Vector Homes Baseline Fabric Performance Report of “Vector V1 Prototype Studio”

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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 Pascals
Q_{50}	Air leakage rate at 50 Pascals
N_{50}	Air change per hour (1/h) at 50 Pascals

1. Introduction

This technical report examines the fabric performance of the Vector V1 studio, built by Vector Homes, and tested under controlled conditions at the Energy House 2.0 research facility at the University of Salford.

The aim was to evaluate the performance of the Vector V1 studio and identify any discrepancies where the fabric performance did not align with the design intent, commonly referred to as the performance gap. The performance gap represents the difference between the design expectations (often established through the Standard Assessment Procedure) and the actual measured performance.

Previous studies by Leeds Beckett University (LBU) have highlighted significant gaps in fabric performance in newly built homes across the UK, with gaps ranging from 5% to 140% in a sample of 30 newly built homes [1]. The performance gap can be caused by many different issues, including poor construction, substitutions of materials, incorrect assumptions within the models, and homes not being used as predicted.

The design and construction of the Vector V1 emphasizes sustainability and the use of cutting-edge materials to enhance energy efficiency and reduce carbon emissions. This investigation aims to analyse the effectiveness of these materials and the overall design in achieving the intended performance outcomes in comparison to the initial design specifications, thus identifying any existing performance gaps.

Our investigation into the fabric performance of Vector V1 included investigating the following:

- Whole building heat loss,
- U-value measurements for floor, walls, windows and doors, and the ceiling,
- Airtightness measurements,
- Thermographic survey.

We used the following methods for our investigations:

- **Heat Transfer Coefficient** (HTC) Measured according to the 2013 Leeds Beckett Whole House Heat Loss Test Method (Co-heating) [2].
- **Airtightness Testing (Fan Pressurisation Tests)** according to ATTMA Technical Standard L1 [3].
- **In-situ Heat Flux and U-value Measurement;** in line with ISO 9869 [4].
- **Thermographic and air leakage survey.**

1.1. Vector Homes Studio (Vector V1) Description

The Vector V1 prototype is a one-bedroom bungalow with a floor area of 40 m². This home is constructed using a lightweight steel frame system. This home will be described in the following subsections.

1.1.1. Design

Vector Homes aim to develop affordable, energy-efficient houses using novel materials. Their homes are designed for cost effective production and assembly. Vector Homes aims to mass-produce homes in various shapes and sizes, which will be sold as flatpacks and assembled by a small team. Figure 1 - Figure 5 below provides the design details of Vector V1.

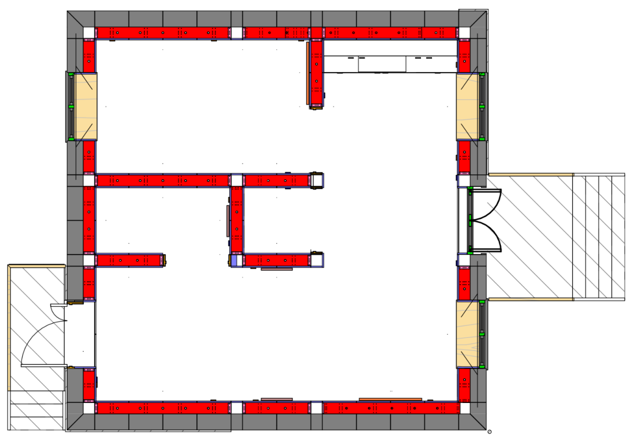


Figure 1. Floor plan of the Vector V1.

Figure 2. Rear façade of Vector V1

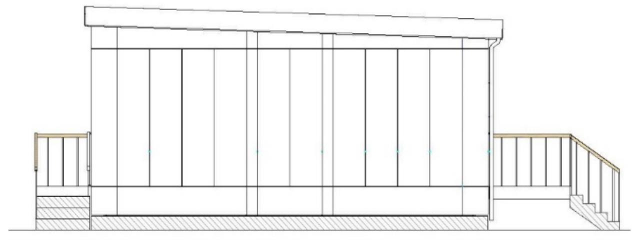


Figure 3. Left façade of Vector V1

Figure 4. Front façade of Vector V1

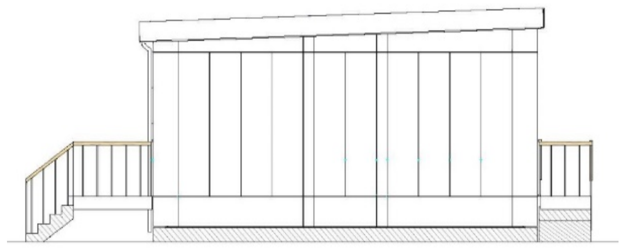


Figure 5. Right façade of Vector V1

1.1.2. Fabric

The fabric performance measurement of Vector V1 was conducted in two phases:

- ***Phase 1: As-Built Material and Design;*** during Phase 1, the measurements were taken on the as-built material and design of Vector V1. The focus was on assessing the fabric performance of the floor, walls, and ceiling in their initial state. However, some issues were identified in the fabric of these elements which needed further examination and adjustments. The main body of this report will consider only Phase 1 results.
- ***Phase 2: Upgraded Fabric Components;*** in response to the issues discovered in Phase 1, upgrades were made to the representative areas of the floor walls, and ceiling (as shown in Figure 6-10). These upgrades aimed to address the deficiencies observed in the initial measurements. U-value measurements were then repeated to evaluate the effectiveness of the improvements made. ***All Phase 2 details and results can be found in Appendix A.***

This section provides detailed information about the fabric used during Phase 1. **All U-value design data was provided by Vector Homes.**

Figure 6. Heat flux measurements - floor

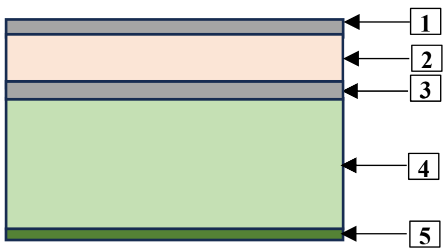
Figure 7. Heat flux measurements – wall

Figure 8. Heat flux measurements - ceiling

1.1.3. Floor

Table 1 shows the Phase 1 floor design and materials of the Vector V1 prototype studio provided by Vector Homes. It should be noted the floor covering has been discounted in these calculations but were included in the measurements. Given the type of covering and thickness, this will have little effect.

Table 1. Floor design and materials of the Vector V1

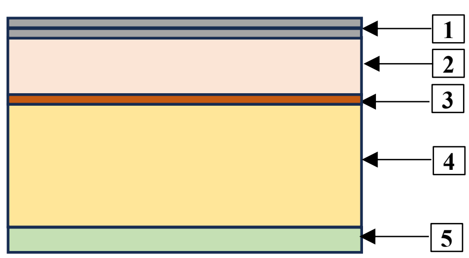


	Material	λ (W/m.K)	Thickness (mm)
1	**OSB**	0.13	12.00
2	**Felt**	0.04	50.00
3	**OSB**	0.13	12.00
4	**Insulation**	0.05	270.00
5	**Panel**	1.00	2.00
Calculated U-value (W/m².K) = 0.12			

1.1.4. External walls

Table 2 shows the Phase 1 external wall design and materials of the Vector V1 prototype studio, as provided by Vector Homes.

Table 2. External wall design and materials of the Vector V1



	Material	λ (W/m.K)	Thickness (mm)
1	Plasterboard	0.16	12.50
1	Plasterboard	0.16	12.50
2	Felt	0.04	50.00
3	OSB	0.13	12.00
4	Insulation	0.05	270.00
5	Render	0.76	20.00
	Calculated U-value (W/m².K) = 0.14		

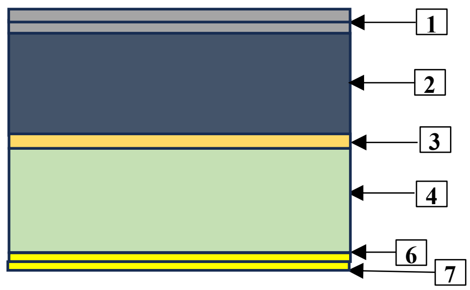
1.1.5. Doors and Windows

The windows in the Vector V1 are PVCu windows with a design U-value of 1.30 (W/m²K). There are two types of doors fitted within Vector V1, these are the French door with a design U-value of 1.4 (W/m²K), and the GRP Composite Door that has a design U-value of 0.60 (W/m²K).

