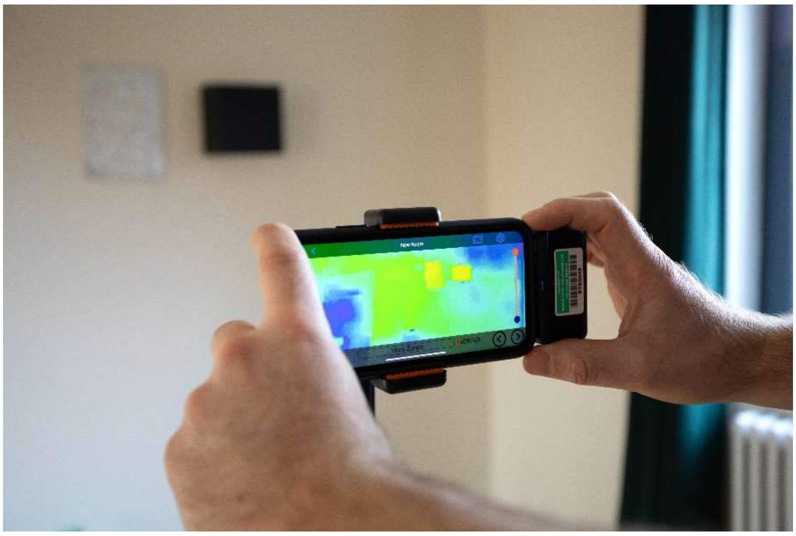
Heat3D Validation Report

Version 1.2
1st December 2021

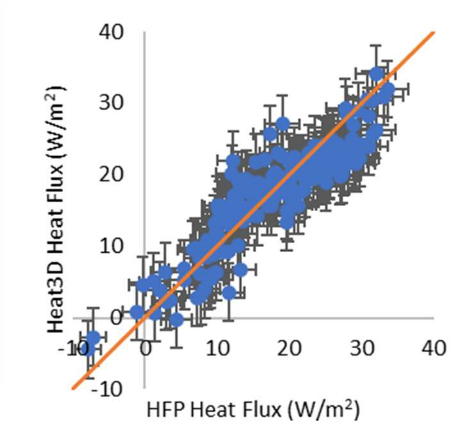
Ground-breaking Tool Validated

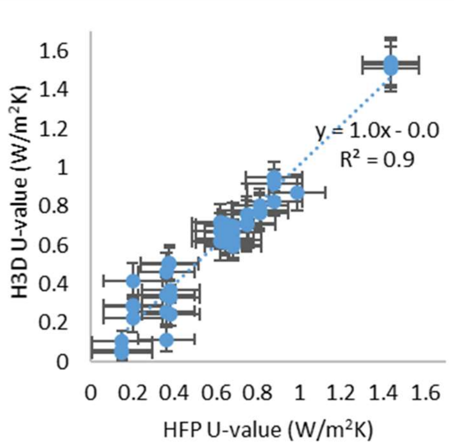
HEAT3D measures and displays the amount of heat flow through building elements and their U value accurately, quicker and cheaper than ever before.

Heat3D is an iOS app that uses an iPhone or iPad with a FLIR One Pro infrared camera to create 3D infrared models of rooms with quantified thermal performance across wall surfaces. Measurements are for whole surfaces in a single visit, rather than for a single point after a week of testing using previous methods.



Heat3D has been developed and validated over a period of three years by a team including the University of Salford, Electric Pocket Ltd and Build Test Solutions. The validation results show accurate and repeatable measurements compared to the existing standard heat flux plate testing method. The validation work includes field trial testing in real buildings of differing performance and detailed laboratory testing in the University of Salford's Energy House.





Across more than 500 comparisons between Heat3D surveys and heat flux plate (HFP) measurements in a variety of different buildings and conditions, there was more than 90% agreement in the measured heat flux. Further, in 42 Heat3D time lapse surveys across 14 walls the Heat3D measured U-values agreed closely with those gathered using the ISO9869 standard method using heat flux plates.

1. Introduction

Heat3D is a new method to measure the U-value of walls developed by Build Test Solutions, Electric Pocket and the University of Salford. This report presents evidence to demonstrate the accuracy of measurements using Heat3D, the evidence has been gathered over three years including laboratory testing in the University of Salford's Energy House facility and field trials in real buildings.

A U-value defines the thermal resistance of a building element, that is how easily heat can flow through it. A lower U-value means better thermal performance as there is less heat transfer per degree of temperature difference between in and out.

U-values are not commonly measured, with most building design, retrofit and management based on calculated U-values. This is problematic as the performance of building elements in practise often deviates from expectations, this can be due to a variety of factors such as missing, damaged or poorly installed insulation, product substitution or an inability to see within existing constructions.

U-value measurement provides an opportunity for quality assurance, feedback on the performance of building materials and processes and more informed building management and retrofit design. It is not common, however, as existing methods are costly, time consuming and invasive. Heat3D addresses these issues, providing a new tool for better building design and management.

2. What is Heat3D?

Heat3D is a method to measure the U-value of walls using bespoke hardware and iOS app. Using the Augmented Reality kit in an iOS device (Apple iPhone or iPad of sufficient specification), the Heat3D app enables the user to create a dimensioned 3D model of a room. The app then allows the user to add infrared images to the model using a FLIR One Pro infrared camera, creating a 3D infrared model of the inside of a room.

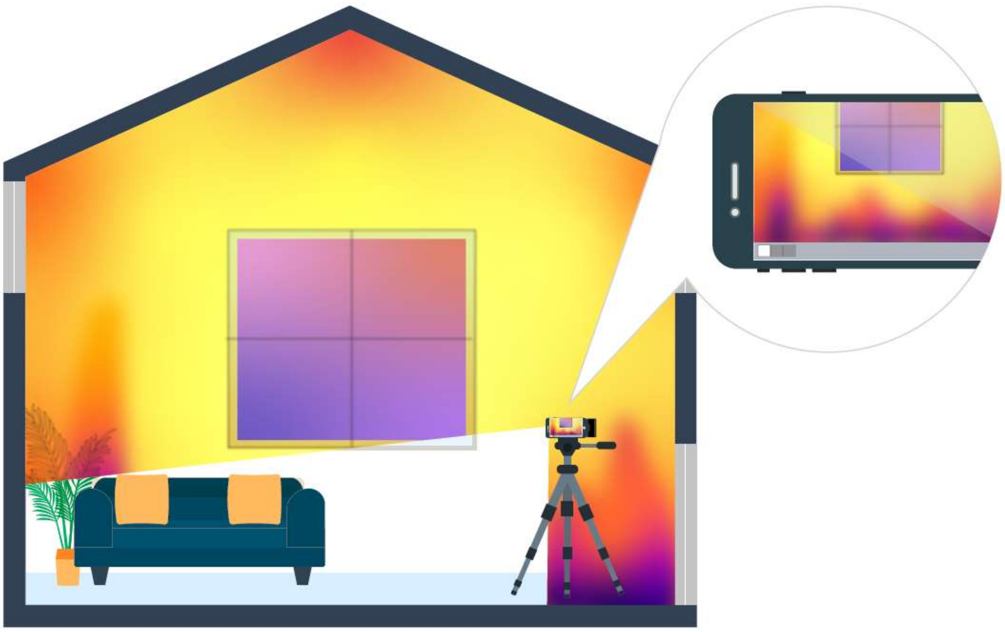


Figure 1: Heat3D creates a 3D heat loss map of a room, showing heat loss and thermal performance across wall surfaces and highlighting thermal defects.

