SAP CONVERSION TOOL V2.3



METHODOLOGY FOR ADJUSTING SAP 10.2 OUTPUTS

FOR GREATER MANCHESTER COMBINED AUTHORITY

January 2026 | P02

Etude

Executive Summary

Background

Greater Manchester Combined Authority would like to provide planning applicants with a tool to help them assess the design-stage energy performance of dwellings based on SAP 10 calculations, without requiring a full set of PHPP calculations. This will reduce design-stage costs for applicants, and also avoids the need for complex guidance around PHPP's many user-definable inputs.

The tool will assist applicants in assessing the energy performance of homes against the following best-practice levels of performance, which are typically based on energy performance calculated in PHPP:

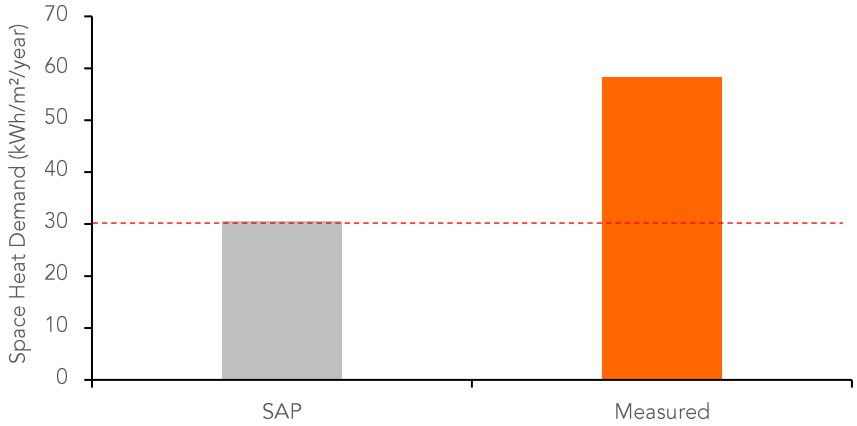
1. Space heating demand ≤15-20 kWh/m²/year
2. Total energy use ≤35 kWh/m²/year
3. Renewable energy generation (solar PV) >= Total energy use

The Standard Assessment Procedure (SAP)

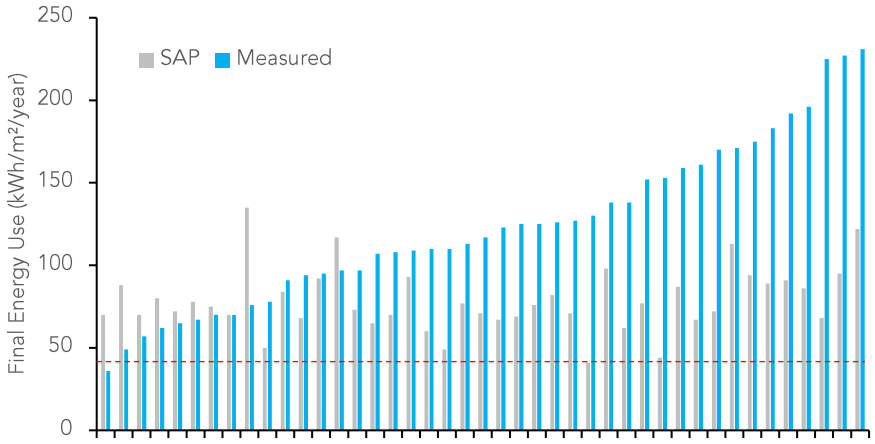
SAP 10.2 is the methodology that is currently used by the government to assess the energy performance of homes. While one of its core purposes is to provide accurate assessments of domestic energy performance, various post-occupancy studies have indicated that it does not provide realistic predictions of real-world energy performance. SAP 10.2 is often viewed by energy modelling professionals as a 'compliance tool', which is not designed to predict real-world energy performance.

A 2020 study by the Building Performance Network measured energy use in homes, and compared it to predictions made by SAP. As the adjacent graphs show, actual space heat demand was found to be twice as high, on average, as that predicted by SAP. Measured final energy use was also found to be significantly higher than predicted. Several other studies, and comparative modelling between SAP 10.2 and the PassivHaus Planning Package (PHPP) by Etude for Cornwall Council's DPD SEC 1 evidence base, have found similar results.

This means that the raw calculation outputs from SAP 10.2 are not currently fit for purpose to assess design stage energy performance of dwellings against net zero energy housing policies.



Space heating energy use predicted by SAP vs measured energy use for 50 new dwellings. Measured energy use was on average 27.8 kWh/m²/yr more than predicted by SAP. © Building Performance Network (2020)



Final energy use predicted by SAP vs measured energy use for 43 new dwellings. Measured energy use was on average 62 kWh/m²/yr more than predicted by SAP. © Building Performance Network (2020)

Executive Summary

Why SAP 10.2 is unrealistic

Most of the core calculations in SAP 10.2 are straightforward, based on a sound approach to building physics, and in many ways similar to other energy modelling software such as PHPP. This report explores why the values calculated by SAP 10.2 can be different despite these similarities and finds that differences in some parts of the calculation methodology and assumptions are the main reasons.

Is the Home Energy Model a Solution?

A replacement for SAP is expected to be released later this year, and this may address some of the current issues with SAP 10.2. However, waiting for this new version may not be an acceptable approach to implement current net zero housing policies given the urgency of addressing climate change, with a near-exhausted 1.5°C carbon budget. Many thousands of new homes that are not net zero policy compliant could be granted planning permission if their performance is assessed with SAP 10.2.

Is the PassivHaus Planning Package a Solution?

The PassivHaus Planning Package is widely accepted as offering more realistic predictions of energy use, and is currently accepted as a means of demonstrating net zero policy compliance. However, the cost and complexity of carrying out PHPP calculations is expected to be prohibitive for many applicants, particularly for small developments. An additional challenge is that although there are hundreds of trained Passivhaus Consultants and Designers in the UK, this is much less than the thousands of trained and experienced SAP assessors.



New homes under construction in Newton Heath. Thousands of new homes are expected to be built each year across GMCA. Until a reliable and well-tested version of the Home Energy Model becomes available, an affordable interim tool is required that can provide realistic predictions of energy performance to ensure planning applications for new homes can reliably demonstrate performance against net zero policy requirements.

Executive Summary

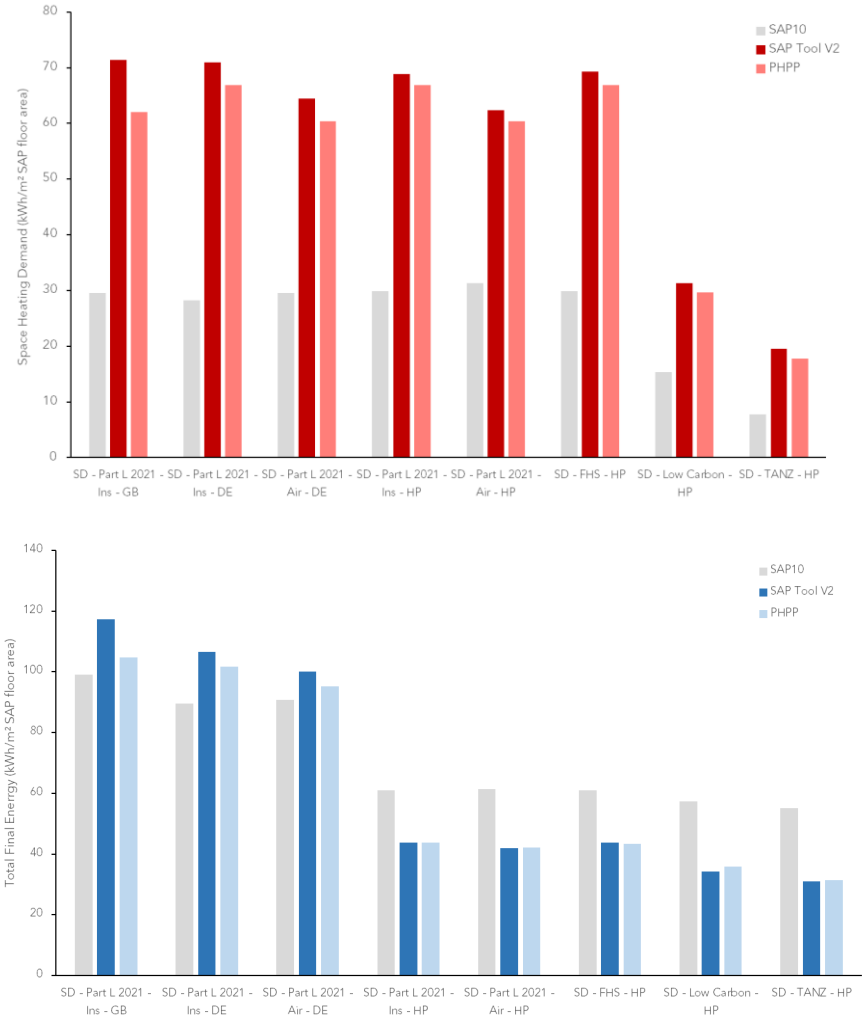
The SAP Conversion Tool

Etude have been commissioned to update the SAP Conversion Tool for Greater Manchester Combined Authority. It is based in one that was developed for, and is being used by, Cornwall Council, Bath & Northeast Somerset council and Essex County Council. The tool applies specific and targeted interventions to a range of SAP 10.2's calculations and assumptions.

To establish transparency around how this has been done, these adjustments are explained in detail in this report. An unlocked version of the tool can also be made available to enable testing and peer-review.

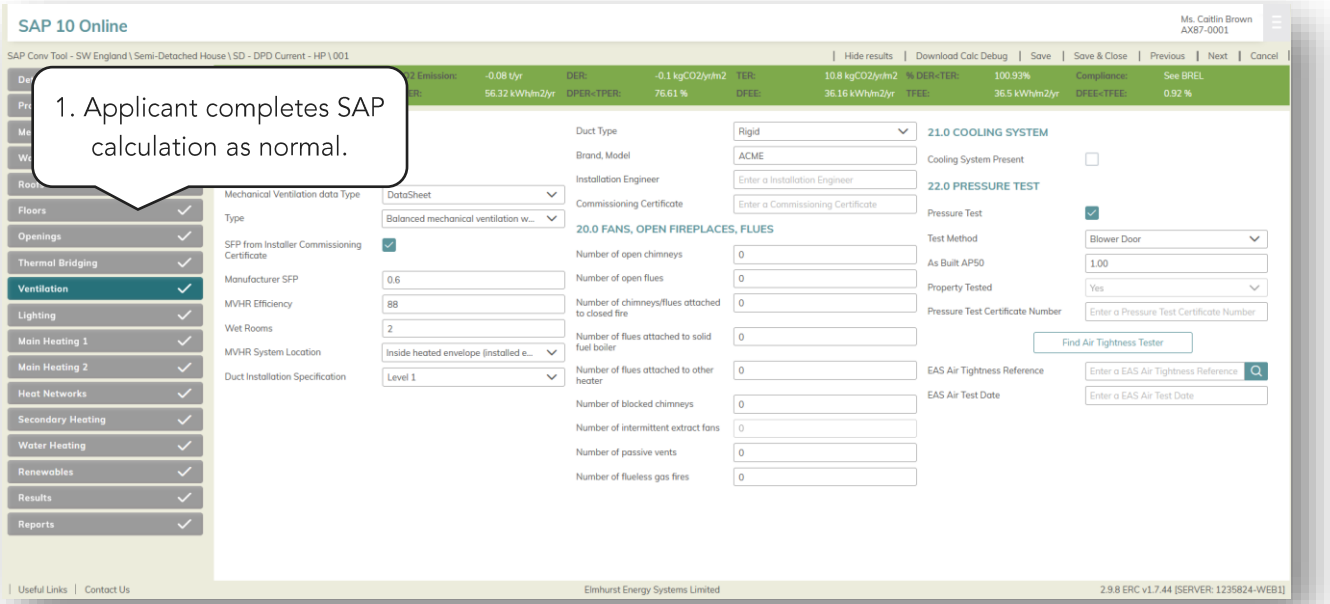
The tool has been carefully developed to require minimal input by the user, by relying on the highest value outputs available from a SAP 10.2 calculation. For example, all a dwelling's heat loss areas, thermal bridge lengths, and their associated thermal performance are entered in detail in SAP 10.2. This could involve anywhere from a few dozen to over one hundred different data entries. The SAP Conversion Tool is able to obtain all this information through a single number that is output in a SAP calculation worksheet.

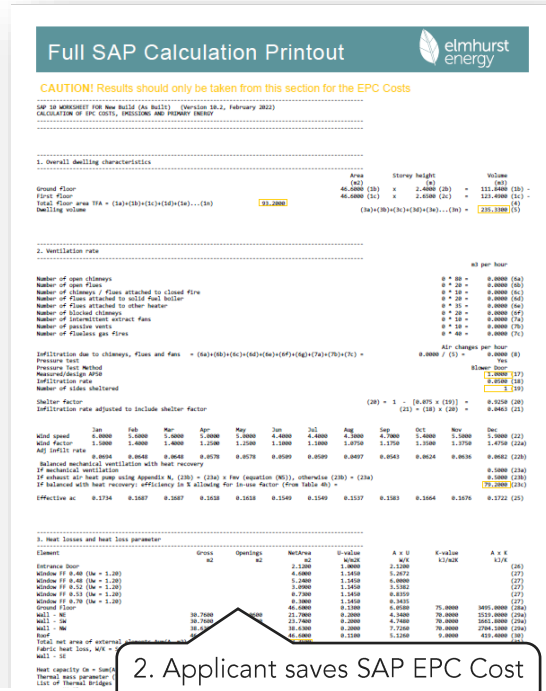
As a result of this approach, it typically takes less than ten minutes for a user to enter a dwelling into the SAP Conversion Tool and determine if it is policy compliant. The new tool also allows the user to adjust many key assumptions such as the airtightness, ventilation system, and heating systems, directly within the tool to test how these changes affect the dwelling's energy performance, without having to update the SAP calculations. This is expected to save applicants a substantial amount of time.



Space heating demand and total energy use predicted using Elmhurst's DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4 for a semi-detached house. The SAP Conversion Tool V2 results show excellent alignment with PHPP 10.4. Space heat demand is lower in PHPP mainly due to higher calculated solar gains specific to this dwelling.

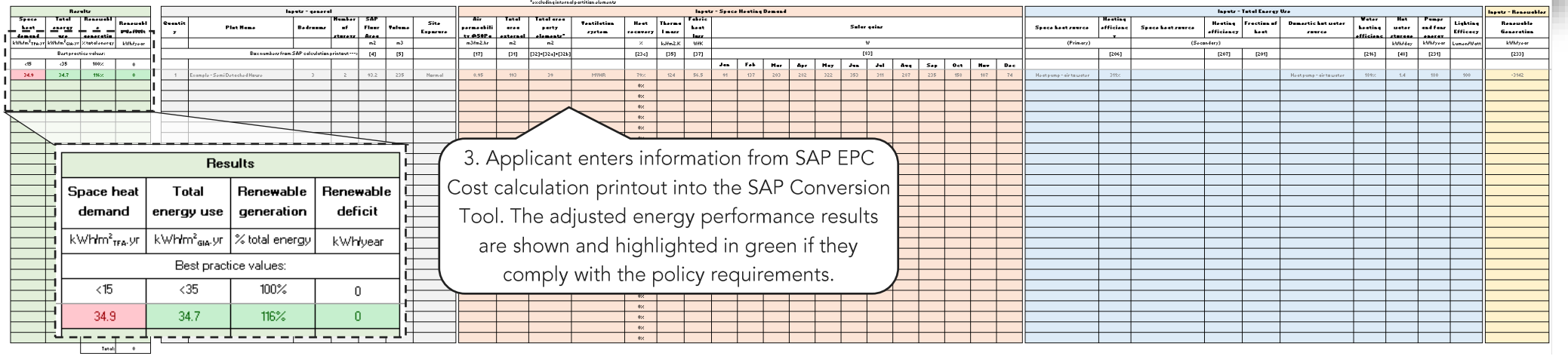
Executive Summary | How the tool works in practice





GMCA GREATER MANCHESTER COMBINED AUTHORITY Etude

SAP Conversion Tool V2.3



1.0

How could a conversion tool work?

This section explores:

- Building physics fundamentals
- The structure of SAP 10
- Potential adjustments that could produce more realistic results

Building Physics Fundamentals

The fundamental approach to calculating the energy flows within a building are similar between SAP 10.2, PHPP and other energy modelling software:

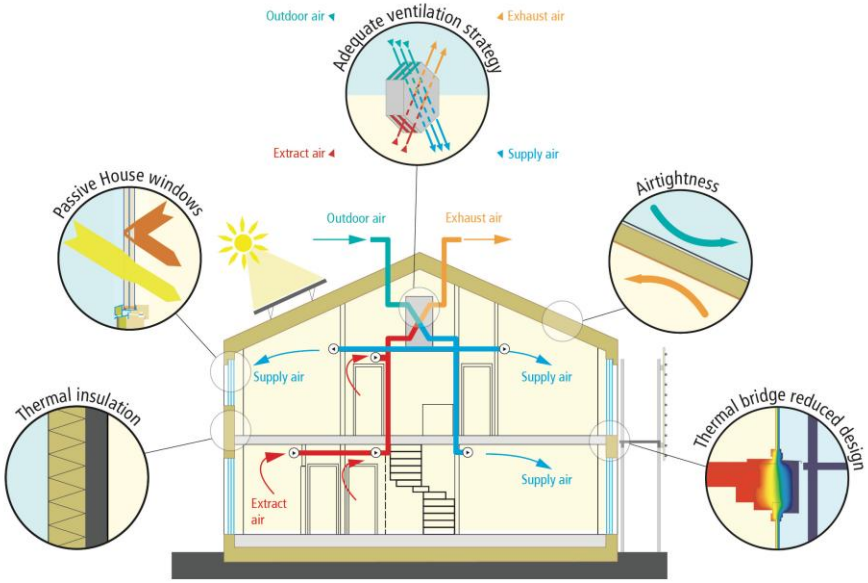
Space heating demand is usually assessed by separately calculating and summing up:

1. Transmission losses of the floors, walls, roofs, windows, doors and thermal bridges
2. Ventilation losses due to infiltration through leaks in the building and ventilation through fans or purpose built openings.
3. Internal heat gains from occupants, appliances, water heating, cooking, lighting, pumps, and fans.
4. Solar heat gains from glazed surfaces such as windows, doors and rooflights.

