Date:	03/05/2024	
Subject:	Cooling Hierarchy Report	
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Rev	Date	Description	Prepared By
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1 EXECUTIVE SUMMARY

The cooling hierarchy study presented in this report has been created for First Avenue house chiller replacement project. First Avenue House is operated by HMCTS and is located on the A40 in High Holborn, London. The court building is set within a largely commercial area and student housing blocks situated adjacent to the eastern side on Warwick Court.

With the continuous focus on energy efficiency and reducing carbon emissions in line with its national climate goals, the role of chiller systems within the cooling hierarchy of commercial and industrial facilities becomes increasingly critical. This project aims to conduct a study targeted at ensuring that replacing chillers will lead to enhancing the overall energy efficiency, reduce operating costs, and align with GLA policy 5.9 for overheating and cooling.

The below table summarises the analysis results.

level	**Conclusion**
Limiting Solar gains	The solar exposure has benefit of adequate day light for all façade spaces, however, it is main contributor for the cooling load. Since there are restrictions on windows which is not part of the project, practical solution to manage solar radiation and glare is internal blinds which building operators can adopt (if not already) to mitigate the solar gains. The analysis shows that blinds with opacity of 55% is adequate to pass Criterion 3 (Solar Heat gain limit) of part L which will be recommended benchmark performance.
Reducing and managing internal gains	As existing building, there is always opportunities for internal heat gain optimisation through the following: 1- Existing Control system to optimise energy use and avoid unnecessary use of internal heat gain sources (i.e. Automatic Switch off of unused Display screen, lights in well daylit areas, etc.) 2- Building users behaviour and awareness to minimise miscellaneous use heat loads. 3- Upgrading high heat dissipation internal heat gain sources with new technologies that dissipates less heats including lighting, ICT, etc.) This also relates to the overall energy efficiency of the building and not just the cooling and to be considered for the future upgrade works plans for the building.
Passive Ventilation	The analysis shows that without mechanical cooling, the building fails CIBSE TM 52 requirements. This verifies the CFD results which showed that the surrounding buildings affects the are flow around the building which will make the use of natural ventilations as main strategy for comfort cooling limited. Air quality and, privacy and noise ingress will be also other reasons to limit the efficiency of use of natural ventilation for comfort cooling.
Mechanical ventilation without cooling	Mechanical ventilation will require substantial air volume that will requires significant additional Fans or Heat recovery system and will require substantial additional core areas (Shafts) to run larger sizes ducts to accommodate such air volumes which is not feasible and not part of the current works
Mechanical ventilation and Cooling	Mechanical Cooling system is capable of maintaining comfort conditions throughout the building. Increasing the chillers capacity by 10% will provide operational future proofing against the extreme weather conditions including intense heatwaves as well as sustaining comfortable conditions inside the building throughout the lifetime of the chiller's operation. Considering the degradation of the existing chiller efficiency since installation date and use of obsolete high GWP refrigerant, the chiller upgrades with new high efficiency with lower GWP refrigerants could save estimate of 42.5% of carbon emissions pending final selection of chillers

Table 1: Cooling Heirchary Summary Results

2 INTRODUCTION

The cooling hierarchy study presented in this report has been created for First Avenue house chiller replacement project. First Avenue House is operated by HMCTS and is located on the A40 in High Holborn, London. The court building is set within a largely commercial area and student housing blocks situated adjacent to the eastern side on Warwick Court.

First Avenue House is not itself heritage listed; however, it does sit within a preservation area and there are restrictions on the windows which does not form part of this project.

With the continuous focus on energy efficiency and reducing carbon emissions in line with its national climate goals, the role of chiller systems within the cooling hierarchy of commercial and industrial facilities becomes increasingly critical. This project aims to conduct a study targeted at ensuring that replacing chillers will lead to enhancing the overall energy efficiency, reduce operating costs, and align with GLA policy 5.9 for overheating and cooling.

The decision to replace existing chillers is prompted by the need to address aging systems, exploit advances in cooling technology, and meet the latest environmental standards that dictate lower greenhouse gas emissions and higher energy efficiency with opportunity for provide future proofing for the building.

This study will perform analysis chiller loads and annual energy consumption. This analysis will establish the baseline needed to understand the potential improvements from implementing newer, more technologically advanced chiller systems. The focus will be on selecting chillers that are not only more energy-efficient but also capable of integrating seamlessly with existing cooling infrastructures and adapting to future operational demands.

Figure 1: First Avenue House Building

3 COOLING HIERARCHY

GLA Policy 5.9 requires all Major development proposals should reduce potential overheating and reliance on air conditioning systems and demonstrate this in accordance with the following cooling hierarchy:

1- Minimise internal heat generation through energy efficient design.
2- reduce the amount of heat entering a building in summer through orientation, shading, albedo, fenestration, insulation and green roofs and walls.
3- manage the heat within the building through exposed internal thermal mass and high ceilings.
4- passive ventilation
5- mechanical ventilation
6- active cooling systems (ensuring they are the lowest carbon options).

Major development proposals should demonstrate how the design, materials, construction, and operation of the development would minimise overheating and also meet its cooling needs. New development in London should also be designed to avoid the need for energy intensive air conditioning systems as much as possible. Further details and guidance regarding overheating and cooling are outlined in the London Climate Change Adaptation Strategy.

Worthy to note that in case of First Avenue project, the scope of works related to replacing the exiting old chiller with a new more efficient ones with no renovations or refurbishment are in the scop. The analysis will cover the hierarchy level to assess the main cooling load contributors and opportunities and limitations to reduce these hear sources.

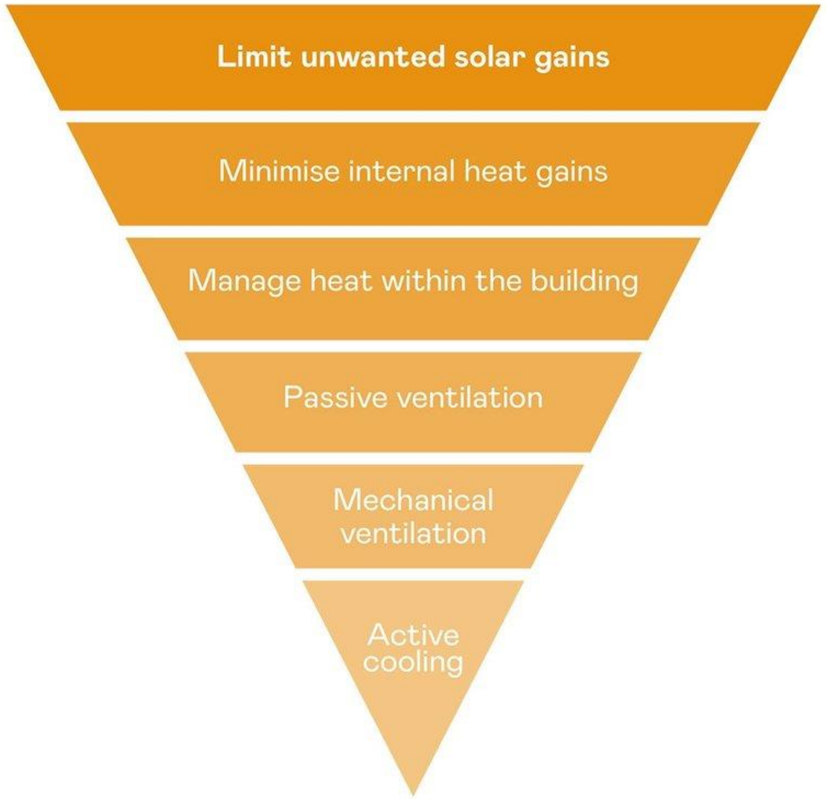


Figure 2: Cooling Heirchary

4 MODELLING PROCESS

Full Scale thermal model using Integrated Environmental Solutions Software (IES) has been created for First Avenue Building. The modelling included scanning of the record as built drawings and converting it to digital CAD drawings which have been used in the thermal model building process.

