Saint Gobain & Barratt Developments "eHome2"
Baseline Performance Report

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1. Introduction

This report will provide the initial results from a larger piece of research on Future Homes. This research consists of a study of two future homes under controlled conditions at the Energy House 2.0 research facility at the University of Salford.
This first report will present the findings of the fabric performance of a plot called "eHome2", this house was delivered through a partnership of Saint-Gobain and Barratt Developments. This will be followed by other reports focussing on space heating, domestic hot water, overheating, thermal comfort and smart systems.

2. Executive Summary

The "**eHome2**" constructed by Saint-Gobain and Barratt Developments is a research project, consisting of innovative fabric design, multiple heating, hot water and ventilation systems, and advanced controls. The eHome2 is designed by Barratt and is a reproduction, although with minor changes, of the "Moresby" housing type that is currently being sold by Barratt and is in line with Nationally Described Space Standard (NDSS) and Approved Document Part M Category 2. The research task covered in this report was to study the performance of the fabric of eHome2.

The research was undertaken at two levels. The first level was to measure the fabric performance of the whole house to establish if it performs as designed. The second level was to measure the performance of individual fabric performance of elements of the house to establish their individual contribution to performance as a whole.

Research in the past has found significant issues with the performance gap in some new build homes in the UK. A study by Leeds Beckett University (LBU) established fabric performance gaps of 5% - 140% in a sample of 30 new build homes [1]. The performance gap can be caused by many different issues, including poor construction, substitutions of materials, incorrect assumptions by energy models/experts, and homes not being used by homeowners as predicted.

Barratt and Saint-Gobain have used this past research to design and construct eHome2 to test how to reduce performances gaps.

This report only focuses on the fabric component of the performance gap, and the following factors were measured; Primary house / unit level measurements – Airtightness and Whole house heat loss. Secondary element performance – U-values and thermographic survey. Our results are highlighted below:

The overall fabric heat loss of eHome2 was 3.9% worse than the design model[a] predicted. This is a smaller performance gap than the homes tested as part of the LBU study shown in Figure 1. The majority of the 3.9% difference was due to the plane element heat loss, such as walls, roofs, doors, and windows, being greater than the design value. Although the greatest measured underperformance was highly localised, and this is discussed below in more context.

The measured air permeability of eHome2, was found to be better than the design, with an over-performance of 6.3%. This is a positive result given the fact that this is a prototype house with many more service penetrations than would be found in a home in the field.

It should be noted that although at an elemental level, there appeared to be a number of areas of localised heat loss, these had a marginal effect when considering the whole house heat loss.

The roof of eHome2 was found to have a key localised issue where areas of the insulation had been moved during the construction process, which affected the result by 26% to these areas only.

The majority of locations measured on the external walls of eHome2 performed in-line with the design prediction. However, there was an issue identified towards the bottom of the two specific panels in a section of the first-floor external wall, in which the U-value didn't meet the design performance by up to 63%. A pathological investigation was carried out, in which two key issues were identified in the prototype panels:

1. Small areas of insulation had not been installed correctly, resulting in localised voids where insulation had been compressed during installation and had not recovered to fill the insulated zone.
2. Direct air movement was observed within the panel when the house was subjected to a pressurisation test. This direct route of airflow navigated from the top of the timber frame panel through to the loft, and finally the eaves - indicating an improper seal. Further investigation of the timber frame panel construction is required to confirm the exact cause of the air movement, as several openings were made into the structure by the research team, compromising the air tightness barrier, as part of the pathology exercise.

The ground floor U-values of eHome2 are difficult to measure. This is not only an issue with this project. Previous research indicates that there are no spot measurements that can be taken that reflect the actual design U-value of a suspended floor [2] , as such, the measured

[a] Steady state model, with similar inputs to SAP, however, it does not account for seasonal changes in the mechanical and passive ventilation of the dwelling.

values presented are the “point thermal transmittance” (PTT). When the uncertainty of the PTT is considered, then the floor was found to be performing broadly in line with the design values. A learning for industry is that there is no standardised method for measuring the thermal performance of suspended floors, as such, when in-situ performance measurement is considered, then this is very difficult to achieve.

The windows and doors of eHome2 performed well, but there was a lack of modelling data for these units, so only basic measurements were taken at the centre pane of the windows which performed in line with their specification. The unglazed front door also had a lack of available data from the manufacturer as to how its U-value had been calculated. Therefore, a simple weighted average calculation was used, which indicated that the door did not perform as designed, further investigation is required.

Overall, eHome2 had a performance gap of 3.9%. If we extrapolate this performance gap by amending the SAP model, the Dwelling Fabric Energy Efficiency (DFEE) will increase by 4.02 kWh/m^2/yr. Whilst this is considered statistically significant, the measurements and supporting analysis have led to identification of the influencing factors, and this has led to identified rectification strategies. This is to be expected in a home that is a prototype, built to explore new fabric types, and multiple HVAC systems.

Figure 1 shows how the percentage performance gap of eHome2 compares to that of other new build properties from the Leeds Beckett University (LBU) coheating database [1], which is the largest published dataset of coheating tests conducted on new build properties. The eHome2 performance gap of 3.9% is below that of the 30 new build dwellings tested by LBU prior to 2015. It should be noted that the measurement of eHome2 was conducted under controlled conditions, whereas the LBU work was conducted in the field. Due to greater control of variables in Energy House 2.0, there is less uncertainty in the measurements, meaning smaller differences in performance can be identified as measurable compared to field trials.

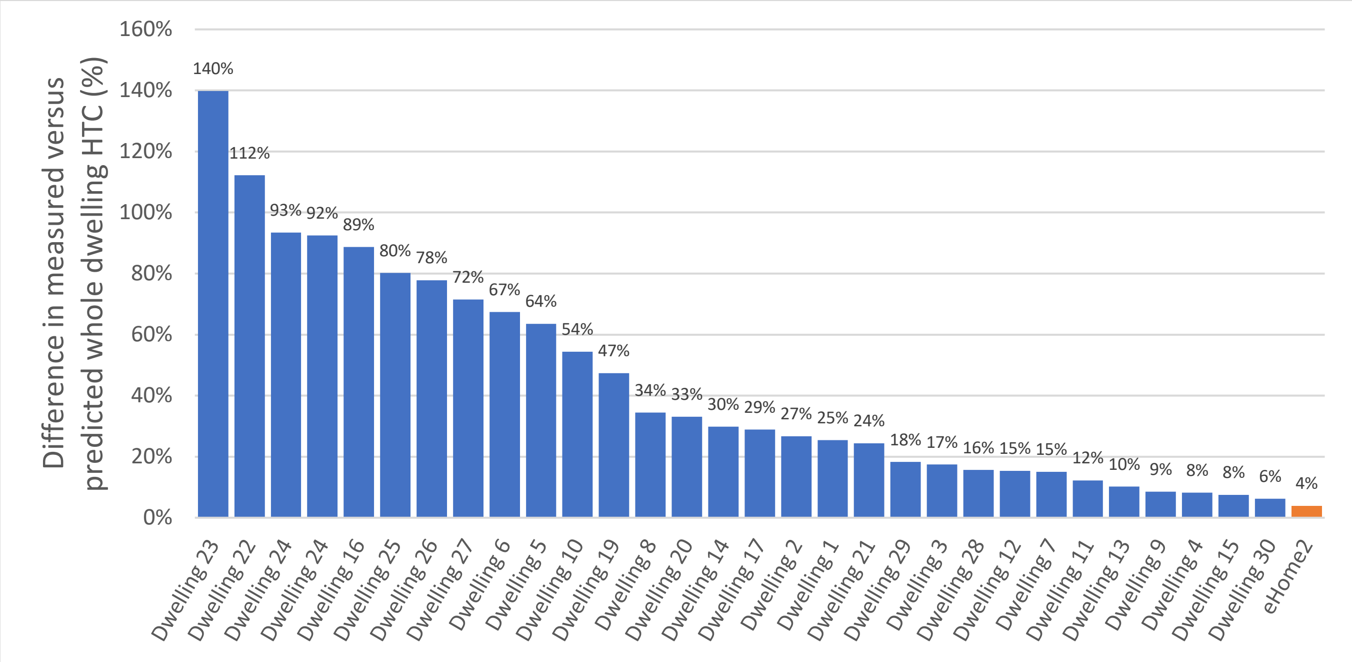


Figure 1. Difference in measured HTC of the predicted steady state HTC of the Leeds Beckett University coheating database (newbuild homes) (as a percentage), including the eHome2 performance gap

Key learnings of the Energy House 2.0 partners have taken from these findings is that as we move to very highly efficient homes to deliver the zero-carbon agenda, it is critical that details and products are applied correctly as minor variances can have localised impacts.

A future report by Energy House Labs on heating and modelling will identify what effect this performance gap means in terms of the impact on heating system performance in a more realistic scenario. It will give a view on whether this gap is material, and the extent of its impact. Following these next periods of modelling and measurement, a further building pathology exercise will be undertaken by the Energy House Labs team to pinpoint the issues that are driving the gaps. Following this, eHome2 will have rectification work to address the identified issues, and then the eHome2 will be re-measured.

In addition, a 2x2 m test cell will be constructed, made up of a new iteration of the external rendered wall panels, again within the chambers of Energy House 2.0. A similar pathological study will be conducted on the panels to test some of the identified localised sources of under-performance and confirm that the issues have been rectified.

3. Nomenclature

Symbol	Description
A_{sw}	Solar aperture m^2
ASHP	Air Source Heat Pump
DWS	Domestic water source
HTC	Heat Transfer Coefficient (W/K)
H_{tr}	Transmission Heat Transfer Coefficient (W/K)
H_v	Ventilation Heat Transfer Coefficient (W/K)
MEV	Mechanical Extract Ventilation
MVHR	Mechanical Ventilation with Heat Recovery
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)
ΔT	Internal to external temperature difference (K)
λ	Thermal conductivity W/mK

Table 1. Nomenclature

4. Background

4.1 The Future Homes Standard

In 2019 the UK government committed to introducing a new standard of energy performance in English homes; the Future Homes Standard (FHS). This is set to be introduced in 2025 (date to be confirmed). This standard will require new homes to be future proofed, have low carbon heating and with high levels of fabric efficiency. Large amounts of this will be delivered through amendments to Approved Document Part L (ADL) which was last updated in 2022.

To provide a staged approach to the rollout of the FHS an update to ADL was implemented in June 2022, requiring a reduction in the carbon emissions of new homes by 31% when compared to the 2013 standard. This was supplemented by changes in other Approved Documents to allow for changes in ventilation (Part F) and overheating (Part O).

The FHS will extend improvements, with government expectations that the average new build home will generate 75% less carbon emissions than those built under the 2013 regulations. These homes are defined as "*zero carbon ready*", with the approach considering the projected decarbonisation of the energy supply.

Whilst much remains unknown about the FHS, as it has yet to seek approvals through consultations and the legislative process, some "*features*" of a home built to these regulations are defined in the current government consultation for the Future Homes Standard.

Table 2.Anticipated features of a FHS home [3]

Item	Draft Future Homes Standard Specification
Floor U-value	0.11 W/m^2K
External wall U-value	0.15 W/m^2K
Roof U-value	0.11 W/m^2K
Window U-value	0.80 W/m^2K
Door U-value	1.00 W/m^2K
Air permeability	5.0 $m^3/h/m^2$ @ 50 Pa
Heating appliance	Low-carbon heating (e.g. Heat pump)
Heat Emitter type	Low temperature heating
Ventilation System type	Natural (with extract fans)
PV	None
Wastewater heat recovery	No
y-value	0.05 W/m^2K

Following the initial consultation on the FHS, the Future Homes Hub was created. This is a collection of industry experts, civil servants, and academics, coming together to help identify solutions and provide advice as to how the FHS can be delivered. The Future Homes Hub has also presented evidence on hypothetical homes that could meet a version of the FHS [4]. These have been developed as "Contender Specifications". These are presented below, alongside the reference values of a 2021 standard home [4] and a home built to the consultation version of the FHS [3].

eHome2 is built to broadly reflect the Contender Specification 3 (CS3), but with fabric levels close to CS4. However, it does have many differences, in terms of energy storage, PV and contains multiple heating systems. However, in terms of fabric this is the closest Contender Specification.

Table 3. Contender Specifications, The nearest to eHome2 is outlined in red [4]

Future Homes Hub specifications with eHome2 added.									
	Ref 2021 (ADL1) [5]	**Ref 2025**	**CS1**	**CS2**	**CS2a**	**CS3**	**CS4**	**CS5**	**eHome2 Design**
Wall U-value W/m²K	0.18	0.15	0.19	0.19	As per CS2	0.15	0.13	0.10 / 0.13	0.13
Roof U-value W/m²K	0.11	0.11	0.11	0.11	As per CS2	0.11	0.1	0.1	0.11
Floor U-value W/m²K	0.13	0.11	0.15	0.15	As per CS2	0.11	0.1	0.08	0.11
Glazing type	Double	Triple	Double	Double	As per CS2	Double	Triple	Triple	Double
Thermal bridging W/m²K	Psi values - Set A	y-value = 0.05	Psi values - Set A	Psi values - Set A	As per CS2	Psi values - Set B	Psi values - Set B	Psi values - Set B	y-value =0.05
Air permeability m³/(h.m²) @ 50 Pa	5.0	5	5	4.5 - 5.0	As per CS2	3	1	0.5	2.5
Ventilation	dMEV	Natural ventilation with extract fans	dMEV	dMEV	As per CS2	MVHR	MVHR	MVHR integral with EAHP	dMEV/MVHR
Heating	Gas boiler	ASHP	ASHP	ASHP	IR	ASHP	ASHP	None	ASHP/IR
DHW / WWHR	Gas boiler	ASHP	ASHP	ASHP & WWHR	Immersion + smart cylinder	ASHP & WWHR	ASHP & WWHR	DHW cyl EAHP & MVHR & WWHR	ASHP&WWHR
PV philosophy	To achieve 2021 Part L Pass	None	None, unless req. for min. 75% redn	40% GF area, max 3.68kWp	Maximise roof area for PV	40% roof area max 3.68 kWp			3.75 kWp
Battery	No	No	No	No	6.5 kWh hybrid	No	No	No	7.8 kWh

The full specification of eHome2 will be discussed in greater detail later in this report.

5. Energy House Labs

5.1 Introduction

Energy House Labs is a research group at the University of Salford in the UK. It consists of 4 research laboratories, focussed on research on energy use in buildings. These facilities are supported by a team of academics and technical staff who work across the fields of building physics, smart energy systems, data analytics and renewable systems. They have globally unique research capability in assessing buildings under controlled conditions in Energy House 2.0 and the Salford Energy House.

6. Energy House 2.0 Description

6.1 Introduction

Energy House 2.0 is a globally unique building performance test facility. The building was constructed to allow for full-scale testing of homes under a controlled range of climatic conditions. The facility consists of two large chambers which can accommodate four family homes (two homes in each chamber). The chambers each contain a soil filled pit, 1200 mm deep which is isolated by insulation from the ground beneath and surrounding the pit. The walls and ceilings of the chamber are well insulated providing isolation from the external climate, with high levels of airtightness.

Both chambers are independently conditioned by a large heating, ventilation, and air conditioning (HVAC) system. In addition, there are weather rigs, which provide additional climatic effects. These control the climate in the chambers as follows:

- 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 can be held at constant steady state or varied in seasonal or daily patterns. The facility is illustrated below in Figure 2, 3 and 4.

Figure 2. Energy house 2.0

Figure 3. Construction of soil pits


Figure 4. HVAC systems to allow climatic control

7. eHome2 Description

7.1 Introduction

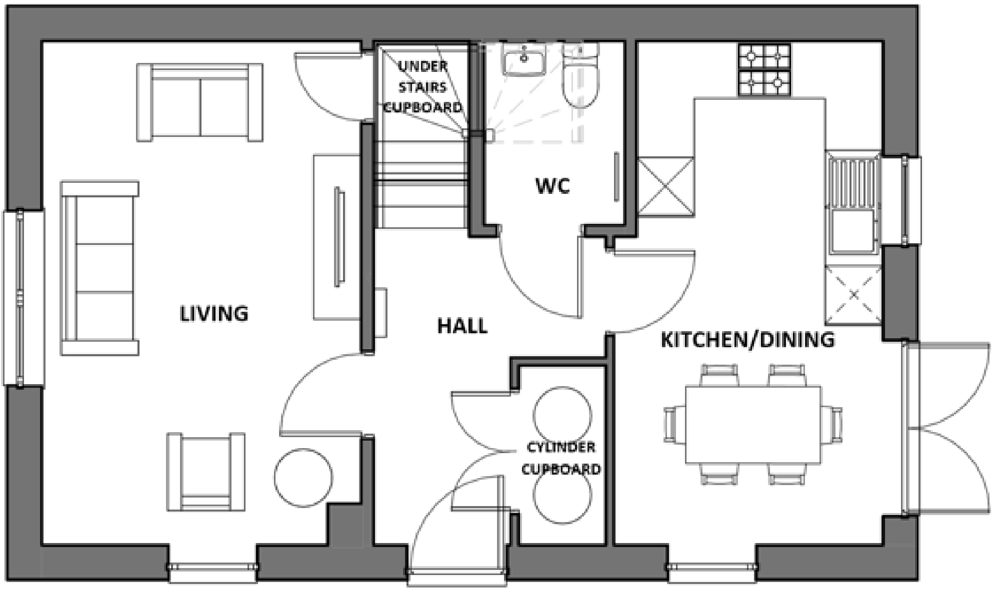
The aim of eHome2 was to provide the first Saint Gobain/Barratt built home that represented the challenges of the upcoming FHS. This would present a home that not only reflected the draft Future Homes Standard, in terms of the fabric and services specifications, but also to extend the research past these standards. This was achieved by developing a home that has fabric options that can be interchanged and updated, such as replacement glazing, alongside multiple heating, hot water, and renewables systems that can easily be "switched" between. This gives the research team several opportunities for ground-breaking research in novel areas, both for fabric and services. The building is illustrated below in Figure 5 and Figure 6.

Figure 5. Front elevation of eHome2

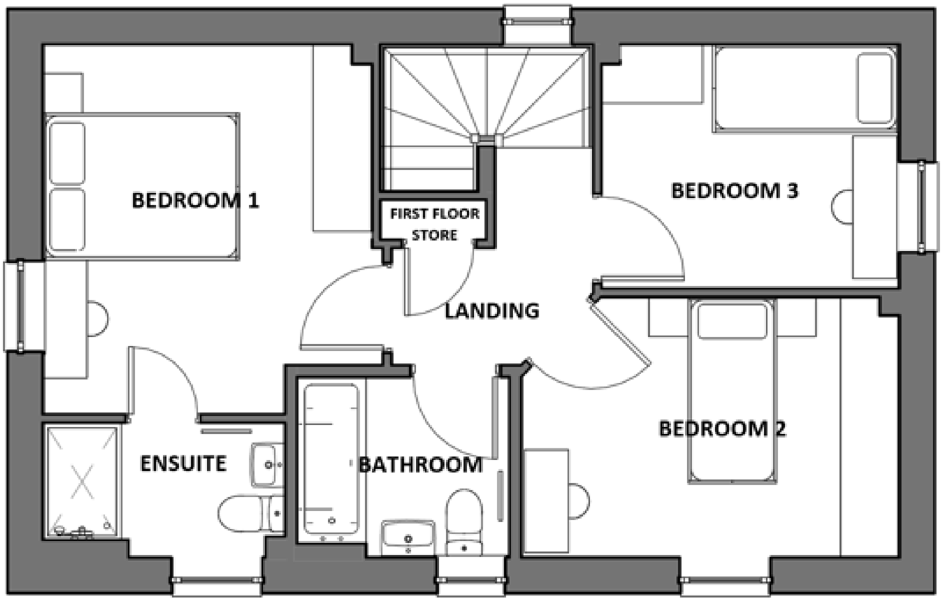
Figure 6. Rear elevation of ehome2

7.2 Architectural layout

The eHome2 is designed by Barratt and is a reproduction, although with minor changes, to the "Moresby" housing type that is currently being sold by Barratt. Figure 7 and Figure 8 below provide the design layouts and elevations of eHome2.



(a) Ground Floor



(b) First Floor

Figure 7. Design layouts of eHome2

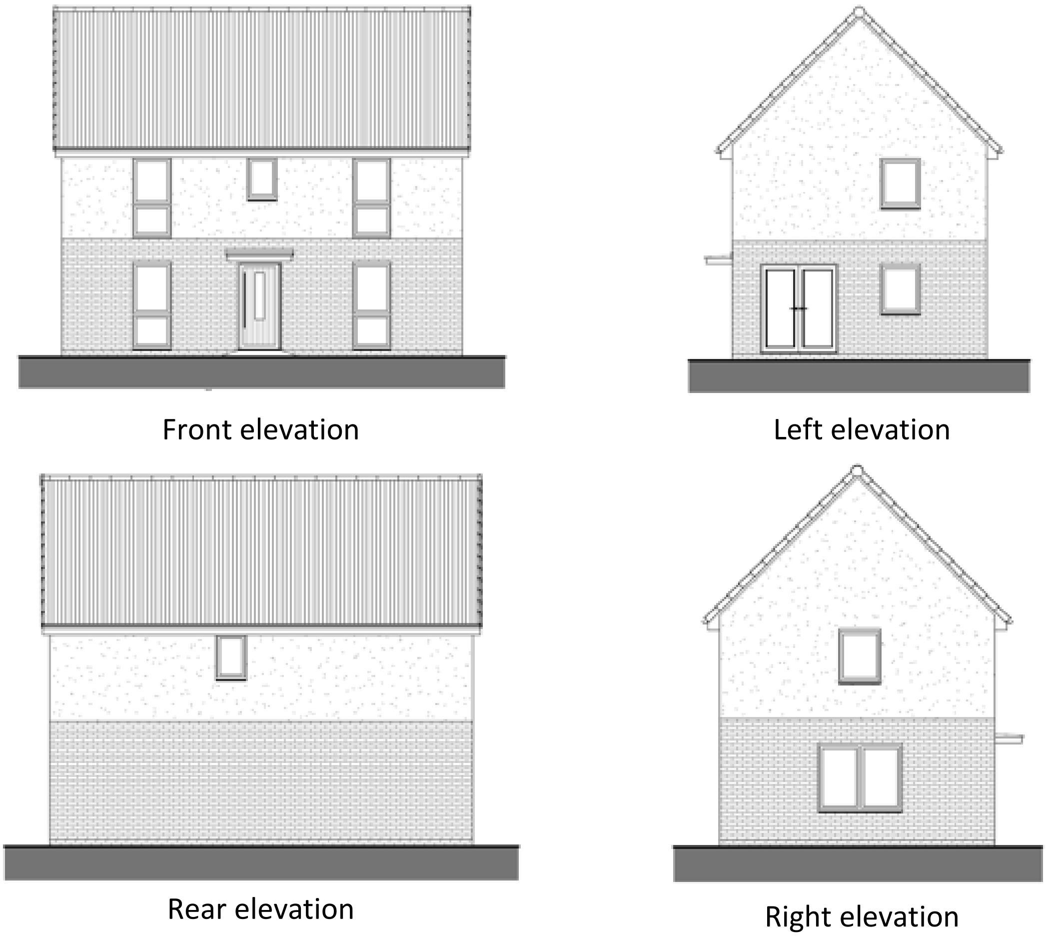


Figure 8. Elevations of eHome2

7.3 Fabric

7.3.1 Sub floor and foundation

eHome2 is built within a laboratory space, this also contains an insulated pit of earth that is surrounded by insulation. This acts to reduce heat transfer from the ground beneath and surround the pit. The pit itself is filled with locally sourced graded soil which is compacted and closely matches both the structural and thermal nature of UK soil. The soil is 6N graded fill. eHome2 has a 600x225 mm concrete strip foundation, this was formed of GEN 3 concrete mix.

7.3.1.1 Floors

The floors in eHome2 are suspended concrete to the ground floor and timber to the first floor.

7.3.1.1.1 Ground floor

This is formed using an insulated precast slab system (NUSPAN375), a concrete slab system with EPS based insulation. The floor has a calculated **U-value of 0.11 W/m²K[b].** This can be seen in Figure 9 and Figure 10 below.

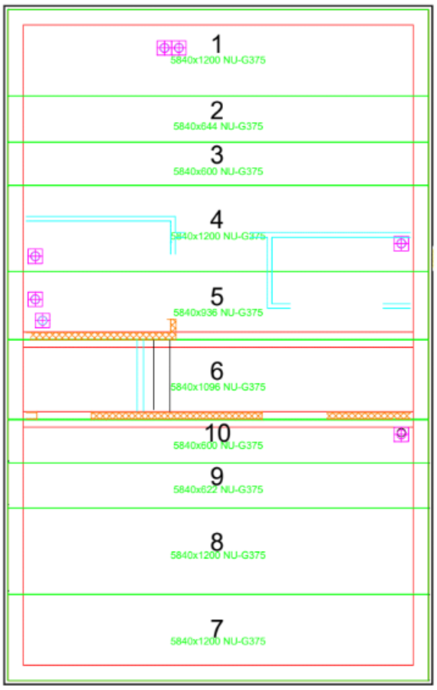


Figure 9. Ground floor Slab Layout

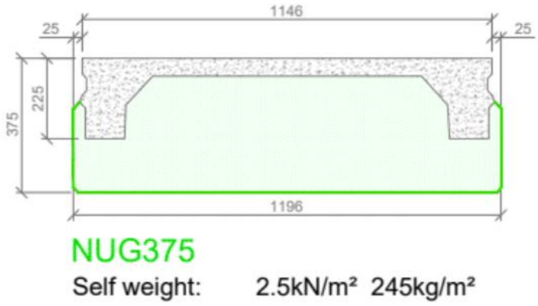


Figure 10. Ground floor Slab Layout section

7.3.1.1.2 First floor

This comprises 22 mm Caberdek chipboard floors with tongue and groove joints, these are glued and sealed with tape. These sit on a 15mm subdeck, 254 mm I-Joists at 600 mm centres and the perimeter is insulated with mineral fibre (λ value of 0.035 W/mK). Finished on underside with 15 mm British Gypsum Gyproc Wallboard.

[b] Refer to Annex A (point 2)

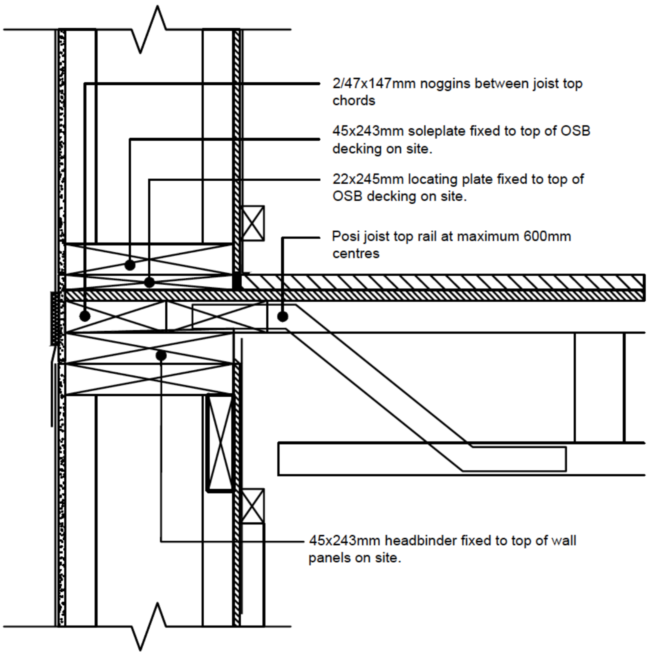


Figure 11. Top hung I-joist

7.3.2 External walls

The walls of eHome2 are split into two types; brick finished (slips) and rendered, whilst the render is decorative it does not affect the U-value. The breakdown of these individual wall types are as follows:

- Main wall - Brick Finish (54.78 m^2)
- Main wall - Rendered Finish (68.34 m^2)

Each wall type is detailed in Table 4 and Table 5.

