THERMAL PERFORMANCE MEASUREMENT HANDBOOK

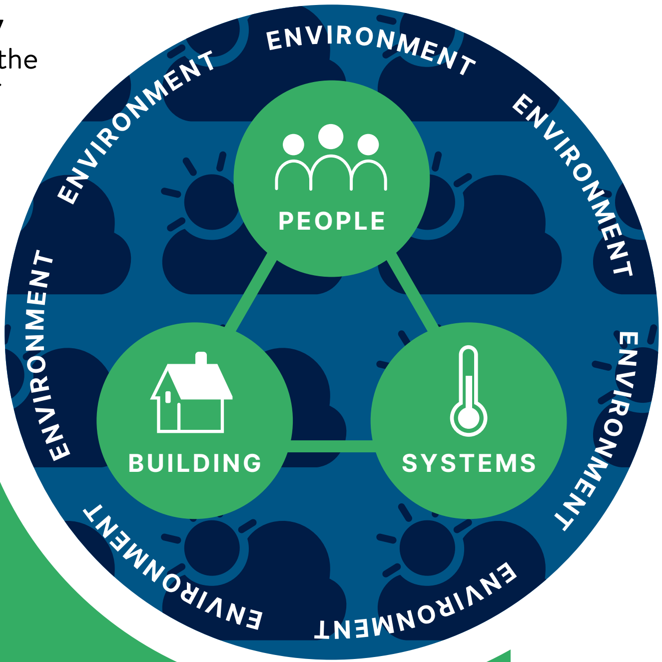
BUILD TEST SOLUTIONS

www.buildtestsolutions.com

This is a simple 'how to' guide for assessment of the thermal performance of buildings. The thermal performance of buildings is critical in determining the amount of energy required to keep them thermally comfortable via heating and/or cooling. In order to ensure that buildings can be maintained to a comfortable temperature without excessive energy consumption and cost, it is essential that their thermal performance is known.

The energy consumption in any building is driven by **four key parameters**, the thermal performance of the building itself, the efficiency of the heating and cooling systems, the actions of the occupants and the local weather conditions.

This guide concentrates on just the thermal performance parameters. This is fundamental because while the other three parameters regularly change, the underlying thermal performance doesn't. Ensuring good thermal performance therefore is key to ensuring buildings are truly low energy and efficient throughout their operational lifespan.



The guide is structured into five key stages:

1. **Survey:**
   Survey the building or proposed building and determine the assumed performance of each element as well as the building as a whole.
2. **Measure:**
   Carry out performance measurements to allow an assessment of whether the building is performing as predicted.
3. **Assess and validate:**
   Compare the predicted and actual performance and identify if there are areas which don't align.
4. **Diagnose:**
   If the aspects of the building's performance don't match expectation, carry out further diagnostic testing to find out why.
5. **Action:**
   Use the measurements for actions like quality control, identifying remedial works and measuring their effect, informing updated retrofit design, feedback to improve build processes, assessment of new building materials.

