Conservatory Fabric Performance Report

Quality Assurance

Report version: V4

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Executive Summary

This report presents the findings of a study investigating the fabric performance of a typical conservatory, with a focus on how different ceiling configurations impact thermal efficiency. The study evaluated the performance of four distinct ceiling scenarios:

- **Scenario 1**: Glass Ceiling.
- **Scenario 2**: Polycarbonate Ceiling.
- **Scenario 3**: Polycarbonate Ceiling with C.H.R.I.S. System.
- **Scenario 4**: Glass Ceiling with C.H.R.I.S. System.

For each scenario, the following measurements were carried out:

- Heat Transfer Coefficient (HTC).
- U-value.
- Airtightness.
- Thermographic survey.

The investigation revealed that installing the C.H.R.I.S. system reduced the Heat Transfer Coefficient (HTC) of the conservatory by **30.8% and 28.8% for the Glass and Polycarbonate ceilings**, respectively.

Further, in terms of U-value, uninsulated Polycarbonate outperformed uninsulated Glass in terms of ceiling U-value. The addition of the C.H.R.I.S. System significantly improved ceiling U-values, with similar results for both configurations. In percentage terms, from each base case, **the percentage reduction was 79% for Glass and 82% for Polycarbonate**.

Airtightness testing identified areas of air leakage, which were confirmed by the thermographic survey. These tests highlighted specific areas within the conservatory's fabric, such as around the ceiling, the insulation around the main door, and the floor, where potential heat loss and air leakage were evident.

Overall, the ceiling insulation proved effective in enhancing the energy efficiency and thermal performance of the conservatory, demonstrating its potential as a valuable solution for improving the building's fabric performance.

Contents

Nomenclature

Symbol	Description
UoS	The University of Salford
EH 2.0	Energy House 2.0 testing facility
LBU	Leeds Beckett University
SAP	Standard Assessment Procedure
RdSAP	Reduced Data SAP
A_{sw}	Solar aperture (m^2)
HTC	Heat Transfer Coefficient (W/K)
H_{tr}	Heat Transfer Coefficient (W/K)
H_v	Ventilation Heat Transfer Coefficient (W/K)
n	Ventilation rate
psi	linear thermal heat transmittance
Q	Power input (W)
q	Heat flow rate (W/m^2)
q_{sw}	Solar irradiance (W/m^2)
U	U-value (thermal transmittance) (W/m^2K)
R	Thermal resistance (m^2K/W)
K	Kelvin= Unit measurement of temperature
T_e	Chamber temperature (External temperature)
T_i	Indoor temperature (Internal temperature)
ΔT	Internal to external temperature difference (K)
λ	Thermal conductivity (W/mK)
HFP	Heat Flux Plate
R_{se}	External surface resistance
R_{si}	Internal surface resistance
AP_{50}	Air Permeability at 50 Pascal
AP_4	Air Permeability at 4 Pascal
Q_{50}	Air leakage rate at 50 Pascal
Q_4	Air leakage rate at 4 Pascal
N_{50}	Air change per hour (1/h) at 50 Pascal
N_4	Air change per hour (1/h) at 4 Pascal

1. Introduction

This technical report reports on the fabric performance of a typical conservatory built by CI Group and measured under controlled conditions at the Energy House 2.0 (EH 2.0) research facility at the University of Salford (UoS). The primary focus of the report is to evaluate the effectiveness of a ceiling insulation solution, the "C.H.R.I.S. System," in enhancing the conservatory's overall performance.

The "C.H.R.I.S. System" is a unique insulation solution introduced by CI Group, with detailed information provided in subsection 2.1.3 – Table 2. The investigation evaluated the conservatory's performance under four different ceiling scenarios:

- **Scenario 1** conservatory with Glass Ceiling.
- **Scenario 2** conservatory with Polycarbonate Ceiling.
- **Scenario 3** conservatory with Polycarbonate Ceiling + C.H.R.I.S. System.
- **Scenario 4** conservatory with Glass Ceiling + C.H.R.I.S. System.

This investigation aimed to analyse the effectiveness of these different ceiling setups and the overall design in achieving the intended performance outcomes. Moreover, our investigation into the fabric performance of the conservatory included investigating the following:

- **Heat Transfer Coefficient** (HTC) Measured according to the 2013 Leeds Beckett Whole House Heat Loss Test Method (Co-heating) [1].
- **Airtightness Testing (Fan Pressurisation Tests)** according to ATTMA Technical Standard L1 [2].
- **In-situ Heat Flux and U-value Measurement;** in line with ISO 9869 [3].
- **Thermographic and air leakage survey.**

The parameters measured in this report cover the fabric's performance and will provide an overview of the overall performance of the conservatory. The parameters measured and the methodologies for conducting these measurements are outlined in section 3 of this report.

2. Conservatory Description

The structure under investigation is a typical conservatory with a floor area of 9 m² and a volume of 22.6 m³. The fabric performance of the conservatory was investigated by the EH 2.0 research team. Figure 1 shows the case study conservatory.

Figure 1. Overview of the case study conservatory

2.1. Fabric

The fabric details of the conservatory are outlined in the following subsections:

2.1.1. Floor

The floor area of the conservatory is 9 m² built on a 101 x 50 mm timber stud base, infilled with 100 mm PIR board and covered with an 18 mm OSB board. We do not have a design U-value figure for the floor.

2.1.2. Walls

The table below shows the conservatory wall details.

Table 1 Wall Details of the conservatory

Component	Layers	Provided U-value (W/m²K)
Glazing	- 4/20/4 Double Glazed - External Pane: Pilkington Optifloat, 4 mm thick. - Internal Pane: Pilkington KS, 4mm thick. - Gas Fill Details; Argon 90%	1.219
PVC Framing	-	-

French Door	- 4/20/4 Double Glazed - External Pane: Pilkington Optifloat, 4 mm thick. - Internal Pane: Pilkington KS, 4 mm thick. - Gas Fill Details; Argon 90% - Glazing u-value: 1.219 W/(m²·K)	1.219

2.1.3. Ceiling

We tested four different ceiling scenarios; these are outlined in the table below.

Table 2 Ceiling Construction Across the Different Scenarios

Scenario	System	Layers	Provided U-value (W/m²K)
1	Glass Roof	**Measured** 1- Glass – 4 mm 2- Argon – 16 mm 3- Glass – 4 mm	2.7
2	Polycarbonate Roof	**Measured** 1- Polycarbonate with air channels – 16 mm	1.5
3	Polycarbonate Roof + C.H.R.I.S. System	**Provided by CI** 1- Internal Cladding 2- Air Gap - 22 mm 3- C.H.R.I.S. - 7 mm 4- Air Gap - 22 mm 5- Polycarbonate - 16 mm[a]	0.43
4	Glass Roof + C.H.R.I.S. System	**Provided by CI** 1- Internal Cladding 2- Air Gap - 25 mm 3- C.H.R.I.S. - 7 mm 4- Air Gap - 25 mm 5- Glass – 24 mm[b]	0.46

[a] The value provided by CI Group was 25 mm, however the research team measured this as 16 mm.
[b] The value provided by CI Group was 4 mm, indicating single glazing. However, the research team measured this as 24 mm (4 mm Glass, 16 mm Air Gap, 4 mm Glass), in line with Scenario 1.

3. Methodology

This section presents the test conditions, monitoring equipment and the methods used to measure the fabric thermal performance of the conservatory.

3.1. Steady-state Thermal Performance Measurements

All the tests and measurements of the conservatory were carried out within the environmental chambers of Energy House 2.0. The chamber's HVAC system was set to maintain 5 °C during the test days, while the indoor temperature was maintained at 20 °C. Figure 2 below illustrates the average temperatures in the UK according to RdSAP10, 2024 [4]. These temperatures were used to provide a representative external temperature of the United Kingdom during the winter months (December to February).

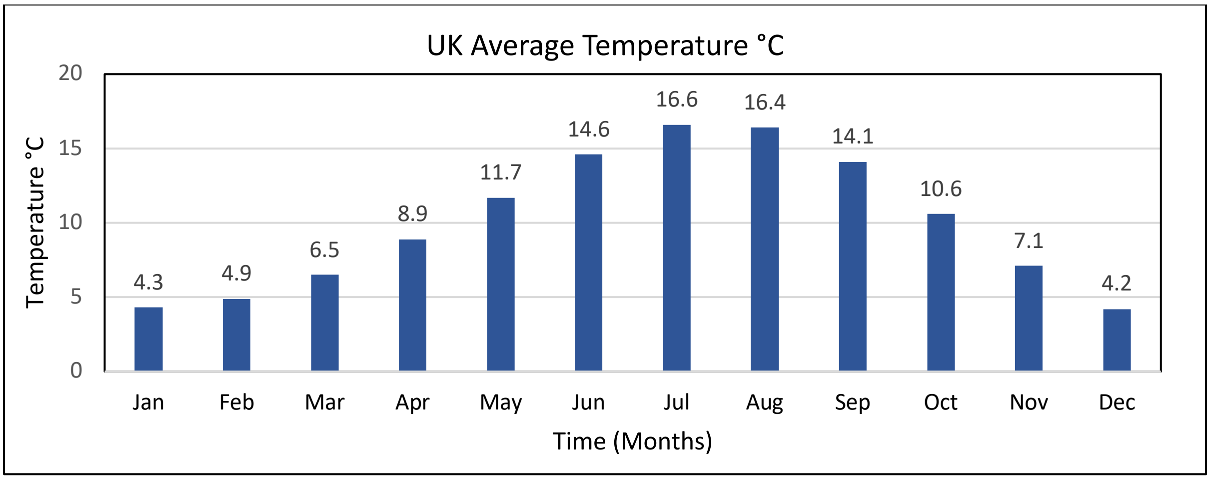

Figure 2 Average Monthly U.K. Temperature [5]

During the steady-state tests, the conservatory was maintained at 20 °C throughout using electric resistance heaters connected to PID controllers with PT-100 RTD temperature sensors.

3.2. Energy House 2.0 Monitoring Equipment

The findings provided in this report are based on measurements obtained using the equipment listed in

Table 3 below. Measurements were recorded at one-minute intervals by the EH 2.0 monitoring system.

Table 3: Measurement Equipment Used in the conservatory Performance Tests.

