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SUSTAINABLE SCHOOL: PHYSICAL ENVIRONMENT AND PERFORMANCE

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ABSTRACT

The objective of this study is monitoring indoor air quality and investigating conditions and performance within selected rooms in a sustainable school and to compare results to accepted standards guidelines. Air temperature, relative humidity (RH%), carbon dioxide (CO2), and Particulate Matter (PM) were monitored. Result has shown that the school meets thermal and relative humidity targets for comfort, although some overheating may be occurring even in non-summer periods. Air quality is indicated to be good, suggesting that the ventilation system is working satisfactorily. Fuel, electricity and water consumption were also analysed. There have been metering problems in the past, which assesses the school's performance against national benchmarks problematic. However, it does seem that the school has succeeded in its aim of significantly reducing water consumption.

Keywords:

air ventilation - Indoor air quality - classroom

المدرسة المستديمة: البيئة الفيزيائية و الأداء

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المستخلص

الهدف الرئيسى من هذه الدراسة هو مراقبة و تحليل جودة الهواء ، و الأداء البيئى داخل فصول مختارة عشوائياً من مدرسة بنيت طبقاً لمواصفات البيئة المستدامة بالمملكة المتحدة البريطانية ، و مقارنة هذه النتائج مع المعايير المتفق عليها بيئياً. المتغيرات التى تم مراقبتها و قياسها داخل كل فصل هى درجة الحرارة - الرطوبة - ثانى اكسيد الكربون - الغبار المتعلق بالهواء. هذا و قد اظهرت نتائج البحث أن معايير الراحة الحرارية و الرطوبة للمدرسة تتفق مع المعايير البيئية المصممة عليها و ذلك على الرغم من وجود فترات ترتفع فيها درجة الحرارة نتيجة لتشغيل اجهزة التدفئة فى فصل الشتاء. ايضا اظهرت الدراسة ان جودة الهواء بالفصول تنم عن ارتفاع مستوى اداء تشغيل لانظمة التهوية العامة فوق مستوى الجيد. تم ايضاً تحليل معدل استهلاك الوقود و الطاقة الكهربائية و الماء و قد اكتشف انه كان هناك خطأ فى ضبط اجهزة القياس لمعدل الاستهلاك اليومى لكل تلميذ و الذى تنص عليه المعايير طبقاً للنظام البريطانى، مما ادى الى مشكلة فى تقييم الاداء اليومى وتحديد نسبة الاستهلاك لهذه المتغيرات. على كل اثبتت نتائج البحث ان المدرسة نجحت تماما فى تحقيق هدف ترشيد الاستهلاك للماء.

INTRODUCTION

Performance of students in a classroom can be reduced due to poor quality of air ventilation. It has been reported that energy-conscious relation was improved by implementing high quality ventilation schemes in classrooms orientations [1]. Other studies showed that the importance of ventilation effectiveness, air exchange, and air flow rate on the air quality of a classroom [2] by carrying out simulation of computational fluid dynamics to provide information of the air quality conditions. Thermal comfort and air quality can be evaluated by the study of school buildings based on a software which takes into account; conductive, convective, radiative and massy phenomena and internal heat generation in the building [3]. In south west Germany the Long term Air Quality Index (LAQx) has been developed to evaluate the well-being and health of people and students in schools [4] by analysing the trend of air pollution from 1985 to 2005 at different urban and rural sites.

School Buildings and their built environment have a crucial impact not only on comfort and performance of teachers and children but also on their health and well-being. Air in most indoor environments contains a variety of particles and microbiological contaminants. These contaminants affect human health and performance. Indoor temperature and relative humidity can also affect health and performance directly. It can also affect human performance indirectly by influencing the airborne level of moulds and bacteria. Comprehensive studies have been carried out in different countries such as Belgium and USA to correlate suspended Particulate Matter (PM) level to air quality [2], [5]. It has been found that the main cause of the elevation of PM in schools and residential homes was tobacco smoking and carpets.

Even though sustainable schools are designed to overcome the above stated problems and provide healthy buildings with good indoor air quality, their classrooms still exhibit poor rates of ventilation during working hours (teaching times) which can produce the right environment for elevated air borne, pathogen bacteria and germs to spread and cause infection.

The aim of this study is to evaluate the air quality, energy consumption and water consumption (physical environment and performance) in sustainable buildings.