Water heating demand is calculated using assumptions on water use per occupant and combining this with the temperature difference between water entering the dwelling and delivered by the heat source.

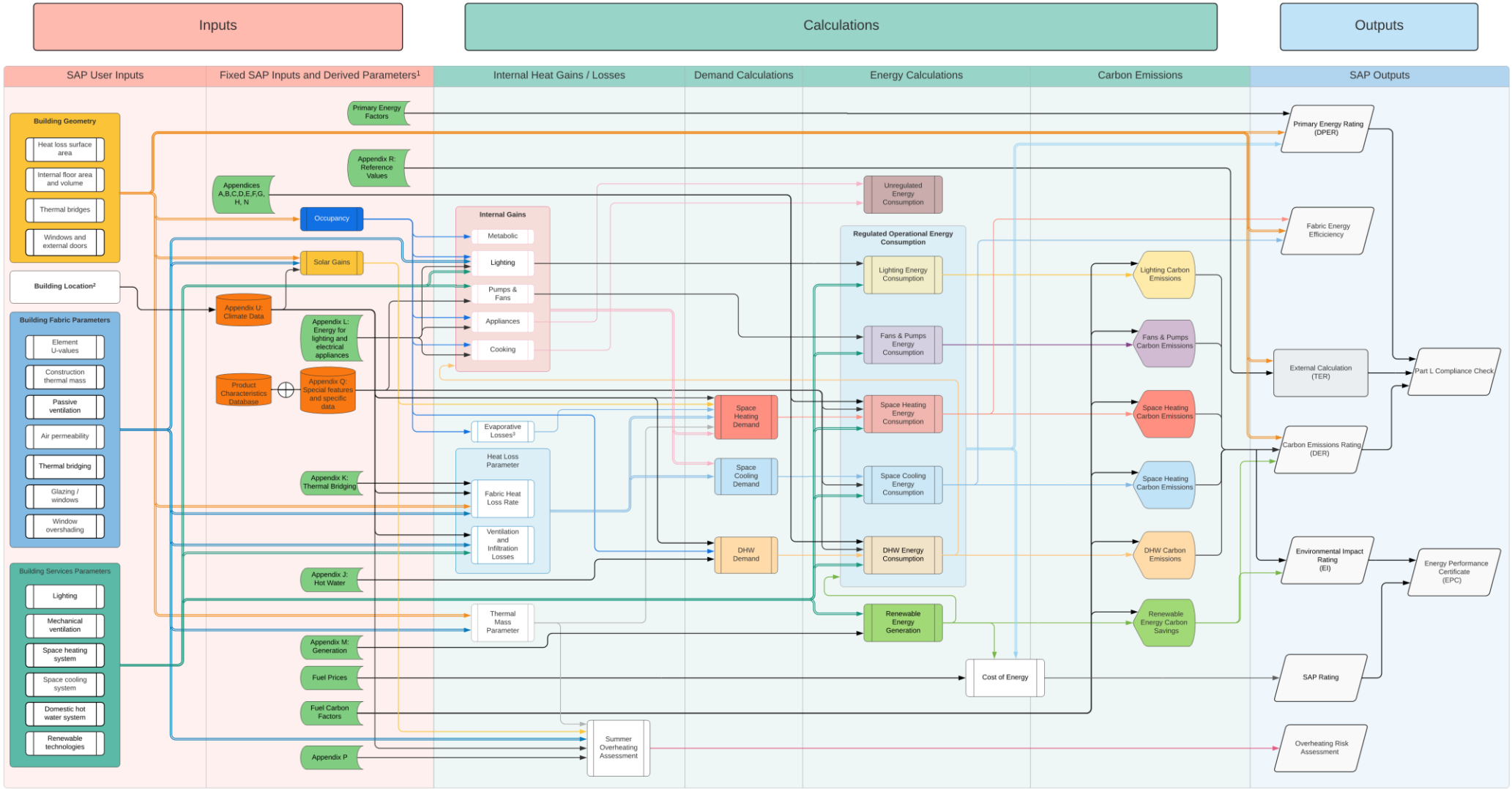
Final energy use for space heating and water heating is calculated by combining the space and water heating demand with the efficiency of the heat source.

Other energy use for appliances, cooking, lighting, and pumps and fans is calculated and added to the final energy use for space and water heating to provide the total energy use.



This diagram summarises the core elements of low energy building fabric: high levels of insulation, high performance doors and windows, thermal bridge free junctions, airtightness, and mechanical ventilation with heat recovery. Net zero policy compliant dwellings combine these principles with low carbon heating systems such as heat pumps, and renewable energy generation.
The SAP Conversion Tool applies targeted adjustments to the way many of these elements are modelled relative to SAP 10.2 to follow an approach that is similar to PHPP. Based on a range of post occupancy studies, this is expected to provide significantly more realistic results. © Passivhaus Institute

How could a conversion tool work? | Structure of SAP 10



Footnotes
1 SAP10 has further fixed inputs that are implicit to its various calculations, this column highlights key inputs and appendices.
2 Location input has an impact on overheating and PV energy generation. Calculations for compliance and ratings are based on UK average weather.
3 Includes losses associated with the heating of incoming cold water and evaporation.

This diagram summarises the core inputs, calculations and outputs present in SAP 10. The underlying principle used in the development of the SAP Conversion Tool V2 was that it is possible to apply a range of targeted adjustments to specific assumptions and parts of the calculations, to produce outputs that are similar to PHPP 10. © Etude, CIBSE, Levitt Bernstein, Elementa, WSP, Clarion Housing Group and UCL.

Space heat demand in SAP 10.2

The table below summarises key technical elements of SAP 10.2's space heat demand calculations, and proposes approaches for adjusting these calculations to be more representative of real-world performance, so they can be compared against the policy requirements. In addition to these specific elements, the internal temperature that is assumed in the energy calculations affects the predicted energy demand, so a different value could be used to adjust the calculation results.

	Element of Space Heating Demand	Notes on SAP 10.2 calculation	Could these be corrected?	Impact on output
Heat Losses	Floors, walls and roofs	Calculations are reasonably robust but oversimplification by SAP assessors is common. This may be an issue where construction build ups vary across a building or for certain shapes of building.	There is no simple way to address this in the conversion tool, however its impact in most homes will likely be negligible.	★
	Windows and doors	Calculations are reasonably robust but oversimplification by SAP assessors is common. Frame proportions and variations in window performance across a building are often overlooked or ignored.	There is no simple way to address this in the conversion tool. SAP assessors should be encouraged to enter calculated frame proportions to improve the accuracy of calculations.	★★
	Thermal bridging	Calculations are reasonably robust, though the methodology permits omission of some thermal bridges and in some cases default performance values can be used which may underestimate losses.	There is no simple way to address this in the conversion tool as differences are building-specific.	★
	Infiltration	Calculations are generally robust, however in SAP 10 a single factor is used to convert the measured air test result into an infiltration rate. This approach does not capture how sheltered or exposed a building is to the wind. SAP also applies fairly coarse allowances for additional infiltration through chimneys and flues.	The effect of the conversion is thought to be minimal in most low rise housing, but could be more important in highly sheltered or highly exposed buildings. It is possible to apply conversion factors to account for these.	★★
	Ventilation	SAP 10 assumes that ventilation rates for some systems are lower for less airtight dwellings. Allowance for air leakage from background ventilators is not consistently included. Modelling of mechanical ventilation with heat recovery is coarse.	It should be possible to recalculate ventilation losses using an approach that is similar to PHPP.	★★★
Heat Gains	Internal heat gains	SAP 10 significantly overestimates internal heat gains. This is partly due to assumptions around appliances, water heating, cooking, lighting, and occupancy patterns, some of which use outdated or very conservative assumptions.	It should be possible to apply an updated internal heat gain allowance that is based on more up to date assumptions and then recalculate the space heating demand.	★★★★
	Solar gains	A single shading value is assumed for the entire building in SAP 10. Depending on the building being modelled, this means solar gains are often under or overestimated.	It should be possible to apply an adjustment for the differences between SAP and PHPP climate files, and also apply a filter to prevent unrealistically high solar gains being included in the calculation.	★★

Total energy use in SAP 10.2

The table below summarises key aspects of SAP 10.2's final energy use outputs, and proposes approaches for adjusting these calculations to be more representative of real-world performance, so they can be compared against the policy requirements.

Energy Use Output	Notes on SAP 10.2 calculation	Could these be corrected?	Impact on output
Space Heating	In general, space heating is significantly underestimated due to issues explained on the previous page. For heat pumps, SAP 10 uses quite a conservative methodology and assumes a continuous heating profile, resulting in additional heat losses relative to other systems.	Correcting the space heating demand output as discussed on the previous page would help to address this. Calculating space heat demand consistently for all heating systems could remove current bias against heat pumps.	★★★★
Hot Water	SAP 10 uses a conservative methodology to calculate energy use for water heating, which is based on potentially outdated data. For example, proportions of showers are now much higher relative to baths than is assumed in SAP 10.	It should be possible to adjust the calculation output to allow for a lower hot water volume that is more representative of new homes and more similar to PHPP.	★★★
Pumps and fans	Pump and fan energy consumption could be overestimated in some cases, for example heat pumps where pump energy consumption is already included in heat pump efficiency test data. It could also be underestimated, for example allowances for boilers are typically low.	As there are various system specific differences and this likely has a relatively small effect on the overall energy use, it is not proposed to adjust these outputs in the SAP Conversion Tool.	★★
Appliances	Estimates of appliance energy use appear very conservative and are likely based on data for older less energy efficient appliances. Estimates may be skewed by inclusion of non-standard and very high energy using products.	The SAP Conversion Tool V2 can implement a similar approach to PHPP, by using a bottom-up calculation of appliance energy use that is based on modern appliance efficiencies.	★★★★★
Cooking	Somewhat conservative allowance, however this doesn't have a significant impact on the calculations.	No adjustment is proposed due to the small influence on results.	★★
Lighting	SAP 10.2 accepts inputs for lighting efficiency. Usage may be conservative but little impact overall due to lighting efficiency.	While lighting energy use is not expected to have a significant impact on the total energy use, it is straightforward to apply an updated calculation that is more similar to PHPP.	★

Renewable energy generation in SAP 10.2

The table below summarises key aspects of SAP 10.2's renewable energy generation outputs, and proposes approaches for adjusting these calculations to be more representative of real-world performance, so they can be compared against the policy requirements.

Energy Use Output	Notes on SAP 10.2 calculation	Could these be corrected?	Impact on output
Solar irradiation data	SAP's EPC Cost calculation outputs for solar generation use regional solar irradiation data, which is more accurate than other calculation outputs such as the Dwelling Emission Rate, which use a national average value.	As the climate regions used by SAP 10.2 are quite large, more accurate solar irradiation data could be used for the specific location of the dwelling, however this would not be straightforward to build into the SAP Conversion Tool. A practical solution to this could be to allow solar generation estimates produced by solar installers using bespoke solar performance software to be submitted as evidence of policy compliance.	★★★
Performance factor	SAP assumes a fixed performance factor of 80%, which is conservative for modern solar technology.	The SAP Conversion Tool V2 can use a performance factor that is more representative of modern solar technology.	★★
Overshading factor	SAP relies on a fairly coarse user-defined input for overshading, which allows solar generation to be reduced by 0%, 20%, 50%, 65% or 80%.	As with the solar gains used to calculate space heating demand, there is no obvious way to improve the accuracy of overshading estimates for solar arrays. A practical solution to this could be to allow solar generation estimates produced by solar installers using bespoke solar performance software to be submitted as evidence of policy compliance.	★★★

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Approach to energy modelling

This section explains our approach to the brief:

- Approach to energy modelling
- The eight performance scenarios
- The four building types

Software

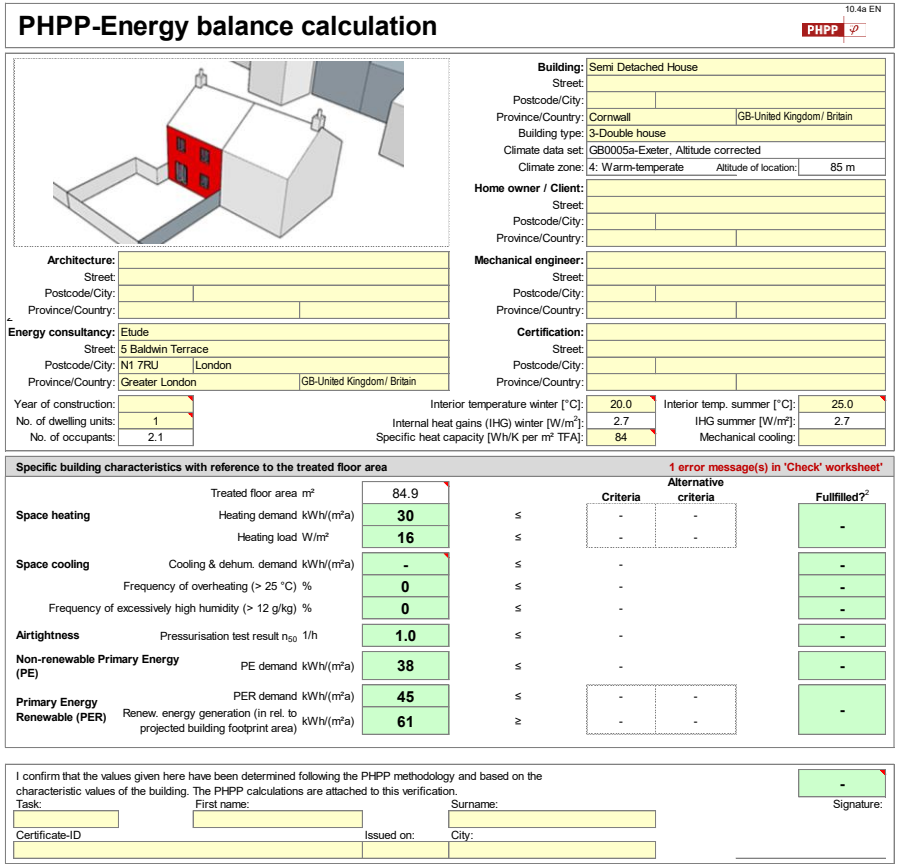
We modelled the performance of several dwellings in **Elmhurst DesignSAP** to provide a baseline set of Part L SAP 10 calculations. Due to the importance of these calculations in calibrating the SAP Conversion Tool V2, more attention to detail was applied than would be typical for a normal SAP calculation. For example, the frame factors were calculated for each individual window.

The same dwellings were then modelled in **PHPP 10.4** and **DesignPH 2.1.15** to provide a set of indicative 'real-world' energy performance figures. PHPP was used for this on the basis that post occupancy studies* have consistently shown it can provide reliable predictions of a building's space heating demand and total energy use. The PHPP results were then used to calibrate the SAP Conversion Tool V2.

DesignPH was used in combination with PHPP to provide more accurate shading analysis, based on a 3D model of the building, its openings, and some allowance for typical surrounding objects.

We carried out thermal bridge modelling using **PSI-Therm 6** to provide two sets of thermal bridge performance values using LABC details for a beam and block floor with masonry cavity wall construction and insulation at ceiling level. One of these sets is based on internal dimensions, and was used in DesignSAP. The other set was based on external dimensions, and was used in PHPP. Each individual PSI-value was selected by interpolating between a best and worst case U-value for the adjacent floor/wall/roof elements, with the best and worst case U-values based on the range permitted under Part L 2021. Appendix A provides further information.

We have also used the European Commission's PVGIS tool to calibrate solar generation calculated by PHPP.



PHPP-Energy balance calculation (10.4a EN)

Building:	Semi Detached House				
Street:					
Postcode/City:					
Province/Country:	Cornwall	GB-United Kingdom/ Britain			
Building type:	3-Double house				
Climate data set:	GB0005a-Exeter, Altitude corrected				
Climate zone:	4: Warm-temperate	Altitude of location:	85 m		
Home owner / Client:					
Street:					
Postcode/City:					
Province/Country:					
Architecture:					
Street:					
Postcode/City:					
Province/Country:					
Mechanical engineer:					
Street:					
Postcode/City:					
Province/Country:					
Energy consultancy:	Etude				
Street:	5 Baldwin Terrace				
Postcode/City:	N1 7RU	London			
Province/Country:	Greater London	GB-United Kingdom/ Britain			
Certification:					
Street:					
Postcode/City:					
Province/Country:					
Year of construction:		Interior temperature winter [°C]:	20.0	Interior temp. summer [°C]:	25.0
No. of dwelling units:	1	Internal heat gains (IHG) winter [W/m²]:	2.7	IHG summer [W/m²]:	2.7
No. of occupants:	2.1	Specific heat capacity [Wh/K per m² TFA]:	84	Mechanical cooling:	

Specific building characteristics with reference to the treated floor area — 1 error message(s) in 'Check' worksheet'

					Criteria	Alternative criteria	Fullfilled?[2]
	Treated floor area	m²	84.9				
Space heating	Heating demand	kWh/(m²a)	30	≤	-	-	-
	Heating load	W/m²	16	≤	-	-	
Space cooling	Cooling & dehum. demand	kWh/(m²a)	-	≤	-		-
	Frequency of overheating (> 25 °C)	%	0	≤	-		-
	Frequency of excessively high humidity (> 12 g/kg)	%	0	≤	-		-
Airtightness	Pressurisation test result n_{50}	1/h	1.0	≤	-		-
Non-renewable Primary Energy (PE)	PE demand	kWh/(m²a)	38	≤	-		-
Primary Energy Renewable (PER)	PER demand	kWh/(m²a)	45	≤	-	-	-
	Renew. energy generation (in rel. to projected building footprint area)	kWh/(m²a)	61	≥	-	-	

I confirm that the values given here have been determined following the PHPP methodology and based on the characteristic values of the building. The PHPP calculations are attached to this verification. -

Task:	First name:	Surname:	Signature:
Certificate-ID	**Issued on:**	**City:**	

PHPP 10.4 was used to model expected real-world energy performance of the four dwelling types.