Measurement	Equipment	Uncertainty[c]	Ref.
Power input	LoRaWAN Milesight WS523	±1%	[6]
Room air temperatures	hygroVUE 10 (20 to 60 °C)	±0.1 °C	[7]
Chamber air temperatures	hygroVUE 10 (–40 to 70 °C)	±0.2 °C	[7]
Internal air temperatures	Type-T thermocouple[d]	±0.1 °C	-
Heat flux density	Hukseflux HFP-01 heat flux plate	±3%	[8]
Air permeability (@ 50 Pa)	Retrotec 5000 Blower Door System [e]	±2.5%[f]	[10]
Air permeability (@ 50 and 4 Pa)	Pulse 2.0 Air Permeability Testing Equipment	±1%	[11]
Thermography	FLIR E96	±2%	[12]

3.3. Building Performance Evaluation Methods

The methods used to evaluate the fabric performance of the conservatory are outlined in this subsection.

3.3.4. Heat Transfer Coefficient (HTC) Measurement

The HTC of the conservatory was determined using the co-heating test method, as outlined in the 2013 Leeds Beckett Whole House Heat Loss Test Method [1]. The co-heating test was conducted within the Energy House 2.0 climate chamber, which allowed for controlled external conditions to be maintained at 5 °C. The internal temperature was sustained at 20 °C throughout the test, with the heating energy consumption being measured over the test duration. The test data was then analysed to calculate the HTC, providing an accurate measure of the overall thermal performance of the building using the following equation; [1].

$$\boldsymbol{Q} + \boldsymbol{A_{sw}}.\boldsymbol{q_{sw}} = (\boldsymbol{H_{tr}} + \boldsymbol{H_v}).\Delta\boldsymbol{T} \qquad \text{Eq. 1}$$

Where:

$\boldsymbol{Q}$ = Power Input (W)
$\boldsymbol{A_{sw}}$ = Solar Aperture (m^2)
$\boldsymbol{q_{sw}}$ = Solar Irradiance (W/m^2)
$\boldsymbol{H_{tr}}$ = Transmission Heat Transfer Coefficient (W/K)
$\boldsymbol{H_v}$ = Ventilation Heat Transfer Coefficient (W/K)
$\Delta\boldsymbol{T}$ = Internal to external temperature difference (K)

In the EH 2.0 test facility, the terms A_{sw} and q_{sw} can be removed from the whole house energy balance, as solar systems were not used in this test and no natural sunlight enters the

[c] uncertainties were taken from supplier data sheet
[d] Energy house 2.0 in house calibration process
[e] Certificate of calibration: UK_52369, UK_52343
[f] The sheltered test environment allows measurement uncertainty to exclude wind-based errors, the ±2.5% uncertainty value applies only to test apparatus

chamber. Thus, the equation is rearranged to show how, at steady state, the HTC can be calculated from measurements of Q and ΔT:

$$HTC = \frac{Q}{\Delta T} \qquad \text{Eq. 2}$$

Where:

$HTC = H_{tr} + H_v$ (W/K)
Q = power input (W) [g]
ΔT = average internal air temperature (T_i) minus average chamber air temperature (T_e).

During the co-heating test, the temperatures on both sides of the fabric remained at a steady state for 4 days.

3.3.5. U-value Measurement

The main aim of this research is to investigate the impact of four different ceiling scenarios on the thermal performance of the conservatory. The U-value measurements were carried out using heat flux sensors and temperature probes, under ISO 9869 [3], for the following elements:

- ***Floor***: measurements were taken at four different locations on the floor and one additional measurement on the timber stud.
- **Wall:** measurements were taken at six different locations; on PVC panel, PVC frame, two on the glass, one on the window and one on the sloped glazing.
- ***Insulation around the door:*** measurements were taken at four different locations; one on the French door, two on the insulation around the door, and one on the timber stud between the insulation panels.
- **Roof:** during the four different scenarios, measurements were taken at seven different locations; three on the middle panel, one on each panel, and two more measuring the PVC frames holding the roof panels.

The figures below show the locations of the HFPs on the different elements of the conservatory.

[g] Q is based on the total cumulative energy input to the conservatory over 24 hours. Refer to Annex B for details of the HTC uncertainty calculation.

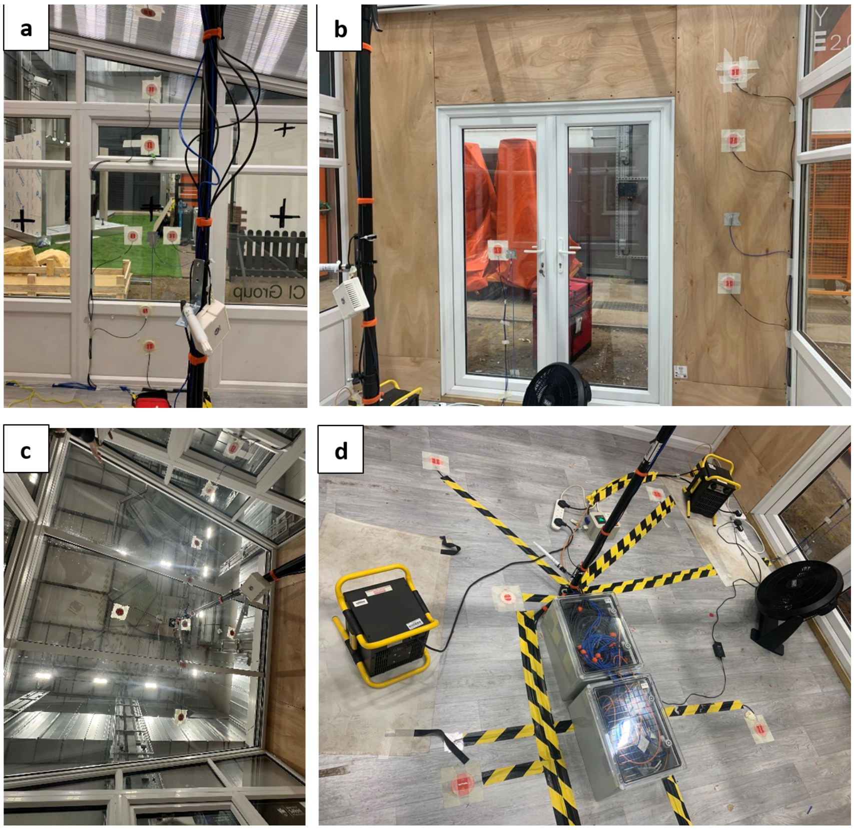

Figure 3. HFP's Locations; (a) Glazing and PVC panel, (b) Insulation and Door, (c) Ceiling and (d) Floor

3.3.6. Airtightness Testing

Airtightness testing was performed using two test methods:

- Blower door test, following the ATTMA Technical Standard L1 [2].
- Pulse Test [13].

Both methods are recognised air pressure testing methodology under both Part L1A building regulations [14] and PAS 2035 retrofit guidelines [15].

3.3.7. Thermographic Survey

A thermographic survey was conducted in conjunction with the depressurisation phase of the blower door test (AP = 50 Pa and AP = -50 Pa) to identify potential thermal bridging and areas of air leakage. The survey was performed using a FLIR E96 thermal imaging camera, which captured infrared images of the building's exterior and interior. The images were analysed to pinpoint areas where insulation might be lacking or where air leakage was compromising the building's thermal performance.

4. Results

4.1. Steady-State Conditions

The figures below illustrate the rate of change in the temperature difference (T_i-T_e), the average heat flux, and the percentage rate of change during the same period. All HFPs during all four test scenarios had similar behaviour.

It can be seen from the figures below that steady conditions were reached for more than 72h for both the temperature and the average heat flux with less than ±0.2 °C and ±0.1 W/m² change for both temperature and heat flux, respectively.

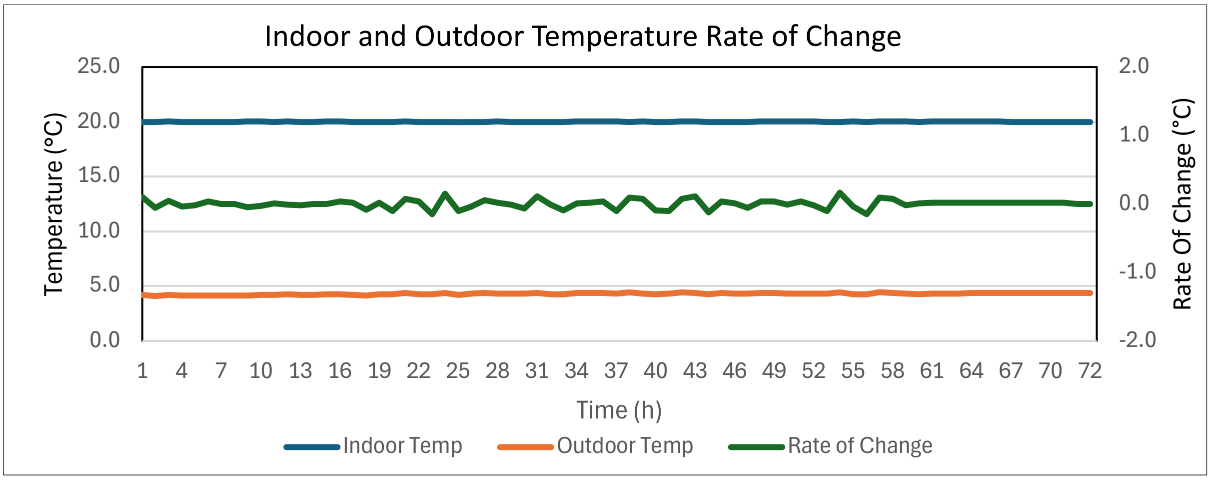

Figure 4 Rate of Temperature Change (°C) During the Steady-state Measurements.