Norfolk Community Primary School, Sheffield [6], UK, has been built with a strong environmental awareness in terms of design, resources and materials. This report discusses a post occupancy study of the school that took place between February and June 2006. The study is a quantitative analysis of the internal physical environment of the school and annual energy, electricity and water use.

MATERIALS AND METHODOLOGY

Indoor air temperatures and relative humidities were measured at six locations in the school using HOBO U12-012 data loggers. Indoor carbon dioxide levels were also recorded in five of the six locations using Telaire 7001 CO_2 meters.

Although CO_2 is not toxic it is commonly used as an indicator of air quality. High levels of CO_2 indicate inadequate ventilation in a space. For practical reasons the loggers had to be positioned on shelves at heights of approximately 1.8 m above the floor. Average values of each variable were collected at 15-minute intervals over a period of three months and 3 weeks (4 January 2006 – 27 April 2006). Figure 1 shows a logger and CO_2 meter in place in the dining room.

Such a measurement programme produces large amounts of information (184,756 data points). The analysis of this information for this study is based upon three levels of detail:

- the overall average monthly values for the entire monitoring period
- the average monthly values for week-days (teaching hours) and weekends
- a more detailed hourly and daily study for a cold ten day period in February

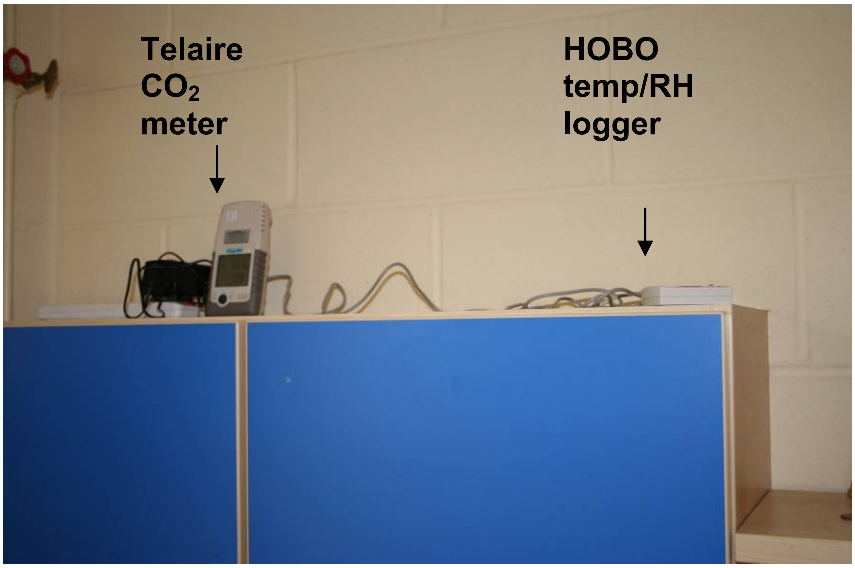

Figure1. Data logger positioned in dining room

Average monthly values from the monitoring:
Table 1 shows the monthly mean averages of temperature, RH and CO_2 for all of the 184,756 data points measured during the study. Therefore, this Table includes weekends, evenings and school holidays. Table 2 shows the average values of all the data recorded.
Average temperature and relative humidity values from all data, divided in to teaching hours (9.00- 15.00) and weekends:
Table 3 shows the average temperature and relative humidity values when the data were divided in to school teaching hours (9.00-15.00) and weekends. Figure 2 shows the data from Tables 3 graphically.
Average monthly CO_2 values from the monitoring:
Table 4 shows the average CO_2 levels in each monitored space for school teaching hours and weekends. Figure 3 presents these data graphically. Building Bulletin 101 *Ventilation of School Building* recommends that for teaching and learning spaces between the start and finish of teaching on any day the average concentration of carbon dioxide should not exceed 1500 parts per million (ppm).

