Evaluation of Energy and Environmental Performance of Three Primary Schools in the Thames Valley

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Abstract

Three similar primary schools in the Thames Valley were examined to evaluate their energy and environmental performance. All three schools had been occupied for 15 – 26 months at the start of the project. Utility data were used to calculate kWh/m^2/annum performance indicators. These were compared to benchmarks for similar buildings. Data loggers measured room temperature, relative humidity (RH), metabolic carbon dioxide (CO_2), and light levels. These results were also compared to the relevant benchmarks. Questionnaires were issued to the occupants to record their impressions of the buildings. Although all three schools were found to be performing well, one in particular was found to be providing a good internal environment for the lowest energy input. This improved performance was attributed to:

- Good communication and collaboration amongst team members;
- Efforts early in the design to use passive architectural techniques to reduce the need for M&E services;
- Members of the design team having worked together on previous projects;
- Brief and clear A4 “Summary Sheets” for the site management at handover;
- Lighting controls that significantly reduced electricity consumption.

Project Brief

This project looked at the energy and indoor environmental performance and the “usability” of three similar primary schools in the Thames Valley, England. The objective was to identify good practice to feed back to the design teams for future projects and to identify difficulties that might be avoided in the future.

Introduction

These three primary schools are located in the Thames Valley and had all been occupied for 15 – 26 months before the start of the project. They are naturally ventilated buildings using mains gas-fired boilers for heat and occupant-controlled windows and rooflights for ventilation. Each school accommodates roughly 350 occupants in 2000 m^2 of treated floor space with approximately 30 computers and limited catering facilities. They all have similar levels of insulation, air-tightness, glazing ratios, and construction

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methods. Schools A and C are shallow-plan linear schools, with the classrooms on the south side, resource areas and circulation in the centre and staff offices on the north side of the building. School B is a shallow-plan courtyard school, with the classrooms facing away from the courtyard, circulation in the centre and resource areas facing into the courtyard. Half of the classrooms in School B are north-facing, and half are south-facing.

Methodology

Energy

Energy performance was measured via electricity and natural gas meter readings taken at handover and one year later. These were used to calculate kWh/m^2/annum performance indicators that were compared with the UK "Typical" and "Good Practice" benchmarks for primary schools.

Environmental Performance

Indoor environmental performance was examined by measuring room temperature, RH, metabolic CO_2 and light levels. In addition to comparing the measured data to the relevant benchmarks, the mitigation of occupant-produced CO_2 was also considered as a first-order estimate of the natural ventilation system's performance. Although acoustic performance is an important component in the consideration of indoor environmental conditions, it could not be linked directly with energy use and was therefore omitted from this particular study.

Usability

Usability was evaluated by primarily anecdotal means. Occupant questionnaires designed and administered by the Local Authority recorded the occupants' perceptions of the indoor environment and their ability to adjust the environmental conditions if needed. The site services staff were interviewed and asked for their impressions about their building's performance. The monitored temperature and illuminance data revealed how the heating and lighting were actually being managed.

Energy

Electricity and natural gas meter readings were taken at handover and again one year after handover. These were used to calculate the following performance indicators that were then compared to the "good practice" benchmark values:

