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Investigating Thermal Performance and Climate Resilience of the Winter Garden in an Educational Building

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Abstract: The GSK Carbon Neutral Laboratory for Sustainable Chemistry is one of the UK's first laboratories to achieve carbon neutrality and net-zero carbon emissions. In this paper, the researchers investigate the risk of overheating and climate resilience of the winter garden in the GSK building. The study was conducted using qualitative and quantitative methods via on-site measurements, occupant surveys, and dynamic building simulations using IESVE. The initial findings indicated that overheating was a significant issue during the summer season in both the current climate and future climate scenarios. Design recommendations to mitigate overheating included optimising the extensive glazing and improving ventilation and shading devices. The study concludes that optimising extensive glazing is essential to address overheating in similar building types.

Keywords: Climate Resilience, Thermal Comfort, Overheating Risk, Passive Design

1. Introduction

The UK has experienced significant climate change over the years; the constant rise in temperature is leading to the risk of overheating in buildings (Climate Change Committee, 2022). Overheating can affect the health and well-being of occupants (Lomas et al., 2018), especially in learning environments; it is imperative to design low-energy buildings allowing them to maintain good thermal comfort for occupant performance and reduce energy consumption (Nayak et al., 2022).

To combat climate change, reducing emissions is essential. The GSK Laboratory (BREEAM outstanding and LEED platinum certified) is the first carbon-neutral laboratory in Nottingham, that utilises the latest technology to offset carbon emissions accumulated during construction over the next 25 years (University of Nottingham, n.d.). The building uses natural materials, such as Cross-Laminated Timber (CLT), the thermal properties of which reduce the building's heating demand. The winter garden is designed to capture heat during the winter season and acts as a comfortable multi-use communal space for the occupants (UKGBC, 2021).

Zhu and Wang (2021) investigated the thermal performance of the winter garden in the current climate scenario and found that the space is uncomfortable in summer and winter. This research aimed to investigate the thermal performance of the winter garden in the current climate, and future 2050 and 2080 climate scenarios. The objective of this research was to assess the overheating criteria and test passive design solutions to check for climate resilience.

2. Building Design

The GSK Laboratory is located within the University of Nottingham’s Jubilee Campus. Nottingham has a temperate climate as per the Köppen Climate Classification: Cfb; the drybulb temperatures range from 2°C to 21°C throughout the year (Met Office, n.d.). The building is oriented on the east-west axis with a tilt of 17°N, maximizing solar gains in the south. With a total area of 4,500m^2, the two-floor facility houses offices, laboratories, study spaces, a winter garden, and mechanical rooms (TRADA, 2019).

The winter garden, as shown in Figures 1 and 3, is a large sun space with a dimension of 4x11m and glazing on three facades, with the longer side taking advantage of southern orientation. Built outside the thermal envelope, it uses a double-glazed timber wall for passive heating and cooling. The cross-ventilation strategy was used with roof apertures that automatically open when the temperature exceeds 25°C. Figure 2 shows other technical design features and sustainable strategies used.

Figure 1: A ground floor plan of the GSK Laboratory showing the winter garden marked in red and other spaces (Estates office University of Nottingham, 2023)

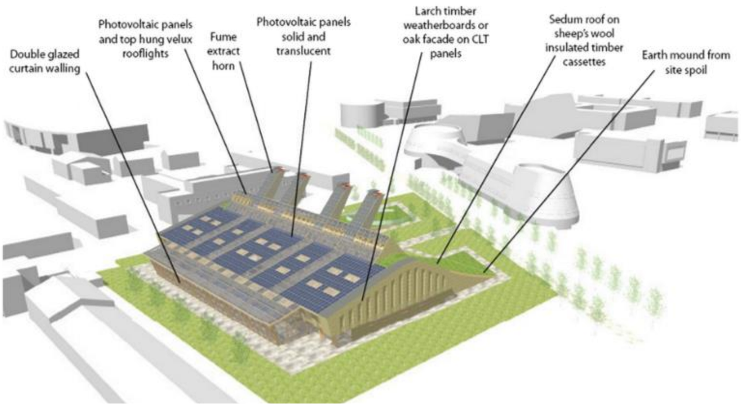

Figure 2: Technical design features and sustainable strategies of the GSK Carbon-Neutral Laboratory (Poliakoff et al., 2018)