Month / Room and & Its variables		January	February	March	April
Class 5	Temp °C	19.7	21.1	21.1	19.6
	RH%	38.9	31.5	32.0	37.4
	CO^2 ppm	699	603	709	559
Class 12	Temp °C	18.2	18.9	19.9	18.5
	RH%	45.9	39.8	37.5	40.2
	CO^2 ppm	827	656	776	515
Class 15	Temp °C	16.4	18.9	18.7	18.1
	RH%	48.1	36.8	36.4	39.8
	CO^2 ppm	672	517	661	468
Class Y1	Temp °C	17.3	20.4	20.5	18.3
	RH%	45.0	34.2	32.5	38.6
	CO^2 ppm	548	432	582	360

Dining Room	**Temp °C**	18.3	19.3	19.1	17.5
	RH%	42.2	35.5	36.2	42.3
	CO^2 ppm	490	479	519	423
Nursery Room	**Temp °C**	18.6	18.0	18.8	16.0
	RH%	41.2	37.4	35.8	45.6
	CO^2 ppm	**N/A**			

Table 3.1: Monthly means of all the measured data

Room	**Temp °C**	**RH %**	**CO_2 ppm**
Class 5	20.4	35	645
Class 12	18.9	41	698
Dining R	18.6	39	480
Nursery R	17.9	40	135
Class 15	18.0	40	583
Year 1	19.2	38	484

Table 2: Overall means from all the measured data

Room	Indoor temperature (°C)		RH%	
	Teaching hours	Weekends	Teaching hours	Weekends
Classroom 5	23.0	18.8	34.4	31.5
Classroom 12	21.4	17.6	44.7	38.3
Year 1	22.3	19.1	36.7	32.0
Dining Room	20.5	16.7	38.3	36.0
Room 15	20.2	17.5	38.0	35.4
Nursery Room	20.4	15.0	37.1	38.9

Table 3. Average indoor temperature and RH% of measured rooms

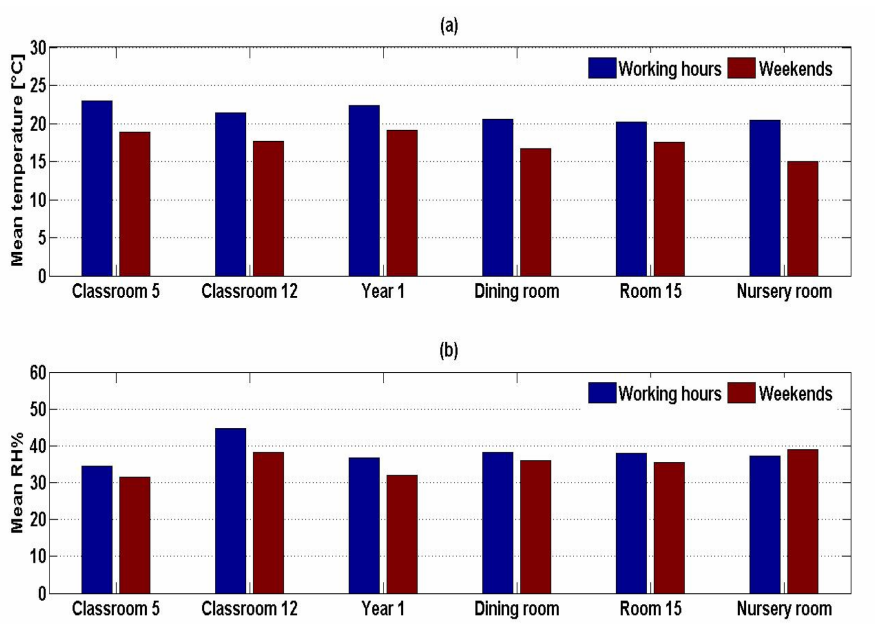

Figure 2 Average (a) air temperatures and (b) relative humidities for teaching hours and weekends from all the measured data

Room	CO_2 (PPM)	
	Teaching hours	Weekends
Classroom 5	1406	457
Classroom 12	2021	373
Year 1	1140	366
Dining Room	1029	371
Room 15	1007	369

Table 4 Average CO_2 in measured rooms

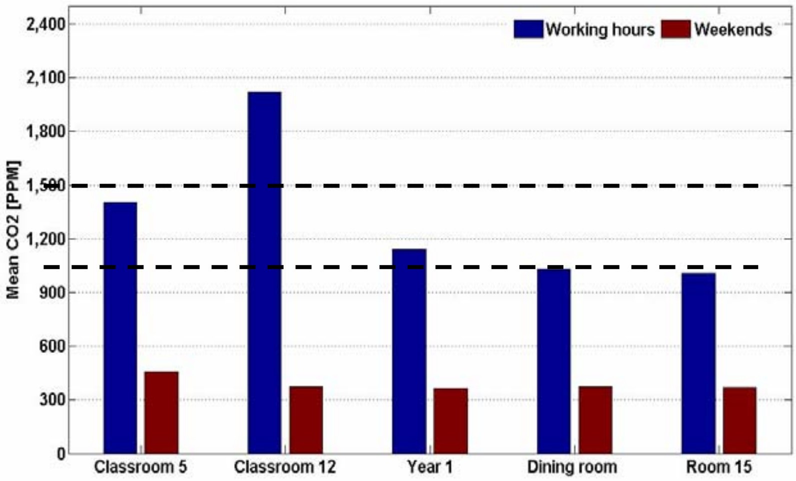

Figure 3 Mean of CO_2 levels for teaching hours and week-ends from all the measured data