Using the bespoke Heat3D hardware, measurements of ambient air and reflected temperature are then recorded within the app. The reflected temperature is determined by the temperature of the surrounding objects in a room, which cause radiative heat transfer to wall surfaces. Using these measurements, the app calculates the heat transfer across the whole internal surface of external walls, creating a 3D heat transfer map to spot thermal bridges or defects.

Figure 2: An example of a Heat3D time lapse-survey being set up, with device and tripod in the foreground and air and reflected temperature targets in the background.

To measure U-values using Heat3D an hour-long time-lapse survey is undertaken. Before the survey the room must have been heated for at least 12 hours, this can be using any installed heating system. During the survey a temperature controller and convective electric heater are used to maintain a steady internal temperature, the iOS device is held steady on a tripod and takes an IR image every minute.

From each image the heat flux through the wall is calculated at minutely intervals within the Heat3D app, using a calculation based on the temperature difference between the air, wall surface and the surface temperature of the surroundings. The external temperature is sourced from an online weather source so that the heat loss rate per degree of temperature difference between inside and out, i.e., the U-value of the wall, can be calculated. At the conclusion of the survey a 3D map of U-values across the surface of external walls is presented.

As well as the Heat3D app and hardware, there is also an online portal where users can view previous surveys and create reports of the results.

2.1. Hardware

The hardware for Heat3D comprises:

- An iOS device (iPhone or iPad)
- A FLIR One Pro infrared camera
- 'Targets' placed close to a wall surface to measure air and reflected temperature
- A temperature controller and heater
- Tripods to hold the iOS device and targets in place.

2.2. Survey Method

Two types of survey are possible, a one-off survey to measure heat transfer and a time lapse survey to measure U-values. For a heat transfer survey, the process is:

1. Position air and reflected temperature targets 100mm from the wall.
2. Use the Heat3D app to create a floorplan of the room by pointing the camera at each corner in turn and selecting it until the floorplan is complete.

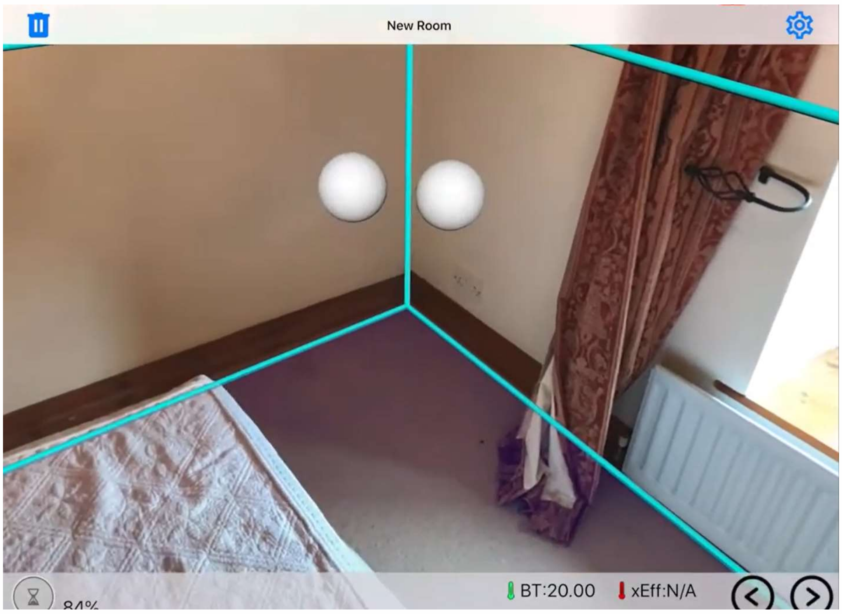


Figure 3: Creating the floorplan in the Heat3D app.

3. Drag up the ceiling height in the newly created 3D model of the room to match the room's height.
4. Take infrared pictures of the external walls.

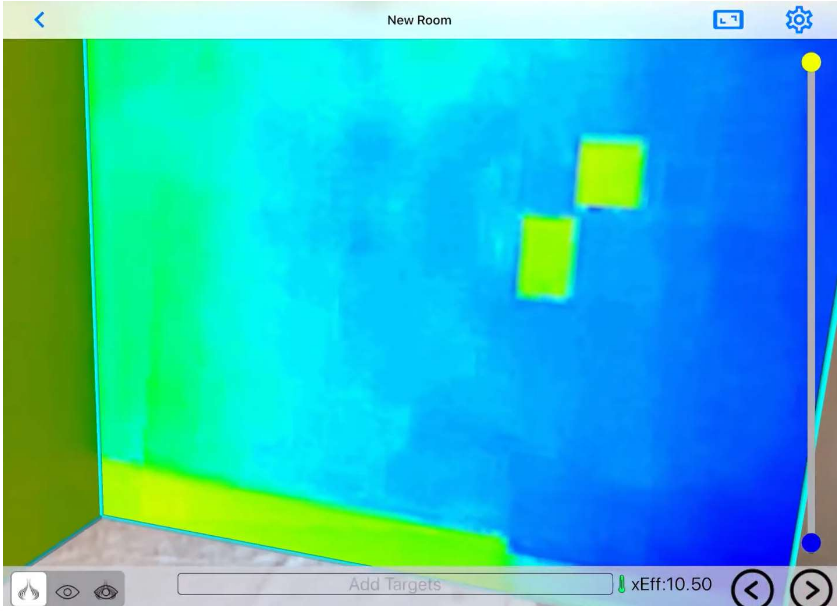


Figure 4: Taking thermal images, the air and reflective temperature targets are clearly visible to the right-hand side of the wall.

5. At this stage a 3D infrared model has been created, in the image select the location of the air and reflected temperature targets.

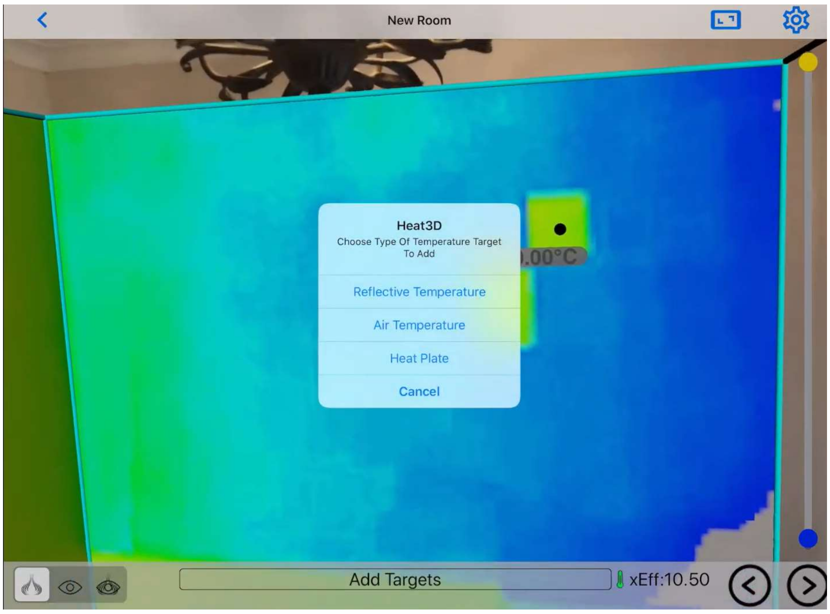


Figure 5: Identifying the air and reflective temperature targets.