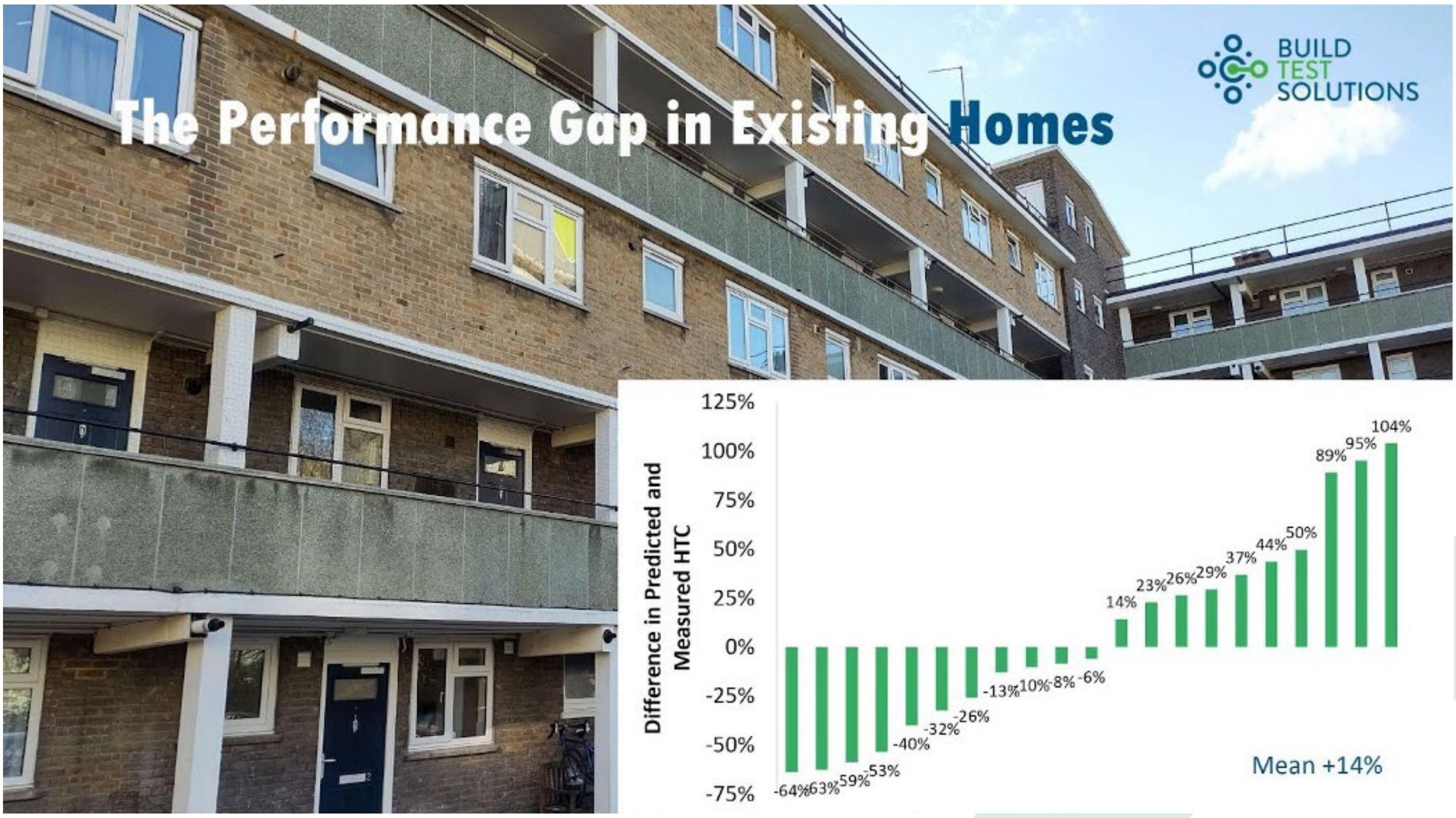
Why Measure?

The actual energy performance of buildings often varies significantly from predictions. In-situ performance measurements provide the means to understand how a building really works, enabling informed building management and quality assurance.

Predictions are based on visual surveys and laboratory-measured material performance metrics, but the reality can be very different. Practically, it can be impossible to produce the inputs required for accurate modeling. Visual surveys are an imperfect tool, with important factors such as insulation continuity in cavities and junctions difficult or impossible to see.

Studies have shown that the measured performance of buildings can vary by 100% and more from the prediction, known as 'the performance gap', undermining key decisions like which materials and processes work in practice, or what size heating system is required. In-situ measurements, therefore, are key to understanding how a building really works.

In the example below the thermal performance of all of the flats in a block was measured, and the results showed that the actual performance of each varied widely from the predicted performance (calculated by a SAP assessment). These measurements highlighted a design flaw where the exposed concrete floor slabs around the walkways and balconies introduced a large thermal bridge which was not accounted for in the SAP model.