Table 4. Main walls - Brick finish (1)

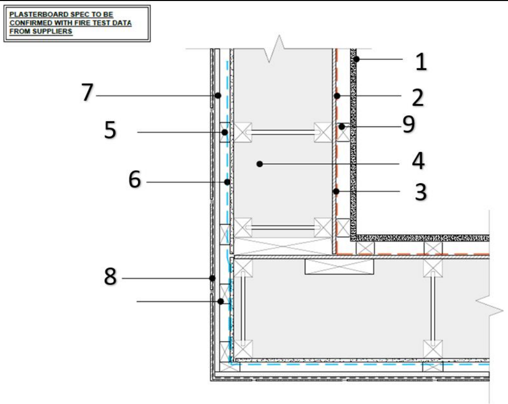
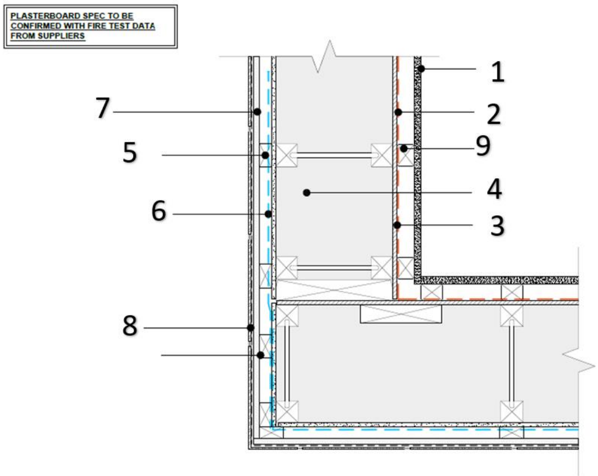
External Perimeter Wall – Brick Finish - Wall Thickness – 360.5 mm	
	1. 15 mm BG Gyproc wallboard 2. 35 mm Unventilated cavity, Low-E Proctor Reflectatherm Plus RVCL 3. 9 mm OSB 4. Isover timber frame roll 245 mm mineral wool insulation 0.035 W/mK 5. 9 mm OSB 6. 25 mm ventilated cavity with Proctor Reflectashield TF RBM 7. 12.5 mm BG glassroc x 8. 5 mm Weberwall brick slip finishing system and 5 mm Weberend LCA rapid base coat 9. Factory fitted Proctor Reflectatherm Plus VCL
Design U-value: 0.13 W/m^{2}K[c] .	

Table 5. Main walls – Rendered (2)

External Perimeter Wall – Rendered - Wall Thickness – 358 mm	
	1. 15 mm BG Gyproc wallboard 2. 35 mm Unventilated cavity, Low-E Proctor Reflectatherm Plus RVCL 3. 9 mm OSB 4. Isover timber frame roll 245 mm mineral wool insulation 0.035 W/mK 5. 9 mm OSB 6. 25 mm ventilated cavity with Proctor Reflectashield TF RBM 7. 12.5 mm BG glassroc x 8. 1.5 mm Webersill TF finish coat, 6 mm Weberend LCA rapid base coat 9. Factory fitted Proctor Reflectatherm Plus VCL
Design U-value: 0.13W/m^{2}K[d].	

[c] Refer to Annex A (point 1)
[d] Refer to Annex A (point 1)

7.3.3 Walls below Damp-Proof Course (DPC)

As external walls – cavities are extended below DPC and filled with insulation, the DPC is approximately 150 mm above ground level. Telescopic vents are provided alongside expanded polystyrene board with a thickness of 70 mm (λ 0.038 W/mK). There are 7 uPVC periscope vents located to the perimeter of the property each with a free area of approx. 6000 mm^2. This is detailed in Figure 12.

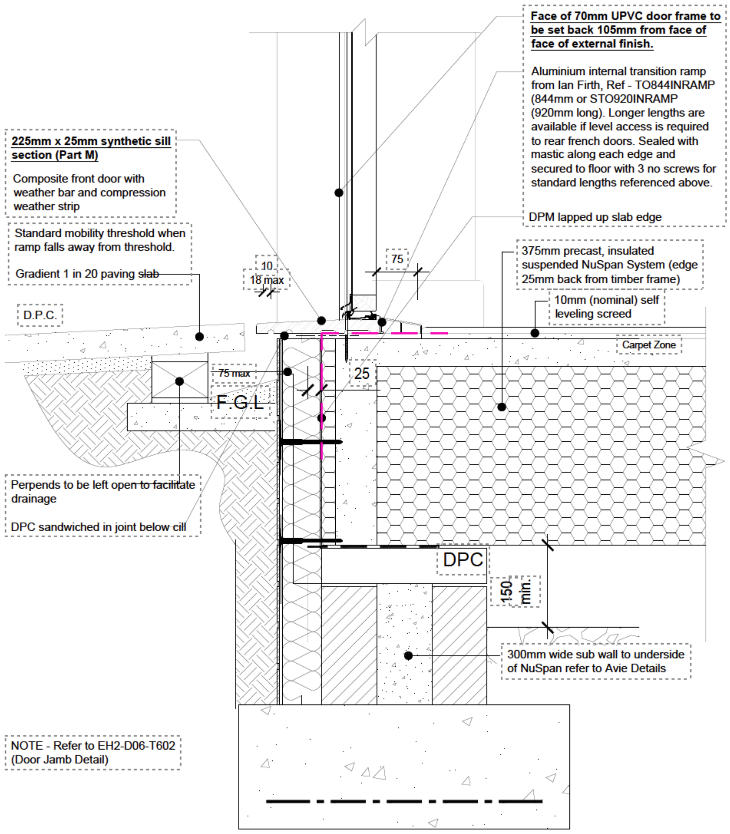


Figure 12. Below Damp-Proof Course (DPC)

7.3.4 Below ground walls

The walls to the underside of the DPC are formed as follows; 140 mm aerated concrete blocks up to underside of NU-span insulated concrete plank. A 72 mm cavity is filled with expanded polystyrene board (λ 0.038 W/m²K).

7.3.5 Windows

The windows to eHome2 have a Eurocell uPVC profile, this is fitted with a 28 mm double-glazed unit. The windows consist of; external glazing sheet is 4 mm thick Saint Gobain Diamant, with a gap of 20 mm filled with 90% Argon and 10% air, a 20 mm Thermobar warm edge spacing bar, the internal glazing sheet is 4 mm Saint Gobain Planitherm One TFG with a low emissivity coating.

A typical bedroom window in eHome2 has a modelled U-value of 1.20 W/m^{2}K[e], with a centre pane U-value of W/m^{2}K of 1.07[f] and glazing G value of 0.51[e]. The BFRC energy rating of this window is Band C. A breakdown of the BFRC can be found in Annex A.

Note:

***(University of Salford (UoS) were not provided a full breakdown of each window U-value**). We relied on the values provided to us in the SAP calculation, these values are generic and are for a building not specific to eHome2.*

7.3.6 Doors

eHome2 has only one external door (to the front elevation), the rear doors are Patio doors, classified under the window section above. U-value = 1.2 W/m^{2}K[g].

7.3.7 Roof

The roof to eHome2 is pitched with interlocking concrete tiles, with underfelt. The roof is ventilated with soffit vents and a ventilated ridge.

The first-floor ceiling of eHome2 is insulated at ceiling joist level with 400 mm of Isover Spacesaver roof insulation (0.044 W/mK), laid between joists in layers, and above them in a perpendicular manner, as shown in Figure 13. Joist centres are 600 mm. This is laid onto the 15mm plasterboard. The loft hatch has 50mm of expanded polystyrene insulation. The U-value for the ceiling is. 0.107 W/m^{2}K, with the correction included for the loft hatch this is amended to 0.11 W/m^{2}K[h].

[e] Refer to Annex A (point 4)
[f] Refer to Annex B
[g] Refer to Annex A (point 6)
[h] Refer to Annex A (point 3)

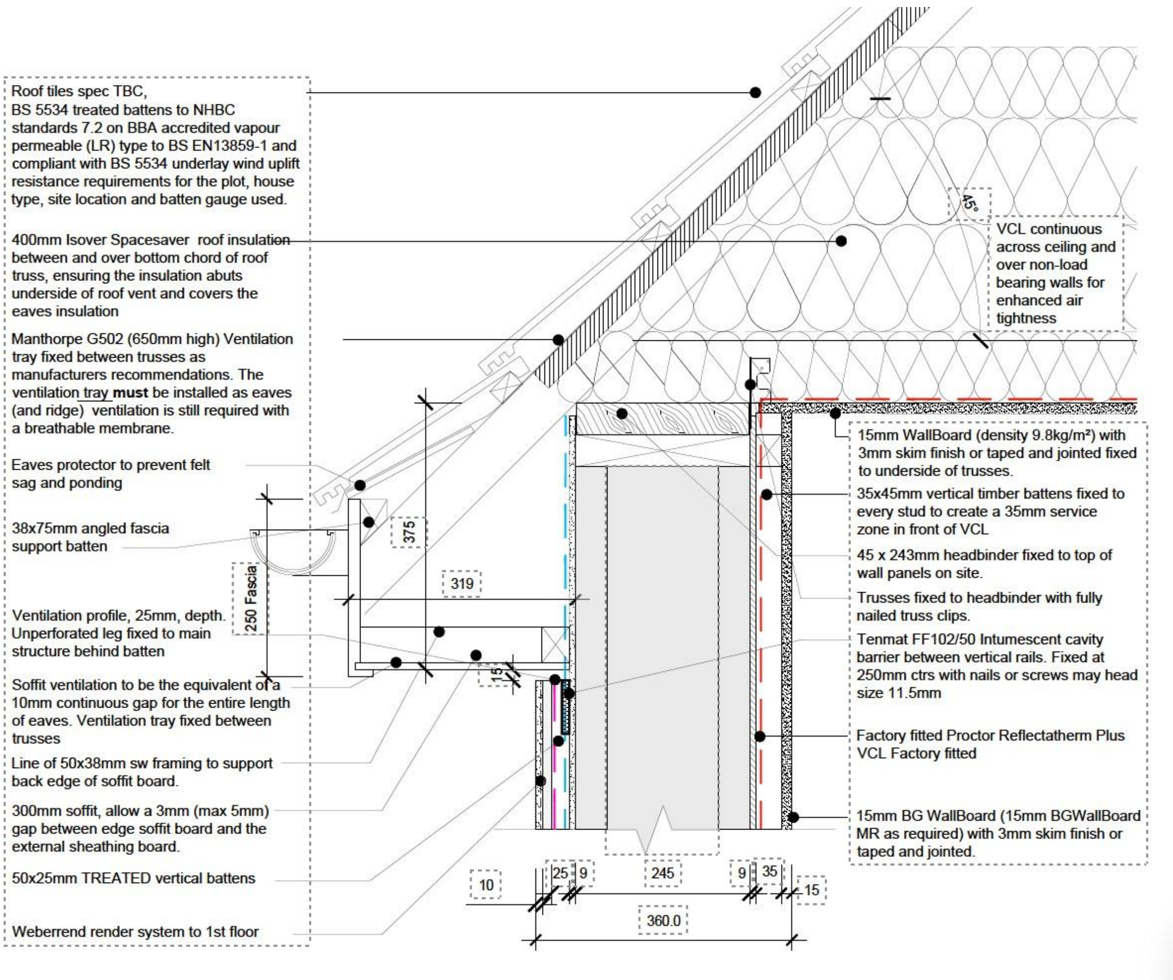


Figure 13. Ceiling section

7.4 Services

This section will serve as an introduction to the services provided in eHome2 for context only. A full report on the performance of the installed services will proceed after this fabric report. The services provided in eHome2 are not limited to one heating or hot water system. There are several different space heating solutions alongside several options for the provision of domestic hot water.

7.4.1 Air Source Heat Pump

The primary source of space and hot water provision is provided by a mono bloc air to water heat pump system. This is a Vaillant Arotherm Plus 5 kW running on R290 refrigerant (propane), this specification will typically provide 6.4 kW of heating with a COP of 4.07 at an outside air temperature of 2 °C, with a hot water flow temperature of 35 °C.

7.4.2 Heat Emitting Systems – Thermaskirt

The heat emitters attached to the heat pump are skirting board emitters. This product is called Thermaskirt (Deco range). These are controlled by addressable TRV heads. The products are sized to meet the specification below (design temperature of 45 °C flow temperature at -3 °C outside).

Table 6. Thermaskirt Specification (sized at 45 °C flow -3 °C design temperature)

Room Type	Emitter length	Heat Output (according to design)
Living Room	11.74m	693 Watts
Kitchen/Dining	5.96m	604 Watts
Kitchen/Dining	4.35m	257 Watts
Bedroom 1	6.41m	378 Watts
Bedroom 2	5.86m	346 Watts
Bedroom 3	4.55m	268 Watts

7.4.3 Heat Emitting Systems – Bathroom towel radiators.

The ASHP in eHome2 uses the Thermaskirt to provide the space heating, however in bathroom areas this system is not used, they are heated by towel heating radiators, as shown below in Table 7.

Table 7. Bathroom towel radiators Specification

Room Type	Height (mm)	Width (mm)	Type
Hall	600	500	Stelrad Compact K2
WC	1211	500	Stelrad Home Classic White Towel Rail
Bathroom	1744	500	Stelrad Home Classic White Towel Rail
Ensuite	1744	500	Stelrad Home Classic White Towel Rail

7.4.4 Infrared Heating System – Curv Wall Mounted

eHome2 has an infrared heating system installed by Curv. This system provides space heating to the areas shown in Table 8. This system has been designed by Curv. This system is controlled through the Loxone system with local temperature sensors in each room.

Table 8. Infrared heating system specifications

Room	Power Rating (W)	Number of Panels	Type	Dimension (mm) (Height x Width)
Kitchen/Dining	1500	1	Flat Glass IR	1500*600
WC	250	1	IR Mirror	800*600
Living Room	750	2	Flat Glass IR	1200*600
Hall	750	1	IR Mirror	1200*600
Bathroom	550	1	IR Towel Rail	1800*350
Bedroom 1	1000	1	Flat Glass IR	1500*600
Bedroom 2	750	1	Flat Glass IR	1200*600
Bedroom 3	650	1	Flat Glass IR	1800*350
Ensuite	300	1	IR Mirror	1000*600

7.4.5 Wet central heating system heating controls

The space heating systems in eHome2 are controlled using the Loxone building management system. Air temperature is sensed at room level and fed to the controller, where time and temperature patterns can be set at room-by-room level. The methods used to deliver this control are below:

The Thermaskirt system is split into zones, controlled by Danfoss HP22 2-port valves. These are controlled by the Loxone control system. The towel radiators are controlled separately using Loxone TRV heads.

7.4.6 Wastewater heat recovery

The shower to the main bathroom is served by a wastewater heat recover system. A Recoup Pipe Hex system (double walled copper tube heat exchanger) has been installed. This provides pre heated water from the shower waste to the shower feed supply.

7.4.7 Hot Water Systems

There are two DHW systems currently installed in eHome2: Firstly, a standalone unit generating hot water using an inbuilt ASHP (Curv system). Secondly, a 200 litre storage cylinder attached to the ASHP with a buffer vessel (Vaillant system).

7.4.7.1 Curv ASHP Hot Water Cylinder

This is a stand-alone air source hot water cylinder, designed to work alongside an infrared heating system. The model is HP250M3C, which has a capacity of 195 litres, with a quoted COP of 3.04 at 7 °C external temperature.

7.4.7.2 Vaillant Unistor

This is a cylinder designed specifically to work with a Vaillant ASHP. It has a capacity of 200 litres and is supplied pre plumbed and is unvented. The installed version has an aroTHERM 45 litre buffer tank which can lead to less short cycling of the ASHP. The cylinder has been sized according to the Building Regulations Part L 2021 for a three-bedroom property with one bathroom and one shower room.

7.4.8 Ventilation Systems

For experimental purposes two ventilation systems are present in eHome2, these systems will be run independently depending on the test required, they will not run together, one system is a whole house system, and the second is an extract system serving the moisture generating areas of eHome2.

7.4.8.1 Mechanical extract (MEV) system

The Vent Axia centralised mechanical extract system (MVDC-MSH 443298) system is installed in the loft and is connected generally by flexible ducting. This system is commissioned to run continuously, it has three modes: normal, boost, and purge. A humidistat will boost the system at higher levels of humidity. This system serves all the bathrooms and the kitchen. Flow rates are shown in Table 9.

Table 9. Flow rates for MEV system

	Extract				
	Design		Measured (Commissioning)		Measured (UoS)
	Boost	Trickle	Boost	Trickle	Trickle
Kitchen/Dining	13	11.5	13	11.5	11.6
WC	6	5.3	6	5.3	4.6
Bathroom	8	7.1	8	7.1	6.4
Ensuite	8	7.1	8	7.1	6.4
Total	**35**	**31**	**35**	**31**	**29**

7.4.8.2 Mechanical ventilation with heat recovery (MVHR) system

A Vent Axia Sentinel Kinetic Advance S (405215) provides the mechanical ventilation with heat recovery to the areas shown in Table 10.

Table 10. MVHR system

Extract				
	Design		Commissioned	
	Boost	Trickle	Boost	Trickle
Kitchen/Dining	13	11.5	13	11.5
WC	6	5.3	6	5.3
Bathroom	8	7.1	8	7.1
Ensuite	8	7.1	8	7.1
Total	**35**	**31**	**35**	**31**
Supply				
	Design		Commissioned	
	Boost	Trickle	Boost	Trickle
Living Room	11.1	9.8	11.1	9.8
Kitchen/Dining	4.4	3.9	4.4	3.9
Bedroom 1	8	7.1	8	7.1
Bedroom 2	6.6	5.8	6.6	5.8
Bedroom 3	4.9	4.4	4.9	4.4
Total	**35**	**31**	**35**	**31**

7.4.9 Renewables

eHome2 has a battery installation and a solar PV inverter; PV panels are installed but will not generate power. This is due to the chamber not having a solar input (solar radiative thermal gain is simulated, but not in the frequency spectrum suitable for PV panels). A DC signal is fed to the inverter to replicate PV input commensurate with the climate in the chamber at the time.

The battery installation comprises a Fox ESS Powercube system provides 7.8 kWh of energy storage.

7.5 Outline of future interventions

eHome2 will undergo a series of interventions during the lifetime of the project:

7.5.1 Triple Glazing

The existing double-glazed windows (minimum U-value of 1.2 W/m^2K[i]) are to be replaced with UPVC triple glazed with Low-E glass soft coating to achieve a minimum U-value of 0.8 W/m^2K.

[i] Refer to Annex B

7.5.2 External doors

Patio doors (minimum U-value currently 1.2 W/m²K) to be upgraded to a new door with a U-value of glazed doors to achieve a minimum U-value of 1.0 W/m²K.

8. Building Fabric Research

8.1 Building performance evaluation methods

This section presents the methods used to measure the thermal performance of fabric of eHome2. The main test found here are industry recognised standard tests with published methodologies and standards. More innovative test methods were also used, to allow for these methods to be compared to the recognised standard methods.

8.1.1 Steady state thermal performance measurements

A unique strength of the Energy House 2.0 facility is the ability to recreate not only realistic weather patterns but also to create and maintain steady chamber temperatures. This was used to carry out this series of tests as it allows for steady state conditions to be reached. This means measurements can be taken with less disturbance from outside factors, such as occupants, solar radiation etc, and for results with lower levels of uncertainty to be produced.

All the tests and measurements of the *eHome2* were carried out within the environment of the Energy House 2.0. Table 11 illustrates the average temperatures in the UK according to SAP, this was used to provide an average representative external temperature of the United Kingdom during the winter months (December to March). The chamber's HVAC system was set to maintain 5 °C during the test days.

Table 11. U1 of SAP10 [3]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
UK average	4.3	4.9	6.5	8.9	11.7	14.6	16.6	16.4	14.1	10.6	7.1	4.2

The steady state test of the fabric performance was divided into two stages, the first was the coheating test to obtain the heat transfer coefficient (HTC), the second stage was a test to obtain the U-value of the individual elements of the envelope to understand where improvements can be made. This allows for a whole house measurement providing a measure of how the total fabric solution performs when compared to designed expectations, and the U-values to be measured without the high airflow rate often associated with coheating, which uses circulation fans. During both tests, eHome2 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.

8.1.2 Building heat transfer coefficient (HTC) measurement

The HTC is defined in ISO 13789:2017 [6] 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".*

The HTC is the rate of heat loss (fabric and ventilation) in Watts (W) from the entire thermal envelope of a building per Kelvin (K) of temperature differential between the internal and external environments and is expressed in W/K. This metric represents the heating power required to maintain a 1 K temperature difference over the building envelope. The HTC captures the aggregate element, thermal bridging, and unintentional ventilation (air infiltration and leakage) heat losses from the house.

The 2013 version of the Leeds University Whole House Heat Loss Test Method [7] was adapted for HTC measurements in eHome2. The principal differences being the test duration and analysis of test data.

A coheating test typically assumes the steady state whole house energy balance in typical coheating test whole house energy balance is expressed as follows[8].

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

Where:
Q = Power input (W)
A_{sw} = Solar aperture (m^2)
q_{sw} = Solar irradiance (W/m^2)
H_{tr} = Transmission heat transfer coefficient (W/K)
H_v = Ventilation heat transfer coefficient (W/K)
ΔT = Internal to external temperature difference (K)

At 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 eHome2 test.

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

Where:

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

To obtain the HTC, a coheating 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 Figure 14. 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.

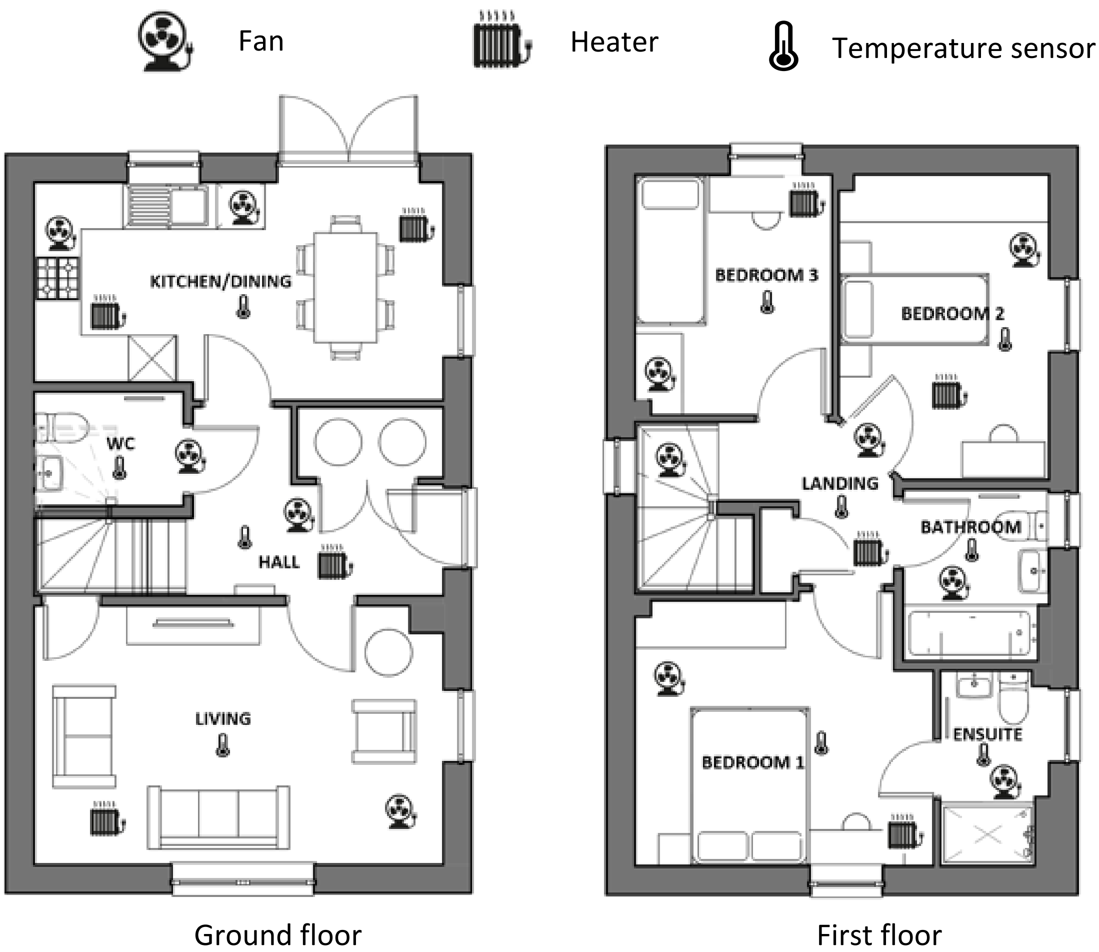


Figure 14. Coheating test heaters and fans locations.

[j] Q is based on total cumulative energy input to the Energy House over 24-hour period. Refer to Annex C for details of the HTC uncertainty calculation.

During the coheating Test, the temperatures on both sides of the fabric remained steady state for 8 days. Figure 15 shows the rate of change of the temperature difference (ΔT) during the coheating test, the ΔT remained steady with variations between 0% and -1%.

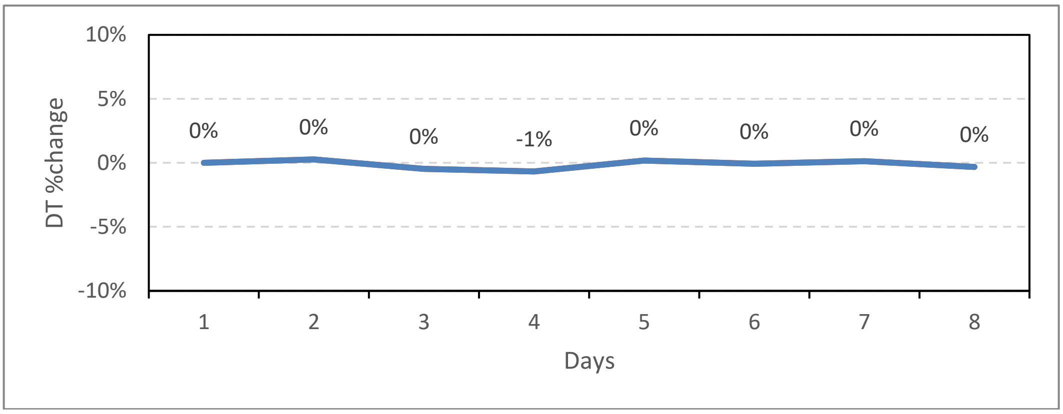


Figure 15. Rate of change of the temperature difference (ΔT) during the coheating test.

8.1.3 Alternative HTC measurement methods

The test programme also provided the opportunity to compare commercial rapid HTC test methods against the coheating test. Saint-Gobain QUB [9] and Veritherm [10] performed dynamic HTC measurements of unoccupied dwellings over one night, as opposed to the coheating test that typically requires a test period of 2-3 weeks in duration.

Both are dynamic methods that involve a stabilisation period of constant internal temperature, followed by a heating period with constant power input, then a free cooling period. They both use assumptions of fabric performance to calculate the power input required for the test. Both also utilise integrated hardware and software to control heat input, monitor power input and environmental conditions, and perform data analysis. The main difference in equipment between the two methods is that Veritherm also uses air circulation fans during the test, but QUB does not.

8.1.4 Ventilation heat transfer coefficient (Hv)

The air infiltration/leakage ventilation rate (n) from which the ventilation heat transfer coefficient was calculated was obtained using two different test methods, the fan pressurisation method, and the Pulse test. For the analysis of eHome2 the data is taken from the fan pressurisation method.

8.1.5 Airtightness testing

8.1.5.1 Fan pressurisation tests

A fan pressurisation test (commonly referred to as a blower door test) was performed to quantify the change in air permeability value at 50 Pa (AP50) and air change rate at 50 Pa (n50). Fan pressurisation test was undertaken in accordance with ATTMA Technical Standard L1 [11]. All intentional ventilation openings such as MVHR ducts, trickle vents, cooker hood and wastewater services were sealed throughout the test programme.

