 doi:10.20944/preprints201811.0290.v1

Research Paper

Effects of Warming Climate on Overheating and Energy Use in Urban Office Buildings

Tanvir Morshed [1,*], Monjur Mourshed [2]

[1] Department of Architecture, Stamford University, Dhaka 1217, Bangladesh; tanvir.morshed@gmail.com
[2] School of Engineering, Cardiff University, Cardiff, CF24 3AA, UK; mourshedm@cardiff.ac.uk
* Correspondence: tanvir.morshed@gmail.com; Tel.: +88-0194-676-9681

Abstract: The UK Government is committed to reducing greenhouse gas (GHG) emissions by 80% by 2050. Buildings are responsible for 37% of the total GHG emissions in the UK and the need to reduce their emissions has resulted in more stringent building regulations in the recent past. The regulations, energy rating systems and voluntary guidelines — all are primarily aimed at reducing the need for heating and associated energy use by increasing insulation and air-tightness. However, future climates are projected to be warmer than the present day. Internal gains dominated non-domestic buildings will likely overheat, the adaptation to which will require energy-intensive cooling solutions, thus defeating the purpose of heating-focused regulations. This research investigated the effects of warming climate on overheating, and energy use and resulting emissions in representative urban office spaces in London in the present-day and future climates using hourly dynamic thermal simulations. Findings suggest that more airtight and highly—insulated office buildings designed for heating—dominated temperate UK climate will overheat in the 2050s. Heating demand reduces but electricity consumption increases by 121% when hybrid cooling is adopted to ameliorate overheating. Despite the rise, adopting a mixed-mode ventilation strategy was one of the ways of achieving overall energy efficiency while meeting benchmark overheating and carbon emissions target in present and future climatic contradictions. Current heating-focused legislations need to be urgently re-evaluated to account for the effects of climatic variability and overheating risks.

Keywords: Climatic change; Office buildings; Overheating; Carbon emissions; Energy consumption; Mixed-mode ventilation; Natural ventilation

---

1. Introduction

Global warming and increased use of fossil fuel has led to unprecedented and unpredictable climatic changes which are evident in the recent extreme weather pattern experienced all around the world. The government is keen on using renewable energy sources such as solar Photovoltaic (PV) and wind farms as future energy source. At the end of 2004, renewable energy sources contributed 3.5% of UK electricity, which improved to 27% by the year 2017. Yet fossil fuel based generation still accounts for more than 50% of the production in the year 2017 contributing a large share in the carbon emissions [1]. Built environment accounts for nearly 40% and non-domestic buildings accounts for around 18% of the total UK carbon emissions [2] [3] [4]. The more we use energy in our buildings more we are going to warm our earth. Improving energy efficiency in building will help reduce global warming. The UK government recently announced reduction of CO2 emission by 80% from 1990 baseline level within the year 2050 [5]. The projection from the Greater London Authority about future London weather is grimmer as summers are set to get hotter – by an estimated 1.6°C in the 2020s and 2.7°C in the 2050s. They are also getting drier by an estimated 7% in the 2020s and 19% in the 2050s. The winters, by contrast, will get warmer and at least 6% wetter in the 2020s & 14% in the 2050s [6]. So, limiting CO2 emission as well designing buildings in 2050s context is the key to achieve low carbon intensive building stock. Innovative building offers prospects to incorporate energy efficient

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

technologies in the built environment. In fact, the trend shows 65% to 70% of the building stock in existence in the 2050s, is likely to have been built before this century. Even in the non-residential sector, much of the 2050 environment will not have been designed or constructed with energy efficiency and decarbonisation standards in mind. Many existing office buildings will have to be retrofitted, refurbished or renovated in the decades ahead [3].

The Building needs to be designed to cope with climates of the future. It is certain from the climatic variability predictions, that future building would need less heating energy. However, the demand for cooling energy would grow mostly in commercial buildings [7] [8]. One way to curb energy demand from the UK office building is to employ natural or mixed-mode ventilation (MMV). Such buildings save up to 75% carbon emissions, compared to industry benchmark of an air-conditioned building [9].

This proposed design-based study with dynamic thermal simulation (DTS) was about assessing overheating prospects, energy consumption and associated carbon emission from a London based office building. MMV and natural ventilation (NV) was employed to achieve benchmark overheating, energy and carbon emissions requirement. Along the process, present day Test Reference Year (TRY) & Design Summer Year (DSY) and year 2050 TRY & year 2050 DSY weather files were commissioned. As an assessment criterion, the building must perform according to the summertime overheating criteria outlined in CIBSE Guide A: Environmental Design. This criteria has also been referred in Part L2A of building regulations [10]. Here, 25°C is the recommended design operative temperature for office buildings and design must limit the expected occurrence of operative temperatures above 28ºC to 1% of the annual occupied period (e.g. around 25–30 hours). It is also recommended that the overheating criteria be assessed against the CIBSE DSY weather file(s) [11]. The explored building was also accounted for with the 'good' and 'typical practice' standards of energy consumption and carbon emissions for both NV and MMV (see **Error! Reference source not found.** below) [12] [13].

The modelling inputs such as fabric U-values of Part L2A regulation was adopted [10]. The simulation results showed that the office building with the adopted fabric attributes performed well within benchmark limits of energy consumption, carbon emissions and overheating hours' target for the warmer year 2050 climatic context when the Mixed-mode (MM) Ventilation strategy was embraced.

2. Materials and Methods

Designing for low carbon is not a necessity or mere expressions of climatic sensibility, but a legally binding process where designers are responsible to produce and prove that their design meets building legislation and regulations. Therefore, it is important that current building related legislation is consulted, various performance targets are met and possible future-proof design is sought. Such designed buildings are termed commonly as low carbon buildings. Future-proofing is not necessarily involved with a huge capital investment. In reality, initial setup cost of energy efficient buildings is somewhat equal to conventional buildings when designed properly only varies 2% to 6% [14]. An integrated approach to building fabric and service design can reduce capital costs. For instance, the cost of external shading to minimise solar gain can actually offset or minimise the size of the air conditioning plant [15]. One way to ensure low carbon intensive design and good IAQ in buildings is to adopt NV or MMV strategy [16].

In order to achieve a design solution which is climate sensitive and capable of adapting to climatic variability, decisions regarding meeting benchmark overheating hours and low energy buildings were emphasised. In UK, Building Regulations deal from structure for buildings to fire safety in space and all sorts of building related codes, guidance and guidelines. These regulations set the thermal efficiency and CO_2 emission standards that buildings must comply with. 'Good' and 'Typical Practice' energy consumption and carbon emission standards are outlined in Error! Reference source not found. [12] [13].

 doi:10.20944/preprints201811.0290.v1

Table 1. Energy and carbon emissions benchmark for naturally ventilated and mixed mode office buildings. Data source: ECG19[13].

Benchmark	Type	Naturally ventilated [1]		Air–conditioned [2]	
		Energy use (kWh/m²·yr)	CO_2 (kgCO_2/m²·yr)	Energy use (kWh/m²·yr)	CO_2 (kgCO_2/m²·yr)
Good practice	Fuel	79		97	
	Electricity	54		128	
	Total	133	43.1	225	85
Typical	Fuel	151		178	
	Electricity	85		226	
	Total	236	72.9	404	151.3

[1] Open plan offices. [2] Similar in energy use characteristics to mixed-mode buildings.

In addition to Part L2A requirements, various benchmarks related guides outline modelling input such as fabric U-values, airtightness rate, target energy demand etc. were consulted [10] [17] [18]. These guides emphasised where the building designers should put the accent in the design phase to save energy, reduce carbon emissions and benchmark overhearing criteria are met. In this research, weight has been put to achieve more than the target values for fuel and electricity efficiency, that are in Part L2Aof the building regulation. This is to examine whether new office buildings can meet climatic challenges of the future.

2.1. Site Analysis and Proposed Design

The **Figure 2.1(a)** shows the zoning of the virtual building in Bear Lane, Camberwell, Greater London (Latitude, Longitude: 51.505636, -0.101862). **Figure 2.2(b)** shows aerial view of the Site & Surroundings, taken from Google Maps. The proposed building within the site as shown in **Figure 2.1(a)** and **Figure 2.2 (b)**, is better understood when read in conjunction with **Figure 2.3(a)** and **Figure 2.4(b)** described later here. The neighbourhood of the 0.81 acre site is constantly changing, which is within one of the busy industrial and commercial parts of London. The City's economic activity and planning policy are such that many buildings are constantly evolving retaining their cultural and sometimes the contextual identity. For instance, north side road of the site is now only for pedestrian and partially used as a cycle stand. The site is now a hotel. The south side road no longer exits and also became part of the hotel building's site. Therefore, this 'design-based research' approach is only to exemplify the context of an office building rather the changing dynamics or fabrics of a busy city such as London. The location of the anticipated design within the site was based on a number of design considerations which are described here. The positioning of the building in the north part of the site was based on the morphing of SunCast Model's output from Integrated Environmental Solutions Virtual Environment (IES VE) software. This shade and shadow analysis of the site was done to determine the optimum location of the building in question, for increased daylight availability of the building during office hours from 9.00 AM to 5.00 PM. IES VE SunCast analysis was carried out for 1st and 15th day of each month initially. Then from the initial two, monthly SunCast images were produced. Then morphing between January and February was carried out. Likewise, February to March, March to April and so & so forth were carried out. A total of 6(six) images were attained here. Again, morphing was carried out from January to April, May to August and September to December. 3(three) images were obtained out of that process. Finally, another morphing was carried out from the 9 (nine) obtained images [see **Figure 2.3(a)**]. To cross check another morphing was plotted for a whole year with 12 (twelve) monthly images [see **Figure 2.4 (b)**]. The outputs of solar availability are comparable to each other and the yellow part of the both images show where the sun receives most sunlight almost all year round [see **Figure 2.3(a)** & **Figure 2.4 (b)**].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