*Examples include the CEPHEUS project and Mitchell, R and Natarajan, S (2020) *UK Passivhaus and the energy performance gap.* Energy and Buildings. Vol 224

Climate

One reason SAP results are less suitable for assessing local policy compliance is that some outputs are based on UK average, rather than local, weather conditions. Table 1 summarises the weather data used for different outputs in SAP 10.2.

Output	Weather Data
Dwelling Emission Rate	UK Average
Fabric Energy Efficiency	UK Average
Energy Rating	UK Average
Energy Performance Certificate Costs	Local

Table 1 – Weather data used for different SAP 10.2 outputs

The SAP Conversion Tool has therefore been developed using Energy Performance Certificate outputs and **it is important that users of the tool also use the Energy Performance Certificate SAP outputs**.

To further account for possible impacts of climate zone between SAP and PHPP, we have modelled the performance of the test dwellings in SAP climate zone: 7 West Pennines to cover the policy area for GMCA.

PHPP modelling carried out to develop the conversion tool also used local weather data, and the building altitudes were set to match the representative heights indicated in the SAP 10.2 manual, shown in the adjacent table. A decision was made to avoid adding an altitude correction to the SAP Conversion Tool V2 space heating demand calculation at this time, to avoid additional complexity.

Table U4: Representative latitude and height above mean sea level

Region	Representative Latitude (°N)	Representative height above sea level (m)
0 **UK average**	**53.5**	**79**
1 Thames	51.6	53
2 South East England	51.1	55
3 Southern England	50.9	50
4 South West England	50.5	85
5 Severn Wales / Severn England	51.5	99
6 Midlands	52.6	116
7 West Pennines Wales / West Pennines England	53.5	71
8 North West England / South West Scotland	54.6	119
9 Borders Scotland / Borders England	55.2	101
10 North East England	54.4	78
11 East Pennines	53.5	79
12 East Anglia	52.1	29
13 Wales	52.6	138
14 West Scotland	55.9	113
15 East Scotland	56.2	117
16 North East Scotland	57.3	123
17 Highland	57.5	218
18 Western Isles	57.7	59
19 Orkney	59.0	53
20 Shetland	60.1	50
21 Northern Ireland	54.6	72

Table U4 from the SAP 10.2 manual indicates that different heights above sea level are assumed for different climate regions. These assumptions have been replicated in PHPP modelling to develop the SAP conversion tool.

Building types

Four types of building that are typical for new developments in GMCA were selected: a terraced house, semi-detached house, a detached house, and a bungalow. Testing a selection of building types was important to ensure that the SAP Conversion Tool functions correctly across buildings with different attributes.

Heat Loss Form Factor

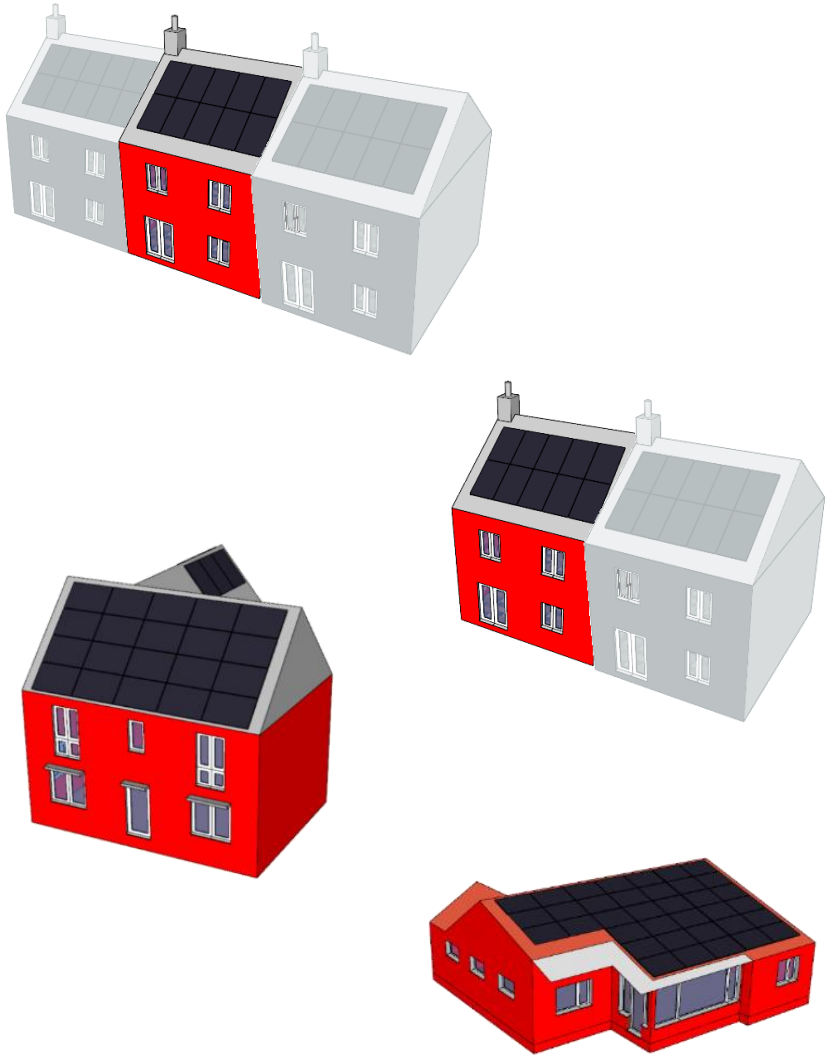
The heat loss form factor, often abbreviated to 'form factor', is the ratio of a building's heat loss area to its internal floor area. Buildings with a high form factor generally require higher levels of insulation and airtightness to reduce heat loss. They may also have greater thermal bridging if their form is more complex. The dwellings modelled covered a wide range of form factors, from 2.2 for the terraced house, to 4.4 for the bungalow.

Potential for Solar PV

The amount of roof area that is suitable for solar PV panels varies across different types of buildings. Single storey buildings such as bungalows typically have a large amount of roof area relative to their energy needs, whereas taller buildings with more complex roof shapes may have less area. The buildings modelled represented a range of roof designs.

Orientation

Limited sensitivity testing was carried out for building orientation. Due to the relatively modest glazing proportions, it was not found to have a significant impact on the space heating demand or total energy use. While renewable energy generation did vary with orientation, all dwellings had more than enough roof area to achieve a net zero energy balance regardless of orientation.



A terraced house, semi-detached house, detached house, and bungalow were modelled. With the exception of the bungalow, these were based on recent designs from large developers.

Eight scenarios, summarised below, were modelled to represent the range of performance specifications that will likely be used with the SAP Conversion Tool. More detailed tables of assumptions used in the modelling are provided later in this report. In developing our assumptions, we have tried to adopt the mindset of a developer, i.e. finding the simplest and most economic ways of complying with the policy requirement.

Part L 2021 – Insulation – Gas Boiler

This scenario is based on the Part L 2021 notional building. We assume air permeability of 5m^3/m^2hr @50Pa and ventilation is achieved mechanically without heat recovery. Part L compliance is achieved by use of waste water heat recovery and solar PV. A gas boiler is assumed to provide all heating. While buildings with gas boilers are not compliant with modern net zero planning policies, it is important to understand and test the performance of such buildings to ensure the SAP Conversion Tool V2 is able to successfully differentiate them from other buildings.

Part L 2021 – Insulation – Direct Electric

This scenario assumes use of direct electric heating for space and water heating, meaning the building is fossil fuel free. The building's fabric otherwise remains the same as for the previous case.

Part L 2021 – Airtightness – Direct Electric

This scenario also assumes direct electric heating, but the airtightness is improved, allowing levels of insulation to be reduced while still maintaining compliance with Part L.

Part L 2021 – Insulation – Heat Pump

This scenario is the same as the insulation led direct electric scenario, except use of a heat pump means a smaller solar PV array is required to achieve a net zero energy balance.

Part L 2021 – Airtightness – Heat Pump

This scenario is the same as the airtightness led direct electric scenario, except use of a heat pump means a smaller solar PV array is required to achieve a net zero energy balance.

Future Homes Standard

This scenario is based on the Future Homes Standard notional building option 2 specification from the most recent public consultation. Effectively the fabric, airtightness and ventilation is the same as Part L 2021, but a heat pump is added. Solar PV was also added in this scenario, based on a 6 June 2025 statement from government confirming intent for mandatory solar on new homes. The amount of solar is based on the formula provided in FHS consultation option 1, where the system's nominal capacity in kilowatts peak equal to 40% x ground floor area 4.5.

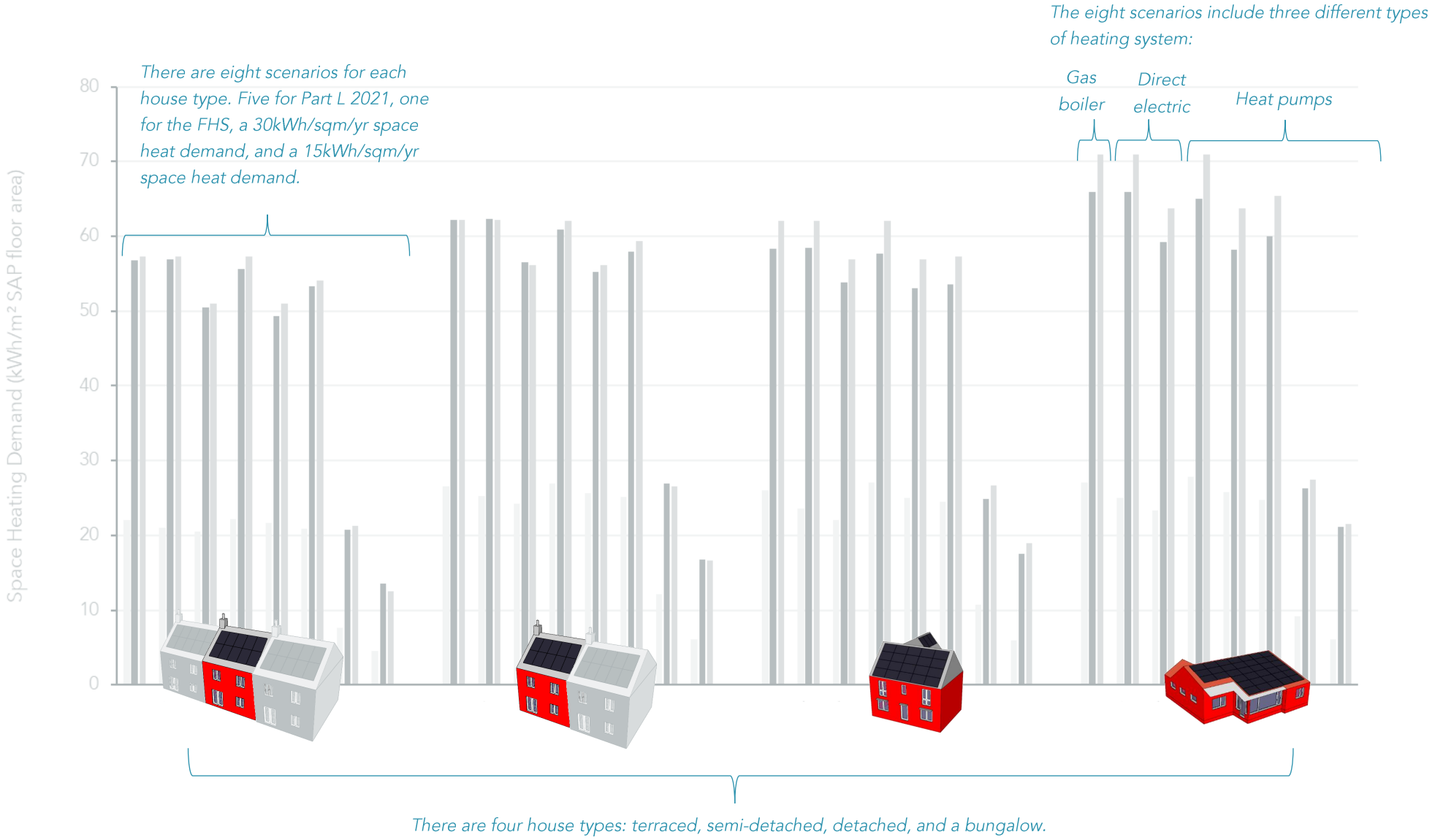
Low Carbon

This scenario uses a Part L 2021 compliant fabric specification, with an improved air permeability of 1m^3/m^2hr @50Pa, and use of heat recovery ventilation to achieve a space heat demand of ≤30$kWh/m^2/yr$. Space heating and water heating is provided by a heat pump, which achieves a total energy use of ≤40$kWh/m^2/yr$. Sufficient solar PV has been installed to achieve a net zero energy balance on site.

'Truly Affordable Net Zero' (TANZ)

This scenario represents GMCA's policy definition of 'Truly Affordable Net Zero', with space heat demand in the ≤15-20$kWh/m^2/yr$ range, and total energy use ≤35$kWh/m^2/yr$. Sufficient solar PV has been installed to achieve a net zero energy balance on site.

Energy modelling | Results Layout



Energy modelling results in the following two sections are generally presented as graphs like the example above. Energy flows are presented primarily as groups of three columns for DesignSAP, SAP Conversion Tool V2, and PHPP results. These are then grouped into eight sets of columns for the different performance scenarios. Finally, there are four sets of each group of performance scenarios – one for each house type.

3.0

Approach to adjusting SAP space heating demand

This section explains how adjustments are applied to key SAP outputs in the SAP Conversion Tool to produce space heating demand results that are more similar to PHPP.

Introduction

Heating energy calculations for buildings estimate the heat flows out of the building (losses) and into the building (gains). These calculations are usually carried out for a given set of internal and external temperatures. The difference between the heat losses and gains is called the space heating demand, which is the energy that the heating system must provide to maintain the desired internal temperature.

Greater Manchester Combined Authority's planning policies include guidance that encourages space heating demand equal to or less than 15 kWh/m²/yr. The SAP Conversion Tool needs to be able to accurately determine whether a dwelling performs at this level.

Heat flows out of a home (losses)

The main heat flows out of a home are **transmission losses** through the floor, walls, roof, windows, doors, and thermal bridges, **infiltration losses** due to the leakiness of the building, and **ventilation losses** due to the home's ventilation system.

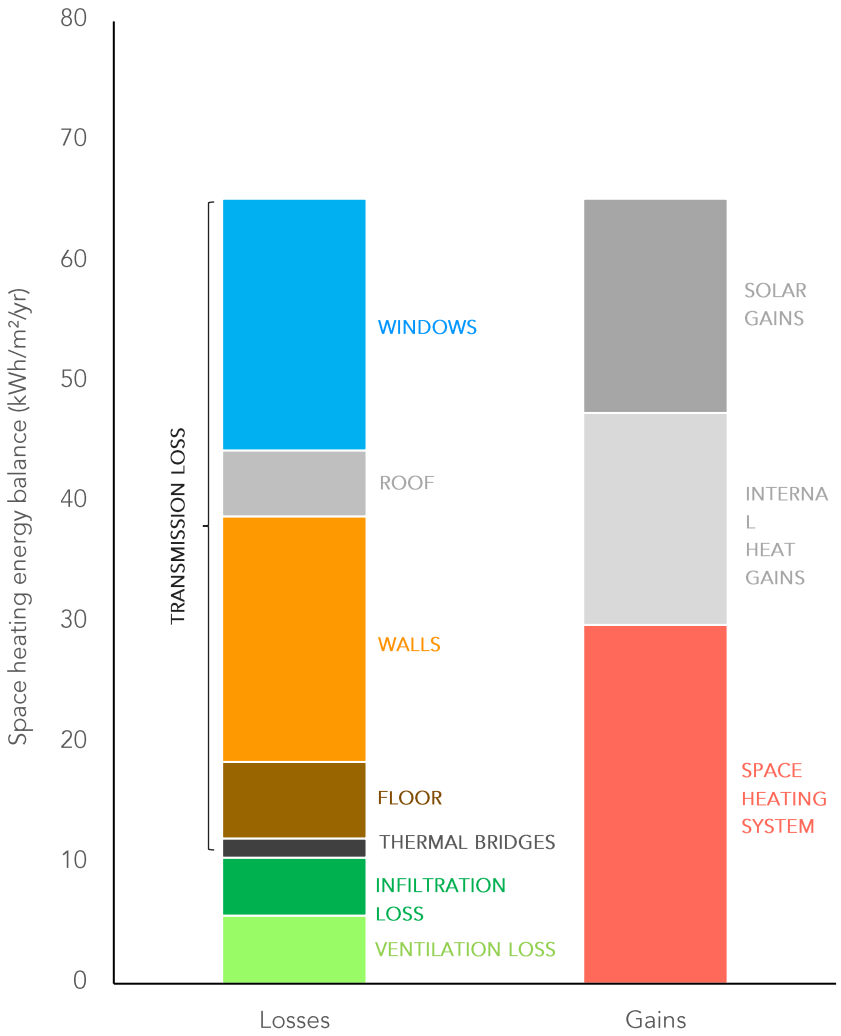
Relative to PHPP, SAP 10.2 provides fairly good estimates of the thermal performance of building elements that affect the transmission losses, reasonable estimates of infiltration losses and inconsistent estimates of ventilation losses.

Heat flows into a home (gains)

The main heat flows into a home are **solar gains** through the building's fabric, **internal heat gains** due to occupants and building systems, and energy from the **space heating system**.

SAP 10.2 provides coarse estimates of solar gains and very optimistic estimates of internal heat gains. This often results in very low estimates of the amount of space heating energy that is required to achieve the desired internal temperature.