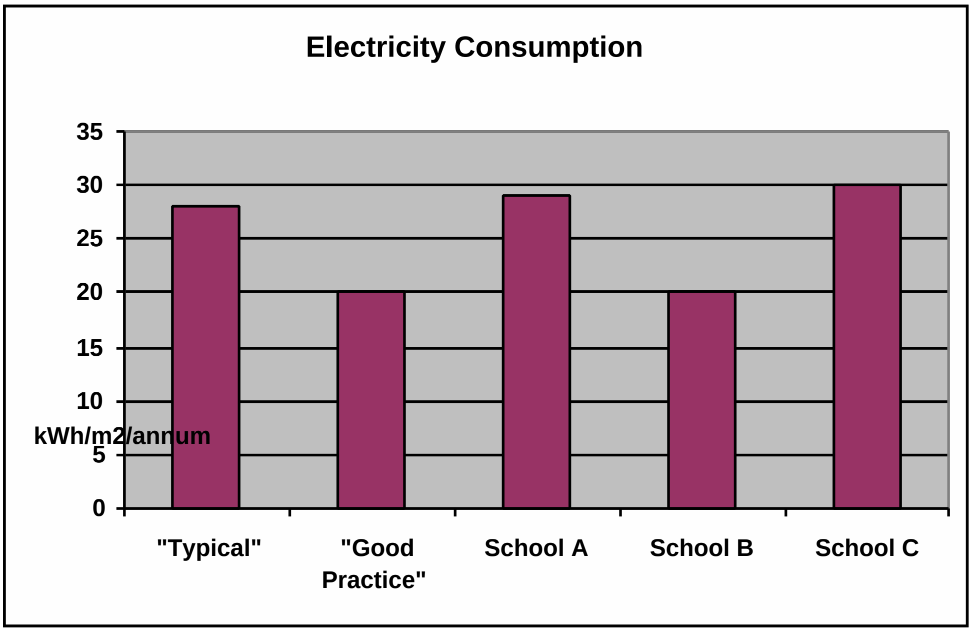

Table 1 – Electricity Consumption for the Three Schools Compared with the "Typical" and "Good Practice" Benchmarks for Primary Schools

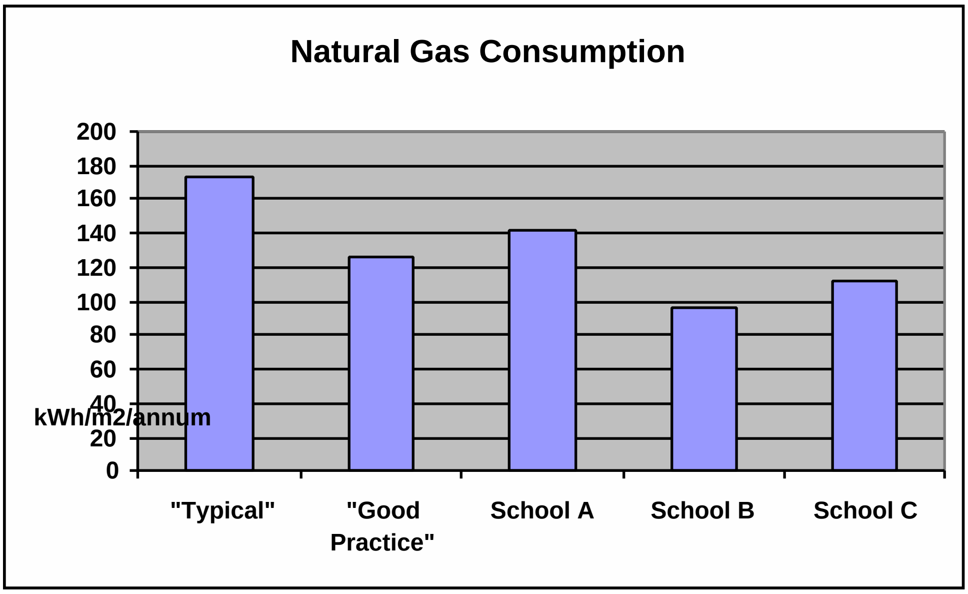

Table 2 – Electricity and Gas Consumption for the Three Schools Compared with the "Typical" and "Good Practice" Benchmarks for Primary Schools

The "Good Practice" benchmarks are calculated across the entire building stock, and therefore show lower electricity use (due to older buildings having little spare capacity for increased small power demands) and higher natural gas use (due to older buildings being generally less fuel-efficient than new schools). Thus the benchmark is not entirely representative of primary schools built within the last five years.

The performance indicators for these three schools show that although they are all performing reasonably well, School B is performing better than the other two, particularly with regards to electrical consumption. Early in the design of School B, before any sketch-scheme drawings were produced, the design team discussed methods to reduce the building's electricity loads. Electricity was targeted in part because of its higher greenhouse gas contribution when compared to natural gas. Analysis of previous schools showed that the two most significant electricity loads under the direct influence of the designers for this building type were the lighting and the domestic hot water (DHW) provision. IT equipment was also recognised to be a significant electricity load, and the designers routinely encourage each school to purchase energy-efficient equipment and to enable the "power down" settings when possible.

