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VERITHERM:
SYSTEM OVERVIEW AND VERIFICATION RESULTS

AUTHORS

Cambridge Consultants is a world-class supplier of innovative product development, engineering, and technology consulting. We work with organisations globally to help them manage the business impact of the changing technology landscape.

We have supported Veritherm in the development and validation of its solution; they have asked us to produce this report on their behalf.

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1 EXECUTIVE SUMMARY

The Veritherm system enables a screening test to be performed at the sign-off of building work. It has been developed to verify that the materials specified by the building's designer have been installed appropriately and that the overall thermal performance of the building is in line with its design specifications.

A Veritherm test is performed in a single overnight automated process and returns a quantitative result. It can be run by a trained operator without specialised knowledge or in-depth technical expertise in the processing of experimental data. The system has been tested on a range of UK housing styles to demonstrate its repeatability, accuracy and robustness to variations in environmental conditions.

In this report we describe a number of experiments that show the Veritherm platform in operation and its immunity to typical weather conditions and outdoor temperature variation. We also discuss the situations where it works best and the performance that can be expected in real-world use.

The results indicate that the Veritherm platform is a valid method for verifying thermal performance of UK houses. It is further affirmed that its adoption as a test and certification process for new builds would have a beneficial impact on the well-known 'performance gap' between design specifications or building standards, and real-world performance.

Addressing this issue is of crucial importance in the context of helping the UK achieve its Net Zero obligations. Veritherm therefore has a number of potential roles within the housing sector. These range from large housebuilders seeking to provide a Certificate of Conformance for their customers, to the providers of Social Housing wishing to ensure that retrofit or building upgrades have been performed correctly.

"This product could contribute to reducing CO_2 emissions from homes, reducing occupant bills and to the UK meeting its carbon budgets"

Ministry of Housing, Communities & Local Government

"The only system I have come across that can go ahead without mess or fuss. Excellent looking product to address an incredibly important issue"

Shropshire County Council

2 INTRODUCTION

The UK government is committed to a significant home-building programme – currently up to 300,000 new homes annually. At the same time, the sustainability imperative is driving new regulations, such as the need to halve the energy usage from new buildings by 2030 and to reach net-zero by 2050 at the latest.

Currently domestic heating accounts for around 18% of the UK's total CO_2 emissions and the average new-build house misses thermal efficiency standards by between 200 and 300%[1]. The fuel bills and the CO_2 emissions associated with them are accordingly 2.6 times greater than expected, on average.

In this key challenge of sustainability, thermal performance is a vital factor in reducing emissions from housing. Insulation, ventilation and high-performing components such as windows and doors are specified and need to be correctly installed in order to generate a return on green stimulus investment. The thermal "performance gap" is therefore a major problem. What is needed is a method to assess if a building has the thermal performance that is specified by its design data, such as might be found in a BIM record. The main aim of this is to ensure compliance with design at the hand-off between construction and management of a building, although it can be used at other times, e.g. checking the effect of a major re-fit or detecting unauthorised modifications.

Currently, a new building's Heat Transfer Coefficient (HTC) – the standardised measure of insulation performance – is not determined directly but calculated on paper using a government-approved methodology (Standard Assessment Procedure – or SAP). There is no currently mandated verification test to compare the specified HTC to the real-world performance. There is therefore no way to ascertain that the design principles have been followed, the specified materials have been used, or that the relevant components (e.g. windows) have been installed correctly. For any buyer of a new-build house, this is a significant omission.

There have been attempts to directly measure thermal performance. One such method, known as a 'co-heating test,' measures the energy input needed to maintain a given temperature inside versus outside. The ratio of heat-in to temperature difference, minus a compensation factor to account for the effects of insolation (solar gain) gives the HTC. This test typically requires between two to three weeks to reach a steady state and collect data, and the house must be unoccupied and undisturbed during this time. As a result, its usage has been restricted entirely to academic studies. Despite its 'Gold Standard' reputation such a test would not be appropriate for commercial applications at building sign-off, due to the required timescale and to the specialist knowledge required for its operation.

Against this background, the Veritherm platform has been developed to address the problem of the performance gap and to provide the building industry with a straightforward way to verify thermal performance. Veritherm has been developed from lab experiments followed by initial building trials in early 2018. Since then the Veritherm test methodology has been performed on a wide range of different buildings including detached, semi-detached and terraced buildings, detached bungalows and flats. It has been used to assess the performance of new builds, existing housing stock and retrofit upgrades. It has also been shown to match calculated HTC values derived from materials datasheet values, and repeated tests on the same buildings have produced consistently repeatable results.

The Veritherm digital system uses a network of sensors and electric heaters and fans to determine whether the thermal performance of a building is within expected bounds compared to the design aims. Data is uploaded to the cloud and analysed automatically, with the proprietary algorithms returning a definitive answer as soon as the test is complete.

This report describes validation tests carried out on the Veritherm method. It includes a comparison to the current 'state of the art' techniques and describes the steps used to demonstrate its effectiveness and accuracy. It should not be used as a guide to conduct a test or issue a certificate of thermal performance without formal training.

[1] See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/497758/Domestic_Building_Performance_full_report_2016.pdf p17

3 VERITHERM TECHNICAL OVERVIEW

The Veritherm thermal validation process is designed to operate over one night. It applies a constant, measured heating power to the building for a period of time while using fans to ensure as even a temperature as possible throughout the interior of the building. The building's thermal response to both heating and subsequent cooling is measured and compared to the calculated response based on the design data.

There are three main stages:

The preparation stage consists of preliminary calculations, determining a suitable quantity of heating to apply and planning a suitable physical distribution of temperature measurement devices, heaters and fans to ensure an even mixture of air throughout.

The measurement stage consists of measuring the temperature inside and outside the building while it is heated, and then when it is left to cool. During this process the building should be sealed against air ingress in a way consistent with the airtightness test to minimise the heat loss through air exchange. If an up-to-date airtightness result is available, the measured rate of air exchange at this level of sealing can be used by the Veritherm calculations.

The validation calculations produce the range of heat loss coefficients for the building which is consistent with the measured data. This range is compared with the building's design data or relevant building standards.