The following pages consider individual elements of the space heating demand calculation in more detail.



Typical space heating energy balance for a net zero home with a space heat demand of just under 30 kWh/m²/yr. SAP 10.2 provides reasonable estimates of the thermal performance of floors, walls, roofs, windows, and thermal bridges, and a coarse estimate of solar heat gains. Other parts of the calculation are not as useful for estimating real-world energy performance.

SAP 10 calculation of floor area and volume

Floor area in SAP 10.2 is calculated by including all accessible floor area within the heated envelope. This includes areas occupied by stairs, cupboards, and the area occupied by internal walls.

The internal volume is calculated by multiplying the SAP floor area by the storey height, which generally includes the depth of any intermediate floors.

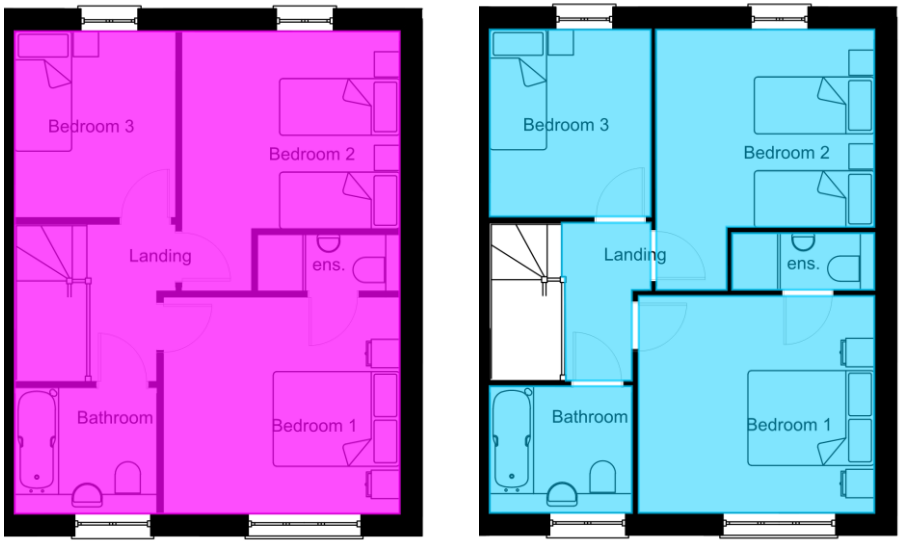
How reliable is the approach in SAP 10?

The definition of floor area used for energy calculations is to some extent arbitrary, ie there is nothing inherently right or wrong about the approach used in SAP versus other software. The floor area measured for PHPP calculations does not include areas occupied by stairs or internal walls, and so is generally smaller.

The definition of internal volume is more important. SAP generally provides an estimate of internal volume that is likely to be higher than the actual volume of internal conditioned air present, due to the inclusion of internal walls and intermediate floors in the volume calculation. This could mean that the volume of air movement due to infiltration and ventilation is overestimated in SAP 10 relative to a calculation that does not include these volumes.

SAP Conversion Tool calculation

The SAP Conversion Tool V2 reduces the SAP floor area by 8%, which for the test dwellings was a typical average amount that was occupied by internal walls and stairs. This means the specific space heat demand per square meter of floor area will be closer to the value reported by PHPP. This adjustment also reduces the internal volume of the dwelling. The internal volume is further reduced by subtracting a volume that is 300mm deep for each intermediate floor, applied to the average floor area for each storey. These adjustments result in a volume that is more similar to the volume that would be assumed in a PHPP calculation.



SAP 10.2 (left) and PHPP 10.4a (right) have different conventions for measuring floor area. The exclusion of internal walls, permanently boxed in areas, stairs, and areas under 1m in height means the floor area used for PHPP calculations was typically about 8-10% lower than SAP for the homes modelled during development of the SAP Conversion Tool.

Approach to Adjusting SAP Space Heating Demand | Internal Temperature

SAP 10 calculation of internal temperature

The mean internal temperature for each month is calculated by SAP 10 based on the dwelling's heating source, heating controls, assumed heating pattern, assumed temperature set points, thermal mass, and heat loss parameter. For the dwellings modelled, this typically resulted in area weighted temperatures around 19-20.5˚C during the heating season.

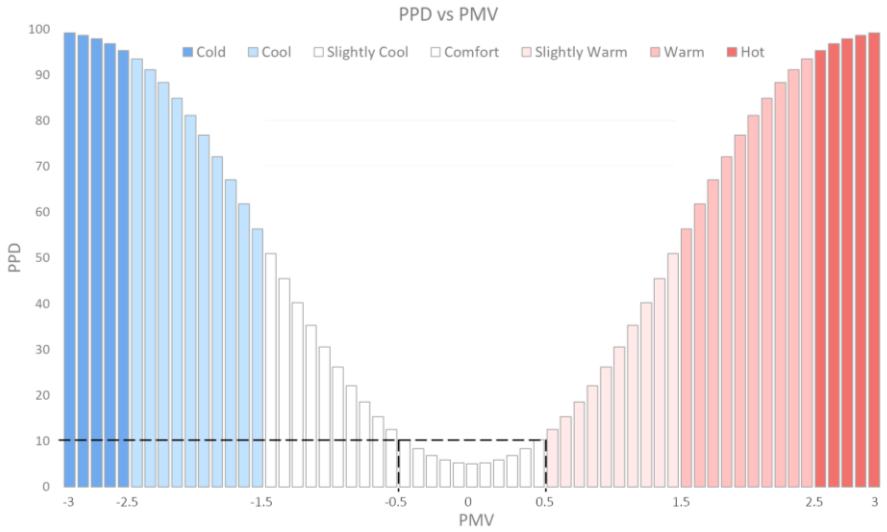
How reliable is the approach in SAP 10?

A variety of studies suggest the temperatures assumed in SAP 10 may be slightly lower than typical values for new buildings, however many of these studies were based on quite small sample sizes.

- Bruce-Konuah et al (2023) – 21.2-21.4˚C
- Oreskovic (2022) – Mean living room temp 20.8˚C, bedroom 20˚C
- McGill et al (2017) – Mean living room 21.6˚C, bedroom 20.6-21.4˚C
- McGill et al (2015) – Average 20.4˚C
- Marmot Review (2011) – 19.5˚C for post 1980 dwellings

SAP Conversion Tool calculation of internal temperature

The SAP Conversion Tool V2 follows BS EN ISO 16798-1, which requires a default design value of at least 20˚C to be assumed for the indoor operative temperature. This is based on achieving <10% on the predicted percentage of dissatisfied index, a level often used by CIBSE and the building regulations. PHPP also assumes a constant 20˚C internal temperature, and so using the same value should result in SAP Conversion Tool V2 outputs that are similar to PHPP.



The predicted percentage dissatisfied index provides an estimate of how many occupants in a space would feel dissatisfied with the thermal comfort. BS EN ISO 16798-1 suggests assuming a 20˚C internal temperature, to ensure that <10% of occupants are dissatisfied with the temperature. © simulationHub

SAP 10 calculation of transmission losses

SAP 10.2 calculates transmission heat losses by combining:

1. Areas of floors, walls, roofs, windows and doors with their thermal performance.
2. Lengths of thermal bridges with their thermal performance.

The sum of these values is combined into a single figure called the **total fabric heat loss**. This is a measure of the transmission heat losses that are expected per degree difference in temperature between inside and outside the home.

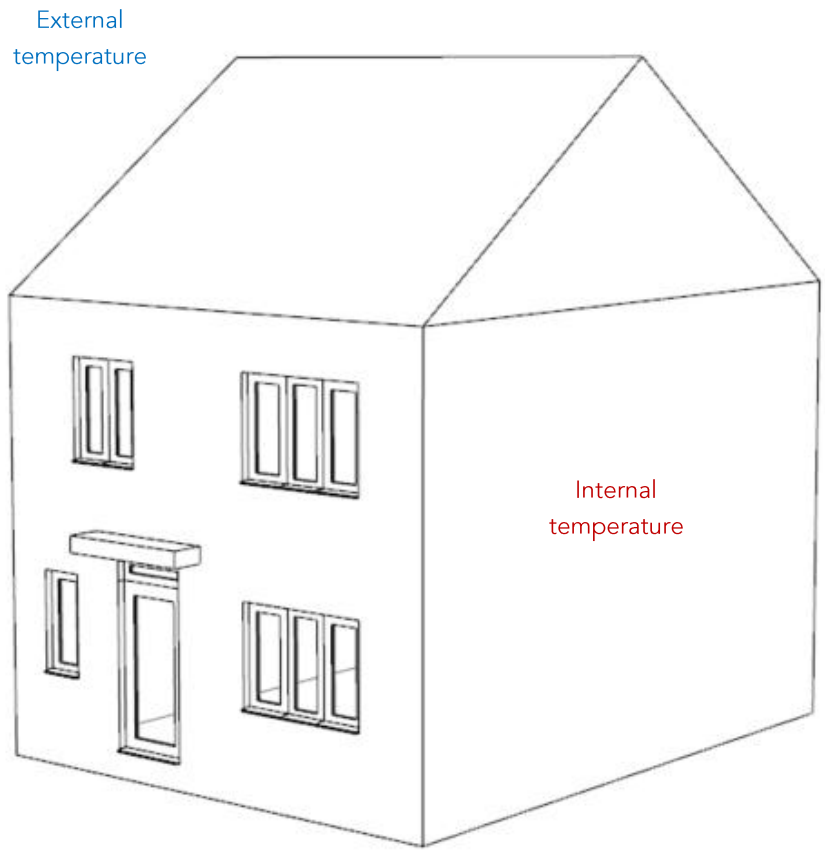
How reliable is the approach in SAP 10?

The total fabric heat loss calculated by SAP should be fairly reliable, however it is subject to some uncertainty as more complex types of thermal bridging may be ignored, and the thermal performance of building elements may be different to what is assumed in the software due to construction quality issues.

The conversion tool does not attempt to adjust for these issues as there is no straightforward solution. Enforcement of existing building regulations on site is likely the main practical solution.

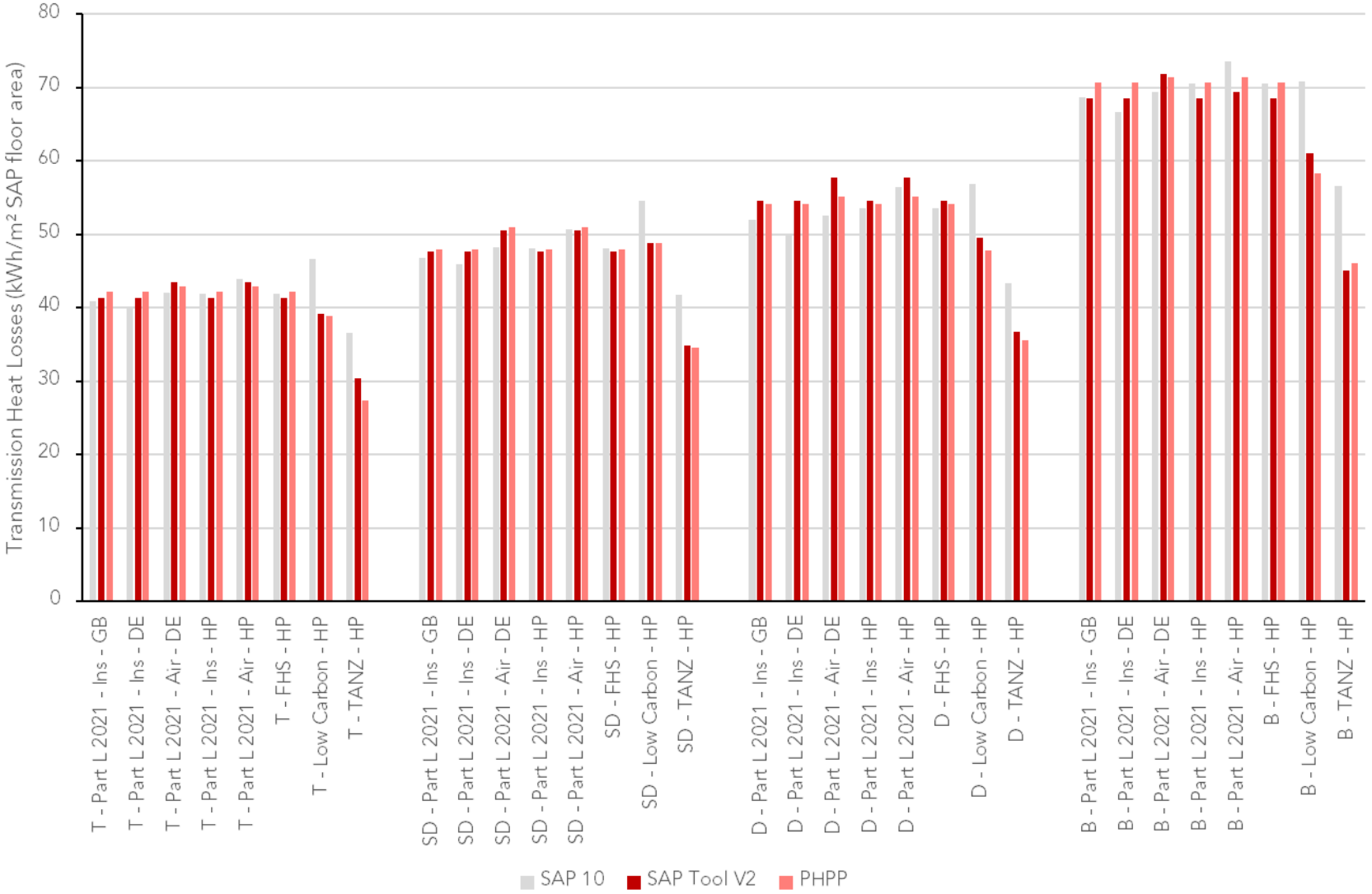
SAP Conversion Tool calculation of transmission heat losses

The SAP Conversion Tool uses a similar approach to SAP 10, by combining the total fabric heat loss with the assumed monthly average internal and external temperatures to calculate the transmission heat loss. Differences in the SAP Conversion Tool include the use of a constant internal temperature of 20°C and the application of a 1% increase to transmission losses. Additionally, the omission of transmission losses in summer months with low space heat demand (explained at the end of this section) reduces transmission losses for the most efficient scenarios to a similar amount to PHPP.



Wireframe image of the semi-detached home used for developing the SAP Conversion Tool. SAP calculations require reasonably accurate input of the various heat loss areas, thermal bridge lengths, and their thermal performance. These are combined into a single figure called the total fabric heat loss, which is used by the SAP Conversion Tool as the foundation for its heating energy balance calculations.

Approach to Adjusting SAP Space Heating Demand | Transmission Losses



Transmission losses calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Transmission losses calculated by the SAP Conversion Tool are very similar to PHPP 10.4a. The main differences are due to assuming a constant 20°C internal temperature and reducing the heating season length for the most efficient dwellings, which reduces transmission losses relative to SAP 10 for the two scenarios with the highest levels of fabric efficiency.

SAP 10 calculation of infiltration losses

SAP 10.2 calculates infiltration losses by applying the 'divide by 20' rule to the air permeability measured at 50Pa. A slightly different approach is used if the airtightness has been determined via a pulse test.

How reliable is the approach in SAP 10?

Infiltration heat loss calculations, particularly using simplified approaches, can be quite inaccurate as infiltration in practice depends on pressure differences caused by local weather conditions, building height, and other factors. The approach used in SAP 10.2 is not clearly better or worse than the approach used in PHPP. The 'divide by 20' rule was developed to be used with airtightness however, rather than air permeability test results. Additionally, while a shelter factor is included for adjacent buildings, it does not account for the general level of site exposure.

SAP Conversion Tool calculation of infiltration losses

The SAP Conversion Tool carries out its own infiltration heat loss calculation using the same approach as PHPP 10, which is based on ISO 13790:2004 (this has since been superseded by ISO 52016-1:2017).