1.1.6. Ceiling

Table 5 below shows the ceiling design and materials of the Vector V1 as provided by Vector Homes.

Table 3. Phase 1 flat roof design and materials of the Vector V1



	Layer	λ (W/m.K)	Thickness (mm)
1	Plasterboard	0.16	12.50
1	Plasterboard	0.16	12.50
2	Felt	0.04	200.00
3	OSB	0.13	12.00
4	Insulation	0.05	270.00
5	Render	0.10	2.00
6	Membrane	0.29	2.00
	Calculated U-value (W/m².K) = 0.09		

2. Methodology

This section presents the test conditions, monitoring equipment and the methods used to measure the fabric thermal performance of Vector V1. The tests found here are industry-recognised standard tests with published methodologies and standards, or tests that are well documented in the academic literature.

2.1. Steady-State Thermal Performance Measurements

All the tests and measurements of the Vector V1 were carried out within the environment of the 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 21 °C. Figure 9 below illustrates the average temperatures in the UK according to the according to RdSAP10, 2024 [5]. These temperatures were used to provide a representative external temperature of the United Kingdom during the winter months (December to March).

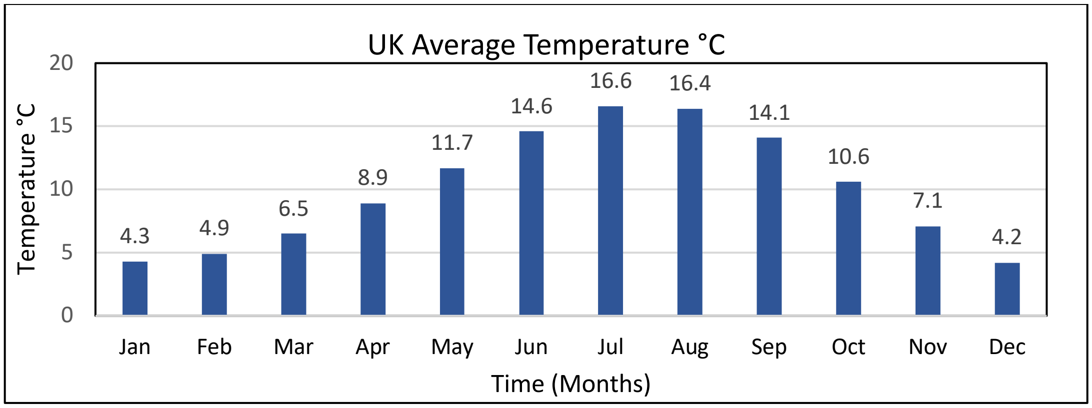


Figure 9. Average monthly UK temperature [5].

The steady-state test of the fabric performance was divided into two stages, the first was the Co-heating test to obtain the Heat Transfer Coefficient (HTC), and the second stage was a test to obtain the U-value of the elements of the envelope. This allows for U-values to be measured without the high airflow rate often associated with Co-heating, which uses air circulation fans. During both tests, Vector V1 was maintained at 21 °C throughout the steady-state measurement period using electric resistance heaters connected to PID controllers with PT-100 RTD temperature sensors.

2.2. Energy House 2.0 Monitoring Equipment

The findings provided in this report are based on measurements obtained using the equipment listed in Table 4 below. Measurements were recorded at one-minute intervals by the Energy House 2.0 monitoring system.

Table 4: measurement equipment used in the Energy House Vector V1 fabric performance tests.

Measurement	**Equipment**	**Uncertainty[1]**	**Ref.**
Power input	Fibaro wall plug type G (FGWPG-111)	±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[2]	±0.1 °C	-
Heat flux density	Hukseflux HFP-01 heat flux plate	±3%	[8]
Air permeability	Retrotec 5000 Blower Door System [3]	±2.5%[4]	[10]
Thermography	FLIR E96	2°C (±3.6°F) or ±2% of the reading	[11]

[1] Uncertainties were taken from supplier data sheet.
[2] Energy house 2.0 in house calibration process
[3] Certificate of calibration: UK_52369, UK_52343
[4] The sheltered test environment allows measurement uncertainty to exclude wind-based errors, the ±2.5% uncertainty value applies only to test apparatus.

2.3. Building Performance Evaluation Methods

The methods used to evaluate the fabric performance of Vector V1 are outlined in this subsection.

2.3.1. Heat Transfer Coefficient (HTC) Measurement

The HTC of the Vector V1 was determined using the Co-heating test method, as outlined in the 2013 Leeds Beckett Whole House Heat Loss Test Method [2]. 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 21 °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; [2].

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

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 Energy House 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 chamber. Thus, the equation is rearranged to show how, at steady state, the HTC can be calculated from measurements of Q and ΔT. Equation 2 shows the HTC calculation in the Vector test.

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

Where:

$\boldsymbol{HTC}$ = H_{tr} + H_v (W/K)
$\boldsymbol{Q}$ = power input (W) [5]
$\Delta\boldsymbol{T}$ = average internal air temperature (Ti) minus average chamber air temperature (T_e).

[5] Q is based on total cumulative energy input to the Vector V1 over 24-hour period. The method for uncertainty calculation of both HTC and U-value can be found in section 2.2.3 of *(Henshaw et al., 2024)* [13]

During the Co-heating test, the temperatures on both sides of the fabric remained at steady state for 5 days. Figure 10 shows the rate of change of the temperature difference (ΔT) during the Co-heating test, the ΔT remained steady with variations between 1% and -1%.

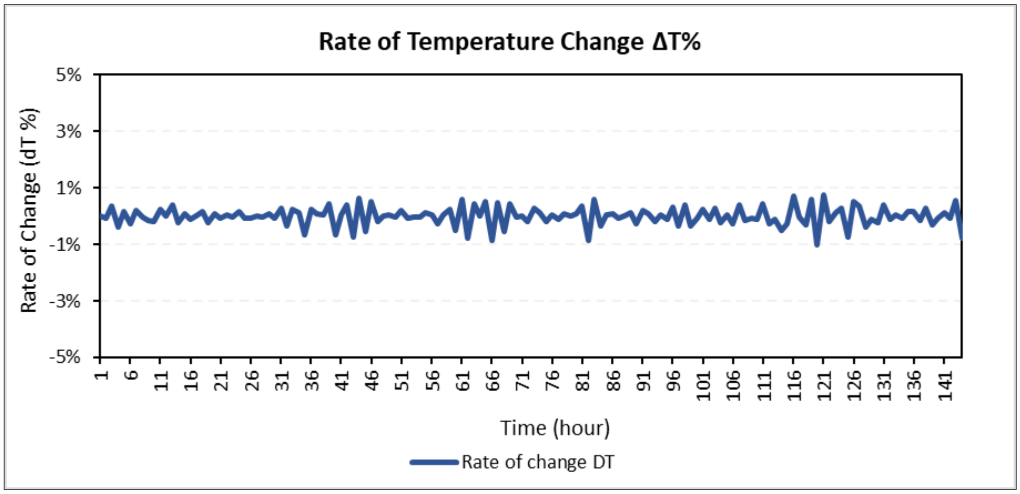


Figure 10. Rate of change of the temperature difference (ΔT) during Co-heating test.

2.3.2. U-value Measurement

U-value measurements were carried out in two phases. In Phase 1, the initial 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 [4]. Following the identification of discrepancies between the measured U-values and the design values, targeted fabric upgrades were made to representative sections of the building envelope. Phase 2 measurements were then conducted to assess the impact of these upgrades on the U-value performance of the Vector V1.

The U-value was calculated as defined by ISO 9869 [4] using equation 3.

$$U = \frac{\sum_{j=1}^{n} q_j}{\sum_{j=1}^{n} (T_{ij} - T_{ej})} \qquad \textbf{Eq.3}$$

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 21 °C. The elements were evaluated for periods longer than 72 hours in accordance with ISO 9869 [4].