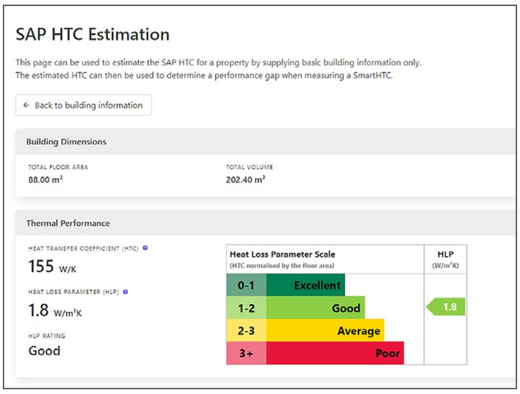


Step 1: Survey

In order to put measurements into context so that it's possible to assess whether results are good or bad, the first step is to survey and model the building. This is a well established process applicable to both new build and retrofits, using techniques and tools such as SAP and RdSAP based Energy Performance Certificate assessment procedures, the Passive House Planning Package, or for non-residential buildings iSBEM or other dynamic simulation modelling tools. As surveying is so commonplace and typically required for compliance purposes, it's very possible that this stage has already previously been carried out so that no new work is required.

In order to compare with measurements, the following key building performance metrics must be included in the modelling. These may be based on design intent and associated manufacturer supplied specifications or may be inferred based on the type and age of the building:

- Elemental performance, with U-values for key elements such as floors, walls, ceilings and windows
- Airtightness
- Ventilation provision
- Whole building heat loss rate (Heat Transfer Coefficient)



All of these metrics are essential inputs and outputs to all modelling packages, including but not limited to SAP. RdSAP, PHPP, iSBEM and Dynamic Simulation tools such as IES, Revit, EnergyPlus and others.

Alternatively, Build Test Solutions provide a simple HTC Estimator which can be used to input design values or estimate each of these metrics using the Standard Assessment Procedure used to create EPCs in the UK.

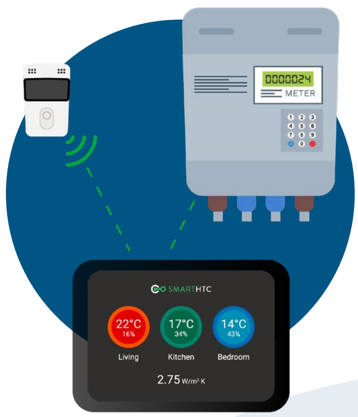
Step 2: Measure

At this stage we recommend that three key measurements are taken to allow an overall assessment of whether the building is operating as designed or assumed in an as-built assessment. These are a measurement of the overall thermal performance, the airtightness and the ventilation provision.

Heat Transfer Coefficient

Overall thermal performance is defined by the 'Heat Transfer Coefficient', with units of Watts per Degree Celsius or Kelvin. The Heat Transfer Coefficient (HTC) is a measure of the rate of heat transfer per degree of temperature difference between inside and out. This means if a building has a Heat Transfer Coefficient of 100W/K then 100W of power input is required to make it 1 degree warmer inside than out.

The HTC is an excellent metric to assess if the building is generally performing as expected, removing all ambiguities about variables such as weather and occupancy factors. The HTC is central to determining the overall heat demand for the property, heating systems can then be designed to meet that heat demand.



The Heat Transfer Coefficient can be measured using **SmartHTC**, this is an online calculator which requires inputs of measured internal temperature and energy consumption collected for 21 days when the daily average internal temperature is more than 7 degrees higher than the daily average external temperature. Data can be collected using sensors installed specifically for the measurement, or using existing equipment like smart thermostats and utility meters.

Airtightness

Airtightness is a measure of the rate at which air is able to escape (and pass into) the building through the building fabric. There is an important distinction between air movement by infiltration and ventilation; ventilation is air movement by deliberate purpose provided means (either openings or mechanically driven), while infiltration is the unwanted and unintentional flow of air through a building's fabric. Infiltration is caused by gaps and cracks, typically at junctions between different building elements.

Lots of air movement can result in lots of heat transfer (loss in cold climates, or gain in warm climates) which results in higher energy consumption. It is also critically important to ensure that there is sufficient fresh air provision for a healthy internal environment.

In practice, every building will have a mixture of infiltration and ventilation. To avoid unnecessary energy use and ensure sufficient ventilation, it's generally recommended to minimise infiltration and provide the right amount of air to the right place by controlled ventilation.