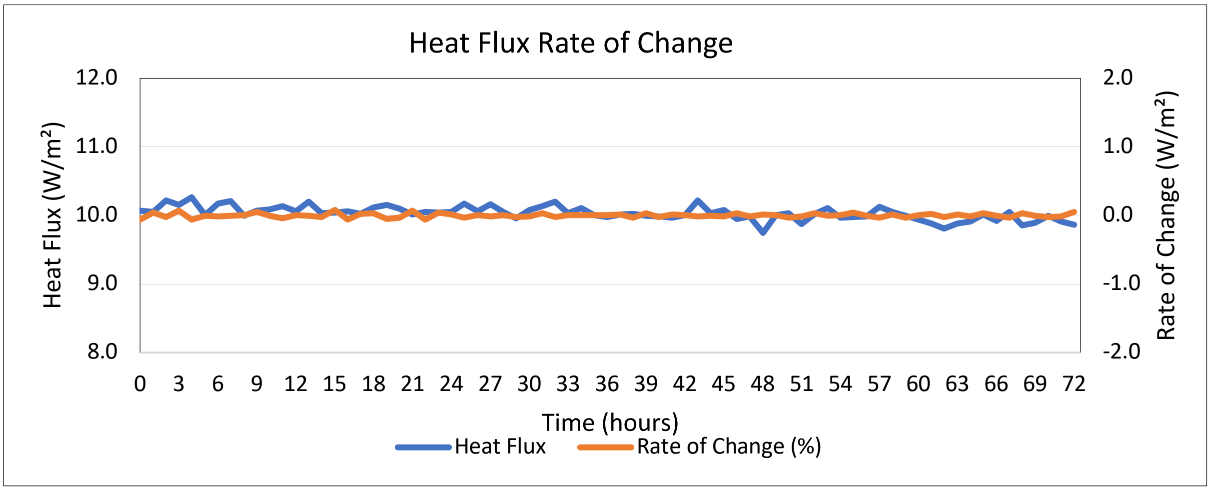

Figure 5. Rate of Heat Flux Change (W/m²) During Steady-state Measurements

4.2. Heat Transfer Coefficient (HTC) Results

The Co-heating test was carried out for an average of 4 days for each test scenario, the chamber temperature was set to 5 °C and the indoor temperature to 20 °C.

The HTC results are as follows:

- **Scenario 1** (Glass roof); the HTC is **72.1 (±0.7) W/K.**
- **Scenario 2** (Polycarbonate) the HTC was **69.9 (±0.6) W/K.**
- **Scenario 3** (Polycarbonate Roof + C.H.R.I.S. System) the HTC is **49.8 (±0.8) W/K.**
- **Scenario 4** (Glass Roof + C.H.R.I.S. System) the HTC is **49.9 (±0.8) W/K.**

Figure 6 below compares the HTC results during the 4 different scenarios.

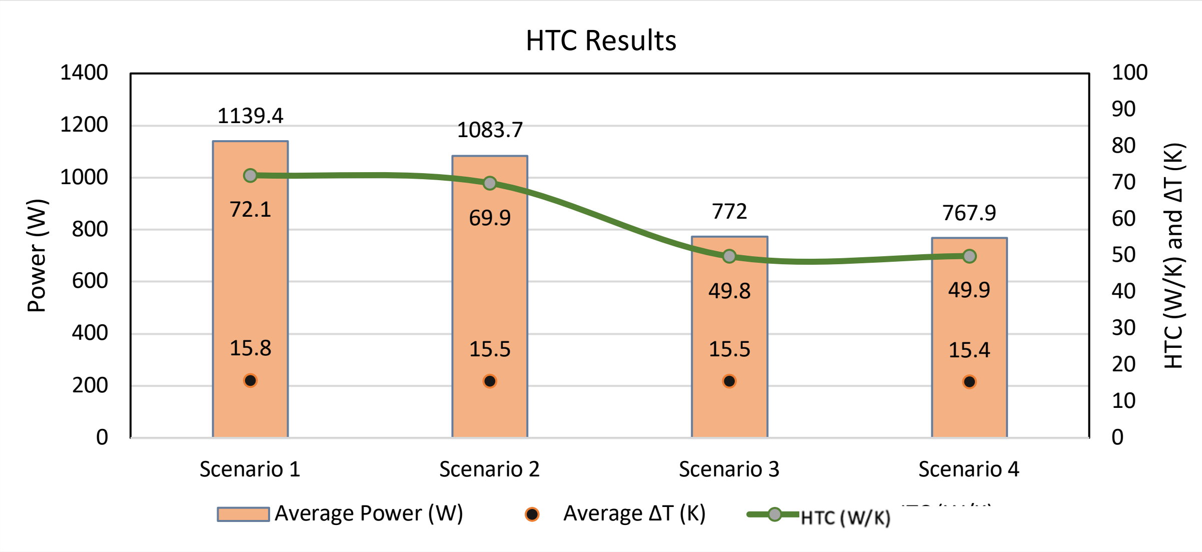

Figure 6. Heat Transfer Coefficient (HTC) Results.

From Figure 6, we observe that the addition of the C.H.R.I.S. System in Scenarios 3 and 4 significantly reduces the HTC by approximately 30%, compared to Scenarios 1 and 2. To maintain an indoor temperature of 20°C in a 5°C environment, the power input requirements are as follows:

- **Scenario 1** requires ~1139.4 W to maintain the 15 K temperature difference, reflecting an HTC of 72.1 W/K.
- **Scenario 2** requires ~1083.7 W to maintain the 15 K temperature difference, reflecting an HTC of 69.9 W/K.
- **Scenario 3** requires ~772.0 W to maintain the 15 K temperature difference, reflecting an HTC of 49.8 W/K.
- **Scenario 4** requires ~767.9 W to maintain the 15 K temperature difference, reflecting an HTC of 49.9 W/K.

4.3. U-value Measurements

In-situ U-value measurements were undertaken on selected thermal elements in the conservatory following ISO 9869 [3].

4.3.1. Floor

In-situ U-value measurements of the floor were taken at five locations. The average calculated U-value of the floor (assuming timber stud is 3.9% of the floor) was **0.23 (± 0.02) W/m²K**.

4.3.2. Wall

In situ U-value measurements of the wall were taken at nine locations. The average calculated U-value for each of the elements measured were as follows:

- PVC (below Glass), measured at one location, the calculated U-value is **1.03 (±0.05) W/m²K**.
- PVC Stud (Frame), measured at one location; the calculated U-value is **1.32 (±0.03) W/m²K**.
- Glass (below the window), measured at two locations; the calculated U-value is **1.41 ± 0.03 W/m²K**.
- Window, measured at one location; the calculated U-value is **1.70 (±0.07) W/m²K.**
- Insulation around the French door, measured at three locations; the calculated U-value (assuming timber stud is 3.9% of the insulation), is **0.19 (±0.02) W/m²K**.

4.3.3. French Door (Centre Pane)

In situ U-value measurements were taken on the centre pane of the French door. The average calculated U-value was **1.30 (±0.05) W/m²K**.

4.3.4. Ceiling

The U-value of the ceiling was measured for four different scenarios (see section 1) the measurements were taken at five different locations with two additional HFPs measuring the PVC stud. The results (assuming the PVC frame is 3.9% of the ceiling), are as follows:

- ***Scenario 1*** *(Glass Ceiling);* the average calculated U-value is **2.60 (±0.16) W/m²K.**
- ***Scenario 2*** *(Polycarbonate Ceiling);* the average calculated U-value is **2.20 (±0.13) W/m²K.**
- ***Scenario 3*** *(Polycarbonate Ceiling + C.H.R.I.S. System);* the average calculated U-value is **0.47 (±0.02) W/m²K.**
- ***Scenario 4*** *(Glass Ceiling + C.H.R.I.S. System);* the average calculated U-value is **0.48 (±0.02) W/m²K**.

Figure 7 compares the ceiling U-value during the four different scenarios.

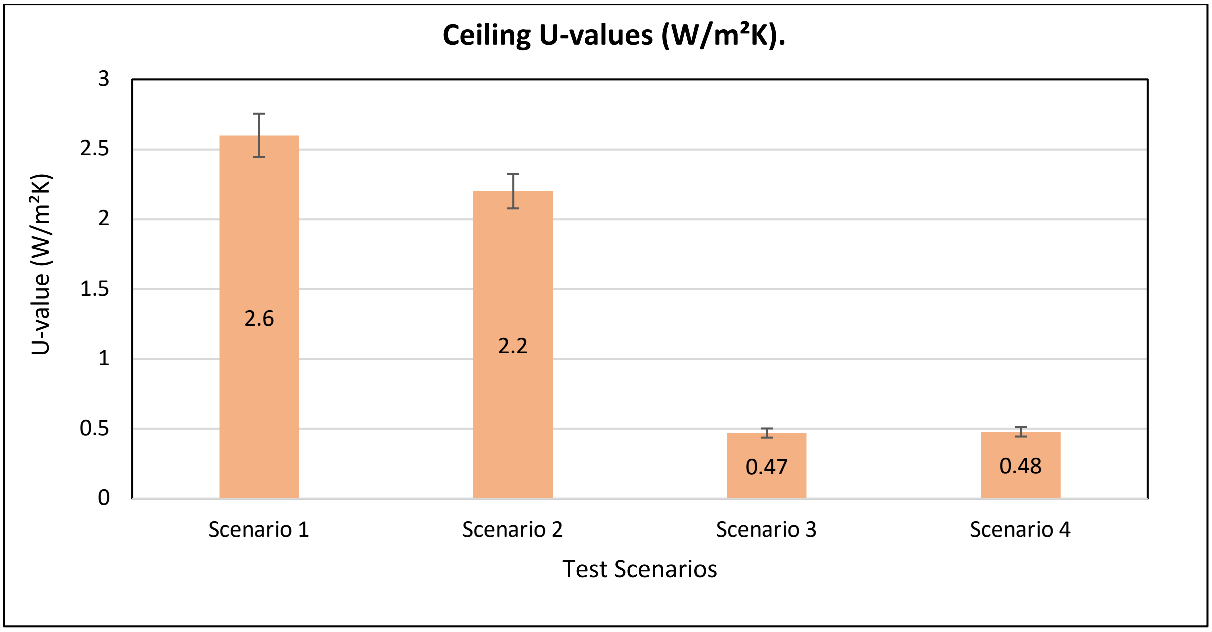

Figure 7 Ceiling U-value Across the Different Test Scenarios

4.4. Airtightness and Ventilation

Figure 8 below provides the AP_{50} value measured using both, the blower door and the Pulse test. Both tests were carried out under the same conditions, 5 °C for the chamber temperature and 20 °C for the indoor temperature.

Figure 8 below provides an AP50 comparison between the four different test scenarios.