In addition, The International Energy Agency (IEA) recommends that the maximum concentration of CO_2 should not exceed 5000 ppm during the teaching day and that for any occupied time, including teaching, the occupants should be able to lower the concentration of carbon dioxide to 1000 ppm. The dashed lines in Figure 3 show the 1500 ppm and 1000 ppm levels suggested in IEA.

Mean daily data for ten days (17th – 27th February 2006:
Figure 4 and Table 5 show how the indoor and outdoor air temperatures varied over a ten day period from Friday 17 February to Monday 27 February 2006. The dashed line in Figure 5 is the internal air temperature of 18.0°C recommended in the School Premises Regulations and quoted in Building Bulletin 87 [9].

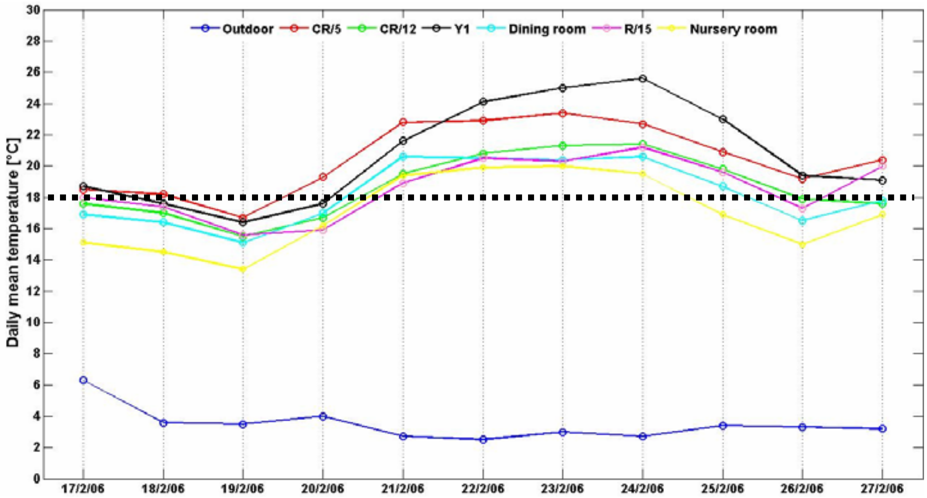

Figure 4: Daily mean of indoor temperature in all rooms and concurrent outdoor temperature

Figure 5 shows a typical daily plot of indoor air temperatures – in this case for Classrooms 5 and 12, the Dining Room and the Nursery for the 24 hour period starting at midnight on Wednesday 22nd February 2006.

ENERGY, WATER AND ELECTRICITY USE IN THE SCHOOL:
Benchmark data for energy, water and electricity use in schools is expressed in terms of annual consumption per m2 of school floor area or annual energy consumption per pupil. The School's floor area is 2,869 m^2. Norfolk Community Primary School was designed for 450 school pupils with an additional 52 nursery places (502 children in total).

Dates	Outdoor (°C)	CR/5 (°C)	CR12 (°C)	Y1 (°C)	Dining room (°C)	R 15 (°C)	Nursery room (°C)
17/2/06	6.3	18.5	17.6	18.7	16.9	18.0	15.1
18/2/06	3.6	18.2	17.0	17.6	16.4	17.4	14.5
19/2/06	3.5	16.7	15.5	16.4	15.1	15.6	13.4
20/2/06	4.0	19.3	16.7	17.6	17.0	15.9	16.2
21/2/06	2.7	22.8	19.5	21.6	20.6	18.9	19.4
22/2/06	2.5	22.9	20.8	24.1	20.5	20.5	19.9
23/2/06	3.0	23.4	21.3	25.0	20.4	20.3	20.0
24/2/06	2.7	22.7	21.4	25.6	20.6	21.2	19.5
25/2/06	3.4	20.9	19.8	23.0	18.7	19.6	16.9
26/2/06	3.3	19.2	17.9	19.4	16.5	17.3	15.0
27/2/06	3.2	20.4	17.6	19.1	17.8	20.0	16.9