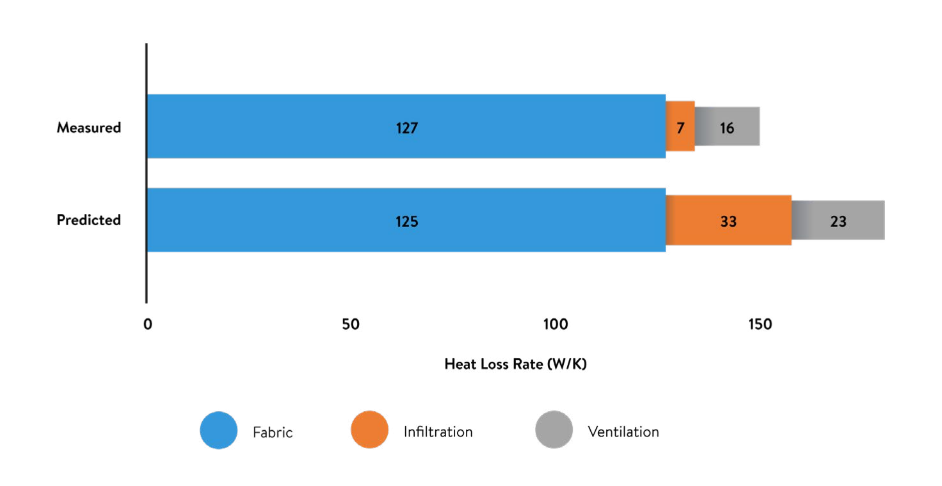
Airtightness can be measured using **Pulse**, which releases a known amount of air from an air receiver containing compressed air. The system then measures the pressure response in the building and the rate at which air moves through the building fabric can be calculated. What is particularly innovative about the Pulse technique is that the air leakage rate is measured directly at a pressure difference between inside and outside of 4 Pascals. This represents the ambient pressure conditions buildings most commonly experience day to day. Other techniques such as the blower door fan exert high pressures (20 to 60 Pascals) which serve as a useful stress test of a building and are great for carrying out air leakage diagnostics as per step 4 in this guide.

Mechanical Ventilation

The volume flow rate provided by installed mechanical ventilation systems should be measured as part of the commissioning process and a building performance assessment. Here we recommend what's called the 'unconditional method'. This uses a powered flow hood, a device that incorporates a fan which rotates at a controlled speed. This means that the device is able to achieve a zero-pressure balance in the hood measurement system when placed over the inlet or outlet of a fan, meaning it is not limited by fan type, model or air flow direction and does not require specific instrumentation characteristics to be input for each test. As soon as the zero-pressure state is achieved, which is normally between 4 and 20 seconds, the instrument displays an air volume flow rate.

Step 3: Assess and Validate

Now that the predicted and measured performance is known, it's time to compare them and check that the building is operating as intended.