3.1 MEASUREMENT DETAILS

The Veritherm system measures the internal and external temperatures of the building over a heating period which is typically around 4-5 hours[2]. If the building shares party walls with adjoining buildings which are not part of the test, the temperatures on the other side of the party walls are also measured. The same measurements continue over a cooling period of at least the same length. Both the heating and cooling period must be timed to occur during the night to avoid the necessity of estimating insolation. For maximum sensitivity the measurement is best carried out during a cold, still night.

Interior temperature measurements are taken at two different heights and in all different rooms of the building. These measurements are checked for quality (allowing the effect of obvious sensor errors to be removed) and then averaged, providing a smoothed measure of the changing temperature. At this stage the efficacy of the layout of heating and fans to evenly distribute heat throughout the interior can be assessed and mistakes in this design can be highlighted rather than using them to produce unreliable results.

During both the heating and cooling phases the power consumption of the building is also measured. This is done using a network of wireless-enabled power monitors.

3.2 CALCULATION DETAILS

The interior and exterior temperature measurements are combined to produce a consolidated estimate of the temperature difference between the inside and outside of the building. Similarly, if adjoining properties are present, the temperature difference to each of them is estimated. Pre-processing is used to reduce measurement jitter and estimate the rate of change of this temperature difference.

The key calculations produce and use estimates of the power consumption, the temperature differences and the rates of change of the temperature difference from both near the end of the heating period and at a similarly timed point in the cooling part of the process. These calculations enable the effects of the effective specific heat capacity (as measured at a time after a step change in the provided heating) to be removed from the evaluation of the HTC.

The Veritherm system then uses an understanding of the potential sensor biases (both temperature and power consumption measurements) and sources of heat loss not associated with the external fabric of the building (primarily air exchange and heat flow to adjoining properties) to determine if the measured temperature and power data is consistent with the building's design specification. In most cases this produces a range of values of HTC for which the measured data could be considered consistent – however note that in some cases an early return from the calculations may indicate lack of conformance without returning a range.[3]

The Veritherm system assesses the building's thermal performance when the building is sealed as if for an airtightness test. Therefore, the HTC ranges produced, and used throughout this report, are of a combined HTC figure for the building fabric and air infiltration (but with flues and fans excluded). The Veritherm system can also use an estimate of the air exchange rate due to air infiltration, e.g. obtained from an air tightness test, to calculate equivalent HTC figures for the building fabric only.

3.3 NOTEWORTHY PROPERTIES

The primary outcome of a Veritherm test is a range of values for the HTC for which the measured data could be considered consistent. To aid comprehension of the test results it may also return a 'best fit' value, but due to the nature of the error models used, the range does not strictly represent the error surrounding this value.

The Veritherm test investigates the thermal properties of the exterior fabric of the building. Best performance will be achieved by minimising other sources of thermal loss (e.g. air exchange, heat loss to adjoining properties) and maximising the thermal loss across the exterior fabric.

There is a limit to suitable temperatures for the inside of a building, so better results can be achieved when the external temperatures are cool. However, good Veritherm results have been observed when the temperature difference peaked at 20 degrees, which should be achievable for most UK nights and the platform provides a weather warning if its results are significantly impacted by poor conditions.

In order to ensure a good accuracy of the Veritherm calculation and also improve the sensitivity, the following should be considered:

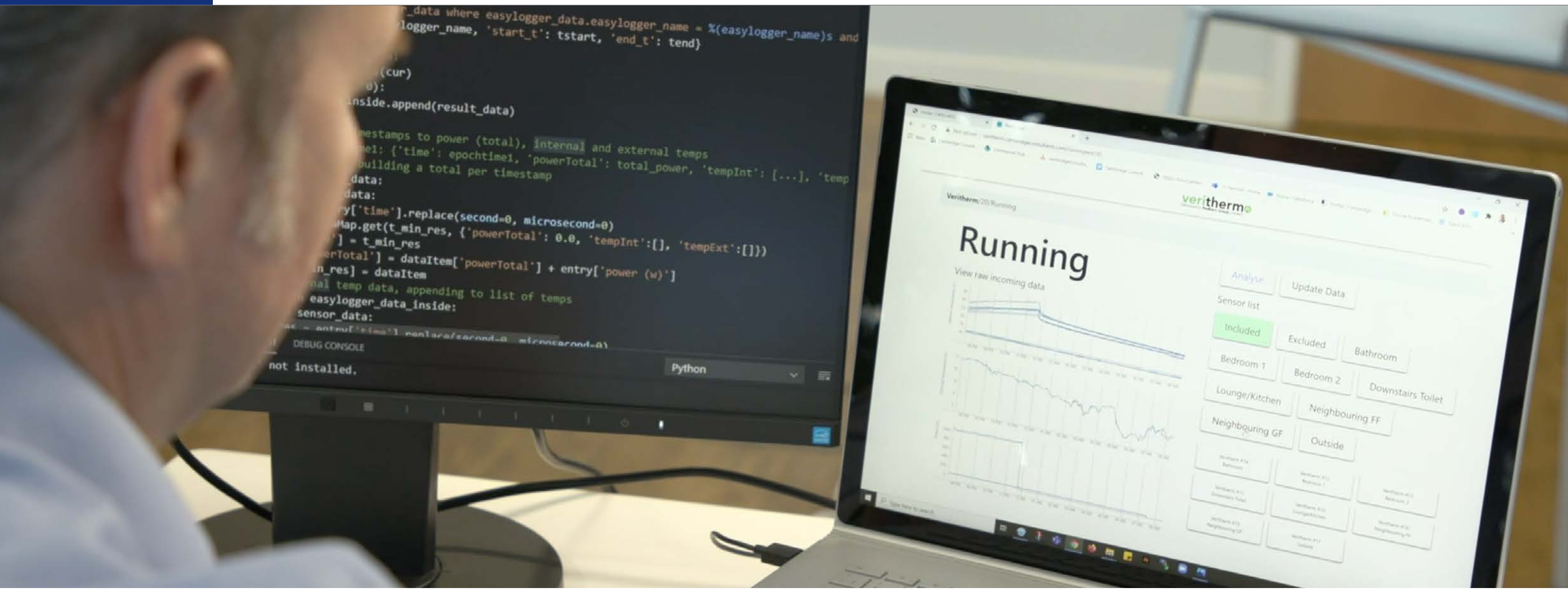
- **Minimising heat loss due to air exchange.** This has to be estimated separately and corrected for in the calculations so errors in this estimation directly affect the quality of the output. The procedure attempts to minimise these by sealing the building as per an air tightness test, and if such a test has been carried out the rate of air loss can be well characterised. However excessively windy nights are best avoided – as discussed later.