Figure 3: View inside the winter garden

3. Methodology

The three-stage investigation utilised both quantitative and qualitative analyses. The first stage involved on-site measurements of daylight and temperature in the winter garden to study the effects of daylighting on thermal perception. An occupant survey (14 questions, 10 participants from various roles) was conducted to gather user perceptions of indoor air quality, temperature, and daylighting in the winter garden. The second stage focused on the thermal performance and the risk of overheating as per CIBSE Guide A using a digital model created in IESVE, considering current and future climate scenarios (2050 and 2080). The final step investigated three passive retrofit strategies informed by results from the previous stage. The strategies included reducing glazing, adding vertical shading and the addition of operable windows in the south facade.

4. Model Assumptions

Table 1 summarises the assumptions considered for the base case modelling.

Table 1: Assumptions for base case modeling on IESVE

COMPONENT/PROFILE		**VALUE/DESCRIPTION**	**REFERENCE**
Climate data Nottingham Watnall, UK	Current year	Design Summer Year (DSY) current year	Weather data files UKCIP
	2050	DSY 2050-low, 2050-high (carbon emissions)	
	2080	DSY 2080-low, 2080-high (carbon emissions)	
U Value		External wall and roof: 0.15 W/m² External Glazing and skylight: 1.6 W/m²	Zhu and Wang, (2021)
Occupant profile and gains		37 people, Gain: 85 W/person Profile: 8 am to 6 pm (Monday to Friday)	Author investigation
Ventilation profile (Natural ventilation)	External window	Bottom hung window aperture 50% Summer: windows open during occupied hours. Winter: closed	Author investigation
	Skylight	Will start to open when the indoor temperature exceeds 25°C	
Infiltration		0.25 ACH (on continuously)	Zhu and Wang, (2021)
Lighting gain and profile		15 W/m², Profile: 8am to 6pm	Author investigation
Comfort range assumed for investigation		20-25°C (broader range of 21°C - 23°C (summer) and 19°C -21°C (winter) respectively.	CIBSE, 2015, pg. no.1-8

5. Results and Discussion

5.1. On-Site Measurements

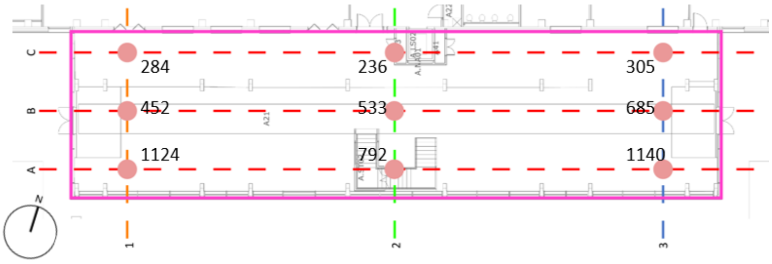

Figure 4: Plan of winter garden showing recorded Illuminance (lux) levels.

During the site visit in early March, lux levels and internal temperature of the winter garden were measured using a digital multimeter at various points, as mentioned in Figure 4. The internal temperature recorded was between 16.9°C and 17.5°C, while the external temperature was 6°C, cloudy with minimal sun exposure. Although the temperature falls just below the assumed comfort criteria, it indicates that the glazing of the winter garden was efficiently harnessing solar gains to keep the indoors comfortable even in the absence of active heating.

The lux levels near windows were higher (900-1500), compared to the middle (400-700) and innermost areas (200-300). Overall, the maintained illuminance of around 300 lux (CIBSE, 2015, p. 1-8) required for exhibition space was achieved throughout the room. Higher lux levels indicate better thermal perception (Chinazzo et al., 2019), which could result in a preferable indoor environment to outdoor due to the increased sunlight incident on the large glazing area.

5.2. Occupant Survey

The survey revealed that 70% of occupants were satisfied with the natural lighting, as shown in Figure 5. Based on on-site data and survey results, it can be concluded that the winter garden has sufficient daylighting to ensure comfortable performance of varied tasks for its occupants.