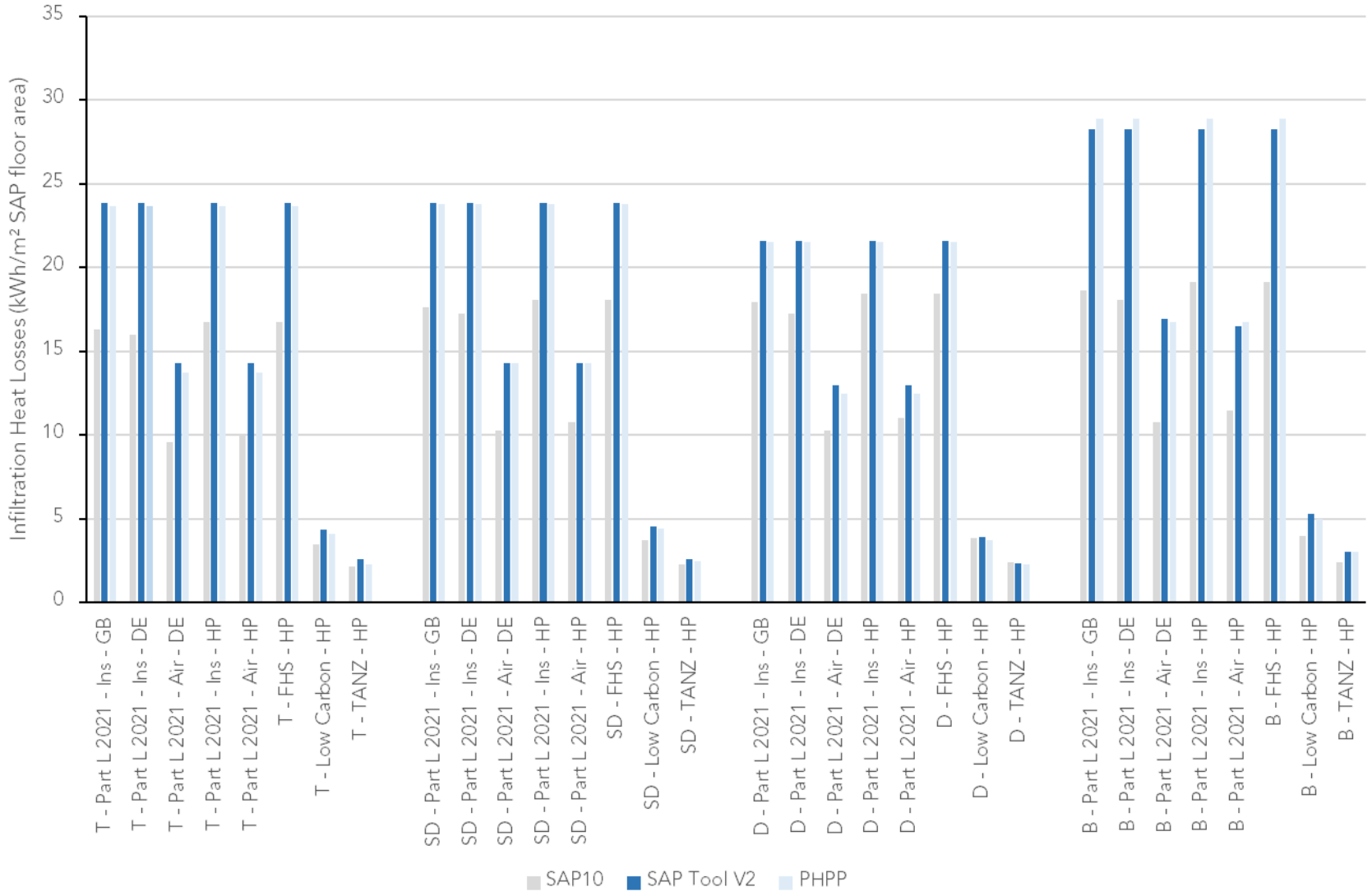
In order to do this, the air permeability test result input to SAP is converted into an airflow rate using the dwelling envelope area from SAP. This airflow rate is then divided by the n50*, which is estimated in the SAP Conversion Tool by taking the dwelling internal volume and subtracting an allowance for the volume of internal walls and floors. This assumes that internal walls occupy 8% of the dwelling's floor area and intermediate floors are 300mm deep. Dividing the airflow rate by the n50* provides the airtightness, which is then input to the infiltration calculation. Finally, the user must select the site's exposure.

**the n50 is the volume of air that is assumed to be heated or cooled.*



Part L 2021 requires that the air permeability of all new dwellings is measured once construction is complete using a blower door (see above) or pulse test. At design stage, when the SAP Conversion Tool is being used, SAP assessors would typically use an assumed air permeability value for their calculations. The SAP Conversion Tool calculates infiltration losses directly from this assumed air permeability value, and provides instant feedback in terms of how this affects the energy performance of the dwelling.

Approach to Adjusting SAP Space Heating Demand | Infiltration Losses



Infiltration losses calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Infiltration losses calculated by the SAP Conversion Tool are very similar to PHPP 10.4a as the same approach is implemented.

SAP 10.2 calculation of ventilation losses

SAP assumes a fixed baseline ventilation rate of 0.5 air changes per hour for all ventilation systems. This figure is then adjusted in one of three different ways, depending on the dwelling's infiltration rate and the type of ventilation system, as shown in the adjacent graph. For systems with heat recovery, the ventilation rate is further adjusted based on the efficiency of the heat exchanger to represent an effective air change rate.

The modified ventilation rate is then combined with the monthly average internal and external temperatures to calculate ventilation heat loss.

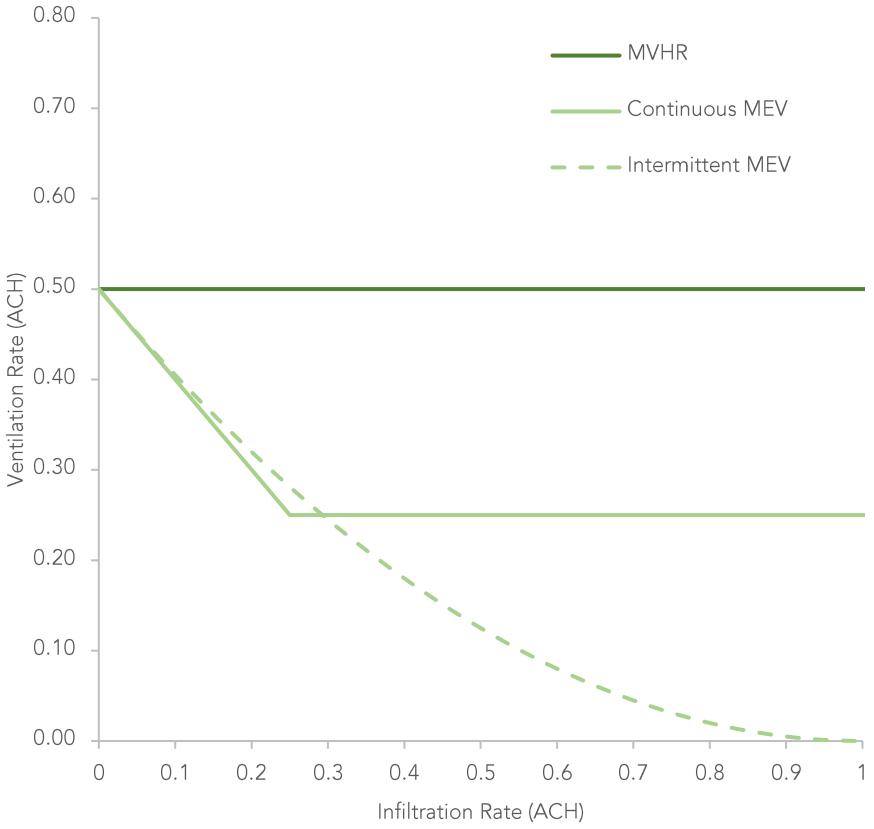
How reliable is the approach in SAP 10?

The manipulation of ventilation rates in SAP 10.2 is intended to represent user control of the ventilation system, for example closing of background ventilators in less airtight dwellings. As this is not assumed in PHPP, it leads to differences in calculated heat loss between the two software.

Part F ventilation rates are typically between 0.45 and 0.55 air changes per hour while ventilation rates for Passivhaus buildings are typically 0.30 - 0.45 air changes per hour. Part F states that background ventilators should normally be left open. This suggests the ventilation rates assumed in SAP 10 are lower than required by Part F, or typically assumed in PHPP, for some dwellings, which could result in underestimation of ventilation losses.

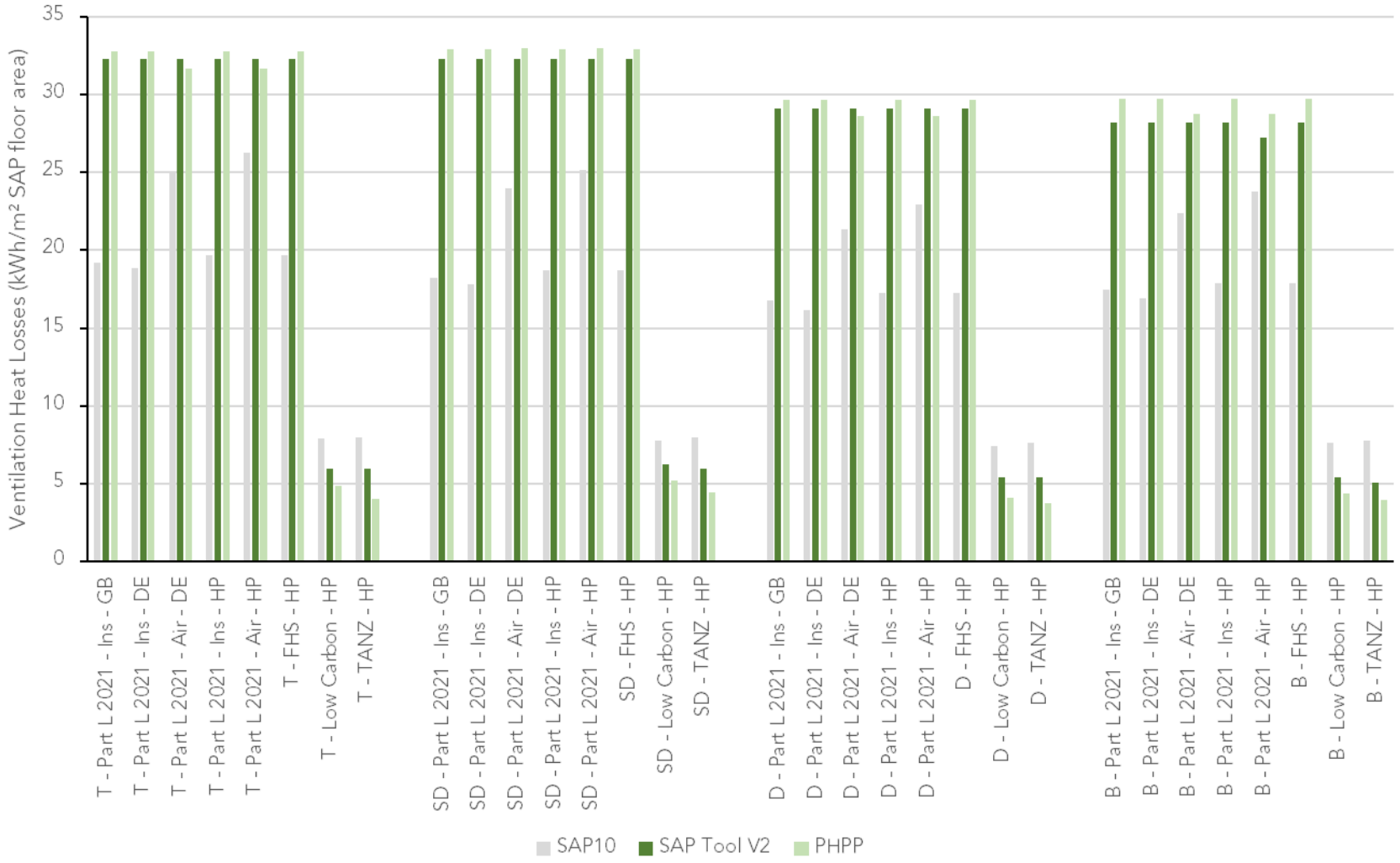
SAP Conversion Tool calculation of ventilation losses

The SAP Conversion Tool calculates the Part F minimum continuous ventilation rate for the home, based on the floor area and number of bedrooms. No additional allowance for background ventilators is included, however use of the Part F ventilation rate is expected to be conservative. If heat recovery ventilation is present, the system heat recovery efficiency is taken from SAP 10 and used to calculate an effective air change rate. This is then combined with the monthly average internal and external temperatures to calculate ventilation heat loss.



SAP 10.2 assumes ventilation rates for intermittent and mechanical extract systems reduce as infiltration increases. The SAP Conversion Tool assumes that ventilation rates consistently meet Part F minimum ventilation rates. This is a conservative assumption for intermittent extract systems, but can be interpreted as providing additional allowance for background ventilators, which are assumed to normally be left open.

Approach to Adjusting SAP Space Heating Demand | Ventilation Losses



Ventilation losses calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Ventilation losses calculated by the SAP Conversion Tool are very similar to PHPP 10.4a as the same approach is implemented. For less airtight dwellings, ventilation losses are generally much higher than would be calculated in SAP 10 as it is assumed that background ventilators remain open at all times, in line with Part F.

SAP 10 calculation of internal heat gains

Internal heat gains are an important part of the space heating demand calculation. The amount of available internal heat gains are a product of:

1. Initial amount of energy available to become internal heat gains. This is due to waste heat emitted from occupants, appliances, water heating, cooking, lighting, pumps and fans, and evaporation.
2. Availability of this energy to subsequently become useful internal heat gains. For example, a lot of the energy within hot water is lost down the drain before it can become useful heat gains within the dwelling.

How reliable is the approach in SAP 10?

SAP 10 is known to overestimate internal heat gains, and this is one of the main reasons why the space heat demand figures are usually lower than calculated in PHPP, or would be expected in reality. The main causes for this are the assumptions around occupancy, appliances, water heating, and to a lesser extent cooking, lighting, pumps and fans. In general, internal heat gains are inflated and based on older less efficient systems, with quite high assumptions for their availability. According to our analysis it is likely that this overestimation will be greater in smaller homes.

SAP Conversion Tool calculation of internal heat gains

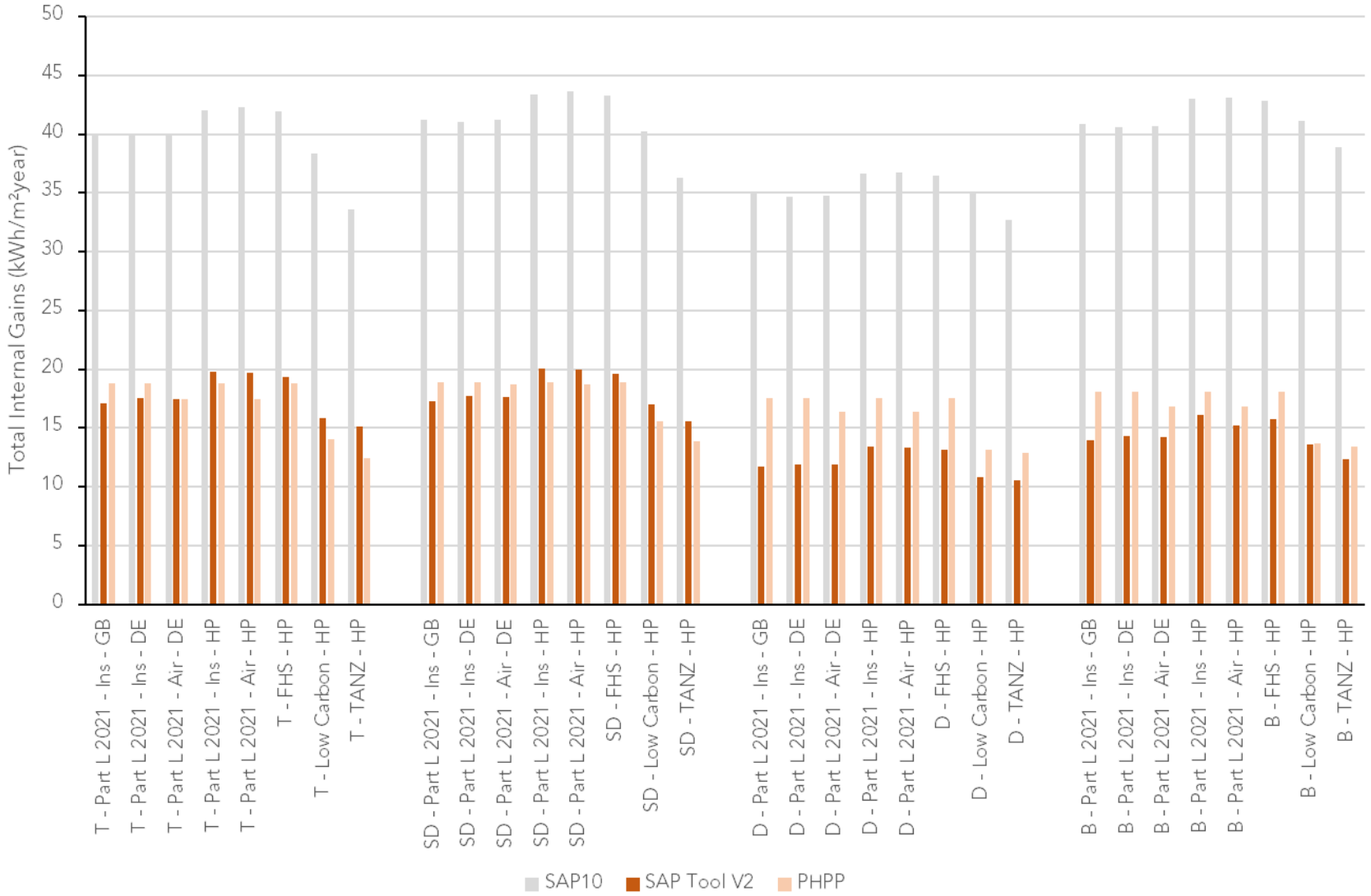
The SAP Conversion Tool performs its own internal heat gain calculation, following the same approach used in SAP 10, but with a modified set of assumptions, outlined in the adjacent table. Further detail on how the initial amounts of energy are calculated, which may then become an internal heat gains, is provided in the next section on total energy use.

The revised assumptions generally result in much lower internal heat gains, which are similar to PHPP. The gains are not exactly the same as PHPP, but this is due to differences in assumptions between the two softwares. For example, in PHPP it is possible to enter whether any primary pipework from a heat pump is internal or external, whereas in the SAP Conversion Tool a simplified assumption is made that half is inside and half is outside.

Category	1. Initial Amount of Energy	2. Availability
Metabolic	Occupants are assumed to release 80W of heat, the same value as PHPP, which is higher than the 60W assumed in SAP 10.	Reduced from 100% in SAP 10 to 55%, the same assumption as PHPP. Results in overall metabolic gains below SAP 10.
Appliances	Appliance energy use is calculated using a bottom-up calculation. This results in much lower appliance energy use than SAP 10.	Reduced from 100% to 67%, which is SAP 10's reduced gains value. This accounts for hot water and air from appliances that is lost outside the thermal envelope.
Water Heating	A reduced volume of hot water is assumed per occupant than in SAP 10. This also reduces distribution losses.	Same value as SAP, 85%. Gains from distribution, storage and primary circuit loss are reduced from 80% to 75%.
Cooking	The reduced gains values from column B of Table 5 in SAP 10.2 are assumed.	Reduced from 100% to 50% to account for venting of cooking outside.
Lighting	A reduced lighting allowance is calculated using a bottom-up calculation.	Same value as SAP 10, 85% availability.
Pumps	Same value as SAP 10 assumed.	Same value as SAP 10, 100% availability.
Fans	Same value as SAP 10 assumed.	Same values as SAP 10, 12% for positive input fans, 6% for MVHR, 0% for extract fans.
Evaporative Losses	Same value as SAP 10 assumed, -40W continuous.	Same value as SAP 10, 100% availability.