Measurements of heat flux density, from which in-situ U-values were calculated, were taken at 35 locations on the external elements of Vector V1 using heat flux plates (HFPs). The HFPs were fixed to surfaces using adhesive tape and thermal contact paste. The ΔT for each in-situ U-value measurement was calculated using the internal and external air temperature differential measured in the vicinity of each HFP. Figure 11 shows the HFP's location within Vector V1.

Figure 11. HFP locations on the external elements of Vector V1 (wall measurements were conducted on the right façade).

2.3.3. Airtightness Testing

Airtightness testing was performed using a blower door test, following the ATTMA Technical Standard L1 [3]. The test involved depressurizing and pressurizing the building to 50 Pa and measuring the resulting air leakage rate. This provided a measure of the building's air permeability, which is crucial for understanding the overall airtightness and its impact on energy efficiency.

2.3.4. Thermographic Survey

A thermographic survey was conducted during blower door test to identify potential thermal bridging and areas of air leakage. The survey was performed using a 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.

3. Results

3.1. Steady-State Conditions

Figure 12 shows the average indoor temperature, the chamber temperature, and the rate of change of the ΔT (T_i-T_e) for the Living Room, Figure 17 below shows the average heat flux and the rate of change (%) during the same period. The HTC was calculated over the entire period of the stable measurement. The U-value calculations were done over 24 hours of these stable measurements.

Figure 12 and Figure 13 show that steady state conditions were reached for more than 72h for both the temperature and the average heat flux with less than 1% and 4% change for both temperature and heat flux, respectively.

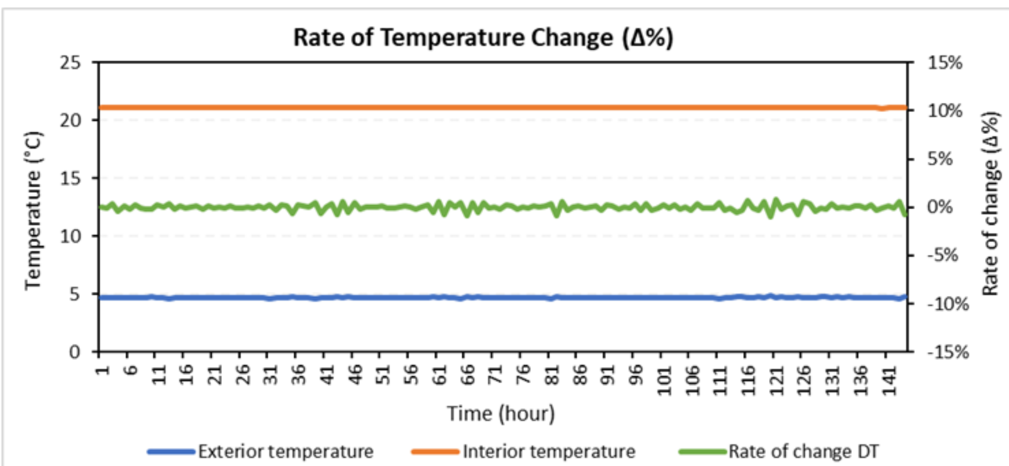


Figure 12. Rate of temperature change (%) during the U-Value measurements.

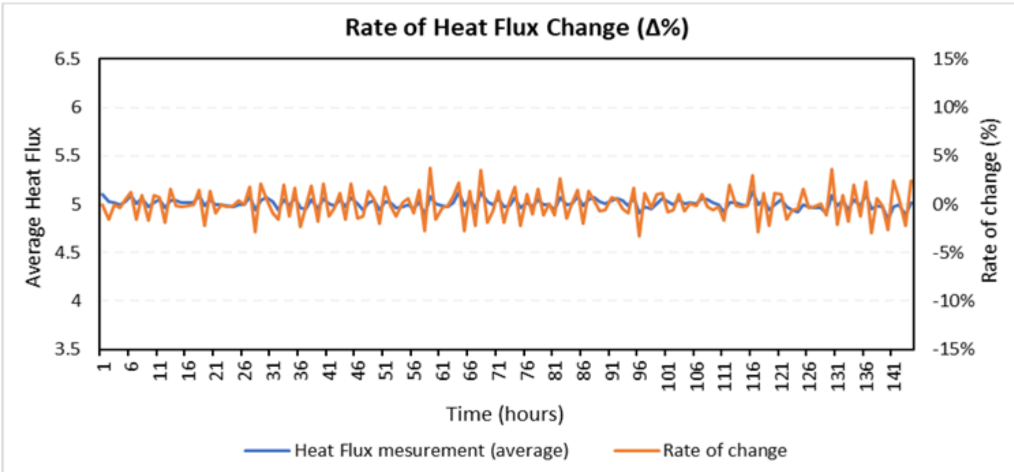


Figure 13. Rate of heat flux change (%) during the U-Value measurements

3.2. Heat Transfer Coefficient (HTC) Results

The Co-heating test results indicated that the HTC of the Vector V1 was **59.1 (±4.8) W/K.** Although this is lower than the design value of **67.2 W/K**[6], it should be noted this value has used the default thermal bridging values from SAP. The thermographic survey suggests greater levels of bridging at junctions, which should have been accounted for in the design value. As such, a direct comparison should not be made. Figure 14 below are the measurements for the HTC.

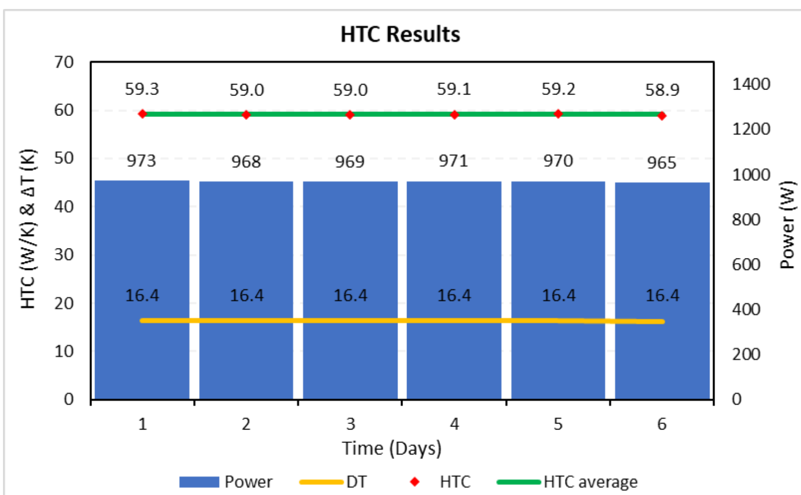


Figure 14. Heat Transfer Coefficient (HTC) results.

[6] SAP Document Box 39 (Appendix F)

Figure 14 shows that to maintain an indoor temperature of 21 °C at a chamber temperature of 5 °C, an average daily power input of ~**970 W** is needed, which reflects a stable HTC measurement. The HTC indicates that to maintain a 1 K temperature difference over the building envelope, **59.1 W** of heating power is required.

3.3. U-value Measurements

In-situ U-value measurements were undertaken on selected thermal elements in Vector V1 in accordance with ISO 9869 [4] .

3.3.1. Floor

In situ U-value measurements of the floor were taken at nine locations, distributed on a 3x3 grid in the Kitchen (Figure 14). The average U-values measured for the floor region are **0.38 (±0.03) W/m²K**. The design U-value was **0.12 W/m²K** (Appendix F).

3.3.2. Windows and Door

It is difficult to assign a figure to the window and door performance that can be used to directly compare with the design performance. Firstly, we did not have the full window U-value calculation, which would generally detail the thermal performance of the frame and glazed element separately. We have SAP values; however, these are generally for typically sized windows and not specific to the Vector V1. If we consider only centre pane values, then the data suggests that the windows appeared to meet their design U-value.

The average U-value measured for the centre pane for windows was **1.21 (±0.05) W/m²K** and the design U-value was **1.26 W/m²K** (Appendix F).

The average U-value measured for the centre pane for the french doors was **1.23 (±0.06) W/m²K** and the design U-value was **1.26 W/m²K** (Appendix F).

For the GRP composite door, the measured and design U-values were the same with **0.52 (±0.02) W/m²K** (Appendix F). It should be noted that only one HFP was used for this measurement, located at the centre of the door.