6. The survey is now complete and heat transfer measurements are displayed, results can be shown in a 0.5m² grid, for selected areas or on average for a wall surface.

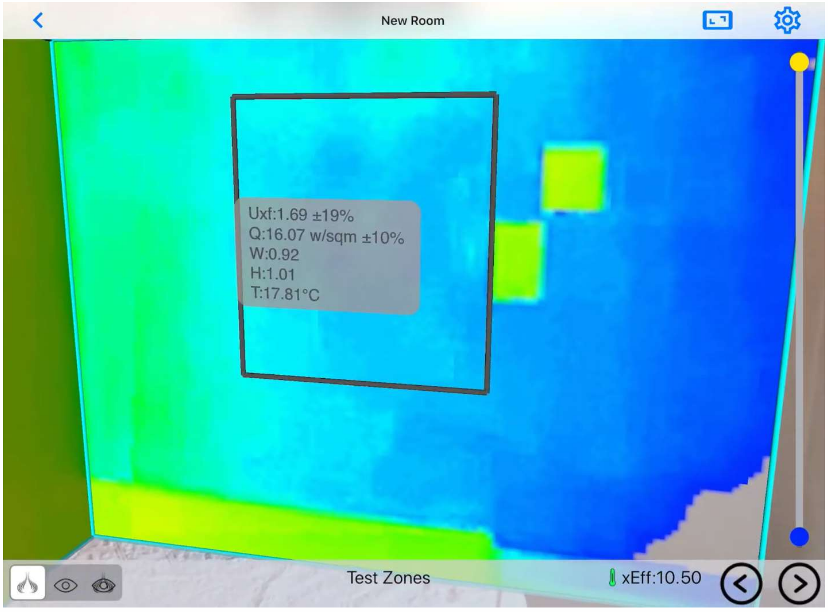


Figure 6: Results page showing the U-value and average heat flux through a highlighted section of the wall.

4. Validation Testing

Heat3D has two primary measurement outputs, heat transfer at the time of the survey and U-values, both were comprehensively validated through laboratory and field trial testing. All validation testing was carried out with baseline measurements gathered using heat flux plates[1], with heat flux plates U-value measurements carried out according to ISO9869.

There are two notable limitations of the validation testing method. It is not possible to measure heat flux in exactly the same location on a wall at the same time as the heat flux plate covers the section of wall surface where its measurement is taken. To mitigate this limitation as far as possible Heat3D measurements were taken for a section of wall as close to the heat flux plates as possible. There is a difficulty in exactly matching measurements temporally given that heat flux plate measurements were only recorded every minute, this is problematic as small changes in internal conditions can cause rapid changes in heat flux as the wall surface.

Figure 7: An example field trial installation with heat flux plates adjacent to an uncovered section of wall where the Heat3D measurement was taken.

Field trials were carried out were carried out over two consecutive winters (2019/20 and 2020/21). During the first winter the field trials concentrated on determining the accuracy and repeatability of Heat3D's measurement of heat flux, and in the second Heat3D's measurement of U-values following the development of the time lapse feature. Similarly, laboratory testing in the Energy House was carried out to test measurements of heat flux and U-values.

4.1. Energy House Testing

The Energy House is a unique research facility at the University of Salford, a highly instrumented solid walled terraced house that has been constructed within a climate-controlled chamber. The ambient temperature, precipitation, solar irradiance and wind can all be controlled within the chamber, and the conditions within the house can be controlled using typical heating controls or thermostatically controlled

[1] For field trials Build Test Solutions' U-Value Measurement System was used (https://buildtestsolutions.com/wp-content/uploads/2020/05/BTS-U-Value-Measurement-Kit-Overview.pdf), for the testing in the Energy House Hukseflux HFP01 heat flux plates were used with a variety of data loggers.

electric heaters. A detailed program was carried out in the Energy House to test the performance of Heat3D in a variety of controlled circumstances.

Figure 8: The Energy House at the University of Salford.

To take advantage of the unique laboratory setting, the testing in the energy house was very heavily instrumented (Figure 9) allowing detailed investigation of the accuracy of both the outputs of Heat3D (heat flux and U-value) and fundamental measurements such as air and surface temperature.

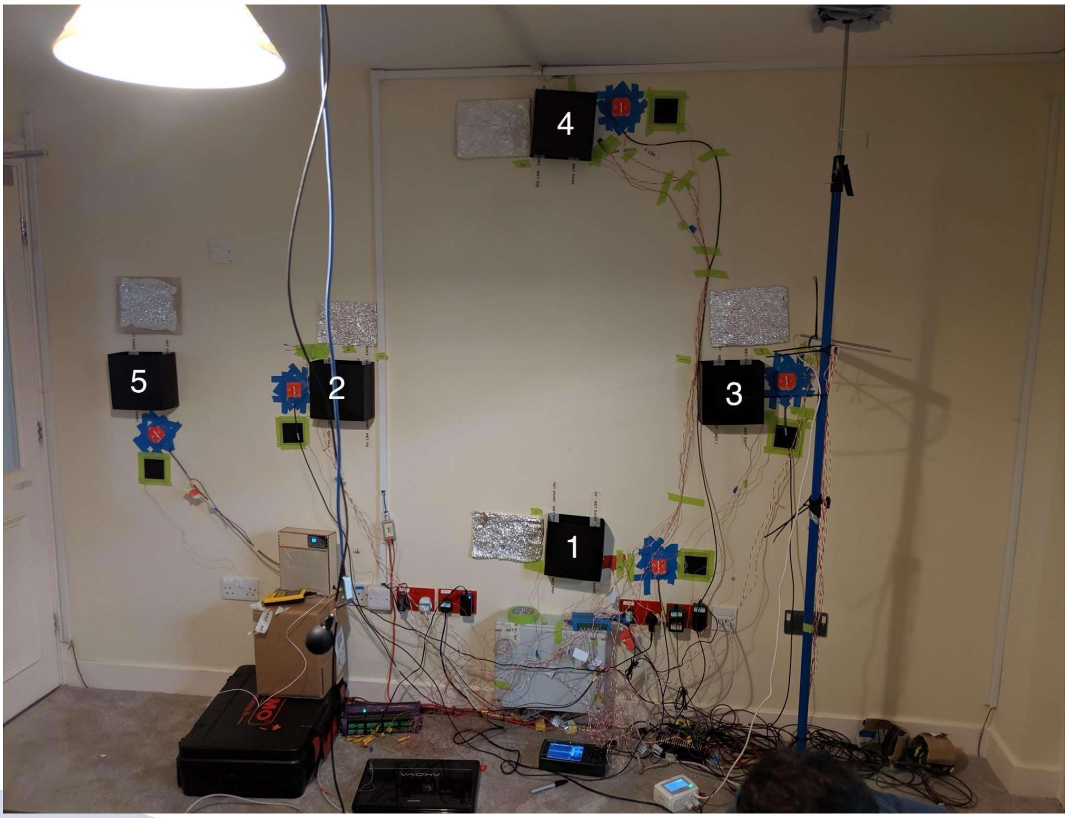


Figure 9: Photo of the measurement equipment in place on the living room wall of the Energy House.

