RECONCILING RESILIENCE AND SUSTAINABILITY IN OVERHEATING AND ENERGY PERFORMANCE ASSESSMENT OF NON-DOMESTIC BUILDINGS

Esfand Burman [1], **Judit Kimpian** [2] **and Dejan Mumovic** [3]

[1] Centre for Urban Sustainability & Resilience, University College London, Chadwick Building, Gower Street, London, WC1E 6BT, UK. (Email address: esfandiar.burman.10@ucl.ac.uk)

[2] Research & Development Division, AHR Global Architects, 5-8 Hardwick Street, London, EC1R 4RG, UK.

[3] UCL Institute for Environmental Design and Engineering, the Bartlett, 14 Upper Woburn Place, London, WC1H 0NN, UK.

ABSTRACT. Sustainability and resilience are generally acclaimed as favourable attributes of techno-socio-economic systems. However, they often encompass system characteristics that are not necessarily consistent. A manifestation of the concept of resilience in the built environment is overheating resilience, which is ever increasingly important given the rise in average global temperatures. A key sustainability objective, on the other hand, is building energy performance. In this paper, overheating risk and energy performance of non-domestic buildings are reviewed in the context of resilience and sustainability frameworks. Subsequently, different engineering approaches adopted to reconcile overheating resilience and energy sustainability along with their environmental outcomes are reviewed using the evidence gathered from two educational buildings in London. The results of this investigation along with other evidence available for non-domestic buildings have been used to develop a risk assessment framework that could help in achieving thermally resilient and energy efficient buildings.

Keywords: Resilience, Sustainability, Overheating, Energy Performance, Non-domestic Buildings

1. INTRODUCTION

Sustainability has been a key objective in developing techno-socio-economic systems ever since the Bruntland Commission's report defined sustainable development as meeting "the needs of the present without compromising the ability of future generations to meet their own needs" [1]. The concept of resilience, on the other hand, has been extensively used in disaster management and climate change adaptation fields over the recent years. Broadly speaking, the word resilient has been used to describe systems that undergo stress and have the ability to recover and return to their original or evolved state [2]. While some researchers are attempting to blend sustainability science and resilience theory to achieve better social and environmental outcomes [3], others point that these concepts are not necessarily consistent in various techno-socio-economic systems. Therefore, it might be better to keep and treat them as distinctive disciplines, with separate theoretical frameworks, to have a better understanding of the dynamics of a system [4]. A classic example of the potential conflict between sustainability and resilience is the objective to minimise energy and material use in a system which might, in turn, reduce the ability of the system to withstand external shocks [5]. Energy performance of a building and its ability to avoid overheating under extreme ambient conditions are manifestations of such conflict in the built environment. The premise of this paper is to put energy and overheating performance of non-domestic buildings in the wider context of sustainability and resilience. A case study approach is followed to investigate the overlaps and potential conflicts between these objectives with a view to develop a risk assessment framework for the future projects that could be used to reconcile resilience and sustainability.

2. BACKGROUND

Energy saving as a form of resource use minimisation has long been viewed as a key sustainability objective, and is highly weighed in building sustainability rating systems such as BREEAM [6] and LEED [7]. However, applying the concept of resilience to overheating problem in buildings requires theoretical elaboration.

The disaster management and climate change adaptation literature have moved on to use other terms such as vulnerability and adaptive capacity along with resilience. However, different researchers have different, and in some cases contradictory, interpretations of these terms that could lead to confusion. For example, while vulnerability has been used as the ‘flip side’ of resilience by some researchers [8], some view these two as separate entities [9], and some consider resilience to be related to one of the components of vulnerability [10]. Adaptive capacity has also been used along with exposure and sensitivity as determinants of vulnerability [11]. However, some authors refer to ‘coping capacity’ [12] or ‘capacity of response’ [10] as a determinant of vulnerability and use adaptive capacity for long term and more sustainable adjustments [10], [13].