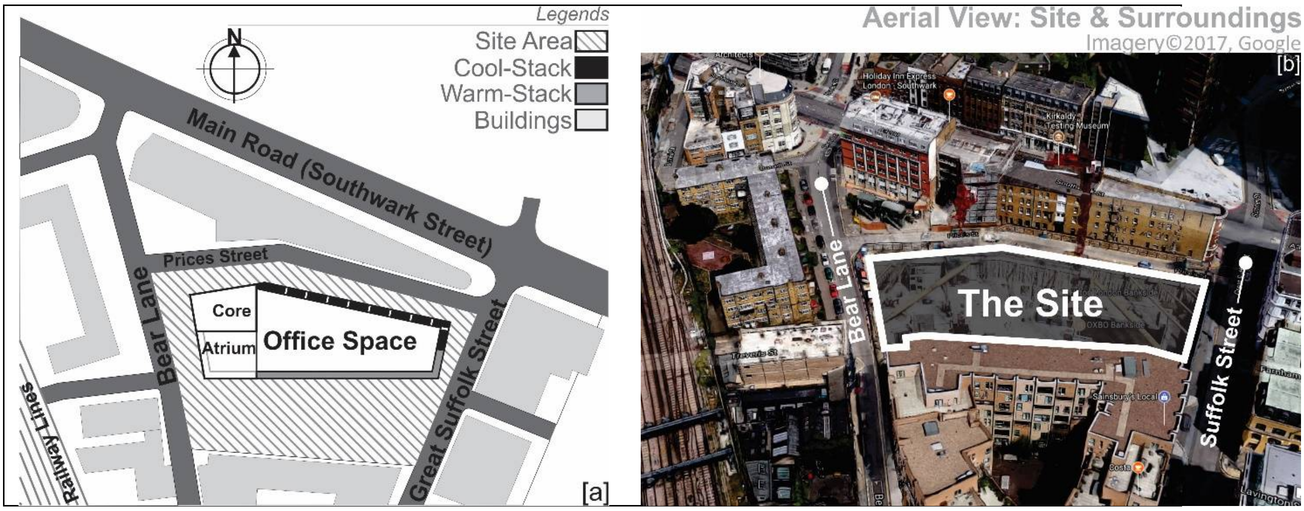

Figure 2.1(a): The Zoning Plan of the Office Building based mostly on Sunlight's Availability within the site.

Figure 2.2(b): Aerial View, showing the Site &Surroundings. (Imagery©2017, Google; www.maps.google.com)

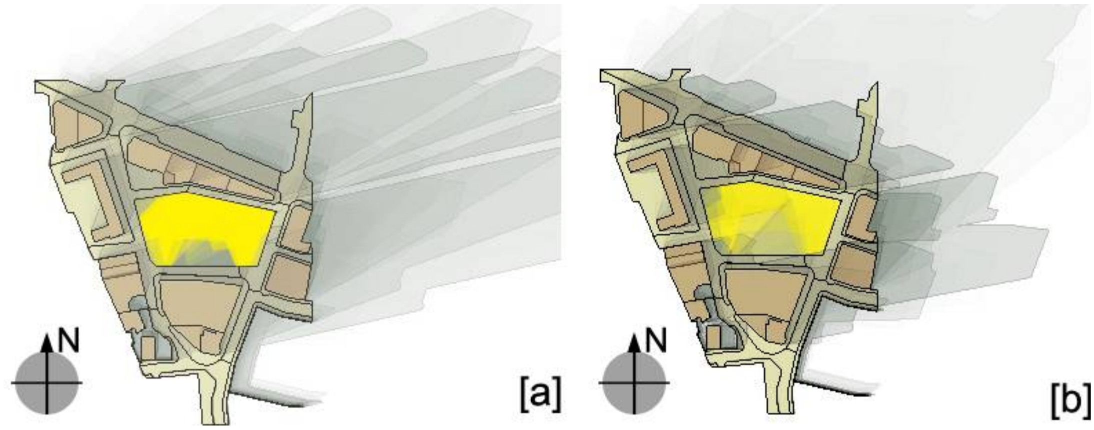

Figure 2.3(a): Result of 50 morphing of IES VE SunCast Study of the site.

Figure 2.4(b): Result of 12 morphing of IES VE SunCast Study of the site.

Now, from the heat gain point of view, the position of the building core helps blocking sun's heat from the west. The Cool-Stack and Warm-Stack created a thermal buffer with the environment which will aid buoyancy driven natural ventilation [(see **Figure 2.5(a)** & **Figure 2.6(b)**]. The Warm-Stack was with double-skin façade (DSF) and Cool-Stack was with wall materials. In **Figure 2.5(a)** the reddish area indicates warm zone (Warm-Stack) and the bluish area indicates the cold zone (Cool-Stack) of the building in a transverse section. The outdoor air was coming through the inlet area on the north side, where wind-breakers avoided turbulent wind. Even in dense urban settings, blustery wind often happens in London. As seen in the figure, the warm air was going out of the building through the outlet at the top of Warm-Stack. From the acoustics point of view, the busy main artery road was avoided for open plan office space, through the placement of the both stacks. Moreover, the core and the atrium area acted as buffers places between open plan office spaces and noise sources from the railway lines. Besides, pergolas on top of the main roof are for minimising solar heat gain.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

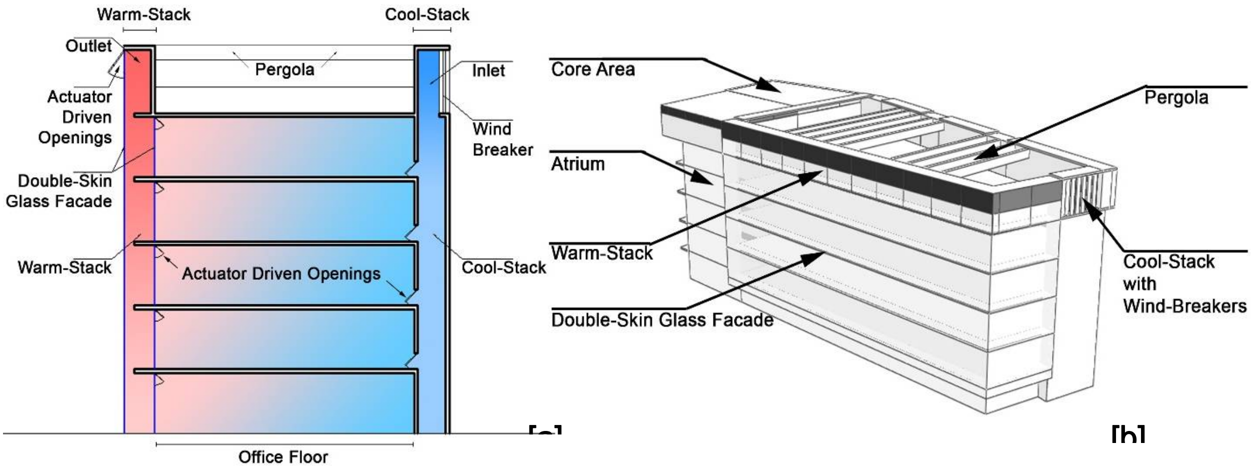

Figure 2.5(a): Transverse sectional view through Stacks delineating the NV strategy.

Figure 2.6(b): IES VE view of the building from the North-East of the site.

2.2. Space Planning Standards

The space requirement and planning for the said design was based on Metric Handbook Planning and Design Data for commercial office buildings [19]. In the design, it was assumed, the width and depth of office space can preferably be minimum of 14m when adopting single-loaded corridor (i.e. the office spaces against one corridor) or double-loaded corridor (i.e. the office spaces against two corridors) [see **Figure 2.7(a)** and **Figure 2.8(b)**]. The width of the toilets, services and the main core area can be within 5.5m when efficiently designed and planned. The floor to floor height considered as 3m, an important factor in efficient displacement type of natural ventilation [20].

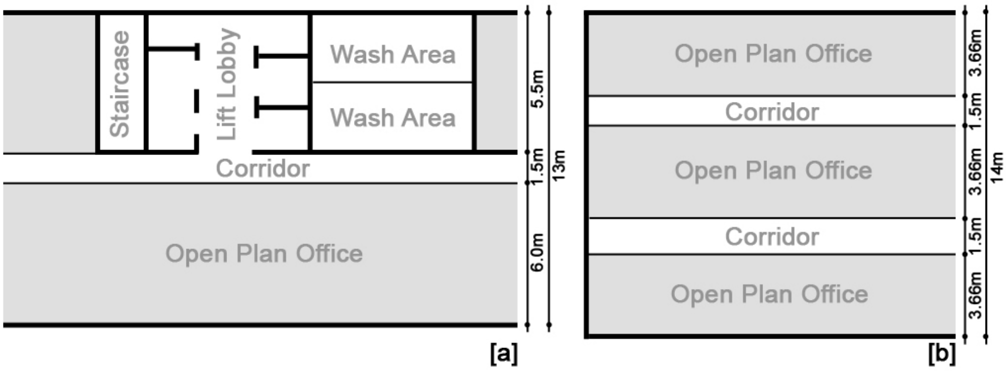

Figure 2.7(a): Typical layout Office Building with single-loaded corridor (after Littlefield, 2008).

Figure 2.8(b): Typical layout Office Building with double-loaded corridor (after Littlefield, 2008).