Lighting, Daylighting, and Lighting Controls

School A has shallow-plan L-shaped classrooms with a shared cloakroom that doubles as a draft lobby. Outside the classroom is an opaque covered walkway that shades the south façade of the building. Although this walkway protects the building from unwanted solar gain, it reduces the amount of daylight entering the classrooms from the south-facing windows. Photos taken near the summer solstice show the south façade of the building to be heavily shaded by the walkway. The "L" part of the classroom is behind the cloakroom with no direct access to the windows. At the back of each classroom there is a ventilation stack with mechanical dampers and high-level glazing to provide borrowed light and there is glazing between the classroom and the daylit corridor to promote the transfer of borrowed light to the back of the classrooms. This strategy was not shown by the hand-held light meter readings to be as effective as originally hoped. At the time of this study, School A did not have lighting controls in the classrooms.

School B has shallow-plan rectangular classrooms with the cloakroom area being shared with the resource area outside the classroom. This shape allows daylight to enter the building with the full length of the classroom having direct access to the south/north-facing windows (depending on which side of the courtyard the classroom is located). The architect located the younger-years classrooms on the south side of the building, since these rooms have lower internal heat gains than the older-years classrooms (due to larger children producing higher occupant heat gains and higher audio-visual equipment density). A transparent covered walkway is on the courtyard side of the building and provides no external shading to the classrooms. However the south side does have an overhang that offers protection against solar gain, and photos taken near the summer solstice show the south façade to be reasonably well-shaded. Openable rooflights in each classroom allow daylight to enter the back of the rooms and provide an additional ventilation route. These rooflights are angled to reduce solar gain into the building and minimise direct sunlight falling on the students during the summer. Because of the even distribution of daylight that was achieved by the architect, the electrical engineer specified lighting controls that used a single combined daylight and occupancy sensor in each room. The occupant comments on the questionnaires report that the lighting controls are generally working well.

School C has shallow-plan L-shaped classrooms with a shared resource area outside the classroom, and an adjacent shared cloakroom that doubles as a draft lobby. The “L” part of the classroom is farthest from the windows, and the architect has included openable rooflights above this area to increase the daylighting. This area is used successfully as a reading and study area, with the children sitting on the floor in a circle with the teacher. The poor distribution of this daylight into the rest of the classroom makes the area close to the windows with the students’ desks and chairs appear darker than it really is. A transparent covered walkway is located just outside these windows on the south side of the building, and it heavily shades the facade to protect the building from unwanted solar gain. This shading inevitably decreases the amount of daylight entering the windows, further adding to the dark appearance of this part of the classroom. At the time of this study, School C did not have lighting controls in the classrooms.

Measurements were taken at each school in representative classrooms to determine the lighting management patterns at each school.

	Lights On Summer (Hours per Day)	Lights On Winter (Hours per Day)
School A	9.5	9.5
School B	0.5	7.0
School C	9.0	9.0

Table 3 – Typical use of electric lighting at each school

These readings show the effectiveness of the lighting controls in School B at reducing the amount of electricity used for lighting. The data also show that, without lighting controls, Schools A and C switch their lights on in the morning and they stay on until the end of occupancy each day.

Domestic Hot Water

In an effort to decentralise the DHW plant, hot water for primary schools was previously provided with 3kW point of use electric heaters, typically six or seven per building. Previous analysis showed that the DHW in the students’ toilets was rarely used, yet these 3kW heaters were still left switched on despite the inevitable standing losses. The designers for each of these three schools decided to provide point of use water heaters for the cleaners sinks only, and to provide DHW heated by natural gas for the students’ toilets and resource areas. These were located in clusters to minimise distribution losses. School A achieves this via a flat-plate heat exchanger run off a modular heating boiler. School C achieves this via a direct gas-fired water heater in the boiler house. School B uses domestic combi-boilers situated locally (adjacent to the toilets) to provide low pressure hot water to indirect cylinders serving these areas. Additionally, each combi-boiler's DHW point provides hot water to the cleaners' sinks which are adjacent to the toilet areas (rather than the electric point-of-use heaters used for cleaners sinks at the other two schools). This approach is a novel attempt to reduce the energy used to keep a constant supply of DHW available to the toilet and resource areas despite the fact that it is rarely used. Although it might seem better not to provide DHW at all, the occupants of the building feel that DHW in the toilets and resource areas is essential to providing a good-quality learning environment.