For clarity and consistency, the theoretical framework formulated by Gallopin [10] is used in this paper with slight modification. According to Gallopin, vulnerability, resilience and adaptive capacity are the attributes of socio-ecological systems that determine the overall response of these systems to external stress or perturbations. Table 1 shows the definitions of these concepts and how the authors have applied these concepts to the overheating problem of buildings (the modification to the framework is highlighted in bold font). It can be seen that Gallopin’s formulation of resilience is a suitable fit for overheating problem. Therefore, it seems justifiable to examine energy and overheating performance of buildings as some representations of sustainability and resilience in the built environment domain.

3. METHODOLOGY

The authors carried out long-term and detailed post-occupancy evaluations on a number of educational buildings in England throughout 2011-2014. The evidence gathered for two schools in East London are presented here to compare and contrast the effectiveness of different strategies adopted to achieve good level of energy performance and overheating resilience.

First, an overview of these case studies is presented with special focus on measures designed to enhance energy performance and thermal comfort. Subsequently, the following outcomes of the post-occupancy evaluations are presented to compare the actual performance with design intents.

TABLE 1. Definitions of the concepts used in the Gallopin's theoretical framework proposed for resilience and their application to overheating problem in buildings

Concept [10]		**Definition [10]**	**Application to overheating problem**
Vulnerability	Sensitivity	The degree to which a system is modified or affected by internal disturbance or external perturbation.	Range of internal temperatures achieved under climatic conditions.
	Capacity of response	A system's ability to cope with a perturbation, an attribute of the system that exists prior to perturbation.	Predicted number of hours below a threshold temperature (e.g. 28 °C) / total number of occupancy hours per annum
	Exposure	Degree, duration, and extent in which system is in contact with or subject to perturbation.	Climatic conditions represented by CIBSE TRY [14], CIBSE DSY [14], UK CIP02 data [15], etc.
Resilience		A component of capacity of response; ***the actual response of a system to perturbation, positive resilience implies bouncing back to original state or a new equilibrium.***	Actual number of hours below a threshold temperature (e.g. 28 °C) / total number of occupancy hours per annum
Adaptive Capacity		An attribute of the socio-ecological system that represents broader and long-term adjustments in the system.	This notion associates resilience with a sense of emergent behaviour that is adaptive [16]. This is consistent with the new adaptive thermal comfort criteria proposed for the built environment [17].

- Summary of air temperatures recorded in a number of sample classrooms over the period 1 May 2011- 30 April 2012. The air temperatures were recorded with calibrated Hobo Onset U12 data loggers every 10 minutes with ± 0.35 °C accuracy over the measurement range. These are compared against the overheating criteria that were in force at the time buildings were designed and thus used as design criteria [18].
- Results of the occupant survey carried out in these schools with special focus on thermal comfort. The Building Use Studies (BUS) questionnaire for non-domestic buildings [19] was used to gauge occupants' *perception* of their building. More than 70% of teaching and support staff in both buildings responded to the questionnaire. Pupils were not included in the survey in accordance with the BUS recommendations. It must be stressed that the occupants' perception of thermal comfort is subjective; however, it can give context to the measurement data presented.
- The measured annual energy performance for both buildings is presented. Total measured energy was recorded using the installed mains meters and cross-checked with the utility bills. Individual energy end-uses were also established using a combination of sub-metering and the method described in CIBSE TM22 [20].
- Subsequently, major findings of the post-occupancy studies related to energy performance and thermal comfort are discussed to give context to the data.
- Finally, lessons learned from these buildings and other non-domestic buildings investigated by the authors [21], [22] are used to develop a risk

assessment framework to reconcile energy performance and overheating resilience in practice.

4. REVIEW OF THE CASE STUDIES

A brief overview of the case study buildings is presented as follows:

4.1 Building A

Building A is a 15,000 square meters secondary school with nominal capacity for 2,000 pupils completed in 2010 and located in East London. It is a 3-storey building with two small 4-storey elements within the building. Two ribbons of teaching spaces are separated by landscaped courtyards and enclosed at either end by a pod (Figure 1).

FIGURE 1. 3D model of building A developed during design stages

The external skin is formed from pre-cast concrete panels finished with brick tiles to achieve air permeability less than 5 $m^3/m^2.hr$. Vertical perforated fins are positioned on east and west elevations to provide solar shading (Figure 2).