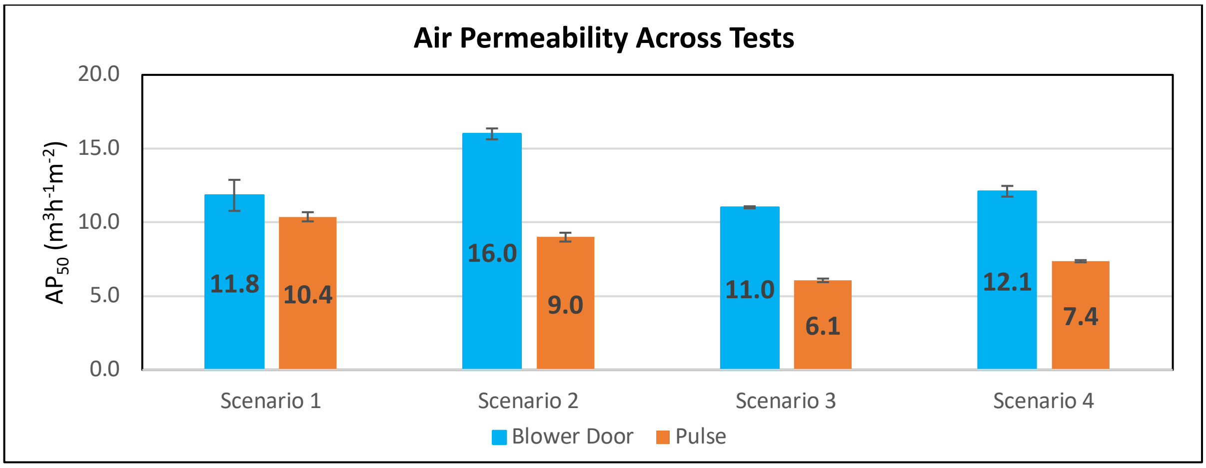

Figure 8 Compares AP50 Across Test Scenarios Using Blower Door and Pulse Test

Figure 8 compares the air-tightness performance of the conservatory across the four different scenarios, using both the blower door and Pulse methods. The highest AP50 value was recorded during Scenario 2 (Polycarbonate), due to gaps in the roof installation, which was particularly evident during the blower door pressure phase (see Figures 9 and 10). Generally, the blower door results are higher than those from the Pulse test. This disparity is due to the conservatory's construction, which becomes more apparent under the abnormal pressure of 50 Pa. These conclusions are supported by the thermography survey results, which will be discussed in later sections of this report.

Figure 9 Show Sealant Disparity Across Different Areas of the Ceiling (More Visible During Scenario 2)

Figure 10 Disturbance to Floor Covering During Airtightness Testing

Note: As observed in the figures above and noted during the blower door test, the high pressure associated with the blower door created abnormal conditions within the conservatory. These conditions included noticeable movement of the floor and ceiling, which we believe led to inflated AP50 results and introduced additional air leakage patterns that are not typically present under normal conditions. Given these factors, we recommend using the Pulse Test results instead, as we believe they provide a more accurate representation of the building's air tightness in this case.

4.5. Thermography

In conjunction with the blower door test, a thermographic investigation was performed on the conservatory. A pressure differential of -50 Pa was maintained while a thermographic survey of the interior spaces was undertaken. The thermographic survey of the exterior of the building was conducted during the pressurisation test with a pressure differential of 50 Pa. It should be noted that conducting thermography on glass is challenging due to its high reflectivity, low emissivity, transparency to infrared radiation, and susceptibility to environmental reflections, which can result in inaccurate temperature readings.

The results of the thermographic survey for each test scenario are illustrated in the figures below.

4.5.1. Scenario 1 (Glass Ceiling).

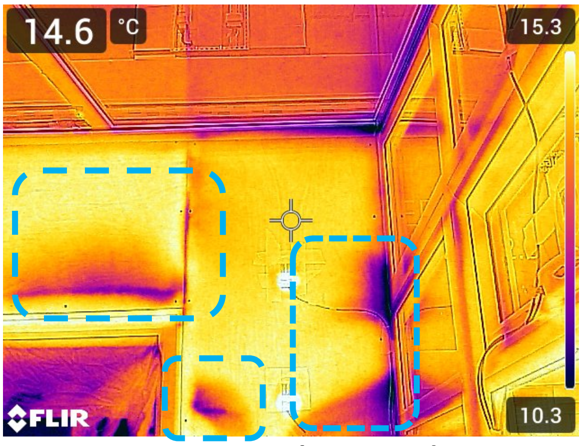

Figure 11 Insulation Under Depressurisation Test-Interior View

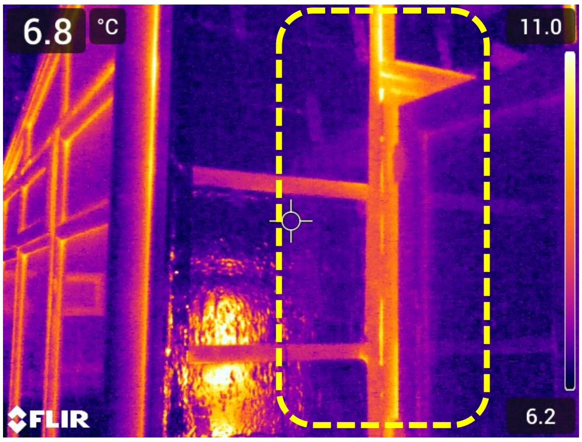

Figure 12 Insulation Under Pressurisation Test-Exterior View

The figures 11 and 12 above show the insulation around the main door. Cold areas (blue colour) and patterns of air movement can be seen around the ceiling behind the wall (between the insulation and outer wood board) and the timber frame. This indicates a deficiency in the insulation, thermal bridges and potential air leaks from these areas.

Figure 13 Floor Under Depressurisation Test

Figure 14 Ceiling Under Depressurisation Test

Figures 13 and 14 above show the interior space of the conservatory during the depressurisation test. Cold areas (blue colour) and patterns of air movement are visible around the floor and the ceiling, indicating potential air leakage through these elements.

4.5.2. Scenario 2 (Polycarbonate Ceiling)

Figure 15 Ceiling Under Depressurisation Test

Figure 16 Insulation Under Depressurisation Test

Figures 15 and 16 above show the internal different areas of the roof under the depressurisation phase of the blower door during Scenario 2. The cold area, highlighted in blue, shows potential areas of air leak and points of heat loss.

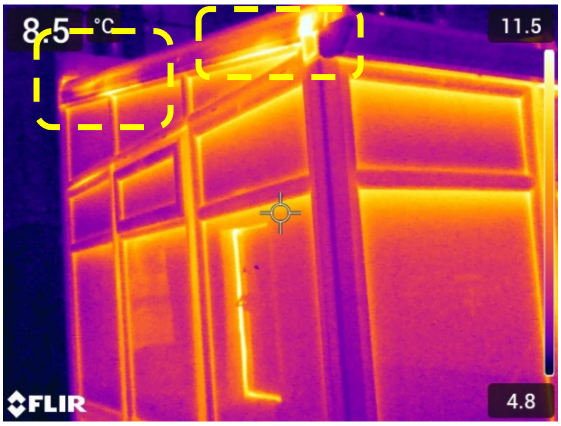

Figure 17 Exterior View (Back) of the conservatory-Pressure Test

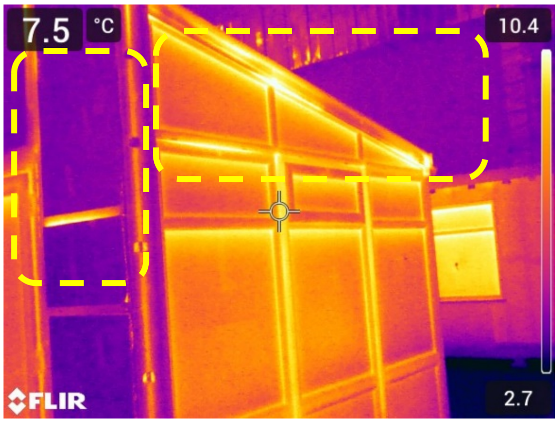

Figure 18 Exterior View (Side) of the conservatory-Pressure Test

Figures 17 and 18 above shows different views of the ceiling of the conservatory during the pressurisation phase of the blower door. Warm spots (orange in colour) can be seen around different areas of the ceiling indicating points of heat loss and air leakage pathways.

4.5.3. Scenario 3 (Polycarbonate Ceiling + C.H.R.I.S. System)

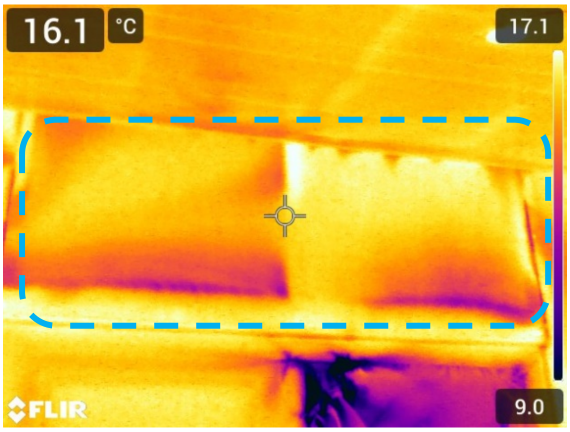

Figure 19 Ceiling Under Depressurisation Test

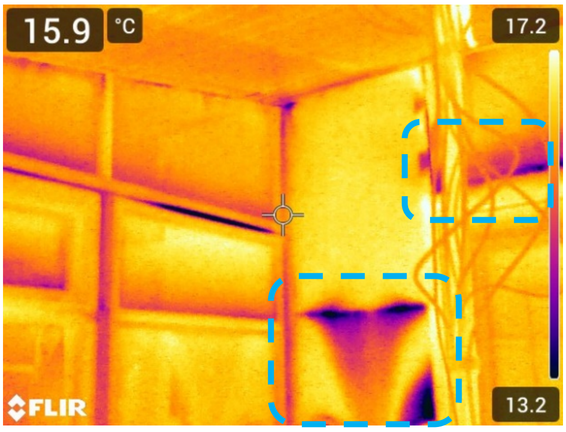

Figure 20 Insulation and Ceiling Under Depressurisation Test

Figures 19 and 20 above show the internal different areas of the ceiling under the pressurisation phase of the blower door during Scenario 3. Visible points of heat loss and air leakage can be seen across different areas of the ceiling. Significant infiltration areas can be also seen in the insulation section.