IT Provision

The three primary schools each have around thirty computers used mostly for pedagogic purposes. The management of the computers was observed over the course of the year that these schools were studied, and it was found to be similar at each school. Each school has typically fifteen computers in the IT suite, a single computer in each of the older children's classrooms, a cluster of two or three computers shared by the younger children, one computer in the library, and a handful of computers used by the office staff and headteacher. The computers in the IT suite are switched on at the start of the day that IT lessons are given, and switched off by the IT teacher at the end of the day. The others are used for lessons "as and when" needed and, at these three primary schools, they tend to be switched off by the teachers when the lessons have concluded.

Environmental Performance

Temperature

Data loggers recorded temperature readings during the summer and the winter. These data show that the three buildings maintained acceptable room temperatures, typically between 19 and 22 ^{o}C during the winter and between 23 and 26 ^{o}C during the summer. With the exception of one hot spot in School B and one cold spot in School C, the perception of acceptable room temperatures was further corroborated by the occupant questionnaires.

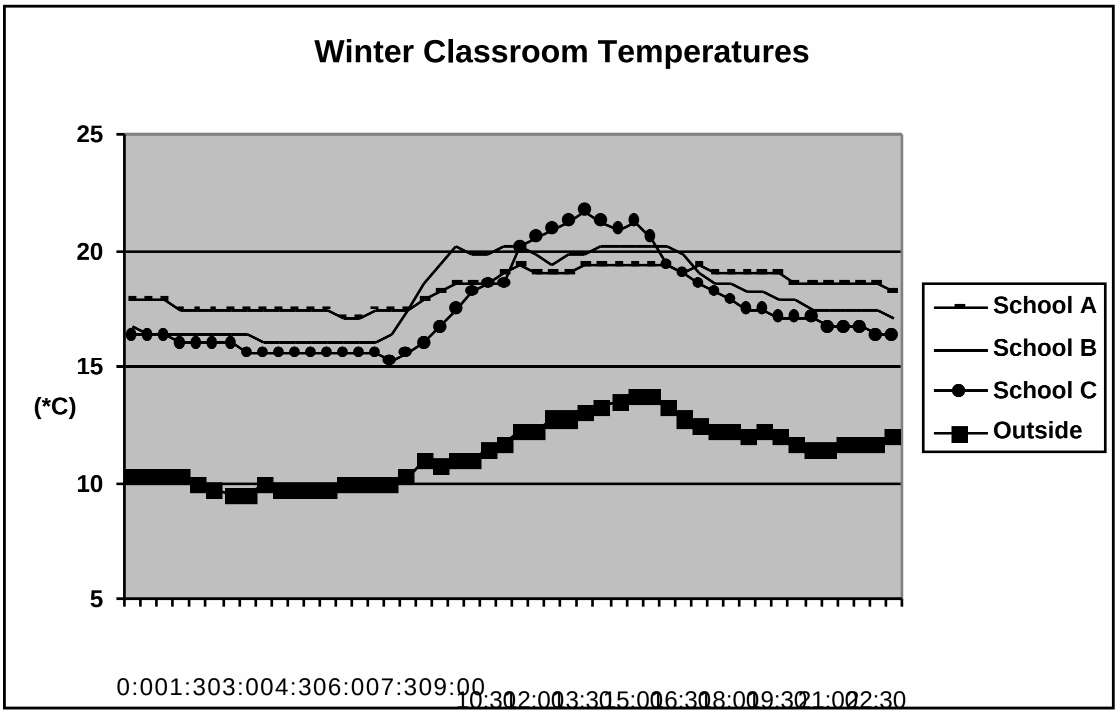

Figure 1 – Winter classroom and outside temperatures (Feb. 2002)