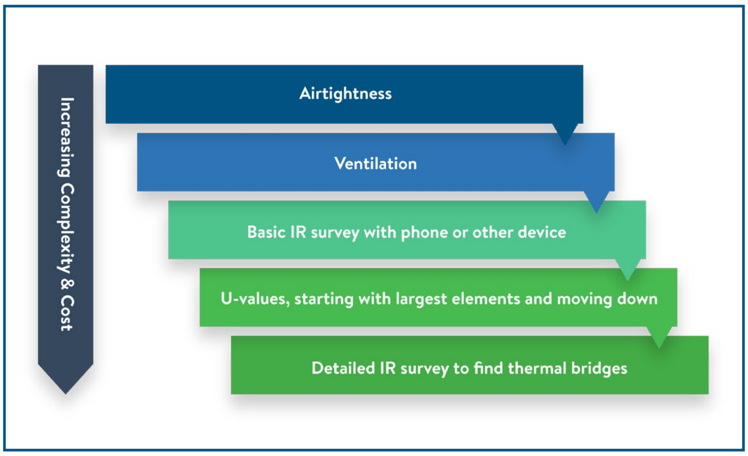


- Compare the measured and predicted HTCs to see if the overall thermal performance is as expected or if there is a 'performance gap' i.e. a higher heat loss rate than expected. When performing this comparison, consider the confidence interval of the measurement, which is typically around ±15%, if the performance gap is less than the confidence interval then the building can be considered to be performing as expected.
- Compare the predicted and measured airtightness and ventilation levels to ensure that the building has an adequate supply of fresh air (some useful guidance for existing buildings is available at: **theiaa.co.uk**).
- Break the total heat transfer down into fabric, airtightness and ventilation components and compare the measured and predicted performance for each. It's possible that the overall thermal performance could match, but for the wrong reasons, if the building is more airtight than it's designed to be there would be less heat loss but at the cost of insufficient ventilation. An example comparison is shown above, in this case the measured HTC is lower than the prediction but this is due to insufficient ventilation compared to the design values.

Step 4: Diagnose

If the building performance is not as expected, the next step is to diagnose the problem. If the building is performing as expected or better, this step could be missed out. It's sensible to follow a staged approach for diagnostics, starting with the most simple and inexpensive tests on the most likely failure method, and building up in complexity and expense until the cause of a discrepancy between predicted and actual performance is found.

The information from the assessment should be used to inform the diagnosis and guide whether the unexpected performance is linked to air movement or fabric heat loss.



If the building's airtightness is more or less than expected, and this accounts for the gap in overall thermal performance, then the diagnosis is already clear. If the building is less airtight (i.e. more leaky) than expected, then a **Leak Checker** or blower door fan can be used to drive a pressure difference and detect leakage pathways.

If the fabric heat loss is not as expected, then the thermal performance of one or more elements (i.e. U-value of floor/walls/ceiling/windows/doors) or the amount of thermal bridging is not as predicted. The next diagnostic step is in-situ U-value measurements to determine whether the performance of these elements is as expected.

The mix of heat loss through each element varies for each building depending on the area of each element and its performance, a good first step is to consider this balance for the building in question.

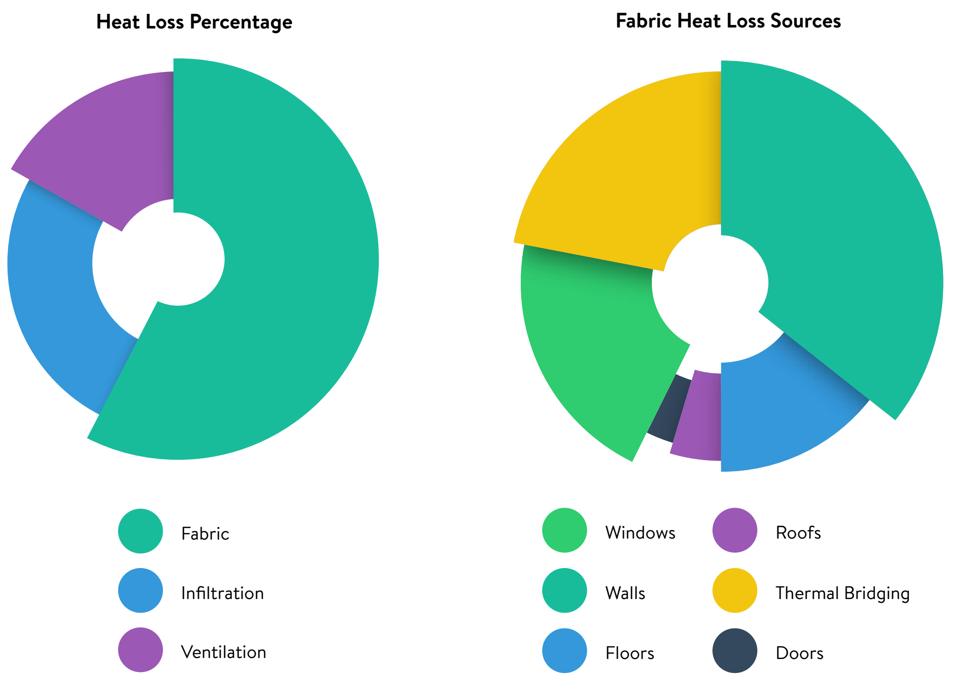
If there is a large difference between the predicted and actual thermal performance, then it's likely that the issue is with one of the elements which contributes a large proportion of the total heat loss. This balance varies between buildings, but given they typically have the largest area external walls, floors and ceilings are a good place to start investigations. The balance for the particular building should be used as a guide for where to target U-value measurements.

