrooms and two reviews (Crandell and Smaldino, 2000; Shield and Dockrell, 2003) which stated that the acoustic environment of a classroom was a critical factor in the academic and psychosocial achievement of children. The DfES (2003b) suggested that 30dBA was the upper limit of performance standards for indoor ambient noise levels. For classrooms, the background noise should be limited to 35dBA or less and not regularly exceed 55dBA.

The above studies are currently the most closely related to the present study. This shows that the need to maintain a comfortable IEQ is a significant requirement in classrooms for pupils' well-being and productivity. However, what these studies also show is that they only focus on one or two environmental factors. Pupils' sensations and perceptions are usually not determined by a single factor, but rather, an overall situation based on many different factors. This has also been addressed by Mumovic et al. (2009), who also worked on the complex interaction between ventilation, thermal comfort and acoustics. In order to provide confidence when embarking on a comfortable and healthy built environment for pupils in the classroom, IEQ needs to be addressed and investigated from a holistic perspective. This study is therefore focused on making a contribution, by examining the classroom's IEQ under the current environmental regulations and recommendations, formulated and verified by fieldwork in 203 classrooms from 30 primary schools in 3 areas within the UK.

2. Method of Study

All schools investigated are in England, UK, located in Blackpool, Hampshire and London. The fieldwork was carried out on random days from November 2012 to December 2012 (Blackpool), June 2013 to July 2013 (Hampshire) and October 2013 to November 2013 (London).

The Councils in each of the three areas provided access to 30 primary schools, of which, 28 were typical, mainstream primary schools with a total of pupils from 143 to 819 and 2 special schools with a total of pupils from 12 to 79. Whilst all schools were purpose-built for primary education, there was a big variation across the sample in terms of pupil size, building years (from 1880s to 2000s) and location (urban:13; 45%, rural:8; sub urban area:9).

The procedure was applied in a similar manner in each school and classroom. The researchers visited the head teacher and explained the purpose of the study and the intended procedure for the work.

A few classroom samples were then discussed and selected. With their permission, each classroom was visited with and/or without the pupils present during the school hours. This was not only to minimize the disturbance to their normal school activity, but also to test the impact of pupils' occupancy on IEQ. Major physical parameters of indoor environmental information were measured: air temperature, relative humidity (RH), illuminance, noise level and CO_2 concentration. A four-in-one, digital, multi-function environment meter was used which is a portable test instrument designed to combine the functions of the Sound Level Meter, Light Meter, Humidity Meter and Temperature Meter. An Indoor Air Quality Monitor was used to measure CO_2 concentration using a non-dispersive infrared sensor. In order to obtain reliable data that could represent the overall situation, the measurement was carried out on pupils' working tables at different spots in the classroom e.g. near, middle and away from the window, heater or fans. The measurements that represented a median situation were used in this study. In addition, a face-to-face interview with the teacher was carried out with the aim of exploring how, from the teacher's point of view, the room functioned through the rest of the year with respect to the IEQ of their classrooms.

3. Results and Analysis

3.1 Illuminance

The illuminance level among these classrooms was quite varied from around 200 to 2000lux, with the highest being 10 times greater than the lowest. The main observation to be drawn from the results was the relatively low brightness found in practice. Statistically, 24.7% (N=194) of lighting levels in the classrooms was lower than 300lux, which was the minimum requirement from the recommendations and codes of practice for classrooms (general teaching). Almost half of the classrooms (49.5%) were lower than the 500lux required for close and detailed work (N=194), (DfES 1999). It was found that those classrooms with low illuminance levels were set up intentionally e.g. blinds were closed and/or the glazed area was obscured with display material and/or furniture. Currently, computer interactive smart boards are widely used and permanently installed in UK primary school classrooms. As teachers' pedagogy becomes more heavily reliant on this technology, a high level of brightness may not be desirable most of the time. The interviews with teachers also indicated the lighting level was often a balance of being low enough to use a smart board whilst being high enough for children to work.