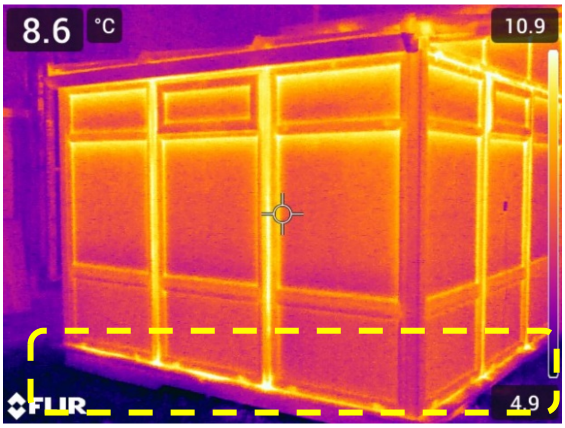

Figure 21 Exterior View of the Floor-Pressure Test

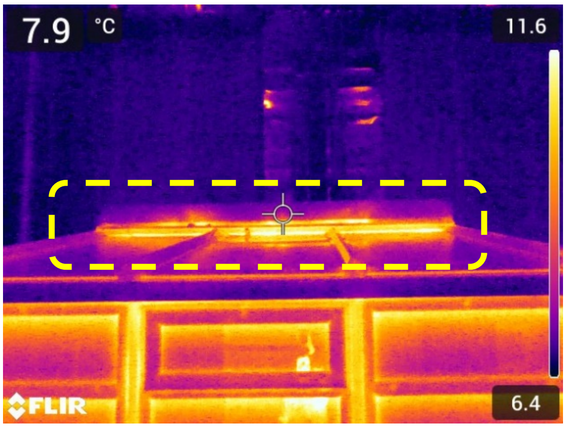

Figure 22 Exterior View of the Ceiling-Pressure Test

Figures 21 and 22 above show external different areas of the floor and ceiling under the pressurisation test of the blower door during Scenario 3. Visible points of heat loss and air leakage can be seen across different areas of the ceiling and the floor.

4.5.4. Scenario 4 (Glass Ceiling + C.H.R.I.S. System)

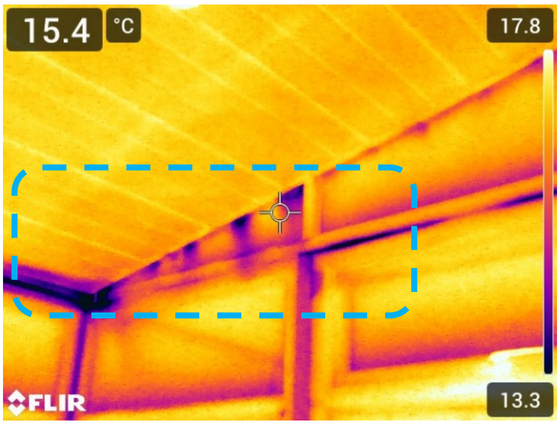

Figure 23 Interior View of the Ceiling (Back)- De-pressure Test

Figure 24 Interior View of the Ceiling (Front)- De-pressure Test

Figures 23 and 24 above show the internal different areas of the ceiling under the pressurisation phase of the blower door during Scenario 4. The figures show potential air leakage and heat loss points through the ceiling.

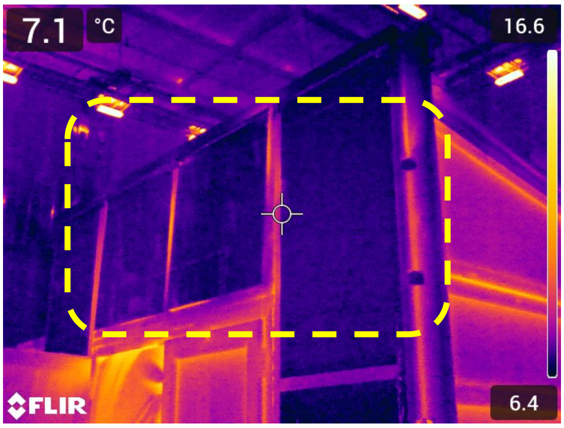

Figure 25 Exterior Front View - Pressure Test

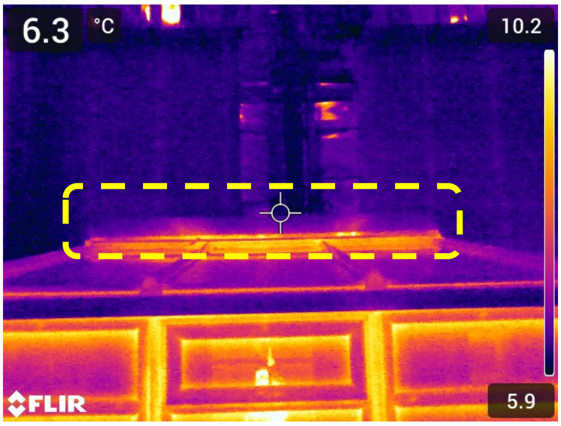

Figure 26 Exterior View of the Ceiling- Pressure Test

Figures 25 and 26 above show external different areas of the ceiling under the pressurisation phase of the blower door during Scenario 4. Visible areas of heat loss and air leakage can be seen across different points of the conservatory ceiling.

5. Discussion

This study involved an in-depth evaluation of the thermal and energy performance of a typical conservatory under four different ceiling configurations:

- **Scenario 1** (Glass Ceiling).
- **Scenario 2** (Polycarbonate Ceiling).
- **Scenario 3** (Polycarbonate Ceiling + C.H.R.I.S. System).
- **Scenario 4** (Glass Ceiling + C.H.R.I.S. System).

Our investigation results showed the following:

Heat Transfer Coefficient (HTC): Our findings indicated that Scenario 1 (Glass Ceiling) had the highest HTC of **72.1 (±0.7) W/K,** representing the least efficient thermal performance. Scenario 2 (polycarbonate roof) had a slightly better HTC of **69.9 (±0.6) W/K**. Notably, the introduction of the C.H.R.I.S. System in Scenarios 3 and 4 significantly reduced the HTC to **49.8 (±0.8) W/K** and **49.9 (±0.8) W/K,** respectively, highlighting the system's effectiveness in improving thermal performance.

U-value Measurements: these were conducted across different areas of the conservatory, including the floor, walls, and ceiling. The addition of "C.H.R.I.S. System" revealed a substantial improvement in ceiling performance in Scenarios 3 and 4. The U-value for the ceiling dropped from **2.60 (±0.16) W/m²K** in scenario 1 **to 0.47 (±0.02**) W/m²K in Scenario 3 and from **2.20 (±0.13) W/m²K** in scenario 2 to **0.48 (±0.02) W/m²K** in Scenario 4, demonstrating enhanced energy efficiency. This suggests that the insulation material positively impacted the overall thermal performance of the conservatory.

Airtightness Testing: conducted using both the blower door and Pulse test methods, revealed significant air leakage around the conservatory's fabric, especially under high pressure from the blower door test. Scenario 3, with a polycarbonate ceiling and C.H.R.I.S. System, showed the lowest air permeability (AP50) value of **6.07 $m^3h^{-1}m^{-2}$ @ 50 Pa**, indicating superior airtightness. However, the blower door test highlighted deficiencies in the ceiling and floor installation, which contributed to higher air leakage in these areas.

A **Thermographic Survey:** conducted under both depressurisation and pressurisation confirmed the presence of air leakage and thermal bridging in the conservatory, particularly around the ceiling, floor, and insulation near the main door. These findings correlate with the HTC and airtightness results, emphasizing the need for improved installation and sealing practices.

Overall, the introduction of the C.H.R.I.S. System notably improved the conservatory's energy and thermal performance, particularly by reducing heat losses through the ceiling. The thermographic survey and airtightness tests highlighted specific areas that require further attention to enhance overall building performance.

Table 4 shows the plane element heat loss calculations, which is used to calculate the fabric and ventilation heat losses below.

Table 4 Plane element heat loss calculations

Element		Area (m^2)	U-value (assuming stud= 3.9%) (W/m^2K)	Heat loss (W/K)
PVC Panel		6.03	1.02	6.15
Glazing (Back)		4.44	1.41	6.26
Glazing (Sides)		10.35	1.41	14.59
Wall		5.01	0.18	0.90
Opening Lights		0.25	1.68	0.42
Door		3.20	1.33	4.26
Floor		9.00	0.23	2.07
Ceiling	**Scenario 1**	9.00	**2.60**	**23.40**
	Scenario 2	9.00	**2.20**	**19.80**
	Scenario 3	9.00	**0.47**	**4.23**
	Scenario 4	9.00	**0.48**	**4.32**

Figure 27 shows the total fabric heat loss across the different test scenarios, along with the percentage contribution of ceiling heat losses to the overall fabric heat loss.

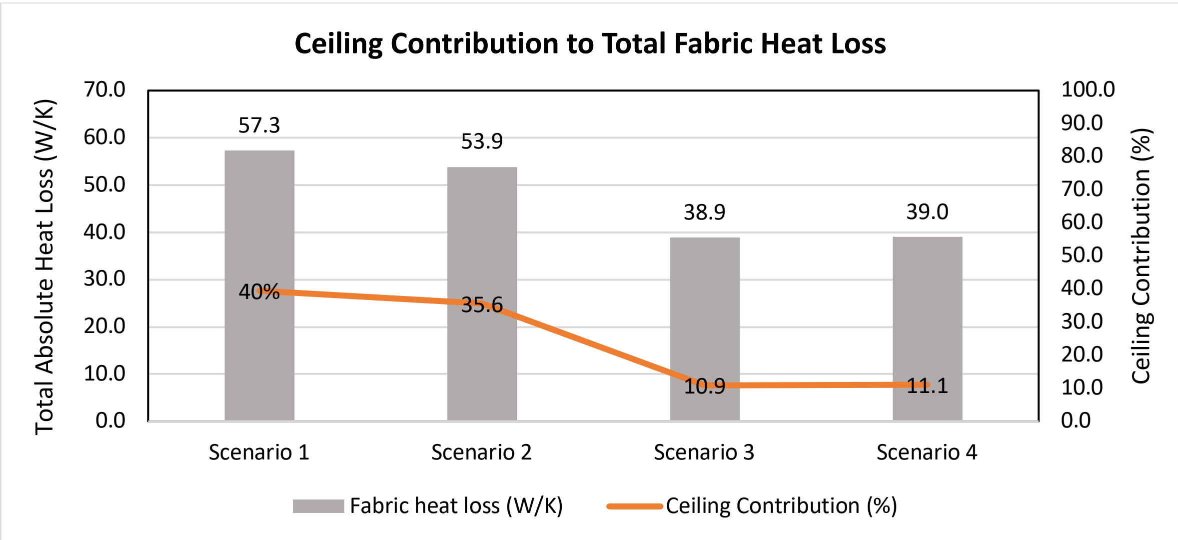

Figure 27 Fabric Heat Loss and Ceiling Heat Loss as Percentage

As shown in the figure, the ceiling's contribution to the overall fabric heat loss decreased significantly from <u>**40%** in Scenario 1 and **36%** in Scenario 2</u> to <u>**11%** in Scenarios 3 and 4,</u> respectively. This reduction in ceiling-related heat loss contributed to a substantial decrease in the total heat losses of the conservatory, as detailed in the Table 5.