- **Decreasing the proportion of heat loss into adjoining properties.** The impact of this effect can vary widely from central flats, where almost all the building boundary is to adjoining properties, to almost detached properties (e.g. sharing one small wall segment). This effect can be reduced by ensuring the adjoining properties are heated similarly to the test property and by having a good understanding of the insulation of the party walls.

- **Avoiding significant pre-test thermal loading.** This will have a disproportionate effect upon the end of the heating phase as compared to the (much later) end of cooling phase. For example, a significant level of pre-test thermal loading by solar radiation should be avoided, as should applying significant pre-test heating via underfloor heating. A delay of several hours between ending pre-test thermal loading and starting the test should be allowed.

[2] If the building is significantly better insulated than its design specification, the heating period may be terminated early due to a maximum temperature being reached. In this case the calculations will be less accurate in determining an HTC value, but will be correctly able to determine that the building reaches its specification.

[3] This may occur if the building is very much below specifications, so the applied heating was insufficient to produce a significant temperature difference. This itself is clear evidence of the building's true thermal properties not achieving their specified values.



4 VERIFICATION TESTS

During the development of the Veritherm system, it has been tested under a range of conditions and on a range of structures – both simulated buildings designed to demonstrate the basic principles, and real buildings.

Two such tests are described below. In each of these, Veritherm has been compared to the results of a co-heating test. Real-building tests require either a structure of exactly known thermal performance or a comparative test against an accepted standard method. In this case a co-heating test has been used as the verification method. The comparative tests were performed in two locations:

The Salford Energy House - which allowed for well-controlled external conditions

A domestic new-build property - it demonstrated performance in a normal use scenario and across variable weather conditions

4.1 HOW CO-HEATING WORKS

A co-heating test is a quasi-steady-state measurement of the heat loss coefficient (W/K) for a whole dwelling, determined by measuring the power required to maintain a given interior temperature (usually 25 °C) in the presence of a lower external temperature. The heat loss coefficient is typically reported every 1-3 days over a period of 1-3 weeks, after an initial stabilisation period of a few days. For co-heating tests conducted in a natural environment (as opposed to an environmental chamber) an averaged value for the outside temperature is used. The method is more accurate for larger temperature differentials; hence it is better conducted during the winter months. Under good conditions the co-heating result will typically be estimated to be accurate to within ±10%, although poor conditions may increase the uncertainty.

The heat loss coefficient is generally separated into transmission and air exchange (ventilation) terms. A separate measurement of the air exchange rate via a tracer gas or pressure test is used to determine the ventilation heat loss.

In addition to the building characteristics which determine the transmission and air exchange heat losses, external environmental factors will also affect thermal measurements:

Solar input provides an additional energy input to the system which must be taken into account. In a co-heating test in an uncontrolled environment, the solar irradiance is monitored, and the resulting heat input is calculated using an effective “solar aperture” for the building.

Wind can affect the air exchange term in the co-heating calculations. As the co-heating test takes place over several weeks it is possible to exclude, or reduce the impact of, a few significantly windy periods while still producing a result.

Rain and humidity can also affect the results – again occasional anomalous weather conditions can be avoided, and this is usually noted in the reporting.

Of these factors, the solar irradiation is typically the largest, and methods for compensating for it form a key part of the co-heating calculations.

4.2 SALFORD ENERGY HOUSE COMPARISON

The Salford Energy House is a full-scale house constructed inside an environmental chamber at the University of Salford, built for the purpose of measuring thermal performance and the impact of modifications designed to improve energy efficiency. The materials and construction are those of a pre 1919 Victorian-style end terrace. Various retrofits can be applied to the baseline construction, including wall, floor and loft insulation as well as changes to the glazing.

Veritherm testing was carried out on the Salford Energy House on three nights, each night with it in a slightly different configuration, referred to in this report as configurations 1, 2, and 3. Interim results for the co-heating performance of the Salford Energy House in each configuration was provided for comparison purposes after the Veritherm results were calculated.

These interim results did not include the estimation of the accuracy of the co-heating value, so we have assumed a good co-heating accuracy value of ±10% has been achieved. The interim co-heating results also do not account for in-situ monitoring equipment in the Energy House – when these are accounted for, the co-heating results are likely to change slightly.

FIGURE 1: The Salford Energy House in environmental chamber with some Veritherm monitoring equipment

There are several potential approaches to estimating a suitable quantity of heating to use in the Veritherm test. These range from ad-hoc approaches or ones based on size and approximate designed thermal performance (e.g. from SAP) to estimating the designed heat transfer coefficient and specific heat capacity from construction details.

For the Salford Energy House the construction is well known, so the Veritherm preparation estimated a suitable heating requirement by estimating U values for the various construction components using standard values for the construction type. This suggested that the baseline design has a heat loss coefficient of very roughly 170 W/K. This figure was used to estimate a heating requirement for the test which was achieved by installing 4 heaters along with 5 fans to mix the air.

The house was instrumented with 5 sets of temperature sensors measuring internal temperatures in different rooms and 2 sets of sensors measuring the external temperatures. Figure 2 shows the building layout in plan view with the location of all the temperature sensors, fans, and heaters.

The house was sealed to prevent air ingress in a similar manner to the air tightness test sealing.

All power consumption in the house was logged. This included using many more power loggers than would typically be needed to ensure the power usage of all the in-situ monitoring equipment was monitored.