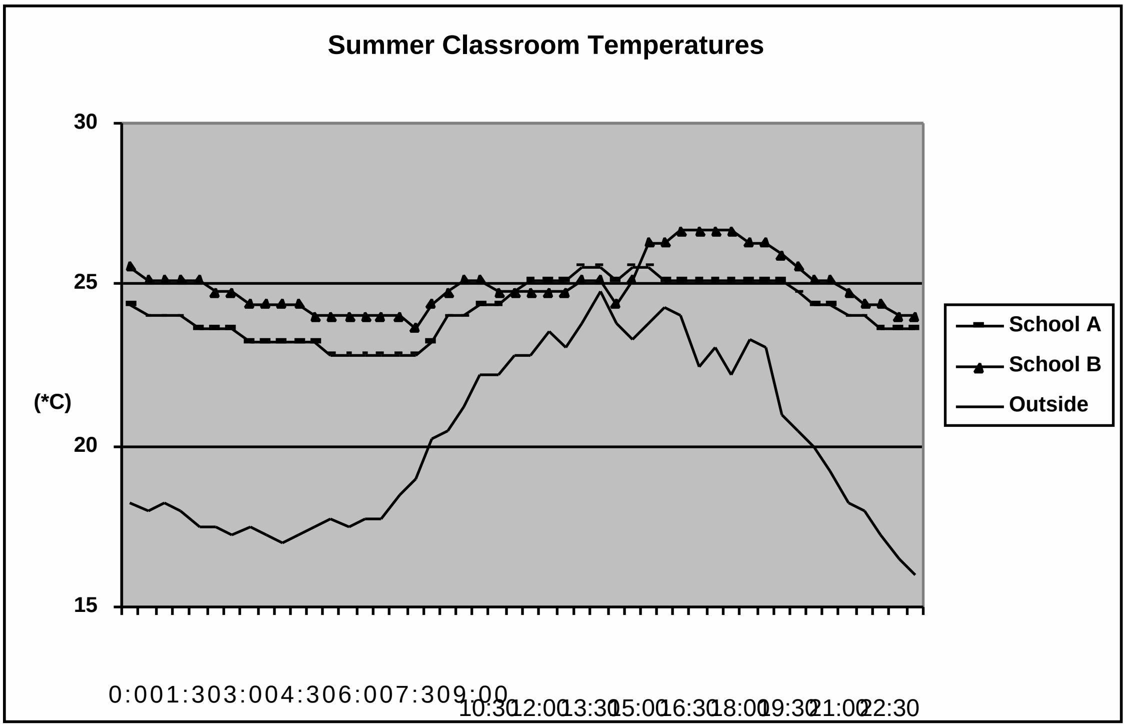

Figure 2 – Summer classroom and outside temperatures (June 2001)

Relative Humidity

Data loggers recorded relative humidity levels during the summer and the winter. These readings show that the RH is typically between 40% and 60%. There were no occupant comments about RH levels in the rooms.