Fan pressurisation test n50 values were used to derive n using the n50/20 'rule of thumb'[12]. The derivation includes the correction factor for dwelling shelter factor contained within SAP 2012 [13].

8.1.5.2 Pulse Test

A Pulse test [14] was performed using a portable compressed air-based system to measure the air leakage of a building at a near ambient pressure level of 4 Pa. In the UK, the system is a recognised air pressure testing methodology under Part L building regulations. All intentional ventilation routes were sealed as in the fan pressurisation test.

8.1.6 Qualitative data collection

8.1.6.1 Thermography

Thermographic surveys of eHome2 were performed in accordance with the guidance set out in BSRIA Guide 39/2011[15]. The thermograms displayed in this report have been corrected to account for the environmental conditions present during the survey, as well as subject distance and emissivity.

8.1.6.2 Air leakage/infiltration identification

The conditions present during the fan pressurisation tests provided the opportunity for air leakage/infiltration identification. During depressurisation, the elevated internal temperatures enabled infrared thermography to be used to observe and record areas of air infiltration.

8.1.7 In-situ heat flux and U-value measurement

For the U-values test, the chamber was set to 5 °C, the elements were evaluated for periods longer than 72 hours in accordance with ISO 9869 [16]. Unlike the coheating test, during the U-value test, no fans were used, only heaters.

The thermal transmittance of a building element (U-value) is defined in ISO 7345 [17] as the *"Heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on each side of a system"*. To account for thermal storage and release, ISO 9869-1 uses a cumulative moving average of the heat flow rate and ΔT to calculate in-situ U-values. However, steady state conditions at the Energy House 2.0 during eHome2 test allowed in-situ U-values to be calculated as defined by ISO 9869 [16]using equation 3.

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

Where:
U = in-situ U-value (W/m^2K)[k]
q = mean heat flow rate (W/m^2)
T_i=indoor temperature (K)
T_e=chamber temperature (K)
j= enumeration of measurements[l]

Measurements of heat flux density (heat flow rate), from which in-situ U-values were calculated, were taken at 57 locations on the external elements of eHome2 using heat flux plates (HFPs). Figure 16 shows the HFP location.

HFP used to measure in-situ U-values were positioned at the mid-point between repeating thermal bridges within an element (such as centre of timber frame panels) and at the location of repeating bridges (such as the battens and studs of the external timber frame). Thermography was used to identify these measurement locations to find areas representative of heat loss through bridged and unbridged heat loss paths through an element, which are shown in Annex G.

HFPs were positioned in 3x3 grids for the ceiling, floor and external walls in locations considered to be representative of the whole element, an extra measurement of the heat flux density of the timber frame studs, positioned with the aid of thermography was also carried out. For the HFP measurements located within the 3x3 grid, a single hygroVUE 10 sensor was

[k] Refer to Annex D for details of the in-situ U-value uncertainty calculation
[l] Based on 10 min average

used for the internal temperature. For spot measurements taken in other areas, a local thermocouple sensor was used for the internal air temperature measurement.

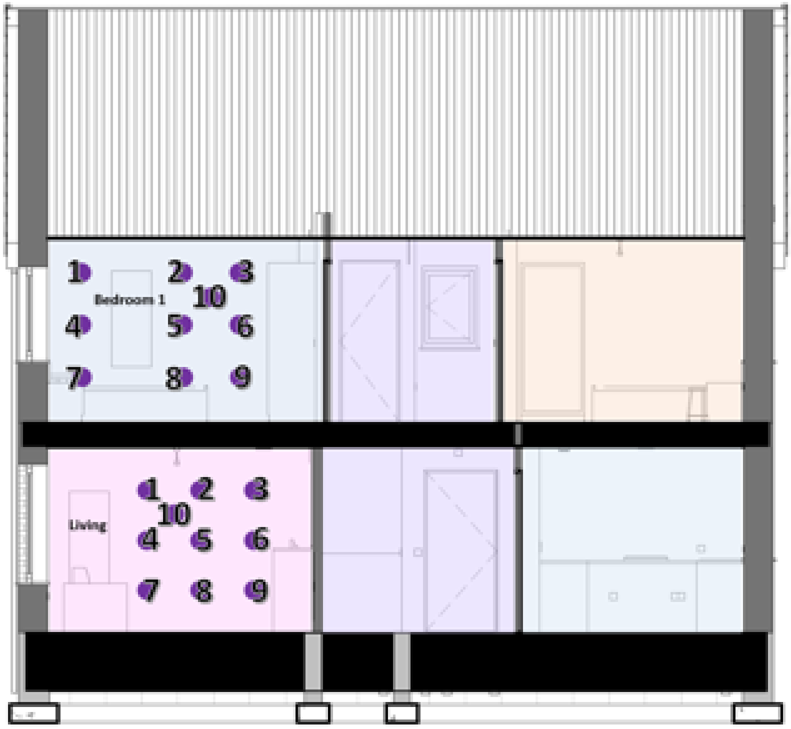
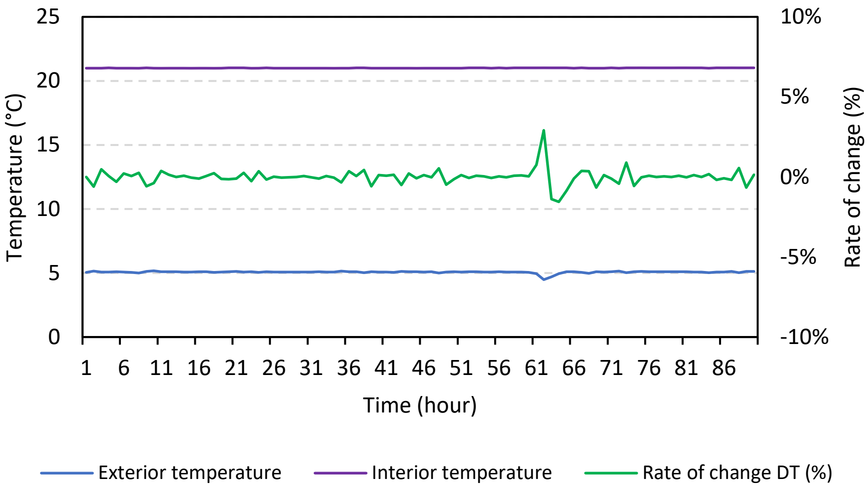


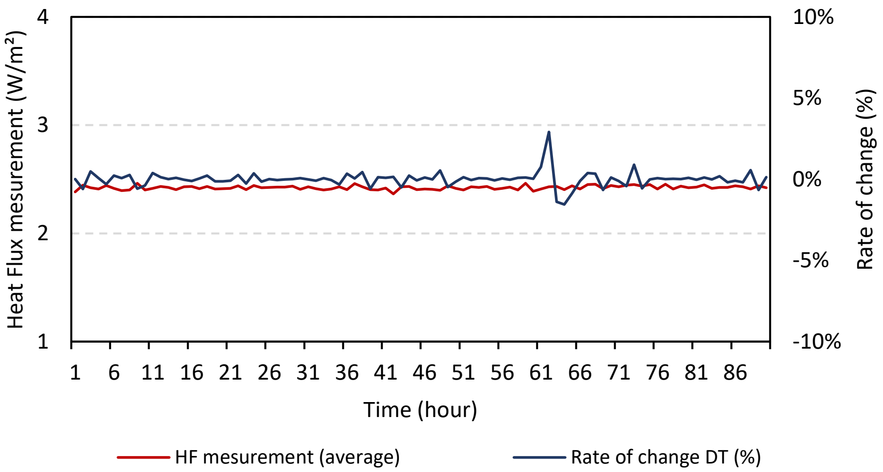
Figure 16. HFP location.

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 17(a) shows the indoor temperature, the chamber temperature, and the rate of change of the ΔT (T_i-T_e) for the living room. This illustrates that the indoor temperature does not present significant changes and the chamber temperature has a difference of up to 3% (~0.5 ℃). Figure 17 (b) shows the rate of change of the average HFP measurement of the grid in the Living Room during the test, it is observed that steady state was reached for more than 86 hours, the rate of change per hour is less than 3% during the test. All the measurements (temperature and heat flux) in the other elements had the same behaviour, with rates of change less than 3% during the test.



(a) Temperature



(b) Heat Flux measurement

Figure 17. Steady state of Living Room measurements

8.2 Energy House 2.0 monitoring equipment

The findings provided in this report are based on measurements obtained using the equipment listed in Table 12. Measurements were recorded at one-minute intervals by the Energy House 2.0 monitoring system:

Table 12. Measurement equipment used in the Energy House eHome2 fabric performance tests. Equipment for novel methods pulse, QUB and Veritherm are not included in this table.

Measurement	Equipment	Uncertainty[m]
Electricity consumption	Eastron SDM230-Modbus [18]	±1%
Room air temperatures	hygroVUE 10 (20 to 60 °C) [19]	±0.1 °C
Chamber air temperatures	hygroVUE 10 (–40 to 70 °C) [19]	±0.2 °C
Internal air temperatures	Type-T thermocouple[n]	±0.1 °C
Heat flux density	Hukseflux HFP-01 heat flux plate[20]	±3%
Air permeability	Retrotec 5000 Blower Door System [o]	±2.5%[p]

9. Results

9.1 Measured HTC compared with predicted HTC

The coheating test was carried out for 8 days, the chamber temperature was set at 5 °C. Table 13 shows the daily power averages (based on energy consumption), the average temperature difference for each of the test days and the daily and average measured HTC.

Table 13. Results of the HTC

Day	Power (W)	DT (K)	HTC (W/K) [q]
1	1203	15.8	76.0±2.2
2	1202	15.7	76.4±2.1
3	1208	15.8	76.6±2.2
4	1215	15.8	77.2±2.2
5	1215	15.8	77.0±2.1
6	1209	15.7	76.9±2.2
7	1207	15.7	76.7±2.2
8	1209	15.7	76.8±2.3
Design			**73.8**
Average HTC			**76.7± 2.1**

[m] uncertainties were taken from supplier data sheet
[n] Energy house 2.0 in house calibration process
[o] Certificate of calibration: UK_52369, UK_52343
[p] The sheltered test environment allows measurement uncertainty to exclude wind-based errors, the ± 2.5% uncertainty value applies only to test apparatus
[q] Refer to annex C to uncertainty calculation

Figure 18 shows the measurements for the HTC. To maintain an indoor temperature of 21 °C when the chamber temperature is 5 °C an average daily power input of ~1200 W is needed. That reflects a steady HTC which indicates that to maintain a 1 K temperature difference over the building envelope 76.7 W of heating power is required.

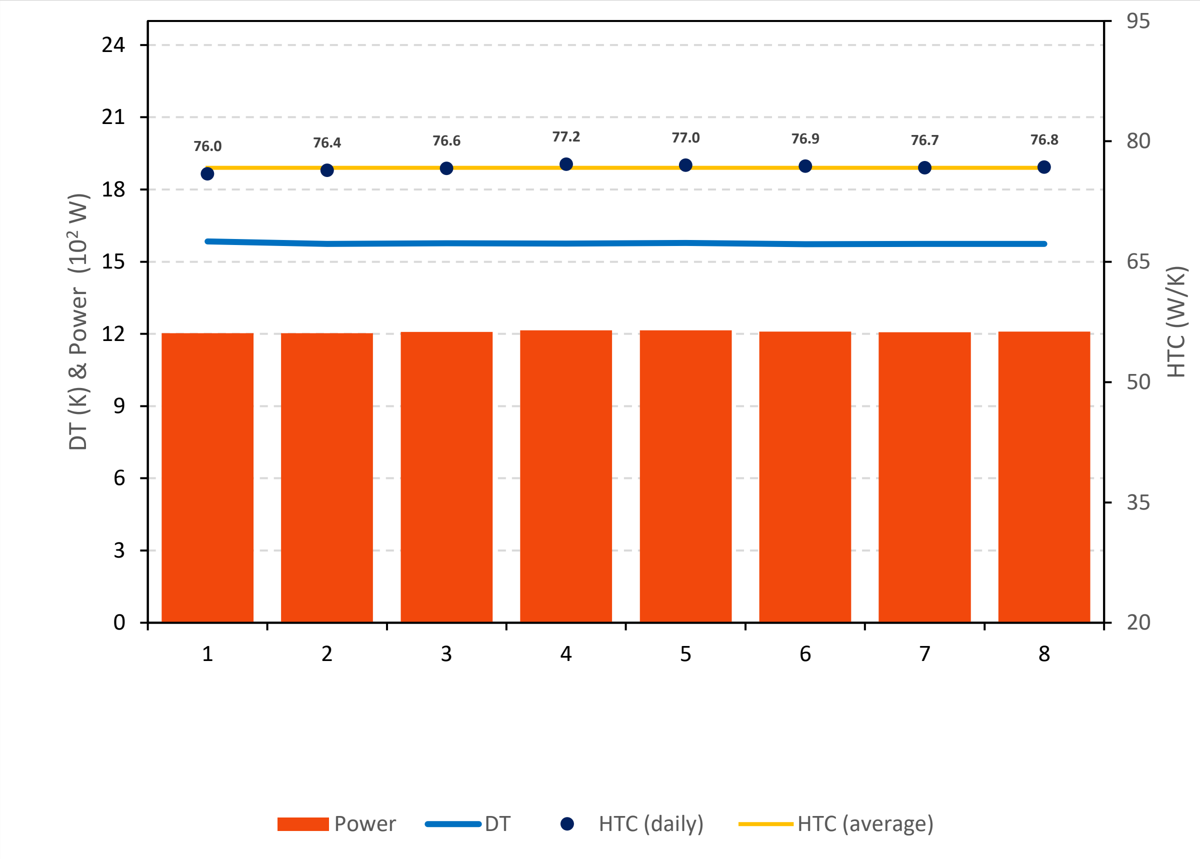


Figure 18. HTC results.

eHome2 has a design HTC of 73.8 W/K, which was extracted from the design model document (Annex A). This considers the total fabric heat loss and the infiltration heat loss. The final measured HTC using the coheating method was 76.7 (± 2.1) thus giving a performance gap of 2.9 W/K or 3.9%. This is higher than the level of uncertainty, so is significant, although minor.

9.2 Alternative in-situ test methods

HTC measurements were also performed using the Saint-Gobain QUB [9] and Veritherm [10] methods. Veritherm and QUB visited eHome2 to carry out tests independent of the research team. These were carried out under the same environmental conditions as the coheating method, with a set point of 5 °C in the chamber, to allow for direct comparison. The results from the coheating and alternative HTC test methods can be found in Table 14 and Figure 19.

Table 14. HTCs measured using the coheating, QUB, and Veritherm tests

Coheating HTC (W/K)	QUB[r] HTC (W/K)	Veritherm[s] HTC (W/K)	QUB difference from coheating	Veritherm difference from coheating
76.7 ±2.1	65.1±5.6	71.9[t]	-15%	-6%

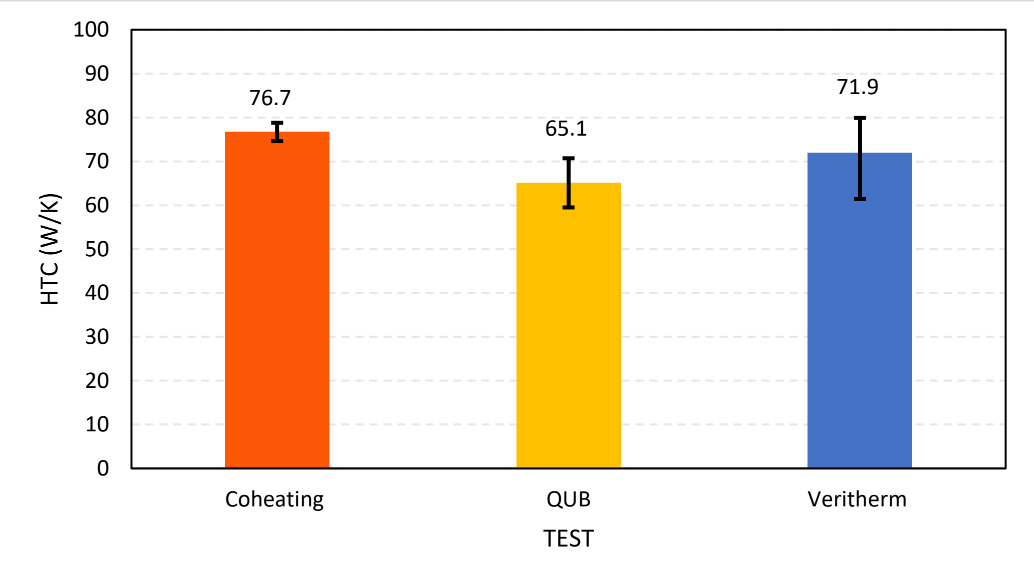


Figure 19: Comparison between HTCs measured using the coheating, QUB, and Veritherm tests

The HTCs measured by the alternative methods were generally in agreement with the coheating test HTCs when measurement uncertainty is considered. Veritherm uncertainty is up to two times bigger than QUB uncertainty. However, the HTC obtained by QUB is 15% lower than the coheating test and Veritherm result is 6% lower than the coheating test. An extended research phase for Rapid HTC methodology testing forms part of the Future Homes research schedule.

[r] Refer to Annex H
[s] Refer to Annex I
[t] Confidence level from 63.9 to 82.5 W/K

9.3 Airtightness and ventilation

Table 15 provides the AP50 value measured using the blower door and pulse test, the tests were carried out under the same conditions, 5 °C for the outside temperature and 21 °C for the interior temperature. All intentional ventilation openings such as MVHR ducts, trickle vents, cooker hood and wastewater services were sealed throughout the test programme.

Table 15 - q50, n50, and derived background ventilation rates and infiltration heat losses for eHome2

House	Air permeability [q_{50}] ($m^3h^{-1}m^{-2}$ @ 50 Pa)	Air change rate [n_{50}] (ACH @ 50 Pa)	Infiltration rate [n] (h^{-1})	Infiltration heat loss (W/K)
Blower Door	2.81±0.05[u]	2.86	0.14	10.6
Pulse	2.69±0.11[v]	2.75	0.14	10.1
Design	**3.0**	**3.06**	**0.15**	**11.3**

Difference between test methods:
The main difference between the methods, is that the blower door fan test measures building air leakage by creating a positive or negative pressure differential across the building fabric of 50 pascals, while Pulse testing measures permeability at a lower pressure differential of 4 Pa created by a pulse of air delivered over a much shorter period.

The results between the test methods show a difference of 0.12 $m^3h^{-1}m^{-2}$ @ 50 Pa for the air permeability and 0.11 ACH for the air change rate. This represents a difference of 5% the ventilation heat loss between the blower door and the pulse test.

Difference between design and as built:
If the measured ventilation heat loss is compared against the design value, the airtightness overperformed by 6.2% (0.7 W/K) and 10.6% (1.2 W/K) for the blower door and Pulse test respectively.

[u] Refer to annex D
[v] Refer to annex E

9.4 Thermography

An air infiltration investigation was performed on eHome2 following the depressurisation phase of the blower door test. A pressure differential of -50 Pa was maintained while a thermographic survey was undertaken. Areas of air infiltration are identifiable in the thermograms below as streak patterns and regions of cooler internal surfaces (indicating air movement behind surfaces). The thermograms in Figure 20 to Figure 22 have the same applied temperature span, so locations of cooler air infiltration generally signify more pronounced and direct air paths.

Direct infiltration paths are shown in Figure 20 - Figure 23, particularly in the ceiling. Indirect infiltration can be observed in Figure 24 - Figure 25, particularly at junctions and behind plasterboard. Cold patches as a result of inconsistently distributed insulation can be seen in Figure 26 - Figure 27.

The thermography aligns with the results of the ceiling U-value which indicates a lower measured performance than the design value, this is mainly attributed to the areas around the wall-ceiling junction, patches of missing insulation to the roof void, detailing around window reveals and the loft hatch.

It is worth noting that when the property is subjected to a pressure differential, the severity of air leakage pathways will be amplified. Also, due to the high energy efficiency of the fabric in eHome2, the cold bridges will be more pronounced by comparison within the thermograms.

9.4.1 Direct infiltration

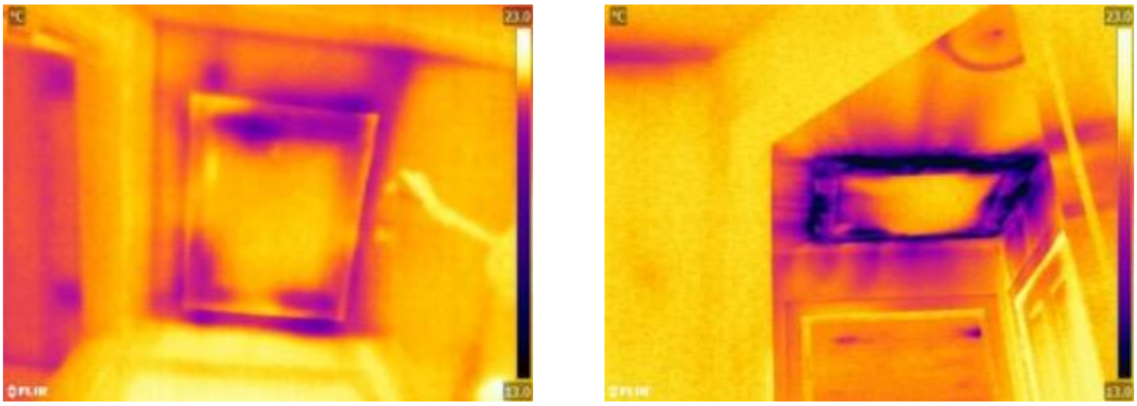


Figure 20 –Landing at atmospheric pressure (left) highlighting issues in insulation placement around the loft hatch. During depressurisation (right) air infiltration visible along the loft access hatch.

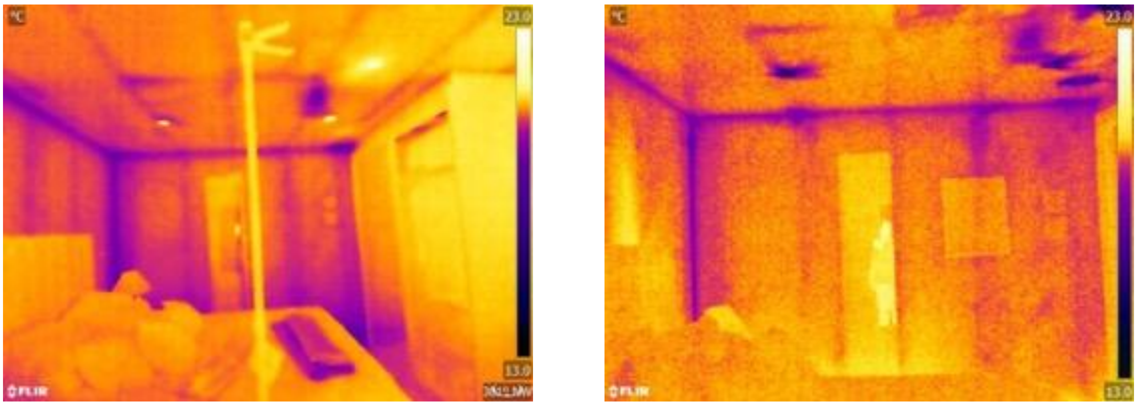


Figure 21. Bedroom 1 atmospheric pressure (left) showing gaps in ceiling insulation and bridging at wall/ceiling junction. During depressurisation (right) minor air infiltration visible along the eaves and walls, as well as air service vents.

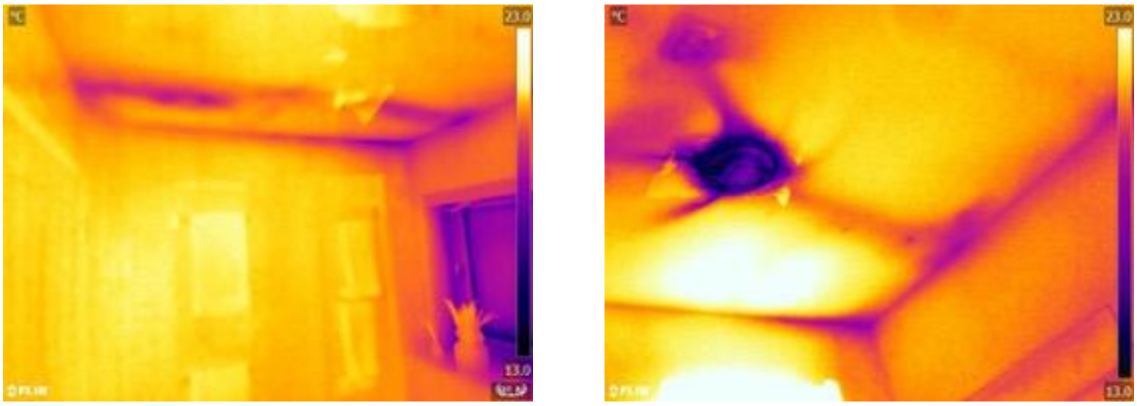


Figure 22. Bathroom at atmospheric pressure (left), cold spots indicating gaps in the loft insulation placement. During depressurisation (right) air infiltration visible along the ceiling particularly at penetrations.

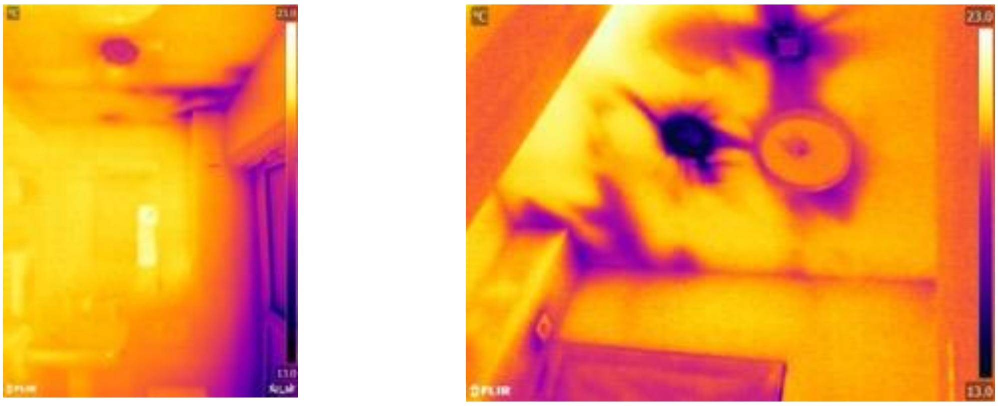


Figure 23. Ensuite at atmospheric pressure (left) showing cold bridging around the service void. During depressurisation (right) air infiltration visible along the ceiling at service penetrations.

9.4.2 Indirect infiltration

Figure 24. Living Room atmospheric pressure (left). During depressurisation (right) air infiltration visible along the ceiling, floor and vents. Particularly cold spot under depressurisation stemming from the inter-floor void, further investigation required to understand the cause.

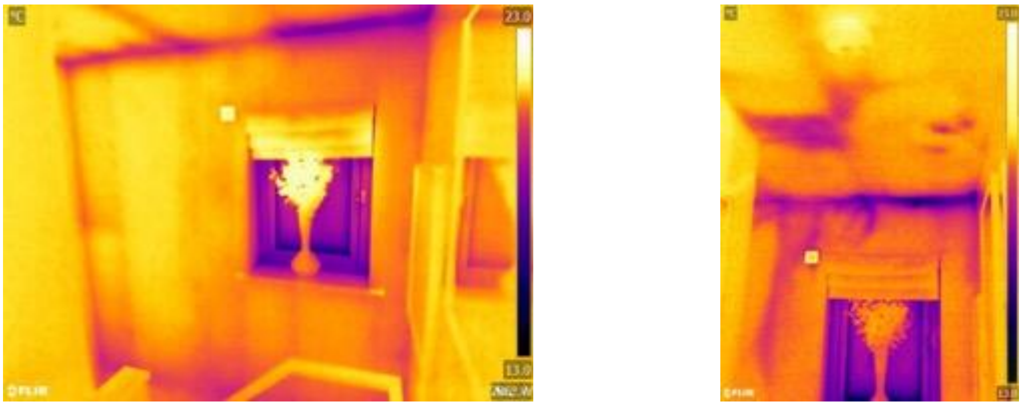


Figure 25. Stairs at atmospheric pressure (left) showing cold bridging at the rear wall/eaves junction. During depressurisation (right) air infiltration visible along the ceiling and wall behind the plasterboard, stemming from the eaves.