Table 5 Total Fabric Heat Loss Breakdown

Element	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Plane element (fabric) heat loss (W/K)	57.26	53.86	38.89	38.98
Ventilation heat loss (W/K)	20.11	27.19	18.74	20.58
Total Fabric and Ventilation Heat Loss (W/K)	77.37	81.05	57.63	59.56
HTC Co-heating (W/K)	72.1	69.9	49.8	49.9

6. Conclusion

This study assessed the fabric performance of a typical conservatory under four different ceiling configurations. The key conclusions are as follows:

- **U-Value Performance**: Scenario 2 (polycarbonate Ceiling) outperformed Scenario 1 (Glass Ceiling) in terms of U-value. The addition of the C.H.R.I.S. System in Scenarios 3 and 4 significantly improved ceiling U-values, with similar results for both configurations. However, condensation was observed between the glass and insulation in Scenario 4, likely due to trapped air between the cold glass surface and the warmer insulation (see Appendix F for details).

- **Airtightness and Infiltration**: Defects in the conservatory fabric were observed under high-pressure conditions, particularly around the floor, insulation near the main door, and the ceiling. These areas were prone to air leakage, which negatively impacted the overall airtightness of the structure.

- **Heat Transfer Coefficient (HTC)**: The introduction of the C.H.R.I.S. System reduced the HTC significantly, improving the thermal efficiency of the conservatory. This was reflected in lower heat losses compared to scenarios without the insulation system.

- **Thermographic Survey**: The survey confirmed areas of heat loss and air leakage identified during the blower door tests. The ceiling, floor, and insulation near the main door were particularly problematic and should be prioritized for improvement.

7. Recommendations for Future Work

To further enhance the conservatory's performance, we recommend the following actions:

- Improve the conservatory's airtightness, focusing on the areas identified as problematic during the pressure tests and thermographic surveys.
- Investigate and address the insulation around the main door.
- Examine the condensation issue observed in Scenario 4, particularly the interaction between the glass roof and the insulation.

To support these improvements, the research team suggests carrying out dynamic simulations using calibrated computer model. This could help with the following:

- **Solar Overheating and Cooling Loads**: Understanding how the conservatory's design influences solar gain can help manage overheating and cooling requirements effectively.

- **Thermal Comfort and Indoor Air Quality**: Assessing thermal comfort is essential for ensuring healthy occupant conditions, while proper ventilation is key to maintaining indoor air quality.
- **Heating Loads**: Investigating how the conservatory can function as a thermal sink or store for managing overheating and cooling loads will enhance energy efficiency.
- **Hygrothermal Performance Modelling**: Modelling the hygrothermal performance of the ceiling can provide insights into the condensation issues observed during testing, helping to develop effective mitigation strategies.

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Appendix A- Energy House 2.0 Lab

Energy House Labs is a research group based at the University of Salford in the UK, specializing in energy use in buildings. This group comprises four research laboratories, each supported by a team of academics and technical staff with expertise in building physics, smart energy systems, data analytics, and renewable systems. Energy House Labs possesses a globally unique capability for assessing buildings under controlled conditions, notably through Energy House 2.0 and the Salford Energy House.

Energy House 2.0 is a pioneering facility designed for full-scale testing of buildings under a range of controlled climatic conditions. The facility features two large chambers, each capable of housing two-family homes, allowing for the accommodation of up to four homes in total. These chambers include a soil-filled pit, 1200 mm deep, insulated from the ground and surrounding areas. The walls and ceilings are also insulated to maintain high levels of airtightness and to isolate the internal environment from external climatic conditions.

Each chamber in Energy House 2.0 is independently managed by an advanced heating, ventilation, and air conditioning (HVAC) system. Additionally, weather rigs simulate various climatic effects to control the environmental conditions within the chambers. The specific controllable conditions include:

- **Temperature**: (-20 °C to 40 °C)
- **Relative Humidity** (20% to 90%)
- **Wind**
- **Rain**
- **Solar Radiation** (up to 1200 W/m^2)
- **Snow**

Temperature and relative humidity within the chambers can be maintained at a constant steady state or varied according to seasonal and daily patterns. Figures 28 below show an external view of the EH 2.0 facility. Figure 29 shows an inside view of chamber 2 with the conservatory in-situ.


Figure 28 External View of EH 2.0


Figure 29 inside view of chamber 2 with the conservatory in-situ

Appendix B- Design Information

Thermal Performance Calculation Summary Sheet

eurocell

All together better

Eurocell Simulation Number	L2342

Window Profiles Summary

System:	Logik 70
Type:	Fixed Light / Side Hung
Outerframe:	EWS7021 / 7721
Sash:	EWS7005 / 7705
Mullion:	EWS7002 / 7702 / EWS7003 / 7703
Bead:	EWS7301 / 7312
Other Notes:	None

Reinforcing Spec:

Outerframe:	EWS7621S
Sash:	EWS7604S
Mullion:	EWS7621S

Calculation prepared by:

Print:	Andy Grosse
Signed:	

BFRC Certified Simulator 022

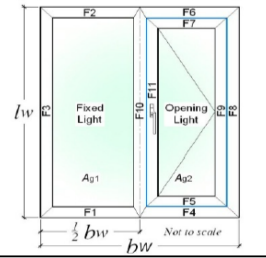
Glazing Unit Summary:

Glazing Overview:	4/20/4 Double Glazed	
External Pane:	Pilkington Optifloat	
Middle Pane:	N/A	
Internal Pane:	Pilkington KS	
Gas Fill Details:	Argon 90%	
Spacer Bar:	Swisspacer Ultimate or Thermobar	
Glazing u-value:	1.219	W/(m²·K)
Glazing g-value:	0.71	g⊥

SEL Licence Number 3221

A++ / A+ / A / B / C / D / E

Rating	B
energy index (kWh/m²/year)	-3
thermal transmittance (U window)	1.4
solar factor (g window)	0.44
air leakge (L factor)	0.00



Sample Style:

Casement

Fixed Light / Side Hung

Blue line illustrates opening light length (air leakage)

Report Number:	L2342	Issue No 22.3:	*04/01/2016*
Report Date:	18 July 2023		
Project Details:	Pilkington Optifloat / Swisspacer or Thermobar / Pilkington KS		

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Input Values:

Yellow input, green intermediary, blue finals — X' DP is no.of decimal places to enter

Parameter	Symbol		Units
Total window height **0DP**	l_w	1480	mm
Total window width **0DP**	b_w	1230	mm

Frame offset:	Yes	

Nominal 4mm etc to **0DP**, others **1DP**

Glazing dimensions and properties:

Thickness of pane 1		4	mm
Pane 1/2 distance		20	mm
Gas fill (1/2)		Argon 90%	
Thickness of pane 2		4	mm
Complete next 3 cells for TG IGU			
Pane 2/3 distance			mm
Gas fill (2/3)			
Thickness of pane 3			mm
Glazing Trans. - **3DP**	U_g	1.219	W/(m²·K)
g-value - **2DP**	$g_\perp$	0.71	

Thermal transmittance of window from hot box test

U_w - 2DP		W/(m²·K)

Frame dimensions:

All frame values round to nearest 1mm, gaskets to **1DP**

	(b_f)	Frame width, b_f (mm)	Frame offset, b_{OF}	Gasket protrusion, b_g (mm)	Frame & gasket widths (mm)	Total
	F1 fixed sill	60	1	0.0	60.0	
	F2 fixed head	60	1	0.0	60.0	
	F3 fixed jamb	60	1	0.0	60.0	
F4 + F5 sash sill	F4 fixed sash sill	60		n/a	60.0	107.0
	F5 moving sash sill	47	1	0.0	47.0	
F6 + F7 sash head	F6 fixed sash head	60		n/a	60.0	107.0
	F7 moving sash head	47	1	0.0	47.0	
F8 + F9 sash jamb	F8 Fixed sash jamb	60		n/a	60.0	107.0
	F9 moving sash jamb	47	1	0.0	47.0	
F10 + F11 mullion	F10 fixed mullion	70	1	0.0	70.0	117.0
	F11 moving mullion	47	1	0.0	47.0	
			Total gasket area	0	m²	

Window Dimensions:

Section	Length (m)	Width (m)	Area: No gasket (m²)	Area: With gasket (m²)
Fixed Light	1.3600	0.5200	0.7072	0.7072
Opening light	1.2660	0.4260	0.5393	0.5393
		Total glazing, A_g	1.2465	1.2465
Frame	(m)	(m)	(m²)	(m²)
F1	0.6150	0.0600	0.0341	0.0341
F2	0.6150	0.0600	0.0341	0.0341
F3	1.4800	0.0600	0.0852	0.0852
F4	0.6150	0.0600	0.0341	0.0341
F5	0.5200	0.0470	0.0222	0.0222
F6	0.6150	0.0600	0.0341	0.0341
F7	0.5200	0.0470	0.0222	0.0222
F8	1.4800	0.0600	0.0852	0.0852
F9	1.3600	0.0470	0.0617	0.0617
F10	1.4800	0.0700	0.0994	0.0994
F11	1.3600	0.0470	0.0617	0.0617
		Total Frame	0.5739	0.5739
		Total Window, A_w	1.8204	1.8204
		Percentage fixed light glass area	38.85%	38.85%
		Percentage opening light glass area	29.63%	29.63%
		Percentage glass area (total)	68.47%	68.47%

