Moving beyond energy, integrating it with Indoor Environment Quality: UK school building case study

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Abstract

The policy-driven focus, at present, is to improve the energy performance of buildings. However, energy-related issues alone do not capture the full impact of buildings on occupants and the wider environment. The performance of a building also includes occupant wellbeing and indoor environmental quality (IEQ). Specifically, for schools, there is a strong association between IEQ (temperature, ventilation rates, and indoor CO_2 concentrations) with cognitive performance. Traffic-related external pollutants such as particulate matter and nitrogen dioxide are linked to adverse health impacts, especially in dense urban environments.

This paper assesses the performance issues and inter-relationships between energy and IEQ in a newly-built and partly-refurbished school campus in London. Based on the evidence gathered from this case study, larger endemic issues and constraints within the construction industry are explored and lessons for improved performance in the design and operation of school buildings are highlighted.

Keywords Energy performance, Indoor Environmental Quality (IEQ), Indoor Air Quality (IAQ), UK school buildings

1.0 Introduction

Building performance evaluations and post-occupancy evaluations currently primarily focus on energy performance issues. This is in line with the current policy objectives related to energy efficiency and climate change mitigation. However, energy performance alone does not capture the full impact of buildings on occupants and the wider environment; there is recent emerging evidence that relates to environmental quality [1]. The performance gap, encompassing building environment performance parameters along with energy, impacts occupant wellbeing and indoor environmental quality (IEQ) [2]. This paper reports on the interim findings of an on-going investigation of performance of a newly-built and partly-refurbished school campus in London.

The aim of this paper is to report how the case study building is performing against the design baselines and industry standards and identification of root causes of underperformance in energy and IEQ aspects. A key objective is to link energy to IEQ performance and determine various design and operation stage decisions that have affected building's performance both positively and negatively. The findings are linked to larger endemic issues and constraints within the construction industry and some lessons for improved performance in the design and operation of school buildings are highlighted.

2.0 Background

Performance gap is the difference between the actual operation of buildings against the design aspirations. There is significant evidence [3] [4] to suggest that buildings underperform post-completion when compared against the anticipated performance during design stages. Various metrics could be used to assess performance gap in the actual operation of a building, out of which, energy performance is the generally the most highlighted and emphasised. CarbonBuzz, a research platform where stakeholders voluntarily provide design and actual energy use data of buildings [5], reports an average 114% increase in operational CO_2 emissions compared to design estimations for school buildings. While this provides evidence for energy performance gap, much of the design stage data provided on CarbonBuzz is based on Building Regulations compliance or Energy Performance Certificate (EPC) calculations. This demonstrates the prevalence of interchangeable and contentious use of the outcomes of Building Regulations compliance calculations or EPC calculations as design predictions for buildings [6].

Moreover, the gap between actual and expected performance is not limited to energy, it may also be identified for the Indoor Environmental Quality (IEQ) parameters such as temperature, relative humidity, air quality (pollutants, CO_2), noise and lighting [7], [8], [9]. The direct relationship of occupant well-being, comfort, and productivity with IEQ in various building types is well measured and documented [10], [11], [12]. Specifically, for schools, there is a strong association between key IEQ parameters (temperature, ventilation rates, and indoor CO_2 concentrations) and cognitive performance [13].

In the current trend of sustainable and low energy building design, the ways to achieve high IEQ (Thermal comfort, lighting, IAQ, and acoustics) and building user satisfaction objectives might contradict measures to achieve better energy performance. For example, overheating and air quality (higher levels of certain Volatile Organic Compounds) issues are uncovered in highly insulated and airtight new buildings constructed to higher energy standards [14], [15], [16], [17], [18]. In urban areas, traffic-related external pollutants such as Particulate Matter and NO_2 are linked to adverse health impacts as well. These have significant implications where energy-efficient strategies such as advanced natural ventilation are adopted and air exchange between the indoor and outdoor environment occurs without any filtration. It is questionable if CO_2 is the only metric used as a proxy for Indoor Air Quality (IAQ). In such circumstances, while CO_2 levels provide the first indication of exposure, indoor levels of traffic-related pollutants need to be considered separately [11]. A holistic, energy and environmental performance approach is necessary to understand the intricate interrelationship between these performance aspects to avoid unintended consequences and address gaps in performance.

3.0 Method

The paper looks at design and operational performance issues, inter-relationships between energy and IEQ and root causes of performance gaps in the context of school buildings, underpinned by findings and observations from a case study building. The case study building is a secondary school and sixth form with academy status, located in London Zone 3, England. The school went under redevelopment in 2014 with construction of six new buildings (including teaching spaces, sports hall and performance arts & dining hall) and refurbishment of a couple of existing ones (swimming pool & gymnasium building and assembly hall). The buildings were generally 4 stories high with total useful floor area is of 21,405 m^2. The project was required to achieve a 20% carbon reduction under the local council planning conditions by implementing on-site renewable technologies. To satisfy this, a Biomass boiler utilising solely wood pellets and solar thermal collectors was implemented. Figure 1 shows the school building and Figure 2 shows the campus layout.

