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Environmentally Responsive Primary School Buildings in the UK

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Abstract

In recent years a large stock of new school buildings was built in the UK as part of large government investment programmes. A particular emphasis was given to sustainability and innovation, creating a large number of experimental built precedents that could be learned from. This paper summarises a research of selected recent school buildings through fieldwork and subsequent analytic studies. The analytic work used dynamic thermal simulations assessing space heating demands as well as indoor temperatures under free-running conditions with the specification of a generic learning space as the basis of the model. These studies showed that space heating energy use can be reduced significantly, compared to current practice. However, the study has also shown how different operational parameters can incur higher energy use. The findings have been synthesised into design guidelines for primary school learning spaces.

Keywords: School Buildings, Case Studies, Performance, Design guidelines

1 Introduction

The physical learning environment plays an important role in the health and well-being of its occupants, thereby affecting learning outcomes. Several researches have shown that poor acoustics, air quality, daylight and thermal conditions have an adverse effect on pupils' health and performance, while enhancing the quality of the learning environment improves pupils' achievements (Earthman, 2002), (Murphy et al, 2010). In addition, school buildings have a significant environmental impact: they amount to 15% of the UK public sector and 2% of the overall UK carbon emissions (Global Action Plan, 2006). They can also act as an educational tool, teaching about environmental responsibility and impact.

Between 2004 and 2011 a large investment in school buildings in the UK took place. Key goals of the programme were sustainability and innovation. As a result, there are a large number of experimental school buildings that could be analysed. This paper summarises a research which aims to learn from these examples and explore those architectural and environmental conditions that contribute to a quality learning environment.

2 Methodology

The initial investigation included literature review to identify the challenges of school buildings' environmental design and formulate benchmarks for assessment. Four built precedents, which had available literature on their performance and operation, were analysed and formed a reality base for the research.

Field work was then carried out in four additional recently built schools across the UK. The field work included two visits to each school, during which spot measurements of

light level, sound, CO_2 and dry bulb temperature were taken and interviews were conducted. Dataloggers were used to measure dry bulb temperature over an extended period of one to three weeks.

Based on the findings of the field work, generic learning space models in Ecotect, Radiance, TAS and Ambiance, were developed. The models were used to evaluate the effect of different parameters on the performance of learning spaces. The conclusions from the research were synthesised into design guidelines which are presented through a design proposal.

3 Assessment criteria

There is limited research on comfort levels of children, therefore for the purpose of this research the thermal comfort assessment is based on the equations presented in European Standard 15251 (CEN, 2007), with a $\pm 3^{o}C$ range for normal expectation in new buildings. This model was chosen as it takes into account the influence of adaptive measures and because it is based on a running mean temperature, giving higher weight to the external temperature experienced within the previous few days. This is particularly suitable to the UK climate, which can have large differences in temperature within the same week.

Daylight level assessment is based on the UK guidance for schools which accompanied the BSF programme with a requirement of a light level of 300 lux and a recommendation of 5% DF and uniformity level of 0.3-0.4 (DoES, 1999). Daylight availability studies show that in overcast conditions, 5% DF would give 300 lux for 80% of the year during the school hours of 9.00-16.00 (BS 8206-2, 2008).

The air quality assessment is based on UK performance standards requirements of a maximum average CO_2 level of 1500 ppm and a recommendation for a maximum level of 1000 ppm (DoES, 2006). These levels correspond to the required average ventilation rate of 5 l/s per person, a minimum rate of 3 l/s and the possibility of achieving a ventilation rate of 8 l/s per person at any time.

4 Field Studies

The schools chosen for the field work were completed between 2009 and 2010. Environmental design was a principal target of their design and they were acknowledged for architectural and environmental achievements in publications and awards.

A common denominator for all schools was an intermittent occupancy pattern and use of space. In the course of a typical day spaces were empty for a large percentage of the day, while at other times they are fully occupied with high internal gains and fresh air requirements. The flexibility and constant movement between spaces require diverse environmental conditions to be provided within a short amount of time, while internal gains are changing.

The field studies and literature review indicated parameters that contribute to good daylight conditions. These include daylight sources from two directions, high-level windows or rooflight, high reflection of surfaces and avoidance of direct sun and glare in formal learning spaces, particularly where white boards are used. In addition, a good daylight level was measured when the window-to-floor ratio was 30% and in 3.5-5m height spaces. Effective solar control was found to contribute to daylight conditions and prevent overheating in summer.

The field studies also showed a challenge of overheating in summer and high levels of CO_2 and a recurring gap between predicted energy consumption and actual use.

5 Analytic work

A generic learning space model was created, combining the successful elements that were identified in the literature review and during field studies. The layout includes three types of internal spaces and a covered external area with flexible connections between them that can accommodate a variety of learning activities, from individual work to group work and lectures (Fig 1). The narrow plan can accommodate daylight from two directions for all spaces, as well as effective cross-ventilation.