3.3.3. External Walls

During both phases, in-situ U-value measurements were taken at 10 locations between the metal framed structure and one location on the metal frame. Heat Flux Plates (HFPs) were distributed in a 3x3 grid with an additional HFP to measure the heat flux of the metal frame. Figure 11 shows the locations of the HFPs on the external wall.

The average U-values measured for the external walls are **0.32 (±0.11) W/m²K**. The design U-value is **0.12 W/m²K** (Appendix F).

A stratification in the measured U-value of the external wall was observed (Table 13), with greater heat flux (and therefore U-value) measured using the three lower HFPs, reducing with the middle three HFPs, and reducing further at the top three HFPs. This could indicate thermal bypass within the wall, with cold air infiltrating the wall at the bottom, and being heated as it rises towards the top.

3.3.4. Ceiling

In situ U-value measurements of the ceiling were taken at nine locations between the timber frame and at one location on the timber joist component. Figure 14 shows the locations of the HFPs on the ceiling of Vector V1. The measured U-value of the ceiling is **0.15 (±0.04) W/m²K,** which is greater than the design value of **0.09 (±0.05) W/m²K** (Appendix F).

More details on the U-value measurements can be found in Appendix D .

3.3.5. Airtightness and Ventilation

Table 5 shows the AP_{50} value measured using the blower door test. The test was carried out under the same conditions as the U-value measurement, 5 °C for the chamber temperature and 21 °C for the indoor temperature. The blower door test measured an air permeability rate of **4.4 m³/h·m² @ 50 Pa**, slightly better than the design value of **5.0 m³/h·m² @ 50 Pa**. Table 5 below shows the blower door results and compares them to design values.

Table 5. Air-tightness results using the blower door method for Vector V1

Results	Design	Blower Door	Difference to design	Difference to design (%)
Air permeability [AP_{50}] ($m^3h^{-1}m^{-2}$ @ 50 Pa)	5.0	4.4	-0.6	11.9
Air change rate [n_{50}] (ACH @ 50 Pa)	7.4	6.5	0.9	11.8
Infiltration rate [n] (h^{-1})	0.5	0.3	-0.1	28.3
Infiltration heat loss (W/K)	11.6	10.3	1.3	11.6

3.4. Thermography

An air infiltration investigation was performed on Vector V1 following the blower door test. 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 presentation test with a pressure differential of 50 Pa. The results of the thermographic survey are illustrated in the figures below.

Interior Spaces

Figure 15 below shows the Living Room floor under no artificially induced pressure differential. Figure 16 below shows the Living Room floor under the depressurisation test.

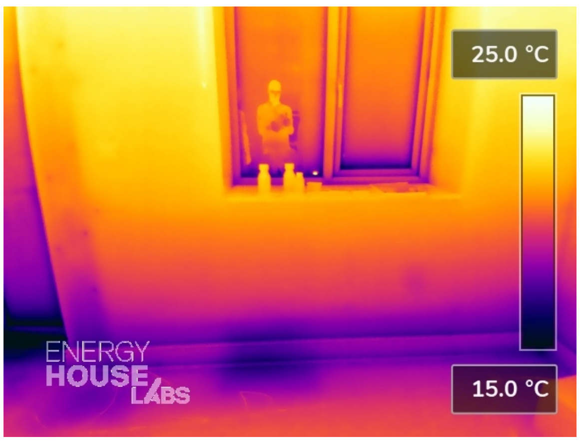


Figure 15. The Living Room floor under no artificially induced pressure differential

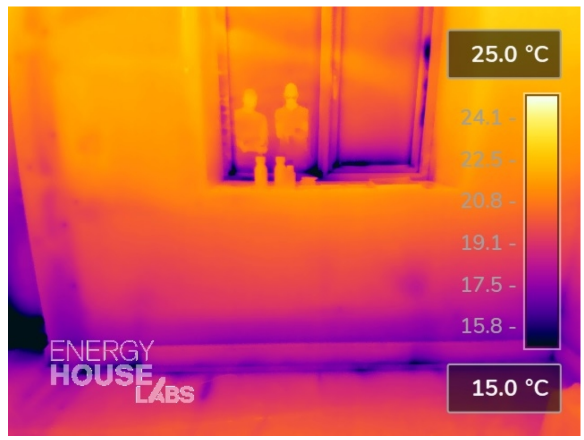


Figure 16. The Living Room floor under depressurisation test

The figures above compare the floor and window of the Living Room of Vector V1 without artificially induced pressure differential (Figure 15) and during the depressurization test of the blower door (Figure 16). In both figures cold areas can be seen around the floor and the edges of the window, indicating poor insulation distribution around these areas. During the depressurization test (Figure 16), areas of air movement are visible in both the window and floor of the Living Room of Vector V1. This air movement can be seen across the entire floor area of Vector V1, indicating poor insulation or insulation deficiency in the floor area.

Figure 17 and Figure 18 below show the french door before and during the pressurisation test of the blower door, respectively.

Figure 17. The french door under no artificially induced pressure differential

Figure 18. The french door under depressurisation test

Figure 17 and Figure 18 compare the french door of Vector V1 without artificially induced pressure differential and during the depressurization test of the blower door. Cold areas are visible around the floor and warmer areas are closer to the ceiling, with a temperature difference of 10 °C. When a pressure difference of -50 Pa was introduced, air movement patterns became visible around the floor, the french door frame, and the window of Vector V1, indicating areas of potential air leakage and insulation deficiencies.

Exterior spaces

Figure 19 - Figure 22 show the exterior of Vector V1 before and during the pressurisation test, respectively.

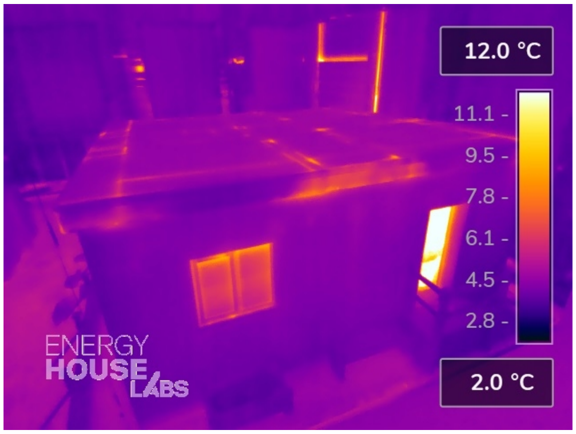


Figure 19. Exterior view of Vector V1 under no artificially induced pressure differential

Figure 20. Exterior view of Vector V1 during pressurisation test

Figure 21. Exterior view of Vector V1 roof under no artificially induced pressure differential

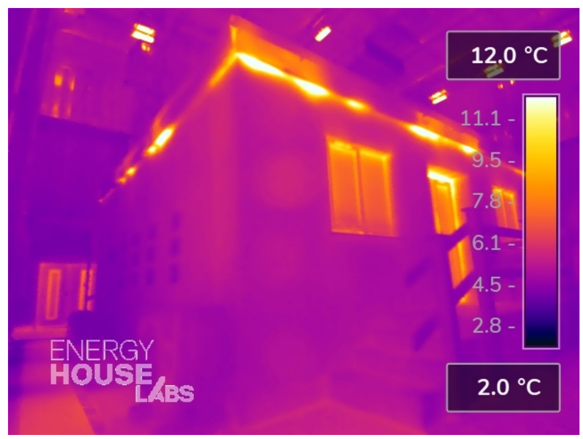


Figure 22. Exterior view of Vector V1 roof during pressurisation test

The figures above are thermal images showing an exterior view of the Vector V1 before and during the pressurisation test of the blower door. The temperature scale on the right indicates a range from 2.0 °C to 12.0 °C, with colour gradients representing different temperatures. Warmer areas (yellow to orange hues) around the windows, the studs, and the roof suggest potential points of heat loss, where warm air from inside the house is escaping. The significant temperature difference between these warmer areas and the cooler exterior surfaces highlights insulation weaknesses, thermal bridges, and air leakage points. This temperature variation indicates that the insulation quality and air sealing are inconsistent across the exterior of the house.