Figure 1: Case study school; (Right) Entrance – West façade, (Left) Central courtyard.

Figure 2: Campus layout

Regular measurements, observations and semi-structured interviews with the facility managers at monthly or bimonthly intervals over a period of one year were used to collect post-occupancy data and information. Metering and monitoring recorded various performance parameters. Electricity and Gas use data was recorded for Energy while Temperature, Relative Humidity, CO_2 - a proxy for cognitive performance, NO_2 – driven by traffic and combustion processes, microparticles (PM1-10), Total Volatile Organic Compound (TVOC), and CO were recorded for IEQ. Additionally, passive sampling using diffuser tubes was used to determine the concentration level of several VOCs such as benzene, formaldehyde, and trichloroethylene that based on previous research [18] may have high concentration levels in low-energy buildings.

Energy use and IEQ performance parameter predictions at the design stage and were compared with post-occupancy operations data and the relevant UK and global standards. Then, reasons for performance gap were identified using post occupancy observations and interviews. The root causes for the gap were validated using a calibrated computer model, and potential building specific and industry processes related improvements were identified. Following section details the building design and monitoring data collection details.

3.1 Building Design stage characteristics

Envelope: The external envelope was made of prefabricated concrete panels, assembled at the site. As the building, designed for high energy efficiency, has low Fabric U-values (Wall: 0.25 W/m^2K; Window: 1.6 W/m^2K; Roof: 0.20 W/m^2K) and high airtightness (5 $m^3/hr/m^2$ @ 50Pa). Emphasis was given to avoid thermal bridging.

Occupancy: The nominal design stage occupancy was 2250 (2000 pupils and 250 staffs). The daily occupancy for students on Mondays was from 8:35am to 2.55pm, Tuesday to Friday from 8:35 am to 3:50 pm and on Saturday the occupied time was from to 9:10 am to 13:00 pm. While these are timings for school occupancy, individual spaces within the building were not occupied the whole time. They followed the classroom timetables provided to the authors by the school management.

Heating, Cooling, and domestic hot water (DHW) system: Heating was provided through a centralised plant for the entire campus via pressurised low-temperature hot water (LTHW) system. A biomass boiler (heating seasonal efficiency: 0.75) for annual DHW demand and two gas-fired boilers (heating seasonal efficiency: 0.84) were installed to provide heat in the building. Rooms with high ICT and server rooms were installed with Variable Refrigerant Flow (VRF) systems that provide both heating and cooling (heating/cooling seasonal energy efficiency ratio: 1.47/3.80). There was not any provision of comfort cooling to any other spaces. Heating and cooling setpoints were 20°C and 23°C respectively.

Mechanical ventilation (MV) system: MV system with heat recovery (Heat Recovery Efficiency: 0.75) via centralised roof mounted AHU plant provided fresh air in the buildings, distributed through wall mounted diffusers/grills. Building Management System (BMS) system controlled ventilation in the spaces based on the installed carbon dioxide sensors in each room.

3.2 Data Collection

Design stage information, such as performance targets for energy and standards used for indoor environmental quality were recorded in design documents. The methods used to collect operational data are described below.

Energy: Gas use in the facility, metered at the site level, was recorded in utility bills on a monthly basis. Each new building had its own heat meter which was linked to the BMS system. The mains electricity meter recorded half hourly electricity use at the site level which was available from utility supplier. At the building level, disaggregated energy use for lights, small power, lifts, server, pumps, and fans could be read through the BMS. It would have been useful to extract the gas consumption of the two retained buildings from the total gas consumption for the whole school to achieve a more comprehensive comparison with UK building stock.

Indoor Environment Quality: Temperature, Relative Humidity (RH), and CO_2 concentration were monitored in representative zones, covering 5-10% of the floor area with a frequency of at least 10 minutes for one year in accordance with BS EN 15251:2007 [19], (measurement accuracies : T: ± 0.4 °C, RH: ± 4.5 %, CO_2: ±75 ppm).

A more in-depth investigation was also conducted in four typical locations of the case study school: Library (Ground Floor, West), sample classroom (Building 3 First Floor, North), sample science lab (Building 4 First Floor, East), and external space (within campus close to the main road). The parameters of thermal comfort and various air pollutants such as CO_2, CO, PM 1-10, NO_2, TVOC were recorded every minute by data loggers and sensors in the monitored spaces. Apart from the active monitoring of TVOC, passive sampling of various VOCs was also applied in a typical week during heating season.