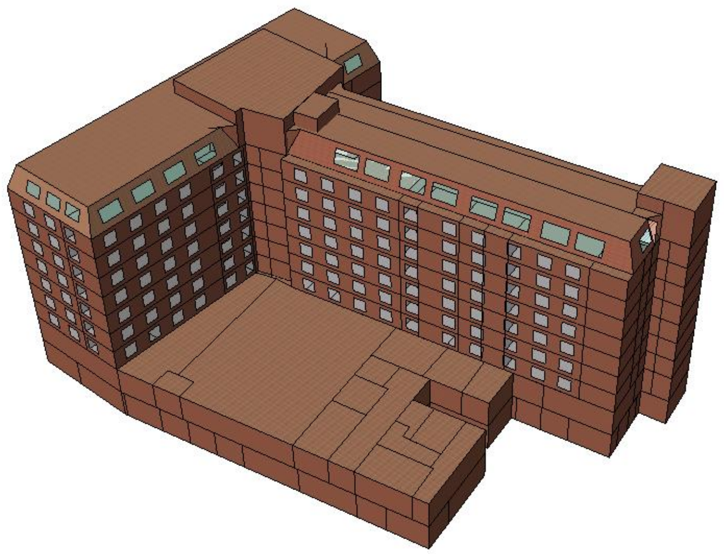


Figure 3: IES Model (First venue House)

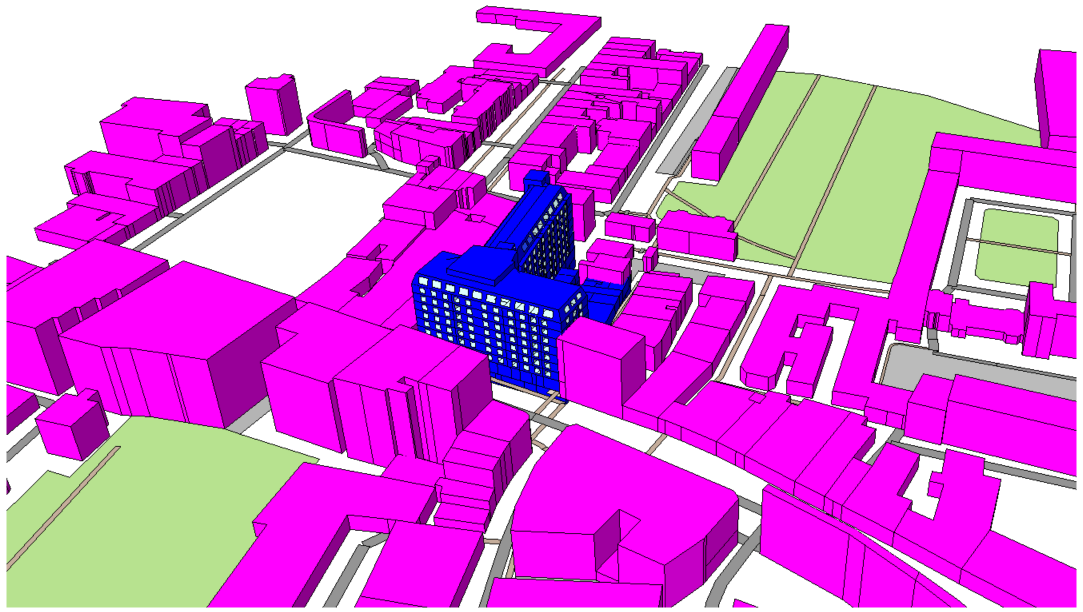


Figure 4: IES Model (First venue House) within master plan.

The model has followed CIBSE AM11 requirements. The below figure shows thermal templates view for the models.

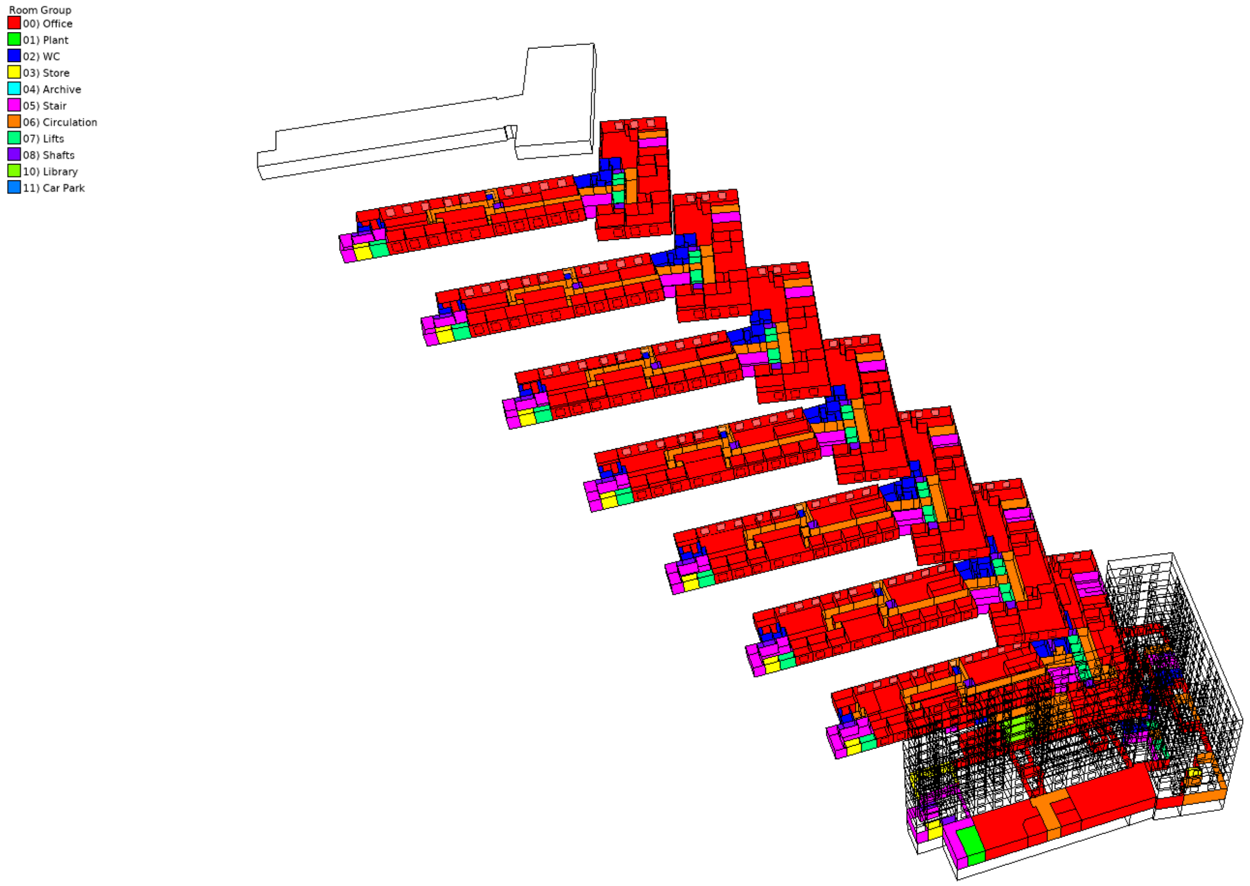


Figure 5: Model Thermal Templates Exploded View

5 MODELLING INPUT

5.1 U-values

The building has undergone refurbishment in 1997, Accordingly, it is assumed that the thermal performance of the building envelope follows the Part L 1995 is expected to be followed at the time of the refurbishment as shown in the below extract.

Table 5 Standard U-values (W/m^2K) for buildings other than dwellings

Element	U-value
Roofs (1)	0.25 (2)
Exposed walls	0.45
Exposed floors and ground floors	0.45
Semi-exposed walls and floors	0.6
Windows, personnel doors and rooflights	3.3
Vehicle access and similar large doors	0.7

Notes

1. Any part of a roof having a pitch of 70° or more may have the same U-value as a wall.
2. For a flat roof or insulated sloping roof with no loft space it will be acceptable if a U-value of 0.35 W/m^2K is achieved for residential buildings or 0.45 W/m^2K for other buildings.

Figure 6: Part L 1995 U-values Extract.

Based on the project brief the design set points for different spaces are listed below:

Temperatures:	Temperature (°C)
Offices and Meeting Rooms:	22 - / + 2
Courts	22 - / + 2
Reception Room and Waiting Areas	22 - / + 2
Photocopier Room:	19 - / + 2
IT Comms Room	21 - / + 2
Store Rooms	19 - / + 2
Kitchen	26 max
Cafeteria	22 - / + 2
WC rooms	18 min
Staircases / Circulation	18 min

Figure 7: Spaces Cooling Set points.

Internal gains assumption has followed the project brief as shown in the below table:

Internal Heat Gains (Assumptions):	
Occupancy (1 person per $8m^2$)	12.5 W/ m^2 Sensible – 6.25 W/m^2 Latent
Lighting Heat Gains	12 W/m^2 Sensible, 8 W/m^2 Sensible (LED)
Small Power General	5 W/m^2 Sensible
Allowance future flexibility	5 W/m^2 Sensible
Standard Work Desk	300 W Sensible
Mechanical Services – Fan coil Units	5 W/m^2 Sensible
Mechanical Services – Fresh Air Units	10 W/m^2 Sensible

Figure 8: internal gains.

Fresh Air requirements has followed the project brief as shown in the below table:

Mechanical Ventilation:	
All Occupied Areas:	1.5 l/s/m^2 fresh air (12 litres per second per Occupant / 1 occupant per $8m^2$). Min fresh air 5 ACH
Toilet / Shower Areas:	6 litres per second per WC or 10 ACH (Whichever greater)

Figure 9: Fresh Air Requirements

The occupancy profile has followed the following timings wit 24 hrs cooling for ICT rooms.

Occupancy Times:	Client Defined
All Office Areas	07:00 to 19:00 (General)
Courts	08:00 to 18:00

The model has considered the estimated operation profile for the building with typical operation hours from 8 am to 7 pm daily including weekends.