3.2 Air Temperature and RH

The field work was carried out in both heating and non-heating seasons (see 2.1). The distribution of the RH points was spread relatively evenly from 35% to 70%, which indicated that the seasonal effect was not significant. The average air temperature of classrooms in the heating season was 20.2^{o}C, and 22.2^{o}C in the non-heating season. However, both temperature variations were quite high. The range of peak-to-peak value in the non-heating season was a little smaller when compared with the heating season (7.6 v 8.3^{o}C). Statistically, points of single data tend to accumulate in the comfort zone, based on Olgyay's bioclimatic chart (1963). Temperatures in most of the classrooms met the regulation standard (92.6% above 18^{o}C, N=202) in winter and all of them were below 28^{o}C in summer (DfES, 2003a). The low temperatures were mainly caused by central, thermostatic control rather than classroom thermostats. Sometimes, these central thermostats were slow to respond or did not adapt to the different situations of the classrooms. Though no measurement shows overheating problems in these classrooms, the interviews with teachers indicated that classrooms facing south were most troubled by glare and with overheating issues. The fact that extreme situations with maximum temperatures (24.2^{o}C) took place in the rooms facing south, while the minimum (15.9^{o}C) was towards north, also implied that solar gain could increase the risk of overheating and temperature variability.

3.3 CO_2 Level

The classrooms in primary schools were normally occupied continuously (albeit with short breaks). The consequence of the occupants' expiration was quite significant. Therefore, when the CO_2 level was measured, careful attention was paid to the occupancy patterns. In this study, 7x difference was found between the lowest (500ppm) and highest CO_2 levels (3500ppm) both without, and with, the pupils in the rooms. Generally, the result revealed poor air quality environments. 30.9% of classrooms did not meet the proposed standards limiting the level of CO_2 level (1500ppm, DfES, 2005). The suggested comfort value for indoor CO_2 is below 1000ppm (ASHRAE, 2004). If this criterion is applied, more than half of the results were higher, accounting for 51.0% of the total measurements made in 203 classrooms. All classrooms investigated had natural ventilation. However, from the teacher's perspective, it is difficult to provide a proper air movement rate due to the size and position of window openings and/or huge furniture and equipment adjacent to the window.

3.4 Noise Level

The schools selected in this study were located in areas with different surroundings: rural, urban or sub-urban. None of the schools were especially near railways and/or airports and only one third (N=203) of classrooms were facing directly towards the road traffic. Some effort has already been taken to reduce the potential noise disturbance by including acoustic baffles e.g. screening trees and zoning spaces. However, the measurements confirmed that classrooms were, unsurprisingly, noisy, with much higher levels than the recommended criteria for classrooms (35dBA, DfES, 2003b). In fact, only one classroom was measured within the upper limits for the indoor ambient noise level. The others deviated between 40 to 80dBA. The interviews with teachers indicated that the main noise source was not from the outside of school, but within the school itself, especially from the corridors or other activity areas adjacent to the classroom e.g. the hall and other classrooms.

3.5 Interactions between each Environmental Value

Whilst illuminance, temperature, CO_2 and noise level represent distinctly different environmental indicators, it is believed that in an actual classroom context, these indicators are interrelated. Table 1 shows the correlation between each of the environmental parameters measured at the site. CO_2 level, in this study, is the most interrelated factor, correlated significantly with all other major parameters. Noise level is the least interrelated factor, only correlated significantly with one major parameter: $CO_{2,}$ which can be explained by the nature of the high density of school buildings.