Additionally, thermal imaging was used to understand the envelope thermal performance and bridging. User satisfaction surveys were conducted to understand the user perceived thermal, visual and acoustic comfort and air quality for summer and winter season.

4.0 Building performance results

The school building was designed, with attention given to various performance aspects. In this section, the intended and actual performance for various metrics is compared and mapped to the relevant benchmarks and standards.

4.1 Energy performance

The available design stage projection of energy performance (electricity use and gas) was done as a part of Building regulations compliance documentation at RIBA Stage 4. The calculation, carried out for the whole facility, reported annual energy use projections for each building separately.

Operational stage electricity and gas use data was available from utility bills for four years (2014-2017). Figure 3 shows the comparison against design estimates (for RIBA Stage D Report); good practice (25th percentile) and typical (median) benchmarks as per DEC database [20], and CIBSE TM46 benchmark [21].

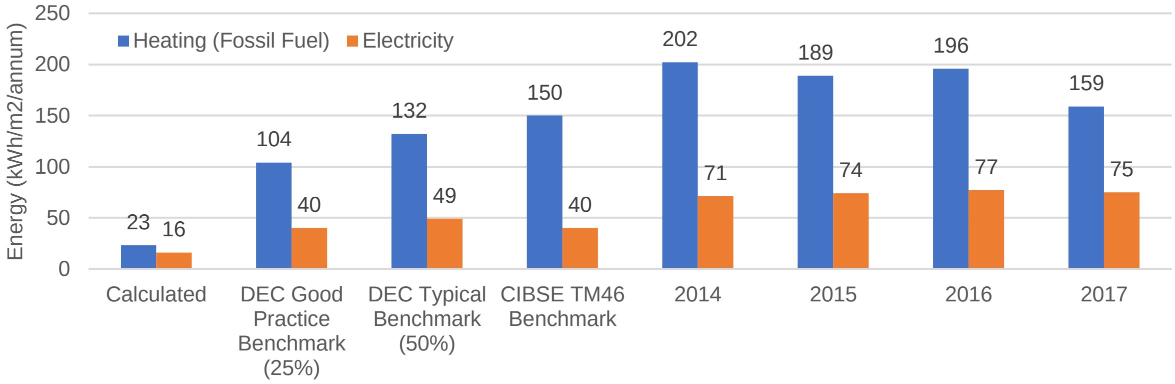

Figure 3 Comparison of actual gas and electricity use of school compared against design estimates and industry benchmarks (kWh/m^2/annum)

It is seen that heating energy use is significantly higher than benchmark buildings – especially for a new build school. Electricity use is also slightly more than benchmark buildings. However, both heating and electricity strikingly much higher than the design estimates. As per the latest display energy certificate, the operational rating of the school is currently DEC-F, i.e. that the energy used is more than 1.5 times of the typical benchmark school building.

Analysing high-resolution building level data helped in identifying specific issues dealing with design, operations, and management. Disaggregated annual operational energy use of individual buildings (Heating Demand, Lighting, Equipment, Auxiliaries, Server and Lifts) was available from the BMS readings taken over a period of one year. Data and operational performance for one building on the campus were analysed using a calibrated building performance model using DesignBuilder software [22]. The model helped in validating many deviations from the design stage intent which were probable causes of the performance gap. These deviations were observed on-site visits, noted during an interview with the facility managers and uncovered in IEQ data trends.

4.2 IEQ performance

During the period of one-year various IEQ parameters were monitored and analysed and an occupant satisfaction survey was undertaken.

4.2.1 Thermal comfort

The building maintained comfortable indoor temperature and relative humidity in most spaces during, both, heating and non-heating seasons. Indoor temperature in the monitored space was kept around 20°C and 23°C during heating and non-heating season respectively. RH was between 40%-55%. Figure 4 and Figure 5 show internal and external temperature and RH ranges of three representative building spaces[1].

Figure 6 shows detailed indoor temperatures during the heating season. It is observed that during occupied times the indoor temperatures in all the sampled rooms were maintained above 23°C. Also, during the holidays, the temperatures were recorded much above the outdoor levels for the lab and the library, whereas the classroom temperature profile was similar to the external measurements.