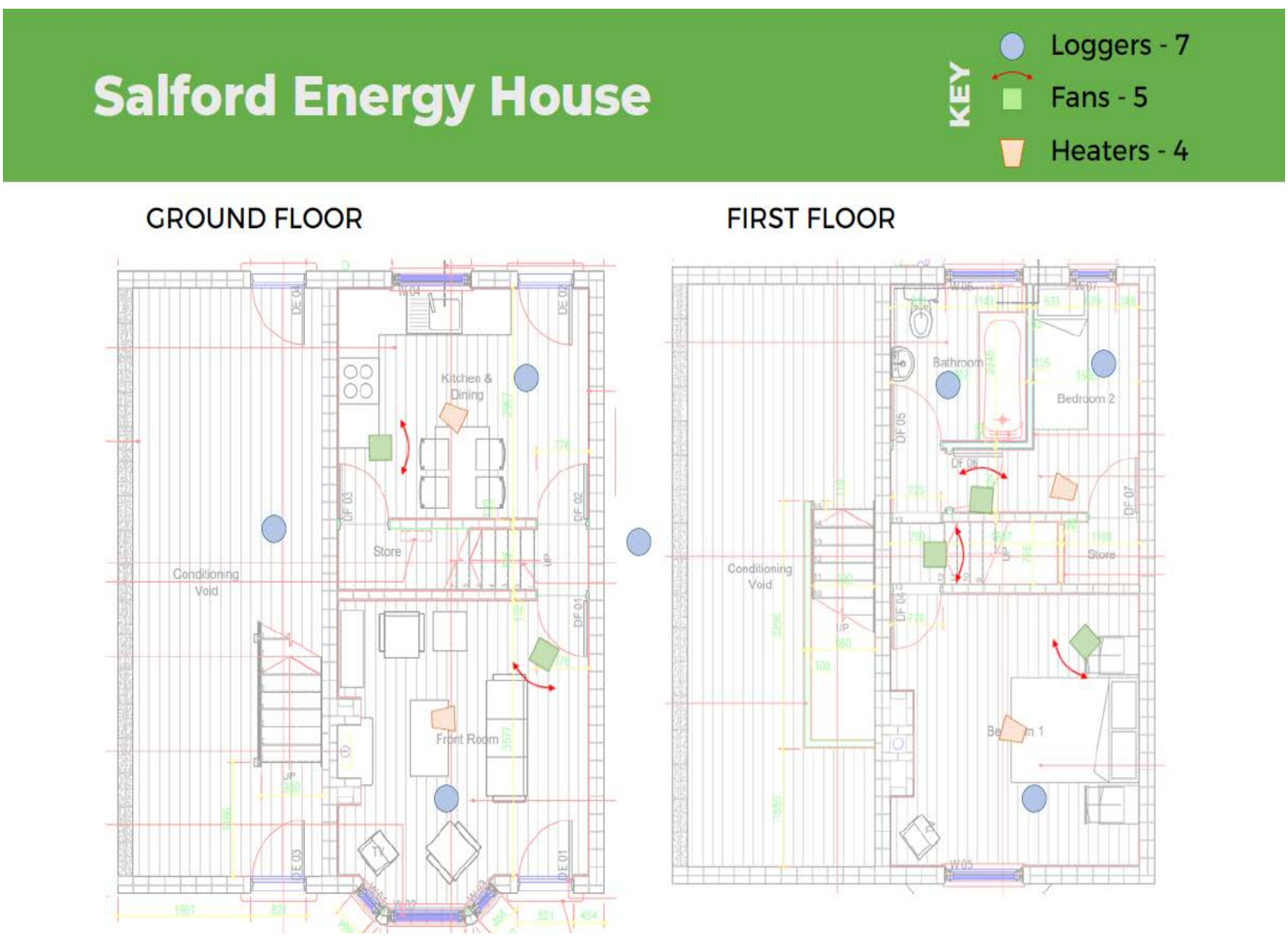


FIGURE 2: Plan view of the Salford Energy House showing the location and direction of operation of the Veritherm equipment

4.3 NEW BUILD PROPERTY COMPARISON

FIGURE 3: External view of the new build property with some Veritherm monitoring equipment

A domestic new-build 2-bedroom detached house was used as a test unit for in-situ testing. The house is a timber frame with brick cladding design built to modern standards, and so should be well-insulated when compared to the Salford Energy House.

Veritherm was used to assess this building on multiple nights. These were widely spaced in time – 3 taking place several months prior to the co-heating test, 4 just prior to the co-heating test and 1 immediately subsequent to it. These 8 experiments were used to confirm the repeatability of the Veritherm results, and their consistency with the co-heating measurements.

During the course of the 8 tests on this building, average (night) external temperature varied from -3 to +9°C, while the peak windspeed during the test night varied from 2 mph to 20 mph and total rainfall varied from 0 to 9.7 mm over the course of the night. These allowed operation across a reasonable range of conditions to be tested – in particular, the overnight temperature range covers expected temperatures across a large part of the year in the UK.

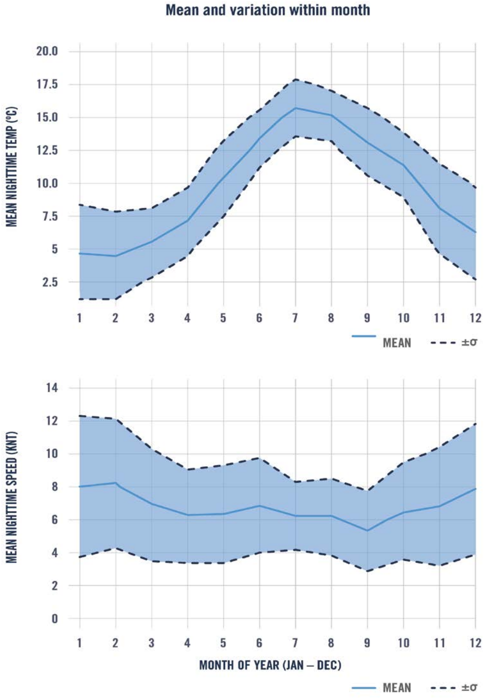


FIGURE 4: Example UK site weather conditions, average over 6 years

The heating requirements for the house were estimated by a similar method of looking at the various constructions to determine U values using standard values for the construction type. These were combined to produce a rough estimate of the design heat loss coefficient of 80 W/K. This figure was used to estimate a heating requirement for the test which was achieved by installing 4 heaters. For two tests (#4 and #5) the heaters were used at lower power settings. 5 fans were used to mix the air.

The house was instrumented with 6[4] sets of temperature sensors internally and one set externally. Figure 5 shows the building layout in plan view with the location of all the temperature sensors, fans, and heaters.

The house was sealed to prevent air ingress in a similar manner to the air tightness test sealing.