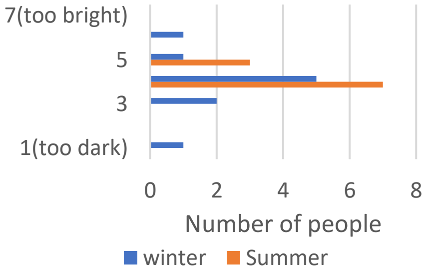

Figure 5: Daylighting levels in summer and winter

Figure 6 depicted that during the summer months, all the participants felt that the space was uncomfortably warm, likely due to excessive solar gains and rising outdoor temperatures. While in winter, 77.8% of occupants felt that the space was too cold, making the space unusable. Over 50% of the users noted that the winter garden became excessively hot during summer and uncomfortably cold during winter. These observations suggest that there might be issues with ventilation and solar gains from extensive glazing in summer. Unfortunately, the on-site data is not suitable to compare and conclude as it was taken for only one day but serves as an observation.

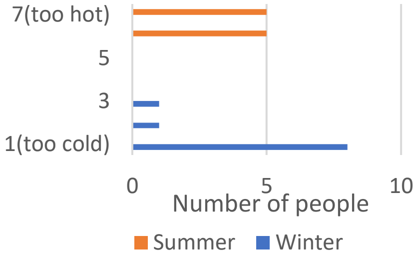

Figure 6: Room temperature in summer and winter

5.3. Dynamic Building Simulation

The comfort range mentioned in Table 1, was considered for simulations for peak summer (May to August) and winter months (December to February). The overheating criteria were assessed based on the CIBSE benchmark for educational buildings, where overheating is considered to occur when 1% of occupied hours exceeds 28°C temperature annually (CIBSE 2015, Table 1.8, p. 1-12).

5.3.1. Base Case

Initial manual calculations for daylight factor yielded a value of 12.3%, and further testing in IESVE resulted in 17.2% as the average daylight factor with higher lux levels near the window. This result aligns with the on-site measurements and occupant survey indication of satisfying levels of daylight for occupants.

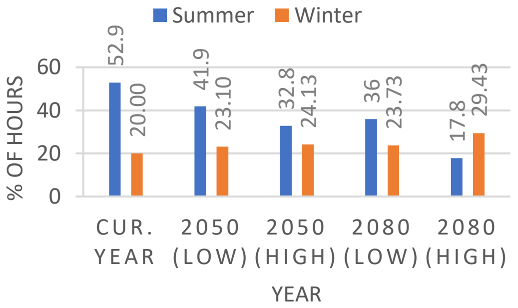

Figure 7: Percentage of comfort hours during summer and winter for the current year, 2050, and 2080 (Base case)

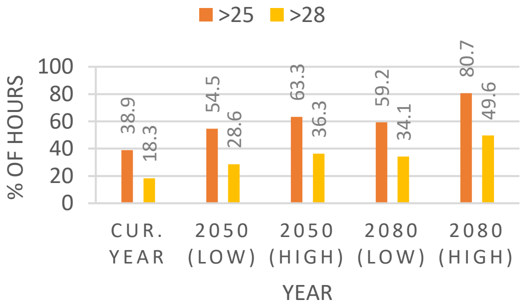

Figure 8: Percentage of hours above 25°C and 28°C during peak summer months for the current year, 2050, and 2080 (Base case)

In terms of thermal comfort, only 52.9% of hours met the criteria for summer comfort based on the current climate, whereas 18.3% of the hours were overheated, which correlates to the data obtained from the occupant's survey (Figures 7 & 8). In the future climate scenarios, the percentage of comfort hours in summer decreases to 32.8% while only 17.8% in 2050 and 2080 high, respectively (Figure 7). The percentage of hours above 28°C doubled in 2050, rising to 36.3% and reaching 49.6% in the 2080 high scenario (Figure 8). Possible factors include extensive glazing, absence of shading in the east and west facades, and insufficient air exchange. The data highlights a potential overheating issue rising in an alarming state, which would make the winter garden inhabitable in future if not resolved sooner. During winters, the comfort hours are lower at only 20% for the current year; this could be attributed to factors such as a larger living space and decreased daylight hours caused by the sun's shallower angle. On the contrary to summer, the winter future climate scenarios predict an increase in the percentage of comfortable hours due to rising global temperatures (Figure 7).

5.3.2. Passive Design Strategies

Three passive design solutions were tested individually informed by Overheating: Approved document O (2022) for mitigating overheating risk and design principles as shown in Table 2.