The testing in the Energy House showed an excellent level of agreement between heat flux measurements taken using a heat flux plate and Heat3D (Figure 10), with 92% of measurements agreeing to within the combined uncertainty intervals of the measurements.

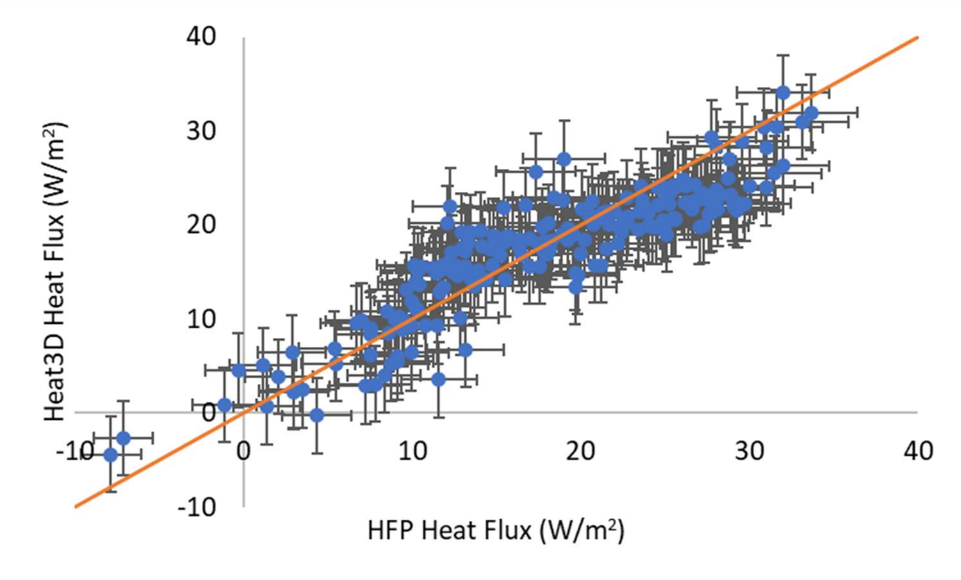


Figure 10: Comparison between heat flux measurements by heat flux plates (HFP) and Heat3D during the Energy House testing.

There was a normal distribution in the variation between the heat flux plate and Heat3D measurements, showing that as well as a high level of accuracy there was not a bias towards over or underestimate of heat flux in the Heat3D measurements (Figure 11).

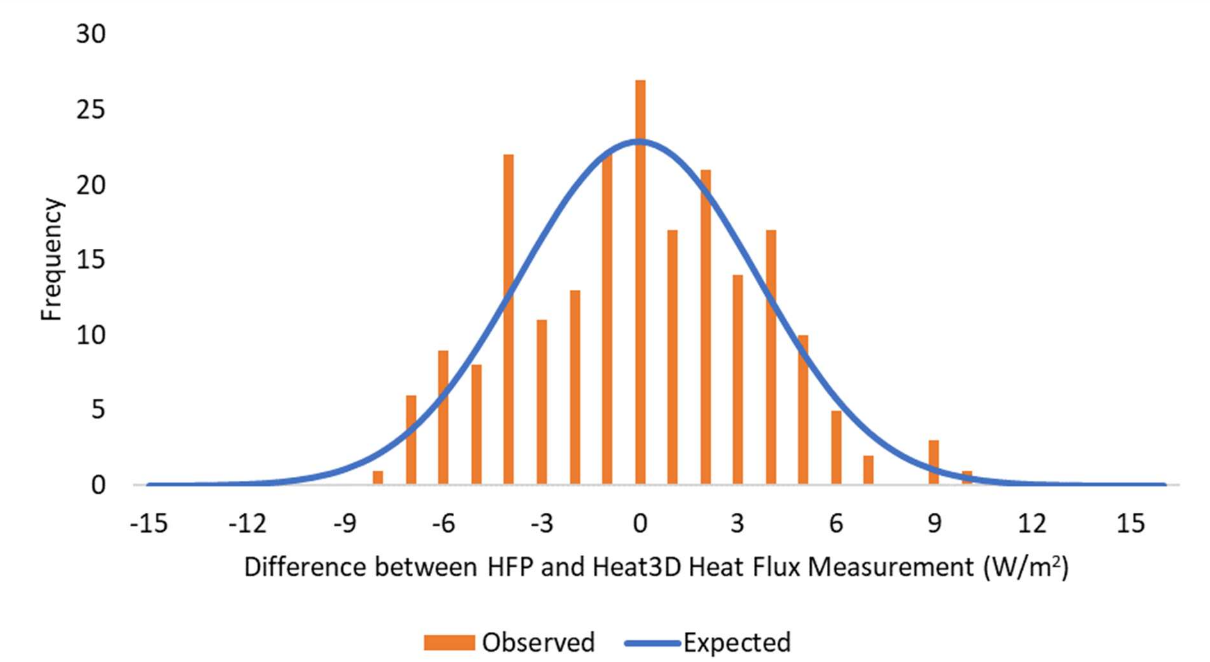


Figure 11: Histogram showing a normal distribution in the difference between the Heat3D and heat flux plate (HFP) heat flux measurements.

4.2. Field Trials

4.2.1 Heat Flux Measurement, Winter 2019/20

During the first winter (2019/20) twenty-five walls were tested across properties of different construction types including an 18th century farmhouse, solid brick Victorian terraced houses and new-build eco houses. For each wall several surveys were taken to investigate the repeatability and accuracy of heat flux measurements using Heat3D, different numbers of surveys were taken depending on the level of access available to building with a total of 292 surveys.

Figure 12: Winter 2019/20 field trial locations.

The walls had a wide range of thermal performance, with a range of U-values measured according to the ISO9869 method from the lowest of 0.13 W/m²K for a PassivHaus new-build flat, to over 2 W/m²K for a 18th century Welsh farmhouse with 2m thick solid stone walls.