The majority of the spaces within the school are naturally ventilated. Provision for cross natural ventilation has been made by operable windows on the external facade and opening vents on the corridor side which are linked to the classrooms via a plenum in the corridor. Feedback from colour coded CO_2 sensors to the teachers prompts them to use manually operated windows to reduce CO_2 levels. Secure night time ventilation is also provided by louver mounted operable windows (Figure 3).

Where cross ventilation into the courtyards is not possible, ventilation shafts are used to provide stack driven ventilation. For example, classrooms near the north and south pods are ventilated via acoustic plenums into common atrium stacks, which terminate in louvered enclosures at roof level. Mechanical ventilation is only provided to core spaces that cannot be naturally ventilated and a number of ICT enhanced classrooms.

4.2 Building B

Building B is a 10,500 square meters academy with nominal capacity for 1,200 pupils completed in 2007 and located in East London. It is a 4-storey building (including lower ground floor) comprising concrete frame and precast slab with exposed ceiling. External envelope of the building consists of lightweight curtain wall with solid panels, internal blinds, and some rendered facades (Figure 4).

FIGURE 2. Building A entrance (left, north facade), and vertical shading (right, west facade)

FIGURE 3. Building A cross ventilation strategy – top hung and secured side windows (left), plenum air intake (middle), and motorised vents on the corridor side (right)

This deep plan building comprises two triangular wings located either side of a central atrium. The classrooms and staffrooms are located around this central space. Two larger facades of the building face North East and North West and, therefore, the design team decided that there is no need for external shading.

FIGURE 4. External view of Building B, south orientation

The building is located close to a main road. Therefore, mechanical ventilation strategy was adopted to satisfy the acoustic requirements of the respective building bulletin for schools [23]. Design assessments showed that some areas of the building will require comfort cooling to mitigate the risk of overheating. Comfort cooling is therefore provided to these classrooms via fan coil units to ensure indoor temperatures do not exceed 25°C. Each classroom has also at least one top-hung operable window (Figure 5).

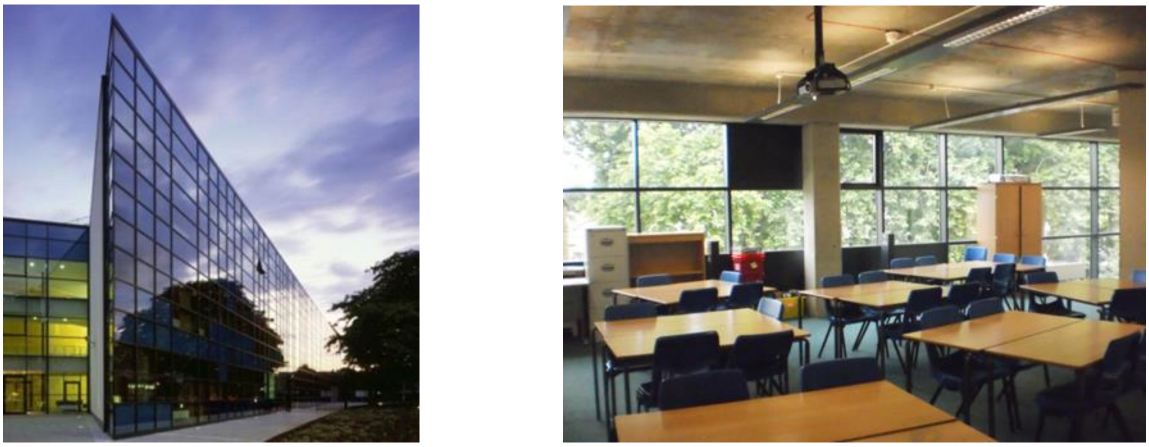

FIGURE 5. Building B north orientation (left), internal view of a classroom with exposed ceiling and one top-hung window (right)

4.3 Energy efficiency and thermal comfort provisions

Table 2 includes a list of specific measures prescribed for the case study buildings to achieve good level of energy performance and thermal comfort.
Overall, it appears that the design for Building A has been primarily focused on fabric first principle and passive measures with a number of energy efficient top-up measures. Building B, on the other hand, utilises a lightweight external envelope with a pro-active building services strategy. It should be noted that this difference in prioritising passive measures and proactive building services strategy, to some extent, reflects the more stringent energy performance requirements demanded for Building A enforced by the Building Regulations 2006, whereas Building B had to comply with the Building Regulations 2002. That said the choice of these strategies is also reflective of design teams' views about the perceived risk of overheating and ways to mitigate it. It would therefore be useful to compare and contrast the effectiveness of these principally different design strategies in practice.