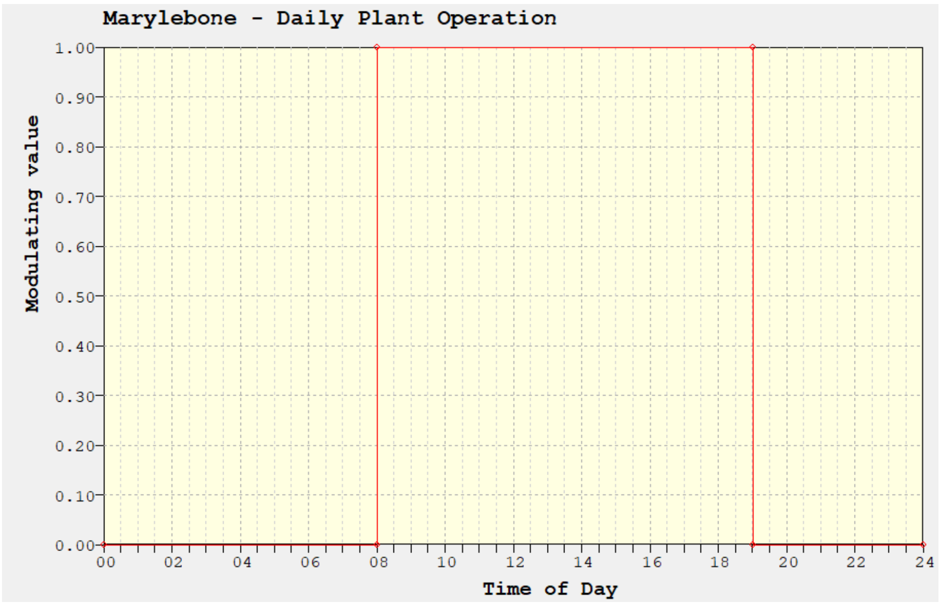


Figure 10: Typical Operational profile for the project.

For thermal comfort assessment the following parameters have been considered for the occupier clothing level and activity

Parameter		Value	Unit
Clothing	Min (Summer)	0.6[1]	Clo
	Max (Winter)	1[2]	Clo
Design system air velocity at the occupied level		0.15[3]	m/s
Metabolic Activity (Office)		1.2 (seated)	met
Metabolic Activity (Retail)		1.4 (Walking)	met

[1] Typical summer clothing (T-Shirt and Trousers)
[2] Typical indoor Winter Clothing (CBE)
[3] At occupancy level

6 WEATHER ANALYSIS

6.1 Current Weather file

The current weather file is set as CIBSE London DSY-2020 H. The below charts show the Dry-Bulb and Wet-bulb temperature variation for London DSY -H 2020 weather file with peak dry-bulb temperature of 34.7 ºC.

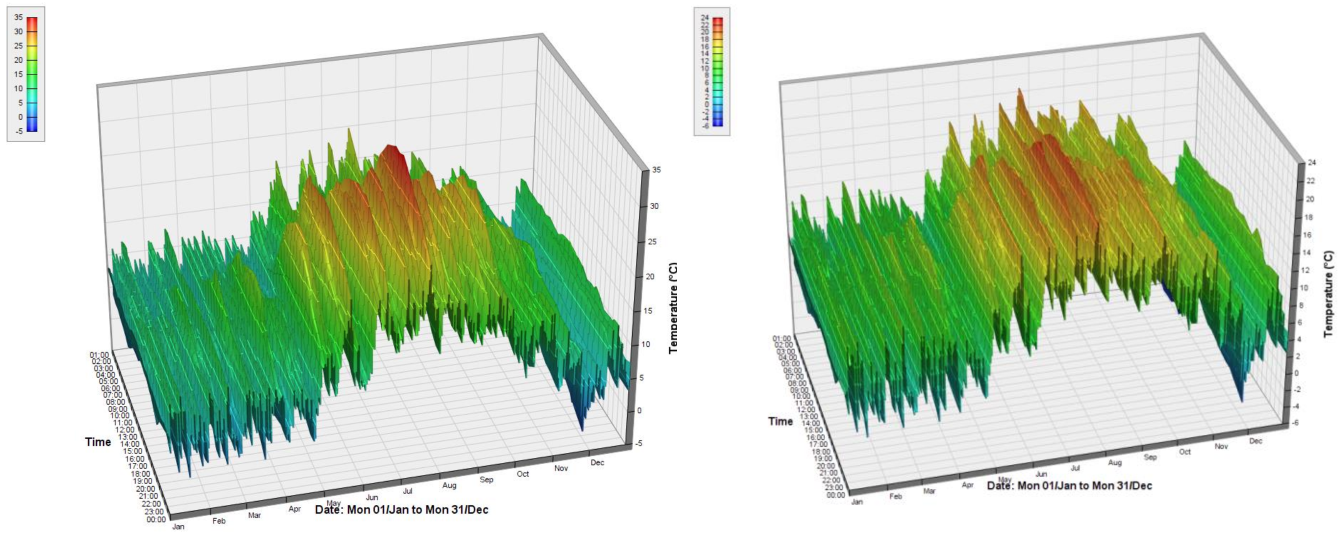
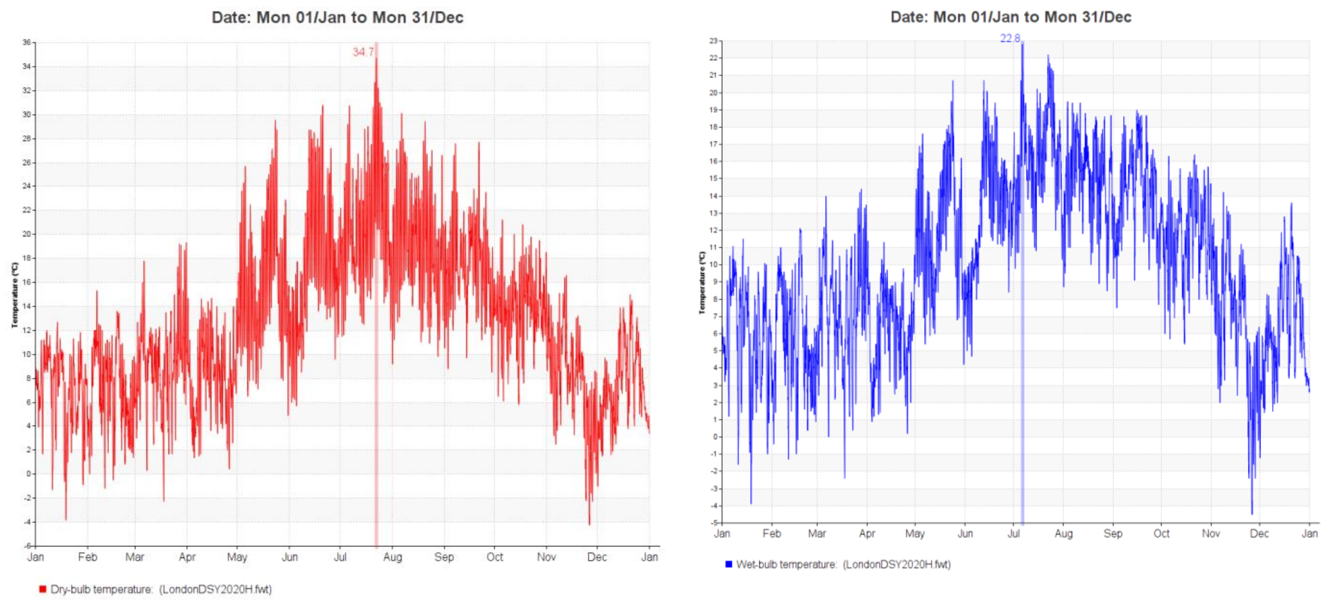


Figure 11: London DSY 2020 High dry-bulb and wet bulb temperatures profile.



6.2 Future weather files

Generally, there is an inherent uncertainty with respect to future climate conditions, there is no way to know which of the files will most closely match actual climate conditions during the specified period so a risk management approach to cooling, overheating, and heating system design is appropriate. In most cases, this will entail making use of more than one set of files. The uncertainty has three main sources. The first is that there is no way of knowing what future emissions of Greenhouse gases (GHG) will be. Second is the variation of the climatic prediction models and the unexpected factors that can arise in the future changing the models' predictions.

As a result of natural variability, there would be a substantial range in possible future climate conditions even if we knew precisely what future emissions would be and if we had a perfect model of the climate. This is the reason that we use multiple projections from multiple climate models, referred to as a multimodal ensemble, to explore the range of future possibilities.

The choice of future time period should be based on the design life of the building in question. For buildings with a design life of 25 years or less, obtaining a set of files for the time period closest to the end of that interval is recommended. For buildings with a design life greater than 25 years, obtaining a set of files for the time period closest to the end of that interval for Low and high conditions recommended, since the difference between projections for the two becomes increasingly greater over time.

For overheating systems, running simulations at DSY high future weather file provide insight into system performance for both midpoint and upper tail warming based on the higher future emissions it assumes.
Future weather file is set as London DSY 2050 High for summer.

The below charts show the Dry-Bulb and Wet-bulb temperature variation for London DSY 2050 high weather file with peak dry-bulb temperature of 37.3 ºC.