2.3. Daylight Requirement and Associated Space Standards

A key goal of avoiding summertime overheating was through taking the full advantage of daylight and reducing heat gain through artificial lighting for a space. Daylight Factor (DF) ensures the daylight performance of a space which is the summation of the sky component, externally reflected components and internally reflected components of a space. For the examined office space, the daylight factors considered to be 5% on average and with a minimum value of 2.5%. The amount of light considered at the desktop level for office space was 500 lux for writing, typing, reading and data processing [11]. Therefore, the depth of the office space kept shallow, based on the idea that the

 doi:10.20944/preprints201811.0290.v1

artificial lighting load of the office building will be reduced by allowing adequate daylight at every corner of a floor. South side of the building was considered as fully glazed with DSF to allow maximum daylight to the office space. Typically, maximum depth of the office building can be considered as 25m for a successful daylit environment, if it is lit from two sides. However, no daylight from the north part of the building limits the floor depth to a maximum of 14m for this building. Here, on the north and north-eastern side of the building, actuator driven openings were placed for aiding NV only, as showed in the **Figure 2.5(a)** and **Figure 2.6(b)** above.

2.4. Fabric Design, U-Values and Infiltration Rate

All the glazed fabric was with double glazing for reducing heat loss in the winter season and to avoid noise pollution. In the south and southeast façade, DSF was integrated to facilitate buoyancy driven natural ventilation for the building [see **Figure 2.5(a)**]. As discussed earlier, Part L2A requirements for commercial office design in urban location were consulted to design the building in question. For maintaining airtightness with good indoor air quality (IAQ) a background ventilation of 1 air change per hour (ACH) was considered as per CIBSE Guide B. Eventual goal was to ensure good indoor air quality with CO2 concentration below 1500 parts per million (ppm) [17]. Enhanced IAQ ensures better performance of office workers. Detailed ventilation strategy and material specification for the examined building is outlined in **Table 2** and **Table 4** later.

3. Selection of Heating and Cooling System

With the current temperature profile and summer condition, most of the UK building can be designed for natural ventilation with no or little mechanical cooling required. Future climatic conditions may require a building to use mechanical cooling (i.e. hybrid ventilation) at some point of a day in extreme summer months. Moreover, when the ventilation system coupled with **Building Automation Systems (BAS)**, it would ensure good comfort condition. Eventually, this strategy would ensure very little energy consumption for the summer months. For space heating, a natural gas generator or boiler was considered with an efficiency of 0.89.

4. The Simulation Model

4.1. The IES VE Model

Following **Figure 4.1(a)** and **Figure 4.2(b)** represents the model of the building based on the design brief and design strategies discussed earlier.

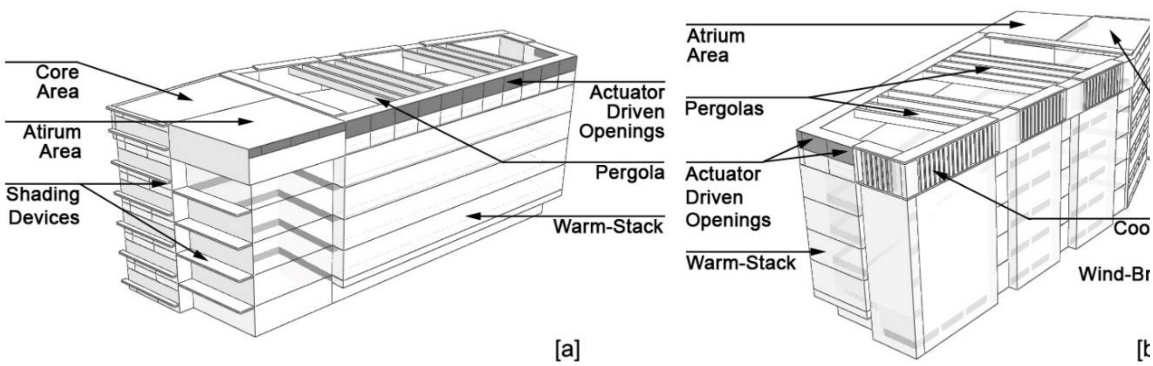

Figure 4.1(a): View from South-West of the site.

Figure 4.2(b): View from the North-East of the Site.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

4.2 Ventilation Profile and Opening Attributes for Modelling

October to March was considered as winter season and April to September as the summer season. On warm days no or little heating is required in the UK. These two seasons form the basis of an annual profile of the building's heat gain and ventilation control strategy. Present day and the year 2050 TRY and 2050 DSY weather files were employed with a peak summer season cooling profile to enhance the building's performance. Annual profile was supported by a weekly profile, from Monday to Friday. Daily profile was from 9:00 am to 17:00 pm as per office hours. Saturday, Sunday and holidays were considered closed based on the UK holiday chart. **Table 2** below outlines opening attributes, functions employed in the simulation and adopted infiltration rate for simulation. Here, the mentioned ramp **Function A** which is typical for this kind of simulation was employed. This sets opening profile for occupied hours of the interior space, where at 21℃ windows open fully and at 16℃ windows close in full. Not only that, if CO_2 level reached 1200 ppm the windows remained shut and if the level were reached 1400 ppm the windows opened in full. Background or night cooling also controlled the out of office hour cooling and remained the same for the whole year. The background cooling was controlled by a step function for weekdays where at 16℃ windows remained shut and 20℃ windows opened in full.

IES VE, MacroFlo Analysis Model was employed for ventilation calculation. There are five ventilation profiles employed in the model which are 'External Window or Door Openable', 'Internal Window or Door Openable', 'Openable Cool-Stack' 'Openable Warm-Stack' and 'External Window Closed' **(see Table 2 below)**. Infiltration rate overrides these profiles when required and acts in conjunction or separately from these profiles. It was considered that the occupants will arrive at 9:00 o'clock in the building. Adopted MacroFlo opening profile ensured, that before occupant had arrived in the building i.e. at 8:00 o'clock, the interior temperature will not become too cold with the background cooling profile. It was because at midnight the openings remained 10% open and gradually opened to 40% at 8 am in the morning**.** However, the openings remained 40% open till 9 am when the space was fully occupied again. Finally, from 5:00 pm onwards the opening profile gradually minimised to 10% status by midnight.

With **Function B** the Warm-Stack modulating profile was controlled. During occupied hours at 35℃ windows opened fully and at 30℃ windows remained close. This was to ensure at least 5 to 10℃ temperature difference between the top and bottom part of the Warm-Stack. In addition, it was also to ensure constant temperature difference between Warm-Stack and Cool-Stack. Eventual goal was to ensure successful buoyancy driven natural ventilation between openings of the Warm-Stack and Cool-Stack. Furthermore, if CO_2 level had reached 2400 ppm the openings of the Warm-Stack will remain shut and if it had reached 3000 ppm the openings opened up in full. A higher level of CO_2 was assumed here since this part of the building has not belonged to any habitable zone i.e. excluding the office area [see **Figure 2.5(a)** above]. Only maintenance personnel will access this space as and when required.

Table 2: Opening attributes and related functions in IES VE

Input Type(s)	Value/Attributes	Function
Opening Category	**External Window or Door Openable:** Crack length: 30% (considering the opening area after 5 years of operation), crack flow coefficient: 0.15, openable area: 50%, co-efficient of discharge: 0.4 and exposure: exposed wall.	**Function A**
	Internal Window or Door Openable: Crack length - 30% (after 5 years of operation), crack flow coefficient: 0.15, openable area: 50%, co-efficient of discharge: 0.4 and exposure: internal.	**Function A**
	Openable Cool-Stack: Crack length - 30% (after 5 years of operation), crack flow coefficient - 0.15, openable area - 30%, co-efficient of discharge: 0.4 and exposure: semi exposed wall.	**Function A**

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

	Openable Warm-Stack: Crack length - 30% (after 5 years of operation), crack flow coefficient: 0.15, openable area: 30%, co-efficient of discharge: 0.4 and exposure: semi exposed wall.	**Function B**
	External Window Closed: Crack length - 30% (after 5 years of operation), crack flow coefficient: 0.15, openable area: 0%, co-efficient of discharge: 0.0 and exposure: exposed wall.	Off Continuously (No Profile)
Opening Threshold Temperature	This was based on typical yearly modulating profile with summer month's night cooling strategy. Top outlet of the Warm-Stack was the exception where **'Function B'** governs the opening attributes.	
Functions	**Function A** (Typical opening modulating profile)	
	Occupied Hours	ramp(ta,16,0,21,1)|gt(co2,1400,1200)
	Night Cooling	step function gt(ta,18,4)
	Function B (Warm-Stack opening modulating profile)	
	Occupied Hours	ramp(ta,30,0,35,1)|gt(co2,3000,2400)
	Night Cooling	step function gt(ta,18,4)
Infiltration (ACH)	Atrium Area	1.0
	Rest Rooms	6.0
	Office Areas	1.0

4.3 Heat Gain Calculations for Modelling

4.3.1 Lighting Gain

The average density of occupation considered to be $10 m^2$/person of office space [11]. The building was designed for mostly daylit environment. Moreover, both sides of the office and atrium have full glass façade; it was assumed that for most of the year, the artificial lighting energy would be half the required limit. Also, the availability and use of Light Emitting Diode (LED) lights would help reduce the internal heat gain drastically. Therefore, 4 W/m^2 of heat gain was considered for lighting instead of typical 8 W/m^2. This calculation is for fluorescent lights only.

4.3.2 Sensible Heat Gain from Occupants

Sensible heat gain of 80 Watts/occupant was considered for moderate (sedentary) office work [11]. It was assumed, on an average 6 persons will occupy the atrium area in a given time along with one receptionist. It was also considered that on an average, at least 10persons will occupy the core area and the toilets, at any given time. Here, heat gain of 60 Watts/occupant was considered for both the atrium and the core area, since no significant work would be done by users when occupying these spaces.

4.3.3 Heat Gain from Computers

It was considered that every person will use a personal computer (PC) in the office area. Heat gain from personal computer including monitor was considered 75 Watt and another 5 Watt/PC was considered for other devices such as an external drive, printers, fax etc. [11]. So actual heat gain from equipment considered is 80 Watt/person in the office area. In reality, heat gain from monitors and PC will be substantially less since laptops are more common these days. Therefore, 60% diversity factor was considered, since not all PCs will remain turned on and some may remain in energy saving mode for a few hours in a day [21].