5. RESULTS

5.1 Overheating analysis

The performance standards for the avoidance of overheating in these schools were set out by Building Bulletin 101 for the occupied period of 9:00 to 15:30, Monday to Friday, outside heating season from 1st May to 30th of September. In order to show that the proposed school design would not suffer overheating, two out of the following three criteria must have been met using CIBSE Test Reference Year as the reference weather file [18].

TABLE 2. Design measures prescribed to achieve good level of energy performance and thermal comfort

Building	**Energy performance measures**	**Measures designed to mitigate overheating risk**
Building A	**Fabric first principle:** • Average design U value for external envelope including glazing: 0.51 W/m^2°K • Air permeability: 5 m^3/m^2.hr **Energy efficiency:** • Condensing gas-fired boilers (efficiency in excess of 90%) • No electricity driven comfort cooling • Very limited mechanical ventilation • Effective heat recovery and variable speed control where mechanical ventilation is used **Low carbon technologies:** • Ground source heat pumps as lead system for heating; the respective heat exchanger was also designed to provide limited free cooling to ICT enhanced spaces via chilled beams	**Passive measures:** • Heavy weight external envelope • Exposed ceilings • Solar shading in form of perforated external fins • Louvered operable window for night time natural ventilation • Large operable areas for effective single-sided ventilation **Active measures:** • Cross natural ventilation or stack ventilation strategy facilitated by motorised vents • Mechanical ventilation to ICT enhanced and core spaces (less than 10% of total floor area) • Limited free cooling available from ground source heat exchanger for ICT enhanced spaces
Building B	**Fabric:** Designed to comply with the Building Regulations 2002 in England and Wales (External Wall U value : 0.35 W/m^2°K, glazing: 2.2 W/m^2°K, air permeability: 10 m^3/m^2.hr) **Energy efficiency:** • Condensing gas-fired boilers (efficiency in excess of 90%) • High efficiency chillers • Mechanical ventilation with heat recovery and variable speed control specified	**Passive measures:** • Exposed ceilings • One top-hung window per classroom **Active measures:** • Mechanical ventilation (including night time ventilation) • Comfort cooling provided by chillers via fan coil units

a) Internal air temperatures above 28 °C limited to maximum 120 hours
b) The average internal to external temperature difference should not exceed 5 °C
c) The internal air temperature when the space is occupied must not exceed 32 °C

Tables 3 and 4 show a summary of actual air temperatures recorded in Buildings A and B respectively. In addition to BB101 overheating temperature thresholds of 28 °C and 32 °C, a more conservative air temperature of 25 °C has also been used to detect high temperatures. It should be noted that this air temperature was prescribed as the cooling set point in Building B. Furthermore, in addition to BB101 overheating analysis, air temperatures recorded during normal operating schedule of heating, ventilation and air conditioning (HVAC) systems and outside this schedule, along with annual overheating hours are also presented to give a holistic picture of annual temperatures in these buildings.