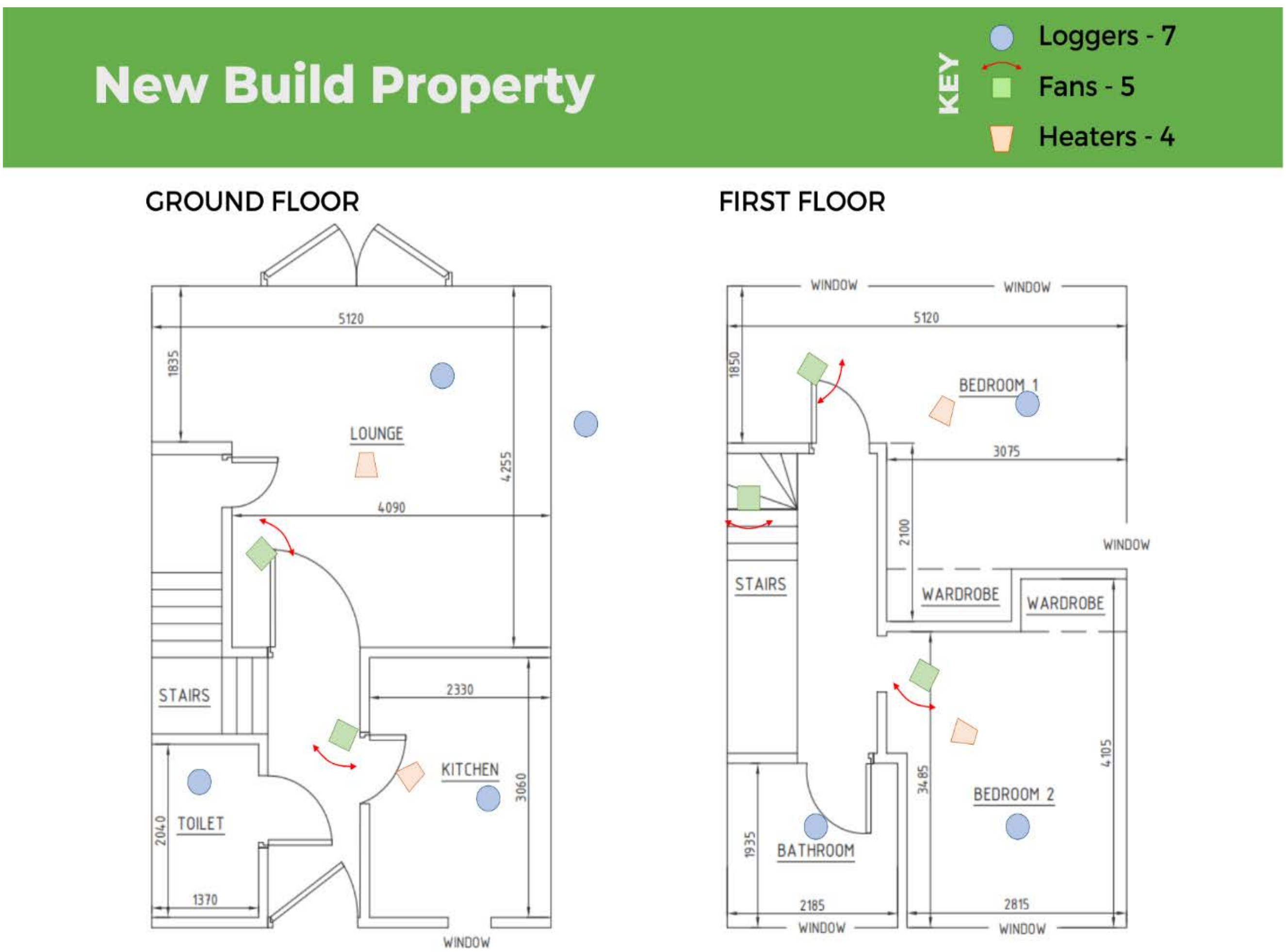


FIGURE 5: Plan view of the new build property showing the location and direction of operation of the Veritherm equipment

[4] One set of 2 sensors was found to be faulty during the first three tests and it was automatically excluded from the calculations.

5 RESULTS

The results of the two sets of tests are presented here, with Table 1 below showing a summary of the results. Analysis of the data suggests:

- In all observed cases Veritherm results are consistent with co-heating measurements.
- The Veritherm results demonstrate a high degree of repeatability with at least 60% overlap of Veritherm reported ranges in repeated experiments on the same building without controlled external environments.
- Veritherm was tested in different environmental conditions, and results are not seen to significantly change with changing exterior temperature, rainfall or windspeed.
- The Veritherm results are expected to be affected by more significant external environmental conditions than those observed during testing, but the conditions covered in testing included a wide range of exterior temperatures, rainfall from 0 to 10 mm per night and windspeed varying from 2 to 20 mph. This provided confidence that the Veritherm approach will operate successfully in common weather conditions.
- The Veritherm range is equivalent to ±15% around a central value, showing that the Veritherm results are only slightly less precise than a good co-heating test.

TEST SITE	CO-HEATING VALUE[5]	VERITHERM RANGE & BEST FIT
Salford – Configuration 1	141 ±14 W/K	Best Fit 144 W/K Range 126-168 W/K
Salford – Configuration 2	145 ±14 W/K	Best Fit 151 W/K Range 131-178 W/K
Salford – Configuration 3	138 ±14 W/K	Best Fit 154 W/K Range 138-174 W/K
New Build Property	104 ±11 W/K	Median Best Fit 99 W/K Median Range 89 -111 W/K

TABLE 1: Summary of co-heating and Veritherm results for the two test buildings

[5] Interim result assuming a ±10% accuracy figure was achieved by the co-heating measurement.

5.1 SALFORD ENERGY HOUSE COMPARISON

The results of the three measurements on the Salford Energy house show a very good match with the co-heating test, as shown below in Figure 6 and lines 1-3 of Table 1. Taken together, these results show strong evidence that the Veritherm results are consistent with co-heating measurements.

In all Veritherm tests the HTC confidence interval estimated by the co-heating test (as shown by the orange bars) has at least a 50% overlap with the range of values Veritherm declared to be consistent with its measurements (teal bars).

In two out of three cases the HTC value Veritherm declared as most consistent with its measurements (black dots) was within the HTC confidence interval estimated by the co-heating test, in the third case it was very close to the confidence interval.

In all cases the central value of the co-heating test HTC estimate (black dot) was within the range of values Veritherm declared to be consistent with its measurements (range of orange bars).

The results here show some evidence of a minor systematic bias above the co-heating value. This is similar to the effect observed in the linked paper[6] when a short timescale method for dynamic measurement of HTC was compared to the co-heating measurement. It is unclear what the origin of this effect might be.