Table 2: Summary of possible design solutions

CASE NAME	NO.	DESCRIPTION
Base case	BC	The current as-built form of the building
Glazing reduction	C1	30% reduction in glazing of a 1m wide strip running the three facades by reducing transmittance from 75% to 50%
Vertical fins	C2	Addition of 1m wide vertical fins on the east and west facades with a tilt of 18°N
Operable window	C3	Addition of 4 operable windows (10m² to 20m²) on the south façade and all skylights changed to operable windows (6m² to 15m²)
Combination	C4	Compilation of all cases(C1+C2+C3)

Figure 9 summarises all the cases of overheating risk. In case 1 (C1), reducing the transmittance level of glazing to 50%, minimised the percentage hours of overheating from 18.3% to 1.5% in the current scenario and significantly reduced to 7.3% and 14.6% in 2050 and 2080 high compared to 36.3% and 49.6% from the base case scenario, respectively. This supports that glazing percentage is an important key aspect in building design when mitigating the risk of overheating.

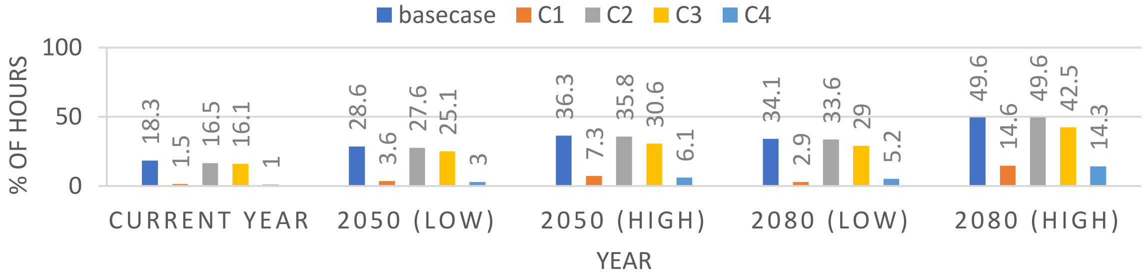

Figure 9: Percentage of hours above 28°C in base case, case 1, 2, 3 and 4 for current year, 2050 and 2080 high and low carbon emissions

In case 2 (C2), the addition of vertical shading in the east and west reduced the overheating by only 9.8% in the current scenario from the base case and with lesser impact in the future climate scenario. The reason for the lesser impact with shading could be attributed to the vertical fins designed effectively shade only 50% of the time during morning and afternoon. Similarly, in case 3 (C3), improving the aperture conditions resulted in a 12% decrease in the current year. Furthermore, it resulted in a decrease of approximately 15.7% and 14.3% in 2050 and 2080-high, respectively, when compared to the base case. This reduction was slightly higher than that achieved in C2.

In case(C4), with all the cases mentioned above combined, the risk of overheating was completely mitigated in the current scenario, with just 1% of the occupied hours going over 28°C, which passes the CIBSE criteria for overheating. In the 2050 and 2080 years, the percentage of hours above 28°C is reduced by almost 83.2% and 72% when compared to the base case scenario, respectively. Even though C4 eradicates the risk of overheating in the current scenario, there is a risk of overheating in 2080 high, which can be uncomfortable for users. However, this can be mitigated with further research and testing out solutions, such as replacing the existing double glazing with triple glazing with reduced U-values and g-values.

6. Conclusion

The study aimed to investigate the thermal performance of the winter garden in current and future climate scenarios (2050 and 2080) and used three methods, namely on-site measurements, occupant survey and dynamic simulations. Daylighting assessments revealed a sufficient amount of daylight (17.2% daylight factor) to perform the required task in all three methods. However, survey results displayed issues with thermal comfort, with 100% of occupants feeling hot in summer and 70% feeling cold in winter. Further testing was carried out to investigate the above using IESVE. The modelling results also indicated a situation of overheating (above 28°C), with 18.3% in current scenarios gradually rising to 36.3% in 2050 high and 49.6% in 2080 high. To mitigate overheating risk, four strategies were tested: reducing the glazing area, adding vertical fins, increasing openable areas, and combination of all three. Reducing glazing proved highly effective, by completely eradicating the risk of overheating in the current year (only 1% of occupied above 28°C) and considerably reducing overheating hours by 80% in 2050-high 71% in 2080-high. This highlights the crucial role of glazing in designing a climate-resilient building where the amount of glazing could either be beneficial or detrimental.

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