TABLE 3. Analysis of Building A indoor temperatures over the period May 2011-April 2012

Room No.	**Location / Orientation**	**Day time annual temperature (°C) (8:00-17:00)**				**Night time annual temperature (°C)**				**Total annual overheating hours**			**Summertime overheating hours (1 May- 30 Sep)**		
		Min	Avg.	Max	SD	Min	Avg.	Max	SD	>25°C	>28°C	>32°c	>25°C	>28°C	>32°c
CR1	GF/West	12.0	21.6	28.3	2.1	11.6	21.4	28.0	2.1	325	3	0	43	1	0
CR2	GF/North	17.8	21.6	25.5	1.0	18.1	21.5	24.8	0.9	2	0	0	2	0	0
CR3	FF/West	10.8	22.3	29.1	2.4	10.7	22.0	29.1	2.8	946	40	0	17	0	0
CR4	FF/West	17.6	21.6	28.4	1.5	17.6	21.3	27.2	1.5	112	1	0	21	1	0
CR5	SF/South	18.0	23.0	27.0	1.2	17.8	22.8	27.1	1.3	471	0	0	13	0	0
CR6	SF/South	18.5	22.9	27.7	1.7	18.4	22.5	27.1	1.6	596	0	0	120	0	0
CR7	SF/ limited cooling, core space	19.9	22.6	27.2	1.2	19.8	23.0	27.1	1.2	530	0	0	15	0	0
CR8	TF/South	15.7	21.7	29.2	1.7	15.8	21.4	28.4	1.7	160	4	0	35	2	0

TABLE 4. Analysis of Building B indoor temperatures over the period May 2011-April 2012

Room No.	**Location / Orientation**	**Day time annual temperature (°C) (7:00-18:00)**				**Night time annual temperature (°C)**				**Total annual overheating hours**			**Summertime overheating hours (1 May – 30 Sep)**		
		Min	Avg.	Max	SD	Min	Avg.	Max	SD	>25°C	>28°C	>32°c	>25°C	>28°C	>32°c
CR1	GF/East	15.3	21.9	28.4	2.2	15.4	21.4	27.8	2.2	529	5	0	57	0	0
CR2	FF/North East	11.5	21.2	29.4	2.7	11.6	20.5	30.0	2.7	559	95	0	74	1	0
CR3	FF/North West	9.1	19.1	26.5	3.7	8.6	18.7	26.0	3.7	53	0	0	25	0	0
CR4	SF/East	12.0	21.7	30.6	2.4	12.1	20.9	28.2	2.3	502	9	0	85	0	0
CR5	SF/North West	12.6	20.0	30.8	3.3	12.6	19.5	31.0	3.3	132	17	0	46	0	0
CR6	SF/South East	14.6	21.9	28.8	2.1	14.7	21.2	27.3	1.9	442	19	0	141	3	
CR7	SF/North East	9.1	20.7	27.7	3.1	9.1	20.2	27.4	3.1	173	0	0	59	0	0

The reference weather file applicable to schools, according to the current version of BB101 at the time, was CIBSE Test Reference Year which is often used for energy performance calculations and represents 20-year average temperatures. This weather file represents moderate summertime temperatures in contrast with the more extreme temperatures represented by CIBSE Design Summer Year [14] which is now being used for overheating analysis of the new wave of schools procured under the Priority School Building Programme. Therefore, given that the summer of 2011 was a moderate one with maximum daily mean temperature of 21.8 °C in August and maximum recorded temperature of 30.2 °C in June [24], it can be concluded that the sample classrooms of both buildings comply with BB101 overheating criteria a and c. Yet there are stark contrasts between expectations raised from design specification and actual performance that will be explored in Section 6.

5.2 Occupant survey

Figures 6 and 7 show the mean scores achieved by Building A and B in the summertime temperature category of the occupant survey respectively. This is the relevant category for the time period set out for overheating analysis of the case studies. It is notable that the mean score for Building A is within the benchmarks and puts Building A in the 58th percentile of the buildings available in the BUS database. However, the mean score for Building B is lower than all benchmarks and puts Building B in the worst 10% of the buildings available in the dataset for this category. While the dissatisfaction of occupants in Building B might be related to their higher expectation of an air conditioned building, the comments recorded during the survey regularly refer to 'extreme' temperature in both summertime and heating season. This is also reflected in the minimum, maximum and standard deviations reported for Building B in Table 4.