HEAT LOSS ESTIMATION

Fabric Heat Loss:
143 W/K

Average Infiltration Heat Loss:
43 W/K

Average Ventilation Heat Loss:
22 W/K



U-value measurements can be undertaken using heat flux plates or using an infrared camera and BTS' Heat3D.

Heat3D U-value measurements can be undertaken in around 1 hour and provide measurements across the whole surface of a wall. Heat3D gives a measurement of the average performance of the whole wall and can highlight if there are any areas of relatively poor performance which could indicate an issue like missing insulation.

Heat flux plate measurements take around 1 hour to install but must be left in place for at least 3 days and only provide a measurement of a small section of the walls, repeated measurements in several locations are therefore recommended.

The U-value of glazing is unlikely to vary from the manufacturer's listed performance, if the exact specification of the windows is known. The more likely cause of variance around windows is in thermal bridging around the install of the window frame.

If the elemental U-values, airtightness and ventilation provision are as expected, but the overall thermal performance (HTC) is not, then it's likely that there is higher than expected thermal bridging. High thermal bridging is most likely around junctions between elements and penetrations through the thermal envelope. A thermal imaging survey is a good tool to detect thermal bridging, though be aware that heat loss paths may be complex, such as heat loss into a ventilated cavity where the heat loss to outside could be well away from the internal source.

A detailed IR survey with a high specification camera may be required to find smaller thermal bridges, but is a specialist and expensive undertaking. Inexpensive IR cameras which plug into phones or other devices are also available and can be a useful tool for finding major thermal bridges quickly and at lower cost.

Step 5: Action

To get maximum value from the measurements carried out, action should be taken in response to the results. Very varied actions are possible based on the measurements undertaken, here are some examples and check out the **Build Test Solutions website** for case studies:

- **Quality assurance** can be provided to demonstrate that the building is operating as expected. This could be carried out by those delivering the building or retrofit or by the clients receiving the delivered product, either for internal quality control and continuous improvement purposes or as a condition of the contract. Doing so stands to benefit all parties in ensuring fewer unintended consequences and complaints, as well as verifying that the energy performance and comfort parameters of the building will be in line with design expectations.
- **Demonstrate compliance with designed performance**, as might be required by local planning policies, building regulations and codes or voluntary standards being worked to.
- **Remedial actions** as a result of reported high running costs or other diagnosed defects. Following remedial actions the measurement process should begin again at stage 2 to ensure the remedial actions have worked.
- **Add measurements to stock management** systems to enable informed building and stock assessment. With the true performance now known, there can be much better targeting of retrofit measures to houses most in need.
- **Feedback and process improvement:** knowledge of the in-situ performance of buildings provides insights into which products and processes really work to enable better design and build of future new-build and retrofit projects. Often measurement is thought of in a punitive sense i.e. trying to catch out the poor workmanship but it can equally highlight high quality work which can be used in marketing and tenders.
- **More accurate heat demand forecasts** which can be used to better size heating systems, this is particularly important for heat pumps which cannot run efficiently if oversized.
- **Better estimates of energy consumption and carbon emissions** which are widely useful for things like effectively alleviating fuel poverty, assessing the effect of retrofit measures and policies, forecasting energy costs and as inputs to system design.
- **Demonstrate effective risk mitigation**, as-designed thermal performance leads to greater assurance that the building will operate as planned with energy costs in line with predictions and fewer causes for complaints and reactive maintenance
- **Gain access to funding opportunities and awards**, due to increasing awareness of the importance of achieving as-designed performance in-situ, funding awards and competitions increasingly require demonstration that the intended performance is delivered.

Contact

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