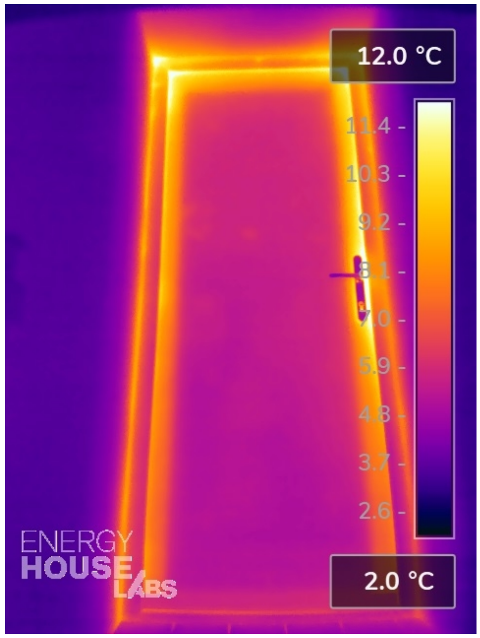


Figure 23. Exterior view of Vector V1 GRP composite door under no artificially induced pressure differential

The figures above show the main door of Vector V1 without artificially induced pressure differential. Greater levels of heat loss can be observed around the perimeter of the GRP composite door, this may be attributed to thermal bridging and air leakage. However, air leakage cannot be confirmed without the induced pressure differential.

4. Discussion

In this report, we reported on the fabric performance of Vector V1 prototype studio built by Vector Homes. The measurements included Heat Transfer Coefficients (HTC) of the whole house, airtightness, U-value measurements of the envelope, and a thermographic survey.

The HTC was measured as **59.1 (±4.8) W/K.** Although this is lower than the design value of **67.2 W/K**[7], it should be noted this value has used the default thermal bridging values from SAP. The thermographic survey suggests greater levels of bridging at junctions, which should have been accounted for in the design value. As such, a direct comparison should not be made.

This section will provide a breakdown of the performance gap of Vector V1. Table 6 shows the results of the U-value measurements and compares them to the design values provided by Vector Homes.

Table 6. U-value performance gap (design and as-built measurements)

Element	Area (m^2)	Design		As-built		Performance Gap	
		U-value (W/m^2K)	Heat loss (W/K)	U-value (W/m^2K)	Heat loss (W/K)	Absolute (W/K)	Percent (%)
Windows	5.01	1.24	6.19	1.21	6.06	**-0.1**	**-2%**
GRP Composite Door	1.88	0.59	1.10	0.52	0.98	**-0.1**	**-11%**
French door	2.54	1.33	3.37	1.23	3.12	**-0.2**	**-7%**
Floor	40.51	0.12	4.86	0.38	15.39	**10.5**	**217%**
External walls	50.53	0.12	6.06	0.32	16.14	**10.1**	**166%**
Ceiling	40.51	0.09	3.65	0.15	6.08	**2.4**	**67%**

Table 6 compares the design and measured U-values of different elements of Vector V1. The table showed a performance gap between the measured and design U-values, with up to **217%** for the floor, **166%** for the external walls and **67%** for the ceiling. These results will be used to calculate the heat losses from fabric and from ventilation to calculate the overall performance gap.

[7] SAP Document Box 39 (Appendix F)

5. Conclusion

This report details the fabric performance of the Vector V1 prototype studio constructed by Vector Homes. The performance was assessed based on several parameters, including:

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

The HTC was measured as **59.1 (±4.8) W/K.** Although this is lower than the design value of **67.2 W/K**[8], it should be noted this value has used the default thermal bridging values from SAP. The thermographic survey suggests greater levels of bridging at junctions, which may not have been accounted for in the SAP design value. As such, a direct comparison should not be made.

An air permeability rate of **4.4 $m^3/h \cdot m^2$ @ 50 Pa**, was lower than the design value of **5.0 $m^3/h \cdot m^2$ @ 50 Pa**.

The U-values of the **floor, external wall and ceiling were respectively 217%, 166% and 67% *greater* than the design**. The U-values of all fenestrations were between 2-11% *lower* than the design, it should be noted these are centre pane U-values in the case of the windows and french doors.

The U-value measurements were repeated due to discrepancies between the calculated and measured values for the external walls and floor. The results from the second set of U-value measurements (Phase 2) are presented in Appendix A.

Future investigation should focus on identifying the causes of these performance gaps by examining construction practices, material selection, and potential thermal bridging. Additionally, the following recommendations are made:

- Addressing air leakage pathways and heat loss points identified in the thermographic survey could improve airtightness and further reduce infiltration heat losses.

- Although Phase 2 measurements showed improvements, the U-value performance gap was not completely resolved, suggesting the need for a more thorough review of the

[8] SAP Document Box 39 (Appendix F)

design calculations and the as-built building.

- The fabric upgrades were limited to small areas, so upgrading the entire house and re-measuring may provide clearer insights and help eliminate the performance gap.

References

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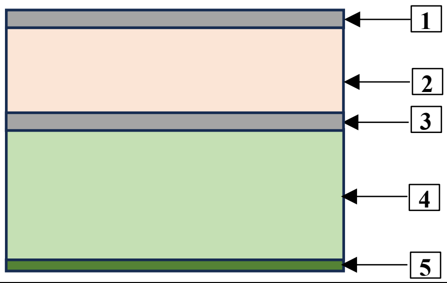
Appendix A - Phase 2 U-values of remedial works

Design

Floor

Table 2 shows the upgraded floor design and materials (Phase 2) of the Vector V1 prototype studio as provided by Vector Homes. It should be noted the floor covering has been discounted in these calculations but were included in the measurements. Given the type of covering and thickness, this will have little effect.

Table 7. Phase 2 upgraded floor design and materials of the Vector V1

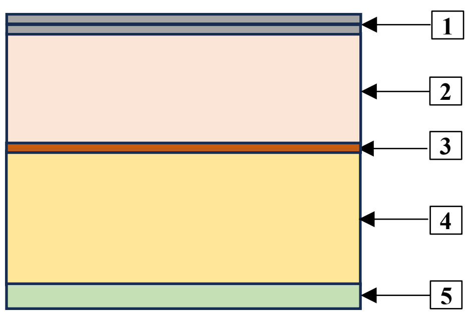


	Material	λ (W/m.K)	Thickness (mm)
1	**OSB**	0.13	18.00
2	**Mineral wool**	0.04	180.00
3	**OSB**	0.13	12.00
4	**Insulation**	0.05	270.00
5	**Panel**	1.00	2.00
	Calculated U-value (W/m².K) = 0.09		

External Wall

Table 8 below shows the upgraded wall design and materials (Phase 2) of the Vector V1 prototype studio, as provided by Vector Homes.

Table 8. Phase 2 external wall design and materials of the Vector V1



	Material	λ (W/m.K)	Thickness(mm)
1	Plasterboard	0.16	12.50
1	Plasterboard	0.16	12.50
2	Mineral Wool	0.03	200.00
3	OSB	0.13	12.00
4	Insulation	0.05	270.00
5	Render	0.76	20.00
	Calculated U-value (W/m².K) = 0.08		

Measurement Location

This section shows the locations of the U-value measurements, highlighting the differences between the initial (Phase 1) and upgraded materials and designs (Phase 2).