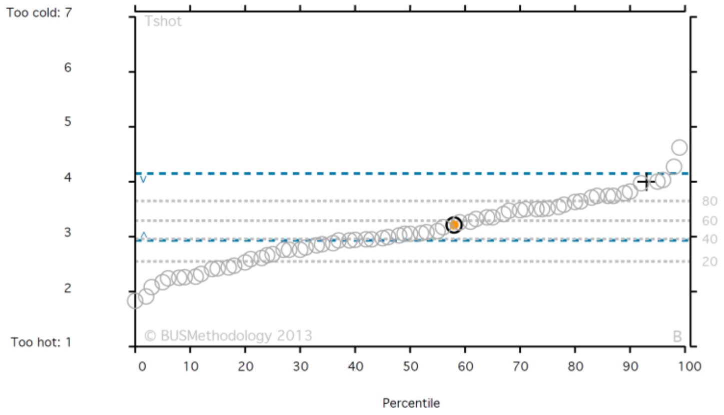

FIGURE 6. Result of occupant survey for Building A (amber) against BUS database: Summer T

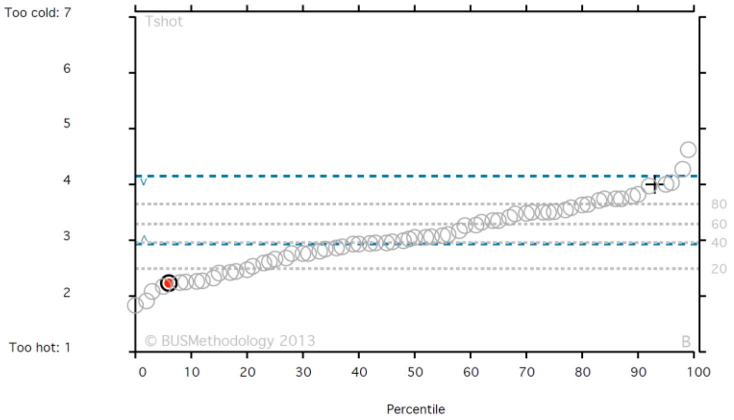

FIGURE 7. Result of occupant survey for Building B (red) against BUS database: Summer T

5.3 Energy performance

Figure 8 compares annual measured electricity and gas use of Building A with Building B. As Building B is air-conditioned and constructed in accordance with an earlier version of the Building Regulations, it is expected to see higher overall energy use in Building B. However, actual energy use of Building B is significantly higher than what is expected. In fact, the fossil-thermal energy use of Building B is worse than the median of existing schools and its electricity use is worse than 90% of the existing schools and academies in England and Wales [25]. Such a performance is not expected from a building completed in 2007. Space heating energy use in Building B is 64% higher than Building A, its fan energy use almost 20 times more than Building A, and 11% of total electricity use in this building is used for comfort cooling. However, this intensive energy use has not led to better thermal comfort as revealed by recorded temperature and occupants' survey. This is indicative of significant operational issues.

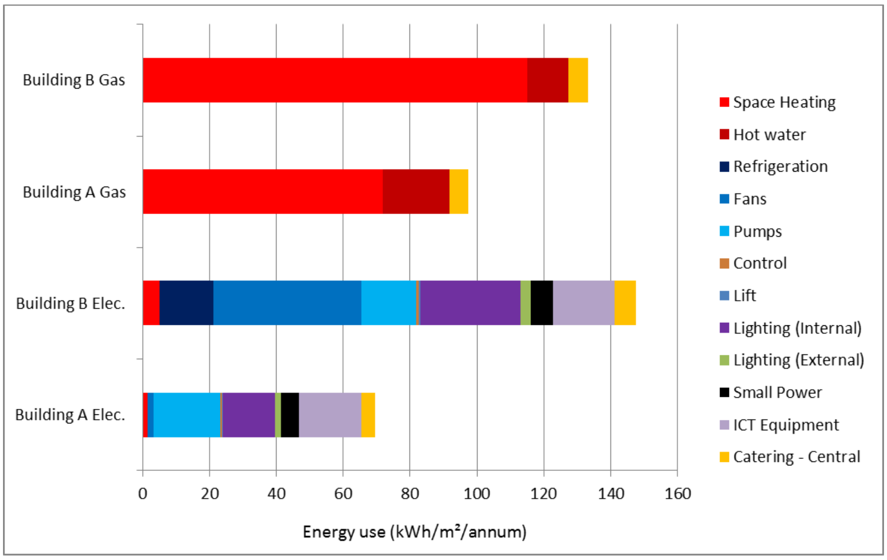

FIGURE 8. Measured energy performance for the case studies

6. DISCUSSION

6.1 Operational performance of the case studies

While both case studies comply with their respective overheating criteria, Building B has not been able to provide better thermal comfort for its occupants despite using significant more energy than Building A.