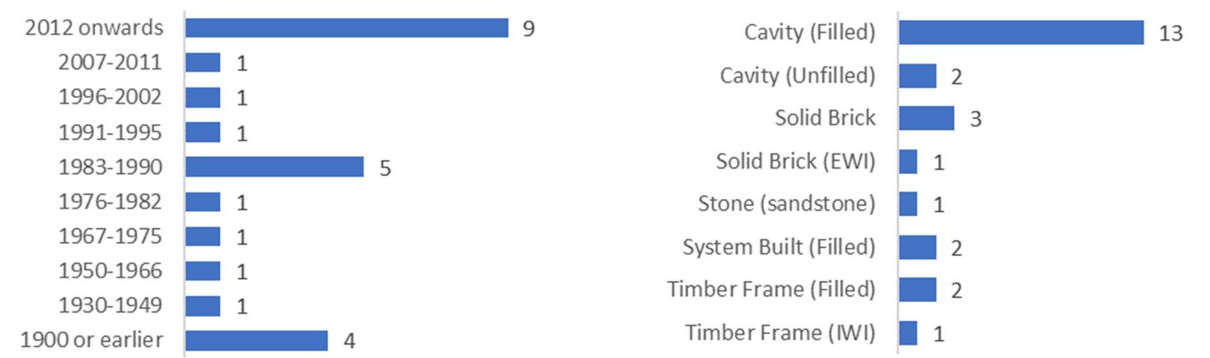


Figure 13: Wall construction age (left) and type (right) for the winter 2019/20 field trial.

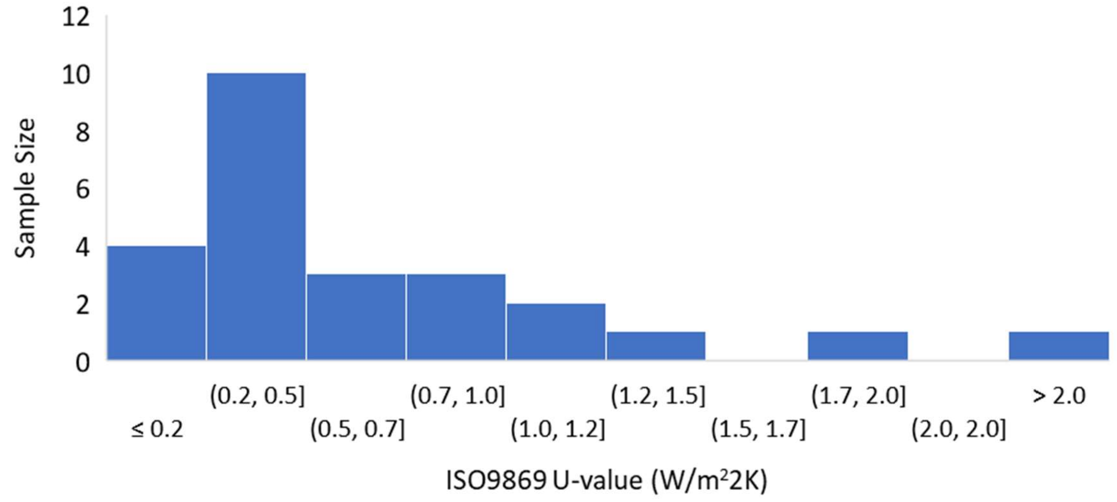


Figure 14: ISO9869 measured U-values for the 2019/20 winter field trials.

There was very close agreement between heat flux measurements taken with Heat3D and heat flux plates, a greater than 90% agreement with the heat flux plates when taking the uncertainty intervals into account. There is a strong correlation with an R^2 of 0.86 (Figure 15) when the results are compared, with a normal distribution in difference between paired measurements (Figure 16).

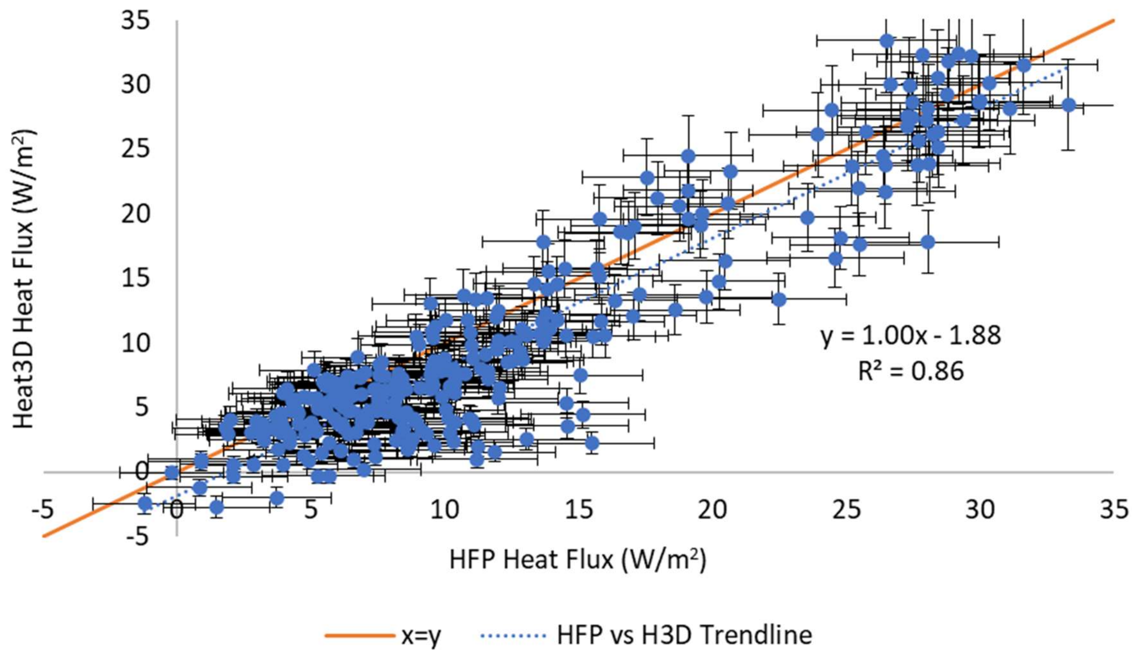


Figure 15: Comparison between heat flux measurements taken with heat flux plates (HFP) and Heat3D from the 2019/20 winter field trial.