9.4.3 Irregular insulation distribution and uncontrolled infiltration paths

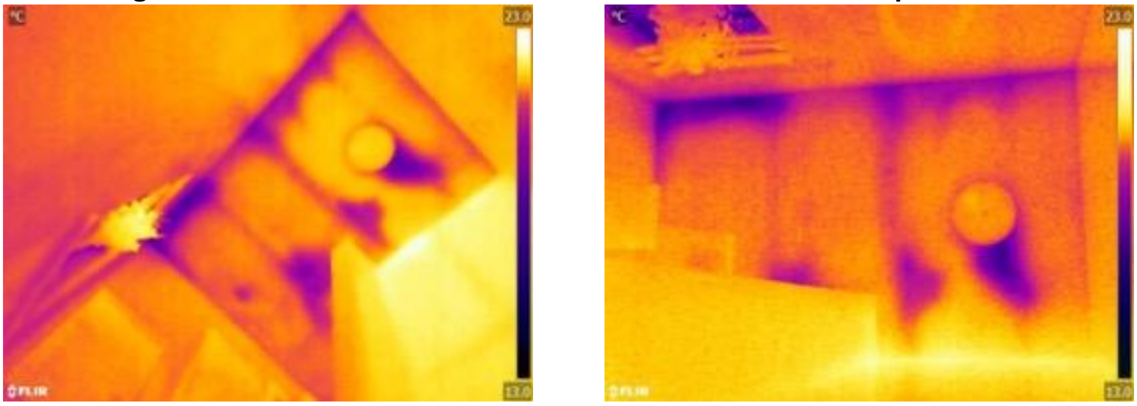


Figure 26. Stairs 2 at atmospheric pressure (left) showing cold areas where insulation has not been fitted correctly. During depressurisation (right) the cold areas can be seen again, however there appears to be no additional air leakage pathways.

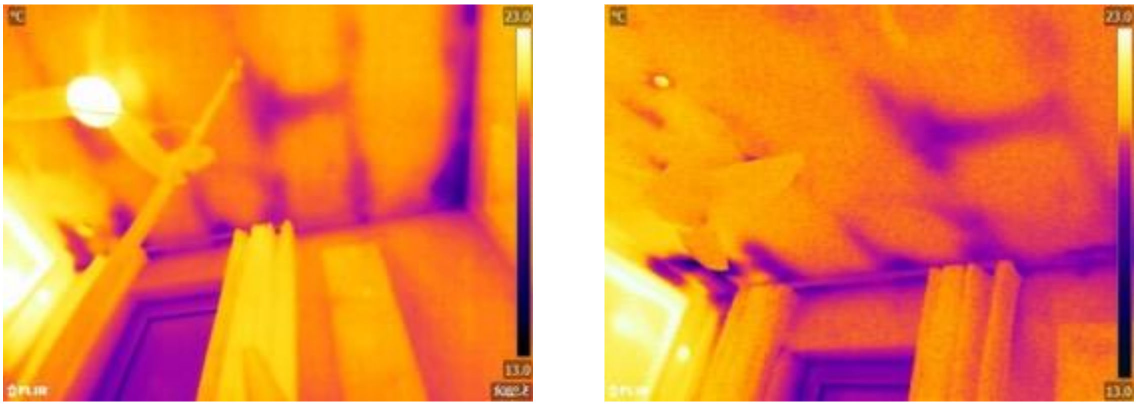


Figure 27. Bedroom 2 atmospheric pressure differential (left). During depressurisation (right) some air infiltration visible along the ceiling/wall junction, both showing gaps in loft insulation, however no additional air movement in the ceiling as a result of depressurisation.

9.5 In-situ U-value measurement

In-situ U-value measurements were undertaken on selected thermal elements in eHome2 in accordance with ISO 9869 . Measurements were used to assess whether elements achieved the design level of thermal performance. In-situ U-value measurements were compared with elemental design U-values.

It is worth noting that U-value measurements using heat flux plates (HFP) are highly localized in nature, and a number of variables can influence this point measurement. To account for this, multiple HFP measurements are taken simultaneously from across the building elements surface to create an average. HFP location selection is aided by thermography to identify areas deemed representative of the whole building element. These should be considered alongside the whole house heat loss figure, provided by the coheating test in section 9.1.

Table 16 summarizes the results of the in-situ U-value measurements and compares them to the design U-value for each measured heating 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 16. Design U-values

Element	Measurement locations	Design U-value (W/m²K)
Door (front) body &window	2	1.20
Windows	7	1.20
Floor (ground floor)	10	0.11
External Walls (brick)	13	0.13
External Walls (render)	13	0.13
External Walls (Timber Stud)	2	
Ceiling	9	0.11
Ceiling (Timber Stud)	2	

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 façade is difficult to replicate.

The air velocity has been mapped for each square metre of wall of eHome2, with an average velocity of 0.23 m/s, with variations ranging from 0 to 0.66 m/s, further details can be found in Annex J. Calculation of U-value with different R_{se}.

We have presented the results here as raw and unadjusted results, which do not account for this discrepancy although this is likely to represent a minor difference of around 1% across a typical wall value of eHome2.

9.5.1 External Walls

In situ U-value measurements of the external walls were taken at 26 locations between the timber frame members and at two locations onto the timber stud. They were distributed as follows: two 3x3 grids placed in the Living Room (Figure 28) and Bedroom 1 (Figure 29), an extra location was also placed in each grid to measure the timber stud components. The other six sensors were located on the remaining exterior walls to take spot measurements, three on the ground floor and three on the first floor as in Figure 16.

In Figure 29 (Bedroom 1), at the locations of HFPs 7,8 and 9 higher U-values are observed, this could be due to anomaly in the makeup, and further investigations are taking place, to be covered in a report around energy pathology issues on eHome2.

Note on U-value measurement adjacent to corners:

It should be noted that although measurements taken in both the Living Room and the Bedroom 1 are adjacent to the wall corners, these are not affected by any thermal bridging issues; the thermal imaging and the U-value measurements (Figure 28 and Figure 29) confirm this, they are 540 mm from the corner point (right hand side) of Living Room wall and 560 mm from the corner point (left hand side) of Bedroom 1 wall.

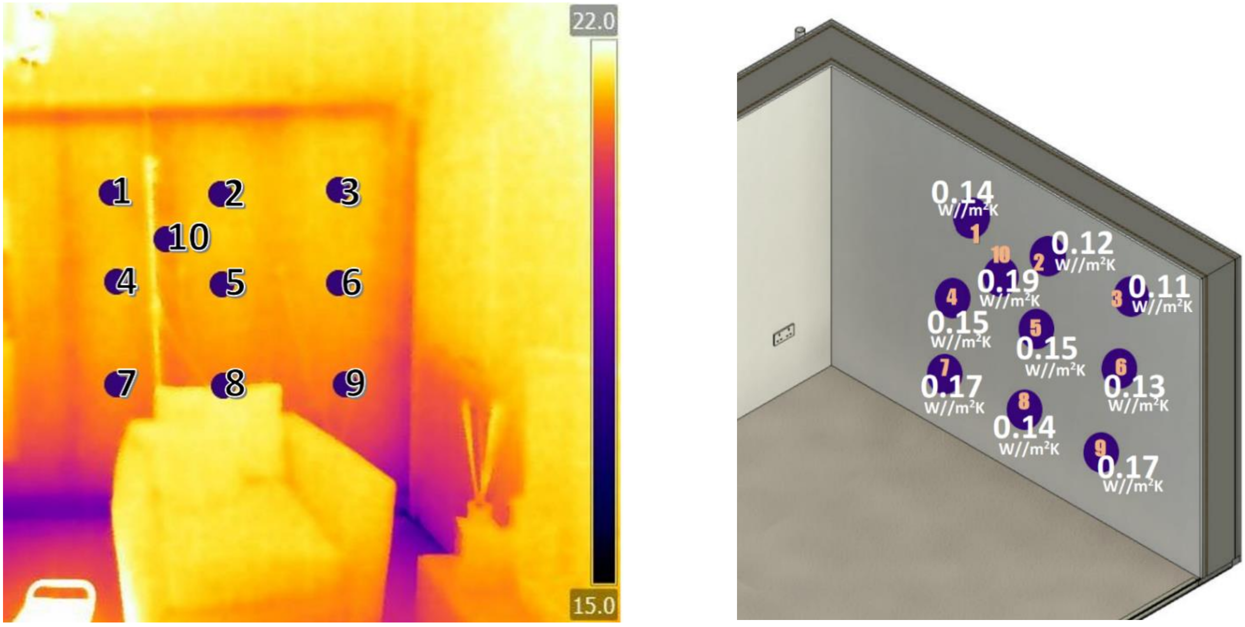


Figure 28. Living Room HFP locations and measured U-values

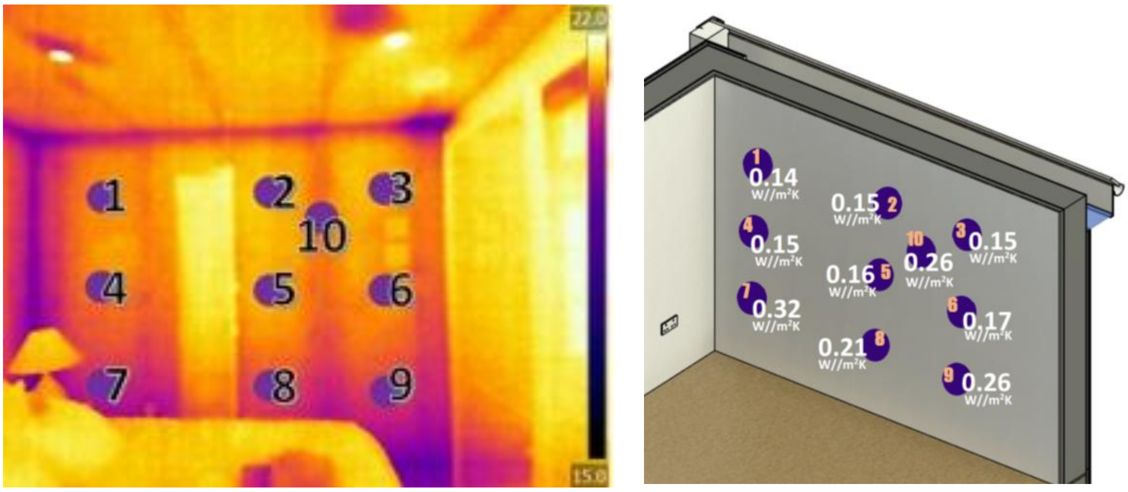


Figure 29. Bedroom 1 HFP locations and measured U-values

Table 17 shows the data of the U-values average for each of the measurements.

Three timber fraction scenarios were considered to obtain the average U-value of the walls. These values were obtained using a weighted average considering 7.8% for the worst scenario, 3.9% for the average scenario and 1.5% for best scenario of the values obtained from the timber stud, these timber fraction calculations were provided to us by Saint Gobain (Annex B) to reflect the building science based principles designed into the concept wall system in order to reduce thermal bridging. They have been used in substitution for the 15% timber fraction used as a default in **BR443** [22]. With reference to section 9.5.1.1 and Figure 29, it was decided by the research team to include locations 7, 8 and 9 in the average U-value calculation. Although the measured U-value in these locations is considerably greater than those measured elsewhere on the same panel, it does account for 1/6th of the total panel area. This was backed up by thermal imagery.

The **average** U-values obtained varied from 0.14 W/m^{2}K to 0.15 W/m^{2}K for the ground floor (brick) wall and 0.17 W/m^{2}K to 0.18 W/m^{2}K for the first floor (rendered) wall, as shown in Table 18. If uncertainty is considered, the values do not agree with the design value.

Table 17. In-situ U-values for External Walls

HFP	Ground Floor (brick slips) Measured U-value (W/m^{2}K)	First Floor (rendered) Measured U-value (W/m^{2}K)
1	0.14±0.02	0.14±0.02
2	0.12±0.02	0.15±0.02
3	0.11±0.02	0.15±0.02
4	0.15±0.02	0.15±0.02
5	0.15±0.02	0.16±0.02
6	0.13±0.02	0.17±0.02
7	0.17±0.02	0.32±0.04
8	0.14±0.02	0.21±0.03
9	0.17±0.02	0.26±0.03
Wall 1	0.12±0.03	0.12±0.04
Wall 2	0.19±0.02	0.12±0.02
Wall 3	0.19±0.03	0.12±0.02
10 (Timber stud)	0.25±0.03	0.26±0.02

Table 18 shows the calculated average external wall U-values when considering different timber fractions, as supplied by Saint Gobain.

Table 18. Average U-Values for External Walls using different timber fractions.

	Ground Floor wall	First Floor wall	First floor wall[w]
Measured U-value (W/m²K) (Timber fraction of 7.8% - **Worst case**)	**0.15±0.02**	**0.18±0.03**	**0.16±0.03**
Measured U-value (W/m²K) (Timber fraction of 3.9% - **Average case**)	**0.15±0.02**	**0.18±0.02**	**0.15±0.02**
Measured U-value (W/m²K) (Timber fraction of 1.5% - **Best case**)	**0.14±0.02**	**0.17±0.02**	**0.15±0.02**
Design (W/m²K)	**0.13**	**0.13**	**0.13**
Difference to design (W/m²K) (Timber fraction of 7.8% - **Worst case**)	**0.02**	**0.05**	**0.03**
Difference to design (%) (Timber fraction of 7.8% - **Worst case**)	**16%**	**38%**	**21%**
Difference to design (W/m²K) (Timber fraction of 3.9% - **Average case**)	**0.02**	**0.05**	**0.02**
Difference to design (%) (Timber fraction of 3.9% - **Average case**)	**12%**	**35%**	**18%**
Difference to design (W/m²K) (Timber fraction of 1.5% - **Best case**)	**0.01**	**0.04**	**0.02**
Difference to design (%) (Timber fraction of 1.5% - **Best case**)	**10%**	**33%**	**16%**

[w] Excluding HFP 7,8 and 9, representing the performance of the first-floor external wall excluding areas where performance was deemed to be compromised as shown in section 9.5.1.1. This value was not used in the whole house plane element analysis.

There was slight difference between the averaged U-values and those provided in the design. For the ground floor wall, U-values differences ranged between 0.01 – 0.02 W/m^2K. For the first-floor wall, differences ranged between 0.04 – 0.05 W/m^2K. This is outside the range of the measurement uncertainty, as such, this wall would be deemed as not performing in line with the design. This can be attributed to a particular area of wall which was deemed to be underperforming, which was investigated in section 9.5.1.1.

9.5.1.1 Pathological Investigation

Following the measurement of the U-values of the external walls, which were found to be underperforming, it was decided by the research team to carry out a series of further investigations. These are detailed below.

9.5.1.1.1 Exposed service void

The timber frame in eHome2 contains a 35 mm unventilated cavity. This was exposed by cutting a square recess of 350x350 mm into the plasterboard and the VCL layer shown in Figure 30.

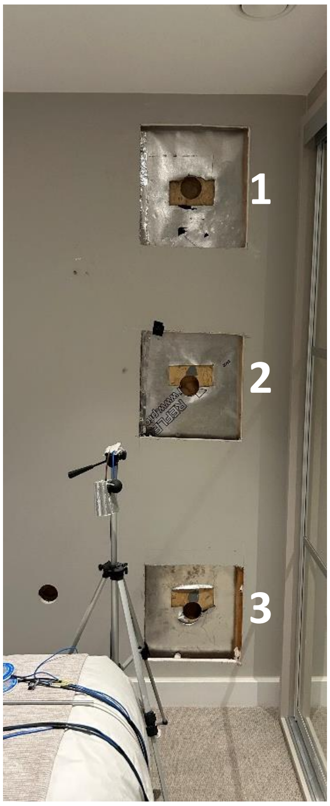


Figure 30. Recess' cut into the plasterboard and VCL layer of the external wall in Bedroom 1

9.5.1.1.2 U-value measurement bypassing service void

U-value measurements were repeated within the recess at points 1,2 and 3, with the HFP placed directly on to the internal face of the timber frame panel (the reflective foil was removed). Saint Gobain provided the U-value calculations which have the service void element removed. These are presented as “design” values in Table 19.

Table 19. U-Value measurement at internal face of the timber frame panel

Design	Top (1)	Middle (2)	Bottom (3)
0.15 W/m²K	0.21 W/m²K	0.39 W/m²K	1.17 W/m²K

9.5.1.1.3 Exposed insulation inside timber frame

A further recess was cut into the timber frame panelling on the internal side. This opened up the glass fibre insulation inside of the panel.

Table 20. Unintended air gap in timber frame panel

Top (1)	Middle (2)	Bottom (3)
39 mm	36 mm	56 mm

9.5.1.1.4 Smoke test

Using a fan pressurisation kit, a 50 Pa positive pressure differential was induced on the property. While under pressurisation, smoke was released within the master bedroom. The smoke was observed entering this unintended air gap, moving upward into the loft space, before escaping through the eaves. This indicates that the integrity of the internal VCL, acting as the primary air barrier, had been compromised.

9.5.1.1.5 Thermography

A thermographic survey of the eaves junction was conducted both with the under atmospheric pressure and the induced positive pressure. These images are shown in Figure 31. Heat can be observed escaping the eaves local to where the pathological investigation was conducted.

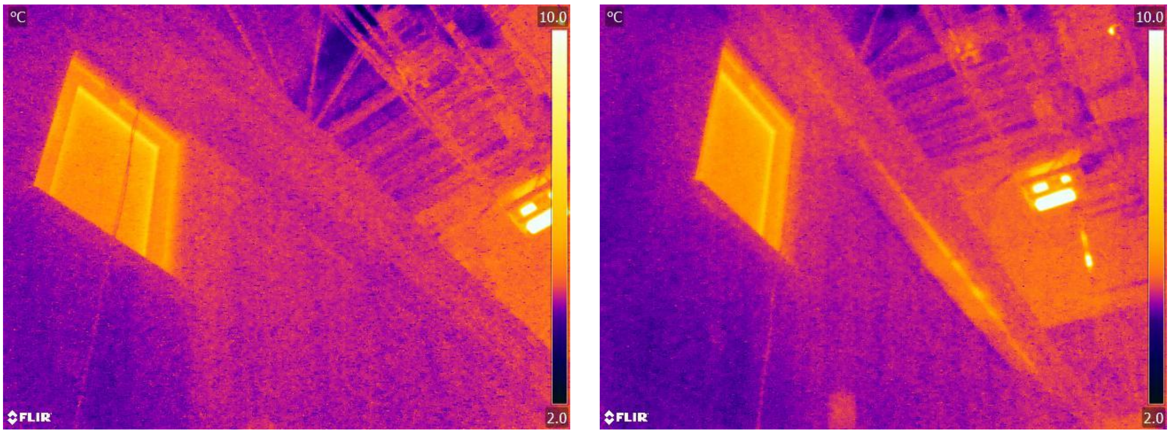


Figure 31. Thermogram showing eaves local to the pathological investigation area under atmospheric pressure (left) and induced positive pressure differential (right)

In summary, the initial findings pointed towards an underperformance in the external wall makeup. Following the pathological study, it was found that the insulation appeared to be inconsistent inside the panel, leaving uninsulated areas. During the installation process, mineral wool fibre had been compressed to a point where it did not recover to fill the insulated stud void, resulting in unintended air voids and underperformance. This was coupled with the fact that the wall-ceiling junction did not appear to be intact. This was highlighted by both the smoke testing and thermographic survey, which indicated a direct route of airflow from the top of the timber frame panel through to the loft, and finally the eaves. It is thought that the primary airtightness barrier had been compromised as part of the pathological instigation. This allowed for greater air movement when under pressurisation. This requires further investigation to be confirmed, the details of which is discussed in section 10.

9.5.2 Ceiling

In situ U-value measurements of the ceiling were taken at 11 locations between the timber frame and at one location on the timber joist component. Figure 32 shows the location and the results of the HFP and U- values. The U-values calculated for the ceiling's panel are 0.13 W/m^{2}K and 0.23 W/m^{2}K for the centre of the timber frame panel and the timber stud component, respectively.

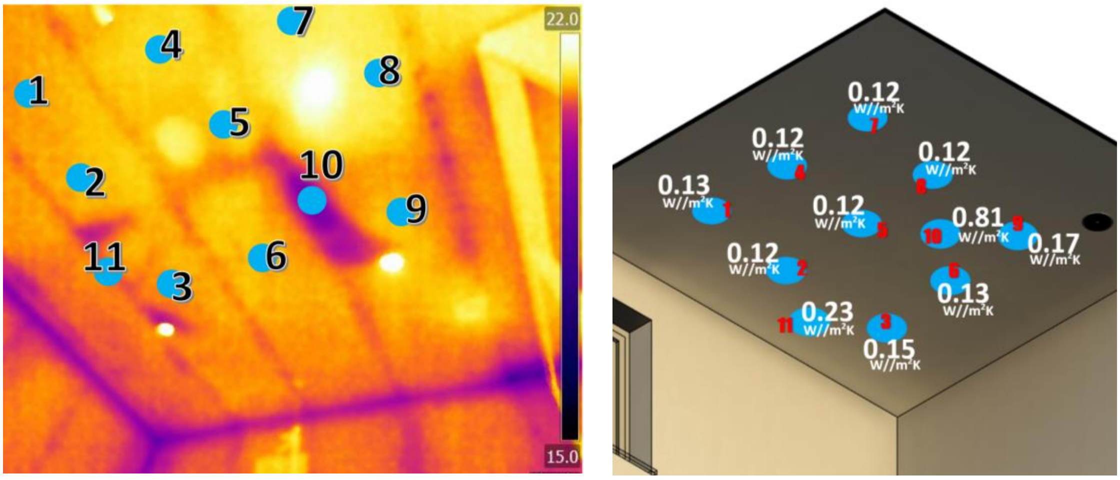


Figure 32. Bedroom 1 ceiling HFP Location

Table 21 illustrates two timber fractions, a worst case scenario of 6.3%, and a best case scenario (1.6%) (Saint Gobain have issued guidance to UoS stating that the first 100 mm of insulation is bridged, whereas the remaining 300 mm is unbridged, this will allow the total bridging to be divided by four). For the purpose of transparency both figures have been presented. **It is the view of UoS that the <u>worst case</u> scenario shall be used.**

Figure 33. Photograph of the loft insulation. It can be observed that the insulation is not homogenous or evenly distributed across the area of the loft. Suboptimal application of insulation around roof trusses can be observed.

The average U-value of the ceiling (0.15 W/m^{2}K) has a difference of 0.04 W/m^{2}K compared to the design U-value (0.11 W/m^{2}K), it is important to mention that these values were obtained using a weighted average considering timber fractions of the values obtained from the timber stud (11). The timber stud (10) is not representative of the timber stud of the entire ceiling, this measurement was taken on an uninsulated layer of plasterboard, rather than a timber element, this was confirmed using thermal imaging, shown in Figure 32. This error is included for transparency and is not included in the averaged values.

Table 21. In-situ U-values for Ceiling

HFP	Measured U-value (W/m^{2}K)
1	0.13± 0.02
2	0.12± 0.02
3	0.15± 0.02
4	0.12± 0.02
5	0.12± 0.02
6	0.13± 0.02
7	0.12± 0.02
8	0.12± 0.02
9	0.17± 0.02
10 Timber frame studs	0.81± 0.11
11 Timber frame Studs	0.23±0.03

Measured U-value Average(W/m^{2}K) (Timber fraction of 1.6% - **Best case**)	**0.13± 0.02**[x]
Measured U-value Average(W/m^{2}K) (Timber fraction of 6.3% - **Worst case**)	**0.14± 0.02**[y]
Design(W/m^{2}K)	**0.11**
Difference to design (W/m^{2}K) (Timber fraction of 1.6% - **Best case**)	**0.02**
Difference to design (W/m^{2}K) (Timber fraction of 6.3% - **Worst case**)	**0.03**
Difference to design (%)(Timber fraction of 1.6% - **Best case**)	**21%**
Difference to design (%)(Timber fraction of 6.3% - **Worst case**)	**26%**

If we consider the wort case scenario, the ceiling is underperforming by 26%, this is outside of the margin of error of the measurement and is therefore an area which requires further investigation. Several issues were found in the ceiling insulation, such as disturbance, non-homogeneity, and non-uniform thickness across the loft zone, there were also some assumed areas of air infiltration identified using thermography, this is found in section 9.4. Some defects were difficult to identify as around 50% of the loft has decking installed.

9.5.3 Ground Floor

Note on U-value measurement of floors:

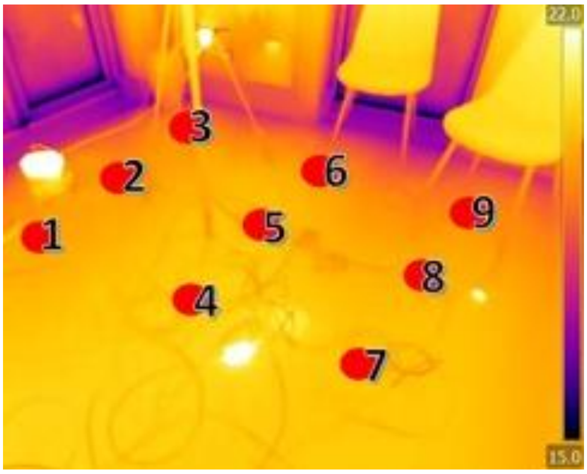
There is no standardised methodology for the in-situ measurement of floor U-values. As such, this next section will present the "**point thermal transmittance**" of the floor of eHome2.
There is no single point on a floor which will provide an representative match with designed U-value [2]. Floor U-value design calculations consider several different variables which are difficult to capture with in-situ measurements, these include:

- Buffering effect of the ground
- Exposed perimeter of the floor
- Ratio of perimeter to area

Given these facts, the authors feel that whilst these "**point thermal transmittance**" (PTT) are indicative, they should not be directly compared to floor design U-values as this could be misleading.

[x] Timber studwork was not included in the calculations
[y] Timber studwork was not included in the calculations

In situ "point thermal transmittance" measurements of the ground floor were taken at 10 locations, nine distributed on a 3x3 grid in the Kitchen (Figure 34) and one located in the Hall. The HFPs 1,2,3,6, and 9 are closer to the exterior walls and has a higher value compared to those closest to the centre of the room.



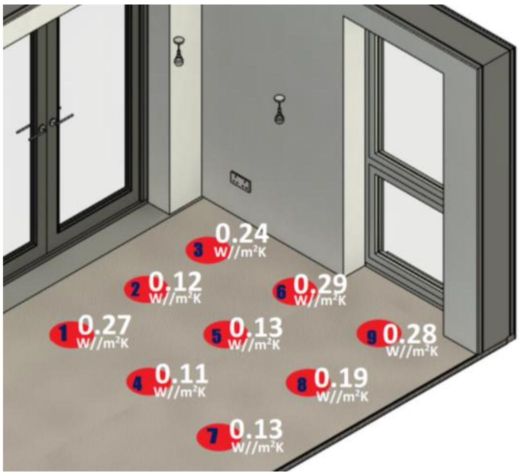


Figure 34. Kitchen floor HFP location

Table 22. In situ PTT for the ground floor

HFP	Measured PTT (W/m^2K)
1	0.27±0.04
2	0.12±0.02
3	0.24±0.03
4	0.11±0.01
5	0.13±0.01
6	0.29±0.03
7	0.13±0.01
8	0.19±0.02
9	0.28±0.03
Hall	0.37±0.05
Measured PTT Average(W/m^2K)	**0.11-0.37**
Design U-value (W/m^2K)	**0.11**

When we consider the range of PTT shown in Table 22 , it can be seen the design value falls within the measurement range. This range can be explained by the placement of sensors being affected by thermal bridging, ventilation to the floor and the unique nature and complex geometry of the NuSpan floor, which has varying resistance across its profile. As we have previously stated, there is no collection of PTT points which would align with the design U-value of *any* suspended floor.