Table 1: Correlation between each of the Environmental Parameters

		Illuminance	Temperature	RH	CO_2	Noise level	Occupancy situation
Illuminance	Pearson Correlation	1					
	Sig. (2-tailed)						
	N	194					
Temperature	Pearson Correlation	.220**	1				
	Sig. (2-tailed)	0.002					
	N	194	194				
RH	Pearson Correlation	0.067	-.151*	1			
	Sig. (2-tailed)	0.351	0.035				
	N	194	194	194			
CO_2	Pearson Correlation	-.217**	-.257**	.304**	1		
	Sig. (2-tailed)	0.002	0	0			
	N	194	194	194	194		
Noise level	Pearson Correlation	0.027	-0.114	0.103	.203**	1	
	Sig. (2-tailed)	0.707	0.114	0.154	0.005		
	N	193	193	193	193	193	
Occupancy situation	Pearson Correlation	-0.046	-0.071	.175*	.404**	.456**	1
	Sig. (2-tailed)	0.523	0.326	0.015	0	0	
	N	194	194	194	194	193	194

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

The interactions between each environmental value heavily relies on the design and usage of classrooms. Large windows are clearly better for ventilation and good lighting levels but issues of excessive heat gain from large south facing windows can be a problem in the UK. High ceilings are better for dilution of CO_2 produced by occupants, however, they take longer to warm in the winter heating season. This has serious classroom design and usage implications, especially when considering how the classroom environment can positively support the requirements of comfort and health for pupils and teachers. For example, optimizing the glazing size with large opening potential, can give teachers more choices to adjust the levels of illuminance, temperature, RH and CO_2 concentration, in order to provide a positive environment for core teaching and learning activities.

4. Discussion

The measurements of basic IEQ physical variables in this study could generally reach the minimal recommendations (DfES, 1999, 2003a, 2003b, 2005). Many potential problems specified in this survey were consistent with other IEQ studies in other schools. For example, Ramasoot and Fotios (2008), also indicated in their study that the widespread use of smart boards probably lowered the requirement of illuminance level for demanding tasks on self-luminous display screens. Similar conclusions were drawn by Mydlarz et al (2013), who also found lighting levels were predominantly below the recommended levels in their classrooms study.

The temperature and humidity were found to be acceptable in most classrooms investigated, which was consistent with Mumovic et al.'s study (2009). However, occasionally low temperatures happened when the central heating responded slowly in terms of heating time and level (Barrett and Zhang, 2012). In addition, whilst no measurement showed overheating problems, the interviews with teachers indicated that their temperature sensation of comfort was lower than the environmental recommendations (DfES, 2003a). The overall CO_2 level was lower than previous studies (Clements-Croome et al., 2008; Mydlarz et al., 2013) though all of the measurements were carried out in UK primary schools. Large variations and high concentrations in CO_2 levels can be seen as a common problem in school classrooms.

5. Conclusion

This research paper has examined the IEQ in primary school classrooms. In particular, the following results have been addressed and are believed to be a contribution to the study area concerned (Table 2).

Table 2: Summary of the Main Findings and Suggestions from this Study

Findings from this study	Suggestions to designers	Suggestions to users

30.9% classrooms did not meet the proposed recommendations limiting the level of CO_2 .	Ceiling height, large opening size and varied opening positions will give users flexibility to decrease the CO_2 level.	No big furniture or equipment to be placed adjacent to the window so they can actively open/close the windows when necessary.
The brightness of classrooms was found notably low (lower than 500lux) because of teachers' pedagogy reliant on computer interactive smart boards.	Windows have large glazing area with manual shading control.	An education programme is suggested to ensure that they actively adjust the lighting levels, maximizing the daylight benefits to pupils.
High noise levels (between 40 to 80dBA) were caused mainly from the adjacent activity areas to the classroom.	Toilet, storage etc. can act as a buffer zone to separate the classrooms in between so that the disturbance can be alleviated.	The more prominent sources of unwanted sound (for others) within the building is might be located away from the classrooms.

Given the disruption to classrooms this sort of study causes, its limitations and weaknesses are unavoidable. Firstly, this study lacks consecutive data. All data were collected at a particular point and at a specific time. The duration of the measurement time was not long enough to represent the whole situation throughout the day or a period of time. This may lead to a large dispersion in the statistics used and may even cause potential bias. Further studies are needed to survey consecutively both indoor and outdoor conditions in order to get a whole picture of the physical environment of classrooms.

Despite the limitations, the survey results are based on site measurements in a large sample of classrooms. It provides data at a level of detail that should enable a better evaluation of the physical environment in the future.

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