The wide variation of indoor air temperatures in Building B and the number of hours temperatures exceed 25 °C threshold show that the building services in this building are not operating in accordance with the design intent. The post-occupancy evaluations revealed quite a few problems with the Building Management System (BMS). The high overnight electricity baseline of the building suggests night-time ventilation is operating continuously throughout the year. Chillers also operate overnight not least because the server room and data hub rooms do not have dedicated air conditioning systems and are served by the centralised chillers. Consequently, the classrooms are mechanically ventilated and partially cooled via leaky fan coil valves overnight when not required. This, in turn, demands the response of the heating system to combat the unnecessary cooling. The lightweight external envelope of the building also compounds this problem in a building that has a very erratic operational pattern in the afternoons during term time and also during half term school breaks. The result is a building which has failed both in terms of energy performance and thermal comfort. Unless the BMS is re-commissioned and the existing control strategy revised, in addition to poor energy performance, there is a serious risk of overheating if the building is subject to high ambient temperatures expected as a result of climate change over the coming years.

Although the situation in Building A looks much better thanks to the fabric first approach and passive measures specified for this building, the post-occupancy study uncovered serious issues that could have been avoided had there been better communication between designers, contractors and sub-contractors of the project. An example is the failure of the Ground Source Heat Pumps to act as the lead heating system due to the high flow temperature setting for the heating system that was not appropriate for GSHP. This compromised energy efficiency of the building as gas-fired boilers were used as the lead heating system instead. Furthermore, it appears that the motorised vents installed to provide cross ventilation can only be actuated based on CO_2 concentrations and not high temperatures, contrary to the design intent. If not addressed, this could have serious implications for the overheating resilience of the building in the future.

The main lesson learned here in the context of sustainability and resilience objectives is that, although these are not entirely consistent, one objective must not be achieved at the expense of the other. There are practical ways to achieve a good level of energy efficiency and thermal comfort together. One can see the temptation to provide a comfortable and risk free thermal environment in Building B by maximising one objective (specifying air conditioning). However, building procurement issues and operational inefficiencies along with under-resourced and over-stretched facilities managers (hardly unexpected in education sector) led to a building that is neither sustainable nor resilient to extreme external conditions. It is therefore vitally important to recognise the potential conflicts between sustainability and resilience objectives, and strike the right balance between competing objectives taking into account the specific building context.

6.2 Toward a risk assessment framework for energy performance & overheating resilience

Table 5 includes a list of the most important risks associated with procurement of natural ventilation, mechanical ventilation and air conditioning systems in regard to energy performance and overheating resilience of non-domestic buildings based on the post-occupancy evaluations the authors carried out on educational and office buildings. While the list is not exhaustive, the framework provided here could be used by the construction teams to identify and rank the specific risks associated with their project at every stage of the project. These risks could be checked and updated as the project moves forwards. Such a dynamic risk register would be a useful point of reference for the construction teams when makings critical decisions such as value engineering to ensure the most critical determinants of energy performance and overheating resilience are identified and preserved.

7. CONCLUSION

It is suggested that sustainability and resilience objectives are not necessarily consistent. Sustainability objectives often deal with long-term outcomes of socio-techno-economic systems. Resilience, on the other hand, represents the ability of a system to withstand shocks and return to its original or evolved state. It is therefore a process-oriented and short-term system characteristic. A system might possess significant adaptive capacity and be very responsive to shocks at the expense of sustainability. However, it is important to withstand shocks while maintaining and achieving long-term sustainability targets.