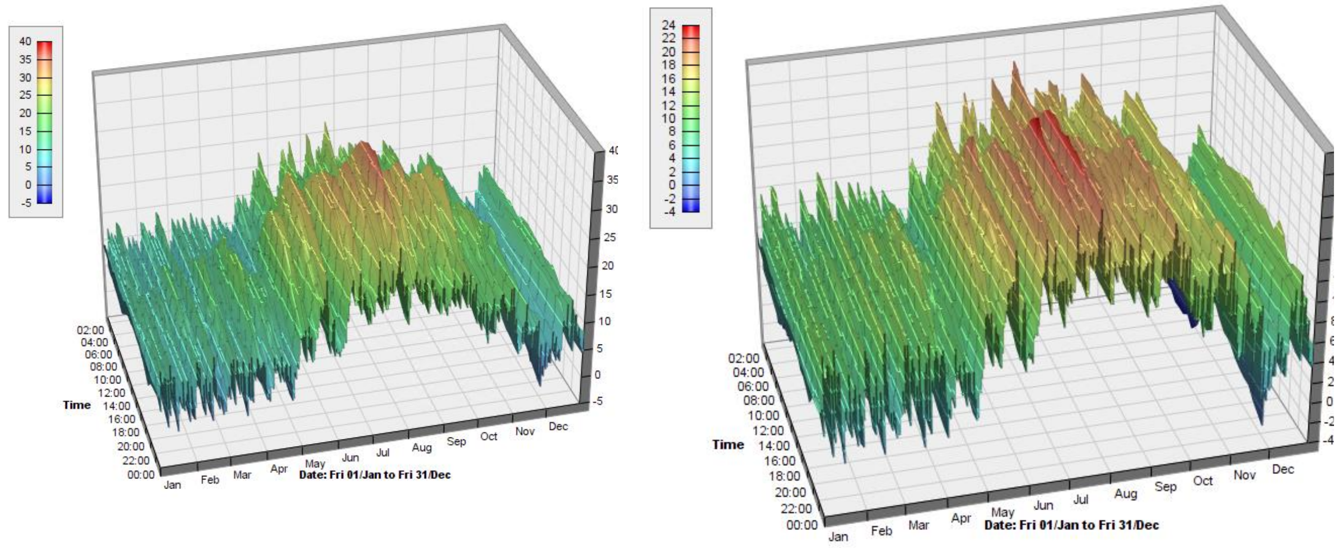


Figure 12: London DSY 2050 High dry-bulb and wet bulb temperatures profile.

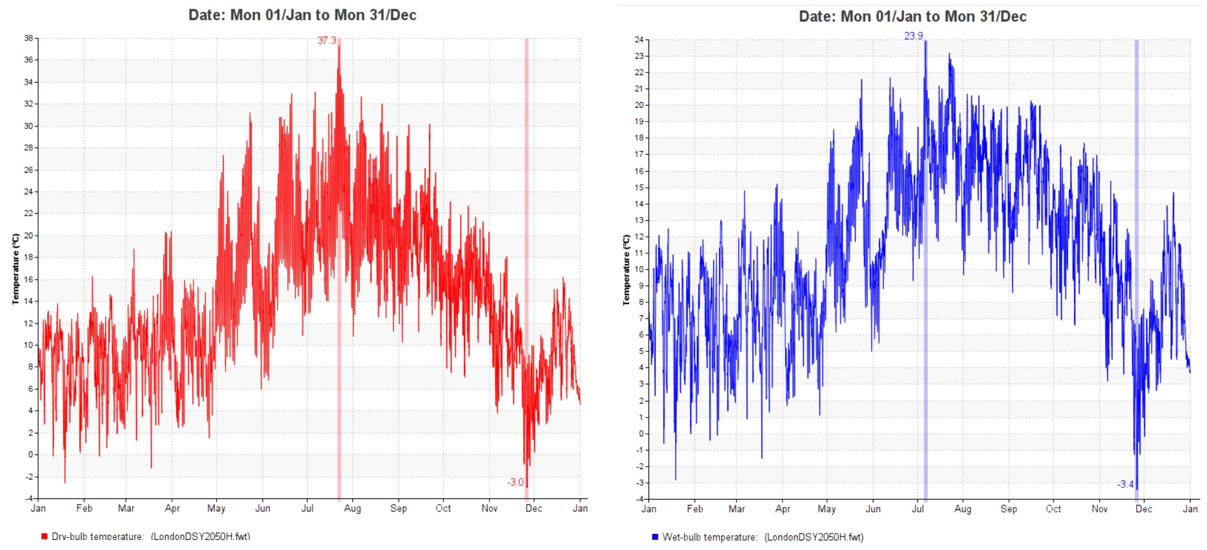


Figure 13: London DSY 2020 High dry-bulb and wet bulb temperatures profile.

6.3 Wind Analysis

Wind Analysis has been conducted for the blocks to assess the blocks that will benefit the most from consistent flow of natural ventilation. The below figures show the wind rose for the Hale Wharf development.

The annual prevalent wind direction is Southwest with average wind speed of 3 m/s. The Summer season shows the same pattern with average wind speed of 2.82 m/s.

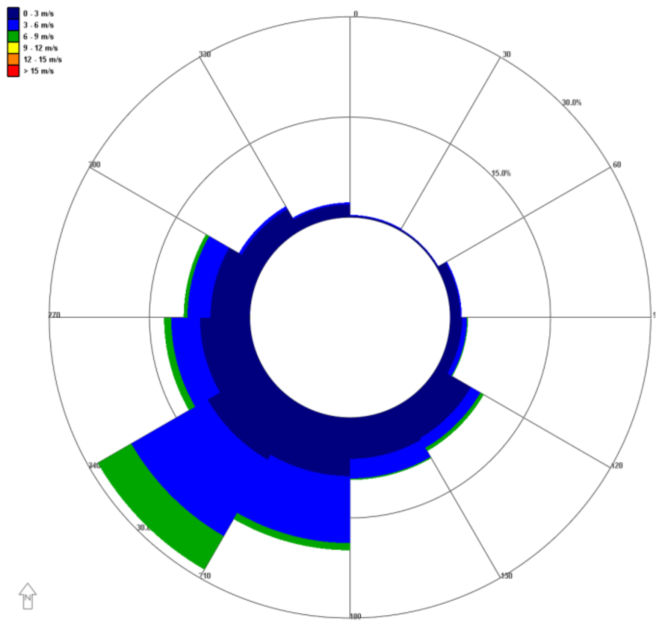


Figure 14: Winter Wind Rose

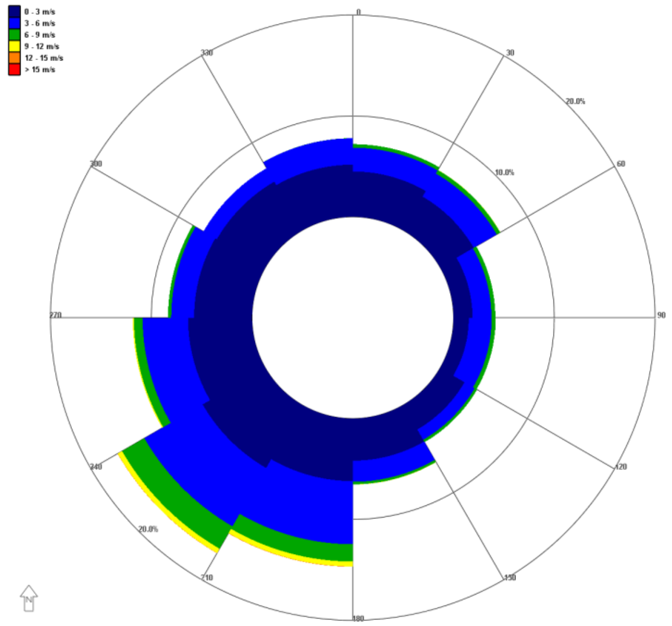


Figure 15: Summer Wind rose

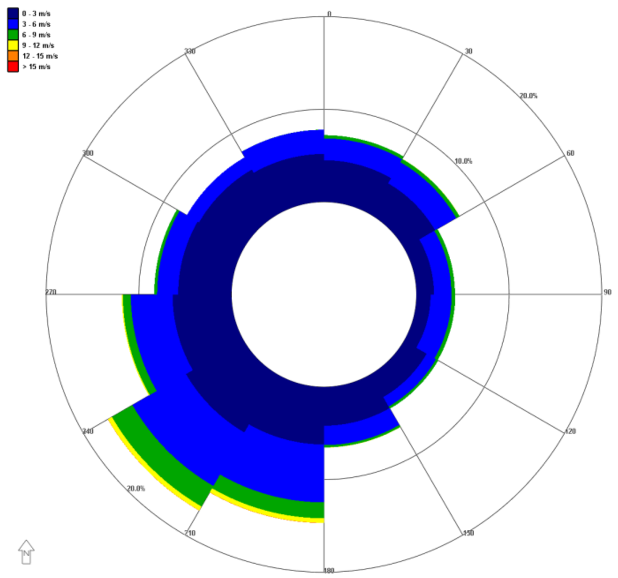


Figure 16: Annual Wind rose.

