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The impact of ventilation strategy on overheating resilience and energy performance of schools against climate change: the evidence from two UK secondary schools

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ABSTRACT

The indoor environmental quality and energy performance of two modern secondary schools in the UK which have fundamentally different environmental strategies were investigated during building performance evaluations. The performances of these buildings against the projected weather data for future were also analysed. The results point to significant risk of future overheating as a result of climate change in the naturally ventilated building with passive measures that go well beyond the existing guidelines for schools. The other school with mechanical ventilation shows resilience to future overheating. However, shortcomings in building procurement and operation have severely compromised its energy performance. It is suggested to carry out integrated life-cycle assessment of energy performance and overheating resilience in the context of climate change during design stages and identify the corresponding risks and mitigation measures required to ensure design intents will be met in practice.

KEYWORDS

Overheating, Energy Performance, Climate Change, Schools, UK

INTRODUCTION

Average global temperatures are rising due to climate change. This has serious repercussions for the risk of overheating in buildings. Our understanding of human response to high ambient temperatures is also evolving and has led to adaptive overheating criteria for free-running buildings and overheating thresholds for mechanically conditioned buildings defined in BS EN 15251 (BSI, 2007) and CIBSE TM52 (CIBSE, 2013). This necessitates revisiting the performance of the existing buildings that were designed in accordance with different sets of overeating criteria and climatic conditions. Furthermore, while resilience against overheating is a key objective in climate change adaptation, improving the energy performance of buildings is also significantly important in the context of climate change mitigation to limit the increase in average global temperatures. Reconciling these competing objectives is therefore essential. This paper adopts a case study approach to investigate how energy efficiency and overheating control measures are being implemented in the UK construction industry. Two educational buildings have been selected for this purpose. Both buildings were constructed in England over the period 2008-2010 under the Building Schools for the Future (BSF) programme, which led to renewal or replacement of one fifth of English secondary schools. These buildings represent fundamentally different environmental strategies and were subject to post-occupancy investigations as part of a wider programme of building performance evaluation (BPE) instigated by the Innovate UK, the UK government innovation agency. The BPE programme, however, was focused on the current performance, and did not consider the potential response of these cases to future climate change. The aim of this paper is thus to adopt a long-term perspective in the context of a changing climate. The key objectives are: 1) to review the performance of the case studies against outdoor temperatures experienced during monitoring along with their energy use, 2) investigate the likely response of the existing design strategies and operational regime to future climate change, and 3) review the potential measures to enhance buildings' resilience against future climate change and the implications of the research for wider building stock.

OVERVIEW OF THE CASE STUDIES

School A: School A is a secondary school in London that was completed in 2010. Total useful floor area of the building is around 14,600 square meters. It was designed as a 2,000-pupil facility. The building is predominantly naturally ventilated and mechanical ventilation is only provided to the core spaces that do not have access to external facades and the ICT enhanced spaces with high internal gain. In total, around 80% of the building area is naturally ventilated. The external skin is formed from pre-cast concrete panels finished with brick tiles to achieve air permeability less than 5 $m^3/(m^2.hr)$ at 50 Pa. The reported air permeability following the pressure test on completion of the building was 4.36 $m^3/(m^2.hr)$. The main facades of the building are east and west oriented. Previous studies found the risks of such a layout for overheating (Pegg, 2007). The design team specified several measures to mitigate overheating: 1) vertical fins are positioned on east and west elevations to provide solar shading; 2) Glazing g values are relatively low between 0.45-0.5; 3) typical classrooms have opening areas at around 7% of the floor area for single-sided ventilation. This is significantly higher than the existing guideline for opening area required for single-sided ventilation in schools which is 5% (DfES, 2006); 4) the facility for cross or stack ventilation has been provided for most classrooms by means of motorised vents controlled by the building management system (BMS). These vents are meant to open in response to poor indoor air quality or high temperatures. 5) the exposed thermal mass of the building can help regulate indoor temperatures; 6) Secure louvered windows facilitate night-time ventilation in summer.

School B: School B is located in Greater Manchester and was completed in 2008. Total useful floor area of the building is around 10,400 square meters. It was designed as a 1,150-pupil facility. The school is a steel frame building with brick facades and cavity wall insulation that was designed to comply with the regulatory air tightness requirement of 10 $m^3/(m^2.hr)$ at 50 Pa. The building is located under the flight path of Manchester airport. Therefore, mechanical ventilation strategy was adopted to meet acoustic requirements. Classrooms facing external facades have at least one operable top-hung window. Glazing g values are between 0.68-0.75, reduced to 0.36 on the south, southeast and southwest elevations by applying solar film after completion. A Ground Sourced Heat Pump (GSHP) system is installed as the lead heating system and is also capable of providing cooling to ICT enhanced spaces of the school that have chilled beams installed for cooling. Other classrooms do not have cooling terminals. However, the main air handling units (AHUs) serving classrooms and labs have cooling coils that are fed by the GSHP system. While the building is not fully air-conditioned, the GSHP system and AHU cooling coils can provide limited cooling when outdoor temperatures are high.