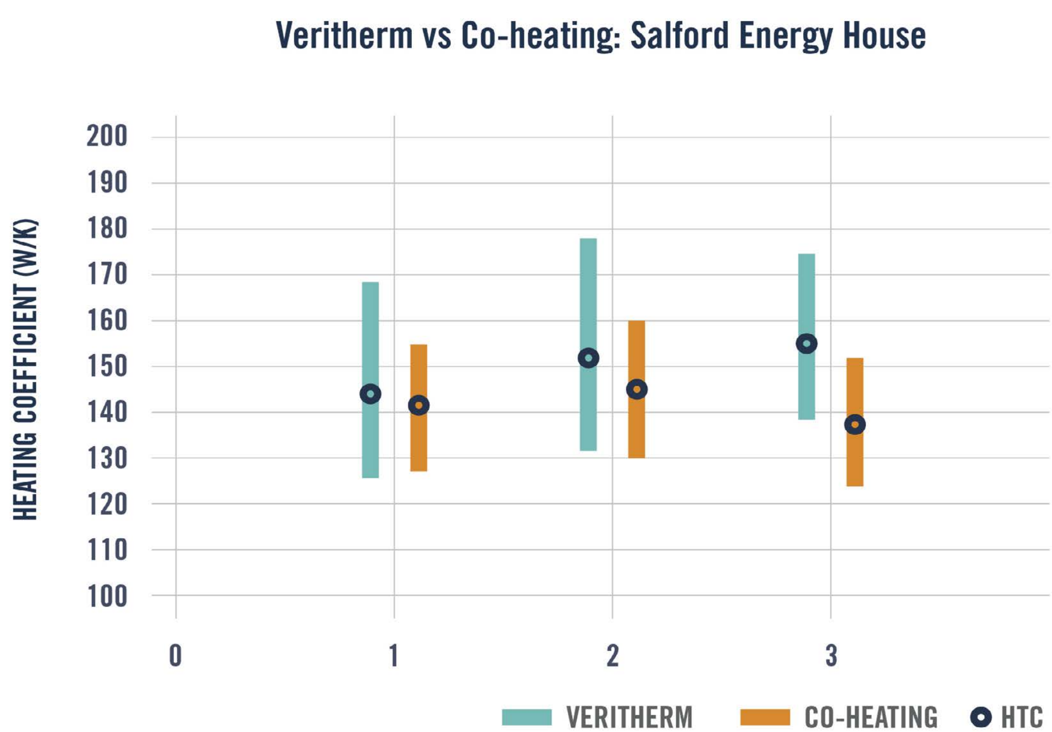


FIGURE 6: Reported Veritherm ranges (shown by green bars) and best fit HTC values compared with co-heating HTC estimates with 10% accuracy range (orange bars) for 3 different building configurations

[6] Reference 4 of referenced documents.

5.2 NEW BUILD PROPERTY COMPARISON

The results of the eight measurements on the New Build house show a good match with the co-heating test, as shown below in Figure 7. Taken together these results show strong evidence that the Veritherm results are consistent with co-heating measurements across a range of background environmental conditions. They also show good evidence of the repeatability of the Veritherm results across repeated tests across a range of background environmental conditions.

In all Veritherm tests the HTC confidence interval estimated by the co-heating test (as shown by the blue dotted lines) has a >50% overlap with the range of values Veritherm declared to be consistent with its measurements (range of green bars).

In six out of eight cases the HTC value Veritherm declared as most consistent with its measurements (black dots) was within the HTC confidence interval estimated by the co-heating test. In the remaining two it was at the lower bound of the range.

In seven out of eight cases the central value of the co-heating test HTC estimate (solid blue line) was within the range of values Veritherm declared to be consistent with its measurements (range of green bars). In the remaining case it was only just outside the range.

All of the Veritherm tests were consistent with the co-heating results, showing strong evidence that Veritherm results are consistent with the co-heating results. These results do not show the bias above the co-heating value seen in the Salford Energy House tests, suggesting that the cause of this effect may be mitigated or removed by considering results in a real outside environment.

The results in Figure 7 also show very good repeatability from test-to-test of the Veritherm method. Even without a controlled external environment, the overlap between the green bars is about 60% of the total range of each, demonstrating a high level of repeatability.

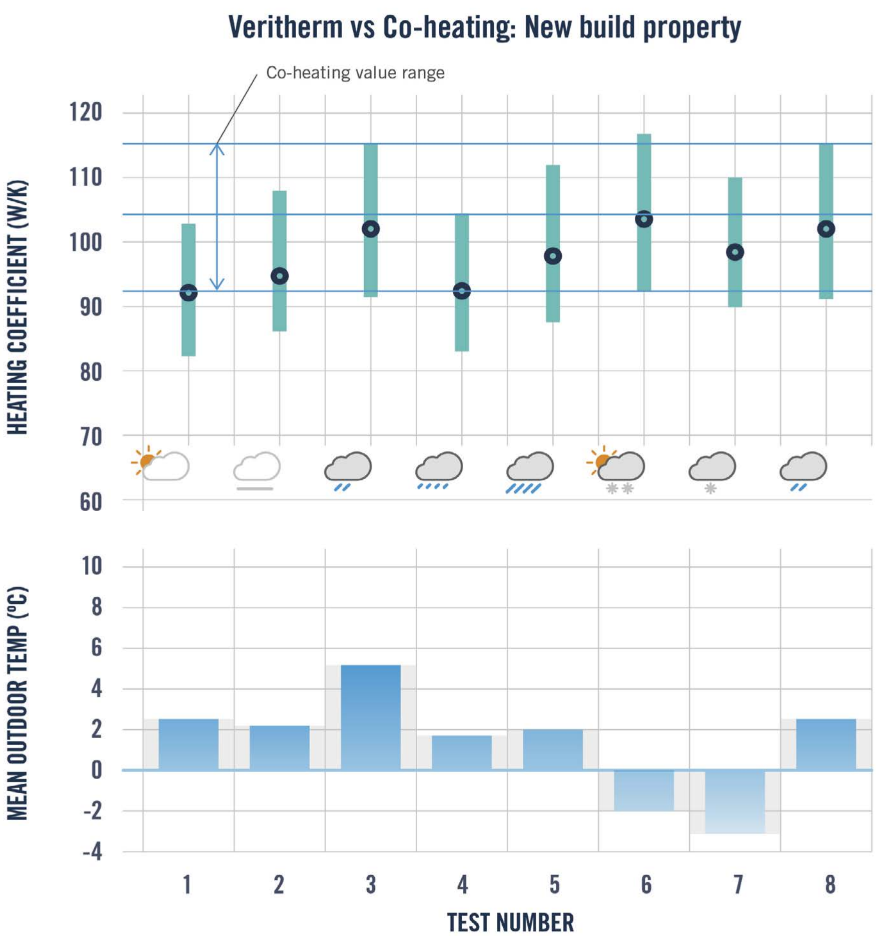


FIGURE 7: Reported Veritherm ranges (shown by green bars) and best fit HTC values compared with co-heating baseline. Note the range of outdoor temperatures and weather conditions.