CFD analysis has been performed to estimate the air flow pattern around the building in such high building density area. The surrounding buildings affects the are flow around the building which will make the use of natural ventilations as main strategy for comfort cooling limited. Air quality and, privacy and noise ingress will be also other reasons to limit the efficiency of use of natural ventilation for comfort cooling.

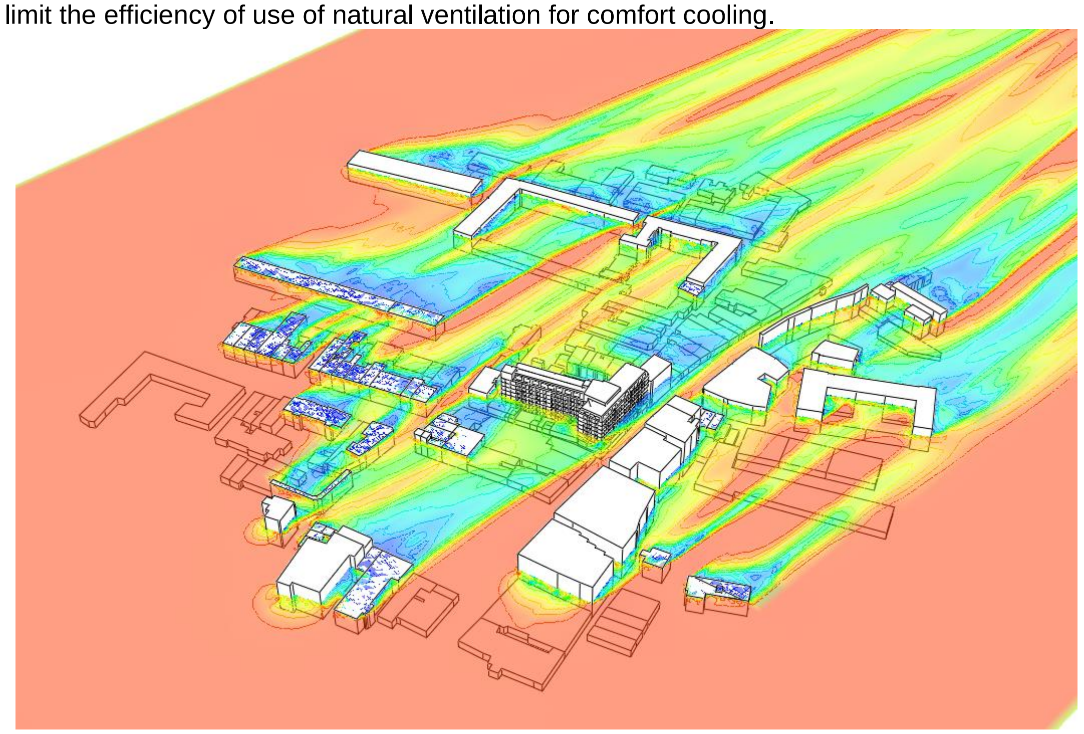


Figure 17: Air flow pattern around the building (Z-Axis)

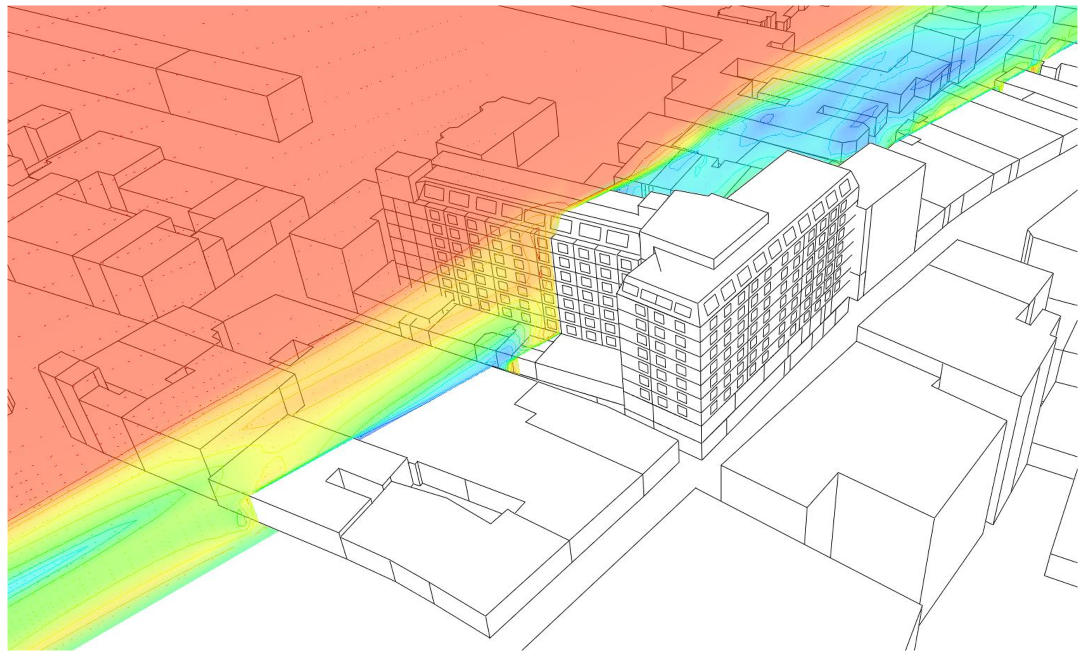


Figure 18: Air flow pattern around the building (Y-Axis)

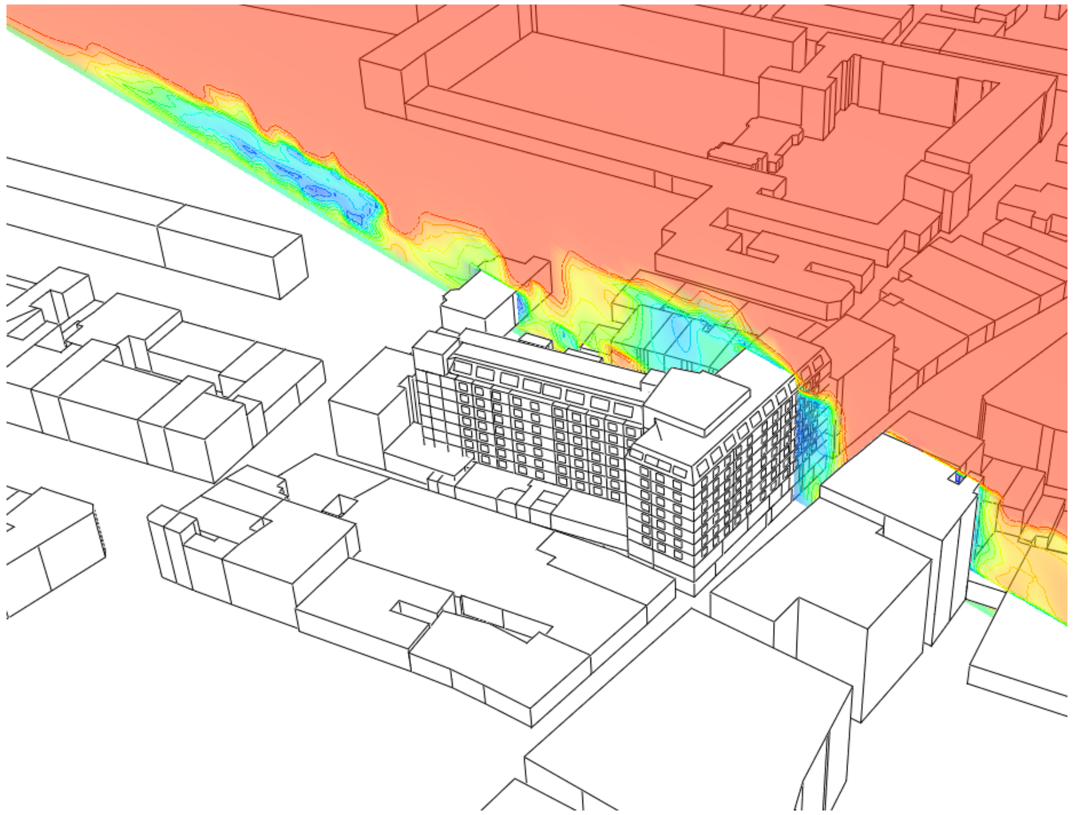


Figure 19: Air flow pattern around the building (X-Axis)

7 LIMITING SOLAR GAINS

Solar analysis has been conducted for the building to assess the building façade solar exposure. The results shows that east and West façade receives an annual incident solar energy of 730 Kwh/m^2/year. Same pattern for the South facade with annual incident solar radiation of 730 Kwh/m^2/year on the upper floor. The north façade has the least solar exposure with annual incident solar radiation of 320 Kwh/m^2/year.