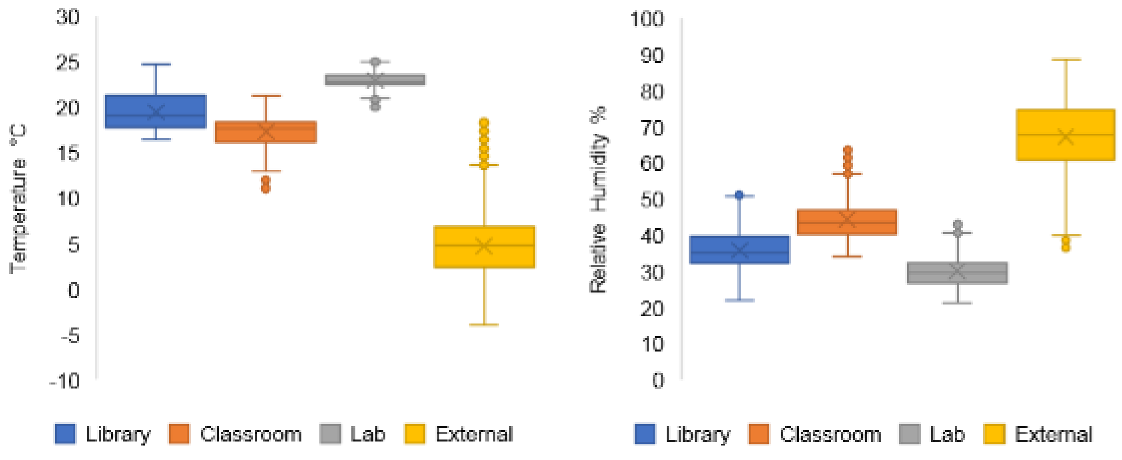

Figure 4 Box and whisker plots showing the spread of Temperature and Relative Humidity during heating season (Feb 2018)

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[1] Box and whisker plots in the paper show Interquartile ranges and outliers.

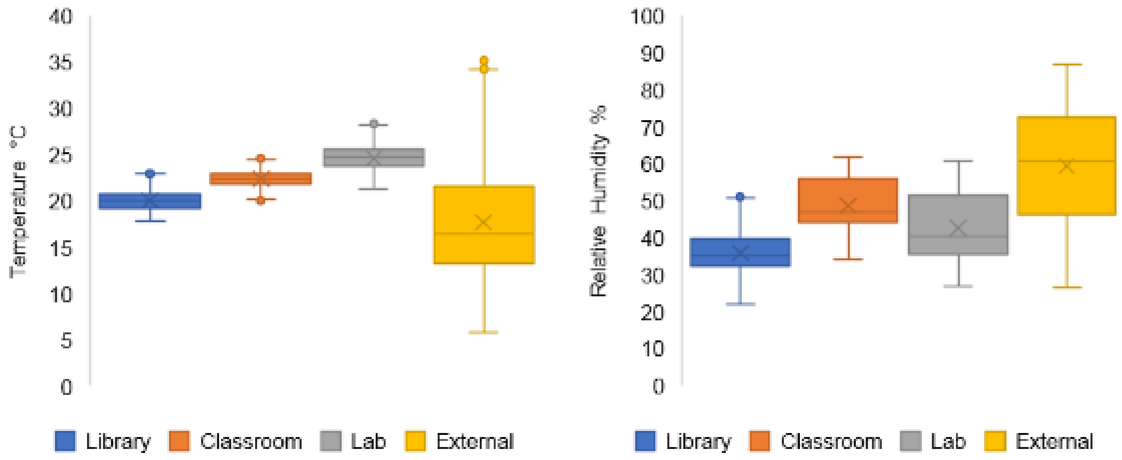

Figure 5 Box and whisker plots showing the spread of Temperature and Relative Humidity during non-heating season (May 2018)