We tested for any dependence of the Veritherm results upon rainfall, wind, or external temperature and no such dependence was found. P-values for comparing against no-effect were 0.89, 0.19 and 0.64 respectively (where p-values <0.05 are needed to be confident in an effect). The comparison with windspeed therefore shows inconclusive evidence of a weak effect, with windspeed changing the estimated HTC values very slightly (estimated as increasing by 0.1% ±0.5% per mph).

In particular, the two most extreme (although still consistent) Veritherm results occurred on test days 1 and 4 which both had unexceptional conditions. However, two of the tests (5 & 6) showed significantly more onerous conditions such as windspeeds >15mph and significant rainfall, yet produced typical Veritherm results.

While the Veritherm results will necessarily be affected by external environmental conditions, these results show that this susceptibility does not lead to detectably worse performance across a significant range of environmental conditions.

Two of the tests (4 and 5) were carried out with approximately 50% lower input heating power compared to the rest of the tests. These produced similar output ranges to the rest of the tests – this demonstrates that the Veritherm method is not highly susceptible to the initial calculation of a suitable heating load.

TEST NUMBER	HEATING POWER (KW)	VERITHERM BEST FIT HTC RESULT	RAINFALL (MM)	MAX WINDSPEED (MPH)	AVG EXTERNAL TEMPERATURE
1	8	92.00	0	2.5	2
2	8	95.50	0.5	6.5	2
3	8	101.50	0.1	3.6	5
4	4	92.00	0.5	5.1	2
5	4	98.50	9.7	17.7	2
6	8	103.00	0.4	20.0	-2
7	8	99.00	1.2	12.3	-3
8	8	101.50	0.1	6.3	2

TABLE 2: Central Veritherm results and test environmental conditions for New Build Property comparison

6 PRACTICALITIES AND LIMITATIONS

This section discusses some of the steps which can be taken to improve Veritherm performance and discusses the relative impact of effects which a user might be unable to control and what this means for practical usage. In general:

- Reducing the relative size of other sources of heat loss as compared to heat loss across the external fabric will improve Veritherm performance
- Improving the ability of Veritherm to accurately characterise other sources of heat loss as compared to heat loss across the external fabric will improve Veritherm performance

Several different aspects of the Veritherm test which can affect the performance are discussed below.

6.1 INCREASING THE HEATING

Performance of Veritherm (as with most other similar approaches) will be improved by increasing the temperature difference that is achieved during the heating phase. There is a limit to suitable temperatures for the inside of a building and this is enforced by the Veritherm hardware. This means that better results can be achieved when external temperatures are low.

However, we have achieved good results with maximum temperature differences of less than 20 degrees, so this should only impact upon performance in the summer.

6.2 AIR EXCHANGE

Performance of Veritherm can be improved by reducing the heat loss due to air exchange and by increasing the accuracy of estimated heat losses due to air exchange.

Building Sealing

Air exchange can be simply reduced by sealing air vents etc. in the building, as for an air tightness test during the preparation phase. If a significant source of air leakage is left, there will be extra heat lost through that route. This will lead to an overestimation of HTC ranges– the impact of this will depend upon the building's thermal properties; it will have a larger effect upon a very well insulated house.

The Veritherm system assesses the building's thermal performance when the building is sealed as if for an airtightness test. Therefore, the baseline HTC ranges produced, and used throughout this report, are of a combined HTC figure for the building fabric and air infiltration (but with flues and fans excluded). Any detected lack of conformity to the design specification could be due to poor performance of either the building fabric or its air tightness.

Measured Air Exchange

The performance will be further improved by accurately estimating the heat losses due to air exchange. If an air exchange rate for the sealed building is available (e.g. from a recent air tightness test) this can be used to improve the Veritherm performance by accurately modelling and accounting for these heat losses. This also enables Veritherm to calculate equivalent HTC figures for the building fabric only, allowing any detected lack of conformity to the design specification to be assigned to the fabric of the building.

This suggests that Veritherm can best be used in conjunction with an air tightness test. However, note that all the results presented in this report have not used air tightness measurements to improve performance and so are a valid indication of baseline Veritherm performance.

Wind

It is known that increasing external windspeeds will increase the air exchange, even if the building has been sealed for an air tightness test. This will affect the Veritherm performance in a similar way to other sources of heat loss through air exchange, with the further issue that it is very difficult to model the impact of windspeed upon the results of the air tightness test, so these figures will no longer be as accurate in compensating for this heat loss.

The tests in this report have demonstrated no appreciable loss of performance in windspeeds of up to 20 mph. This suggests that Veritherm is capable of operating across a range of windspeeds which cover the majority of potential operational nights.

There is scope for potential further work to improve the understanding of the robustness of Veritherm to windspeed. This kind of study is known to take a long time to carry out, as high-windspeed nights are relatively uncommon, making collecting suitable data sets time-consuming.

6.3 LOSS TO NEIGHBOURING PROPERTIES

The performance of Veritherm can be improved by reducing the heat loss to neighbouring properties and by increasing the accuracy of estimations of these heat losses.

Reduced Exposure to Neighbouring Properties

Veritherm will work better on buildings with limited exposure to neighbouring properties.

Veritherm tests have been successfully run on detached and semi-detached buildings achieving the baseline performance. Mid-terraced properties will show reduced performance, and mitigation strategies should be considered. It is very difficult for Veritherm to achieve good performance on individual flats, although a single building containing flats can be tested effectively as one building.

Reduced Impact of Neighbouring Properties

The Veritherm performance can be improved by reducing the heat loss to neighbouring properties, and by better measuring it.