Figure 1 shows the external views of the case studies.

Figure 1. External view from the courtyard of School A (left), and southside of School B

METHODS

Occupants' perception of the current conditions: The Building Use Studies (BUS) questionnaire survey (Leaman & Bordass, 2001) was used to assess the satisfaction of teaching and support staff with the current performance. The response rate in both schools was 75%. The results for comfort variables are presented in this paper.

Overheating analysis and simulation under current climate conditions: Calibrated Type T copper-constantan thermocouple data loggers were used to record air temperatures every 10 minutes for one full year (measurement accuracy: ± 0.35 ºC). At least 10% of teaching zones, representatively chosen, were covered. The results were compared against the overheating criteria for schools which were prevalent at the time the buildings were designed (DfES, 2006). Actual measurements were also compared with the outcomes of building simulations carried out with IES software (using current Test Reference Year weather file for London) to ensure a reasonable base model is available for future climate scenario analysis.

Energy Performance: the actual annual energy performances of the schools were established through regular recording of all main meters and submeters. Annual energy performances were then compared against the median of secondary schools in the UK to evaluate the success of energy efficiency measures adopted.

Projections for performance under future climate scenarios: The IES models developed based on the current performance were used to investigate the effects of the expected changes in weather conditions in future. It is envisaged that the buildings will be subject to major refurbishment within the next 20-30 years, the usual life-expectancy of most building services. This sets out a reasonable time horizon for investigating the effects of future climate change (CIBSE, 2014). Prometheus weather files developed by the Exeter University were used for this investigation. The current Design Summer Year (DSY), and the central estimate (50th percentile) for the effects of the medium carbon emissions scenarios in 2030 and 2050 were used to consider the effect of current climate change mitigation policies. The results for two classrooms in each school, which according to the technical measurements are prone to high temperatures, are presented against the new overheating assessment criteria set out in CIBSE TM52. Where a classroom fails 2 criteria (i.e. is overheated according to CIBSE TM52 criteria), the findings of building performance evaluations are used to identify improvement opportunities within the existing environmental strategies or suggest low cost interventions that may be used to improve overheating resilience.

RESULTS

Figure 2 shows the BUS survey comfort variables generally score higher than the median benchmarks which represent the results of the last 50 survey in the database. However, the score for temperature in summer is the lowest among variables for both case studies and the benchmark. This is indicative of challenges of achieving occupant satisfaction in summer.

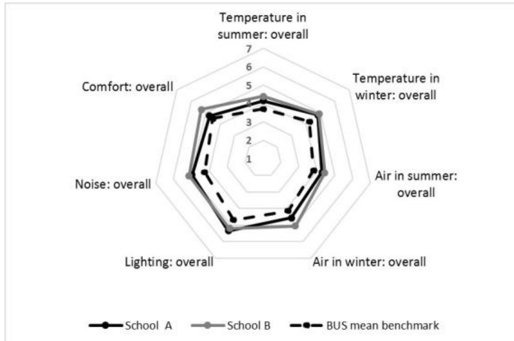

Figure 2. BUS results for comfort variables in the case studies

Figure 3 shows the measured and simulated air temperatures under ambient conditions close to Test Reference Years which are representative of the current climatic conditions. All sample classrooms comply with the overheating criteria prevalent at the time of design (DfES, 2006). Uncertainties in occupancy pattern, internal heat gains, and window positions can explain the discrepancies observed between measured data and simulation. Overall, the models appear to be reasonable representations of the thermal performance of the schools to be used for future climate scenario analysis. Classrooms with significant discrepancies between measurement and simulation were discounted from future climate analysis.

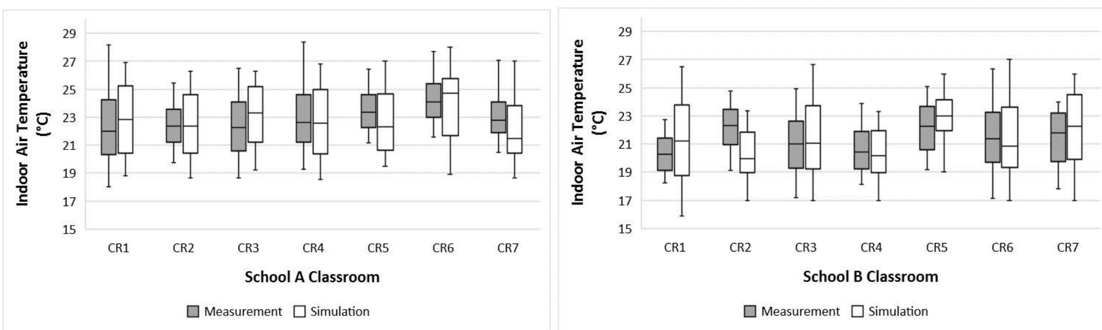

Figure 3. Whisker plots of current summertime air temperatures (May-September, 9:00-15:30)

Figure 4 compares the CO_2 emissions associated with operational energy use in these schools against the median stock (typical benchmark for schools in the UK).