Energy performance and overheating resilience are examples of the potential conflicts that may arise when dealing with sustainability and resilience objectives. Air conditioning is an easy short-term solution to mitigate the risk of overheating. However, once installed and treated by building users as permanent service strategy, air conditioning can jeopardise long-term climate change mitigation initiatives. Post-occupancy studies on two educational buildings also showed that the complexity associated with the mechanical ventilation and air conditioning systems mean, if the respective operational control strategies are flawed, a building can end up using a significant amount of energy while unable to provide expected level of thermal comfort for its occupants. Simple low risk design measures such as fabric first principle and passive overheating design could lead to good level of overheating resilience and energy performance.

A process-system based risk assessment framework is also proposed that could be used as a dynamic focal point for the construction teams to strike the right balance between competing objectives and ensure the critical determinants of building performance are preserved throughout the project.

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TABLE 5. Risk assessment framework for energy performance and overheating analysis

Risk category	**Project stage**	**Ventilation Strategy**					
		Natural Ventilation	**Impact**	**Mechanical Ventilation**	**Impact**	**Air Conditioning**	**Impact**
Energy performance	Design stages	Energy calculations under *expected* operating conditions (including scenario analysis), or regulatory only?	🟥 **H**	Energy calcs.: cascade from N.V.	🟥	Energy calcs.: cascade from M.V.	🟥
				System pressure loss calculated and updated accurately?	🟧 **M**	N.V. & M.V. alternatives considered?	🟥
		Trade-offs between air permeability and comfort investigated?	🟧	Optimum variable speed control & heat recovery for AHUs?	🟥	Highest Energy Efficiency Ratio?	🟩 **L**
	Construction	Energy efficiency measures protected in value engineering?	🟥	Value engineering and fabric: cascade from N.V.	🟥	Value engineering and fabric: cascade from M.V.	🟥
		Actual U values and air permeability consistent with design specifications?	🟥	Installed equipment consistent with design specifications?	🟥	Installed equipment consistent with design specifications?	🟥
	Commissioning	Renewable systems commissioned as lead? (in line with control strategy)	🟥	N.V. risks: cascade	🟥	EER as-designed?	🟩
						Energy efficient cooling set points?	🟧
		As-commissioned efficiencies of HVAC systems consistent with design intents?	🟥	As-commissioned specific fan powers consistent with design intent & regulations?	🟥	Dead-band set between heating and cooling systems? (min 5°C)	🟥
		Energy meters & sub-meters all in order?	🟧	Fan inverters enabled over full range?	🟥	Free cooling provision checked?	🟩
		Seasonal commissioning?	🟥	Seasonal commissioning?	🟥	Seasonal commissioning?	🟥
	Handover	Effective logbook & training?	🟧	Effective logbook & training?	🟧	Training (set-points & dead-bands)	🟧
	Post-occupancy	Early stage fine tuning & energy metering?	🟥	Fine tuning & energy metering?	🟥	Sub-meter and benchmark chillers?	🟥
Overheating resilience	Design stages	Adequate passive measures in place (e.g. shading)?	🟥	Adequate passive measures in place? (What if AHUs fail due to technical issues?)	🟥	All passive measures in place? (A.C. only to address excessive internal gain; NOT solar gain)	🟥
		Adequate opening areas provided?	🟥				
	Construction	Critical ventilation measures not compromised in value engineering?	🟥	Passive measures protected from value engineering?	🟥	Passive measures protected despite A.C. system?	🟥
	Commissioning	Motorised vents (if any) properly checked?	🟥	Minimum fresh air provided to all zones?	🟧	Cooling set points appropriate?	🟧
		Control interfaces for Nat. Vent. checked?	🟧	Air fans checked over full range?	🟥	Heating and cooling systems fighting?	🟥
	Handover	Control switches labelled clearly?	🟧	Control switches labelled clearly?	🟧	Control switches labelled clearly?	🟧
		Adequate training provided?	🟧	Adequate training provided?	🟧	Adequate training provided?	🟧
	Post-occupancy	Early stage training & fine-tuning?	🟥	AHUs checked regularly? (e.g. filters)	🟥	Early stage training & fine-tuning?	🟥