Heat loss can be reduced by ensuring the neighbouring properties are heated similarly to the test building. Ensuring they are well heated will improve matters, but if they can be well heated until around the time Veritherm ceases heating and then allowed to cool in the same way as the test building this will further reduce their impact upon the Veritherm results.

Heat loss can also be reduced if there is good insulation between neighbouring properties. This may well not be the case, but where it is it should be considered a mitigating factor.

The heat loss to neighbouring properties can be better estimated by ensuring suitable numbers of temperature measurements in the neighbouring properties (i.e. not missing any cold / hot neighbouring rooms) and by having a good understanding of the insulation of the party wall.

6.4 OTHER HEAT PERTURBATIONS

The Veritherm performance can also be impacted by any significant perturbations to the heating process inside or outside the house. Potential sources of this are:

- Power or heat sources not being measured by Veritherm (e.g. computer servers, district heating pipes). In some cases, it may be possible to modify equipment to account for the impact of these heat sources, and future Veritherm developments may allow this.
- Significant pre-test thermal loading which changes near the start of the test. This should be avoided as this will have a disproportionate effect upon the end of the heating phase as compared to the (much later) end of cooling phase. If unavoidable, the effects can be reduced by allowing a delay of several hours between ending such pre-test thermal loading and starting the test. Examples of pre-test thermal loading include:
- A significant level of pre-test thermal loading by solar radiation
- Applying significant pre-test heating via underfloor heating
- Large heat sink features – the impact of such features (e.g. a swimming pool) on Veritherm has not been assessed.
- Significant rain or humidity causing evaporative cooling losses across the surface of the building. Evidence in this report shows this is not a major source of losses in normal operation; however further experimentation would be needed to fully quantify the impact of these losses on Veritherm performance. Any developments in the scientific literature for modelling and estimating these losses could be included in the Veritherm process to mitigate the impact of these losses; however best performance will be achieved by avoiding operation on nights with significant precipitation.
- Disruption to the process – either by failure of one or more of the heaters or fans during the heating process, unexpected operation of a different heating system or opening of doors/windows (e.g. for entry to the building) will perturb the measurements and can lead to poor performance. Several of these can be monitored for automatically (e.g. heater failure) and tests where these occur will not return a reading. However, addition of an external source of heating of cooling remains a risk of modifying the results.

7 CONCLUSIONS

Although an unoccupied house represents a simple system of a thermal mass insulated from the outside environment, there are many variables to take into account such as weather, air leaks and air mixing within the building. Research-level techniques try to either control or average out these effects over a period of several weeks. The Veritherm approach takes a different route – building a model which accounts for expected unknown values, and then confirms whether the expected HTC value is in range. This allows for a representative test to be carried out overnight.

This report shows that the Veritherm approach is repeatable and robust against a range of unwanted effects such as moderate weather conditions, changing outdoor temperatures and losses to neighbouring properties. Also, the method does not rely on precise heat input – in two tests the heat input was deliberately halved and good results were still obtained.

The measured performance of the Veritherm approach shows it is capable of detecting deviations from the specified HTC of ±15%. This is only slightly less precise than a good co-heating test, yet requires only a single night's testing.

The main limitation to performance found is significant heat losses through party walls – these can be accounted for accurately if the thermal resistance of the walls is known and the temperature in the adjacent property is accurately measured. Without an air tightness test measuring air infiltration Veritherm can only measure the HTC for fabric and air infiltration, and if it determines a lack of conformity to specification it cannot say if this is a fabric or air-tightness issue. If combined with an air tightness test Veritherm can measure the HTC for fabric alone and can determine if a lack of conformity is a fabric or air-tightness issue.

In summary, the Veritherm approach has shown good repeatability and robustness across a range of conditions and, from the trials data, good agreement with measured values obtained using the more extensive co-heating test. It is shown to be a system that can verify the thermal specification of housing, and could prove valuable as a test at the point of building sign-off or handover.

REFERENCED DOCUMENTS

REFERENCE NO.	SUBJECT	VERSION/DATE	ISSUED BY
Reference 1.	Meta study of the energy performance gap in UK low energy housing	Summer Study 2019 Proceedings	R. Gupta, A. Howard, A. Kotopouleas,
Reference 2.	United Kingdom Housing Energy Fact File	2013	UK Dept. of Energy and Climate Change
Reference 3.	'Measuring thermal performance of buildings'	2021	Redbarn ltd
Reference 4.	Comparison of whole house heat loss test methods under controlled conditions in six distinct retrofit scenarios	June 2018	Energy and Buildings 168(1):35-41

TABLE 3: Referenced documents

APPENDIX A

SALFORD ENERGY HOUSE CONSTRUCTIONS

ELEMENT	DESCRIPTION	AREA (M2)	HEAT TRANSFER COEFFT, U (W.M2/K)	MASS PER UNIT AREA (KG/M2)	SPECIFIC HEAT CAPACITY (J/(KG,K))
External wall	222.5 mm (8 3/4") brick + 9 mm (3/8") lime mortar & 10.5 mm British Gypsum Thistle hardwall plaster	62.36	1.8	180	800
Party wall	As external wall (plastered on both sides).	37.4	0	20	800
Roof	Purlin and rafter cold roof structure with insulation at ceiling level. 270 mm mineral wool insulation ceiling joists above lath (6 mm) and plaster (17 mm) ceiling.	27.37	0.3	16	900
Loft hatches	Three no. timber loft hatches with 100 mm rigid insulation board (0.022 W/mK).	1.01	0.02	0	0
Ground floor	Suspended timber ground floor above ventilated void. 150x22 mm floor boards on 200x50 mm floor joists at 400 mm centres. Underfloor void of ~20 mm depth. 250 mm concrete slab plinth below underfloor void which supports the test dwelling.	28.38	0.15	64	800
Windows	'E' rated DGUs in PVCu frames.	9.92	1.7	12	0
Front door	Solid PVCu panel door in PVCu frame.	1.77	1.5	12	1800
Rear door	Half glazed ('E' rated) PVCu panel door in PVCu frame.	1.71	1.5	12	1800
Internal Floor/ Ceiling		56.76	0	16	840
Furniture		56.76	0	5	800

TABLE 4: A summary of the construction of the Salford Energy House baseline setup and thermal characteristics used for estimating required Veritherm heating (configuration 1).

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