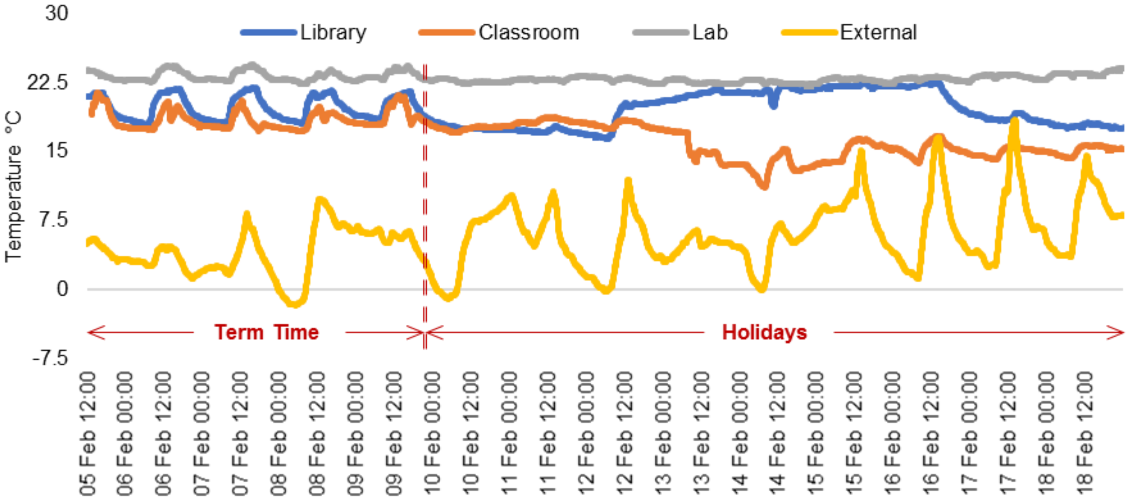

Figure 6 Temperature and during term time and holidays in the heating season

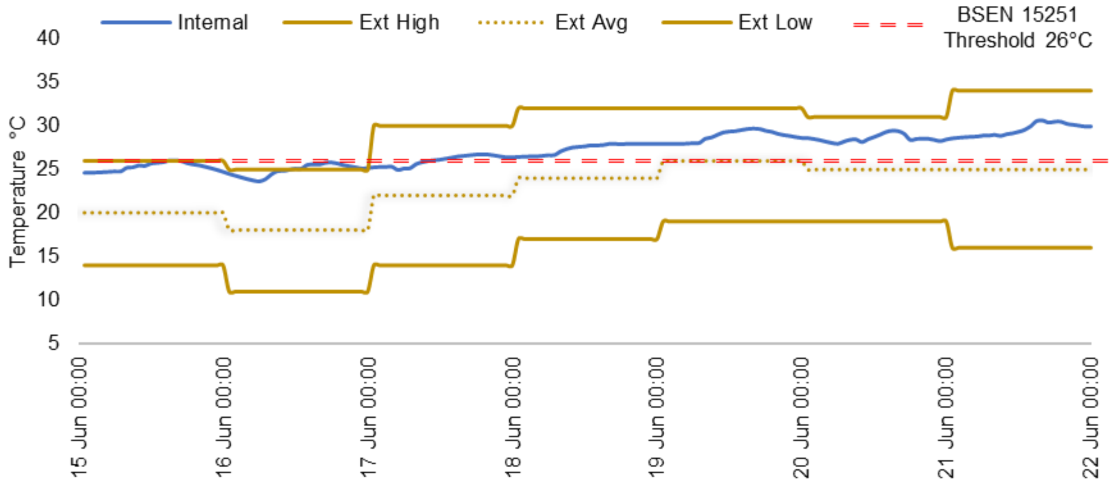

Figure 7 Indoor monitored temperatures in a classroom during a hot summer week

During the non-heating season, while most of the spaces did not suffer from overheating, rooms on the south façade, lacking solar controls (blinds/shades) had high heat gains. They were susceptible to overheating risks in peak summers. Figure 7 shows indoor temperatures in a south facing classroom on the second floor during a hot spell in the month of June. To evaluate the overheating risk of mechanically ventilated buildings, a threshold 26°C is specified by BS EN 15251 [23]. Overheating during summer has also been regularly flagged in occupant survey results with two-thirds of respondents reporting the spaces to be Warm or Hot.

4.2.2 CO_2 concentrations

Because of mechanical ventilation with CO_2 based controls in the building, most spaces had adequate fresh air supply during occupancy hours. Figure 8 shows that CO2 levels during the heating and non-heating season in the monitored space were generally under 1500 ppm, as recommended by BB101:2006 [24].

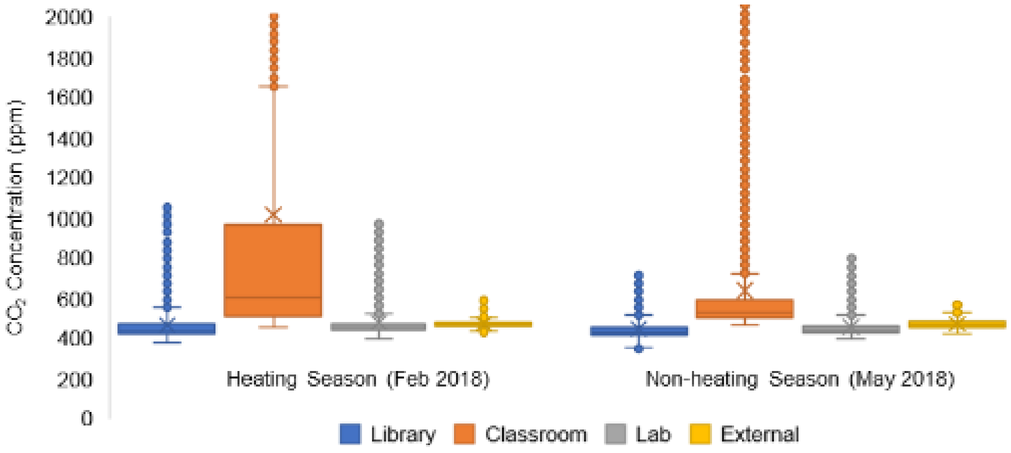

Figure 8 Indoor monitored CO_2 concentrations

4.2.3 Particulate Matter

Being mechanically ventilated, the building has good airtightness and fresh air intake is controlled and filtered. $PM_{2.5}$ and PM_{10} concentrations in the monitored spaces were always below external values and significantly below the WHO 24-hour mean threshold of 25 µg/m^3 and 50 µg/m^3 for $PM_{2.5}$ and PM_{10} respectively (Figure 9).