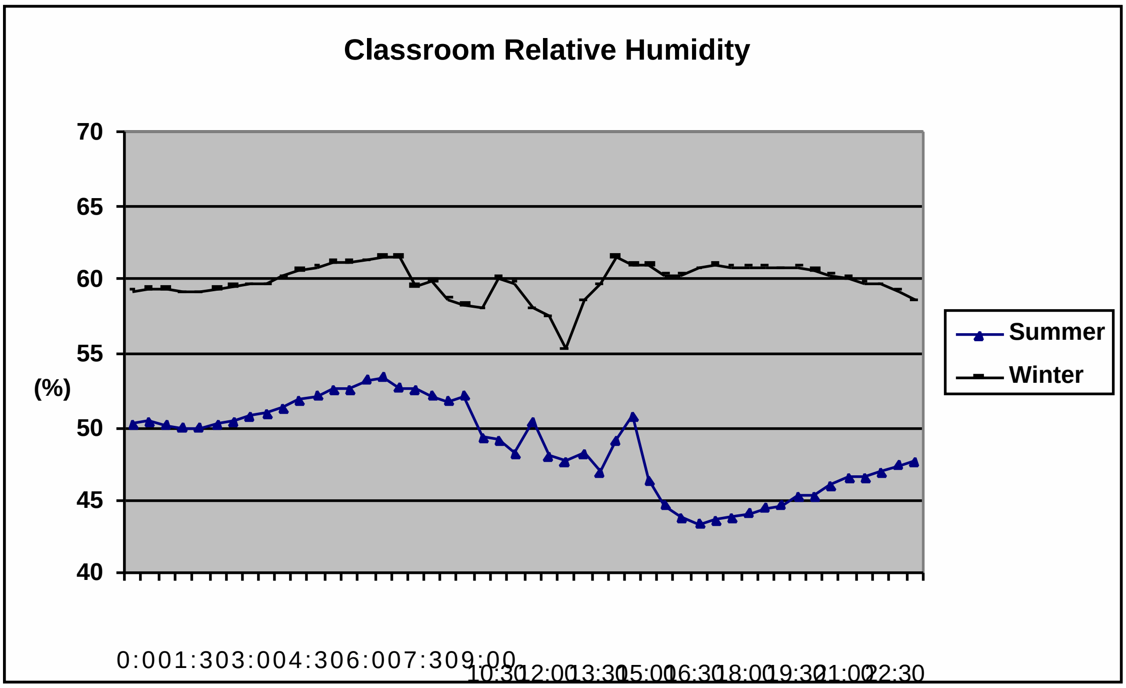

Figure 3 – Classroom Relative Humidity Levels (typical)

Ventilation and Metabolic Carbon Dioxide

CO_2 readings show that the occupants' metabolic CO_2 builds up when the rooms are occupied. The maximum value can reach 2500 - 3000 ppm, though this level quickly falls when the occupant density drops at mid-day, rises when they return after the dinner hour and again falls quickly when they leave in the afternoon. Although these levels would be considered high in a mechanically ventilated building, they remain within the 2000-3000 ppm range that is considered acceptable for this type of building in the UK. The readings return to the 350-400 ppm range overnight which reflects the typical outdoor levels of carbon dioxide at each site. This provides a first-order indication that the natural ventilation systems are able to purge occupant-produced pollutants from the building overnight and provide a fresh volume of air for the next day. The questionnaires indicated that the occupants were generally happy with the amount of ventilation and the indoor air quality in the classrooms.