Table 5 Summary of temperature data (daily mean) from six rooms with the concurrent outdoor temperature

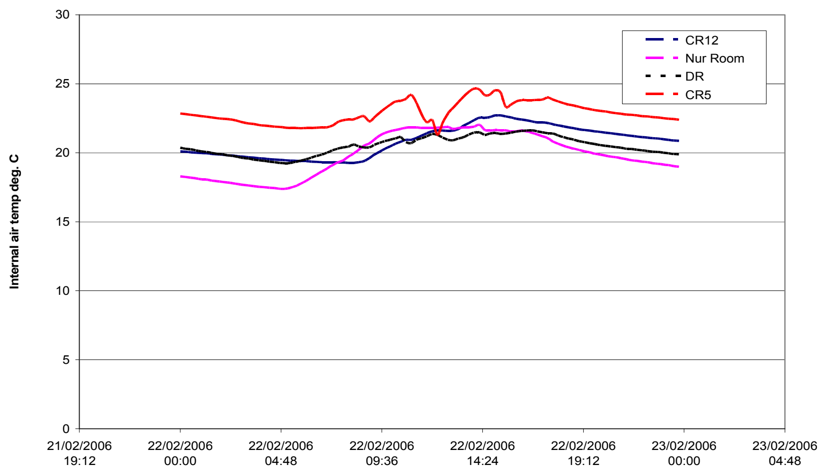

Figure 5: 24 hour cycle of internal temperature measurements

The 50 percentile median benchmark value (half of schools above value and half below) and the 10 percentile value (10% of schools below the value) have been used to show typical and very high levels of performance.

Annual consumption data were provided by Sheffield City Council. The data available were the heat meter readings from Onyx, water meter values and electricity usage.

It was apparent in the analysis that the data sets for the School were not coherent records. They contained data affected by meter faults and several estimated values. Tables 6 and 7 show the heat and water consumption data as made available by the Council. The electricity consumption data was also influenced by errors and estimates and so a single annual consumption figure of 103,190 kWh was provided.

Annual consumption benchmarks:
From Table 6 the annual energy consumption for the period June 2004 to June 2005 was 79350 kWh. This period contains the smallest number of estimates. Table 8 compares Norfolk and English benchmark figures (for fossil fuel consumption – thought to be the closest to the Onyx CHP heating).

The annual estimated electricity consumption was 101,390 kWh. Table 9 compares Norfolk and English benchmark figures. The annual water consumption has been taken from 24th November 2004 to 23rd November 2005, which gives an annual consumption of 799 m^3. Table 10 compares Norfolk and English benchmarks:

Norfolk Community Primary School

Onyx heat - data from bills

Month	Read date	Heat meter reading	Heat consumption	Estimated read	Meter thought to be faulty
		MWh	**MWh**		
	01/02/2004	29.51			
Feb-04	19/02/2004	32.86	3.35		F
Mar-04	29/03/2004	38.33	5.47		F
Apr-04	28/04/2004	42.44	4.11		F
May-04	25/05/2004	45.58	3.14		F
Jun-04	28/06/2004	49.13	3.55		
Jul-04	27/07/2004	52.57	3.44		
Aug-04	27/08/2004	55.57	3.00		
Sep-04	21/09/2004	59.71	4.14		
Oct-04	27/10/2004	63.17	3.46		
Nov-04	26/11/2004	66.52	3.35		
Dec-04	04/01/2005	71.37	4.85		
Jan-05	28/01/2005	74.50	3.13		
Feb-05	28/02/2005	90.47	15.97		
Mar-05	31/03/2005	100.47	10.00	E	
Apr-05	27/04/2005	118.06	17.59		
May-05	26/05/2005	123.70	5.64		
Jun-05	30/06/2005	128.48	4.78		
Jul-05	31/07/2005	128.48	0.00	E	
Aug-05	31/08/2005	131.48	3.00	E	
Sep-05	28/09/2005	138.50	7.02		
Oct-05	31/10/2005	145.25	6.75		
Nov-05	30/11/2005	160.79	15.54		
Dec-05	03/01/2006	183.13	22.34		
Jan-06	30/01/2006	202.59	19.46		