Where a *Uw* value from hot box testing is available, no L_f^{2D} or L_ψ^{2D} values need to be entered

Frame conductance: All *L* values to **4DP**. All b values to **0DP**

		L_f^{2D} W/(m·K)	b_p (mm)		L_ψ^{2D} W/(m·K)	b_g (mm)
F1 fixed sill	L_f^{2D}	0.2903	190	L_ψ^{2D}	0.3535	190
F2 fixed head		0.2903	190		0.3535	190
F3 fixed jamb		0.2903	190		0.3535	190
F4 + F5 sash sill		0.3663	190		0.4295	190
F6 + F7 sash head		0.3663	190		0.4295	190
F8 + F9 sash jamb		0.3663	190		0.4295	190
F10 + F11 mullion		0.5788	380		0.7050	380

Frame:

Section	Frame width, b_f (m)	Frame U-value, U_f (W/(m²·K))	Frame areas, A_f (m²)	Frame heat flow, HU (W/K)	Linear trans, Ψ (W/(m·K))	Linear length, l_g (m)	Junction heat flow, HΨ (W/K)
F1 fixed sill	0.0600	1.5737	0.0341	0.0536	0.0275	0.5220	0.0143
F2 fixed head	0.0600	1.5737	0.0341	0.0536	0.0275	0.5220	0.0143
F3 fixed jamb	0.0600	1.5737	0.0852	0.1341	0.0275	1.3620	0.0374
F4 + F5 sash sill	0.1070	1.5927	0.0563	0.0896	0.0275	0.4280	0.0118
F6 + F7 sash head	0.1070	1.5927	0.0563	0.0896	0.0275	0.4280	0.0118
F8 + F9 sash jamb	0.1070	1.5927	0.1469	0.2340	0.0275	1.2680	0.0348
F10 + F11 mullion	0.1170	1.5987	0.1611	0.2576	0.0547	1.3150	0.0720
		Totals	0.5739	0.9121		Total	0.1964

Solar Factor, *g*-value:

F_w	0.9	
g_w	0.44	

Other parameters needed for calculation, taken from simulations:

						$d_p = d_g$ =	0.028	m
λ_p =	0.035	W/(m·K)	R_{se} =	0.04	m²·K/W	R_{se} =	0.13	m²·K/W
R_p =	0.8000	m²·K/W	R_{tot} =	0.9700	m²·K/W	U_p =	1.0309	W/(m²·K)

U_{window}	No bars; or attached bars	1.44	W/(m²·K)
	Single cross bar in IGU	1.5	
	Multiple cross bar in IGU	1.6	
	Glazing bar (Georgian bar)	1.8	

Air Leakage loss:

Air leakage at 50 Pa per hour & per unit length of opening light (BS 6375-1) - **2DP**			0.00	m³/(m·h)
Opening light length	3.7600	m	Total air leakage: 0.000	m³/h
L_{50}	0.00	m³/(m²·h)	Heat loss = 0.0165 L_{50}: 0.00	W/(m²·K)

Energy Window

Energy Index

-3

Window Rating

B

BFRC Rating

kWh/(m²·yr)

≥20	A++	
>10 to 20	A+	
0 to <10	A	
-10 to <0	B	✓
-20 to <-10	C	
-30 to <-20	D	
-50 to <-30	E	

BFRC Rating =	
218.6*g*$_{window}$ - 68.5 x (U_{window} + Effective L_{50}) =	**-2.99**
Climate zone is:	**UK**

Thermal transmittance, W/(m²·K)	U_{window}	**1.4**
Solar factor	g_{window}	**0.44**
Window air leakage heat loss, W/(m²·K)	L_{factor}	**0.00**

BFRC Certified Simulator No **022**

Simulator Name: Andy Grosse

Thermal Performance Calculation Summary Sheet

eurocell
All together better

Simulation No. LD1382

Door Profiles Summary

System:	Logik 70
Type:	French Door
Outerframe:	EWS7006 / 7706
Sash:	EWS7019 / 7719
Meeting Stile:	EWS7002 / 7702
Threshold:	EWS7150
Bead:	EWS7301 / 7312
Notes:	None
Reinforcing Spec:	
Outerframe:	EWS616S
Sash:	EWS618S
Meeting Stile:	EWS7621S
Calculation prepared by:	
Print:	Andy Grosse
Signed:	

BFRC

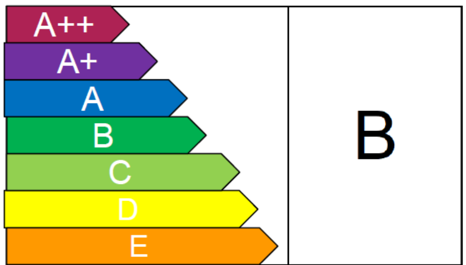
BFRC Certified Simulator 022

Glazing Unit Summary:

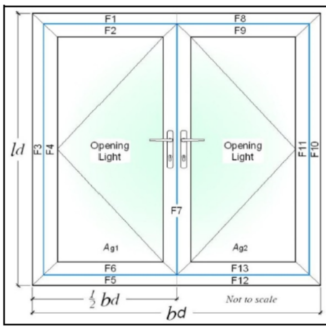
Glazing Overview:	4/20/4 Double Glazed	
External Pane:	Pilkington Optifloat	
Middle Pane:	N/A	
Internal Pane:	Pilkington KS	
Gas Fill Details:	Argon 90%	
Spacer Bar:	Swisspacer Ultimate or Thermobar	
Glazing u-value:	1.219	W/(m²·K)
Glazing g-value:	0.71	g⊥

DSEL Licence Number

D1654



Energy index (kWh/m²/year)	-10
Thermal transmittance (u-door)	1.4
Solar Factor (g-door)	0.41
Air leakge (L factor)	0.01



Sample Style: **French Door**

Blue line illustrates opening light length (air leakage)

Report Number:	LD1382	Issue 2.7:	*04/01/2016*
Report Date:	02 August 2024		
Project Details:	Pilkington Optifloat / Swisspacer Ultimate or Thermobar / Pilkington KS		

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Input Values:
Yellow input, green intermediary, blue finals — X' DP is no.of decimal places to enter

Parameter	Symbol		Units
Total door height **0DP**	l_d	2180	mm
Total door width **0DP**	b_d	2000	mm

Frame offset:	Yes

Nominal 4mm etc to **0DP**, others **1DP**

Glazing dimensions and properties:			
Thickness of pane 1		4	mm
Pane 1/2 distance		20	mm
Gas fill (1/2)		Argon 90%	
Thickness of pane 2		4	mm
Complete next 3 cells for TG IGU			
Pane 2/3 distance			mm
Gas fill (2/3)			
Thickness of pane 3			mm
Glazing Trans. - **3DP**	U_g	1.219	W/(m²·K)
g-value - **2DP**	$g_\perp$	0.71	

Thermal transmittance of door from hot box test		
U_{d-2dp}		W/(m²·K)

Frame dimensions: All frame values to nearest 1mm, gaskets to 1DP	Frame heights, (b_f)	Without gasket (mm)	Frame offset	Gasket protrusion (mm)	With gasket (mm)	Total (mm)
F1 + F2 left head rail	F1 left fixed head	75	n/a	n/a	75.0	152.0
	F2 left opening head	77	1	0.0	77.0	
F3 + F4 left jamb	F3 left fixed jamb	75	n/a	n/a	75.0	152.0
	F4 left opening jamb	77	1	0.0	77.0	
F5 +F6 left threshold	F5 left fixed threshold	27	n/a	n/a	27.0	119.0
	F6 left opening threshold	92	1	0.0	92.0	
F7 Meeting Stile	F7 Meeting Stile	224	1	0.0	224.0	
			1	0.0		
F8 + F9 right head rail	F8 right fixed head	75	n/a	n/a	75.0	152.0
	F9 right opening head	77	1	0.0	77.0	
F10 + F11 right jamb	F10 right fixed jamb	75	n/a	n/a	75.0	152.0
	F11 right opening jamb	77	1	0.0	77.0	
F12 + F13 right threshold	F12 right fixed threshold	27	n/a	n/a	27.0	119.0
	F13 right opening threshold	92	1	0.0	92.0	
		Total gasket area		0	m²	

Door Dimensions:	Length (m)	Width (m)	Area: No gasket (m²)	Area: With gasket (m²)
Left Opening light	1.9090	0.7360	1.4050	1.4050
Right Opening light	1.9090	0.7360	1.4050	1.4050
Total glazing, A_g			2.8100	2.8100
Frame	(m)	(m)	(m²)	(m²)
F1	1.0000	0.0750	0.0722	0.0722
F2	0.9250	0.0770	0.0639	0.0639
F3	2.1800	0.0750	0.1597	0.1597
F4	2.0780	0.0770	0.1535	0.1535
F5	1.0000	0.0270	0.0260	0.0260
F6	0.9250	0.0920	0.0764	0.0764
F7	2.0780	0.2240	0.4465	0.4465
F8	1.0000	0.0750	0.0722	0.0722
F9	0.9250	0.0770	0.0639	0.0639
F10	2.1800	0.0750	0.1597	0.1597
F11	2.0780	0.0770	0.1535	0.1535
F12	1.0000	0.0270	0.0260	0.0260
F13	0.9250	0.0920	0.0764	0.0764
Total Frame			1.5500	1.5500
Total door, A_d			4.3600	4.3600
Percentage left light glass area			32.23%	32.23%
Percentage right light glass area			32.23%	32.23%
Percentage glass area (total)			64.45%	64.45%
Solar Factor, *g*-value:		F_d	0.9	
		g_d	0.41	

Where a U_d value from hot box testing is available, no L_f^{2D} or L_ψ^{2D} values need to be entered

Frame conductance: All L values to **4DP**. All b values to **0DP**		W/(m·K)	b_p (mm)		W/(m·K)	b_g (mm)
F1 + F2 left head rail	L_f^{2D}	0.4440	190	L_ψ^{2D}	0.5071	190
F3 + F4 left jamb		0.4440	190		0.5071	190
F5 +F6 left threshold		0.4125	190		0.4756	190
F7 Meeting Stile		0.7705	380		0.8967	380
F8 + F9 right head rail		0.4440	190		0.5071	190
F10 + F11 right jamb		0.4440	190		0.5071	190
F12 + F13 right threshold		0.4125	190		0.4756	190