4,3.4 Total Heat Gain for 'Open Plan Office' part of the building per floor

Total heat gains from each floor of the 'Open Plan Office', is described in **Table 3** below.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

Table 3: Total heat gain for each office floor of the building

Type/ Source	Heat Load/Unit	Unit	Heat Gain
	Watt/unitŦ	**-**	**Watt**
Lighting Fixtures	**4**	**757***	**3028**
Occupants	**80**	**50**	**4000**
Computers	**80**	**50**	**4000**
Total	**-**	**-**	**11028**

Ŧ unit is described in each section above for Lighting Fixtures, Computers and for Occupants.
* Open plan office is estimated to be 757m² in each floor.

4.3.5 Total Heat Gain from 'Warm-Stack' and 'Cool-Stack' part of the building

As the Warm-Stack was located at the entry part of the building and acted as prestigious looking glass façade, it was obvious that it has to be well lit. Therefore, the lighting energy considered for this area as 4 W/m². The Cool-Stack part will be rarely used for maintenance and no lighting energy was considered for this part.

4.4. Material Properties of the Model

The following table shows the material properties employed in the IES VE model.

Table 4: Materials adopted for the building fabric.

Type	Construction Properties	U-Value
	(Comprised of)	**W/m²-K**
Ground Contact Concrete Floor	London clay, cast concrete, mineral fibre slab, screed and synthetic carpet.	0.2190
Internal Ceiling or Floor	Synthetic carpet, cast concrete and ceiling tiles.	1.6216
Internal Partitions	Gypsum plasterboard and cavity	1.6598
External Walls	Rendering material, mineral fibre slab, concrete block and gypsum plasterboard	0.2391
Roof	Aluminium, mineral fibre slab and ceiling tiles.	0.2172
External Windows (including DSF)	Pilkington 6mm double glazed window with air cavity	1.9773
Internal Windows	Clear Float Glass 6mm	3.7642

5. Results

Analysis of the results presented here is based on overhearing hours, energy consumption and carbon emissions standards set by the guidelines. As discussed earlier six different simulation scenarios with TRY and DSY weather files of the present and the year 2050 were put to task. From the number of simulation runs, it is seen that present TRY weather file simulation results, nearly met summertime overheating criteria. Present DSY and 2050 TRY & 2050 DSY seen overheating outside the suggested limit. In terms of meeting overheating hours, the 2050 DSY NV scenario is the worst situation of all. Detailed results & analysis are offered below.

In fact, UK legislation is currently focused towards airtightness and adoption of low U-values for building envelope materials. Heating and hot water accounts for 20 to 45% of total air–conditioned building's energy consumption. Naturally ventilated UK office building, usually requires more

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

heating energy than cooling. The following plot shows that the office building with the present TRY and DSY weather scenarios is consuming more energy than future climatic scenarios (see **Figure 5.1**). It is because future is warmer and less heating energy will be required in 2050s than the present scenario. Not only that heating energy requirement in 2050 TRY and DSY file is more than that of the MM operation of that time. It is because energy intensive background ventilation and fresh air intake are more extreme in NV mode than MM of operation, to maintain IAQ and thermally comfortable indoor. In MMV method, optimum fresh air intake and mechanical air conditioning are balanced by the building control system (BCS). This is more true near the warm stack area owing to the BCS for IAQ as described in the simulation modelling section earlier. When the building is not running in MM, the building ventilation system tries to balance the 'heated up area near' the warm stack with more fresh air intake, even during the winter months. In fact, the BCS is geared to provide optimum temperature and IAQ regardless of the season it runs. The more 'fresh air' the more 'the energy' building requires for the heating, especially in the winter months and also for cooling in NV or hybrid mode. The lower heating requirement in MM operation is also because of the Warm-Stack's control regime. It always has to stay between 30 to 35 °C for aiding buoyancy mode of ventilation with the Cool-Stack. Therefore, the office area near the Warm-Stack is warmer than other parts of the office. To null out the overheating near the DSF, the MM operation's control algorithm adopts local cooling when needed without having to resort to energy intensive fresh air intake via Cool-Stack or in the form of increased background ventilation. Consequently, in 2050s, the hybrid operation is less energy intensive maintaining a better total overheating criteria than in other NV mode of operation. The maintained overheating hours below benchmark level is also represented in the total overall greater volume of summertime energy consumption (see **Figure 5.1**). Another important inference can be made here is that MM operation is more efficient than NV operations. Maintaining target overheating temperature for all building zones are costlier in NV mode's winter operation, because of the requirement of frequent fresh air intake for keeping acceptable air temperature and to maintain better IAQ. Nonetheless, NV operation still sees less yearly energy consumption than the 'good practice' or 'typical' air–conditioned building. Moreover, research shows that naturally ventilated building is good at maintaining IAQ than their air–conditioned counterpart due to the high possibility of recirculation of the pollutant with most HVAC systems.

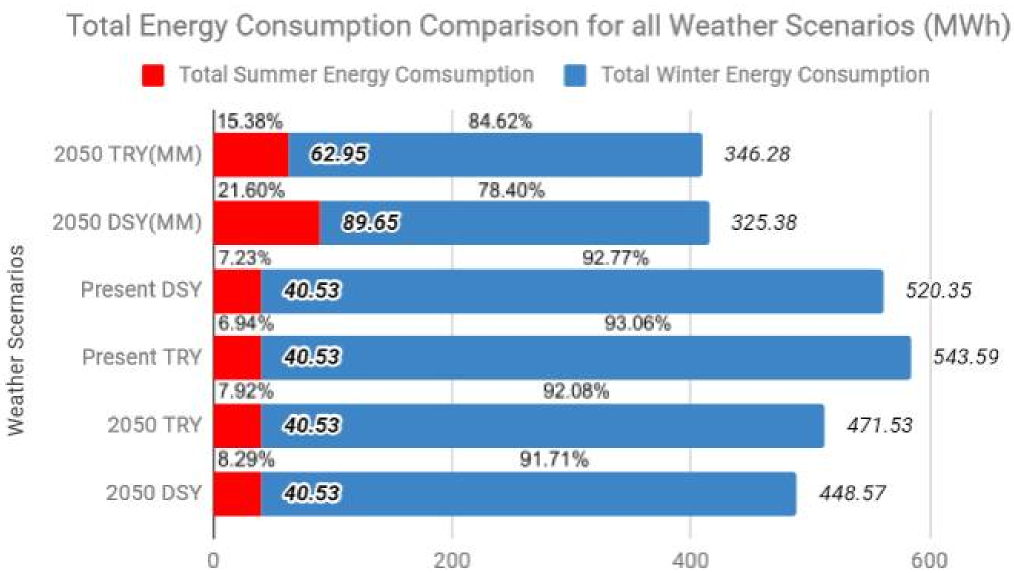

Figure 5.1: Energy Consumption Comparison for all Weather Scenarios

The following figure shows the comparison of 'typical', 'good practice' and the 'simulated' building's energy consumption in kWh/m²·yr (see **Figure 5.2**). The energy consumption of the present weather

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

scenario is well below the 'typical' limit and barely misses the 'good practice' boundary. However, the simulated building will meet 'good practice' benchmark value in 2050 climatic scenario. Not only that hybrid operation would see more than 50% less energy consumption than 'good practice' requirement. It also would see lower energy consumption than naturally ventilated building and the reason for that is already explained above. Naturally ventilated building of the present time is consuming only 11% and 16% more energy than 'good practice' naturally ventilated office space for TRY and DSY weather files respectively. Not only that examined present building is consuming at least 35% less energy than any 'typical' NV building may consume. For 2050s condition, the simulated model is performing even better consuming at least 45% less energy than 'typical' office building's benchmark value and close to 'Good practice' value (see **Figure 5.2**). On an average NV operation of the building sees only 2% of the overheating hours annually, yet consuming energy near to the 'good practice' values of present and future climatic scenarios. It is to be mentioned here open plan naturally ventilated office buildings are considered as 'Office Type 2' and hybrid buildings as 'office type 3' or 'typical air–conditioned building' in ECG19 document [13]. Not only that hybrid operation even performs better than naturally ventilated building in terms of overheating criteria and overall energy consumption. In the next figure below the comparison of overheating hours in various weather scenarios (see Figure 5.3) were plotted. As mentioned earlier, PART L2A of the building regulation allows only 1% of overheating i.e. 30 hours annually, outlined as 'benchmark overheating hours' in the plots ahead. **Table 5** below summarises the fuel and electricity consumption of various weather scenarios.