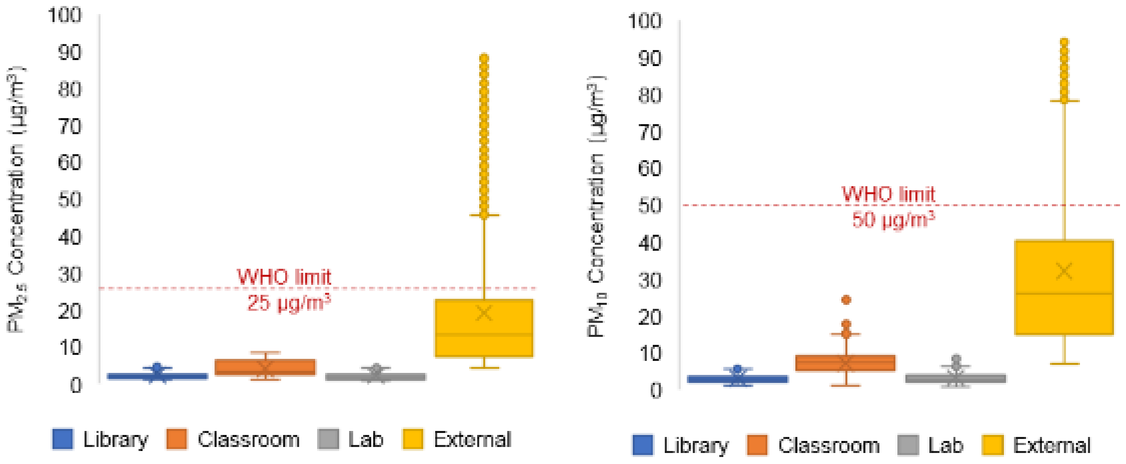

Figure 9 Daily mean PM_{25} and PM_{10} concentrations during heating season

4.2.4 VOCs, Formaldehyde, NO_2 and O_3

These pollutants were measured through passive sampling. Results (Table 1) show that most compounds were below the standard limits [25], except for Benzene and NO_2. The comparison with outdoor concentration levels suggests that the exceedance of these two pollutants was due to outdoor sources, mainly traffic. VOC levels were within the standard limits.

Table 1 Indoor and outdoor concentrations of VOCs (µg/m^3) and other pollutants measured with diffusing sampling during the heating season

	Lab (µg/m^3)	Classroom (µg/m^3)	Library (µg/m^3)	Outside (µg/m^3)	Lab (blank) (µg/m^3)	Limit *[25]* (µg/m^3)
Benzene	**<1.90**	**2.50**	**2.10**	**2.60**	**<1.90**	0.20
Toluene	<1.60	3.50	1.60	1.70	<1.60	250.00
Trichloroethylene	<0.90	<0.90	<0.90	<0.90	<0.90	2.00
Tetrachloroethylene	<1.10	<1.10	<1.10	<1.10	<1.10	100.00
Styrene	<1.00	3.60	<1.00	<1.00	<1.00	30.00
Naphthalene	<0.80	1.00	<0.80	<0.80	<0.80	2.00
Formaldehyde	<0.13	<0.13	<0.13	1.10	<0.13	9.00
NO_2	**42.94**	23.49	24.55	**48.61**	1.76	40.00
O_3	14.25	5.10	5.18	57.76	0.01	100.00

4.2.5 Lighting and Acoustics

Most of the performance issues for lighting and acoustics were reported in occupant feedback surveys. Occupant satisfaction with the brightness of the light was very high, with less than 15% people dissatisfied, however, there were significant issues with glare with only 25% occupant satisfaction.

Majority of the occupants were satisfied with the acoustic environment of the building. However, there was some dissatisfaction due to noise transmission from internal sources, especially from surrounding zones and circulation spaces (stairwells).

5.0 Performance analysis, root causes, and solutions

5.1 Energy

The higher than intended energy use for both gas and electricity was partially due to some technical issues with building systems, but the main reason was suboptimal operations and their maintenance. Some of the identified and validated deviations are listed below [22].