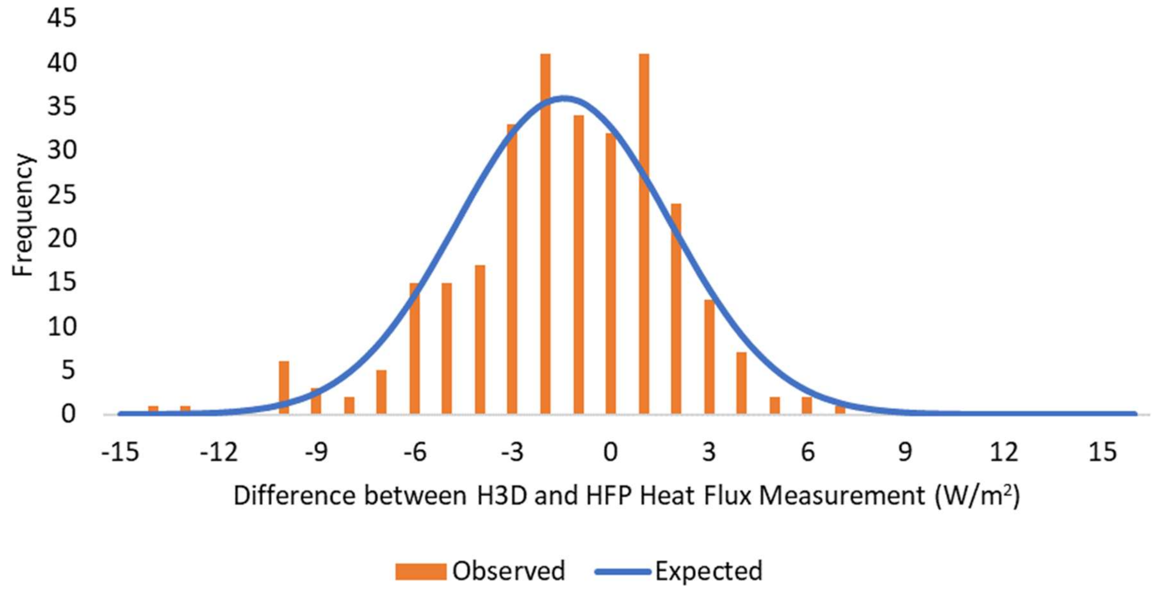


Figure 16: Histogram showing the difference between heat flux measurements taken by Heat3D and heat flux plates (HFP).

4.2.2. U-Value Measurement, Winter 2020/21

During 2020 the time lapse function of Heat3D was developed to carry out U-value measurements. Over the 2020/21 winter a second round of field trials was carried out to test the accuracy of U-value measurements using Heat3D, surveys were carried out on 14 walls with a good geographic spread across England and Wales (Figure 17). Repeat surveys were carried out for each wall, with as many taken as possible depending on access to the building, in total 42 surveys were completed.

Figure 17: Locations for the winter 2020/21 field trial.

The sample included walls of a variety of construction ages and types (Figure 18), leading to a good range of U-values including 5 with a U-value of less than 0.4W/m²K (Figure 19).

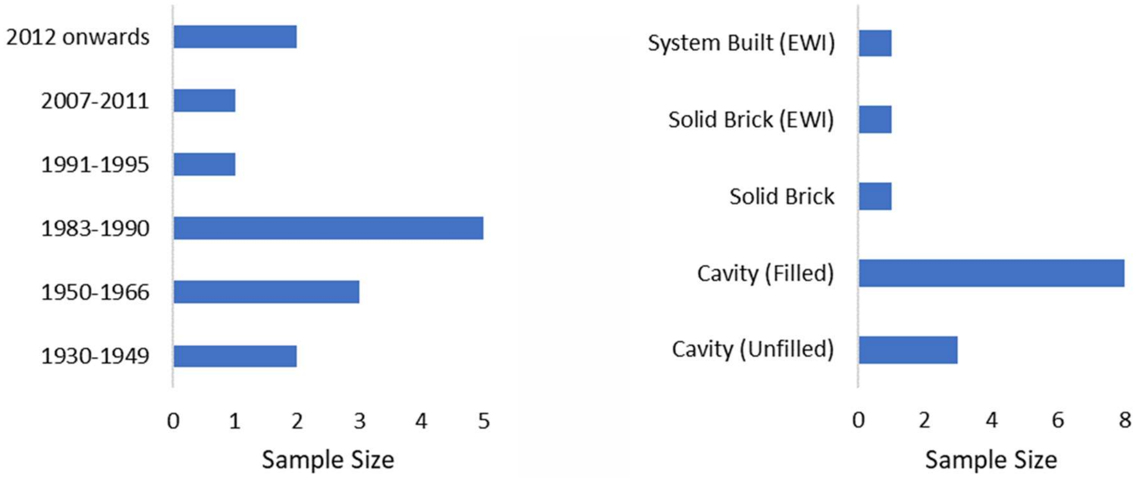


Figure 18: Age and construction type for the walls in the winter 2020/21 field trial.

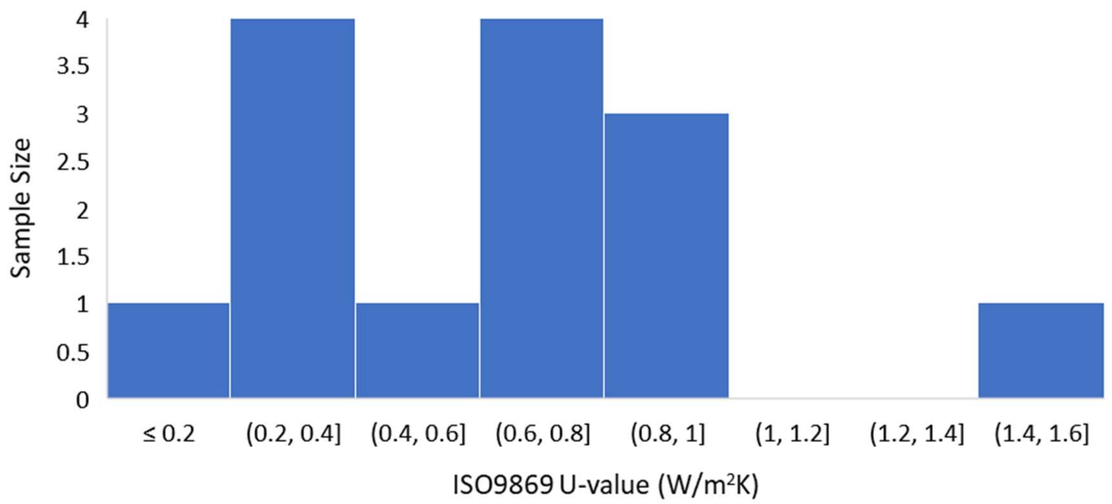


Figure 19: ISO9869 measured U-values for the 2020/21 winter field trials.

The results of the phase 3 field trial were very positive, with a close and direct relationship between the measurements by Heat3D and by heat flux plates according to ISO9869 (Figure 20). In 36 of the 42 surveys the U-value measurement by Heat3D fell within the combined uncertainty interval of the ISO9869 measurement. There was very close agreement between the two methods for U-values above 0.2W/m2K, but more divergence in the results below this level.