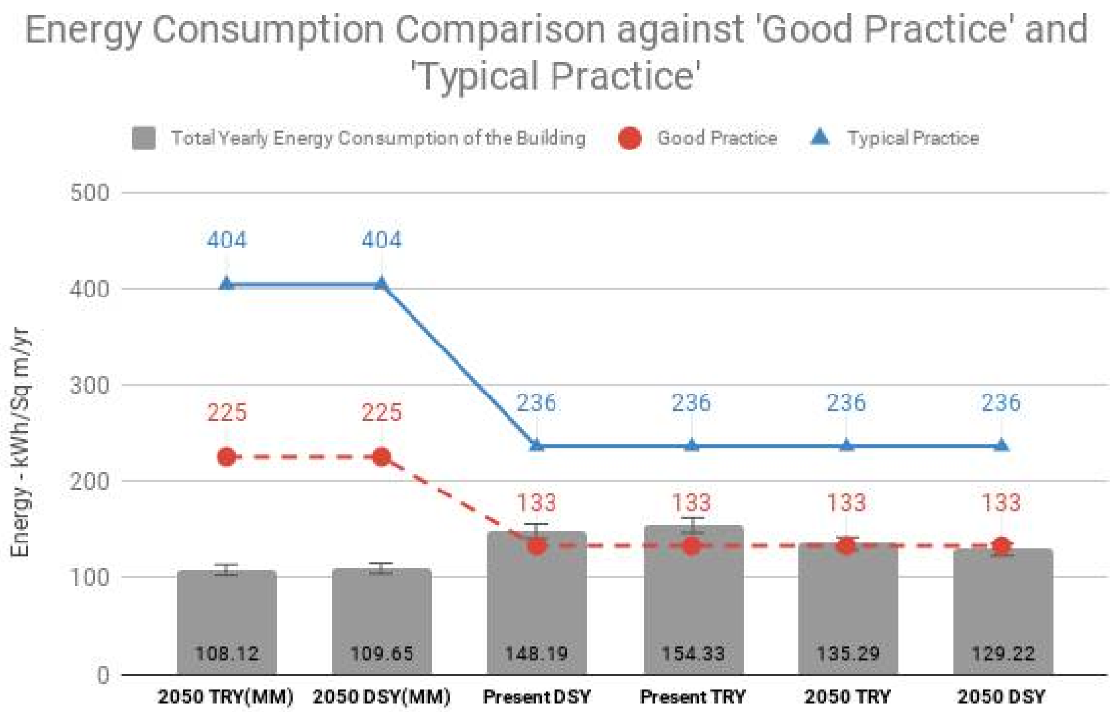

Figure 5.2: The building's Energy Consumption Comparison against 'good practice' and 'typical practice' with 5% error bar placed for the consumption values.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

Table 5: Electricity and Fuel Consumption for different Weather Scenarios

Energy Type	Present TRY	Present DSY	2050 TRY	2050 DSY	2050 TRY MM	2050 DSY MM
	MWh	*MWh*	*MWh*	*MWh*	*MWh*	*MWh*
Total Electricity	**142**	**142**	**142**	**142**	**164**	**191**
Total Fuel	**420**	**443**	**370**	**348**	**245**	**224**
	kWh	*kWh*	*kWh*	*kWh*	*kWh*	*kWh*
Total Electricity/m²	**25.81**	**25.81**	**25.81**	**25.81**	**29.82**	**34.73**
Fuel Per/m²	**76**	**80.54**	**67.27**	**63.27**	**44.55**	**40.73**

MM models performed best with overheating hours well below the benchmark limit (see **Figure 5.3**). Not only that energy consumption of the MMV model is far better than present and future NV mode. The figure also shows that without the hybrid operation of buildings and with current building fabric standard, it would not be possible to provide occupants with a thermally comfortable environment. Even though the envelope properties are same for all studied models, their U values did not impact the overall energy consumption or overheating criteria. The simulation results deduce that the sensitivity of present and future proof building with low emission, lies with the ventilation strategy, not the mere airtightness or fabric attributes of buildings.

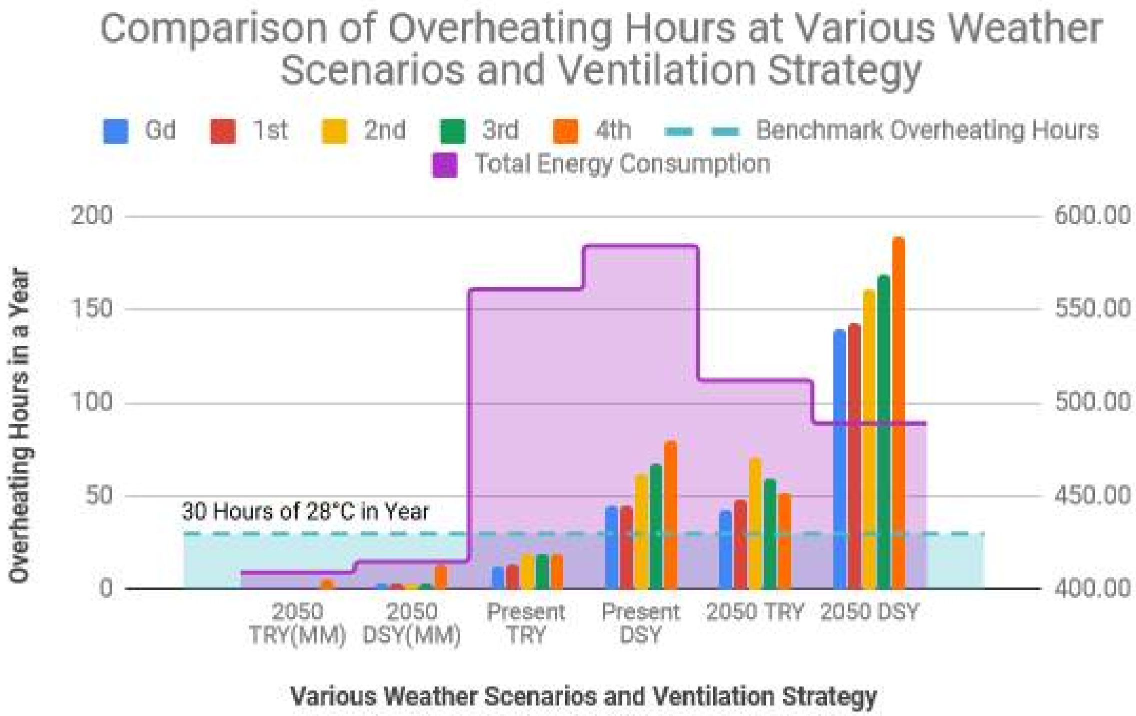

Figure 5.3: Comparison of Overheating Hours at Various Weather Scenarios along with Mixed-mode and Natural Ventilation Strategy

The naturally ventilated building seems not performing well enough in DSY weather files of present and future scenarios as can be seen from the following sensitivity plots (see **Figure 5.4**) (see **Figure 5.5**) (see **Figure 5.6**) (see **Figure 5.7**). However, as seen above the building is performing well within overheating benchmark values in MMV method. It also can be seen from the sensitivity **Figure 5.7** that the upper floors are at greater risk of overheating than lower floors when DSY weather files were explored. However, hybrid building is performing well below overheating criteria boundary set forth in the building related guidelines (see **Figure 5.7** below).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

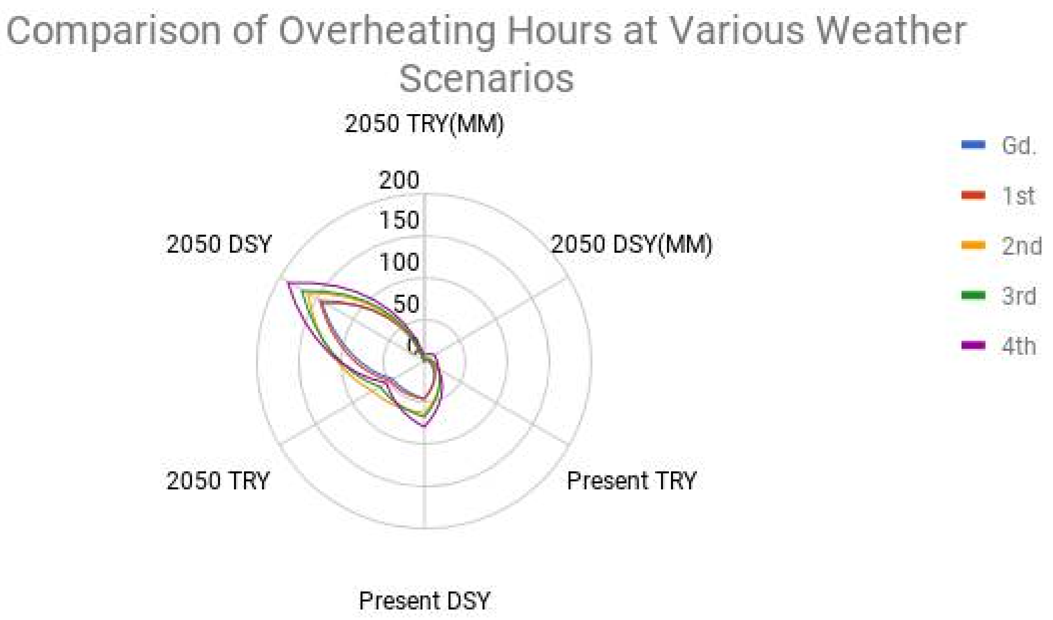

Figure 5.4: Comparison of Overheating Criteria in Various Weather Scenarios

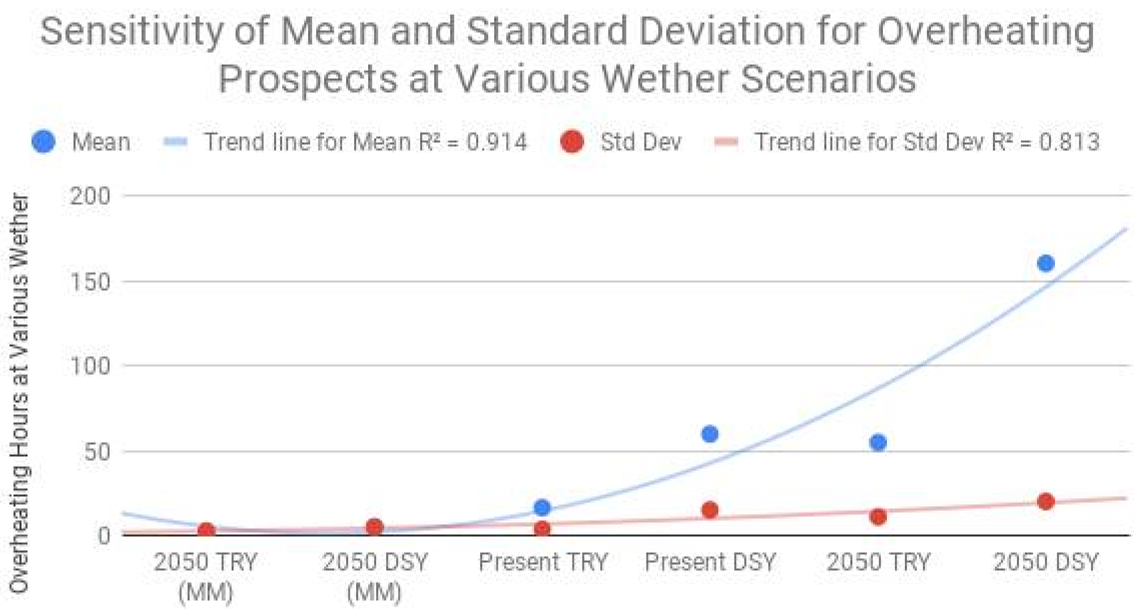

Figure 5.5: Sensitivity of Mean and Standard Deviation for Overheating Prospects at Various Weather Scenarios