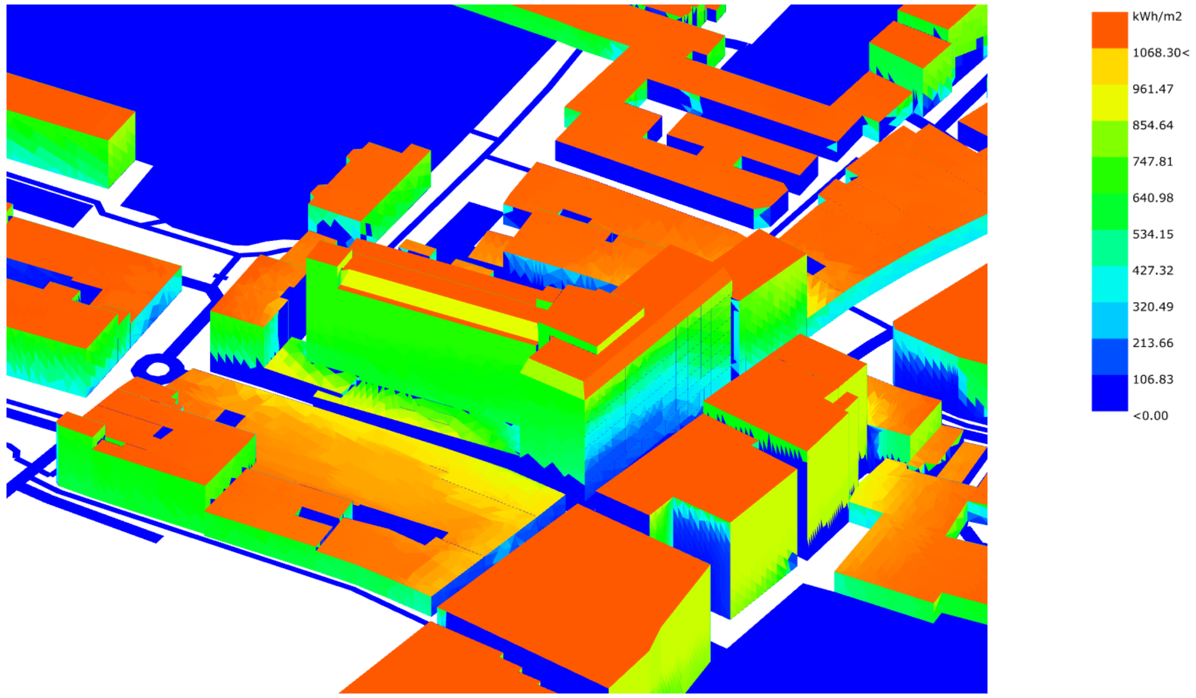


Figure 20: The Building Solar Exposure West and South facade.

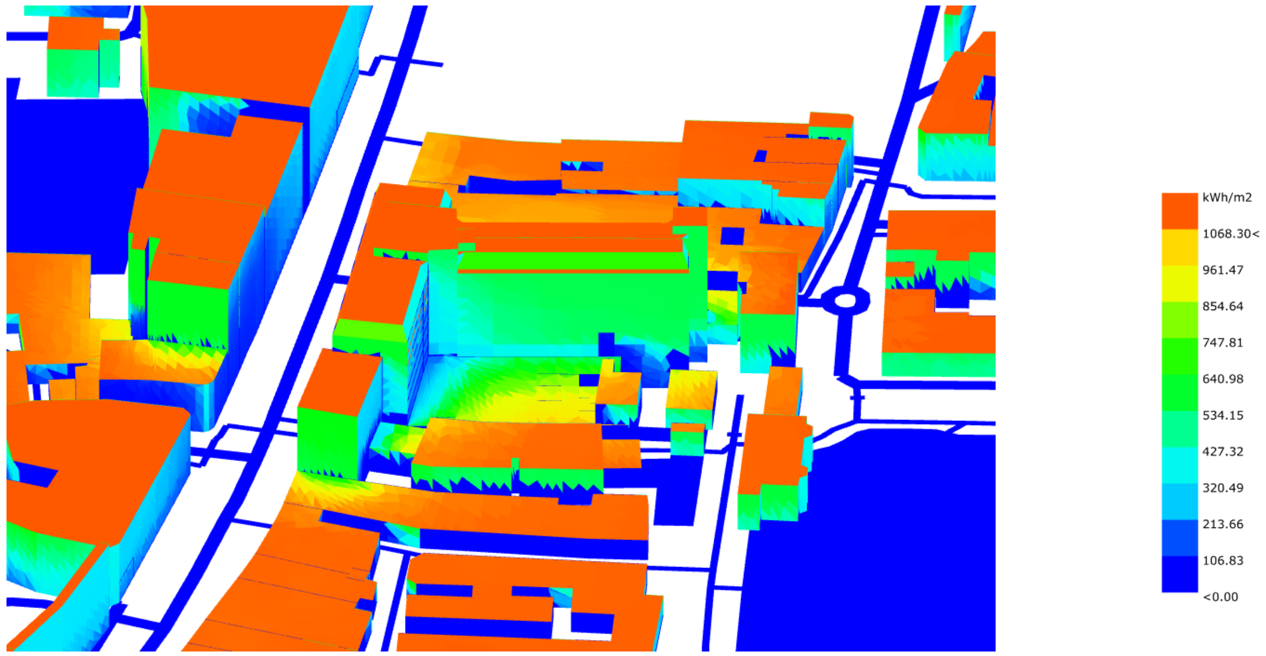


Figure 21: The Building Solar Exposure east facade.

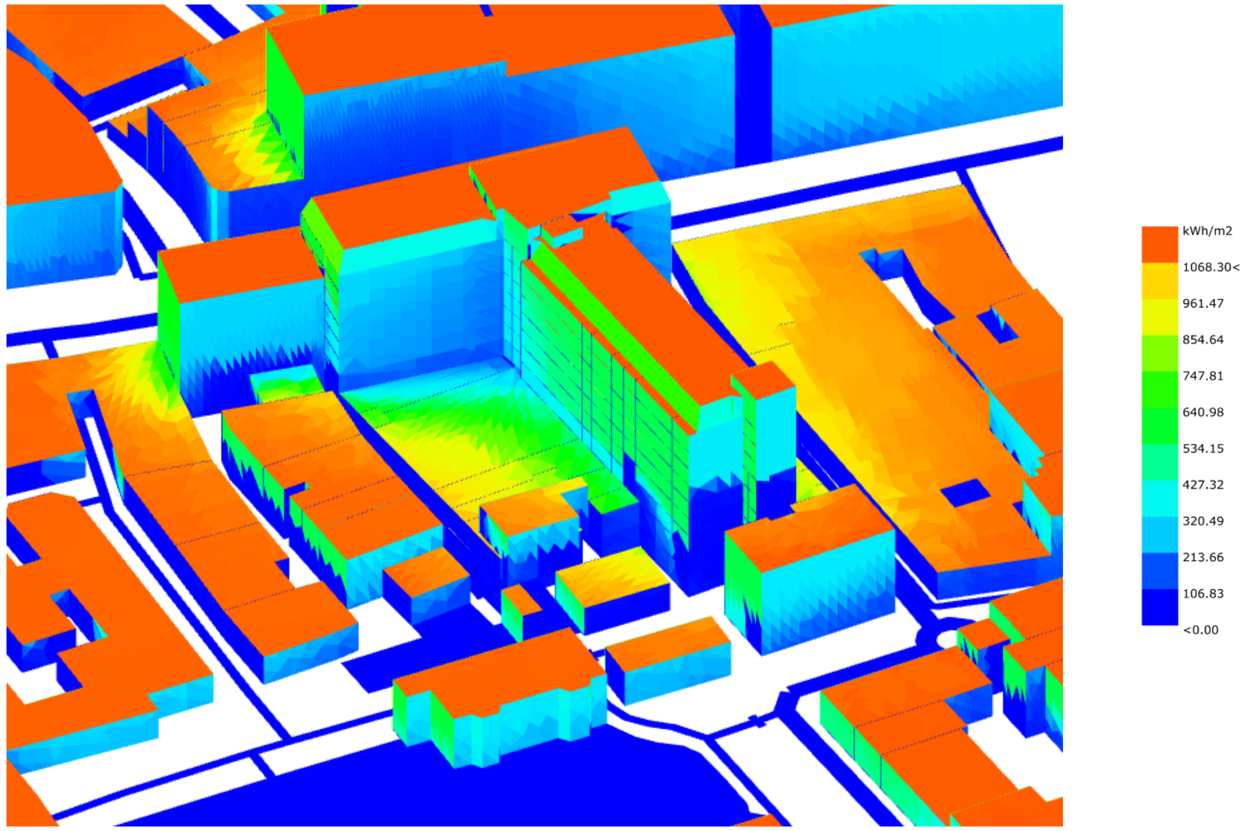


Figure 22: The Building Solar Exposure North and East facade.

The solar exposure has benefit of adequate day light for all façade spaces, however, it is main contributor for the cooling load. Since there are restrictions on windows which is not part of the project, practical solution to manage solar radiation and glare is internal blinds which building operators can adopt (if not already) to mitigate the solar gains. The analysis shows that blinds with opacity of 55% is adequate to pass Criterion 3 (Solar Heat gain limit) of part L which will be recommended benchmark performance.