Two sectional variations of the model were checked; a model containing rooflights and a model with clerestory windows in the classroom and group room spaces. Solar control to the south facing windows of the clerestory model was provided with an overhang (Fig 1).

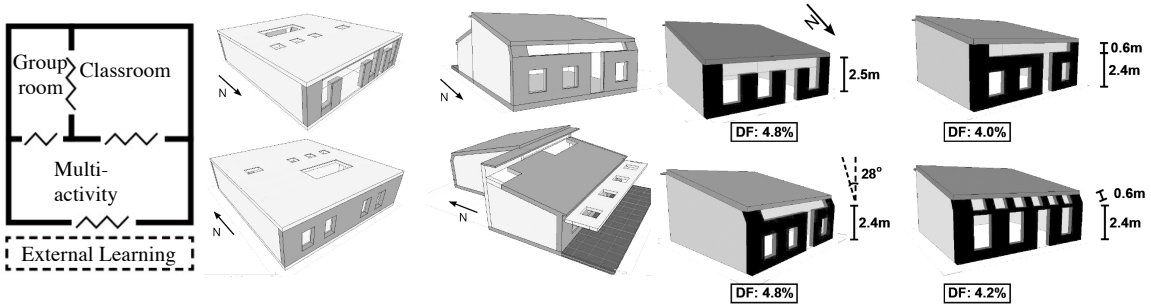

Figure 1: Rooflight and clerestory layout, models and results.

5.1 Daylight and Solar Control

The rooflight model indicated that a W/F ratio in the range of 25% to 30% can achieve 5% DF. Based on these results and on the field studies observations, a clerestory model with fixed W/F ratio of 27.5% was used in order to assess the other parameters of windows configuration. Reflectivity levels were also kept constant with 0.7 for walls and 0.5 for floors.

It was found that clerestory windows positioned higher than 2.5m from the floor reduce the amount of daylight brought in, when compared to lower ones (4.8% DF versus 4.0% DF) (Fig. 1). When the north clerestory window was tilted towards the sky, the light levels increased significantly (from 4.0 % DF to 4.8% DF). Increasing the height of clerestory above 0.6m did not contribute significantly to the daylight level; however, reducing its area by staggering windows reduces the daylight level (from 4.8% to 4.2%). W/F of 30% achieved an average DF level of 5% in this configuration.

5.2 Thermal and ventilation

In order to test the model's reliability, it was simulated with heating and ventilation settings that were observed during the field studies. The inputs of the model included an occupancy pattern of a typical day and heating thermostat set to 21^{o}C between the hours of 5.00 and 18.00 (the overall occupied times). The ventilation followed the occupancy with levels of 5-8l/s and also considered windows left open at times. The result was 52.7kWh/m^2. When considering boiler efficiency of 75% - 90%, the energy consumption for heating will be 58-78 kWh/m^2, which is in the range of the available energy

consumption data for new schools. As a comparison, an ideal scenario containing minimum ventilation of 3l/s provided accurately during occupied times in spaces at full capacity was run. The result was a low heating demand of 5kWh/m^2/y. This exercise demonstrates the weight of occupancy pattern, appliances gains, ventilation and heating settings on the energy consumption and confirms the Post-Occupancy-Evaluations that were reviewed and showed a gap between prediction and consumption.

In order to understand the influence of the operation settings, the factors of ventilation, heating settings and internal gains were checked separately. The dominance of the ventilation parameter is shown when the difference between a 5l/s provision which accurately follows the intermittent occupancy and a scenario of 8l/s provision according to the spaces full capacity is 20.5kWh/m2, reaching 40.7kWh/m^2 (50% higher). The heating settings are also dominant when a thermostat of 18^{o}C operating 8.00-16.00 incurs a lower heating demand of 9.2kWh/m^2 in comparison to 20.2kWh/m2 with a 20^{o}C thermostat operating 5.00-18.00.

The occupancy gain of 65W is almost equal to the heat loss incurred by 5l/s ventilation. Therefore it did not have a significant influence when ventilation settings were according to the occupancy. Appliances internal gains made a difference of 5kWh/m^2, when a scenario using a laptop per pupil and a white board at every class was compared to a low scenario of partial use of laptops during one hour and white board use during 3 hours.

Investigation of the influence of windows configurations and height of the space showed that larger rooflights and south-facing windows contribute to reducing the heating demand, while north-facing windows and higher space increase it. However, the influence of design changes of this scale in this layout were small (2-3%), in comparison to ventilation settings. An examination of the influence of the height of the space showed a higher consumption of 17kWh/m^2 in a 4.5m model in relation to a 3m model, with 13kWh/m^2.

Simulations of the model during a summer week in June showed that with windows set to start open when the temperature reaches 21^{o}C and be 30% open at 23^{o}C, the internal temperatures were within the comfort zone. Ambience model with air intake of 1.2m/s (for 15ach) and 0.02m/s (for 8l/s) showed that displacement of air is taking place at a comfortable velocity up to 0.1 m/s.