 doi:10.20944/preprints201811.0290.v1

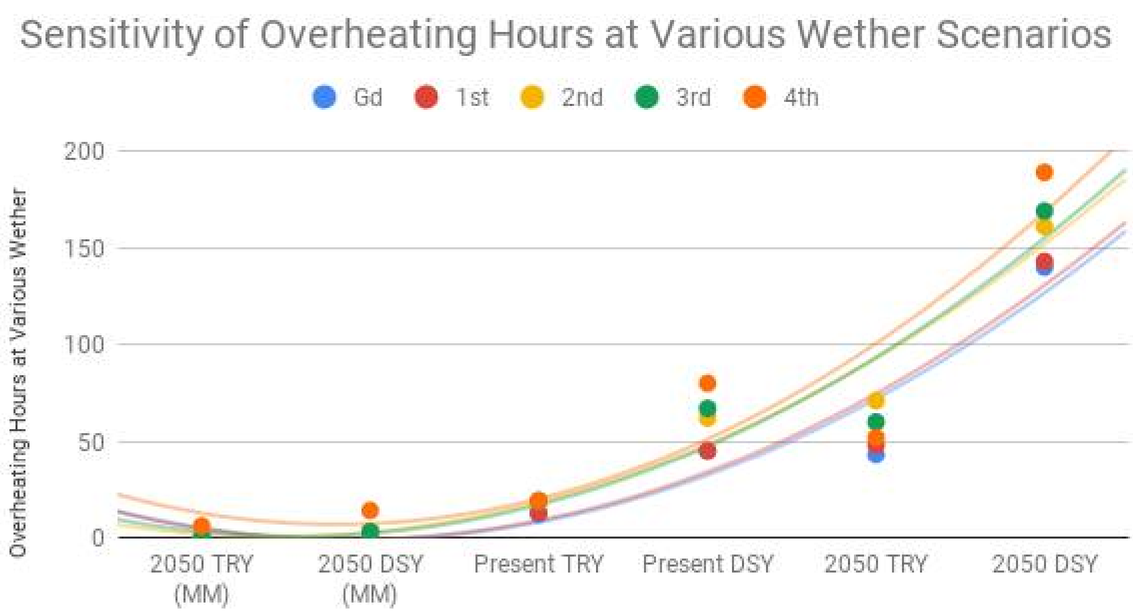

Figure 5.6: Sensitivity of Overheating Hours at Various Weather Scenarios

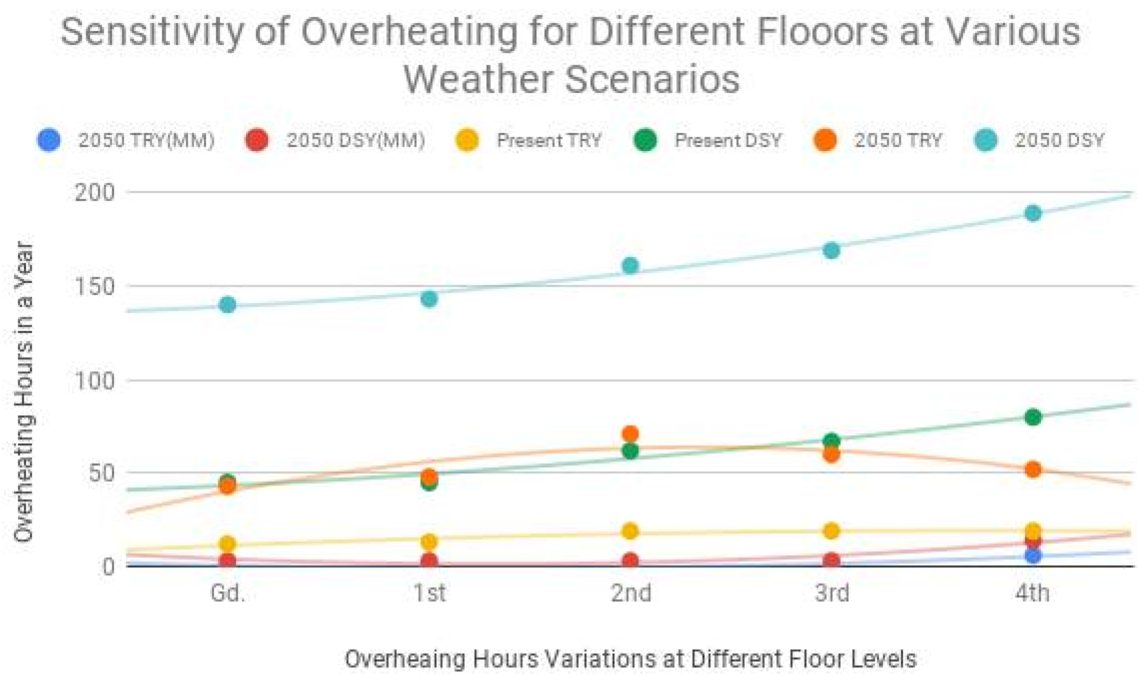

Figure 5.7: Sensitivity of Overheating Hours at Different Floors at Various Weather Scenarios

The following plot also shows that hybrid operations may be a necessity instead of relying solely on natural ventilation scheme for future-proof building in terms of overheating assessment (see **Figure 5.8**). Even the standard deviation assessment from calculated overheating hours did not comply in meeting benchmark values. Decarbonisation of buildings with fabric enhancement seems to play a lesser role than in the selection of the right ventilation strategy. In fact, hybrid operation has way more prospect of reducing carbon emissions from buildings than its' natural ventilation counterpart and air-conditioned building would be far-fetched in this goal (see **Figure 5.11** and **Figure 5.12**). Only MM operations set itself within overheating, energy and carbon emission requirement set forth in the building code (see **Figure 5.8**, **Figure 5.12** and **Figure 5.13**).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

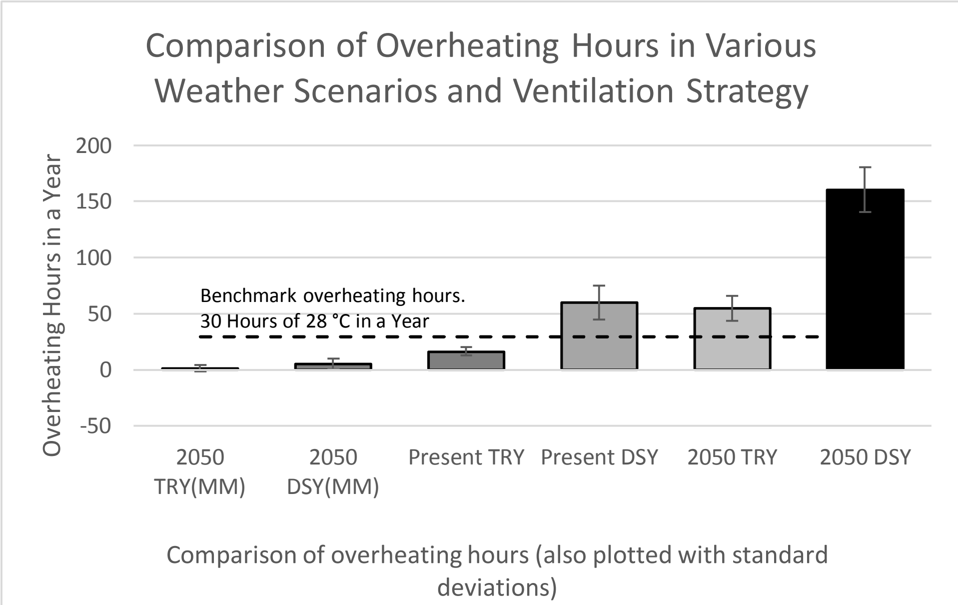

Figure 5.8: Standard Deviation Assessment in Overheating Hours

As delineated before, owing to the warming trends in climate, a reduction of more than 15% of the heating plant load is witnessed for 2050 TRY and 2050 DSY scenarios (see **Figure 5.9** below). Hence, comfort cooling will also become more of a prominent issue in future climatic conditions than space heating alone. High standard air-conditioned building can provide thermal comfort for occupants with the expense of much higher energy consumption yield than naturally ventilated buildings. Therefore, there probably is no alternative but to adopt the hybrid ventilation strategy in building. As it is witnessed in this study that; in 2050s the hybrid operations can achieve overheating criteria with 50% less energy consumption than standard air-conditioned building (see **Figure 5.2** above). To meet the target emission rate set in various agendas and protocols in pursuit of negating the effect of climatic variability and to make a future-proof office building stocks, passive and mixed-mode operations of building should be the primary goal of legislative efforts, rather solely relying on present trend of reduction of building heating demand. This is because overheating in workspace risks health, well-being and productivity of the work force.