Summary of the SAP Conversion Tool's approach to calculating internal heat gains.

Approach to Adjusting SAP Space Heating Demand | Internal Heat Gains



Internal heat gains calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Internal heat gains calculated by the SAP Conversion Tool are similar to PHPP, but not identical due to some simplifications to make the tool easier to use. Gains are significantly lower than calculated in SAP 10 for all scenarios.

SAP 10 calculation of solar heat gains

Solar heat gains are calculated in SAP 10 using a formula similar to the adjacent example. The main part of the calculation focuses on working out how much solar energy falls on each glazed surface. This depends on the climate region, the time of year, and the orientation and tilt of the surface.

Once this has been calculated, additional characteristics of each glazed surface are taken into account, including: the area of the glazed surface (ie not including the frame), overshading, how much energy is transmitted through the specific type of glazing, and an additional allowance for shading due to dirt build-up.

How reliable is the approach in SAP 10?

The calculation provides a coarse estimate of solar heat gains that are expected to occur through glazed surfaces. The accuracy of the solar gain calculation is naturally limited by a range of simplifications, which include:

- Permitting a single frame percentage to be assumed for all glazing
- Not accounting for overshading for individual glazed surfaces
- Not accounting for reveal or overhang shading

Comparisons with PHPP indicate SAP 10 both over and under estimates solar heat gains, relative to more detailed calculations in PHPP.

SAP Conversion Tool calculation of solar heat gains

The values from SAP 10 are input to the SAP Conversion Tool and a new feature in V2.3 is that they are then rescaled to minimise differences between SAP and PHPP radiation data. Once the dwelling's heat loss has been recalculated by the tool, solar gains are adjusted to ensure that when combined with internal heat gains they do not exceed the total heat losses. Additionally, solar gains are capped at 50% of total annual heat losses to prevent excessive reliance on solar gains to reduce space heat demand. In practice, this cap is not expected to have any impact on the majority of dwellings. For the test dwellings, solar gains varied from 14% - 35% of total annual heat loss, for example.

Data item	Symbol	Type	Units	Notes
Monthly average solar gain	$G_{s,m}$	Calculated	W	Step A
Incident solar flux for selected orientation, pitch and month	$Fx_{i,m}$	Calculated	W/m²	Calculated for each element, i (or group of similar elements) as described in §2.4.1, using the actual pitch (usually 90°, except for roof windows).
Area of glazed element i	Aw_i	User input	m²	Gross area of opening (including opaque areas such as frame). Ensure this adds up to the same as the window area used for the U-value calculation.
Solar access (overshading) factor	Ov_i	User input / from table	Dimensionless	From Table 23
Frame factor	Fr_i	User input / from table	Dimensionless	From Table 2 in §1
Transmission factor	Tx_i	User input / from table	Dimensionless	Solar energy transmittance factor of the glazing at normal incidence. Use actual value if known; otherwise take value from Table 24.

A. $G_{s,m} = \sum Fx_{i,m} \times Aw_i \times Ov_i \times Fr_i \times Tx_i \times 0.9$

Table 23: Solar access factors

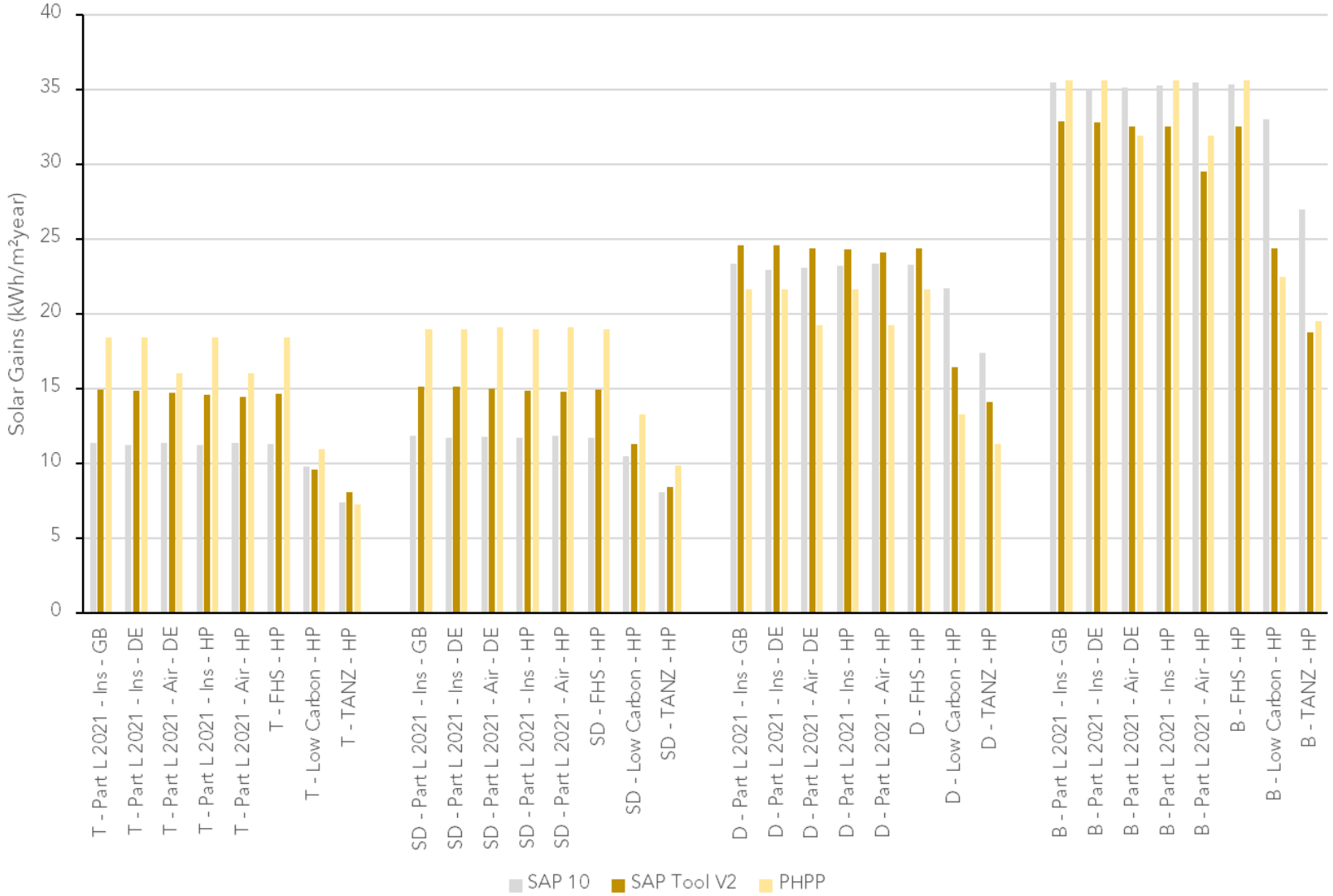
Over-shading	% of sky blocked by obstacles	Solar access factor, Ov_i
Heavy	>80%	0.3
More than average	60-80%	0.54
Average or unknown	20-60%	0.77
Very little	<20%	1.00

Table 24: Solar gains transmission factors

Glazing type	Transmission factor, Tx_i
Single glazed	0.85
Double glazed (air or argon filled)	0.76
Double glazed (low-E hard coat)	0.72
Double glazed (low-E soft coat)	0.63
Window with secondary glazing	0.76
Triple glazed (air or argon fill)	0.68
Triple glazed (low-E hard coat)	0.64
Triple glazed (low-E soft coat)	0.57

Summary of the calculation for solar gains used in the BRE Domestic Energy Model, which SAP 10 is based on. Compliance calculations are not permitted to assume 'very little' overshading, but this is permitted for EPC ratings. The same overshading factor must be assumed for all glazing. © BRE

Approach to Adjusting SAP Space Heating Demand | Solar Heat Gains



Solar heat gains calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Solar heat gains calculated by the SAP Conversion Tool can be higher than those calculated by SAP 10 if the total dwelling heat loss is higher, as this means a greater amount of available gains are used in practice. For scenarios with better fabric efficiency, fewer solar heat gains may be included in the calculation due to rescaling to avoid gains exceeding total heat losses.

SAP 10 calculation of gains utilisation

Whether or not internal and solar heat gains help to reduce the space heat demand depends on when they occur. SAP adjusts for this using a 'utilisation factor', which identifies which proportion of gains are useful. As an example, 90% of gains may be useful in the winter, but only 40% in summer when less heating is required.

How reliable is the approach in SAP 10?

Comparisons with PHPP indicate that the formulae in SAP 10 produce similar results. Due to the similarity of the SAP 10 gains utilisation factors to those from PHPP and the lack of available data on which to base any potential revisions to the calculation, no further investigations were carried out.

SAP Conversion Tool calculation of gains utilisation

The current approach in SAP 10 was assumed to be satisfactory and has been implemented in the SAP Conversion Tool.

Table 9a: Utilisation factor for heating

Symbols and units

H = heat transfer coefficient, $(39)_m$ (W/K)

G = total gains, $(84)_m$ (W)

T_i = internal temperature (°C)

T_e = external temperature, $(96)_m$ (°C)

TMP = Thermal Mass Parameter, (35), (kJ/m²K) (= C_m for building / total floor area)

HLP = Heat Loss Parameter, $(40)_m$ (W/m²K)

τ = time constant (h)

η = utilisation factor

L = heat loss rate (W)

Calculation of utilisation factor

τ = TMP / (3.6 × HLP)

$a = 1 + \tau / 15$

$L = H (T_i - T_e)$

$\gamma = G / L$ *Notes: if L = 0 set $\gamma = 10^6$; to avoid instability when γ is close to 1 round γ to 8 decimal places*

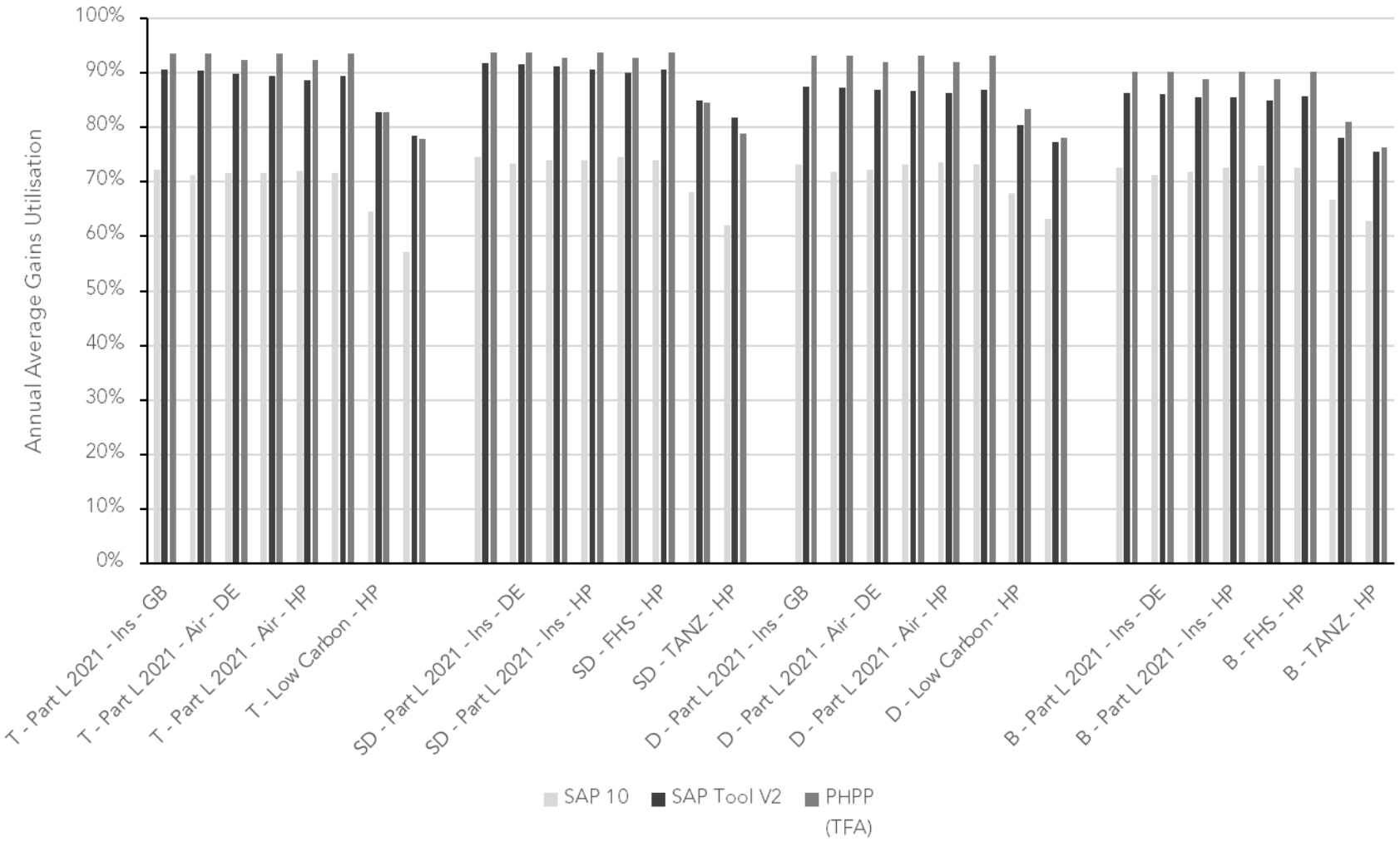
if $\gamma > 0$ and $\gamma \neq 1$: $\eta = \frac{1-\gamma^a}{1-\gamma^{a+1}}$

if $\gamma = 1$: $\eta = \frac{a}{a+1}$

if $\gamma \leq 0$: $\eta = 1$

SAP 10's calculations for gains utilisation appear to be well-developed and produce similar results to PHPP. These calculations were retained for use in the SAP Conversion Tool. © BEIS/BRE

Approach to Adjusting SAP Space Heating Demand | Gains Utilisation



Gains utilisation calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Although the SAP Conversion Tool uses the same formula as SAP 10, the actual gains utilisation calculated by the tool varies from SAP 10 because the dwelling's heat loss and therefore the amount of available internal and solar gains is different between the two. This is due to other adjustments made to the calculations, as explained in this section. The SAP 10 formula for gains utilisation used in the SAP Conversion Tool generally produces results that are similar to PHPP.

SAP 10 calculation of space heat demand

Space heat demand in SAP 10 is calculated by combining the transmission and ventilation losses into a total monthly loss. This is then balanced against internal heat gains and solar heat gains, after application of monthly gains utilisation factors. For any months where losses exceed useful gains, space heat demand is assumed to occur, which must be met by the building's heating system.

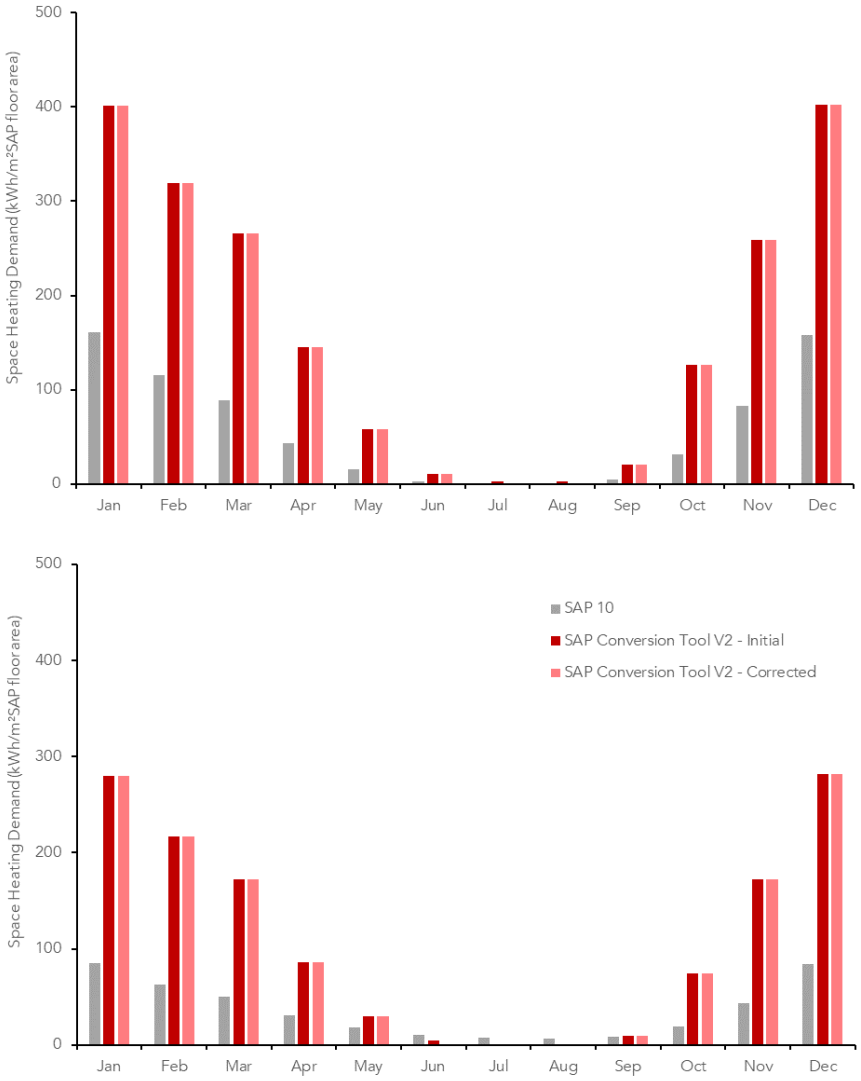
How reliable is the approach in SAP 10?

The fundamental approach to summing losses and gains in SAP 10 is sound and is effectively the same as the approach used in PHPP and other energy modelling software.