Table 6 Onyx heating energy data for Norfolk Community Primary School

From	Reading	Narrative Code	(M3)
14/02/2004	0	Reading	0
09/09/2004	460	(X) High consumption	460
24/11/2004	627	(Y) Estimated	167
15/02/2005	790	Reading	163
01/06/2005	1023	(Z) Book / individual estimate	233
12/09/2005	1215	Reading	192
23/11/2005	1426	Reading	211
01/03/2006	1629	(Y) Estimated	203

Table 7 Water consumption for Norfolk Community Primary School

	kWh per m^2	kWh per pupil
Norfolk Community Primary School	28	158
Benchmark fossil fuel median (50 percentile) value, 2002-03	158	918
Benchmark 10 percentile value, 2002-03	50	290

Table 8 Heating benchmark figures

	kWh per m^2	kWh per pupil
Norfolk Community Primary School	35	202
Benchmark median (50 percentile) value, 2002-03	37	219
Benchmark 10 percentile value, 2002-03	18	109

Table 9 Electricity benchmark figures

	m^3 per m^2	m^3 per pupil
Norfolk Community Primary School	0.28	1.59
Benchmark median (50 percentile) value, 2002-03	0.68	4.02
Benchmark 10 percentile value, 2002-03	0.34	2.08

Table 10 Water benchmark figures (no swimming pool)

RESULTS

Temperature and relative humidity (RH%) results:
Temperature and relative humidity levels within an indoor environment will vary with the time of year, and physical indoor environment. However, increased temperature within a confined space such as an indoor environment can create a more suitable environment for the growth of unwanted bacteria and fungi. In general it would be reasonable to maintain a temperature of around 18 °C (or standard guideline of sustainable schools) within a building.

Humidity can have adverse affect on the growth of mould and dust mites within an area if allowed to become too high. Rapid growth occurs when levels of humidity increase above 70%, with great effects to respiratable illnesses such as asthma. In the same aspect if levels of humidity become too dry, below 30% this too can have adverse effects, with some people susceptible to sore throats due to the dryness of the air. The optimum level of humidity should be 30 – 70%, with much dependant on the indoor environment in question, and the seasonal variation as to the best level for the area in question.

The data collected from the indoor monitoring equipment were statistically analysed to investigate the condition of indoor air temperature and relative humidity RH%.

Figure 6 (a), and (b) shows the indoor temperature, relative humidity and outdoor temperature levels against days of measurements. It can be seen that levels of indoor temperature and RH% followed a pattern in the six rooms and were seen to rise during working days (20 to 24 February 2006) and drop in weekends (18, 19, 25, 26 February 2006). The mean air temperature and relative humidity were calculated for the weekends and working hours of working days i.e. for classrooms 5, 12, year1, nursery room, and room 15 their mean value was evaluated from 9:00 to 15:00 hours on 20th, 21st, 22nd, 23rd and 24th of February. The dining room average value was calculated on the same days but from 12:00 to 13:00 hours (lunch time). The results are shown in Table 3 and Figure 2 (a and b). It can be seen that difference between weekends and working hours mean values, during working hours the six room had mean values ranged form 20.2 to 23°C of temperature and from 36.7 to 44.7 of RH% which agrees with the standard guidelines.