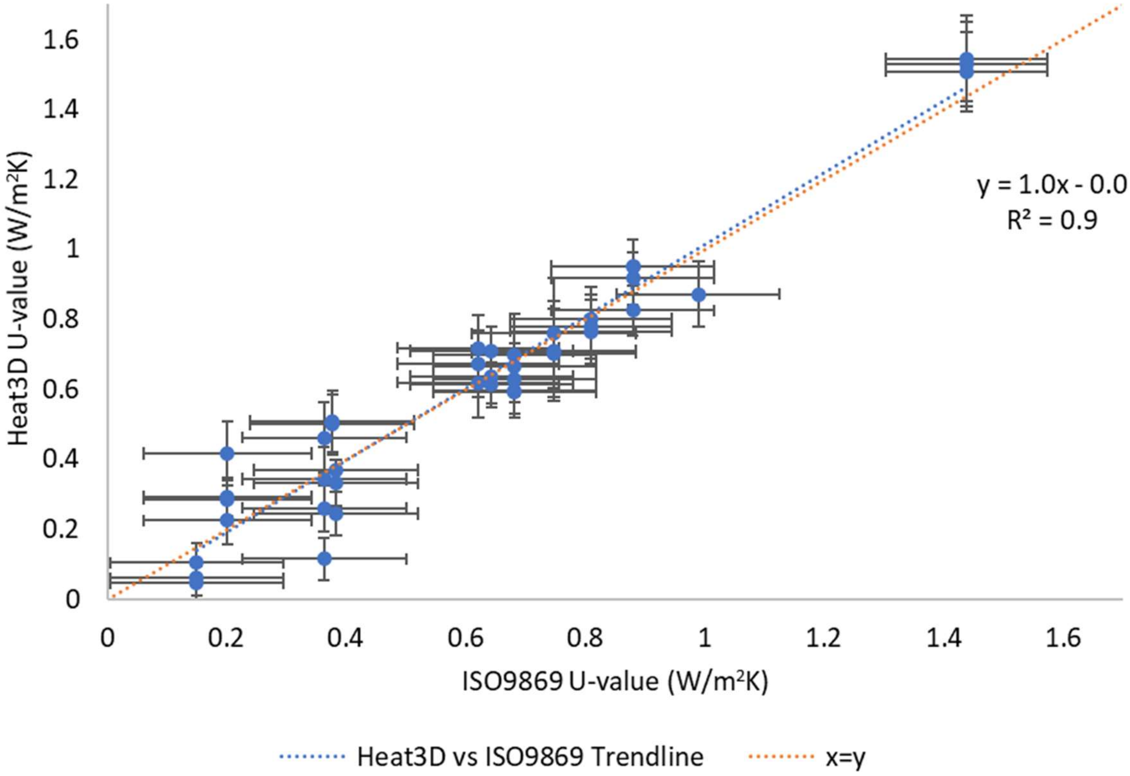


Figure 20: Results of the winter 2020/21 field trial, including 42 Heat3D surveys carried out across 14 different walls.

The uncertainty of a Heat3D measurement is determined to a large extent by the accuracy of the heat flux measurement, which is in turn defined by how accurately the temperature difference between the air and wall surface can be measured. When there is less heat flux, there is a lower air-surface temperature difference, and hence the heat flux can be measured with a lower degree of confidence. The amount of heat flux through a wall is determined by a combination of its thermal performance and the internal-external temperature difference, that is to say that there is generally less heat flux for walls with low U-values or when there isn't much of a temperature difference between inside and out.

Heat3D has a maximum resolution of 4W/m², which means that for walls with a U-value of lower than 0.2W/m²K a rather large internal-external temperature difference is required to accurately measure the U-value. This compromise is true of heat flux measurements with heat flux plates also, with the exact relationship between confidence interval and heat flux dependent on the sensitivity of the heat flux plate and the accuracy of the data logger. Heat3D has higher uncertainty in U-value measurements compared to a typical heat flux plate apparatus at low heat flux levels, but similar levels of uncertainty for higher heat flux (Figure 21).

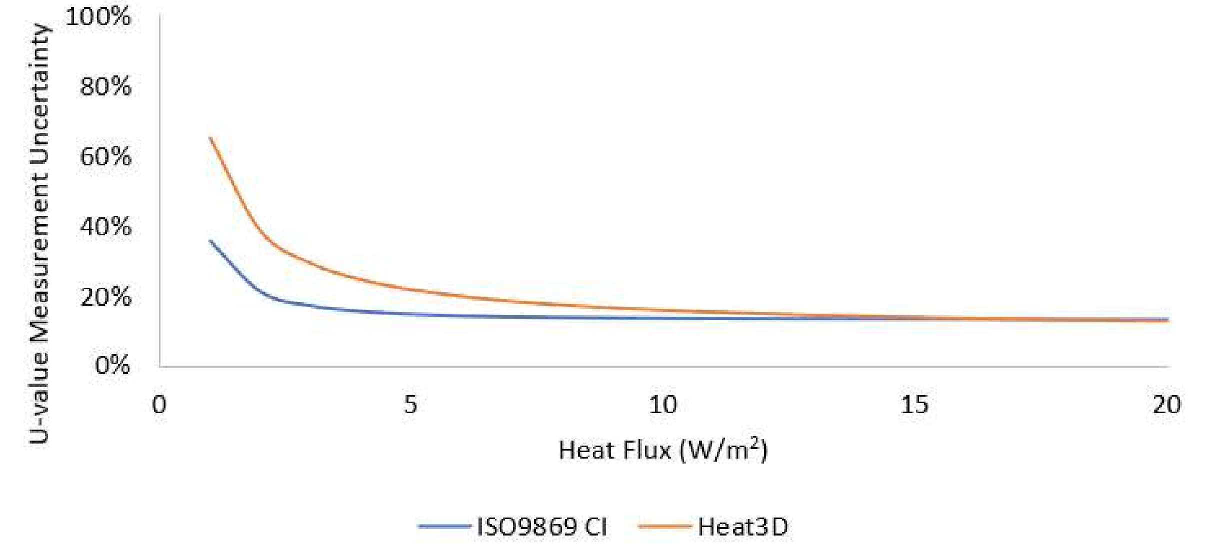


Figure 21: The relationship between heat flux and U-value measurement uncertainty for Heat3D and an ISO9869 measurement using a Hukseflux HFP01 heat flux plate and a Datataker DT80 data logger.

The amount of heat flux during a particular measurement is defined by a combination of the U-value of the wall and the internal-external temperature difference (Figure 22). This relationship would be different for different desired confidence intervals, for higher confidence intervals the required internal-external temperature difference would be lower. In this example, for a confidence interval of ±25%, to measure a U-value of lower than 0.2W/m²K an internal temperature difference of more than 15°C is required between inside and out. Practically, a larger temperature difference than this would be difficult to achieve and 0.2W/m²K could therefore be considered as a practical minimum U-value for accurate measurements using Heat3D in conditions typically found in buildings. By comparison, for heat flux plates a U-value of around 0.1W/m²K is the practical minimum when defined using the same method.