Occupancy: During term breaks the school was not completely shut; there were extra-curricular activities and events that taking place, especially during the summer holidays. This was seen in school's half hourly load profiles. More realistic calculations should be undertaken for performance estimations and baseline identification at the design stage.

Operational inefficiencies Lights in the circulation areas, computers in ICT rooms, heating system and MV systems were operational even after the end of the classes. During out-of-hours and half-term breaks, when there is very low occupancy, mechanical ventilation and heating are provided to multiple zones. Moreover, the supply fan during unoccupied times was operating at 30% to 40% of its nominal speed. Additionally, the heating system maintains an elevated temperature in the range of 22-23°C or higher in the winter season, which is more than the intended setpoint temperatures of 20°C (Figure 6).

HVAC system equipment: The Specific Fan Power in AHU specification sheets was 66% high than the values used in the design stage estimations of 1.8 W/l/s.

Along with the above factors, another reason for a poor DEC rating was that low carbon strategy of using biomass as fuel was not implemented. Biomass boiler was installed to provide more than 50% of the total heating demand (including DHW) with the intent of decarbonising energy use, a measure recommended by the local council. However, biomass boiler was never used, all the heating was provided using gas, due to practical and logistic issues of using biomass as fuel. Finally, some of the performance issues can also be attributed to the fact the actual energy use also includes the two possibly underperforming existing buildings, that were refurbished.

5.2 IEQ

Thermal Comfort: Temperature and RH monitoring graphs show that heating system operation and pre-conditioning of fresh air from MV system are appropriate. Also, there is a high level of airtightness in the buildings as the sampled zones are able to retain heat and temperatures overnight during the heating season (see term time temperatures in Figure 6). However, there were summertime overheating issues reported in the occupant surveys and observed in indoor temperature monitoring in some of the south facing zones. These issues were further worsened by the airtight envelope and inadequate operable windows. Figure 7 shows the increased indoor temperatures and on hot summer days in the classroom because, due to maintenance issues, the MV system was not operational and windows were not able to provide enough fresh air.

Air Quality: Fresh air availability in indoor spaces was generally good with low levels of CO_2 concentrations (except in the classroom because of malfunctioning MV system) across the building (Figure 8). MV system effectively controlled the ingress of micro particles (Figure 9), however, increased Benzene and NO_2 levels show that (Table 1), there is a need for additional activated carbon filters in polluted urban environments. Low levels of VOCs indicate appropriate indoor finishes and material selection.

Lighting: Glare prevention is particularly important in schools. Excessive glare hinders teaching as interactive screens, projectors and whiteboards become difficult to read. Glare also has adverse health effect for students suffering from migraines [26]. Blinds, while reducing the natural lights, are an easy solution to avoid glare.

Acoustics: The acoustic underperformance of the building was conflicting with the exposed thermal mass requirements. As seen in Figure 10, classrooms, stairwells and common spaces, all have exposed concrete ceiling for exploiting the use of thermal mass for better thermal comfort and energy efficiency. However, this leads to a conflict with acoustics because of longer reverberation times and noise transmittance through the structure. Baffling in the stairwells and exposed ceilings and acoustic breaks in construction assemblies can be used to avoid noise issues and its transmission through the structure.

Figure 10 Exposed concrete ceiling in common areas and classrooms

5.3 Balancing other energy and IEQ requirements

It is a challenge for designers to balance the energy efficiency and the IEQ due to potential conflicts of these two-performance metrics. Besides the conflicts noted earlier, another factor that requires the right balance is the complexity and disaggregation of building controls. The building services control strategy in the building was not responsive enough to partial demand during out-of-hours use. This results in unoccupied spaces being heated during transitional occupancy times, leading to excessive energy use (see Figure 6 – holiday time). The zoning arrangements of environmental sensors could also benefit from fine-tuning. One space controlling the temperature in other teaching spaces was observed in our monitoring and reported by occupants in the feedback surveys.

Generally, Provision of operable windows for natural ventilation and comfort cooling in summer needs to address outdoor noise ingress issues. However, it also needs to be integrated within lighting comfort requirements. While the outdoor noise was not a major issue in the school, use of roll-up blinds for glare prevention was. As internal blinds conflict with airflow from open windows because of rattling an integrated design solution for the façade balancing all the requirements is needed.

6.0 Discussion

This school’s energy consumption is higher than the typical benchmarks, with the gas energy use significantly higher than expected. This is due to the combination of extended hours of operation, operational inefficiencies, and maintenance issues. Moreover, the biomass boiler, although installed, has never been put into function. Consequently, the operational DEC rating of the school is currently G. IEQ performance in terms of thermal comfort and indoor air quality is generally within acceptable levels except overheating during very hot summer spells and some exposure from pollutants in dense urban environments. In this section, we look at these factors in a larger context.