9.5.4 Windows

UoS were not provided with specific U-value design calculations for the windows or doors of eHome2, as such we have used in SAP document (Annex A). BFRC (Annex B) provides the value of the centre pane of the window.

In situ measurements of the centre pane of windows were taken at five locations on the windows. Additionally, for the window of Bedroom 1, two extra locations were measured as shown in the Figure 35. The others four locations are shown in the Figure 16. Figure 36 shows two measurement locations on the door, one in the main body and one on the door glazing.

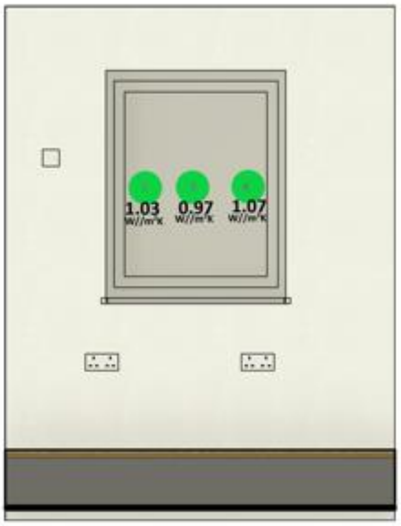


Figure 35. Bedroom 1 window glass HFP location

The average measured U-values for the centre pane of the windows is 0.98 W/m2K (Table 23) which agrees with the centre pane design value of 1.07[z] W/m^{2}K with a difference of up to 8% between them. If the uncertainty (±0.14 W/m^{2}K) is considered, this is higher than the difference between the design value and the measured value (0.09 W/m^{2}K), so it is considered that the U-value measured agrees the design U-value.

[z] Refer to Annex B

Table 23. In-situ centre pane values for the Windows.

HFP	Measured centre pane (W/m^2K)
Kitchen/Dining	0.91±0.12
Living Room	0.98±0.13
WC	1.00±0.14
Bath	1.04±0.14
Bedroom1_Centre	0.97±0.14
Measured centre pane Average(W/m^2K)	**0.98±0.14**
Design centre pane (W/m^2K)[aa]	**1.07**
Difference to design (W/m^2K)	**0.09**
Difference to design (%)	**8.4%**

Table 24 shows the data of the U-values of the door elements (body and window) as Figure 36 shows. The design U-value is 1.20 W/m^2K[bb], if the mean average of the measured elements is considered (1.42 W/m^2K), the measured U-value is 18.3% higher than the design value and if the weighted average is considered (0.61 W/m^2K), the U-value is measured is 49.1% lower than the design value.

[aa] Refer to Annex B
[bb] Refer to annex B

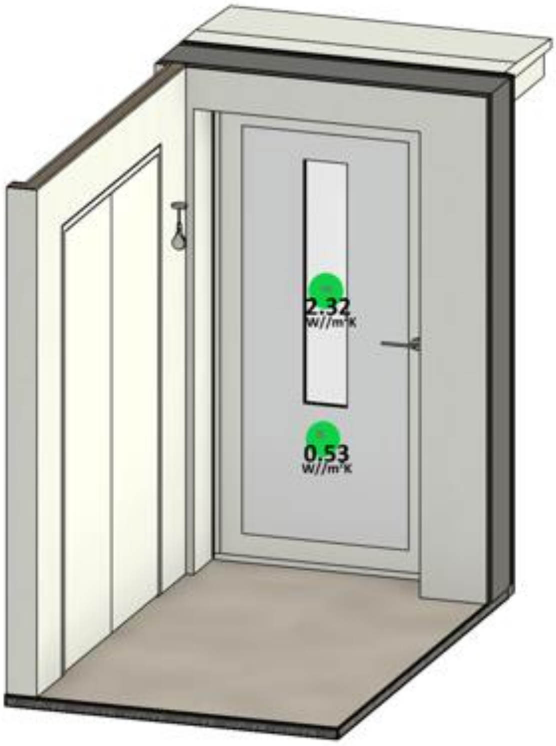


Figure 36. Front Door HFP location

Overall, 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 actual window and door design figures. For the door, we only have the value given in SAP, in order to make a better evaluation of the performance of the door, it is necessary to have the values of each of the elements of the door.

Table 24. In-situ centre pane for the Door.

HFP	Measured U-value centre pane (W/m^{2}K)
Body	0.53±0.07
Window	2.32±0.33
Weighted Average	**0.61±0.10**
Mean Average	**1.42±0.11**
Design U-value (W/m^{2}K)	**1.2**
Difference to design Weighted Average (W/m^{2}K)	**-0.59**
Difference to design Weighted Average (%)	49.2
Difference to design Mean Average	**0.22**
Difference to design Mean Average (%)	18.3

For the windows, generally the thermal performance of the frame and the glazing element would be detailed separately. We have a BFRC and SAP value, however these are for a typically sized windows and not specific to the ehome2. If we consider only centre pane values, then the data suggests that window appeared to meet the design U-value.

9.6 Performance Gap

This section will focus on the whole house performance gap highlighted in Section 9.4. A minor performance gap was found in eHome2, which will be quantified in this section, but a more detailed pathological report will be prepared. This will use some more in-depth testing methods to identify specific intervention points and will assist Saint Gobain/Barratt in improving the fabric of the home and thus reduce the performance gap measured at 3.9%.

9.6.1. Element breakdown

Table 25 shows the results of the HTC of the fabric calculation, in which three HTC values are compared, the first is the design HTC (73.8 W/K), the second is the HTC obtained using the measured U-values and measured infiltration heat loss (73.0 W/K) and the third HTC obtained in the coheating test (80.0 W/K).

The difference between the second and third HTC -1.82 W/K. This difference may be due to the uncertainties related to the measured values and potential discrepancies between calculated and as-built thermal bridging heat losses. It is important to mention that in the case of the HTC obtained from the U values, the uncertainties of the windows and doors were not considered, as there was not enough data to obtain the measured U-value of each element (only centre pane was measured). However, both tests broadly agree with the value of the HTC.

Table 25. Performance gap

Element	Area	Design		As-built	
	(m^2)	U-value (W/m^2K)	Heat loss (W/K)	U-value (W/m^2K)	Heat loss (W/K)
Doors (front door)	2.25	1.2	2.70	1.2[cc]	2.70
Windows (inc pat doors)	19.23	1.2	23.08	1.2[cc]	23.08
Floor	45.63	0.11	5.02	0.14±0.03[dd]	6.39
Walls (Brick)	50.69	0.13	6.59	0.15±0.02	8.11
Walls (Render)	65.43	0.13	8.51	0.16±0.03	10.47
Ceiling	45.63	0.11	5.02	0.14±0.04	6.84
Plane element heat loss (W/K)		50.91		57.8	
Thermal bridging heat loss (W/K)		11.5		11.5	
Total fabric heat loss (W/K)		62.43		69.3	

cc Design values were used for openings because only centre pane was measured.

dd For plane element analysis, it was necessary for a measured in-situ "U-value" to be calculated. For this, the measurements of HFP 4,5,7,8 and Hall were considered for the average. The average U-value calculated for the floor region is 0.14 W/m^2K. ***This is not a U-value which can be compared to a design figure.***

Infiltration heat loss (W/K)	11.3	10.6	
HTC (design) (W/K)[ee]		73.8	
HTC (measured fabric and measured infiltration) (from U-value) (W/K)[ff]		80.0	
HTC coheating (W/K)[gg]		76.7±2.01	
Unexplained fabric performance gap (W/K)		-3.26	
Gap		**Absolute (W/K)**	**%**
Design fabric and infiltration performance gap		**2.9**	**3.9%**
Fabric performance gap		**3.6**	**5.9%**
Infiltration performance gap (W/K)		**-0.7**[hh]	**-6.3%**
Contribution to design and fabric performance gap			
Fabric performance gap contribution		124%	
Infiltration performance gap contribution		-24%	

The HTC obtained in the coheating test 76.6±2.01 W/K shows a design fabric and infiltration performance gap is 2.9 W/K (3.9%). Figure 37 shows a gap of 3.6 W/K due to fabric performance and -0.7 W/K due to infiltration performance. The fabric performance gap is 5.9% which indicates a good performance of the fabric. However, in case of infiltration performance gap represents -6.3% which indicate a better airtightness than the design value. Of the 2.9 W/K gap, 124% is due to the fabric and -24% to infiltration, indicating plane element heat loss under performance is negated by an over performance in terms of airtightness.

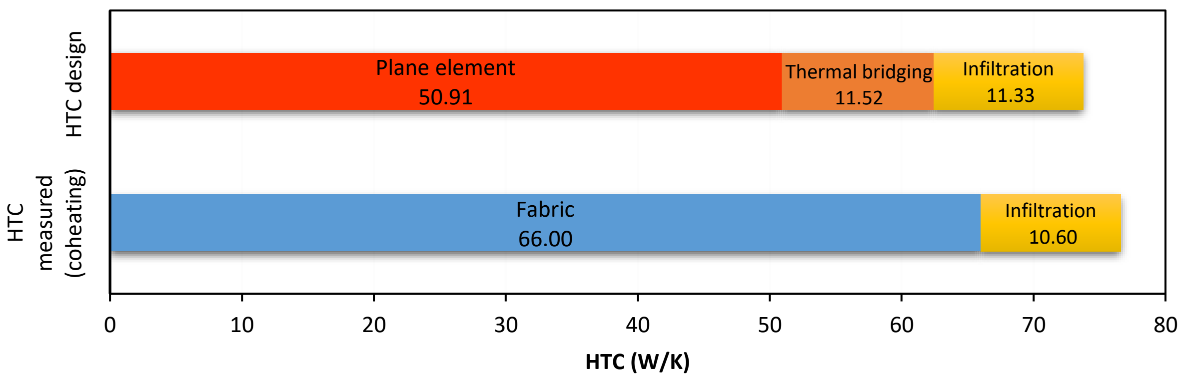


Figure 37. HTC design vs measured.

If the design plane element is compared vs the plane elements obtained with the U values, it shows that in the design, the openings represent 50.6% of the heat loss, the walls 29.6%

[ee] Theory based on design values
[ff] Both theory based with design fabric performance and measurement based with the infiltration
[gg] Measurement based
[hh] Refer to Table 15 to see results of the blower door test

and ceilings/floor 9.9% each. However, in the measurements, the openings represent only 43.6%, the walls 32.8%, the floor 13.0% and the ceiling 10.7%.

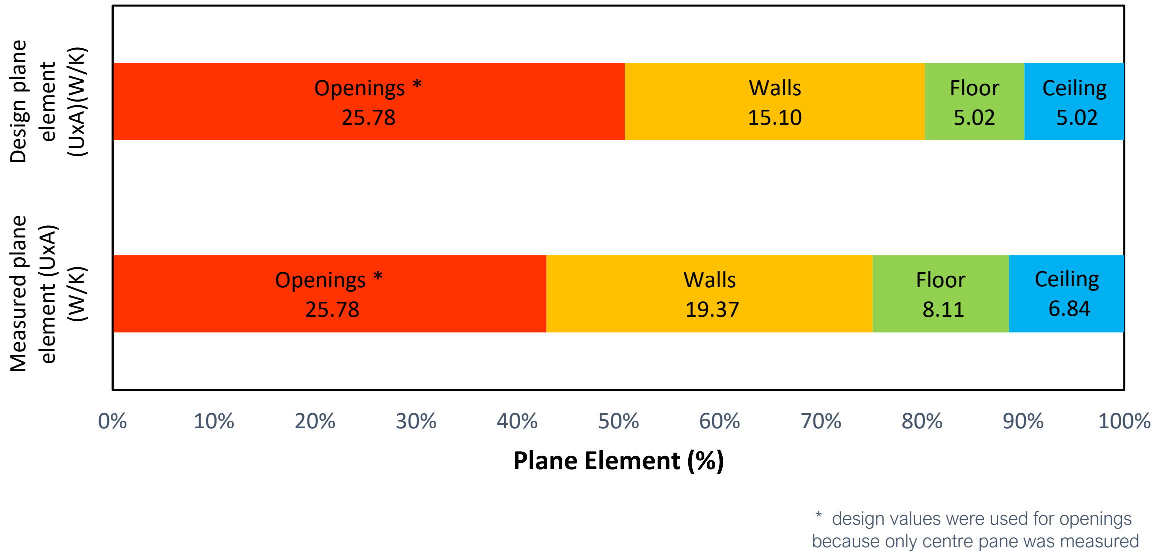


Figure 38. Plane elements components

9.6.2. Different test methods

Figure 39 compares the HTC obtained by the different methods with the design HTC. The performance gap measured by the coheating test is 3.9%, -11.8% by QUB and -2.5% by Veritherm.

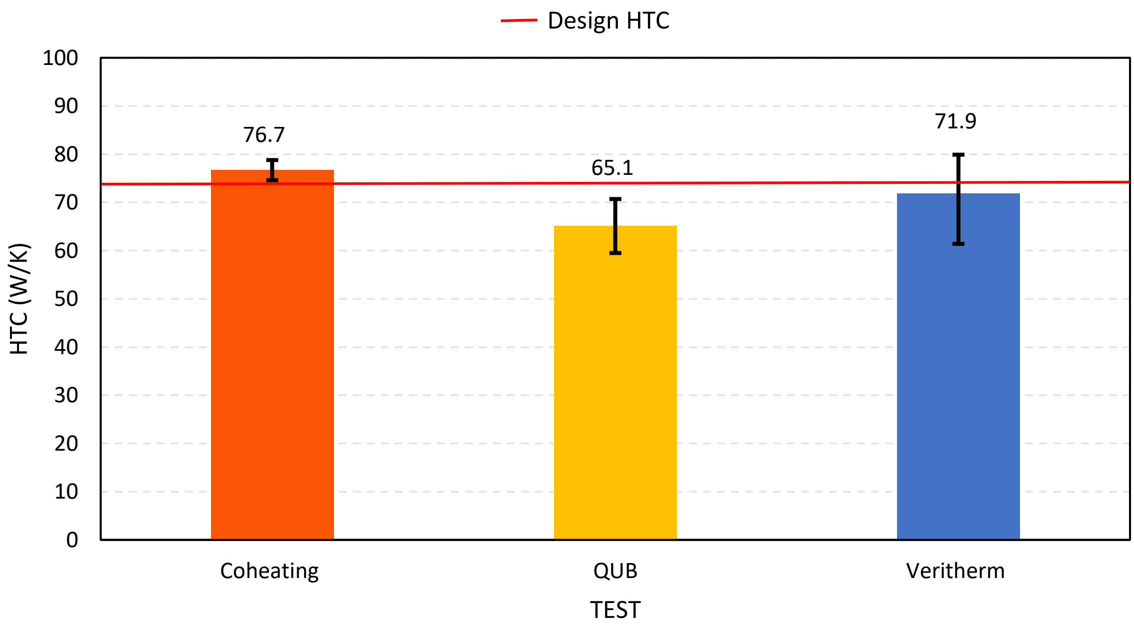


Figure 39. HTC different methods.

9.6.3. As-built SAP assessment

UoS were provided with the as designed SAP file (xml). This file was manipulated in the following way, to achieve an as-built HTC:

- Inserted the as-built air permeability test result (section 9.3)
- Manipulated the U-values to give us an as-built plane element fabric heat loss value

The output files were then generated to produce the results as shown in Table 26. This helps to contextualise the performance gap, utilising the assumptions and normalised process found within SAP.

Table 26. Performance Gap as obtained from the Design and As-Built SAP assessments

	Design	As Built	Difference
CO_2 (t/yr)	0.07	0.10	0.03
Primary Energy Use (kWh/m^2/yr)	4.0	8.0	4.00
SAP Rating	99 (A)	97 (A)	2
Dwelling Fabric Energy Efficiency (kWh/m^2/yr)	38.68	42.70	4.02

As shown in Table 26, the performance gap does have an effect on the primary energy use of eHome2, with the house consuming an additional 4 kWh/m^2/yr to run as a result of the underperformance. If we then consider CO_2 emissions, then there is an additional 0.03 tonnes per year.

10. Summary

Overall, the fabric of eHome2 performed well, with the in-situ measurement of several building elements being in-line with the design performance in terms of the heat loss through the fabric by conduction and radiation. It is worth highlighting the issue found with the external first floor wall, in which a considerable increase in U-value (63%) was measured towards the bottom of the panel. Following a pathological investigation, it was found that two issues were the cause of this:

1. Insulation appeared to be placed inconsistently inside the panel, leaving uninsulated voids.
2. A direct air leakage pathway was observed at the wall-ceiling junction when the house was subjected to a pressurisation test. This direct route of airflow navigated from the top of the timber frame panel through to the loft, and finally the eaves - indicating an in-proper seal. Further investigation of the timber frame panels construction is required to confirm this.

Localized underperformance of the external walls and roof is responsible for a fabric performance gap of 3.9%, which is outside of our margin of measurement error (±2.7%) and therefore indicative of a measurable gap. As the airtightness of the property overperformed, this performance gap can be attributed to the plane element and thermal bridging heat loss. In terms of energy modelling, the Dwelling Fabric Energy Efficiency (DFEE) has a 4.02 kWh/m^2/yr increase, according to SAP.

Figure 40 shows how the percentage performance gap of eHome2 compares to that of other newbuild properties from the Leeds Beckett University (LBU) coheating database [1], which is the largest published dataset of coheating tests conducted on new build properties. The eHome2 performance gap of 3.9% is below that of the 30 new build dwellings tested by LBU prior to 2015. It should be noted that the measurement of eHome2 was conducted under controlled conditions, whereas the work carried out by LBU was conducted in the field.

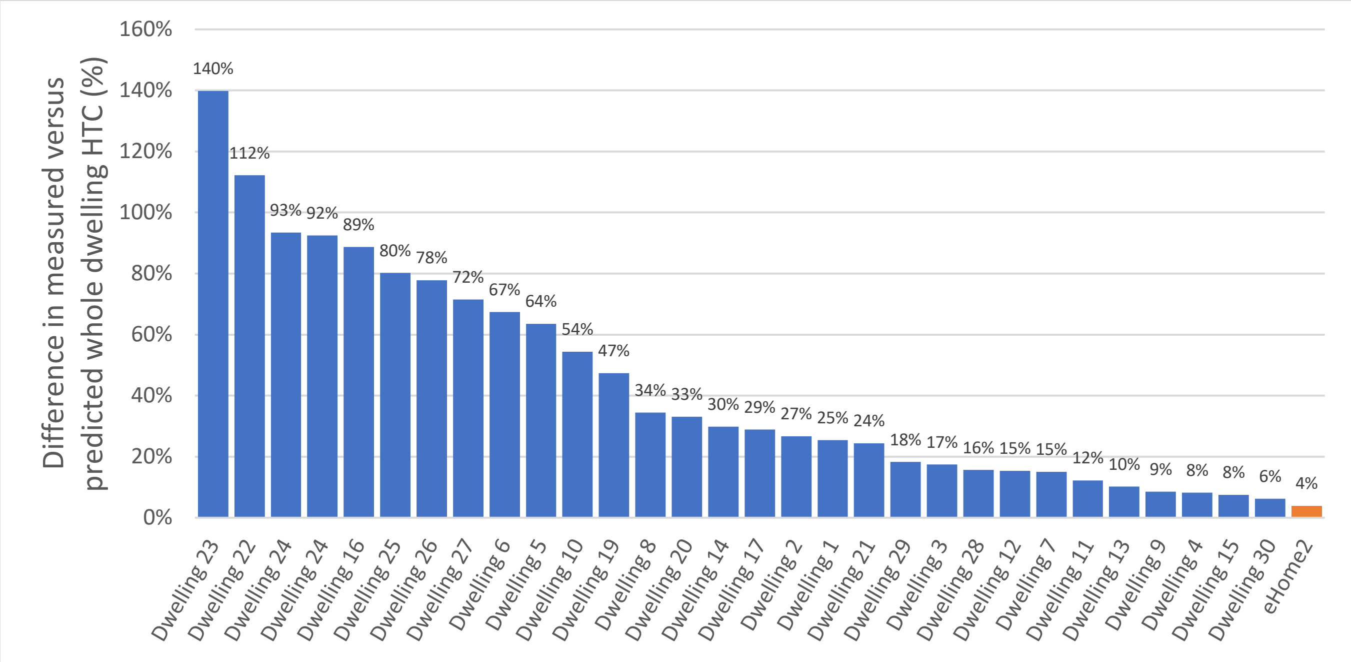


Figure 40. Difference in measured HTC of the predicted steady state HTC of the Leeds Beckett University coheating database (newbuild homes) (as a percentage), including the eHome2 performance gap

A key area which will have contributed to this are the aforementioned issues identified with the external first floor wall. Another contributing factor may be the timber fraction which was used in the U-value calculations. Although three different timber fractions were supplied to the research team, a conservative approach was deemed most suitable, as such the worst-case scenario was used in all calculations. It is important to remember when considering these issues that eHome2 is a prototype building - the approaches and techniques in the design and delivery of the building were new to the developer.

Further work will involve the construction of a 2x2 m test space, made up of a new iteration of the external wall panels. A similar pathological investigation to what is described in section 9.5.1.1 will be conducted to confirm the issue has been rectified.

11.Annex A – SAP (design)

Regulations Compliance Report

Approved Document L1A, 2013 Edition, England assessed by Stroma FSAP 2012 program, Version: 1.0.5.60
Printed on 05 September 2023 at 10:33:13

Project Information:

Assessed By: Steven Baxter (STRO036591) **Building Type:** Detached House

Dwelling Details:

NEW DWELLING AS BUILT Total Floor Area: 91.26m²
Site Reference : Salford Energy House - REV H **Plot Reference:** Salford - Option 2 - As Built 05-0
Address : Energy House 2.0, University of Salford, Statham Street, Salford, M6 6PU

Client Details:

Name:
Address :

This report covers items included within the SAP calculations.
It is not a complete report of regulations compliance.

1a TER and DER

Fuel for main heating system: Electricity		
Fuel factor: 1.55 (electricity)		
Target Carbon Dioxide Emission Rate (TER)	28.72 kg/m²	
Dwelling Carbon Dioxide Emission Rate (DER)	-2.05 kg/m²	OK

1b TFEE and DFEE

Target Fabric Energy Efficiency (TFEE)	63.0 kWh/m²	
Dwelling Fabric Energy Efficiency (DFEE)	44.8 kWh/m²	
		OK

2 Fabric U-values

Element	Average	Highest	
① External wall	0.13 (max. 0.30)	0.13 (max. 0.70)	OK
② Floor	0.11 (max. 0.25)	0.11 (max. 0.70)	OK
③ Roof	0.11 (max. 0.20)	0.11 (max. 0.35)	OK
④ Openings	1.20 (max. 2.00)	1.20 (max. 3.30)	OK

2a Thermal bridging

Thermal bridging calculated from linear thermal transmittances for each junction

3 Air permeability

⑤ Air permeability at 50 pascals	3.00	
Maximum	10.0	OK

4 Heating efficiency

Main Heating system:

Heat pumps with radiators or underfloor heating - electric
Vaillant aroTHERM plus 5kW + AI

Secondary heating system: None

5 Cylinder insulation

Hot water Storage:	Measured cylinder loss: 1.20 kWh/day	
	Permitted by DBSCG: 2.23 kWh/day	OK
Primary pipework insulated:	Yes	OK

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Regulations Compliance Report

6 Controls

Space heating controls	TTZC by plumbing and electrical services		OK
Hot water controls:	Cylinderstat		OK
	Independent timer for DHW		OK
Boiler interlock:	Yes		OK

7 Low energy lights

Percentage of fixed lights with low-energy fittings	100.0%	
Minimum	75.0%	OK

8 Mechanical ventilation

Continuous supply and extract system		
Specific fan power:	0.66	
Maximum	1.5	OK
MVHR efficiency:	93%	
Minimum	70%	OK

9 Summertime temperature

Overheating risk (West Pennines):	Not significant	OK
Based on:		
Overshading:	Average or unknown	
Windows facing: North East	4m²	
Windows facing: South East	1.14m²	
Windows facing: North West	2.78m²	
Windows facing: North East	4.42m²	
Windows facing: South East	1.14m²	
Windows facing: South West	0.72m²	
Windows facing: North West	1.14m²	
Ventilation rate:	4.00	
Blinds/curtains:	Dark-coloured curtain or roller blind Closed 100% of daylight hours	

10 Key features

5	Air permeablility	3.0 m³/m²h
1	Roofs U-value	0.11 W/m²K
2	External Walls U-value	0.13 W/m²K
	Floors U-value	0.11 W/m²K
3	Photovoltaic array	
4		

SAP Input

Property Details: Salford - Option 2 - As Built 05-09-23

Address:	Energy House 2.0, University of Salford, Statham Street, Salford, M6 6PU
Located in:	England
Region:	West Pennines
UPRN:	RRN-3476-1460-8012-8916-4214
Date of assessment:	04 September 2023
Date of certificate:	05 September 2023
Assessment type:	New dwelling as built
Transaction type:	New dwelling
Tenure type:	Unknown
Related party disclosure:	No related party
Thermal Mass Parameter:	Indicative Value Low
Water use <= 125 litres/person/day:	True
PCDF Version:	512

Property description:

Dwelling type:	House	
Detachment:	Detached	
Year Completed:	2023	
Floor Location:	**Floor area:**	**Storey height:**
Floor 0	45.63 m²	2.32 m
Floor 1	45.63 m²	2.61 m
Living area:	18.86 m² (fraction 0.207)	
Front of dwelling faces:	North East	

Opening types:

Name:	Source:	Type:	Glazing:	Argon:	Frame:
D1 - Front Door	Manufacturer	Half glazed	low-E, En = 0.05, soft coat	Yes	PVC-U
D2 - Dining French	Manufacturer	Half glazed	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1 - N Wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1 - E Wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1 - W wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1a - N Wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1a - E Wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1a - S Wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U
WT1a - W Wds	Manufacturer	Windows	low-E, En = 0.05, soft coat	Yes	PVC-U

Name:	Gap:	Frame Factor:	g-value:	U-value:	Area:	No. of Openings:
D1 - Front Door	16mm or more mm	0.7	0.63	1.2	2.25	1
D2 - Dining French	16mm or more mm	0.7	0.63	1.2	3.89	1
WT1 - N Wds	16mm or more	0.7	0.63	1.2	4	1
WT1 - E Wds	16mm or more	0.7	0.63	1.2	1.14	1
WT1 - W wds	16mm or more	0.7	0.63	1.2	2.78	1
WT1a - N Wds	16mm or more	0.7	0.63	1.2	4.42	1
WT1a - E Wds	16mm or more	0.7	0.63	1.2	1.14	1
WT1a - S Wds	16mm or more	0.7	0.63	1.2	0.72	1
WT1a - W Wds	16mm or more	0.7	0.63	1.2	1.14	1

Name:	Type-Name:	Location:	Orient:	Width:	Height:
D1 - Front Door		WT1 - GF External	North East	0	0
D2 - Dining French		WT1 - GF External	South East	0	0
WT1 - N Wds		WT1 - GF External	North East	0	0
WT1 - E Wds		WT1 - GF External	South East	0	0
WT1 - W wds		WT1 - GF External	North West	0	0
WT1a - N Wds		WT1a - FF External	North East	0	0
WT1a - E Wds		WT1a - FF External	South East	0	0

SAP Input

WT1a - S Wds	WT1a - FF External	South West	0	0
WT1a - W Wds	WT1a - FF External	North West	0	0

Overshading: Average or unknown

Opaque Elements:

Type:	Gross area:	Openings:	Net area:	U-value:	Ru value:	Curtain wall:	Kappa:
External Elements							
(1) WT1 - GF External	64.75	14.06	50.69	0.13	0	False	N/A
(1) WT1a - FF External	72.85	7.42	65.43	0.13	0	False	N/A
(3) RT1 - Flat Ceiling	45.63	0	45.63	0.11	0		N/A
(2) FT1 - Ground Floor	45.63			0.11			N/A
Internal Elements							
Party Elements							

Thermal bridges:

Thermal bridges: User-defined (individual PSI-values) Y-Value = 0.0503

Length	Psi-value		
2.92	0.065	E1	Steel lintel with perforated steel base plate
2.92	0.262	E3	Sill
8.4	0.04	E4	Jamb
4.7	0.062	E2	Other lintels (including other steel lintels)
2.72	0.028	E3	Sill
13.8	0.04	E4	Jamb
1.85	0.138	E4	Jamb
23.14	0.151	E5	Ground floor (normal)
9.28	0.045	E16	Corner (normal)
5.18	0.055	E1	Steel lintel with perforated steel base plate
5.18	0.029	E3	Sill
16.8	0.04	E4	Jamb
17.44	0.063	E6	Intermediate floor within a dwelling
10.46	0.06	E6	Intermediate floor within a dwelling
3.3	0.1	E10	Eaves (insulation at ceiling level)
14.14	0.069	E10	Eaves (insulation at ceiling level)
10.46	0.05	E12	Gable (insulation at ceiling level)
10.44	0.046	E16	Corner (normal)

Ventilation:

Pressure test:	Yes (As built)
Ventilation:	Balanced with heat recovery Number of wet rooms: Kitchen + 3 Ductwork: Insulation, rigid Approved Installation Scheme: True
Number of chimneys:	0
Number of open flues:	0
Number of fans:	0
Number of passive stacks:	0
Number of sides sheltered:	0
Pressure test:	3 (Assessed dwelling is tested)

Main heating system:

Main heating system:

Heat pumps with radiators or underfloor heating
Electric heat pumps
Fuel: Electricity
Info Source: Boiler Database
Database: (rev 512, product index 104415, SEDBUK 227%):
Brand name: Vaillant
Model: aroTHERM plus 5kW + AI
Model qualifier: VWL55/6A230V S2 + VWZAIMB - Radiators
(provides DHW all year)

SAP Input

	Design flow temperature: Design flow temperature<=45°C Boiler interlock: Yes MCS Installation Certificate
Main heating Control:	
Main heating Control:	Time and temperature zone control by suitable arrangement of plumbing and electrical services Control code: 2207
Secondary heating system:	
Secondary heating system:	None
Water heating:	
Water heating:	From main heating system Water code: 901 Fuel :Electricity Hot water cylinder Cylinder volume: 198.4 litres Cylinder insulation: Measured loss, 1.2kWh/day Primary pipework insulation: True Cylinderstat: True Cylinder in heated space: True Immersion: Dual Waste Water Heat Recovery System: Total rooms with shower and/or bath: 2 Product index: 080146, Recoup Pipe HEX System A Number of mixer showers in rooms with a bath: 1 Number of mixer showers in rooms without a bath: 1 Solar panel: False
Others:	
Electricity tariff:	Standard Tariff
In Smoke Control Area:	Yes
Conservatory:	No conservatory
Low energy lights:	100%
Terrain type:	Low rise urban / suburban
EPC language:	English
Wind turbine:	No
Photovoltaics:	Photovoltaic 1 Installed Peak power: 3.75 Tilt of collector: 45° Overshading: None or very little Collector Orientation: South West
Assess Zero Carbon Home:	Yes

SAP WorkSheet: New dwelling as built

User Details:

Assessor Name:	Steven Baxter	**Stroma Number:**	STRO036591
Software Name:	Stroma FSAP 2012	**Software Version:**	Version: 1.0.5.60

Property Address: Salford - Option 2 - As Built 05-09-23

Address : Energy House 2.0, University of Salford, Statham Street, Salford, M6 6PU

1. Overall dwelling dimensions:

	Area(m²)		Av. Height(m)		Volume(m³)	
Ground floor	45.63	(1a) x	2.32	(2a) =	105.86	(3a)
First floor	45.63	(1b) x	2.61	(2b) =	119.09	(3b)
Total floor area TFA = (1a)+(1b)+(1c)+(1d)+(1e)+.....(1n)	91.26	(4)				
Dwelling volume				(3a)+(3b)+(3c)+(3d)+(3e)+.....(3n) =	224.96	(5)

2. Ventilation rate:

	main heating		secondary heating		other		total		m³ per hour	
Number of chimneys	0	+	0	+	0	=	0	x 40 =	0	(6a)
Number of open flues	0	+	0	+	0	=	0	x 20 =	0	(6b)
Number of intermittent fans							0	x 10 =	0	(7a)
Number of passive vents							0	x 10 =	0	(7b)
Number of flueless gas fires							0	x 40 =	0	(7c)

Air changes per hour

Infiltration due to chimneys, flues and fans = (6a)+(6b)+(7a)+(7b)+(7c) =	0	÷ (5) =	0 (8)

If a pressurisation test has been carried out or is intended, proceed to (17), otherwise continue from (9) to (16)

Number of storeys in the dwelling (ns)		0	(9)
Additional infiltration	[(9)-1]x0.1 =	0	(10)
Structural infiltration: 0.25 for steel or timber frame or 0.35 for masonry construction		0	(11)
if both types of wall are present, use the value corresponding to the greater wall area (after deducting areas of openings); if equal user 0.35			
If suspended wooden floor, enter 0.2 (unsealed) or 0.1 (sealed), else enter 0		0	(12)
If no draught lobby, enter 0.05, else enter 0		0	(13)
Percentage of windows and doors draught stripped		0	(14)
Window infiltration	0.25 - [0.2 x (14) ÷ 100] =	0	(15)
Infiltration rate	(8) + (10) + (11) + (12) + (13) + (15) =	0	(16)
Air permeability value, q50, expressed in cubic metres per hour per square metre of envelope area		3	(17)
If based on air permeability value, then (18) = [(17) ÷ 20]+(8), otherwise (18) = (16)		0.15	(18)
Air permeability value applies if a pressurisation test has been done or a degree air permeability is being used			
Number of sides sheltered		0	(19)
Shelter factor	(20) = 1 - [0.075 x (19)] =	1	(20)
Infiltration rate incorporating shelter factor	(21) = (18) x (20) =	0.15	(21)

Infiltration rate modified for monthly wind speed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly average wind speed from Table 7												
(22)m=	5.1	5	4.9	4.4	4.3	3.8	3.8	3.7	4	4.3	4.5	4.7

SAP WorkSheet: New dwelling as built

Wind Factor (22a)m = (22)m ÷ 4

(22a)m=	1.27	1.25	1.23	1.1	1.08	0.95	0.95	0.92	1	1.08	1.12	1.18

Adjusted infiltration rate (allowing for shelter and wind speed) = (21a) x (22a)m

0.19	0.19	0.18	0.16	0.16	0.14	0.14	0.14	0.15	0.16	0.17	0.18

Calculate effective air change rate for the applicable case

If mechanical ventilation: 0.5 (23a)

If exhaust air heat pump using Appendix N, (23b) = (23a) × Fmv (equation (N5)) , otherwise (23b) = (23a) 0.5 (23b)

If balanced with heat recovery: efficiency in % allowing for in-use factor (from Table 4h) = 79.05 (23c)

a) If balanced mechanical ventilation with heat recovery (MVHR) (24a)m = (22b)m + (23b) × [1 – (23c) ÷ 100]

(24a)m=	0.3	0.29	0.29	0.27	0.27	0.25	0.25	0.24	0.25	0.27	0.27	0.28	(24a)

b) If balanced mechanical ventilation without heat recovery (MV) (24b)m = (22b)m + (23b)

(24b)m=	0	0	0	0	0	0	0	0	0	0	0	0	(24b)

c) If whole house extract ventilation or positive input ventilation from outside
if (22b)m < 0.5 × (23b), then (24c) = (23b); otherwise (24c) = (22b) m + 0.5 × (23b)

(24c)m=	0	0	0	0	0	0	0	0	0	0	0	0	(24c)

d) If natural ventilation or whole house positive input ventilation from loft
if (22b)m = 1, then (24d)m = (22b)m otherwise (24d)m = 0.5 + [(22b)m² x 0.5]

(24d)m=	0	0	0	0	0	0	0	0	0	0	0	0	(24d)

Effective air change rate - enter (24a) or (24b) or (24c) or (24d) in box (25)

(25)m=	0.3	0.29	0.29	0.27	0.27	0.25	0.25	0.24	0.25	0.27	0.27	0.28	(25)

3. Heat losses and heat loss parameter:

ELEMENT	Gross area (m²)	Openings m²	Net Area A ,m²	U-value W/m2K	A X U (W/K)	k-value kJ/m²·K	A X k kJ/K	
④ Doors Type 1			2.25	x 1.2	= 2.7			(26)
④ Doors Type 2			3.89	x 1.2	= 4.668			(26)
④ Windows Type 1			4	x1/[1/(1.2)+ 0.04]	= 4.58			(27)
④ Windows Type 2			1.14	x1/[1/(1.2)+ 0.04]	= 1.31			(27)
④ Windows Type 3			2.78	x1/[1/(1.2)+ 0.04]	= 3.18			(27)
④ Windows Type 4			4.42	x1/[1/(1.2)+ 0.04]	= 5.06			(27)
④ Windows Type 5			1.14	x1/[1/(1.2)+ 0.04]	= 1.31			(27)
④ Windows Type 6			0.72	x1/[1/(1.2)+ 0.04]	= 0.82			(27)
④ Windows Type 7			1.14	x1/[1/(1.2)+ 0.04]	= 1.31			(27)
② Floor			45.63	x 0.11	= 5.0193			(28)
① Walls Type1	64.75	14.06	50.69	x 0.13	= 6.59			(29)
① Walls Type2	72.85	7.42	65.43	x 0.13	= 8.51			(29)
③ Roof	45.63	0	45.63	x 0.11	= 5.02			(30)
Total area of elements, m²			228.86					(31)

* *for windows and roof windows, use effective window U-value calculated using formula 1/[(1/U-value)+0.04] as given in paragraph 3.2*

** *include the areas on both sides of internal walls and partitions*

Fabric heat loss, W/K = S (A x U) (26)…(30) + (32) = 50.07 (33)

Heat capacity Cm = S(A x k) ((28)…(30) + (32) + (32a)…(32e) = 6475.05 (34)

Thermal mass parameter (TMP = Cm ÷ TFA) in kJ/m²K Indicative Value: Low 100 (35)

For design assessments where the details of the construction are not known precisely the indicative values of TMP in Table 1f

SAP WorkSheet: New dwelling as built

can be used instead of a detailed calculation.

Thermal bridges : S (L x Y) calculated using Appendix K — 11.52 (36)

if details of thermal bridging are not known (36) = 0.05 x (31)

Total fabric heat loss — (33) + (36) = 61.59 (37)

Ventilation heat loss calculated monthly — (38)m = 0.33 × (25)m x (5)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
(38)m=	21.97	21.7	21.42	20.03	19.75	18.35	18.35	18.08	18.91	19.75	20.3	20.86	(38)

Heat transfer coefficient, W/K — (39)m = (37) + (38)m

(39)m=	83.56	83.28	83	81.61	81.33	79.94	79.94	79.66	80.5	81.33	81.89	82.45	

Average = Sum(39)1...12 /12= 81.54 (39)

Heat loss parameter (HLP), W/m²K — (40)m = (39)m ÷ (4)

(40)m=	0.92	0.91	0.91	0.89	0.89	0.88	0.88	0.87	0.88	0.89	0.9	0.9	

Average = Sum(40)1...12 /12= 0.89 (40)

Number of days in month (Table 1a)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
(41)m=	31	28	31	30	31	30	31	31	30	31	30	31	(41)

4. Water heating energy requirement: kWh/year:

Assumed occupancy, N — 2.64 (42)
if TFA > 13.9, N = 1 + 1.76 x [1 - exp(-0.000349 x (TFA -13.9)2)] + 0.0013 x (TFA -13.9)
if TFA £ 13.9, N = 1

Annual average hot water usage in litres per day Vd,average = (25 x N) + 36 — 96.96 (43)

Reduce the annual average hot water usage by 5% if the dwelling is designed to achieve a water use target of not more that 125 litres per person per day (all water use, hot and cold)

Hot water usage in litres per day for each month Vd,m = factor from Table 1c x (43)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
(44)m=	106.66	102.78	98.9	95.02	91.14	87.27	87.27	91.14	95.02	98.9	102.78	106.66	

Total = Sum(44)1...12 = 1163.53 (44)

Energy content of hot water used - calculated monthly = 4.190 x Vd,m x nm x DTm / 3600 kWh/month (see Tables 1b, 1c, 1d)

(45)m=	158.17	138.34	142.75	124.45	119.42	103.05	95.49	109.57	110.88	129.22	141.06	153.18	

Total = Sum(45)1...12 = 1525.58 (45)

If instantaneous water heating at point of use (no hot water storage), enter 0 in boxes (46) to (61)

(46)m=	23.73	20.75	21.41	18.67	17.91	15.46	14.32	16.44	16.63	19.38	21.16	22.98	(46)

Water storage loss:

Storage volume (litres) including any solar or WWHRS storage within same vessel — 198.4 (47)

If community heating and no tank in dwelling, enter 110 litres in (47)

Otherwise if no stored hot water (this includes instantaneous combi boilers) enter '0' in (47)

Water storage loss:

a) If manufacturer's declared loss factor is known (kWh/day): — 1.2 (48)

Temperature factor from Table 2b — 0.54 (49)

Energy lost from water storage, kWh/year — (48) x (49) = 0.65 (50)

b) If manufacturer's declared cylinder loss factor is not known:

Hot water storage loss factor from Table 2 (kWh/litre/day) — 0 (51)

If community heating see section 4.3

Volume factor from Table 2a — 0 (52)

Temperature factor from Table 2b — 0 (53)

12. Annex B – Supporting evidence for U-values

12.1 Ground Floor

NUSPAN PRECAST INSULATED FLOORS

Bellway, Energy House

Documentation of the component
Thermal transmittance (U-value) according to BS EN ISO 6946
Source: **own catalogue - Bellway, Energy House**
Component: **Bellway, Energy House**

30. March 2023
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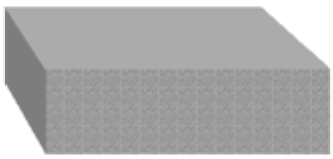
INSIDE



OUTSIDE

Assignment: Suspended ground floor

		Manufacturer	Name	Thickness [m], number	Lambda [W/(mK)]	Q	R [m²K/W]
		Rsi					0.1700
☑	1	Nuspan	NUG375+75MM Screed	0.4500	0.058	E	7.6923
		Rse					0.1700
				0.4500			

U = 0.11 W/(m²K)

Explanation see next page

Q .. The physical values of the building materials has been graded by their level of quality. These 5 levels are the following
A .. A: Data is entered and validated by the manufacturer or supplier. Data is continuously tested by 3rd party.
B .. B: Data is entered and validated by the manufacturer or supplier. Data is certified by 3rd party
C .. C: Data is entered and validated by the manufacturer or supplier.
D .. D: Information is entered by BuildDesk without special agreement with the manufacturer, supplier or others.
E .. E: Information is entered by the user of the BuildDesk software without special agreement with the manufacturer, supplier or others.

U = 0.11 W/(m²K) R_T= 8.03 m²K/W

Calculated with BuildDesk 3.4.6

Suspended floor according to BS EN ISO 13370

U_f - thermal transmittance of the floor between internal environment and basement according to BS EN ISO 6946

R_T	Total thermal resistance [m²K/W]	8.032	($R_T = R_{si} + \Sigma(d/\lambda) + R_{se}$)
U_f	Thermal transmittance [W/(m²K)]	0.120	

Further input data:

λ	Thermal conductivity [W/(mK)]	1.50	(Thermal conductivity of the ground)
A	Floor area [m²]	47.40	
P	Exposed perimeter [m]	28.04	
R_g	Thermal resistance [m²K/W]	0.0	(any insulationon on the base of underfloor space)
w	Thickness of basement wall w [m]	0.30	(walls of underfloor space)
U_w	Thermal transmittance [W/(m²K)]	0.50	(walls of underfloor space)
h	Height of floor above ground [m]	0.150	

ε	Ventilation openings [m²/m]	0.0015
v	Average wind speed at 10m height v [m/s]	5.0
f_w	Wind shielding factor [-]	0.05

Intermediate results:

B'	Characteristic dimension [m]	3.381
d_g	Equivalent thickness [m]	0.615
U_g	Thermal transmittance [W/(m²K)]	0.776
U_x	Thermal transmittance [W/(m²K)]	0.205

U = 0.11 W/(m²K) **Thermal Transmittance**

L_S = 5.1 W/K **Steady-state thermal coupling coefficient**

12.2 Roof

U-value calculation
by BRE U-value Calculator version 2.04g
Printed on 30 Nov 2022 at 16:17

Filename: E:\Scotframe\SAP Work\OSS\Salford\4 - U-Value Calculations\U-Values\Roofs\RT1 - Ceiling Tie.uva (File saved: 30 Nov 2022 16:17)

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

RT1 - Ceiling Tie

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.100		Rsi
1	15	0.190			0.079		Gyproc Wallboard
2	100	0.044	0.130	0.0900	2.273	0.769	Spacesaver / Timber Rafter
3	150	0.044			3.409		Spacesaver
4	150	0.044			3.409		Spacesaver
5		R-value[1]			0.300		Roof Space
					0.040		Rse
	415 mm				9.610		

[1]Roof space - tiled roof, with felt and sarking boards

Total resistance: Upper limit: 9.452 Lower limit: 9.270 Ratio: 1.020 Average: 9.361 m²K/W

U-value (uncorrected) 0.107

U-value corrections
Air gaps in layer 2 ΔU = 0.0006 (Level 1)
Loft hatch ΔU = 0.0037 (Insulation thickness = 50 mm)

Total ΔU 0.004 (4.0% of U)

U-value (corrected) 0.111
U-value (rounded) 0.11 W/m²K

Calculated by:
Steven Baxter
Baxter's Energy & Technical Services

12.3 External Walls – Brick Slips (Ground Floor)

U-value calculation
by BRE U-value Calculator version 2.04g
Printed on 30 Nov 2022 at 16:15

Filename: E:\Scotframe\SAP Work\OSS\Salford\4 - U-Value Calculations\U-Values\External Walls\Fabric Comparison\Timber-Render\245 I-Beam-2B- Render System.uva (File saved: 30 Nov 2022 16:14)

Element type: Wall - Timber framed - insulation between studs
Calculation Method: BS EN ISO 6946

245 I-Beam-2B- Render System

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.130		Rsi
1	15	0.190			0.079		BG Gyproc Wallboard
2	35	R-value[1]	0.130	0.0880	0.670	0.269	Cavity Unventilated Low-E / SV
3							Reflectatherm Plus RVCL
4	9	0.130			0.069		OSB
5	47	0.035	0.130	0.0880	1.343	0.362	TFR35 Insulation / Flange
6	151	0.035	0.130	0.0170	4.314	1.162	TFR35 Insulation / Web
7	47	0.035	0.130	0.0880	1.343	0.362	TFR35 Insulation / Flange
8	9	0.130			0.069		OSB
9							Reflectashield TF RBM
10	25	R-value					Cavity Ventilated Low-E
11	12.5	0.190					BG Glassroc X
12	10	0.770					Weberwall / Weberend
					0.370[2] #		Rse
	361 mm (total wall thickness)				8.387		

[1]Calculated with specified emissivity of 0.05
[2]Calculated with specified emissivity of 0.05
this resistance substitutes for Rse and the resistance of layers 10-12 because of the ventilated air layer (layer 10)

Total resistance: Upper limit: 8.070 Lower limit: 7.602 Ratio: 1.062 Average: 7.836 m^2K/W

U-value (uncorrected) 0.128

U-value corrections
Air gaps in layer 6 ΔU = 0.003 (Level 1)

Total ΔU 0.003 (2.1% of U)

U-value (corrected) 0.128 (ΔU not added since it is less than 3% of U)
U-value (rounded) 0.13 W/m²K

Calculated by:
Steven Baxter
Baxter's Energy & Technical Services

12.4 External Walls – Rendered Walls (First Floor)

U-value calculation
by BRE U-value Calculator version 2.04g
Printed on 30 Nov 2022 at 16:15

Filename: E:\Scotframe\SAP Work\OSS\Salford\4 - U-Value Calculations\U-Values\External Walls\Fabric Comparison\Timber-Render\245 I-Beam-2B- Render System.uva (File saved: 30 Nov 2022 16:14)

Element type: Wall - Timber framed - insulation between studs
Calculation Method: BS EN ISO 6946

245 I-Beam-2B- Render System

Layer	d (mm)	λ layer	λ bridge	Fraction	R layer	R bridge	Description
					0.130		Rsi
1	15	0.190			0.079		BG Gyproc Wallboard
2	35	R-value[1]	0.130	0.0880	0.670	0.269	Cavity Unventilated Low-E / SV
3							Reflectatherm Plus RVCL
4	9	0.130			0.069		OSB
5	47	0.035	0.130	0.0880	1.343	0.362	TFR35 Insulation / Flange
6	151	0.035	0.130	0.0170	4.314	1.162	TFR35 Insulation / Web
7	47	0.035	0.130	0.0880	1.343	0.362	TFR35 Insulation / Flange
8	9	0.130			0.069		OSB
9							Reflectashield TF RBM
10	25	R-value					Cavity Ventilated Low-E
11	12.5	0.190					BG Glassroc X
12	10	0.770					Weberwall / Weberend
					0.370[2] #		Rse
	361 mm (total wall thickness)				8.387		

[1]Calculated with specified emissivity of 0.05
[2]Calculated with specified emissivity of 0.05
this resistance substitutes for Rse and the resistance of layers 10-12 because of the ventilated air layer (layer 10)

Total resistance: Upper limit: 8.070 Lower limit: 7.602 Ratio: 1.062 Average: 7.836 m²K/W

U-value (uncorrected) 0.128

U-value corrections
Air gaps in layer 6 ΔU = 0.003 (Level 1)

Total ΔU 0.003 (2.1% of U)

U-value (corrected) 0.128 (ΔU not added since it is less than 3% of U)
U-value (rounded) 0.13 W/m²K

Calculated by:
Steven Baxter
Baxter's Energy & Technical Services

12.5 Wall-Timber Fractions

Saint-Gobain Insulation UK
Technical Support Centre
Lady Lane Industrial Estate
Hadleigh, Suffolk. IP7 6BA
Tel: 01473 820850
Email: technicalsupport@saint-gobain.com

Project Information

Reference T1154305-HM
Date 13 April 2021
Client Tom Cox
Saint-Gobain Offsite Solutions
Orchard Court III, Harry Weston Road
Coventry
CV3 2TQ
Email: tom.cox@saint-gobain.com

Project Wall & Roof Cassettes

Construction Type

Element : Wall - 021 Timber Wall - 245mm I-Beam Isover between only +S/Void
Timber framed wall
Internal surface emissivity : High External surface emissivity : High
Building use : BS5250 dry/moist occupancy

	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Pitch (º)	Bridge details Air gaps (Level, Delta U")
Outside surface resistance	-	-	0.130		
Cladding	-	-	0.000		
Ventilated and drained cavity between battens	-	-	0.000		
Breather membrane	-	-	-		
OSB	9.0	0.130	0.069		
Isover Timber Frame Roll 35 between top cord of Studs	45.0	0.035	1.286		7.833% Timber (45.0mm) L:1 0.010W/m²K
Isover Timber Frame Roll 35 between web of studs	155.0	0.035	4.429		1.500% Timber (155.0mm) L:1 0.010W/m²K
Isover Timber Frame Roll 35 between bottom cord of Studs	45.0	0.035	1.286		7.833% Timber (45.0mm) L:1 0.010W/m²K
Reflective VCL + Air Leakage Barrier - Proctor Reflectashield	-	-	-		
Cavity (low emissivity) between battens - 35 x 45 @ 600 ctrs	35.0	-	0.780		7.500% Timber (35.0mm)
Gyproc Wallboard	12.5	0.189	0.066		
Inside surface resistance	-	-	0.130		

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U-value = 0.13W/m²K

U-value, Combined Method : 0.130W/m²K (upper/lower limit 7.889 / 7.454m²K/W, dUf 0.0000, dUg 0.0034, dUp0.0000, dUr0.0000, dUrc1 0.0000, dUrc2 0.0000)

Correction factors

Air gaps, Delta Ug = 0.003W/m²K

(Based on the combined method for determining U-values of structures containing repeating thermal bridges)

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Technical Support Centre
Lady Lane Industrial Estte
Hadleigh, Suffolk. IP7 6BA
Tel: 01473 820850
Email: technicalsupport@saint-gobain.com

Project Information

Reference	T1154305-HM		
Date	13 April 2021		
Client	Tom Cox Saint-Gobain Offsite Solutions Orchard Court III, Harry Weston Road Coventry CV3 2TQ	Project	Wall & Roof Cassettes
Email:	tom.cox@saint-gobain.com		

Construction Type

Element : Wall - 073 Timber Wall - 245mm I-Beam Isover between only - no finishes

Timber framed wall

Internal surface emissivity : High External surface emissivity : High

Building use : BS5250 dry/moist occupancy

	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^2K/W)	Pitch (º)	Bridge details Air gaps (Level, Delta U")
Outside surface resistance	-	-	0.130		
Cladding	-	-	0.000		
Ventilated and drained cavity between battens	-	-	0.000		
Breather membrane	-	-	-		
OSB	9.0	0.130	0.069		
Isover Timber Frame Roll 35 between top cord of Studs	45.0	0.035	1.286		7.833% Timber (45.0mm) L:1 0.010W/m²K
Isover Timber Frame Roll 35 between web of studs	155.0	0.035	4.429		1.500% Timber (155.0mm) L:1 0.010W/m²K
Isover Timber Frame Roll 35 between bottom cord of Studs	45.0	0.035	1.286		7.833% Timber (45.0mm) L:1 0.010W/m²K
Reflective VCL + Air Leakage Barrier - Proctor Reflectashield	-	-	-		
Unsealed cavity and plasterboard finish	-	-	-		
Inside surface resistance	-	-	0.130		

U-value = 0.15W/m²K

U-value, Combined Method : 0.145W/m²K (upper/lower limit 7.074 / 6.706m²K/W, dUf 0.0000, dUg 0.0043, dUp0.0000, dUr0.0000, dUrc1 0.0000, dUrc2 0.0000)

Correction factors

Air gaps, Delta Ug = 0.004W/m²K

(Based on the combined method for determining U-values of structures containing repeating thermal bridges)

12.6 Ceiling -Timber Fractions

Celotex SAINT-GOBAIN
Lady Lane Industrial Estate,
Hadleigh, Ipswich,
Suffolk IP7 6BA

ISOVER SAINT-GOBAIN
White House Industrial Estate,
Preston Brook, Runcorn,
Cheshire WA7 3DP

Saint-Gobain Insulation UK
Technical Support Team
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technicalsupport@saint-gobain.com
Lady Lane Industrial Estate,
Hadleigh, Ipswich,
Suffolk IP7 6BA

Project Information

Reference	T1154305-HM		
Date	13 April 2021		
Client	Tom Cox Saint-Gobain Offsite Solutions Orchard Court III, Harry Weston Road Coventry CV3 2TQ	Project	Salford House
Email:	tom.cox@saint-gobain.com		

Construction Type

Element	: Pitch roof, horizontal ceiling - 049 Ceiling Isover Spacesaver - boarded		
Roof pitch	: 30.0°		
Cold pitched roof			
Internal surface emissivity	: High	External surface emissivity	: High
Building use	: BS5250 dry/moist occupancy		

	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Pitch (°)	Bridge details Air gaps (Level, Delta U")
Outside surface resistance	-	-	0.040	30.0°	
Tiling including batten space	-	-	0.000	30.0°	
Loft space	-	-	0.200		
OSB	15.0	0.130	0.115		
Isover Spacesaver Plus (in 2 layers) between joists @ 600 ctrs	250.0	0.040	6.250		7.833% Timber (250.0mm) L:1 0.010W/m²K
Isover Spacesaver between joists @ 600 ctrs	169.0	0.044	3.841		7.833% Timber (169.0mm) L:1 0.010W/m²K
Polythene, 1000 gauge, VCL + Air Leakage Barrier	-	-	-		
Wallboard	12.5	-	0.066		
Inside surface resistance	-	-	0.100		

U-value = 0.11W/m²K

U-value, Combined Method : 0.113W/m²K (upper/lower limit 9.273 / 9.161m²K/W, dUf 0.0000, dUg 0.0048, dUp0.0000, dUr0.0000, dUrc1 0.0000, dUrc2 0.0000)

Correction factors

Air gaps, Delta Ug = 0.005W/m²K

Loft hatch (No loft hatch), Delta U = 0.000W/m²K

(Based on the combined method for determining U-values of structures containing repeating thermal bridges)

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This u-value calculation is provided by way of illustration only and includes various assumptions and input factors incorporated within the software used. We accept no liability for errors and/or omissions. Thermal performance can be affected by many factors including the method of construction and installation of the product and the end use application. The provision of this calculation is not to be construed as offering any advice on compliance with any aspect of Building Regulations. Saint-Gobain Insulation UK (comprised of Celotex and Isover) makes no warranty, express or implied, as to the suitability of the product for your particular application.