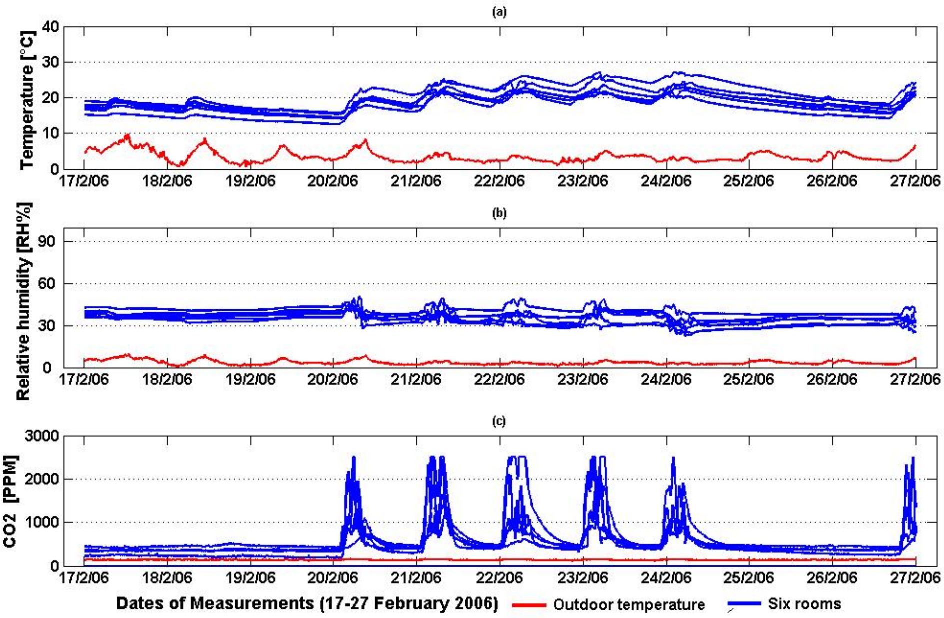

Figure 6: Mean of indoor temperature and RH% of rooms

Additionally there was a significant negative correlation between average daily outdoor temperature and indoor temperature of the six rooms as shown in Figure 7 to indicate that any decrease of outdoor temperature has an increase of indoor temperature. Correlation analysis of indoor daily mean RH% and indoor daily mean temperature of the six room figure 8 indicated that any decrease of indoor temperature has an increase of indoor RH%.

CO^2 results:

Carbon dioxide is present in the natural environment, being produced by combustion of biological processes. Carbon dioxide is present at typical

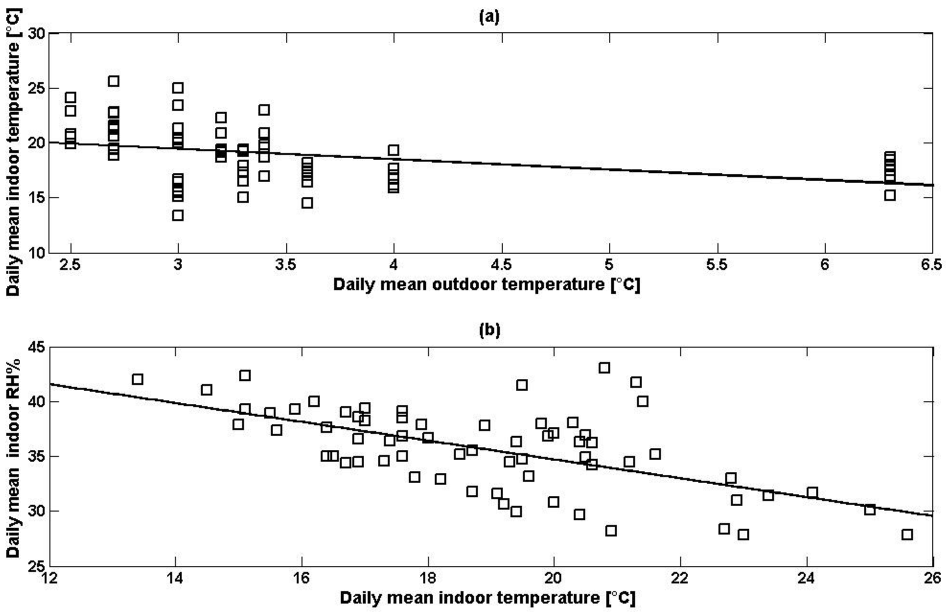

Figure 8: Mean of indoor temperature and RH% of rooms

levels of about 320 ppm in the ambient urban environment though this can rise substantially inside occupied buildings. However, carbon dioxide levels are often used as a guide to whether or not a space has a sufficient quantity of fresh air.

The average indoor CO^2 levels at the six rooms during working hours ranged between 1007 to 2021 ppm Table 4 and Figure 3. The indoor CO2 level followed a pattern in the all rooms. Levels were seen to drop during weekends and rise afterwards during the working days.

Mean daily indoor and outdoor air temperature and mean daily CO^2 of six rooms were correlated with statistically significant results. Figure 9(a) and 9(b) show this indirect relation with outdoor temperature and the direct relation with indoor temperature. These results may indicate that warmer outdoor weather the higher ventilation rate and lower indoor temperature and vice versa.