6 Applicability

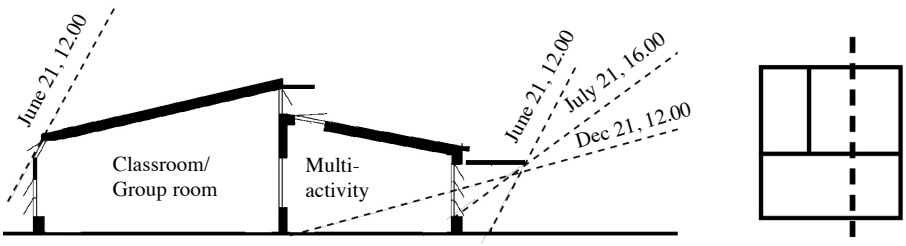

Figure 2: Proposed learning space model.

Model of a learning space positioned in London (Fig. 2), synthesises the findings of the research. The more formal learning spaces of the classroom and group room where laptops and white boards or screens are frequently used and which have higher internal

gains are facing north, getting diffused light and minimal solar gain. The window-to-floor ratio is 30%. Clerestory windows and view level windows are provided to the north. The north clerestory window is tilted, increasing the daylight level. The south clerestory window is protected from high-altitude sun by an overhang. This configuration achieves an average of 5% DF in overcast sky conditions and 0.4 uniformity.

The circulation and multi-activity spaces with flexibility of position in space and less internal gains are able to accommodate a wider range of conditions. Daylight is provided through a rooflight and façade windows which are protected from high-altitude sun by an overhang. In overcast conditions 5% DF is achieved, with 0.5 uniformity. In sunny conditions low winter sun is provided as an amenity and for useful solar gain through the south windows.

The rooflight's position does not allow direct sun onto the working surfaces. However, contrast and glare are generated when direct sun hits the wall. This contrast can increase the use of electric lighting in the multi-activity space and also affects the perception of daylight level in the classroom.

Cross-ventilation is provided to all spaces. Both the north and south façades contain two rows of easy-reach, manually operable windows and a row of high-level windows manually operable by switch. In addition the clerestory windows and the rooflight contain switch operable windows. The high-level windows are used in the winter to give a minimal required amount of fresh air without causing draughts. This was demonstrated through Ambience simulations with 5l/s provision.

In summer simulations in the analytic work showed that 30% of opening of the windows during occupied times is sufficient to keep the internal temperature within the comfort zone. This gives a flexibility of opening windows to a larger extent or for longer hours in warmer conditions or higher internal gains. Case studies review showed that even with good manual operation a CO_2 detector is likely to be needed in order to maintain good air quality.

All windows are manually operated directly or by switch. A large proportion of windows are situated within easy reach. In particular, the height of the lower-level windows is adjusted to the height of the children, thus providing children both with a view out while seated and with the opportunity to open windows independently.

The winter ventilation setting used is a fixed opening of windows according to an average required amount of fresh air of 5l/s. Based on the field studies, it is assumed that a routine can be formalised whereby the windows are opened to this extent every morning and closed at the end of the day by the caretaker. Any additional required opening of windows can be done by the occupants during the day.

The simulation model showed that with 5l/s ventilation in winter, provided according to occupancy and heating between 8.00-18.00, with Thermostat 20^{o}C, 15.5 kWh/m^2/y was reached. However, the studies also showed that much higher consumption can be reached when the ventilation and heating settings are higher.

7 Conclusions

The research indicates that it is possible to achieve a quality learning environment with good daylight, good thermal conditions and low energy consumption. It demonstrated

that a low heating demand of 15.5 kWh/m^2/y could be reached with intermittent occupancy scenarios and with simple ventilation settings that can be operated manually.

This result was achieved by adopting a design that is attuned to the conditions generated by the different orientations and in relation to the required internal conditions. In this way, the challenge of providing flexibility of space use, while maintaining energy efficiency is addressed. The occupancy and operation patterns were based on the field studies that were conducted, in order to take into account a realistic operation.

The simulations also showed the sensitivity of heating demand to operation settings and, in particular, to ventilation. Together with heating settings they could incur high heating demand, highlighting the importance of controlled ventilation during the cold months. Trickle ventilation from high-level windows was shown to be a good strategy with a potential to not cause draughts. Design parameters that reduce heating demand were found to be exposed south-facing windows and rooflights.

During the warm period, daytime cross-ventilation combined with solar control was shown to be effective in keeping the internal temperature within the comfort level. Additional out of hours purging was shown to be effective in case studies and it can be used in warmer conditions or higher internal gains giving future flexibility.

The core school hours of 9.00-16.00 correspond with daylight hours for most of the year, thus demonstrating potential for school buildings' lighting to be mostly natural. It was found that a combination of 30% window-to-floor ratio and daylight provision from two directions can achieve good daylight conditions and no requirement of electric light for 80% of the year during school hours. Continuous high-level windows not higher than 2.5m enhance light level and uniformity. Tilting north-facing, high-level windows towards the sky further increases the daylight level.

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