Celotex SAINT-GOBAIN
Lady Lane Industrial Estate,
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ISOVER SAINT-GOBAIN
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Preston Brook, Runcorn,
Cheshire WA7 3DP

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Hadleigh, Ipswich,
Suffolk IP7 6BA

Project Information

Reference	T1154305-HM		
Date	13 April 2021		
Client	Tom Cox Saint-Gobain Offsite Solutions Orchard Court III, Harry Weston Road Coventry CV3 2TQ	Project	Salford House
Email:	tom.cox@saint-gobain.com		

Construction Type

Element : Pitch roof, horizontal ceiling - 048 Ceiling Isover Spacesaver - unboarded
Roof pitch : 30.0°
Cold pitched roof
Internal surface emissivity : High External surface emissivity : High
Building use : BS5250 dry/moist occupancy

	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^2K/W)	Pitch (°)	Bridge details Air gaps (Level, Delta U")
Outside surface resistance	-	-	0.040	30.0°	
Tiling including batten space	-	-	0.000	30.0°	
Loft space	-	-	0.200		
Isover Spacesaver over joists	300.0	0.044	6.818		
Isover Spacesaver between joists @ 600 ctrs	97.0	0.044	2.205		6.333% Timber (97.0mm)
Polythene, 1000 gauge, VCL + Air Leakage Barrier	-	-	-		
Wallboard	12.5	-	0.066		
Inside surface resistance	-	-	0.100		

U-value = 0.11W/m²K

U-value, Combined Method : 0.111W/m²K (upper/lower limit 9.316 / 9.181m²K/W, dUf 0.0000, dUg 0.0000, dUp0.0000, dUr0.0000, dUrc1 0.0000, dUrc2 0.0000)

Correction factors

Air gaps, Delta Ug = 0.000W/m²K
Loft hatch (50mm loft hatch insulation), Delta U = 0.003W/m²K

(Based on the combined method for determining U-values of structures containing repeating thermal bridges)

12.7 Windows

Thermal Performance Calculation Summary Sheet

eurocell — All together better

Simulation No. M75-678

Window Profiles Summary

System:	Modus
Type:	Casement
Outerframe:	LSF1021
Sash:	LSF1005
Mullion:	LSF1002/03
Bead:	LSF1301
Reinforcing Spec:	
Outerframe:	None
Sash:	None
Mullion:	EWS801P
Calculation prepared by:	
Print:	Andy Grosse
Signed:	

BFRC

BFRC Certified Simulator 022

Glazing Unit Summary:

Glazing Overview:	28mm Double Glazed	
External Pane:	4mm Saint Gobain Diamant	
Centre Pane:	N/A	
Internal Pane:	4mm Saint Gobain Planitherm One T FG	
Gas Fill Details:	90% Argon 10% Air	
Spacer Bar:	Swisspacer Ultimate/Thermobar	
Glazing u-value:	1.07	W/(m²·K)
Glazing g-value:	0.51	g⊥

SEL Licence Number
N/A

Rating scale: A++, A+, A, B, C, D, E	C
energy index (kWh/m²/year)	-13
thermal transmittance (U window)	1.20
solar factor (g window)	0.32
air leakge (L factor)	0.00

13. Annex C. HTC uncertainty

HTC uncertainty was calculated by considering type A and type B uncertainties.

Type A uncertainty

Type A uncertainty considers statistical variation in the recorded data [23] is calculated as the standard error of the average of each measurement. For HTC measurements 10 minutes averages were used for type A uncertainty.

$$u_A = \frac{\sigma}{\sqrt{n}} \qquad \textit{Eq. C1}$$

Type B uncertainty

Type B uncertainty considers the uncertainty attributed to the accuracy of the measurement device.The accuracy and standard uncertainty of equipment used in the HTC calculation are stated in Table E1.

Table C1: Accuracy and standard uncertainty of equipment used in the HTC calculation

Variable	Device	Accuracy	Probability distribution	Divisor	Standard Uncertainty
Q [W]	Eastron SDM230-Modbus digital power meter	1% of measurement	-	-	1% of measurement
Ti [°C]	hygroVUE 10/thermocouple	±0.1 °C (20 to 60 °C)/ ±0.1 °C	normal	2	0.05
Te [°C]	hygroVUE 10	±0.2 °C (–40 to 70 °C)	normal	2	0.10

The type B uncertainty of total power input is calculated by taking the average power input (based on cumulative energy data) and multiplying by the stated accuracy (1% of measurement).

The type B uncertainty of both the T_{i_vw} and the average external temperature is calculated using Table E2 and Table E3. The standard uncertainty of each individual temperature sensors is scaled by the same coefficient using the volume of each sensed area to form the weighting. These are then summed following the residual sum of squares (RSS) method.

Table C2: T_{i_vw} type B uncertainty

Zone	Weighting	hygroVUE 10 sensor uncertainty	Scaled uncertainty
Kitchen	0.11	0.05	0.006
Dinning	0.11	0.05	0.006
Living Room	0.181	0.05	0.009
WC	0.035	0.05	0.002
Hall	0.072	0.05	0.004
Bedroom 1	0.146	0.05	0.007
Bedroom 2	0.095	0.05	0.005
Bedroom 3	0.107	0.05	0.005
Bath	0.055	0.05	0.003
Ensuite	0.049	0.05	0.002
Landing	0.041	0.05	0.002
Quadrature sum (k = 1)			0.017
k = 2			0.034

Table C3: T_e type B uncertainty

Elevation	Weighting	hygroVUE 10 sensor uncertainty	Scaled uncertainty
Front	0.25	0.1	0.025
Left	0.25	0.1	0.025
Right	0.25	0.1	0.025
Rear	0.25	0.1	0.025
Quadrature sum (k = 1)			0.05
k = 2			0.10

Combined Uncertainty

The Type A and Type B uncertainty attributed to each measurement are combined through the RSS method prior to error propagation in the HTC calculation.

$$u_{combined} = \sqrt{u_A^2 + u_B^2} \qquad Eq.\ C2$$

Uncertainty Propagation

The uncertainty propagation of the HTC calculation is given by the following equation:

$$u_{HTC} = \sqrt{\left(\frac{u_Q}{\Delta T}\right)^2 + \left(\frac{Q^2}{\Delta T^4}\right) \cdot \left(u_{T_i}^2 + u_{T_e}^2\right)} \qquad \textit{Eq. C3}$$

Expanded Uncertainty

All prior uncertainties have been given as k=1. When stating the uncertainty on plots, the expanded uncertainty (k=1.96) is stated, such that:

$$U = k \cdot u \qquad \textit{Eq. C4}$$

Such a coverage factor should result in a 95% confidence interval.

14.Annex D. In-situ U-value uncertainty

ISO 9869 [16] applies an uncertainty value of 14-28% to in-situ U-value measurements. However, this uncertainty is based on measurements undertaken in the field without control of external conditions. The ISO 9869 uncertainty calculation was modified for the controlled environment and to include type A and type B uncertainties.

Type A uncertainty

Type A uncertainty considers statistical variation in the recorded data (GUM), is calculated as the standard error of the average of each measurement. For U-values measurements 10 minutes averages were used for type A uncertainty.

$$u_A = \frac{\sigma}{\sqrt{n}} \qquad \text{Eq. D1}$$

Type B uncertainty

Type B uncertainties are based on the sources of uncertainty listed in ISO 9869. Table C1 lists the measurement uncertainties provided by ISO 9869 and modifications that were made for eHome2 based on the apparatus and test environment. It must be noted that many of the assumptions regarding sources of uncertainty contained within ISO 9869 are not accompanied with background information as to how they have been derived.

Table C1: Measurement uncertainties provided by ISO 9869 and modifications made for eHome2

ISO 9869 consideration	Notes	% error	Absolute error
Apparatus - Logger	Based on logger accuracy	0.3	
Apparatus - HFP	Hukesflux HFP01 datasheet	3	
Apparatus - hygroVUE 10 temperature sensor	Based on steady state ΔT	0.5	0.3
HFP contact	ISO 9869 - unadjusted	5	
Isotherm modification	ISO 9869 - unadjusted	2	
Variation in temp & heat flow	ISO 9869 ~10%. Removed as steady state measurement reported. Captured in type A uncertainty	0	
Variation in air (T_i) & radiant (T_r) temperature differences	ISO 9869 suggests 5%.	2.5	

type B uncertainty	**Quadrature sum**	**6.7**

Combined Uncertainty

The Type A and Type B uncertainty attributed to each measurement are combined through the sum of squares (RSS) method prior to error propagation in the U-value calculation (as described in GUM).

$$u_{combined} = \sqrt{u_A^2 + u_B^2} \qquad \textit{Eq. D2}$$

Uncertainty Propagation

The uncertainty propagation of the U-value calculation is given by the following equation:

$$u_{U-value} = \sqrt{\left(\frac{u_q}{\Delta T}\right)^2 + \left(\frac{q^2}{\Delta T^4}\right) \cdot \left(u_{T_i}^2 + u_{T_e}^2\right)} \qquad \textit{Eq. D3}$$

Expanded Uncertainty

All prior uncertainties have been given as k=1. When stating the uncertainty on plots, the expanded uncertainty (k=1.96) is stated, such that:

$$U = k \cdot u \qquad \textit{Eq. D4}$$

Such a coverage factor should result in a 95% confidence interval.

15.Annex E. Blower door Test

Summary

retrotec FanTestic	version: **5.12.84**	licensed to: **Salford University**
Test date: **2023-03-07**	By: **TJLH, HDH, GH, DF, RF**	
Customer:		
Building Lot Number:		
Building address:		

Building and Test Information	
Test file name:	**ATTMA 2023-03-07 1209 eh2 Barratt updated**
Building volume [m³]:	**225**
Envelope Area [m²]:	**228.9**
Floor Area [m²]:	**45.6**
Building Height (from ground to top) [m]:	**0**

Results	
Air flow at 50 Pa, Q_{50} [m³/h]	**643.55**
Air changes, n_{50}	**2.86**
Equivalent leakage area at 50 Pa [cm²]	**114.0**
Permeability at 50 Pa [m³/h/m²]	**2.812**

Compliance

If you are not happy with my service, please contact me: TJLH, HDH, GH, DF, RF, or the Scheme Manager at BINDT.

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Document1

Building Information

Building Measurements

Building Volume [m³]: 225

Envelope Area (A_T) [m²]: 228.9

Building Height (from ground to top) [m]: 0

Heating/Ventilation System

HVAC Systems Present:

Pictures

Test Method

Carried out in accordance with the following standards:

- ATTMA TS1 Issue 2 – Measuring Air Permeability of Building Envelopes
- BS EN13829:2001 Thermal Performance of Buildings
- BINDT – Quality Procedures and Explanatory Notes for Air Tightness Testing

The building was tested using the equipment listed in the equipment appendix.

Openings and Temporary Sealing

Deviations from Standard Methods:

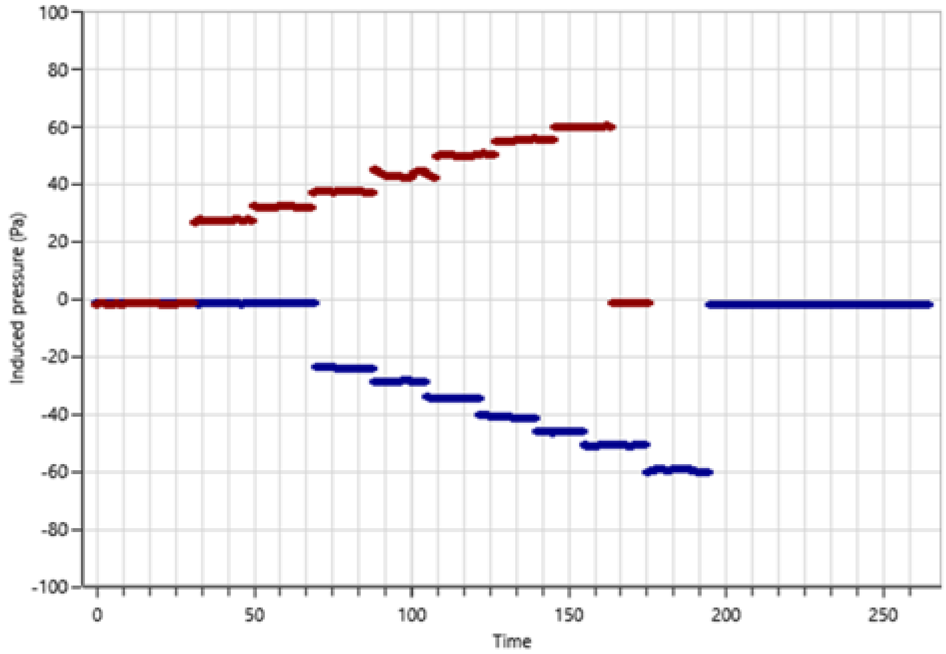
Large Building Setup Notes:

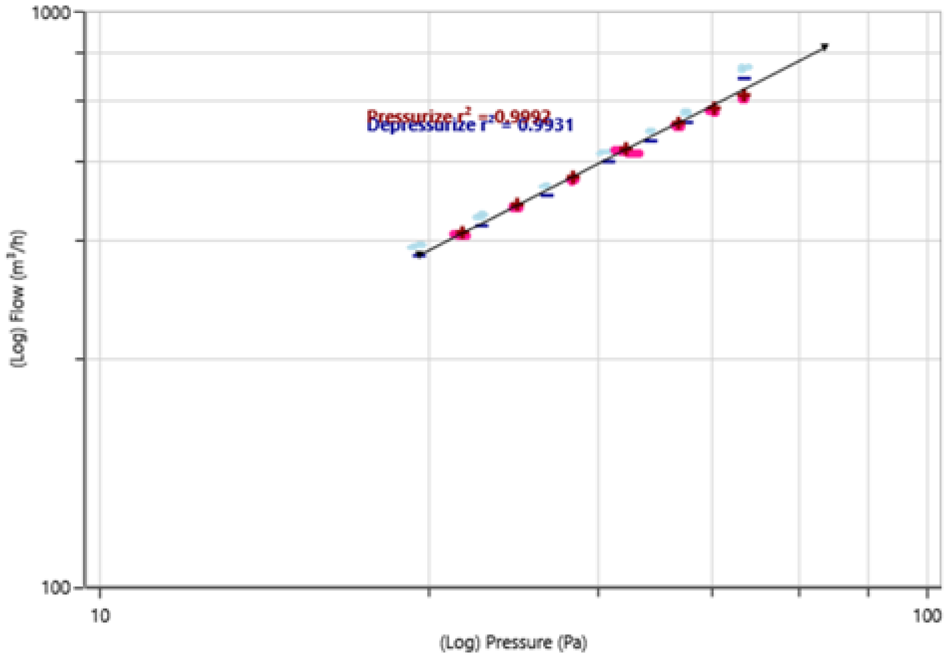
Tester Complaints:

Discussion of Results

Combined Test Data (Average Values)

	Results	Uncertainty
Air flow at 50 Pa, Q_{50} [m³/h]	643.55	+/-1.8%
Air changes, n_{50}	2.86	+/-1.8%
Equivalent leakage area at 50 Pa [cm²]	114.0	+/-1.8%
Permeability at 50 Pa [m³/h/m²]	2.812	+/-1.8%





Air Leakage Test Data Appendix–

Depressurize Data Set

Test Dataset Date: 2023-03-07

Start time: 12:47:30

Test was carried out under Method B (method A, B or C).

Environmental Conditions		
Wind speed:	0	from the
Operator Location:	Inside the building	
Initial Bias Pressure:	-1.68 Pa	
Final Bias Pressure:	-1.87 Pa	
Average Bias Pressure:	-1.78 Pa	
Initial Temperature:	indoors: 20 C	outdoors: 5 C
Final Temperature:	indoors: 20 C	outdoors: 5 C
Barometric Pressure	99.500 kPa	from Direct measurement

Test Analysis			
Coefficient of Determination, r^2:	0.9931	95% confidence limits	
Slope, n:	0.763	0.68953	0.83610
Intercept, C_{env} [m³/h/Pa^n]:	32.619	24.91	42.71
	Results	Uncertainty	
Air flow at 50 Pa, Q_{50} m³/h	650.56	+/-2.8%	
Air changes, n_{50}:	2.892	+/-2.8%	
Equivalent leakage area at 50 Pa [cm²]	101.4	+/-2.8%	
Permeability at 50 Pa, AP_{50} [m³/h/m²]	2.8426	+/-2.8%	

Measured pressure [Pa]		-26.0	-30.6	-36.3	-42.8	-47.9	-52.7	-61.6					
Induced Pressure [Pa]		-24.2	-28.8	-34.6	-41.0	-46.2	-50.9	-59.8					
#1, Range B2	Fan Pressure [Pa]	71.9	89.5	110.9	140.2	162.2	185.5						
	Flow [m³/h]	391.4	441.2	498.5	570.0	619.1	666.6						
#1, Range B4	Fan Pressure [Pa]							57.9					
	Flow [m³/h]							795.9					
Total Flow, Q_r [m³/h]		391.367	441.227	498.485	570.017	619.114	666.558	795.948					
Corrected Flow, Q_{env} [m³/h]		377.146	425.193	480.370	549.303	596.615	642.336	767.023					
Error [%]		1.7%	0.4%	-1.3%	-1.0%	-1.7%	-1.8%	3.7%					

7 induced pressures each taken for 20 of the required 20 seconds.

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Document1

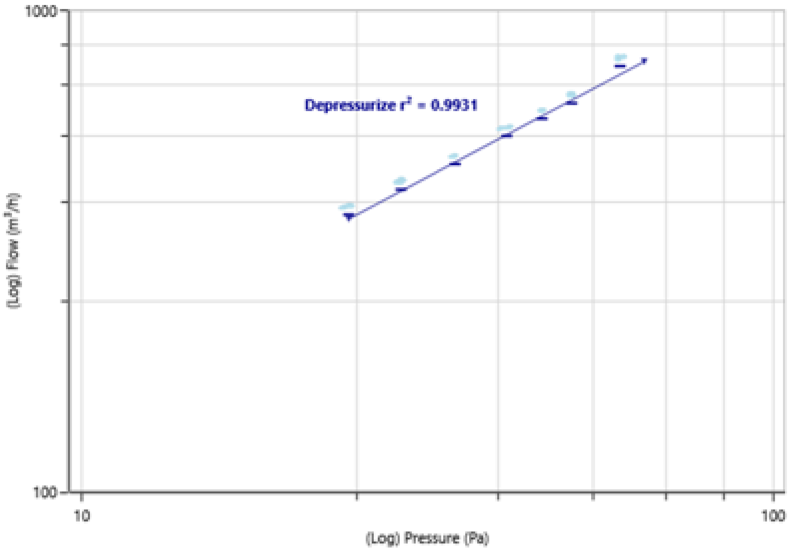
7 baseline pressures each taken for 10 of required 10 seconds.

Average Baseline, ΔP: -1.78 Pa

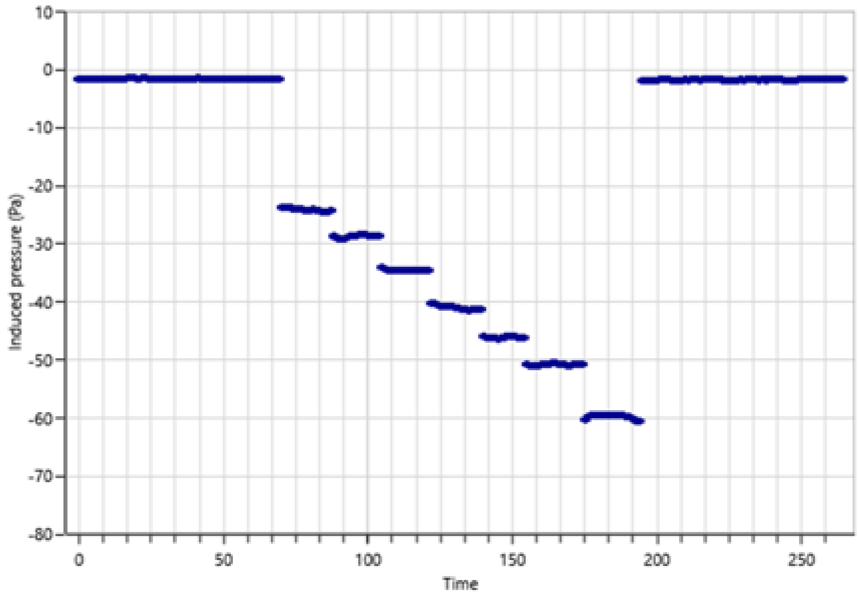
Static Pressure Averages:			
Average Baseline [Pa]	ΔP -1.78		
initial [Pa]	ΔP01 -1.68	ΔP01- -1.68	ΔP01+ 0.00
final [Pa]	ΔP02 -1.87	ΔP02- -1.87	ΔP02+ 0.00

Baseline, initial [Pa]	-1.70	-1.63	-1.66	-1.71	-1.69	-1.70	-1.70					
Baseline, final [Pa]	-1.91	-1.91	-1.84	-1.89	-1.84	-1.87	-1.80					

Flow vs Induced Pressure (Depressurize Set)



Building Gauge Pressure (Depressurize Set)



Pressurize Data Set

Test Dataset Date: 2023-03-07
Start time: 13:01:54

Test was carried out under Method B (method A, B or C).

Environmental Conditions		
Wind speed:	0	from the
Operator Location:	Inside the building	
Initial Bias Pressure:	-1.72 Pa	
Final Bias Pressure:	-1.39 Pa	
Average Bias Pressure:	-1.56 Pa	
Initial Temperature:	indoors: 20 C	outdoors: 5 C
Final Temperature:	indoors: 20 C	outdoors: 5 C
Barometric Pressure:	99.500 kPa	from Direct measurement

Test Analysis			
Coefficient of Determination, r^2:	0.9992	95% confidence limits	
Slope, n:	0.707	0.68384	0.73049
Intercept, C_{env} [m³/h/m²]:	40.245	36.88	43.92
	Results	Uncertainty	
Air flow at 50 Pa, Q_{50} m³/h	636.56	+/-0.7%	
Air changes, n_{50}:	2.830	+/-0.7%	
Equivalent leakage area at 50 Pa [cm²]	126.9	+/-0.7%	
Permeability at 50 Pa, AP_{50} [m³/h/m²]	2.7815	+/-0.7%	

Measured pressure [Pa]		25.7	30.2	35.6	41.5	48.2	53.4	58.2					
Induced Pressure [Pa]		27.3	31.8	37.2	43.1	49.8	55.0	59.8					
#1, Range B2	Fan Pressure [Pa]	103.3	125.1	150.5	181.4	216.1	241.3	265.4					
	Flow [m³/h]	407.9	456.3	508.9	569.6	631.3	671.2	706.7					
Total Flow, Q_r [m³/h]		407.926	456.285	508.934	569.589	631.320	671.209	706.722					
Corrected Flow, Q_{env} [m³/h]		415.443	464.693	518.312	580.085	642.952	683.577	719.744					

Error [%]		-0.4%	0.0%	-0.1%	0.8%	0.8%	-0.1%	-0.9%					

7 induced pressures each taken for 20 of the required 20 seconds.

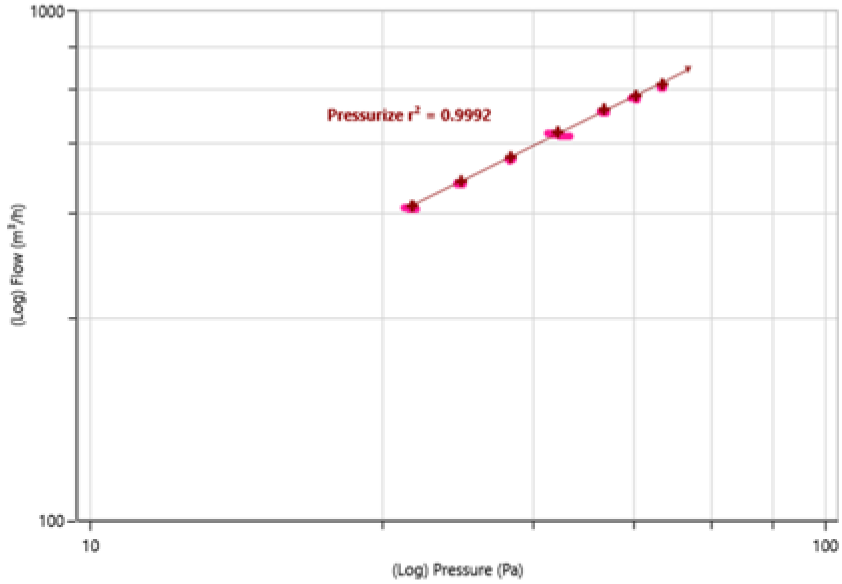
7 baseline pressures each taken for 10 of required 10 seconds.

Average Baseline, ΔP: -1.56 Pa

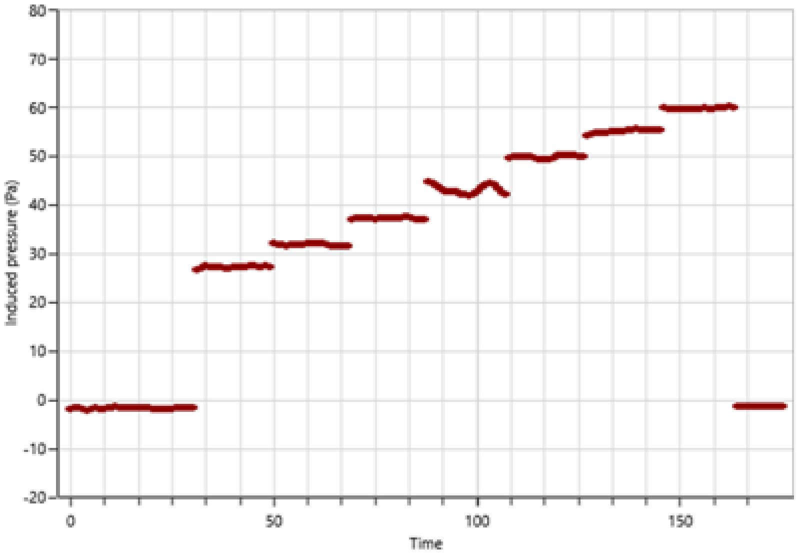
Static Pressure Averages:			
Average [Pa]	ΔP -1.56		
initial [Pa]	ΔP01 -1.72	ΔP01- -1.72	ΔP01+ 0.00
final [Pa]	ΔP02 -1.39	ΔP02- -1.39	ΔP02+ 0.00

Baseline, initial [Pa]	- 1.91	- 1.72	- 1.43	- 1.70	- 1.73	- 1.87	- 1.68					
Baseline, final [Pa]	- 1.24	- 1.36	- 1.40	- 1.40	- 1.46	- 1.43	- 1.44					

Flow vs Induced Pressure (Pressurize Set)



Building Gauge Pressure (Pressurize Set)



Test Equipment

The following test equipment was used in the performance of the air leakage tests.