Yes, it is true that heating energy dominates in present weather condition, however in future warmer environments, the cooling energy will also come into with a greater share of energy consumption, as can be seen in the surface plot later (**Figure 5.10**). The goal should be not only to reduce carbon emission from building stocks, but to make buildings resilient to summertime overheating. As can be seen from the surface plot that MM operations are much more effective in dealing with the reduction of energy consumption and subsequent decline in carbon emissions than other simulation strategies undertaken in this research.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

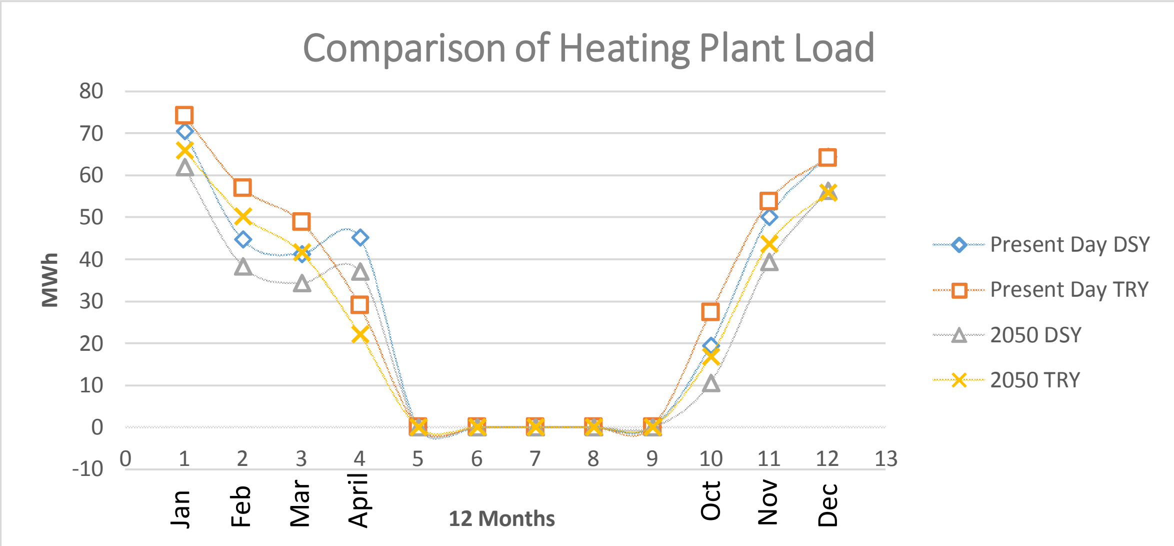

Figure 5.9: Comparison of Heating Plant Load at Various Weather Scenarios and Months

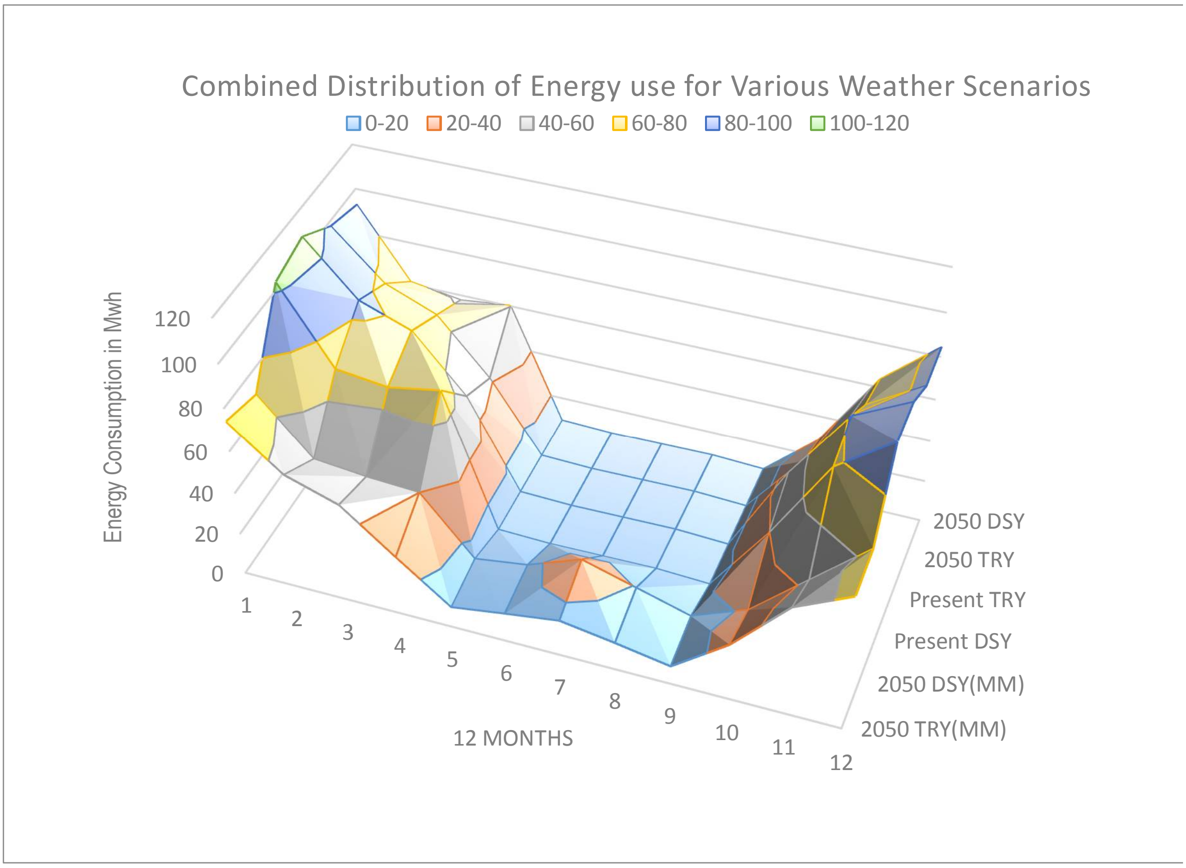

Figure 5.10: Combined distribution of Energy use for Various Weather Scenarios

In further assessment, it is witnessed that carbon emission in present and future weather scenarios closely follow the building's total energy consumption, except for the MM operations (see **Figure 5.11** below). It is because electricity consumption in both MMV cases is higher than other scenarios for summertime comfort cooling. However, overall carbon emission for hybrid operations is still 14 to 19% less than present scenarios. Also the 2050 NV operations of the building will witness an

8% reduction in carbon emissions than present NV scenarios. When comparing energy consumption against 'good' and 'typical practices'; the building performed well in all examined weather scenarios (see **Figure 5.13** below). For the case of carbon emission all simulation scenarios performed within the 'good practice' yearly target of 'office type 2 – Naturally Ventilated Open Plan Office' mentioned in the ECG19 guide (see **Figure 5.12** below). For instance, against a good practice 43.1 kgCO2/m²·yr carbon emissions target the simulated buildings show emission of 37, 38, 35 and 34 kgCO2/m²·yr for present DSY, present TRY, 2050 DSY and 2050 TRY respectively. Besides, against a good practice 85 kgCO2/m²·yr carbon emissions target for MM operation, the simulation resulted in 31 and 32 kgCO2/m²·yr of emission in the year 2050 DSY and 2050 TRY case.

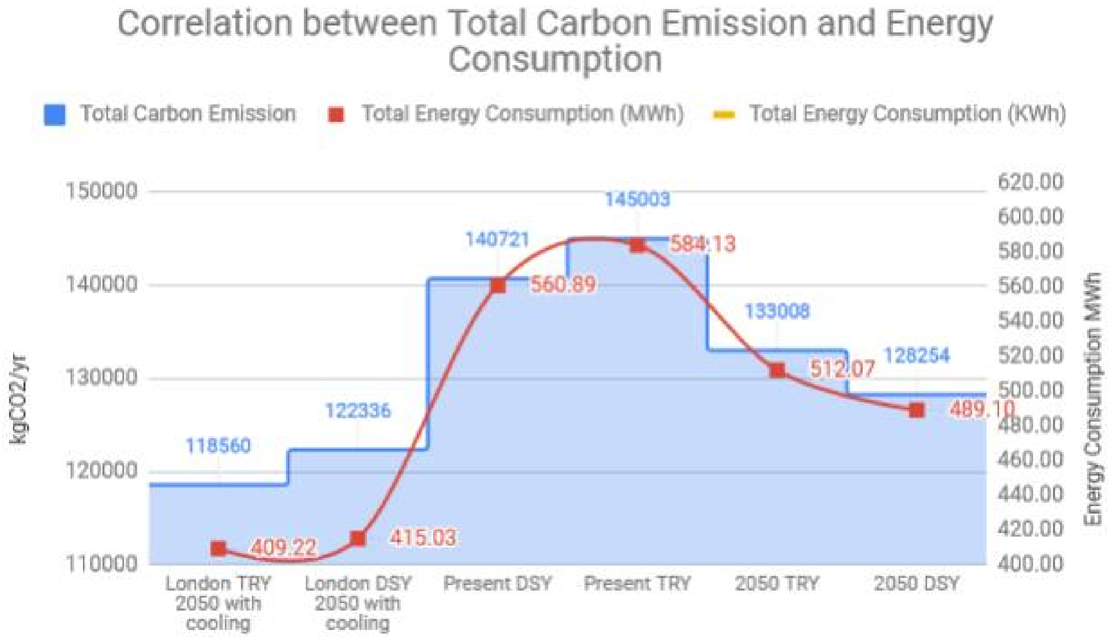

Figure 5.11: Correlation between Total Carbon Emission and Energy Consumption

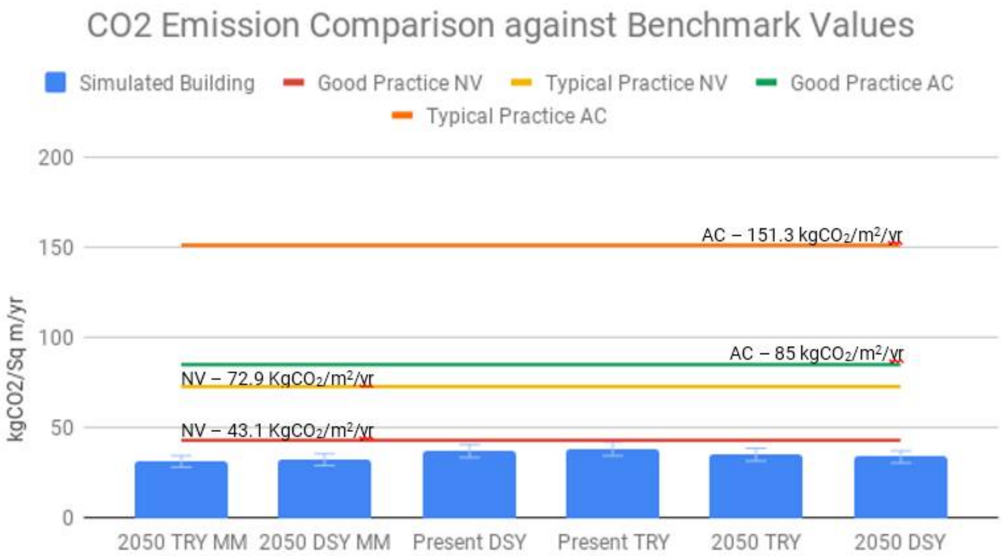

Figure 5.12: CO_2 Emission Comparison against Benchmark Values (with 10 % error bars)