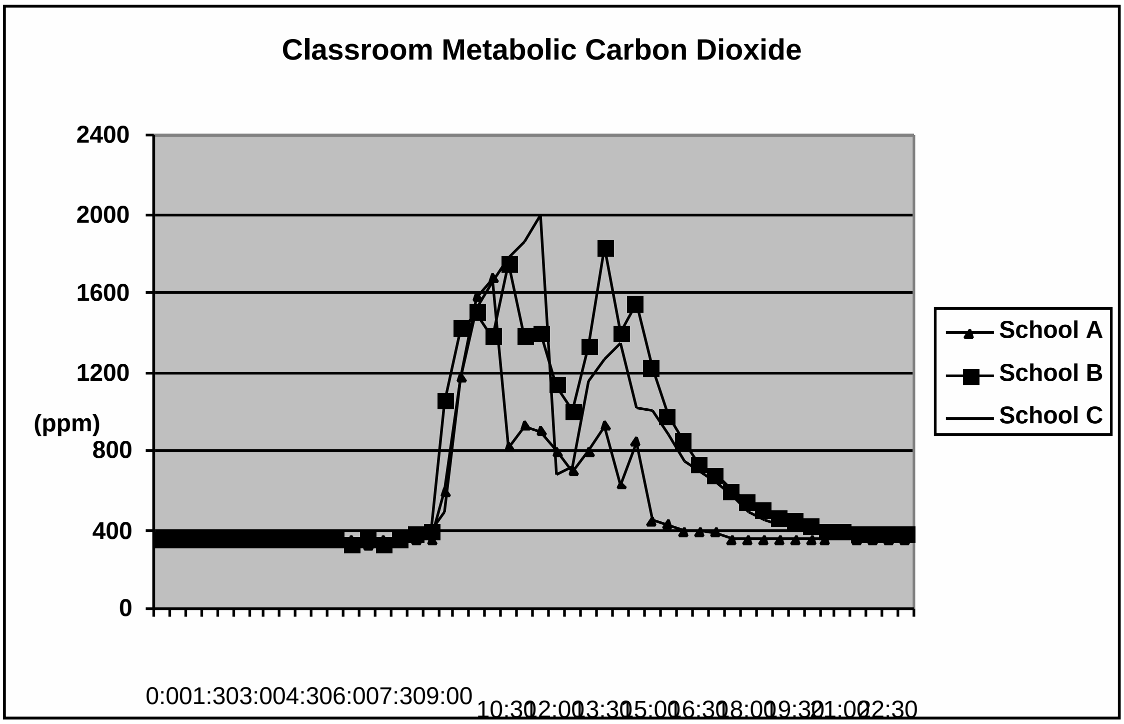

Figure 4 – Classroom Metabolic Carbon Dioxide (Feb. 2002)

Light Levels

An illuminance logger measuring light on the working plane showed that the mixture of daylight and electric light consistently provides adequate light for the occupants (300 Lux or greater). Additionally, event loggers on the light fittings showed how often the lights were switched on or off. From these readings it could be seen that Schools A and C had a poor lighting management factor, whilst the combination of even daylight distribution and lighting controls significantly reduced School B's usage of electric lighting (see Table 3).

Usability

"Usability" is taken to relate to the way that occupants interact with the building (including any passive design strategies) and the building's control systems.

Questionnaire

Although the questionnaires were designed and administered by the Local Authority, the comments that the occupants made about the buildings were used by this project to gauge the occupants' perceptions about the building. Although the full breakdown of the comments is beyond the scope of this paper, it should be emphasised that most of the occupants felt able to adjust the items under their control, namely lighting, heating, and ventilation. Due to the client's historical resistance to local control, there were a few instances where it was not provided, and the questionnaire highlighted the teachers' frustration at not being able to adjust the internal conditions. This feedback was presented to the client and a case was made, balanced with concerns about tampering and vandalism, for limited local control to be provided to all classrooms in the future.

Site Management

The site services staff reported few complaints from the occupants. They were not included in the Local Authority's questionnaire, so the only details collected from them were via the interviews.

Monitored Data

The temperature data show that the heating system is left running during half-term holidays in Schools A and C. Although all three schools have a "holiday" switch to set their heating back while maintaining frost protection, only School B used it to keep their heating from running during half-term. This is attributed to an A4 "summary sheet" posted by the heating controls to explain how to do the "basics", including heating individual zones after hours rather than heating the entire building for one evening meeting and changing the system from "winter" to "summer" to provide DHW outside the heating season without running the main boilers.

Conclusions

Although all three schools provide an internal environment that the occupants are generally pleased with, the consumption data show that School B provides this environment whilst using less energy. This is attributed to the early communication amongst School B's design team. The architect worked on providing an even distribution of daylight throughout each room, the electrical engineer considered the different types of lighting controls that would be appropriate and cost-effective for this scheme, and the mechanical engineer minimised the use of electrically-produced DHW. The effect of this is clear from the electricity data. The fact that these designers had worked together on previous projects also contributed to this, as the daylighting and natural ventilation strategies had been used and improved upon in several iterations. The mechanical engineer's "summary sheet" of brief and clear instructions posted by the heating controls in School B allows the site management to better use the controls as intended. The effect of this increased understanding can be seen by the natural gas data.

The occupants' comments on the questionnaires from all three schools revealed that most teachers feel able to control the internal environmental conditions in their classrooms when local controls are available to them. They additionally feel that all three schools are providing good learning environments for the children.