SAP Conversion Tool calculation of space heat demand

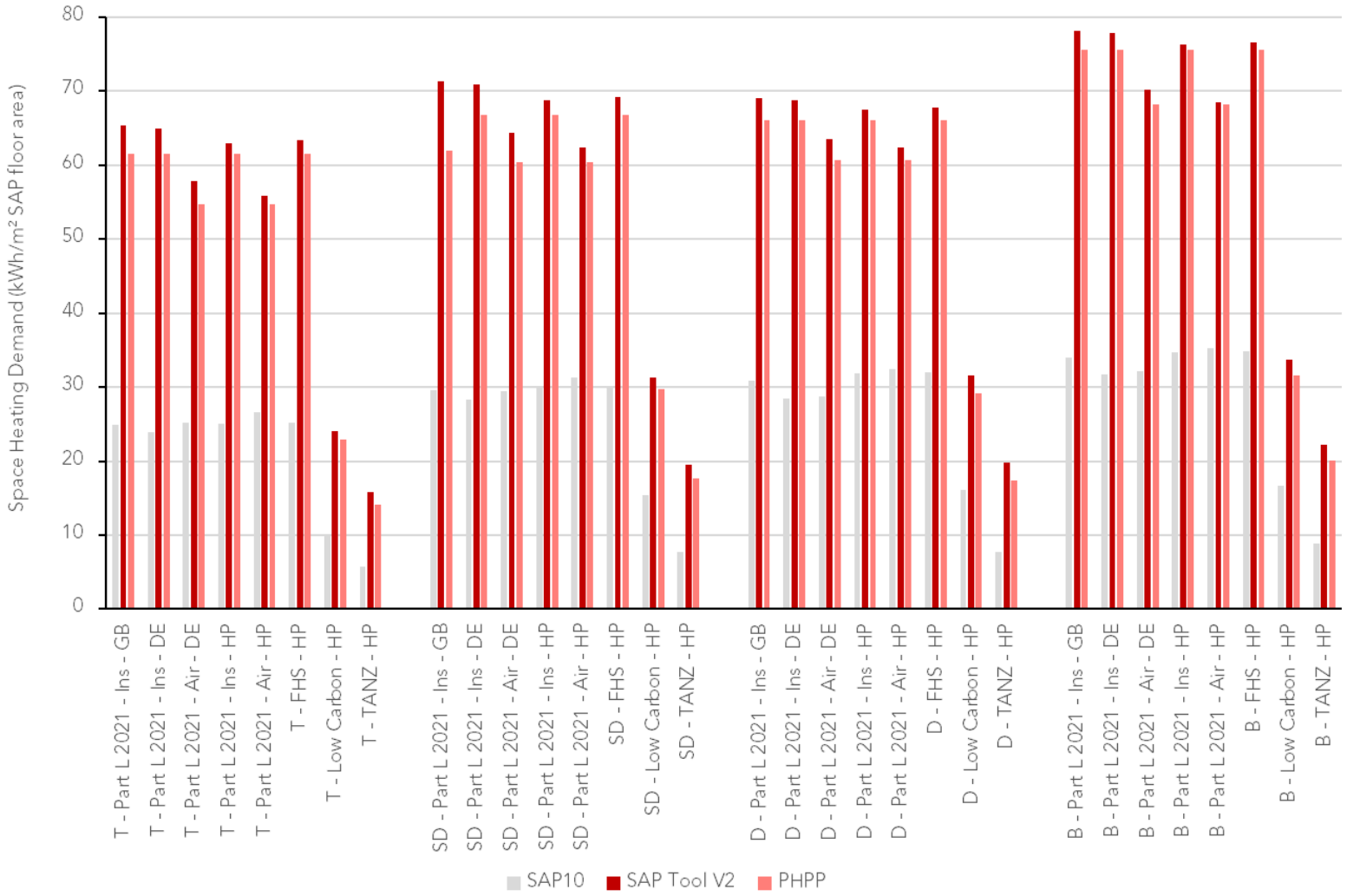
The current approach in SAP 10 was assumed to be satisfactory and has been implemented in the SAP Conversion Tool.

Comparisons with PHPP indicated that space heat demand for the most efficient dwellings were initially being overestimated by the SAP Conversion Tool relative to PHPP. This was found to be due to slightly higher space heating demand being assumed in summer months in the tool versus PHPP. This was addressed through a minor correction, where any transmission losses, ventilation losses, or space heat demand are ignored for months where the space heat demand is below 0.4% of annual space heat demand. In practice, this adjustment assumes that the heating system is not required, and is turned off, during summer months in the most efficient dwellings. This is also the approach adopted in PHPP, however it uses a slightly higher threshold of 1%.



A small correction is applied to remove any monthly space heating demand that is less than 0.4% of the annual total space heat demand to prevent overestimating space heat demand in the most efficient dwellings. Examples above for a terraced house with a space heat demand of 30 kWh/m²/yr (top) and 15 kWh/m²/yr (bottom).

Approach to Adjusting SAP Space Heating Demand | Space Heat Demand



Space heat demand calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Adjustments made to the space heat demand by the SAP Conversion Tool show good alignment with PHPP 10.4a. The differences are mainly due to differences in solar gains and internal heat gains calculated by SAP 10.2 vs PHPP. Some residual difference is expected due to key inputs that differ between SAP and PHPP, such as the site shading, which is calculated in more detail for PHPP. Results suggest the tool should be able to differentiate with good accuracy between homes that are policy compliant and those that are not. Results in this graph are reported per square meter of SAP floor area for consistency with the rest of this report, however the SAP Conversion Tool reports space heat demand per square meter of Passivhaus treated floor area, which is assumed to be 8% lower than the SAP floor area in the tool to allow for floor space occupied by internal walls, boxed in areas, and stairs.

4.0

Approach to adjusting SAP total energy use outputs

This section explains how adjustments are applied to key SAP outputs in the SAP Conversion Tool to produce total energy use results that are more similar to PHPP.

Introduction

Total energy use calculations for buildings estimate the energy flows into a building. These are typically the same as the metered energy use, which is useful for understanding operational costs and greenhouse gas emissions.

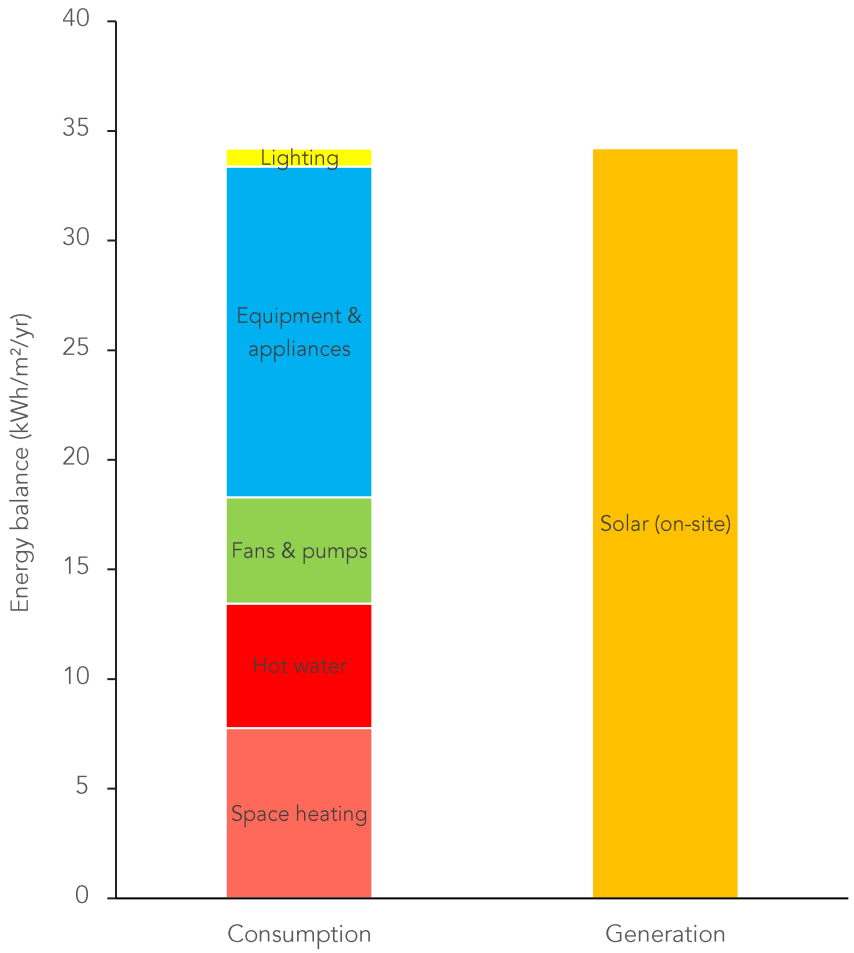
Greater Manchester Combined Authority planning policies include a recommendation for total energy use to be ≤35 kWh/m²/yr. The SAP Conversion Tool needs to be able to accurately determine whether a dwelling performs at this level.

Energy flows into a home

The main energy flows into a home are due to appliances and electrical equipment, space heating, water heating, cooking, pumps and fans, and lighting.

Relative to PHPP, SAP 10.2 provides very conservative estimates of appliance energy use, very optimistic estimates of space heat demand, quite conservative estimates of water heating demand, and reasonable estimates of energy use for pumps and fans, cooking and lighting.

The following pages explore these different end uses of energy in more detail and explain why and how any differences in the SAP Conversion Tool have been applied, relative to SAP 10.



Typical balance of total energy use (consumption) versus solar generation for a typical policy compliant dwelling. For dwellings with a heat pump, the majority of energy use is usually due to electrical appliances, followed by space and water heating, pumps and fans, and lighting.

SAP 10 calculation of appliance energy use

SAP 10 calculates appliance electricity consumption based on the dwelling's floor area and occupancy (which is itself calculated based on the floor area) using the following formula:

The initial value of the annual energy use in kWh for electrical appliances is:

$$E_A = 207.8 \times (TFA \times N)^{0.4714}$$

where TFA is the total floor area in m² and N is the assumed number of occupants

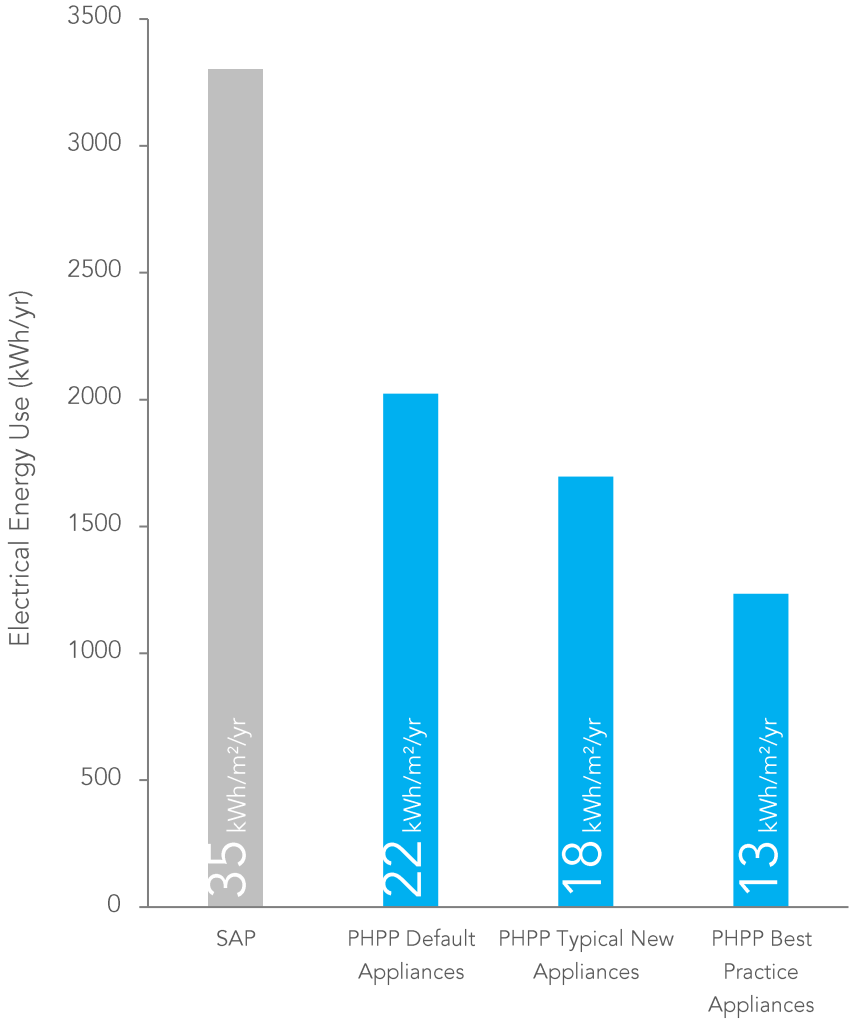
The calculated energy use is then adjusted to account for some monthly variation to provide a slightly revised final figure.

How reliable is the approach in SAP 10?

The formula that is used in this calculation was developed based on appliance energy use surveys from the late 1990's. This data is now over 25 years old and no longer representative of modern appliances. Additionally, this data includes some electricity used by gas boilers, and a range of very high energy using and non-essential appliances such as aquariums, vivariums, hot tubs, patio heaters, pool pumps, kilns, saunas and dehumidifiers. Electricity use calculated by SAP is typically about twice as high as that calculated by PHPP using up to date appliance efficiencies, as shown in the adjacent graph.

SAP Conversion Tool calculation of appliance energy use

The SAP Conversion Tool calculates appliance energy use using a bottom up calculation for refrigeration, dishwashing, clothes washing, clothes drying, and an allowance for small electrical devices of 75 kWh/year per occupant and 150 kWh/year per dwelling. Appliance efficiencies are assumed to be the worst available under the EU energy labels, which were rescaled in 2021. Assumed frequencies of use are the same as PHPP 10.4a, 65/occupant/year for dishwashing and 57/occupant/year for clothes washing and drying.



Electrical energy use calculated by SAP and PHPP 9.6a for appliances, lighting, pumps and fans. Calculations assume a dwelling with the UK average floor area of 94m². PHPP modelling assumes the UK average occupancy of 2.38 estimated by the Office for National Statistics. Energy consumption for 'typical new appliances' and 'best practice appliances' is based on an April 2021 survey of Bosch appliances.

SAP 10 calculation of energy use for pumps and fans

SAP 10 calculates electricity consumption for pumps and fans based on the approach outlined in Table 4f, shown opposite. Energy use for pumps and flue fans is calculated using fixed annual allowances. For ventilation systems, energy use is calculated by combining the volume of ventilation air required with an in-use factor to account for duct losses, and a specific fan power that is either taken from the Product Characteristics Database, or a conservative default value.

How reliable is the approach in SAP 10?

The approach used in SAP 10 is reasonable, however fan energy use for ventilation systems is highly dependent on the assumed mechanical ventilation rate. As described in the section on space heating demand, for less airtight dwellings SAP assumes ventilation rates reduce below Part F rates, which is likely to result in underestimates of fan electricity consumption.

SAP Conversion Tool calculation of energy use for pumps and fans

As the overall amount of electricity used by pumps and fans is relatively small, the current approach in SAP 10 has been implemented in the SAP Conversion Tool, which reuses the values calculated in SAP.

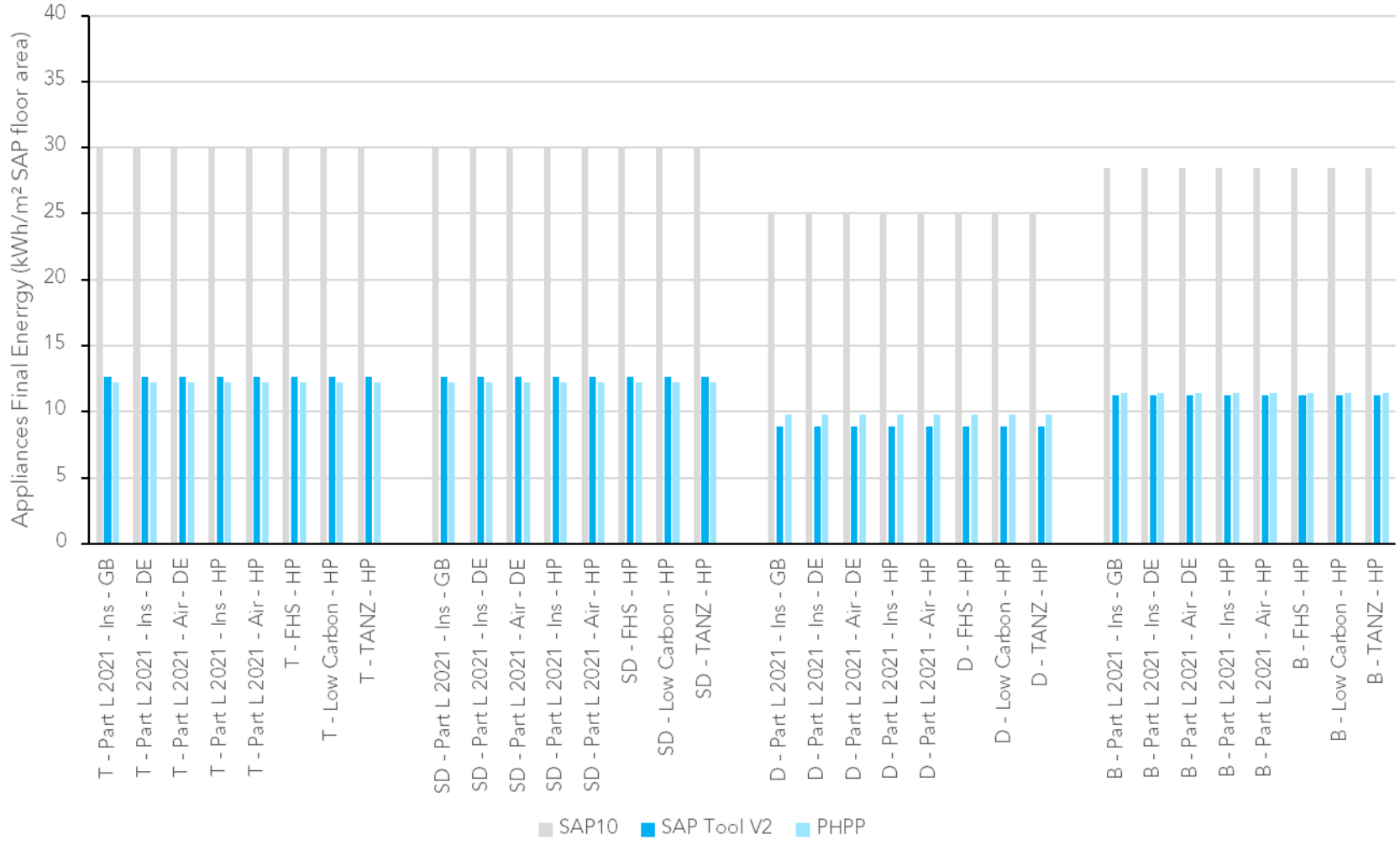
Comparisons with PHPP 10.4a indicated that electricity use for pumps and fans was up to 3 kWh/m²/year higher than calculated for the same dwelling and ventilation system type in SAP 10. It is expected that this is mostly due to the lower ventilation rates assumed in SAP 10.