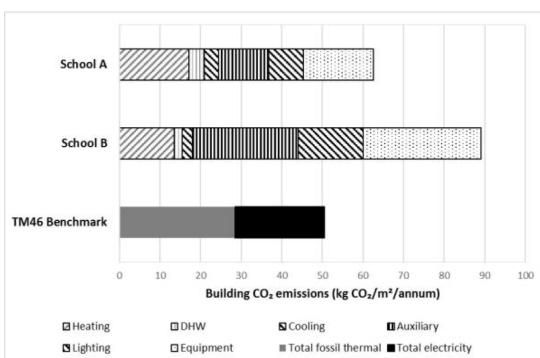

Figure 4. Carbon dioxide emissions associated with operational energy use

Table 1 reports the results of future climate change analysis (grey color indicates failure to meet the overheating criterion). The following additional passive measures were considered for School A that showed risk of overheating with the existing environmental strategies: 1) increasing the window opening from the design value of 250 mm to 400 mm, 2) applying solar films to glazing to reduce the g value to 0.15.

Table 1. Overheating risk assessment (CIBSE TM52/ BS EN 15251 method)

School / Classroom	Internal gain of people, lighting, and small power (W/m²)	Simulation scenario	Current Design Summer Years (DSY): more extreme dataset than TRY			2030 DSY for medium emissions scenario (50th percentile)			2050 DSY for medium emissions scenario (50th percentile)		
			Exceedance (%)	Degree-hours above limit	Max Δ T (°C)	Exceedance (%)	Degree-hours	Max Δ T (°C)	Exceedance (%)	Degree-hours	Max Δ T (°C)
A CR 3	Min: 29 (current 'average' use of the space)	Single-sided ventilation	14 (fail)	27	6	38	37	7	39	43	8
		As-designed: cross & night-time ventilation	2 (ok)	8	3	8	17	5	10	25	6
		Additional passive measures	1	5	2	3	10	4	4	19	5
	Max: 42 (full load mode for internal gain)	Single-sided ventilation	20	31	6	45	41	8	45	46	9
		As-designed: cross & night-time ventilation	3	9	3	10	19	5	13	27	6
		Additional passive measures	2	6	3	5	13	4	6	21	5
A CR 5	Min: 30	Single-sided ventilation	7	14	4	25	27	6	28	32	7
		As-designed: stack & night-time ventilation	1	4	2	3	9	4	4	17	5
		Additional passive measures	1	4	2	1	7	3	2	15	5
	Max: 42	Single-sided ventilation	13	20	5	36	33	7	37	38	8
		As-designed: stack & night-time ventilation	2	6	3	4	6	4	4	11	6
		Additional passive measures	1	4	2	2	9	3	3	16	5
B CR5	Min: 30	Existing building	0	0	0	0	0	0	0	0	0
	Max: 42	Existing building	0	0	0	0.3	0	0	0	0	0
B CR6	Min: 31	Existing building	0	0	0	0	0	0	0	0	0
	Max: 43	Existing building	0	0	0	0.2	0	0	0.4	0	0

DISCUSSION

Both case studies had been designed to comply with the requirements set out in the Schools Building Bulletin 101 (DfES, 2006) when exposed to a weather file representative of 'average' weather conditions. Applying the new overheating criteria and the more stringent DSY weather conditions (representative of 'extremes' for overheating analysis) shows the resilience of the environmental strategies adopted for these buildings to more extreme conditions. School A would comply with the overheating criteria under the current DSY conditions if the design strategy is followed in practice. However, a number of interventions would be required to mitigate the risk of overheating over the coming years. Table 1 shows that overheating is not merely a result of exceeding certain threshold temperature (Exceedance criterion), but the severity of it also exceeds the 6 degree-hours limit set out by CIBSE TM52.

School B, on the other hand, is quite resilient to the current and future weather conditions even under the new overheating criteria set out for mechanically conditioned buildings that specify fixed threshold and upper limit temperatures lower than Building Bulletin 101. Figure 4 shows that this resilience comes at a huge price in terms of energy use and specifically auxiliary energy that includes the energy used by air handling units. However, building performance evaluations revealed significant shortcomings in the procurement of School B that compromised its operational energy, notably failure of demand-controlled ventilation and specific fan powers being much worse than the design intents.

CONCLUSIONS

The future overheating risk in new school buildings in the UK is currently not adequately addressed at design stage. This can have implications for capital expenditure on the necessary interventions across the school estate in future that are not quite transparent.

This study found that a naturally ventilated school with several measures to protect the building against overheating in current climate will almost certainly experience severe overheating during teaching hours over the expected life cycle of its environmental strategy unless additional measures are specified to enhance its resilience. Mechanical measures to improve overheating resilience, on the other hand, can increase energy use and carbon emissions of schools. It is therefore recommended to carry out integrated life-cycle assessment for both energy performance and overheating resilience at design stage and identify major risks and mitigation measures to ensure design intents will be met in practice.

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