	Fan	Fan serial	Fan location	Gauge	Gauge serial	Gauge Calibration
#1	Retrotec 5000		EH2 Barratt	DM32	405420	

Fan Calibration Certificate Retrotec 5000:

Retrotec 5000	Fan last calibrated: (Flow Equation Parameters - B1) . . CFM						
Range	n	K	K1	K2	K3	K4	MF
Open	0.498	548	0	0.3	0	1	10
A	0.502	287	0	0.4	0	1	20
B8	0.54	113.25	0	0.7	0	1	40

Polynomial Range	g	f	a	b	c	d	K2	MF
B4	29	-0.19	0.000007943	-0.00864	4.9	206	0.8	40
B2	30	0.1	0.00000088	-0.0029	2.15	90	1	50
B1	30	0	0.0000005	-0.00128	1.02	54	1	60
B74	25	0.15	0.000000796	-0.00095	0.59	18	0.8	35
B47	25	0.09	0.000000269	-0.0003591	0.2435	12.05	1	50
B29	25	-0.02	0.000000111	-0.000149	0.092	4.4	0.6	50

Fan Pressure (FP) is the measured fan pressure when using a self-referenced fan or when Room Pressure (RP) is negative. If using a fan which is not self-referenced, and Room Pressure is positive, Fan Pressure is calculated by subtracting the measured Room Pressure from the Absolute Value of the Fan Pressure.

If PrA>0 and fan is not self-referencing: FP = |PrB|-PrA
If PrA<0 or fan is self-referencing: FP = PrB

Flow calculations are not valid if Fan Pressure is less than either MF or (K2 x |RP|).

Flow in CFM using the above coefficients is calculated as follows for standard Ranges:

$$flow = (FP - (|RP| \times K1))^{N} \times (K + (K3 \times FP))$$

Flow in CFM using the above polynomial coefficients is calculated as follows:

$$flow = (a \times FP^{3}) + (b \times FP^{2}) + (c \times FP) + d + ((g - |RP|) \times f)$$

16. Annex F. Pulse Test

Air Permeability Test Report

PULSE

University Of Salford Allerton Building Frederick Road Salford M6 6PU	Air Permeability @ 4Pa **0.5** m³/m²h	Air Changes @ 4Pa **0.5** 1/h

Report Date	Unique Reference
21 April 2023	**62C7EA46-A2B5-4A04-AC31-3105BC6E2468**

Test Date	21 Apr 2023 - 10:01	**Test Method**	Low Pressure Pulse
Technician	Anestis Sitmalidis	**Registration No.**	-
Company Name	University Of Salford		
Company Address	-		

Building Reference	Saint-Gobain & Barratt - EHome2		
Building Type	House / Bungalow	**Envelope Area**	227.7 m²
Building Age	L (2012 onwards)	**Volume**	223.1 m³
Wall Construction	Timber Frame		

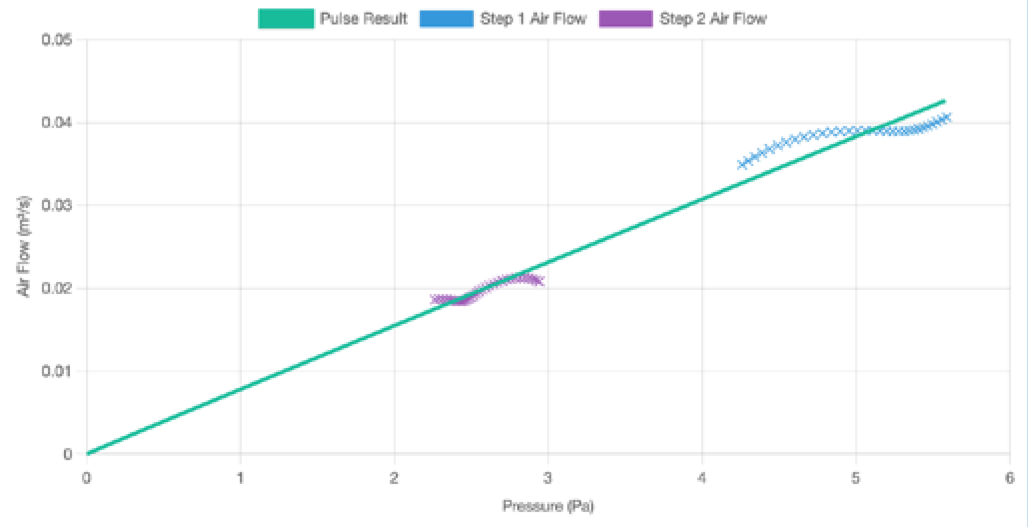
Result

	Measured @ 4Pa			Extrapolated @ 50Pa		
Air Leakage Rate	**Q4**	111	m³/h	**Q50**	614	m³/h
Air Permeability	**AP4**	0.49	m³/m²h	**AP50**	2.69	m³/m²h
Air Changes per Hour	**N4**	0.50	1/h	**N50**	2.75	1/h
Equivalent Leakage Area		0.01	m²		0.02	m²
Calculation Uncertainty		1	±%		4	±%

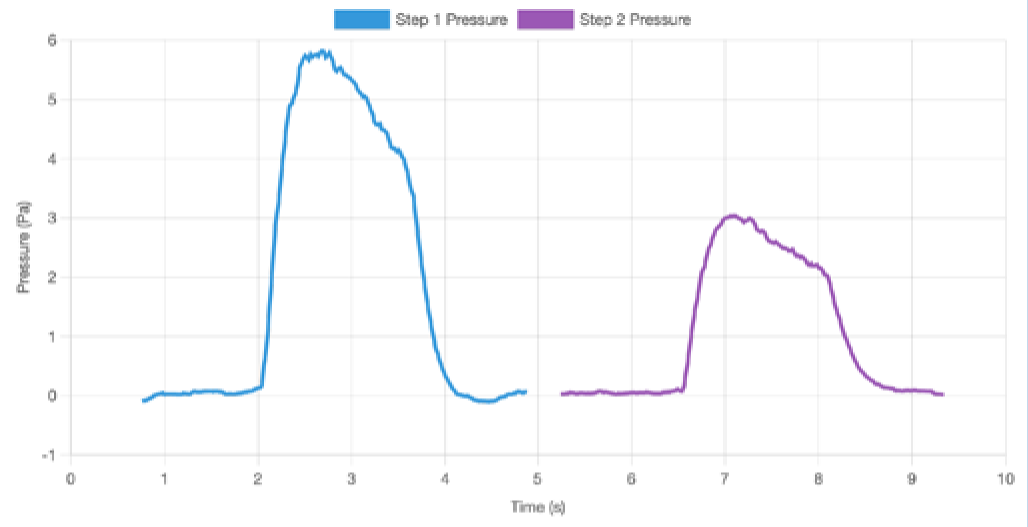
Test Status	Valid		
Number of Tanks	1	**Pulse Duration**	1.5 secs
Number of Steps	2	**Steps Used**	1, 2

Calculation Details		Test Conditions	
Achieved Pressure Range	2.3 - 5.6 Pa	Atmospheric Pressure	101,325 Pa

Air Flow Chart



Air Pressure Chart



The Low Pressure Pulse (LPP) method has been approved as an airtightness testing method under Part L building regulations. Full test prodedure and airtightness testing methodology are detailed in CIBSE TM23.

16. Annex G. HFP Thermography locations

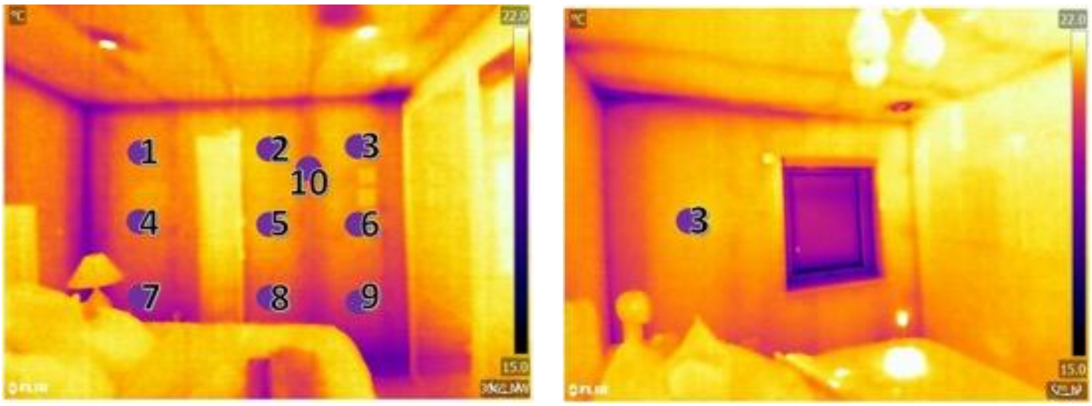


Figure 41. Thermogram showing locations of external wall in-situ U-value measurements.
(a) Main Bedroom grid (b)wall location.

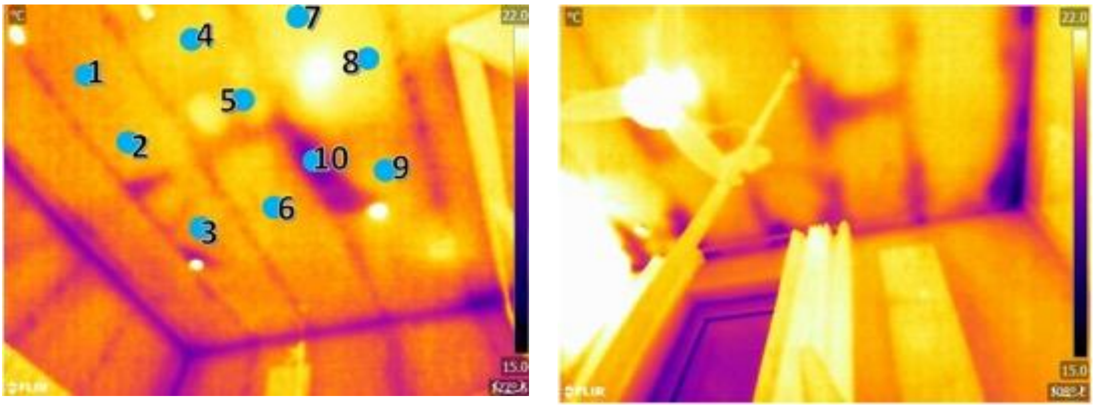


Figure 42. Thermogram showing ceiling.
(a) Main Bedroom locations of ceiling in-situ U-value measurements (b)bedroom 2 ceiling.

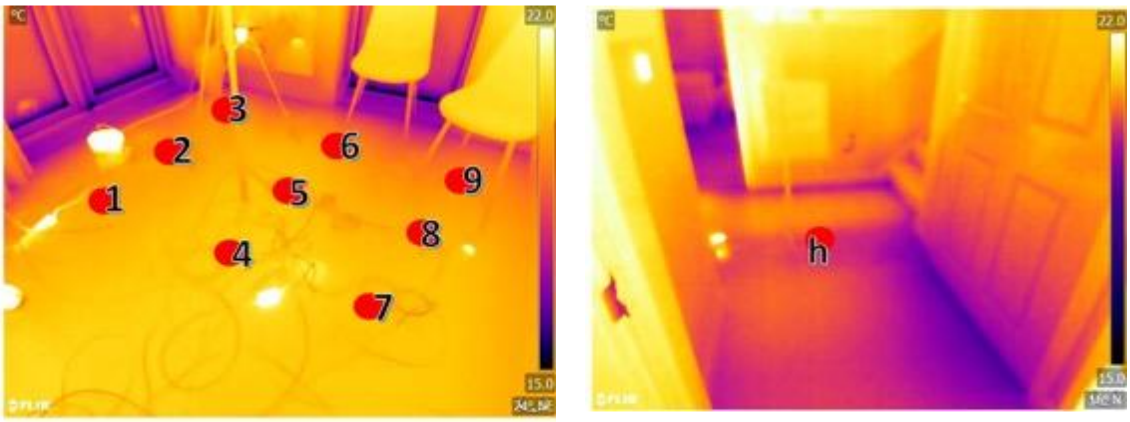


Figure 43.Thermogram showing locations of floor in-situ U-value measurements (a) Kitchen (b)Hall.

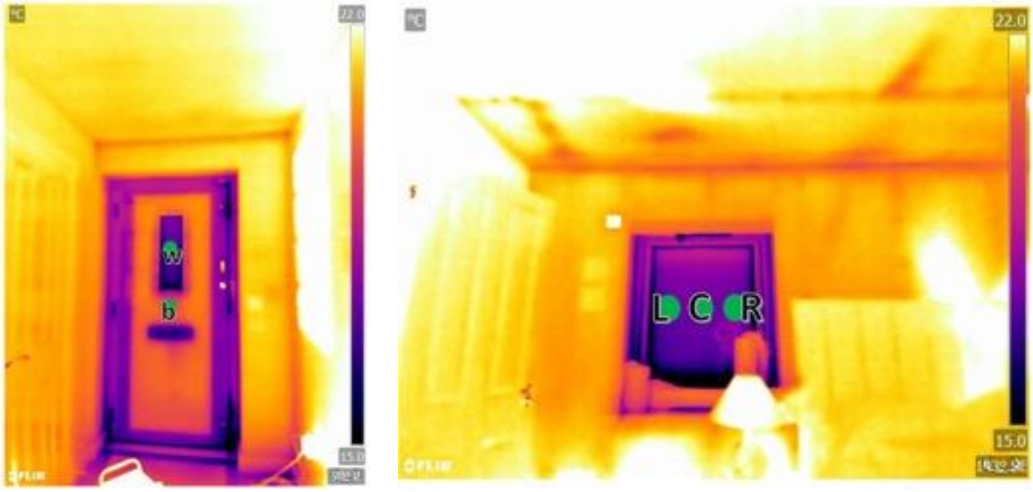


Figure 44. Thermogram showing locations of windows and door in-situ U-value measurements.
(a) Main bedroom window (b)door.

17.Annex H. QUB test

Barratt
Plot No A

Salford EH2
Frederick Road Campus
University of Salford
Salford

M6 6PU

QUB

As Designed

SAP Entry	Unit	Value
total floor area	m2	93.08
dweling volume	m3	236.89
air permeability q50	m3/h/m2	**2.68**
total fabric heat loss	W/K	62.65
ventilation heat losses	W/K	19.45
Heat Losses attributed to Infiltration	W/K	10.89
Heat Losses attributed to Ventilation	W/K	8.56
HTC	W/K	**82.09**
HLP	W/m2/K	**0.88**
QUB	W/K	**73.53**

As Tested

SAP Entry	Unit	HTC	
total floor area	m2	93.08	
dweling volume	m3	236.89	
air permeability q50	m3/h/m2	**2.68**	
total fabric heat loss[1]	W/K	**54.21**	
ventilation heat losses	W/K	19.45	
Heat Losses attributed to Infiltration	W/K	10.89	
Heat Losses attributed to Ventilation	W/K	8.56	
HTC[2]	W/K	**73.66**	
HLP[3]	W/m2/K	**0.79**	
QUB as measured	W/K	**65.10**	+/- 5.6

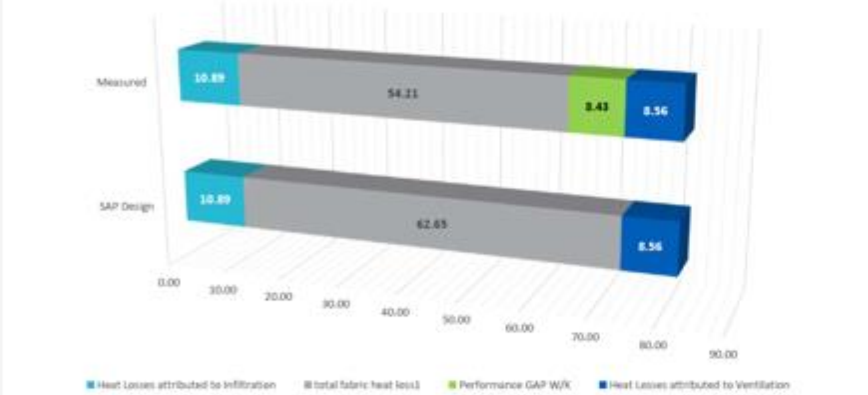
Calculations used based on the QUB measurement result

$^{1}\,\textbf{total fabric heat loss} = QUB - (Heat\ Loss\ Attributed\ to\ Infiltration)$

$^{2}\,\textbf{HTC} = QUB + (Heat\ Loss\ Attributed\ to\ Ventilation)$

$$^{3}\textbf{HLP} = \frac{QUB + (Heat\ Loss\ Attributed\ to\ Ventilation}{total\ floor\ area}$$

Comparison - SAP Worksheet
Delta to SAP Worksheet: 10% Over Performance



Report Date: 26/05/2023 QUB by Saint Gobain Issued by : Bill Parker

18.Annex I. Veritherm test

Test Credentials			
Issued by:	Veritherm UK		
Address:	Malvern Hills Science Park, Geraldine Road, Malvern, WR14 3SZ	Technician:	-
		Registered No:	RED-002
		Qualification:	-
Telephone:	-		
Email:	admin		
Report Reference:	ID 410		
Client:	University of Salford EH2		
Client Contact:	Heidi Diaz Hernandez	Role:	Research Fellow

Building Details			
Building identifier:	ritual.basin.toxic		
Address:	Barratt Energy House 2.0 Frederick Road Campus, University of Salford, Manchester M6 6PU		
Type:	Dwelling	Description:	detached
Status:	TestStatus.Review	Construction:	timber
Contractor:	Barratt Homes	Heating Source:	-
SAP reference:	FSAP 2012	SAP software:	Stroma
Floor area (m^2):	93.08	Property height (m):	5.09
Envelope (m^2):	236.47	Volume (m^3):	236.89
Air Perm (m^3/hm^2@50PA):	3.0 (designed)	2.82 (measured)	
Number of ring mains:	2	Passive Property?	-

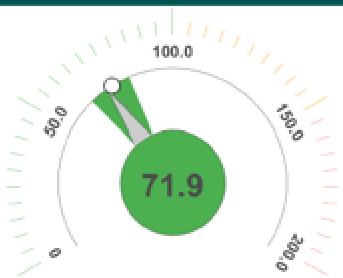
Test Details			
Date:	23-05-2023		
Heating Phase:	17:00 UTC - 22:30 UTC	Cooling Phase:	22:30 UTC - 04:00 UTC
External Conditions:	Average 9.3°C (min 8.6°C, max 11.4°C), max 10.1kmph winds, 0.0mm precipitation		
Temporary Sealing:	Temporary seals in place		
Notes:	NOTE - two minor drops in the heat load were observed during the heating phase, please reference power graphs. The external weather data API can be ignored due to testing within a controlled climate chamber.		

Test Results		
This is to certify that the above named building has been tested by an approved Veritherm Testing Engineer.		
Measured Veritherm Result:	**71.9 W/K**	
Confidence Range:	63.9 W/K - 81.9 W/K	
	Designed	**Measured**
Fabric	62.65 W/K	60.5 W/K
Air Infiltration	12.2 W/K	11.4 W/K
Ventilation	7.44 W/K	
Heat Transfer Coefficient	82.29 W/K	79.34 W/K

Enquiries should be made to Veritherm, Priebe Building, Redbarn Drive, Hereford, HR4 9DX
or visit www.veritherm.co.uk

Veritherm

Result Summary (HTC)



Result Breakdown

Measured

v	Infiltration ** 11.4 W/K	Fabric 60.5 W/K
	Veritherm Measured Result (Fabric + Infiltration) 71.9 W/K	

63.9 81.9

Designed

HTC (Fabric + Infiltration + Ventilation)
82.3 W/K

v	Infiltration ** 12.2 W/K	Fabric 62.6 W/K

v Ventilation: 7.4 W/K *

* Ventilation not measured by Veritherm, figure supplied from design information
** Infiltration is calculated from provided air permeability data

Thermal Efficiency Rating

Very energy efficient - lower running costs

- (0-1) VERY GOOD < This property (0.9)
- (1-2) GOOD
- (2-3) POOR
- (3+) VERY POOR

Not energy efficient - higher running costs

Performance Gap

+4%

Average U-Value:	0.26 W/m²K

Enquiries should be made to Veritherm, Priebe Building, Redbarn Drive, Hereford, HR4 9DX
or visit www.veritherm.co.uk

19.Annex J. Calculation of U-value with different R_{se}

The thermal transmittance of a building element is obtained by combining the thermal resistance of its component's parts and the adjacent air layers as in Equation 1.

$$U = \frac{1}{R_t} = \frac{1}{R_{si}+R_t+R_{se}} \qquad \text{(eq. 1)}$$

Where U is the thermal transmittance (W/m^{2}K) R_{si} is internal surface resistance (m^{2}K/W) R_t is the sum of all the thermal resistances components (m^{2}K/W) and is the external surface resistance (m^{2}K/W).
By having a measurement, we obtain the U-value and if we assume that the R_{si} and R_t value is not affected by the wind speed we can obtain Equation 2 where R_p is the sum of R_{si} and R_t.

$$U_{measured} = \frac{1}{R_p+R_{se}} \qquad \text{(eq. 2)}$$

According to CIBSE Design Guide A the external surface resistance is given by Equation 3.

$$R_{se} = \frac{1}{Eh_r+h_c} \qquad \text{(eq.3)}$$

Where E is the emissivity factor, h_r is the radiative heat transfer coefficient (W/m^{2}K) and h_c is the convective heat transfer coefficient (W/m^{2}K). CIBSE Design Guide A also suggests that the correlation of h_c is given by Equation 4. Where WS is the wind speed.

$$h_c = 5.8 + 4.1\ \text{WS} \qquad \text{(eq.4)}$$

The standard value of R_{se} in ISO 6946 is 0.04 m^{2}K/W for Wind speeds of 4 m/s, 0.02 m^{2}K/W for speeds of 2 m/s. If we assume a speed of 2 m/s for a R_{se} of 0.02 m^{2}K/W and calculate Eh_r, and then we substitute a new value of h_c using measured WS and recalculate R_{se} and the U value. If we compare the difference of the U value using R_{se} standard vs the measured WS value this difference is less than 1%.

20. References

[1] D. Johnston, D. Miles-Shenton, and D. Farmer, "Quantifying the domestic building fabric 'performance gap,'" *Building Services Engineering Research and Technology*, vol. 36, no. 5, pp. 614–627, Sep. 2015, doi: 10.1177/0143624415570344.

[2] S. Pelsmakers *et al.*, "Heat-flow variability of suspended timber ground floors: Implications for in-situ heat-flux measuring," *Energy and Buildings*, vol. 138, pp. 396–405, Mar. 2017, doi: 10.1016/j.enbuild.2016.12.051.

[3] MHCLG, "The Future Homes Standard: 2019 Consultation on changes to Part L (conservation of fuel and power) and Part F (ventilation) of the Building Regulations for new dwellings," 2021. Accessed: Apr. 13, 2023. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/956094/Government_response_to_Future_Homes_Standard_consultation.pdf

[4] Future Homes Hub, "Ready for Zero :Evidence to inform the 2025 Future Homes Standard," 2023, [Online]. Available: https://irp.cdn-website.com/bdbb2d99/files/uploaded/Ready%20for%20Zero%20-%20Evidence%20to%20inform%20the%202025%20Future%20Homes%20Standard%20-Task%20Group%20Report%20FINAL-%20280223-%20MID%20RES.pdf

[5] MHCLG, "Approved Document L Conservation of fuel and power Volume 1 Dwellings 2021 edition incorporating 2023 amendments." 2023. Accessed: Oct. 30, 2023. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1133079/Approved_Document_L__Conservation_of_fuel_and_power__Volume_1_Dwellings__2021_edition_incorporating_2023_amendments.pdf

[6] ISO, "ISO 13789:2017." Accessed: Jun. 21, 2023. [Online]. Available: https://www.iso.org/standard/65713.html

[7] D. D. Johnston, D. Miles-Shenton, D. Farmer, and D. J. Wingfield, "Whole House Heat Loss Test Method (Coheating)," 2013.

[8] R. Everett, "RAPID THERMAL CALIBRATION OF HOUSES".

[9] F. Alzetto, G. Pandraud, R. Fitton, I. Heusler, and H. Sinnesbichler, "QUB: A fast dynamic method for in-situ measurement of the whole building heat loss," *Energy and Buildings*, vol. 174, pp. 124–133, Sep. 2018, doi: 10.1016/j.enbuild.2018.06.002.

[10] "Veritherm Testing," Veritherm. Accessed: Jul. 17, 2023. [Online]. Available: https://veritherm.co.uk/testing/

[11] ATTMA, "ATTMA Technical Standard L1 (TSL1) - Measuring Air Permeability in the Envelopes of Simple Buildings Fan Pressurisation Method - Issue 4.0." Northampton, UK. Accessed: Jun. 21, 2023. [Online]. Available: https://www.bcta.group/attma/download/attma-technical-standard-1-tsl1/

[12] J. Kronvall, "Testing of houses for air leakage using a pressure method," presented at the ASHRAE transactions, 1978, pp. 72–9.

[13] 2019 BRE, "Standard Assessment Procedure (SAP 2012) - BRE Group." Apr. 23, 2019. Accessed: Jun. 21, 2023. [Online]. Available: https://bregroup.com/sap/standard-assessment-procedure-sap-2012/

[14] admin.crisp_design, "'Pulse' Air Tightness Test Approved for UK Buildings | ATT," Air Tightness Testing. Accessed: Jul. 18, 2023. [Online]. Available: https://airtightnesstesting.co.uk/pulse-air-tightness-test-approved-for-uk-buildings-att/

[15] Pearson C, “Thermal Imaging of Building Fabric (BG 39/2011).” BSRIA, Oct. 2011. Accessed: Jun. 21, 2023. [Online]. Available: https://www.bsria.com/uk/product/jnENED/thermal_imaging_of_building_fabric_bg_392011_a15d25e1/
[16] ISO, “ISO 9869-1:2014.” Accessed: Jun. 21, 2023. [Online]. Available: https://www.iso.org/standard/59697.html
[17] ISO, “ISO 7345:2018.” Accessed: Jun. 21, 2023. [Online]. Available: https://www.iso.org/standard/65000.html
[18] E. E.- sales@eastroneurope.com, “SDM230M Series | Eastron Europe.” Accessed: Oct. 16, 2023. [Online]. Available: https://www.eastroneurope.com/products/view/sdm230modbus
[19] “HygroVUE10 - Digital Temperature and Relative Humidity Sensor with M12 Connector.” Accessed: Jul. 04, 2023. [Online]. Available: https://www.campbellsci.com/hygrovue10
[20] “HFP01 heat flux plate | Hukseflux | the world’s most popular heat flux sensor.” Accessed: Jul. 04, 2023. [Online]. Available: https://www.hukseflux.com/products/heat-flux-sensors/heat-flux-sensors/hfp01-heat-flux-sensor
[21] “5100 - Blower Door System.” Accessed: Jul. 04, 2023. [Online]. Available: https://retrotec.com/5000-series-blower-door-package-1.html
[22] B. Anderson and L. Kosmina, *Conventions for U-value calculations (BR443 2019)*. BRE Electronic Publications, 2020. Accessed: Oct. 03, 2023. [Online]. Available: https://www.brebookshop.com/details.jsp?id=328041
[23] “JCGM 100:2008(E).” Accessed: Jul. 06, 2023. [Online]. Available: https://www.iso.org/sites/JCGM/GUM/JCGM100/C045315e-html/C045315e.html?csnumber=50461