8 REDUCING AND MANAGING BUILDING INTERNAL GAINS

As existing building, there is always opportunities for internal heat gain optimisation through the following:

4- Existing Control system to optimise energy use and avoid unnecessary use of internal heat gain sources (i.e. Automatic Switch off of unused Display screen, lights in well daylit areas, etc.)

5- Building users behaviour and awareness to minimise miscellaneous use heat loads.

6- Upgrading high heat dissipation internal heat gain sources with new technologies that dissipates less heats including lighting, ICT, etc.) This also relates to the overall energy efficiency of the building and not just the cooling and to be considered for the future upgrade works plans for the building.

9 PASSIVE DESIGN-NATURAL VENTILATION

The design approach for the First Avenue Building is to rely on cross flow natural ventilation opening on the both the West and East side. However, this should be attempted without compromising the thermal comfort of the users.

Accordingly, adaptive thermal comfort and overheating assessment has been conducted based on CIBSE TM 52 overheating and adaptive cooling criteria.

CIBSE TM 52 defines the limits of thermal comfort and avoiding overheating in European buildings.

CIBSE TM 52 sets three criteria which taken together, provide a robust yet balanced assessment of the risk of overheating of buildings in the UK and Europe. A room or building that fails any two of the three criteria is classed as overheating.

- DT is the difference between the space operative temperature and the outdoor temperature.
- The number of hours (He) during which DT is greater than or equal to one degree (K) during the period May to September inclusive shall not be more than 3 per cent of occupied hours.
- The hours during which the operative temperature exceeds the specified range within the occupied hours, weighted by a factor, is limited to 6-degree hours.
- To set an absolute maximum value for the indoor operative temperature the value of DT shall not exceed 4 K.

The below figure shows the comfort limits for naturally ventilated spaces as outlined by BS EN 15251 standard.

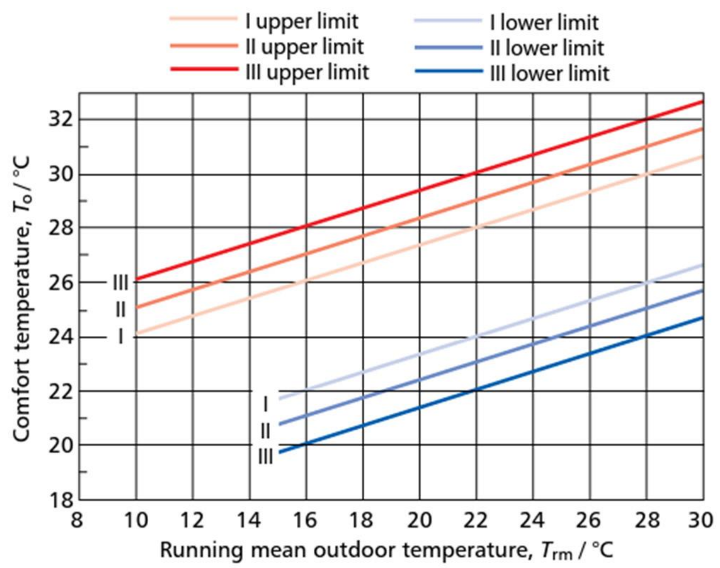


Figure 23: BS EN 15251 Adaptive comfort model.

The CIBSE TM 52 Extract shows the acceptable temperature range for different building categories with maximum acceptable exceedance of 4 ºC for existing buildings.

Table 2 Suggested applicability of the categories and their associated acceptable temperature range for free-running buildings and of PMV for mechanically ventilated buildings (from BSI, 2007). The CIBSE suggestion is that designers should aim to remain within the Category II limits.

Category	Explanation	Suggested acceptable range (K)	Suggested acceptable limits PMV
I	High level of expectation only used for spaces occupied by very sensitive and fragile persons	± 2	± 0.2
II	Normal expectation (for new buildings and renovations)	± 3	± 0.5
III	A moderate expectation (used for existing buildings)	± 4	± 0.7
IV	Values outside the criteria for the above categories (only acceptable for a limited periods)	>4	> 0.7

Figure 24: Acceptable temperate range for naturally ventilated spaces.

The below figures show the overheating risks in relation to the increase of the indoor temperature relative to the acceptable comfort temperature.

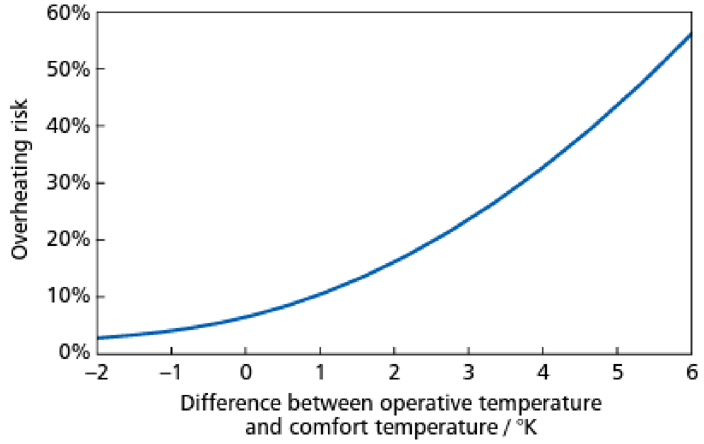


Figure 25: Risk of overheating in relation to operative temperature.

The analysis shows that without mechanical cooling, the building fails CIBSE TM 52 requirements.

Failed					
	Occupied days (%)	Criteria 1 (%Hrs Top-Tmax>=1K)	Criteria 2 (Max. Daily Deg.Hrs)	Criteria 3 (Max. DeltaT)	Criteria failing
	100	4.1	20	5	1 & 2 & 3

This verifies the CFD results which showed that the surrounding buildings affects the are flow around the building which will make the use of natural ventilations as main strategy for comfort cooling limited. Air quality and, privacy and noise ingress will be also other reasons to limit the efficiency of use of natural ventilation for comfort cooling.

10 MECHANICAL VENTILATION

10.1 Thermal Comfort Criteria

PMV is an index that aims to predict the mean value of votes of a group of occupants on a seven-point thermal sensation scale. Thermal equilibrium is obtained when an occupant's internal heat production is the same as its heat loss. The heat balance of an individual can be influenced by levels of physical activity, clothing insulation, as well as the parameters of the thermal environment. For example, thermal sensation is generally perceived as better when occupants of a space have control over indoor temperature (i.e., natural ventilation through opening or closing windows), as it helps to alleviate high occupant thermal expectations on a mechanical ventilation system.
Within the PMV index, +3 translates as too hot, while -3 translates as too cold, as depicted below.

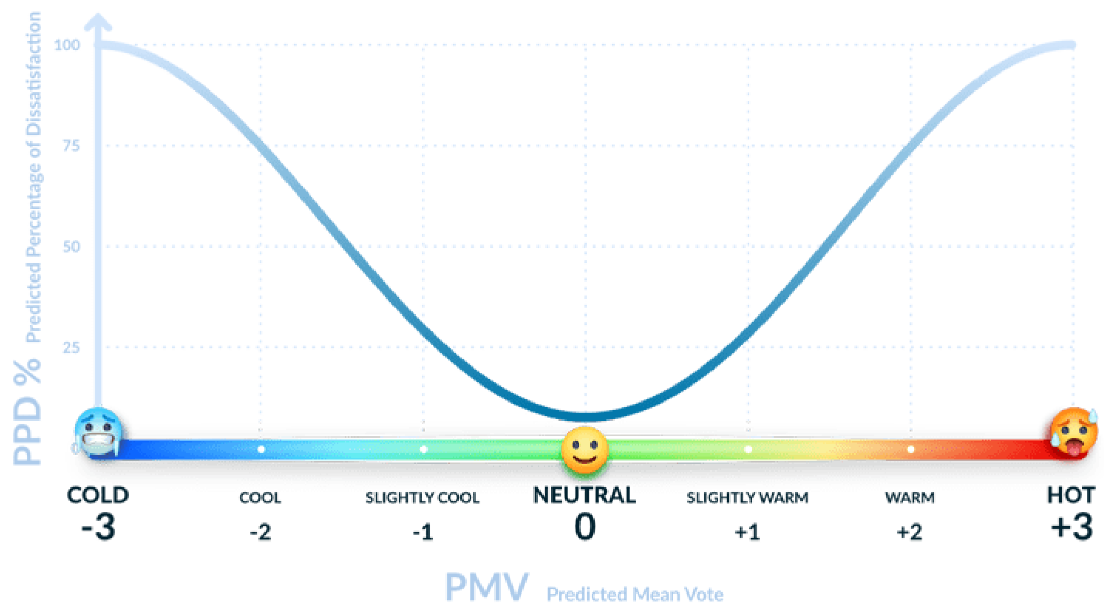


Figure 26:PMV/PPD Model

Different methods outlined in the ASHRAE 55 and ISO standards for certain types of environments can be used to assess and gather information for various combinations of metabolic rate, insulation, temperature, airspeed, mean radiant temperature, and relative humidity that factor into PMV.
In order to compute PMV, the simulated temperature and airspeed velocity (i.e., the ASHRAE/ISO standards recommend making an adaption for speeds above 0.2m/s) of a given environment are used as inputs. These variables, along with given inputs for clothing insulation, relative humidity, and mean radiative temperature provide the basis to calculate PMV.