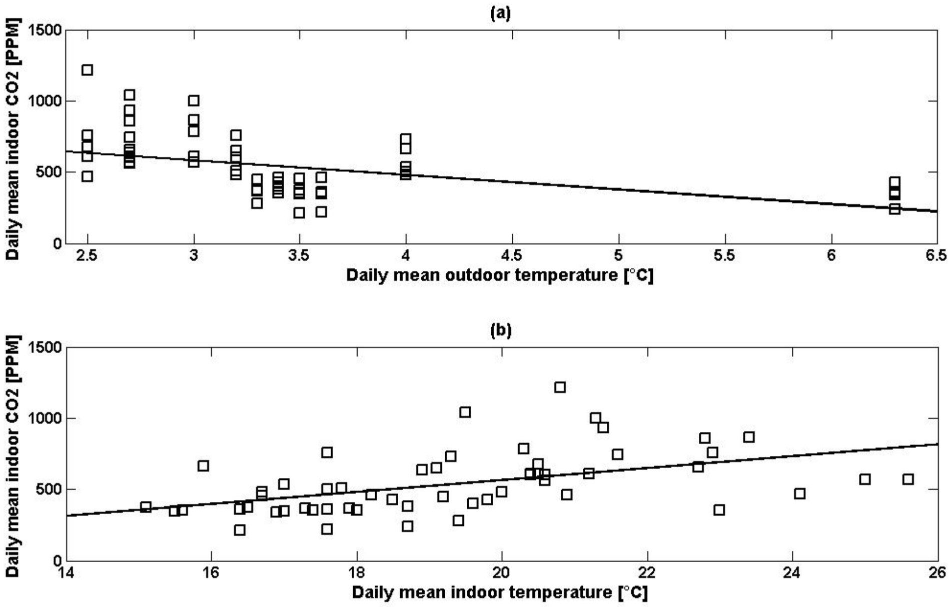

Figure 9: Correlation of outdoor temperature and indoor temperature

Particulate Matter PM results:

Particulate matter (PM) ranging from 0.5 to 5 microns in diameter are important in relation to indoor air quality, so snapshot measurements were taken for the six rooms. While it is not feasible to provide a clean room environment (i.e. a room that is void of particulate matter), 50,000 particles per litre (p/l) is a conservative design guideline for non-industrial indoor environments 18. Table 11 shows the results of all rooms with PM of 0.5 to 5 microns in diameters and 2.5 microns. The results indicate that all rooms were well under the recommended guidelines.

Room	Particulate Matter PM	
	0.5-5µm(p/l)	2.5 µm(p/l)
Classroom 5	6696	96
Classroom 12	4370	88
Year 1	6522	134
Dining Room	6031	126
Room 15	3200	42
Nursery Room	5909	105

Table 11: Mean of indoor PM of measured rooms

***Key findings from the quantitative study are highlighted here*:**
Temperature and relative humidity

- the school was kept at an air temperature throughout the monitored winter / spring teaching periods that consistently met or exceeded the temperature of 18.0°C recommended in the School Premises Regulations and quoted in Building Bulletin 87

- some internal temperatures were quite high, suggesting a lack of thermal control (either mechanical or personal)

- relative humidity values were always within an acceptable range of values

- it was noticeable that internal air temperatures were high during periods when the school was unoccupied (evenings and weekends) – temperatures during the night between 18°C and 20°C were not uncommon (see Figure 5)

- carbon dioxide levels were generally kept well within the range of values recommended in Building Bulletin 101 (1000 – 1500 ppm). Classroom 12 had the highest CO_2 levels (although still a very long way short of the maximum of 5000 ppm given in IEA). Interestingly, Classroom 12 also had the highest values of relative humidity, suggesting that it had the poorest ventilation performance of the rooms monitored

Annual consumption benchmarks

- reliable metering of the school's heat, electricity and water consumptions needs to be established to enable the school to test and validate its green design credentials

- the English benchmarks for fossil fuel consumption do not easily translate in equivalence to a school heated by a waste burning CHP system

- the electricity consumption figures suggest that Norfolk Community Primary School is close to the average benchmark value but is using nearly twice as much electricity as the 10% of best performing schools – the caveat here is that the electricity consumption data for the school may be unreliable

- the water consumption figures for Norfolk Community Primary School are very encouraging and indicate that the school is performing much better than the typical figure for the 10% of best performing schools

CONCLUSIONS

This study has provided the opportunity for a physical post occupancy evaluation of Norfolk Community Primary School to be carried out. The physical survey has shown that the school meets thermal and relative humidity targets for comfort, although some overheating may be occurring even in non-summer periods. Air quality is indicated to be good, suggesting that the ventilation system is working satisfactorily. There have been metering problems in the past which makes assessment of the school's performance against national benchmarks problematic. However, it does seem that the school has succeeded in its aim of significantly reducing water consumption.

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