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

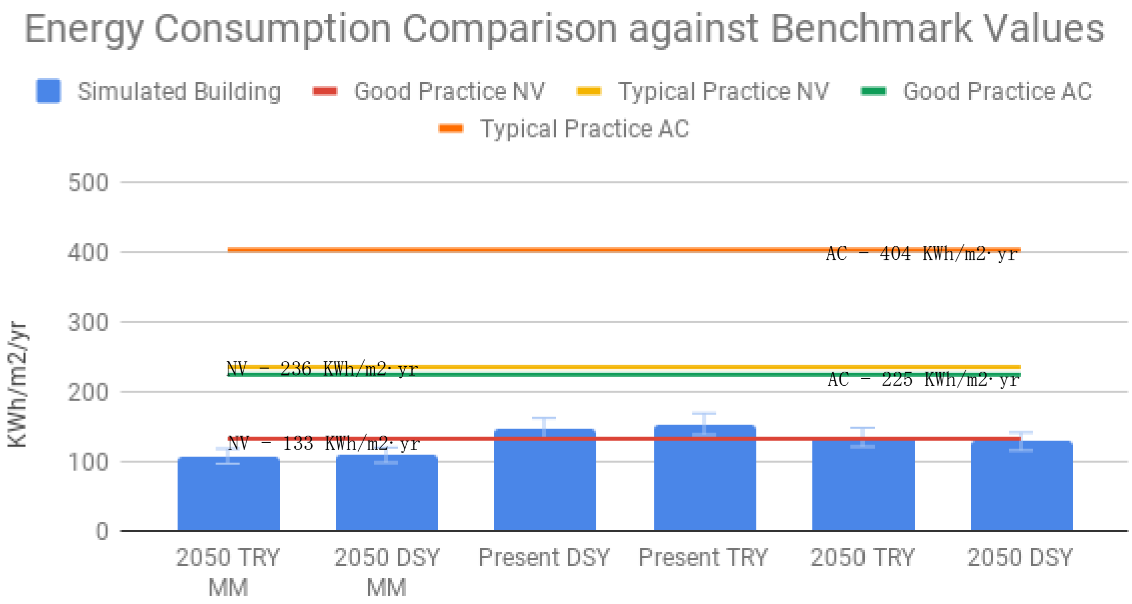

Figure 5.13: Energy Consumption Comparison against Benchmark Values (with 10 % error bars)

6. Conclusion

It is known that naturally ventilated building witness some form of overheating in extreme summer months, especially on a warm still day with little air movement [22]. However, the building with current PART L2A fabric attributes, standards and airtightness option, performed well enough due to the adoption of low carbon design strategies such as natural and hybrid ventilation options for space conditioning. The DSF of the building is itself non-conventional than most office buildings and hybrid operation has enabled the building to reach an acceptable indoor temperature range for warmer 2050 climatic scenarios. Furthermore, the building is within the benchmark energy level in all simulated scenarios.

Current building code is biased on adopting stringent air tightness and hygrothermal properties of fabric materials, to reduce energy consumption and to achieve a reduction in carbon emissions from UK building stocks. However, from this study, it seems those efforts need to be in adoption of passive and low carbon design options. Otherwise, it certainly would need to suffer from the warmer climate of the future in terms of occupant comfort due to overheating and would lag behind in curbing carbon emissions from building operations. Therefore, the discussion should be whether to go with a sealed building envelope of current code practice or to emphasise the adoption of passive or hybrid design options to offset the adverse effect of a warming climate of the future. In light of this research it is therefore expected, that in order to adapt to future climatic conditions any office building design need a critical analysis of future-proofing during the design phase. Proper space planning, optimum orientation to maximize daylight, aligning longer part of the building in the east-west direction to reduce solar heat gain, use of efficient envelope materials and low energy options such as natural ventilation along with night cooling strategy would make a building resilient to extreme future climate. Furthermore, adoption of mixed-mode ventilation for buildings ensures optimal thermal comfort for occupants while ensuring energy benchmark goal is met. As per Morshed's study, it is seen that mixed-mode operation ensure good IAQ owing to better mixing of fresh air in a space [16]. Automation in the BCS has enabled building space to be easily run in NV or MMV type operation. All in all, these ventilation strategies have to be combined with the present need of a more airtight building to save heating cost of winter months. Moreover, any legislative effort in addressing the decarbonisation options of the present time should compute future warming weather scenarios. The overall goal is to design office buildings that bear the capability of withstanding both extremes of winter and summer conditions in the warmer years to come.

 doi:10.20944/preprints201811.0290.v1

7. Recommendations for Future Work

A study with various other passive design options such as earth-coupled ventilation, adoption of solar tower or chimney, windcatcher, phase-change material based façade as thermal retention technique to reduce overheating etc. could lead to better understanding of future weather suitability of office buildings in the UK environment. Special emphasis on comparison between natural and mixed-mode ventilation for UK office buildings shall be the main focus of future similar studies. Climatic suitability and a plea to assess the reduction of carbon emission from such building stock shall be the eventual goal.

9. References

[1] DBEIS, "UK Energy Statistics, Q1 2018," London, UK, Jun. 2018.

[2] I. C. Ward, "What are the energy and power consumption patterns of different types of built environment?," *Energy Policy*, vol. 36, no. 12, pp. 4622–4629, Dec. 2008.

[3] T. Delay, S. Farmer, and T. Jennings, "Building the future, today," London, UK, 2009.

[4] UK GBC, "UKGBC's vision for a sustainable built environment is one that mitigates and adapts to climate change.," *Climate Change*, 2014. [Online]. Available: https://www.ukgbc.org/climate-change/. [Accessed: 11-Jul-2018].

[5] DECC, "Climate Change Act 2008." The Stationery Office Limited, 2010.

[6] London.gov.uk, "Meeting the challenges of climate change." 2015.

[7] U. DECC, "The Future of Heating: A Strategic Framework for Low Carbon Heat in the UK." Department of Energy and Climate Change, May-2012.

[8] M. Kolokotroni, X. Ren, M. Davies, and A. Mavrogianni, "London's urban heat island: Impact on current and future energy consumption in office buildings," *Energy Build.*, vol. 47, pp. 302–311, Apr. 2012.

[9] U. Carbon Trust, "A Natural Choice: Lessons Learned Form The Low Carbon Buildings With Natural Ventilation," London, UK, Jul. 2011.

[10] BRE, *Guide to Part L of the Building Regulations: Conservation of Fuel and Power Other Than Dwellings*. Newcastle, UK: NBS, RIBA, 2016.

[11] M. Humphreys, F. Nicol, J. David, A. Guy, D. Handley, and D. Wood, *CIBSE Guide A: Environmental design*, Seventh. Norwich, UK: CIBSE Publications, 2006.

[12] WRAP, *Green Office: A Guide to Running a More Cost-effective and Environmentally Sustainable Office*. 2014.

[13] Carbon Trust, "ECG 19: Energy efficiency in offices," pp. 1–24, 2003.

[14] Ministry for the Environment, "Value Case for Sustainable Building in New Zealand - 4 Value Case | Ministry for the Environment," *Value Case for Sustainable Building in New Zealand*, 2015. [Online]. Available: http://mfe.govt.nz/publications/sus-dev/value-case-sustainable-building-feb06/html/page7.html. [Accessed: 22-Jan-2015].

[15] GGGC Pennsylvania, "What is Green Building? Fundamental Principles of Green Building and Sustainable Design," *Building Green in Pennsylvania*, 13-Nov-2013. [Online]. Available: http://www.epa.gov/statelocalclimate/documents/pdf/12_8_what_is_green_GGGC.pdf. [Accessed: 22-Jan-2015].

[16] T. Morshed, "An investigation of naturally ventilated teaching spaces with windcathers in secondary school where site is constrained by noise and air pollution," *Build. Simul.*, vol. 7, no. 5, pp. 547–561, Oct. 2014.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 13 November 2018 doi:10.20944/preprints201811.0290.v1

[17] G. Henderson, N. Barnard, D. Jaunzens, J. Armstrong, D. Butler, and D. G. Leventhall, *CIBSE Guide B: Heating, ventilating, air conditioning and refrigeration*. Norwich, UK: CIBSE Publications, 2005.

[18] K. Butcher *et al.*, *Climate change and the indoor environment: impacts and adaptation*. London, UK: Chartered Institution of Building Services Engineers, 2005.

[19] D. Littlefield, *Metric Handbook Planning and Design Data*, Third Edition. United Kingdom: Elsevier Ltd, 2008.

[20] H. Skistad, *Displacement Ventilation*. England, UK: John Wiley and Sons Inc., 1994.

[21] I. Knight and G. Dunn, "Evaluation of Heat Gains in UK Office Environments," 2003.

[22] NHBC Foundation, *Understanding Overheating: Where to Start*. Milton Keynes, UK: NHBC Foundation, 2012.

Acknowledgement

Conflicts of Interest: "The authors declare no conflict of interest."