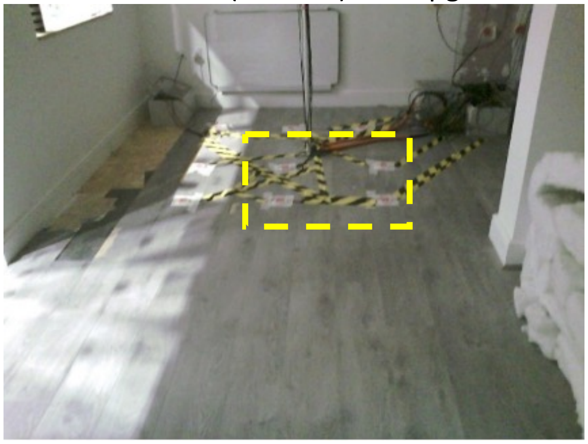


Figure 24. Phase 2 heat flux measurements - floor

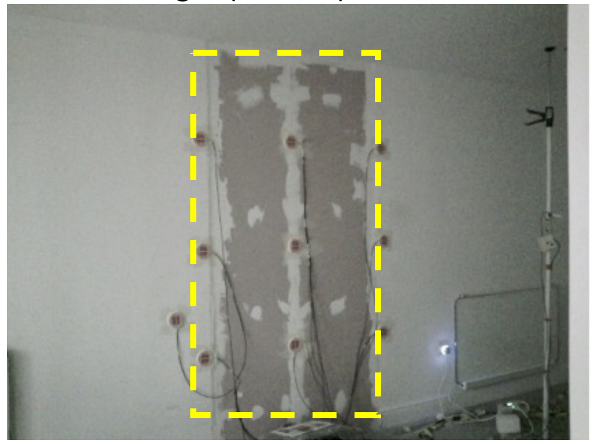


Figure 25. Phase 2 heat flux measurements – wall

Results

Floor

In situ U-value measurements of the floor were taken at nine locations, distributed on a 3x3 grid in the Kitchen (Figure 24). The average U-values measured for the floor region was **0.19 (±0.03) W/m^{2}K** during the second phase. This is a 50% reduction on the Phase 1 U-value; however, it is 111% greater than the design value (Table 7).

External Wall

In-situ U-value measurements were taken at 10 locations between the metal framed structure and one location on the metal frame. Heat Flux Plates (HFPs) were distributed in a 3x3 grid with an additional HFP to measure the heat flux of the metal frame. Figure 25 shows the locations of the HFPs on the external wall.

The average U-values measured for the external walls were **0.14 (±0.10) W/m^{2}K** for Phase 2. This is a 53% reduction on the Phase 1 U-value; however, it is 75% greater than the design value (Table 8).

Appendix B - Energy House Labs

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. Figure 26 below show an external view the EH 2.0 facility. Figure 27 shows an inside view of Chamber 2 with Vector V1.

Figure 26. External view of EH 2.0

Figure 27. Inside view of Chamber 2 of EH 2.0

Appendix C - HTC Setup

The HTC is defined in ISO 13789:2017 [12] as "*the sum of transmission and ventilation heat transfer coefficients of a building, where the transmission Heat Transfer Coefficient represents heat flow rate due to thermal transmission through the fabric of a building, divided by the difference between the environment temperatures on either side of the construction and the ventilation Heat Transfer Coefficient represents heat flow rate due to air entering a conditioned space either by infiltration or ventilation, divided by the temperature difference between the internal air and the supply (external) air temperature*".

To obtain the HTC, a Co-heating test was carried out. During the test, to increase the homogeneity of the air temperature inside the house, air circulation fans were used, which remained in the same location and at the minimum speed setting during the test as in the Figure 28. This setting allows for the air to be mixed but without significantly altering any surface resistance to the external elements. The fans and heaters were positioned in such a way that they do not directly affect the temperature sensors.

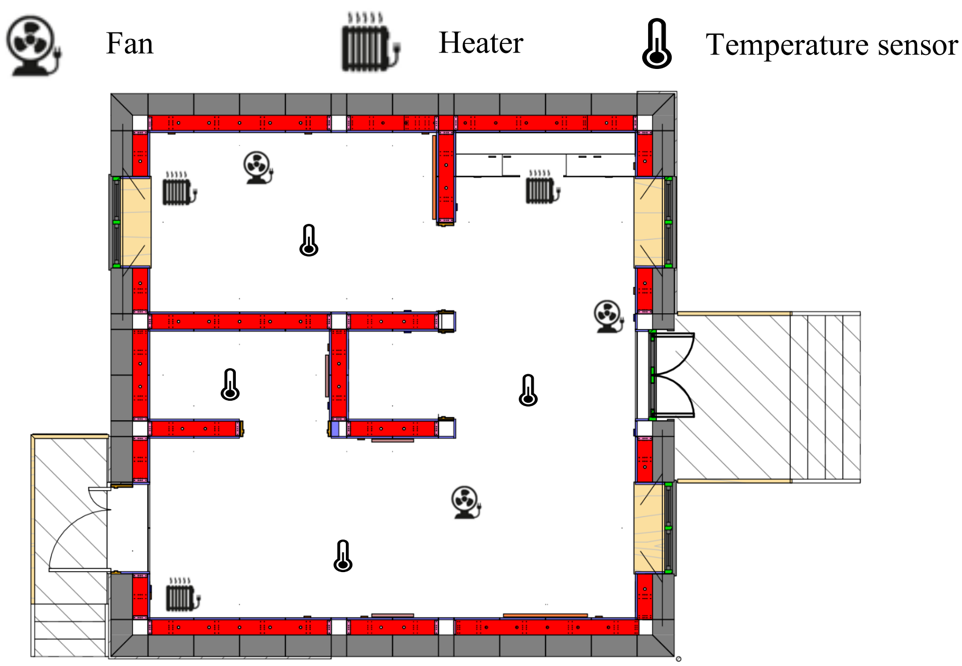


Figure 28. Heater and fan locations during the Co-heating test

Table 9 shows the average daily power (based on energy consumption), the average temperature difference for each of the test days and the daily and average measured HTC. The Measured HTC is than compared to the design HTC obtained from the SAP Document Box 39 (Appendix F).

Table 9. Results of the HTC of Vector V1

DAY	Power (W)	ΔT (K)	HTC (W/K)
1	973	16.4	59.3 (±2.85)
2	968	16.4	59.0 (±2.85)
3	969	16.4	59.0 (±2.85)
4	971	16.4	59.1 (±2.85)
5	970	16.4	59.2 (±2.85)
Design HTC*			**67.2***
Average (measure) HTC			**59.1 (±4.8)**
Difference to Design (W/K)			**8.1**
Difference to Design (%)			**12.1**

**SAP Document Box 39 (Appendix F)*

Appendix D - U-value measurements

Table 12. below shows the HFPs locations used for the U-value measurements, summarizes the results of the in-situ U-value measurements during Phase 1 and Phase 2 and compares them to the design U-value for each measured element. The detail of the calculation of the U-values for each of the elements in-situ can be found in the following section.

Table 10. Design U-Values, HFPs locations and measured U-Values.

Element	Design U-value (W/m^2K)	Measurement Locations	Measured U-value (W/m^2K)-Phase 1	Measured U-value (W/m^2K)-Phase 2
French Door	1.32	1	1.22	1.22
GRP Composite Door	0.59	1	0.52	0.52
Windows	1.23	5	1.22	1.22
Floor	0.12	9	0.38	0.19
External Walls	0.12	9	0.30	0.11
External Walls (Stud)	-	1	0.43	0.43
Ceiling	0.09	9	0.15	0.14
Ceiling (Stud)	-	1	0.17	0.21

Floor

Table 11. Measured U-Values of the floor in comparison with design U-Value.

HFP	Design U-value (W/m^2K)	Measured U-value (W/m^2K)-Phase 1	Measured U-value (W/m^2K)-Phase 2
1	-	0.33 (±0.04)	0.17 (±0.04)
2	-	0.32 (±0.04)	0.15 (±0.04)
3	-	0.48 (±0.04)	0.18 (±0.04)
4	-	0.33 (±0.04)	0.17 (±0.04)
5	-	0.33 (±0.04)	0.16 (±0.04)
6	-	0.49 (±0.04)	0.22 (±0.04)
7	-	0.41 (±0.04)	0.25 (±0.04)
8	-	0.39 (±0.04)	0.21 (±0.04)
9	-	0.38 (±0.04)	0.24 (±0.04)
U-value Average (W/m^2K)	**0.12**	**0.38 (±0.06)**	**0.19 (±0.03)**

Windows and Door

The measurements of windows and doors U-value are provided in Table.16 below.

Table 12. Measured U-Values of the windows and door in comparison with design U-Value.