6.1 Design projections of energy performance

Building Regulation compliance models use simplified calculations intended to ensure that minimum regulatory requirements are met and to benchmark energy use for entire building stock. Using these results as a projection of energy use of a building is not appropriate as it generally leads to significant underestimation. The approach for estimating operational energy use at the design stage should be as per CIBSE TM54 guidelines, accounting for all end users in the building alongside realistic operating patterns and occupant behaviour.

6.2 Considerations in transitionally/seasonally occupied buildings

Schools buildings have partial occupancy during half-term breaks and extracurricular activities. Even during term times, all the spaces are not fully occupied throughout the day. Optimum space-time utilisation is a cost-effective way of saving energy. Strategies such as demand-controlled ventilation should be used effectively. Moreover, hydraulic isolation of heating/cooling zones that are not occupied, would ensure that large areas are not unnecessarily conditioned in these types of buildings.

6.3 Use of new low-carbon technologies

A biomass boiler was installed in the school to meet the CO_2 emissions criterion of the Part L of Building Regulations and local council’s intention to use and promote low carbon technologies in the borough. However, this system was not operational post-handover, due to logistic limitations of running it and a lack of understanding between the occupants and the council. This meant that the expected CO_2 emissions of this building are significantly higher than what was assumed on the completion of the building.

6.4 Managing building energy performance

Most of the energy performance gaps were due to the sub-optimal operation and irregular maintenance of building systems. This was partly due to a centralised system design (one control and sensor for many zones) and lack of user-friendly BMS controls to manage it. A more streamlined building operation and management strategy envisaged in design and incorporated at handover would enable a building to operate reasonably close to what is assumed at the design stage.

6.5 Ventilation strategies

Natural ventilation strategy may not be suitable for dense urban environments where external air can be more polluted than indoor air. MV systems provide the necessary controls and create more air-tight envelopes. The industry’s main metric for assessment of IAQ is currently CO_2 concentrations. Most existing control strategies for ventilation systems also use this metric. In mechanically ventilated buildings filtration is used provide a level of protection against outdoor sources of pollution such as microparticles. However, some traffic-related pollutants such as NO2 are not mechanically filtered and advanced activated carbon filters or other measures are required to enact chemical filtration

Additionally, advanced control strategies that consider the balance between requirement for fresh air and protection from outdoor sources of pollution could provide a healthier environment and at the same time save energy in both mechanically and naturally ventilated buildings that rely on automated ventilation. Provision of natural ventilation through operable windows or vents, when specified, should consider interdependent aspects of acoustic and visual comfort requirements.

6.6 Design resilience for future climates

Current building design and operation strategy catering to today's climatic conditions shows overheating risks in hot summer spells in certain zones. In the context of future climate, this risk can be significantly higher. The future performance can be tested using future climate data in building performance simulations.

The current building systems (with no mechanical cooling) would be able to provide comfortable environments until they are required to be refurbished or replaced at the end of their life. Modifications to environmental strategy to cater to changing climate can be undertaken then. However, at this stage, the building design itself could be made resilient and adaptable so as to avoid major disruptions during retrofits. Passive solutions, such as integrated shading design, night purge ventilation and circulation fans could be adopted or planned for future retrofits. Similarly, mechanical systems can be planned in building design such that retrofitting air-conditioning is possible without significant disruptions.

6.0 Conclusions

The work highlights many useful lessons that can potentially be used to inform and improve current building design practices. The findings regarding performance issues might be specific to the case study, especially the technical issues regarding building systems, but the larger issue of optimal operations and maintenance of building systems for better energy and IEQ has applicability for other schools in general.

Firstly, at the design stage it is important to project energy use accounting for all end uses and probable variabilities that might occur during operations. The changing trend of schools' occupancy patterns in general, beyond regular school hours and term times, needs to be considered when estimating performance. Factoring resilience in design, in the context of climate change, safeguards the performance of the building over its entire lifecycle.

Addressing energy & IEQ performance holistically is important so as to ensure that energy efficiency is not achieved at the expense of IEQ and other aspects of building performance. For example, ventilation strategies should be balanced with acoustic comfort requirements and external pollution in dense urban environments need to be addressed for both naturally and mechanically ventilated buildings.

At the policy and regulatory level, robust safeguards, such as measurement and verification of building and system performance in first few years, are needed to ensure the installed low or zero carbon strategies and technologies will be used in practice. This can be supplemented by a performance contracting approach, in which the designers, contractors and building managers are accountable and a stakeholder in ensuring the operational performance of the building. The purview of performance contracting should account for specific requirements for both energy and IEQ (Environment and Energy Performance Contracting).

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