Frame: Section	Frame width, b_f (m)	Frame U-value, U_f (W/(m²·K))	Frame ares (no gaskets), A_f (m²)	Frame heat flow, HU (W/K)	Linear trans, ψ (W/(m·K))	Linear length, l_g (m)	Junction heat flow, $H\psi$ (W/K)
F1 + F2 left head rail	0.1520	1.6324	0.1361	0.2222	0.0274	0.7380	0.0202
F3 + F4 left jamb	0.1520	1.6324	0.3132	0.5112	0.0274	1.9110	0.0523
F5 +F6 left threshold	0.1190	1.8204	0.1024	0.1864	0.0274	0.7380	0.0202
F7 Meeting Stile	0.2240	1.6908	0.4465	0.7550	0.0547	1.9110	0.1046
F8 + F9 right head rail	0.1520	1.6324	0.1361	0.2222	0.0274	0.7380	0.0202
F10 + F11 right jamb	0.1520	1.6324	0.3132	0.5112	0.0274	1.9110	0.0523
F12 + F13 right threshold	0.1190	1.8204	0.1024	0.1864	0.0274	0.7380	0.0202
		Totals	1.5500	2.5947		Total	0.2900

Other parameters needed for calculation, taken from simulations:

λ_p =	0.035	W/(m·K)	R_{se} =	0.04	m²·K/W	$d_p = d_g$ =	0.028	m
R_p =	0.8000	m²·K/W	R_{tot} =	0.9700	m²·K/W	R_{se} =	0.13	m²·K/W
						U_p =	1.0309	W/(m²·K)

U_{door}			
	No bars; or attached bars	1.45	W/(m²·K)
	Single cross bar in IGU	1.5	
	Multiple cross bar in IGU	1.6	
	Glazing bar (Georgian bar)	1.8	

Air Leakage loss:

Air leakage at 50 Pa per hour & per unit length of opening light (BS 6375-1) - **2DP**			0.22	m³/(m·h)
Opening light length	9.9340	m	Total air leakage 2.185	m³/h
L_{50}	0.50	m³/(m²·h)	Heat loss = 0.0165 L_{50} 0.01	W/(m²·K)

Energy Door
Energy Index
-10
Door Rating
B

BFRC Rating
kWh/(m²·yr)

≥ 20	A ++	
>10 to 20	A +	
0 to <10	A	
-10 to <0	B	✓
-20 to <-10	C	
-30 to <-20	D	
-50 to <-30	E	

BFRC Rating =		
218.6g_d - 68.5 x (U_d + Effective L_{50}) =		**-9.68**
Climate zone is:		**UK**
Thermal transmittance, W/(m²·K)	U_{door}	**1.4**
Solar factor	g_{door}	**0.41**
Door air leakage heat loss, W/(m²·K)	L_{factor}	**0.01**

Simulator Name: Andy Grosse

BFRC
BFRC Certified Simulator No
022

U-value calculation
by BRE U-value Calculator version 2.04a

Element type: Roof - Pitched roof - insulated slope, sloping ceiling
Calculation Method: BS EN ISO 6946

Polycarbonate Conservatory Roof U-value using ConservaHeat Pro System (Trial product)

Layer	d (mm)	l layer	l bridge	Fraction	R layer	R bridge	Description
					0.100		Rsi
1	6	0.210			0.029		Internal Cladding
2	22	R-value[1]	0.130	0.0633	0.490	0.169	25mm Batten
3	7	R-value	R-value	0.0120	1.120	0.670	ConservaHeat PRO
4	22	R-value[2]	0.130	0.0633	0.490	0.169	25mm Batten
5	25	0.190			0.132		25mm Polycarbonate
					0.040		Rse
	82 mm (total roof thickness)				2.400		

[1]Calculated with specified emissivity of 0.02
[2]Calculated with specified emissivity of 0.02

Total resistance: Upper limit: 2.347 Lower limit: 2.286 Ratio: 1.027 Average: 2.317 m²K/W

U-value (uncorrected) 0.432

U-value corrections
Air gaps in layer 2 DU = 0.000 (Level 0)
No fixings in layer 3

Total DU 0.000

U-value (corrected) 0.432
U-value (rounded) 0.43 W/m²K

Calculated by:
ConservaHeat Insulation

U-value calculation
by BRE U-value Calculator version 2.04a

Element type: Roof - Pitched roof - insulated slope, sloping ceiling
Calculation Method: BS EN ISO 6946

Glass Conservatory Roof U-value using ConservaHeat Pro (Trial Product)

Layer	d (mm)	l layer	l bridge	Fraction	R layer	R bridge	Description
					0.100		Rsi
1	6	0.210			0.029		Internal Cladding
2	22	R-value[1]	0.130	0.0633	0.490	0.169	25mm Batten
3	7	R-value	R-value	0.0120	1.120	0.670	ConservaHeat PRO
4	22	R-value[2]	0.130	0.0633	0.490	0.169	25mm Batten
5	4	1.000			0.004		Glass
					0.040		Rse
	61 mm (total roof thickness)				2.273		

[1]Calculated with specified emissivity of 0.02
[2]Calculated with specified emissivity of 0.02

Total resistance: Upper limit: 2.219 Lower limit: 2.159 Ratio: 1.028 Average: 2.189 m²K/W

U-value (uncorrected) 0.457

U-value corrections
Air gaps in layer 2 DU = 0.000 (Level 0)
No fixings in layer 3

Total DU 0.000

U-value (corrected) 0.457
U-value (rounded) 0.46 W/m²K

Appendix B HTC Measurements

Test	DAY	Power (W)	ΔT (K)	HTC (W/K)
Scenario 1	1	1164.7	16.1	72.2
	2	1139.8	15.8	72.2
	3	1141.7	15.7	72.9
	4	1111.5	15.6	71.0
	Average HTC = 72.1 (W/K)			
Scenario 2	1	1089.1	15.5	70.3
	2	1090.2	15.5	70.3
	3	1067.0	15.5	68.8
	4	1088.3	15.5	70.2
	Average HTC = 69.9 (W/K)			
Scenario 3	1	751.7	15.5	48.5
	2	774.0	15.5	49.9
	3	780.2	15.5	50.3
	4	782.2	15.5	50.5
	Average HTC = 49.8 (W/K)			
Scenario 4	1	783.4	15.4	50.8
	2	755.9	15.4	49.1
	3	755.2	15.4	49.1
	4	777.1	15.4	50.6
	Average HTC = 49.9 (W/K)			

Appendix C- U-value Measurements

U-values for the walls, floor, roof, and windows were measured in situ using heat flux sensors and temperature probes, in accordance with ISO 9869 [3].

The U-value was calculated as defined by ISO 9869 [3] using the equation below.

$$\boldsymbol{U} = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_{ij} - T_{ej})}$$

Where:

U = in-situ U-value (W/m^{2}K)
q = mean heat flow rate (W/m^2)
T_i=indoor temperature (K)
T_e=chamber temperature (K)
j= enumeration of measurements

For the U-value test, the chamber was set to 5 °C, and the indoor temperature to 20 °C. The elements were evaluated for periods longer than 72 hours in accordance with ISO 9869 [4].

Table 4 Design U-Values, HFPs Locations and Measured U-values.

Element	Measurement Locations	Measured U-value (W/m²K)			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
PVC Panel	Mid	1.06	1.09	0.99	0.97
PVC Frame	Mid	1.31	1.37	1.35	1.28
Glazing	Right	1.32	1.29	1.31	1.23
	Left	1.32	1.30	1.34	1.28
	Top	1.55	1.66	1.71	1.61
Glazing Average		1.39	1.41	1.45	1.37
Opening Lights	Mid	1.58	1.66	1.78	1.71
Wall	Top	0.15	0.17	0.19	0.20
	Bottom	0.17	0.19	0.18	0.18
	Stud	0.32	0.34	0.34	0.34
Wall Average (ex-stud)		0.16	0.18	0.19	0.19
Door	Mid	1.22	1.33	1.33	1.33
Floor	Front	0.23	0.21	-	0.21
	Right	0.24	0.21	0.21	0.21
	Left	0.28	0.22	0.21	0.20
	Back	0.24	0.20	0.22	0.21
	Stud	0.37	0.35	0.35	0.32
Floor Average (ex-stud)		0.25	0.21	0.21	0.21
Ceiling	Mid 1	2.27	2.03	0.39	0.40
	Mid 2	2.61	2.13	0.49	0.51
	Mid 3	2.53	2.33	0.44	0.45
	Front	2.70	1.97	0.45	0.46

	Back	2.38	2.14	0.46	0.46
Ceiling Average (ex-stud)		2.50	2.12	0.45	0.46
Ceiling (Frame)	Left frame	2.34	2.09	0.64	0.70
	Right frame	1.93	2.00	0.42	0.42

Note on U-values measured in chamber conditions:

BS EN ISO 6946:2017 (simplified method) states that the external surface layer of insulation for a wall element, has assumed wind speed of 4 m/s. This allows for wind to be considered when comparing buildings in-situ to designs. However, the chamber environment found at Energy House 2.0 does not impose these wind loads as standard, although they can be if required. However, in a chamber environment, well distributed laminar flow, which is consistent across each facade is difficult to replicate. The air velocity has been mapped across a variety of test structures across both chambers, with an average velocity of 0.39 m/s, with variations ranging from 0.01 to 1.30 m/s.

Appendix D- Air Permeability Measurements

Test	Results	Blower Door	Pulse
Scenario 1	Air permeability [AP_{50}] ($m^3h^{-1}m^{-2}$ @ 50 Pa)	11.8	10.38
	Air change rate [n_{50}] (ACH @ 50 Pa)	25.23	22.13
Scenario 2	Air permeability [AP_{50}] ($m^3h^{-1}m^{-2}$ @ 50 Pa)	16.00	10.38
	Air change rate [n_{50}] (ACH @ 50 Pa)	34.12	22.13
Scenario 3	Air permeability [AP_{50}] ($m^3h^{-1}m^{-2}$ @ 50 Pa)	11.03	6.07
	Air change rate [n_{50}] (ACH @ 50 Pa)	23.51	12.97
Scenario 4	Air permeability [AP_{50}] ($m^3h^{-1}m^{-2}$ @ 50 Pa)	12.11	7.37
	Air change rate [n_{50}] (ACH @ 50 Pa)	25.82	15.75

Appendix F- Ceiling Condensation