HFP	Design centre pane (W/m^2K)	Measured centre pane (W/m^2K)
Window top	1.23	1.13 (±0.05)
Window centre pane*	1.23	1.21 (±0.05)
Window bottom	1.23	1.25 (±0.06)
French door centre pane*	1.32	1.23 (±0.06)
French door bottom	1.32	1.12 (±0.05)
GRP Composite Door*	0.59	0.52 (±0.02)

**Indicates values used in report*

External Walls

Table 13. In-situ U-values of the external walls in comparison with design U-values

HFP	Design U-value (W/m^2K)	Measured U-value (W/m^2K)-Phase 1	Measured U-value (W/m^2K)-Phase 2
1	-	0.19 (±0.04)	0.08 (±0.04)
2	-	0.19 (±0.04)	0.08 (±0.04)
3	-	0.19 (±0.04)	0.10 (±0.04)
4	-	0.27 (±0.04)	0.11 (±0.04)
5	-	0.25 (±0.04)	0.10 (±0.04)
6	-	0.28 (±0.04)	0.11 (±0.04)
7	-	0.44 (±0.04)	0.14 (±0.04)
8	-	0.45 (±0.04)	0.13 (±0.04)
9	-	0.44 (±0.04)	0.13 (±0.04)
10 (Metal frame)	-	0.43 (±0.04)	0.43 (±0.04)
Average U-value (W/m^2K)[9]	**0.12**	**0.30 (±0.11)**	**0.14 (±0.10)**

[9] Using weighted average using 15% of the metal frame

Ceiling

Table 14. In-situ U-values of the ceiling in comparison with design U-value

HFP	Design U-value (W/m²K)	Measured U-value (W/m²K)-Phase 1	Measured U-value (W/m²K)-Phase 2
1	-	0.11 (±0.04)	0.10 (±0.04)
2	-	0.10 (±0.04)	0.11 (±0.04)
3	-	0.07 (±0.04)	0.09 (±0.04)
4	-	0.15 (±0.04)	0.12 (±0.04)
5	-	0.20 (±0.04)	0.17 (±0.04)
6	-	0.14 (±0.04)	0.12 (±0.04)
7	-	0.17 (±0.04)	0.21 (±0.04)
8	-	0.22 (±0.04)	0.21 (±0.04)
9	-	0.17 (±0.04)	0.16 (±0.04)
10 (Timber joist)	-	0.17 (±0.04)	0.21 (±0.04)
Average U-value (W/m²K)	**0.09**	**0.15 (±0.04)**	**0.14 (±0.05)**

Appendix E – SAP Summary Sheet

Scotframe

Estimating/Design SAP Summary Sheet

Customer Name	Vector Homes Ltd
Customer Address	126 Park Road, Manchester,
	Greater Manchester, UK
	M25 0DU

Scotframe Ref No	Option 1
Assessment By	Alan Brodie
Date	23/08/2023
Revision	0

Property Information

Site Address	Energy House 2.0, University of Salford, Manchester, M6 6PU

Property Type	Bungalow Unit	Storeys	1

Construction Details

Floor Types	Reference	U-Value	Construction - Inside to Outside
Ground Floor	FT1	0.12	12mm OSB3 / 50 mm Thermafleece (within structural cavity) / 12mm OSB3 / FR rated foam 270mm (K = 0.05 W/m.K) / Graphene composite sheet 2mm (K = 0.35 W/m.K) / 200 mm raised floor

Wall Types:	Reference	U-Value	Construction - Inside to Outside
External Wall	WT1	0.12	Terrix render system (total thickness = 15mm) / FR rated foam 270 mm (K= 0.05 W/m.K) / 12mm OSB3 / 100 mm felt (within structural cavity / Plasterboard (15 mm) x2 / Internal Terrix spray render (5 mm)

Roof Types:	Reference	U-Value	Construction - Inside to Outside
Flat Roof	RT1	0.09	1.2mm EPDM Rubber Roof Membrane / Graphene composite sheet 2mm (K= 0.35 W/m.K) FR rated foam 270 mm (K = 0.05 W/m.K) / 18mm OSB3 / 200 mm felt (within structural cavity) / Gyprock board (12.5 mm) x2 / Internal Terrix spray render (5 mm)

Window Type	uPVC	Front Door Type	GRP Composite
Window U Value	1.30 W/m^{2}K	Door U Value	0.60 W/m2K
Rear Door Type	N/A	Sliding Door Type	N/A
Door U Value	N/A	Door U Value	N/A
French Door Type	uPVC	Rooflight Type	N/A
Door U Value	1.40 W/m2K	Rooflight U Value	N/A

Primary Heating System

Heating Type	
Manufacturer	
Model	

Output Power @ 4.7°C	N/A	Pump in heated Space	N/A
Boiler Interlock	N/A	Delayed Start Thermostat	N/A

Heating Emitter	Panel Heater
Heating Controls	Programmer and Room Thermostat
Electric Tariff	Standard

Secondary Heating System

Heating Type	N/A
Manufacturer	N/A
Model	N/A

Hot Water System

Cylinder Make	Heatraesadia	Cylinder in Heated Space	Yes

Appendix F – SAP Document – Heat Losses

Full SAP Calculation Printout

elmhurst energy

Property Reference	Vector Homes	Issued on Date	23/08/2023
Assessment Reference	00001	Prop Type Ref	Prototype
Property	Energy House 2.0, University of Salford, Manchester, M6 6PU		

SAP Rating	60 D	DER	13.29	TER	14.56
Environmental	92 A	% DER < TER			8.72
CO_2 Emissions (t/year)	0.51	DFEE	60.61	TFEE	50.89
Compliance Check	See BREL	% DFEE < TFEE			-19.11
% DPER < TPER	-78.43	DPER	138.69	TPER	77.73

Assessor Details	Mr. Alan Brodie	Assessor ID	AX18-0001
Client			

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---------------------------------------------------------------------------------------------------
SAP 10 WORKSHEET FOR New Build (As Designed)   (Version 10.2, February 2022)
CALCULATION OF DWELLING EMISSIONS FOR REGULATIONS COMPLIANCE
---------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------

---------------------------------------------------------------------------------------------------
1. Overall dwelling characteristics
---------------------------------------------------------------------------------------------------
                                                                    Area        Storey height              Volume
                                                                    (m2)                  (m)               (m3)
Ground floor                                                     40.5100 (1b)    x     2.3500 (2b)    =    95.1985 (1b) -
Total floor area TFA = (1a)+(1b)+(1c)+(1d)+(1e)...(1n)           40.5100                                           (4)
Dwelling volume                                                         (3a)+(3b)+(3c)+(3d)+(3e)...(3n) =  95.1985 (5)

---------------------------------------------------------------------------------------------------
2. Ventilation rate
---------------------------------------------------------------------------------------------------
                                                                                                  m3 per hour

Number of open chimneys                                                                  0 * 80 =      0.0000 (6a)
Number of open flues                                                                     0 * 20 =      0.0000 (6b)
Number of chimneys / flues attached to closed fire                                       0 * 10 =      0.0000 (6c)
Number of flues attached to solid fuel boiler                                            0 * 20 =      0.0000 (6d)
Number of flues attached to other heater                                                 0 * 35 =      0.0000 (6e)
Number of blocked chimneys                                                               0 * 20 =      0.0000 (6f)
Number of intermittent extract fans                                                      2 * 10 =     20.0000 (7a)
Number of passive vents                                                                  0 * 10 =      0.0000 (7b)
Number of flueless gas fires                                                             0 * 40 =      0.0000 (7c)

                                                                                          Air changes per hour
Infiltration due to chimneys, flues and fans   = (6a)+(6b)+(6c)+(6d)+(6e)+(6f)+(6g)+(7a)+(7b)+(7c) =   20.0000 / (5) =   0.2101 (8)
Pressure test                                                                                                  Yes
Pressure Test Method                                                                                   Blower Door
Measured/design AP50                                                                                        5.0000 (17)
Infiltration rate                                                                                           0.4601 (18)
Number of sides sheltered                                                                                        0 (19)

Shelter factor                                                          (20) = 1 - [0.075 x (19)] =         1.0000 (20)
Infiltration rate adjusted to include shelter factor                        (21) = (18) x (20) =            0.4601 (21)

                 Jan      Feb      Mar      Apr      May      Jun      Jul      Aug      Sep      Oct      Nov      Dec
Wind speed     5.1000   5.0000   4.9000   4.4000   4.3000   3.8000   3.8000   3.7000   4.0000   4.3000   4.5000   4.7000 (22)
Wind factor    1.2750   1.2500   1.2250   1.1000   1.0750   0.9500   0.9500   0.9250   1.0000   1.0750   1.1250   1.1750 (22a)
Adj infilt rate
               0.5866   0.5751   0.5636   0.5061   0.4946   0.4371   0.4371   0.4256   0.4601   0.4946   0.5176   0.5406 (22b)
Effective ac   0.6721   0.6654   0.6588   0.6281   0.6223   0.5955   0.5955   0.5906   0.6058   0.6223   0.6340   0.6461 (25)