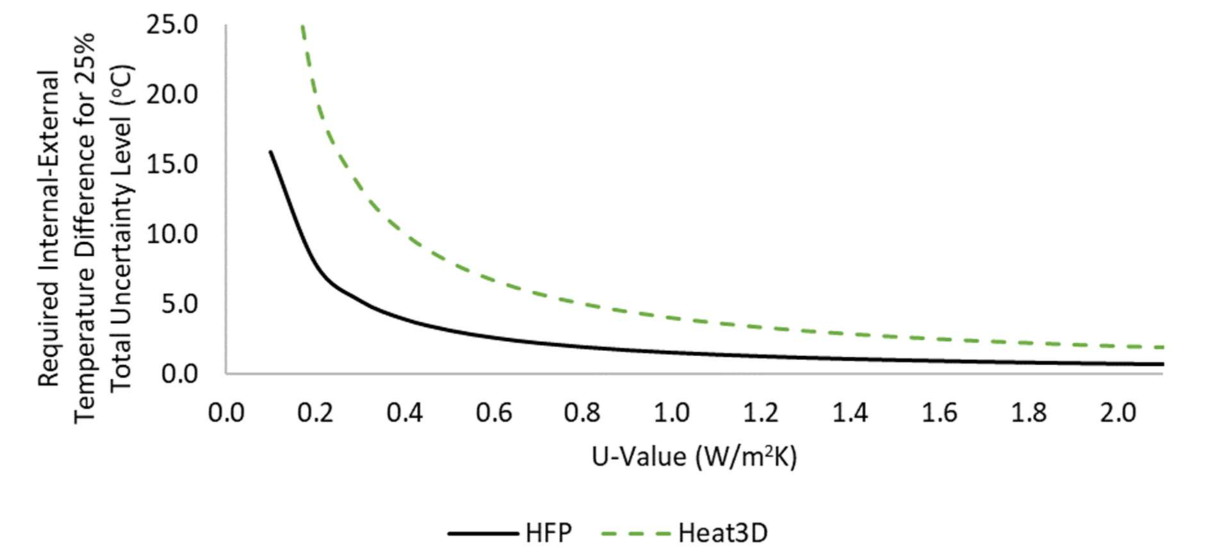


Figure 22: Chart showing the required internal-external temperature difference required to drive sufficient heat flux to achieve an uncertainty of ±25% in a U-value measurement by heat flux plates (HFP, using the same specification defined in the previous figure) and Heat3D.

U-Value (W/m²K)	0.1	0.2	0.3	0.4	0.5	0.6
Required int-ext DT for Heat3D uncertainty <25%	40°C	20 °C	13 °C	10 °C	8 °C	7 °C

Table 1: Tabular version of Figure 22, showing the minimum internal-external temperature difference (DT) required for an uncertainty in a Heat3D U-value measurement of less than 25% for ascending U-values.

3. Comparison to Traditional U-value Assessment Methods

3.1. U-value Calculations and Lookup Tables

In the vast majority of cases design and assessment of the thermal performance of buildings is based on U-value calculations. A U-value calculation is carried by summing the thermal resistance of each layer in a construction element, with the thermal resistance calculated based on the thickness of the material and the thermal conductivity of the material (an example is shown in Figure 23). The thermal conductivity is determined by a laboratory measurement of a sample of the material.

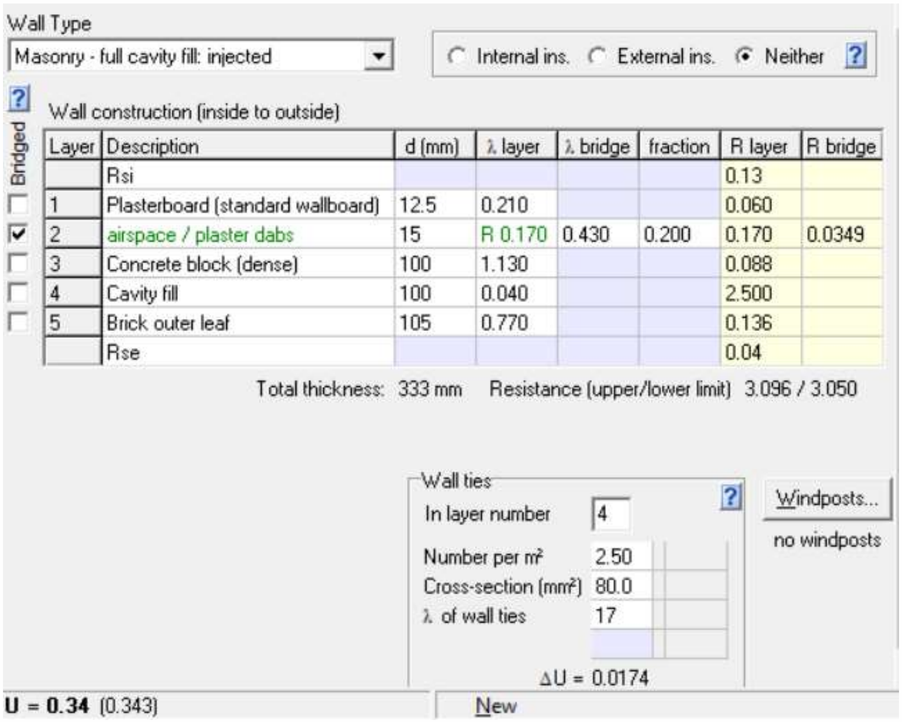


Figure 23: Example U-value calculation for an insulated cavity wall where the calculated U-value is 0.34W/m²K.

Although these calculations should give a good indication of the thermal performance of a wall, there are limitations to their accuracy.

- In the case of existing buildings, it can be difficult or impossible to identify exactly what materials are present. For example, even very thin air gaps can dramatically improve the thermal performance of an element if the air is contained, these are common in 'solid' brick walls but impossible to identify visually.
- The U-value calculation does not account for building defects, such as areas of missing or damaged insulation or partially wet building materials.
- Not all building materials have a laboratory measured thermal conductivity, in these cases the properties of a similar material are often substituted.

- Product substitution is common and can mean that the actual construction is different to the design intent.
- Thermal bypasses such as air movement through a layer which is assumed to be unventilated are not uncommon, can be very difficult to identify visually, and dramatically increase (worsen) the U-value.

All of these issues mean that the actual U-value of a construction can be different to the design intention, and indeed different across the surface of the element. These differences are critical if attempting to accurately assess the thermal performance of a building or predict energy requirements, determining what retrofit measures are required, what impact they would have or whether they've been successfully installed.

3.2. Heat Flux Plate Measurements

By far the predominant method to measure U-values is using heat flux plates, these are relatively small sensors which measure the heat transfer through a small area of a wall surface (Figure 24). Measuring U-values using heat flux plates is a well-established process with a standard testing process defined by the International Standards Organisation (ISO9869-1:2014).

Figure 24: Heat flux plates being installed on a wall.

Heat flux plate measurements are an excellent tool to measure U-value with a proven track record. They have provided several key insights into building performance and will continue to have a role in detailed diagnostic testing, but they also have two key limitations:

- **Time and cost**. In order to account for heat storage as well as heat transfer through an element (i.e. a wall, floor or ceiling), ISO9869 requires that the heat flux plates are installed for a minimum of 72 hours and they often need to be in place for a week or more to satisfy the specified testing conditions. Practically, this means makes access to buildings more difficult and significantly increases cost due to more time required on site and expensive equipment being committed to each test for a longer period.

- **Measurement area.** Heat flux plates only measure heat flux through the area of an element that they cover, and further are prone to inaccuracy if they are located in areas of heat flux concentrations. This means that they are well suited to measuring the U-value of a homogeneous section of an element, but this section of wall might not be representative of the performance of the whole surface of the element.

Contact

enquiries@buildtestsolutions.com
www.buildtestsolutions.com

Build Test Solutions Ltd, 16 St John's Business Park, Lutterworth, Leicestershire, LE17 4HB