Through PMV, we can predict the thermal sensation of a population, but this does not paint the whole picture. We also need to consider the level of satisfaction of the occupants in a space, to get a more holistic idea of if and how thermal comfort can be achieved. For this, Fanger developed another equation to relate the PMV to the predicted percentage of dissatisfied (PPD).

Once the PMV is calculated, the PPD, or index that establishes a quantitative prediction of the percentage of thermally dissatisfied occupants (i.e., too warm, or too cold), can be determined. PPD essentially gives the percentage of people predicted to experience local discomfort. The main factors causing local discomfort are unwanted cooling or heating of an occupant's body. Common contributing factors are drafts, abnormally high vertical temperature differences between the ankles and head, and/or floor temperature.

The below table shows the range of the PMV for the building spaces based on DSY 2020H weather file.

PMV occupied hours max / min	Analytical method (pass / fail)
0.2/-0.3	Pass

For future weather file, the below table shows the range of the PMV for the building spaces based on DSY 2050H weather file considering 10% increase in the Current chiller capacity which maintains the comfort levels as the current weather files of DSY 2020H.

PMV occupied hours max / min	Analytical method (pass / fail)
0.2/-0.3	Pass

11 FUTURE PRROFING AND CARBON ANALYSIS

A predictive assessment has been conducted for the building cooling demand requirements at 3 stages as follows:

1- 1997: where the building refurbishments took place

2- 2024: Current Cooling demand prediction

3- Future Cooling Demand after 20 years (Chiller Lifespan)

The results shows that load will increase 10-15% in 2045 compared to 2024 given that building followed the same energy use patterns with no upgrades or energy uplifts occurred in the 20 years after the chiller installation.

Thus, increasing the chillers capacity will provide operational future proofing against the extreme weather conditions including intense heatwaves as well as sustaining comfortable conditions inside the building throughout the lifetime of the chiller's operation.

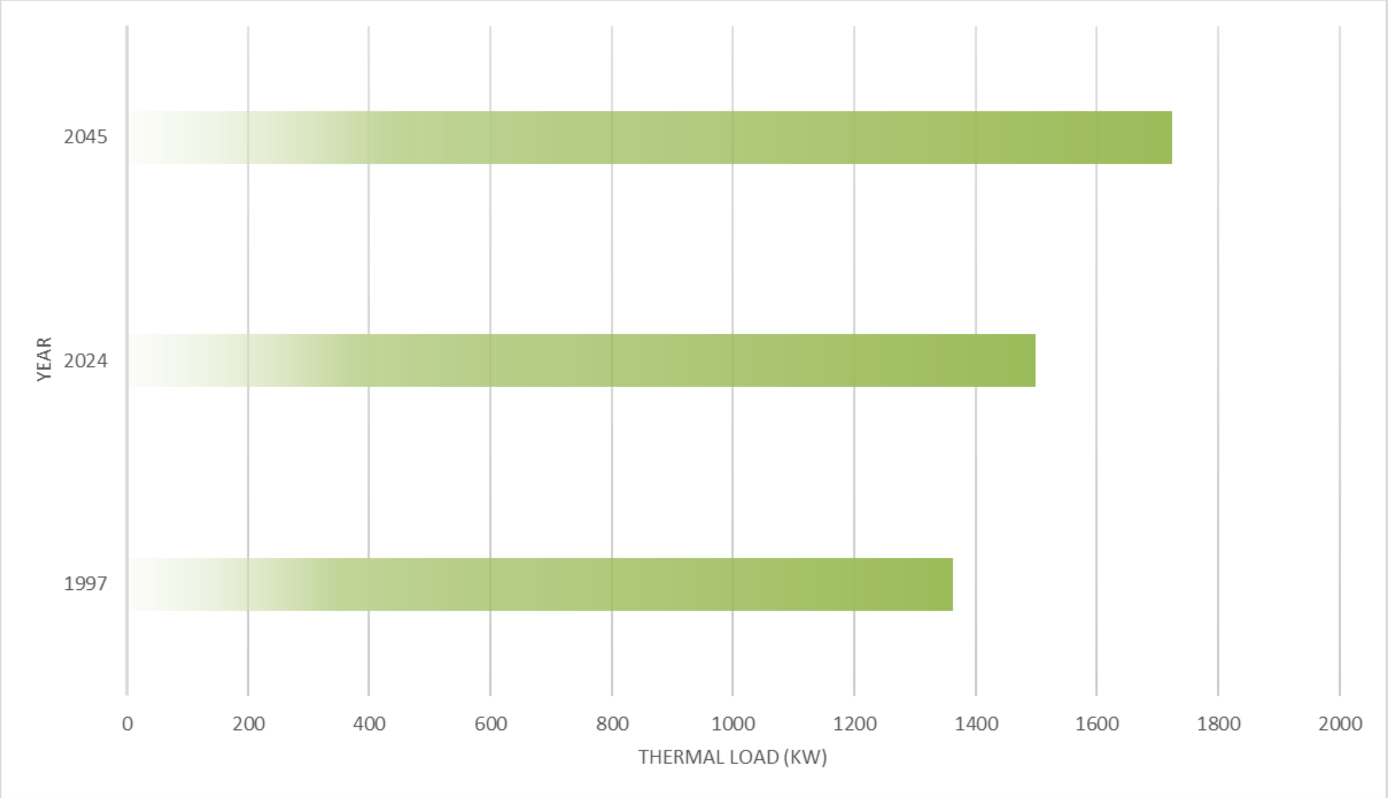


Figure 27: Cooling Demand (kW)

Considering the degradation of the existing chiller efficiency since installation date and use of obsolete high GWP refrigerant, the chiller upgrades with new high efficiency with lower GWP refrigerants could save estimate of 42.5% of carbon emissions pending final selection of chillers.

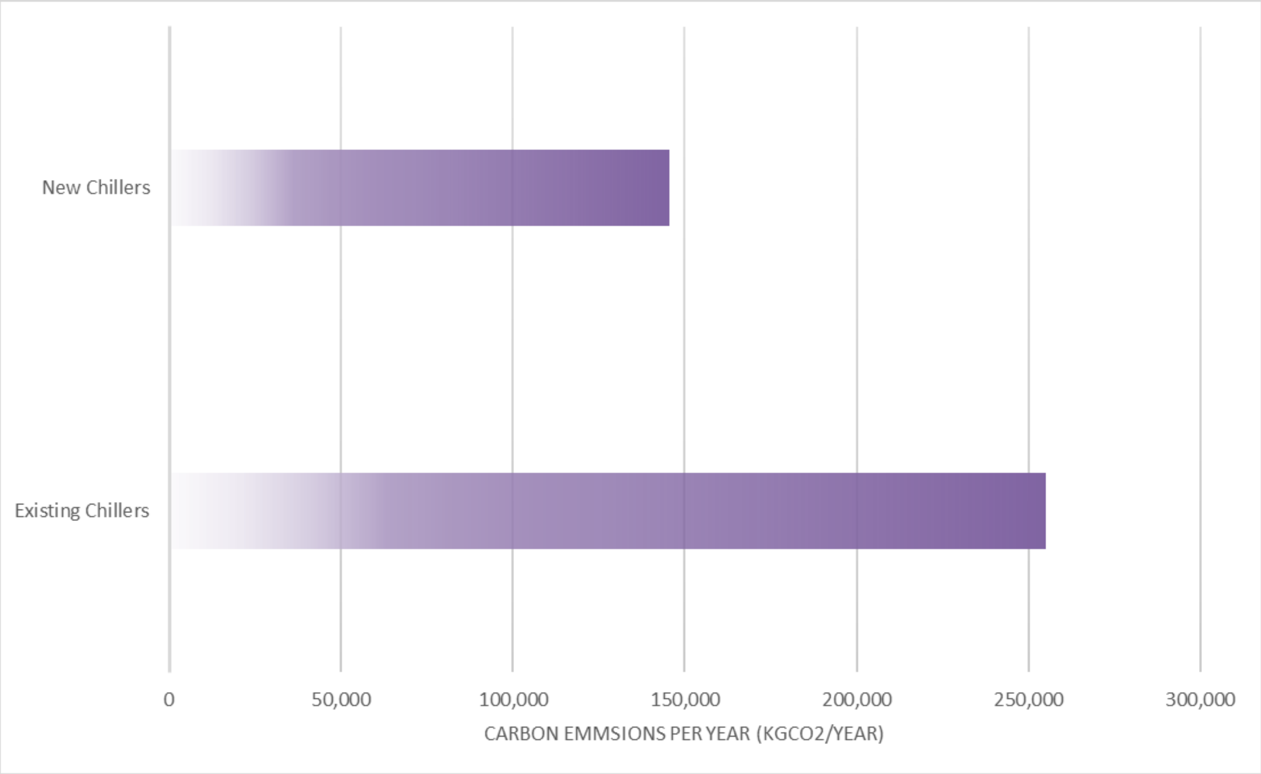


Figure 28: Annual Carbon emissions predictions.