---------------------------------------------------------------------------------------------------
3. Heat losses and heat loss parameter
---------------------------------------------------------------------------------------------------
Element                                      Gross     Openings      NetArea      U-value       A x U      K-value       A x K
                                                m2           m2           m2        W/m2K         W/K       kJ/m2K        kJ/K
uPVC Windows (Uw = 1.30)                                             5.0100       1.2357      6.1911                        (27)
French Door (Uw = 1.40)                                              2.5400       1.3258      3.3674                        (27)
GRP Composite Door (Uw = 0.60)                                       1.8800       0.5859      1.1016                        (27)
Heatloss Floor 1                                                    40.5100       0.1200      4.8612       0.0000      0.0000 (28a)
External Wall 1                            59.9600       9.4300     50.5300       0.1200      6.0636      14.0000    707.4200 (29a)
External Roof 1                            40.5100                  40.5100       0.0900      3.6459       9.0000    364.5900 (30)
Total net area of external elements Aum(A, m2)                     140.9800                                                 (31)
Fabric heat loss, W/K = Sum (A x U)                             (26)...(30) + (32) =          25.2308                        (33)
```

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Full SAP Calculation Printout

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```
Internal Wall 1                                                     54.3600                              9.0000      489.2400 (32c)

Heat capacity Cm = Sum(A x k)                                                       (28)...(30) + (32) + (32a)...(32e) =   1561.2500 (34)
Thermal mass parameter (TMP = Cm / TFA) in kJ/m2K                                                                          38.5399 (35)
List of Thermal Bridges
        K1 Element                                                                        Length      Psi-value       Total
        E5 Ground floor (normal)                                                          25.4600        0.3200       8.1472
        E14 Flat roof                                                                     25.4600        0.1600       4.0736
        E16 Corner (normal)                                                                9.4000        0.1800       1.6920
        E2 Other lintels (including other steel lintels)                                   6.0000        1.0000       6.0000
        E3 Sill                                                                            3.5900        0.1000       0.3590
        E4 Jamb                                                                           19.9200        0.1000       1.9920
Thermal bridges (Sum(L x Psi) calculated using Appendix K)                                                                22.2638 (36)
Point Thermal bridges                                                                                         (36a) =      0.0000
Total fabric heat loss                                                                                (33) + (36) + (36a) =     47.4946 (37)

Ventilation heat loss calculated monthly (38)m = 0.33 x (25)m x (5)
                 Jan        Feb        Mar        Apr        May        Jun        Jul        Aug        Sep        Oct        Nov        Dec
(38)m          21.1130    20.9031    20.6974    19.7310    19.5502    18.7086    18.7086    18.5527    19.0328    19.5502    19.9160    20.2984 (38)
Heat transfer coeff
               68.6075    68.3977    68.1919    67.2256    67.0448    66.2031    66.2031    66.0473    66.5273    67.0448    67.4105    67.7929 (39)
Average = Sum(39)m / 12 =                                                                                                   67.2247

                 Jan        Feb        Mar        Apr        May        Jun        Jul        Aug        Sep        Oct        Nov        Dec
HLP             1.6936     1.6884     1.6833     1.6595     1.6550     1.6342     1.6342     1.6304     1.6422     1.6550     1.6640     1.6735 (40)
HLP (average)                                                                                                                 1.6595
Days in mont        31         28         31         30         31         30         31         31         30         31         30         31



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4. Water heating energy requirements (kWh/year)
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Assumed occupancy                                                                                                             1.4200 (42)
Hot water usage for mixer showers
                0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (42a)
Hot water usage for baths
                0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (42b)
Hot water usage for other uses
               29.1718    28.1110    27.0502    25.9894    24.9286    23.8678    23.8678    24.9286    25.9894    27.0502    28.1110    29.1718 (42c)
Average daily hot water use (litres/day)                                                                                     26.5198 (43)

                 Jan        Feb        Mar        Apr        May        Jun        Jul        Aug        Sep        Oct        Nov        Dec
Daily hot water use
               29.1718    28.1110    27.0502    25.9894    24.9286    23.8678    23.8678    24.9286    25.9894    27.0502    28.1110    29.1718 (44)
Energy conte   46.2010    40.0297    41.5751    35.5782    33.5587    29.3483    28.8660    30.8668    32.0475    36.7068    40.0492    45.6759 (45)
Energy content (annual)                                                                                 Total = Sum(45)m =    440.5033
Distribution loss  (46)m = 0.15 x (45)m
                6.9301     6.0044     6.2363     5.3367     5.0338     4.4022     4.3299     4.6300     4.8071     5.5060     6.0074     6.8514 (46)
Water storage loss:
Store volume                                                                                                                125.0000 (47)
a) If  manufacturer declared loss factor is known  (kWh/day):                                                                 1.0500 (48)
  Temperature factor from Table 2b                                                                                            0.6000 (49)
Enter (49) or (54) in (55)                                                                                                    0.6300 (55)
Total storage loss
               19.5300    17.6400    19.5300    18.9000    19.5300    18.9000    19.5300    19.5300    18.9000    19.5300    18.9000    19.5300 (56)
If cylinder contains dedicated solar storage
               19.5300    17.6400    19.5300    18.9000    19.5300    18.9000    19.5300    19.5300    18.9000    19.5300    18.9000    19.5300 (57)
Primary loss    0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (59)
Combi loss      0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (61)
Total heat required for water heating calculated for each month
               65.7310    57.6697    61.1051    54.4782    53.0887    48.2483    48.3960    50.3968    50.9475    56.2368    58.9492    65.2059 (62)
WWHRS           0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (63a)
PV diverter     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (63b)
Solar input     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (63c)
FGHRS           0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (63d)
Output from w/h
               65.7310    57.6697    61.1051    54.4782    53.0887    48.2483    48.3960    50.3968    50.9475    56.2368    58.9492    65.2059 (64)
                                                                                    Total per year (kWh/year) = Sum(64)m =   670.4533 (64)
12Total per year (kWh/year)                                                                                                     670 (64)
Electric shower(s)
               50.4022    44.9088    49.0387    46.7970    47.6751    45.4774    46.9933    47.6751    46.7970    49.0387    48.1165    50.4022 (64a)
                                              Total Energy used by instantaneous electric shower(s) (kWh/year) = Sum(64a)m =   573.3220 (64a)
Heat gains from water heating, kWh/month
               43.5864    38.6491    41.7074    38.6490    38.7010    36.2477    36.9703    37.8060    37.4750    40.0887    40.4655    43.4118 (65)



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5. Internal gains (see Table 5 and 5a)
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Metabolic gains (Table 5), Watts
                 Jan        Feb        Mar        Apr        May        Jun        Jul        Aug        Sep        Oct        Nov        Dec
(66)m          70.9978    70.9978    70.9978    70.9978    70.9978    70.9978    70.9978    70.9978    70.9978    70.9978    70.9978    70.9978 (66)
Lighting gains (calculated in Appendix L, equation L9 or L9a), also see Table 5
               61.9477    68.5849    61.9477    64.0126    61.9477    64.0126    61.9477    61.9477    64.0126    61.9477    64.0126    61.9477 (67)
Appliances gains (calculated in Appendix L, equation L13 or L13a), also see Table 5
              122.8182   124.0927   120.8810   114.0439   105.4132    97.3016    91.8825    90.6080    93.8197   100.6568   109.2875   117.3991 (68)
Cooking gains (calculated in Appendix L, equation L15 or L15a), also see Table 5
               30.0998    30.0998    30.0998    30.0998    30.0998    30.0998    30.0998    30.0998    30.0998    30.0998    30.0998    30.0998 (69)
Pumps, fans     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000     0.0000 (70)
Losses e.g. evaporation (negative values) (Table 5)
              -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982   -56.7982 (71)
Water heating gains (Table 5)
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