Future updates to the SAP Conversion Tool could consider building in a calculation for electricity use from pumps and fans, which accounted for the ventilation flow rates assumed in the tool.

Equipment	kWh/year
Heating system:	
Circulation pump, 2013 or later[i] Circulation pump, 2012 or earlier Circulation pump, unknown date	41 [a) b)] 165 [a) b)] 115 [a) b)]
Liquid fuel boiler [c] – flue fan and fuel pump	100 [d]
Liquid-fuel-fired warm air system – flue fan and fuel pump	100
Gas boiler – flue fan (if fan assisted flue)	45 [d]
Gas-fired heat pump – flue fan (if fan assisted flue)	45
Gas-fired warm air system – flue fan (if fan assisted flue)	45
Warm air heating system fans [e]	SFP × 0.4 × V
Electricity use by heat interface unit	From PCDB entry (kWh/day), multiplied by 365. *A default HIU is listed in the PCDB for use if the actual system is unknown or unlisted so data always comes from PCDB*
Keep-hot facility of a combi boiler:	
Electricity for maintaining keep-hot facility [f) g)] - keep-hot facility, controlled by time clock - keep-hot facility, not controlled by time clock	 600 900
Ventilation system:	
Mechanical extract ventilation [h]	IUF × SFP × 1.22 × V
Balanced whole house mechanical ventilation fans [h]	IUF × SFP × 2.44 × n_{mech} × V
Positive input ventilation (from loft space)	0
Positive input ventilation (from outside) [h]	IUF × SFP × 1.22 × V
Solar thermal system pump:	
Solar thermal system pump, electrically powered Solar thermal system pump, PV powered	[25 + (5 × (H1))] × (2000 ÷ 1000) 0

SAP 10 Table 4f contains the main assumptions for energy use from pumps and fans. As the SAP Conversion Tool uses the pump and fan energy use figure directly from SAP 10, these same assumptions are effectively also used in the SAP Conversion Tool. © BEIS/BRE

Approach to Adjusting SAP Total Energy Use | Appliances



Appliance energy use calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The appliance energy use calculation in the SAP Conversion Tool results in very similar amounts of electricity use for appliances to PHPP 10.4a. Calculated appliance energy use is typically around half the value that would be calculated in SAP 10.2. This means the amount of waste heat available as internal heat gains for the space heating demand calculation is also significantly reduced. Appliance electricity use per square meter is typically lower in larger buildings like the detached house, as energy use does not increase proportionately with dwelling floor area.

SAP 10 calculation of space heating energy use

SAP 10 calculates space heating energy use by combining the space heating demand with the efficiency of the heating system, and then making adjustments based on the type of heating controls. The space heating system efficiency can be a product-specific value that is looked up from SAP's Product Characteristics Database, otherwise conservative default values are provided for the main heating technologies.

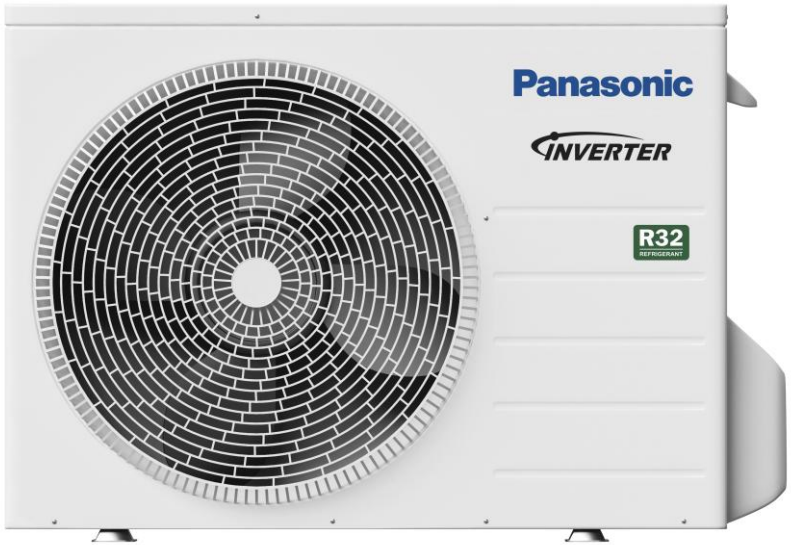
If heating is provided by a heat pump, the space heating demand is increased as SAP assumes that the heating system operates for longer periods, resulting in higher internal temperatures on average. The heat pump's performance is also calculated for each month using the BRE's Domestic Annual Heat Pump System Efficiency calculation, which accounts for variations in the heat pump's efficiency due to operation at part load.

How reliable is the approach in SAP 10?

Heating system efficiencies in SAP generally appear to be reasonable and similar to PHPP, although heat pump efficiencies are consistently lower in SAP than both PHPP and what could be expected from well designed and properly commissioned systems based on a range of field trials in the UK and Europe. The assumption that average indoor temperatures are higher where heat pumps are present may be reasonable, but this produces unequal results based on providing different levels of thermal comfort.

SAP Conversion Tool calculation of space heating energy use

The SAP Conversion Tool assumes that indoor temperatures are maintained at 20°C regardless of heating system. This removes additional heat demand that would otherwise be assigned to homes with heat pumps in SAP 10. The SAP Conversion Tool uses the same heating system efficiencies as SAP 10, and so captures some effects of the heating system controls and calculations for part-load operation of heat pumps. The tool increases the efficiency of heat pumps by 15% relative to SAP, which results in values that are close to those calculated in PHPP 10.4a, and reported for systems in recent field trials.

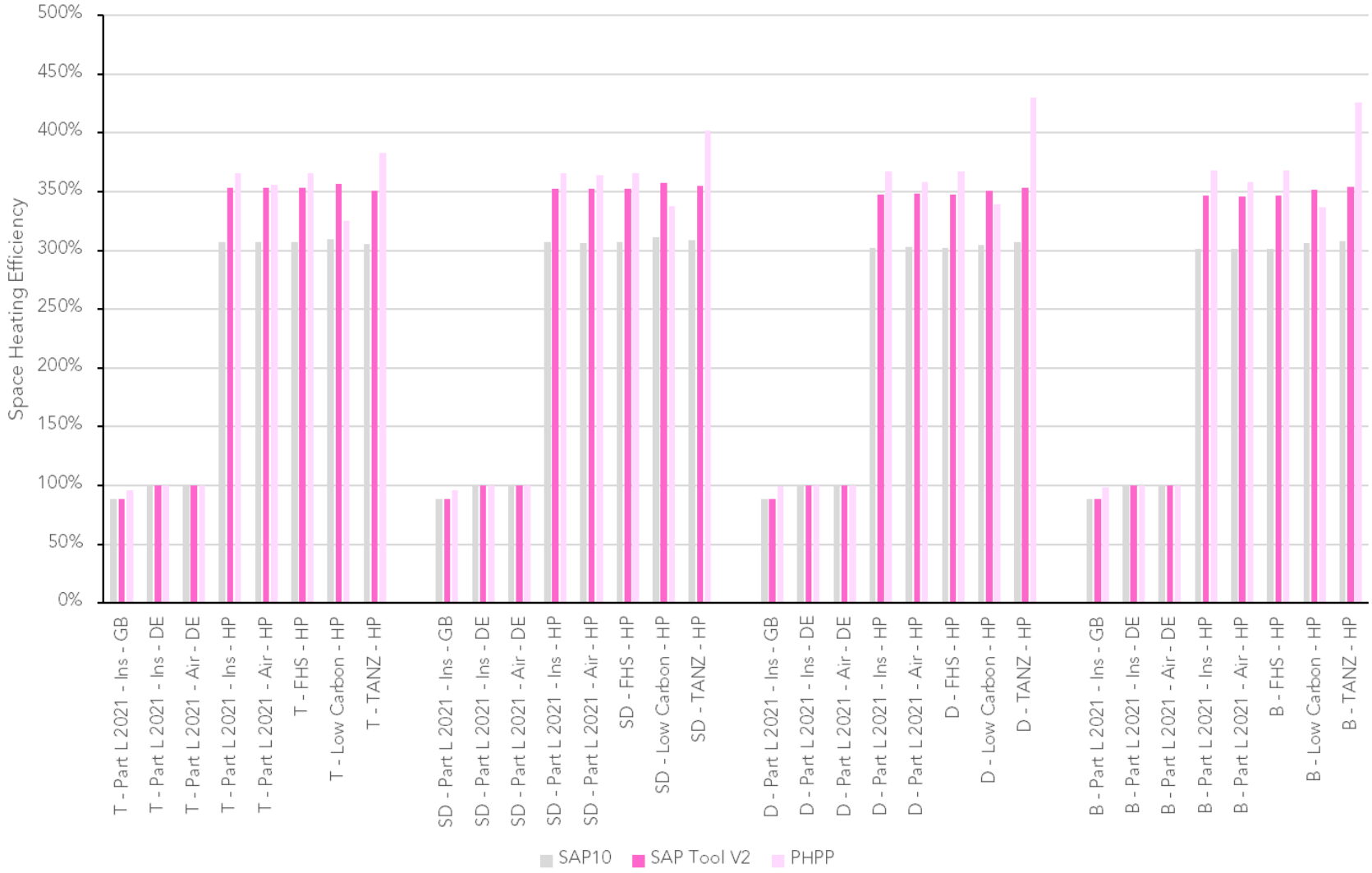


The majority of new homes in Greater Manchester Combined Authority will need to use heat pumps to ensure their total energy use is within the policy requirement. For development of the SAP Conversion Tool V2, a Panasonic J series heat pump was modelled in both DesignSAP 10.2 and PHPP 10.4 so the calculated efficiencies could be directly compared.

Unlike SAP 10, the SAP Conversion Tool assumes that dwellings are heated to the same internal temperature regardless of heating system type. The tool also uses less conservative efficiencies for heat pumps, based on comparison with efficiencies calculated in PHPP 10.4a, and a survey of various field trials.

© Panasonic

Approach to Adjusting SAP Total Energy Use | Space Heating



Heating system efficiency calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The SAP Conversion Tool uses the same efficiencies as SAP 10, with the exception of heat pumps where the efficiency is increased by 15%. This results in similar efficiencies to PHPP 10.4a, with the exception of the most efficient scenarios, where the flow temperature was assumed to be 35˚C in PHPP, but the lowest flow temperature available in SAP's Product Characteristics Database for the same heat pump was 45˚C. The revised efficiencies used in the tool are conservative in relation to monitored heat pump data, which shows space heating efficiencies of 400-500% are achievable.

SAP 10 calculation of water heating energy use

SAP 10 calculates water energy use by estimating the hot water volume required for baths, showers and other uses based on the number of occupants, assumed user behaviour, the number of showers, and the shower flow rates. This volume is assumed to be heated from the supply water temperature up to 60˚C. Allowances for losses from storage, primary and secondary pipework, and combi boilers are added to produce a total hot water demand. This is then combined with the efficiency of the water heating system. As with the space heating system, the efficiency can be a product-specific value that is looked up from SAP's Product Characteristics Database, otherwise conservative default values are provided for the main heating technologies.

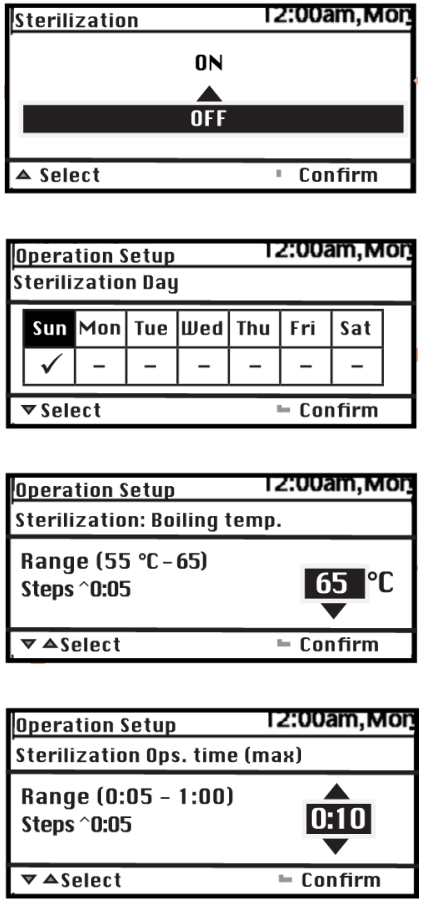
If heating is provided by a heat pump, the heat pump's performance is calculated for each month using the BRE's Domestic Annual Heat Pump System Efficiency calculation, which accounts for variations in the heat pump's efficiency due to operation at part load.

How reliable is the approach in SAP 10?

The estimated hot water use in SAP 10 is conservative compared to PHPP and heat pump efficiencies tend to also be conservative. This is partially due to SAP's assumption that hot water is stored and used at 60˚C. In practice, most heat pumps are expected to be commissioned to heat water to around 55˚C, with a weekly sterilisation cycle to higher temperatures to mitigate risk from legionella.

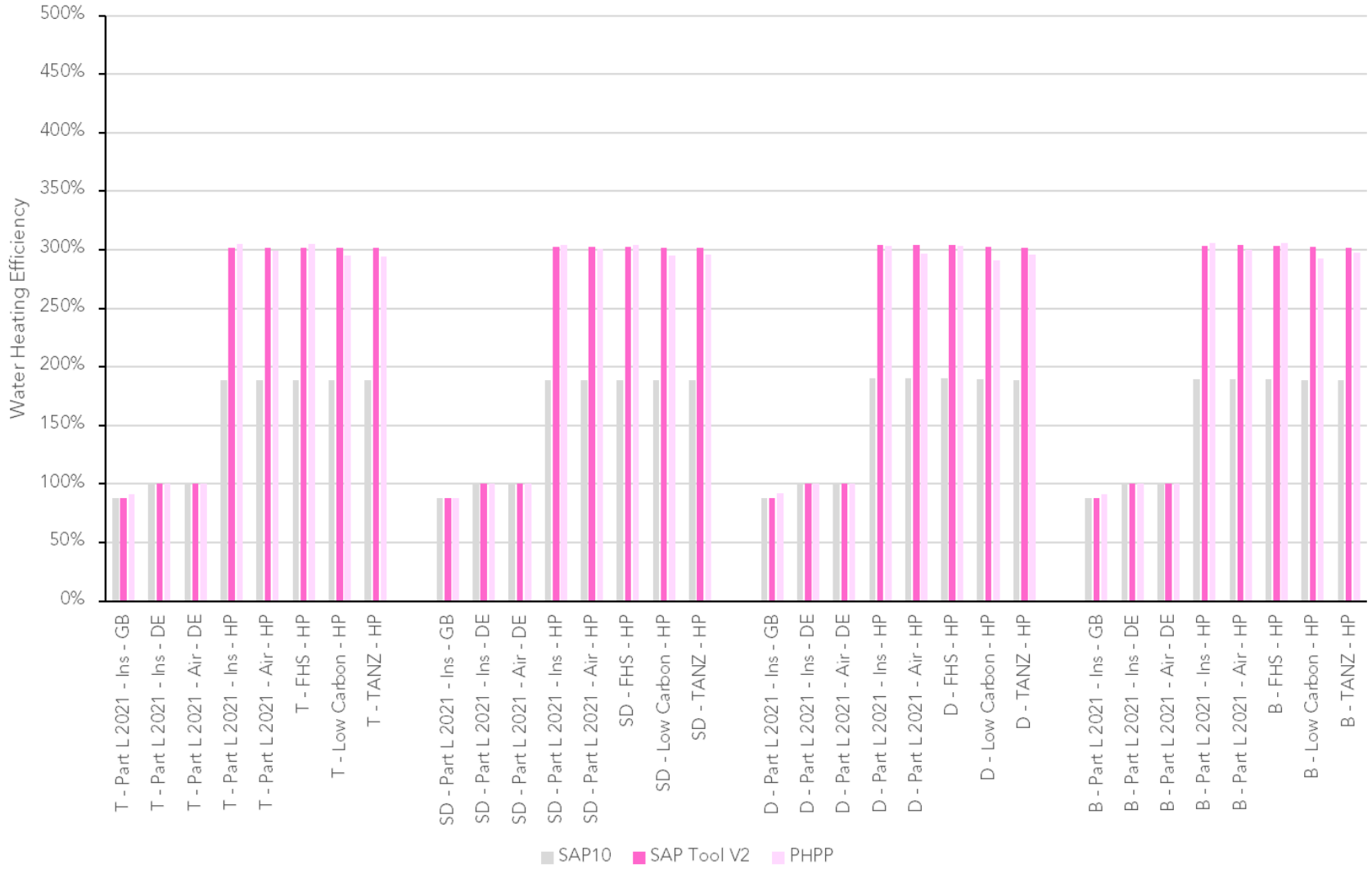
SAP Conversion Tool calculation of water heating energy use

The SAP Conversion Tool assumes the same level of hot water demand as PHPP 10.4a, 25 litres per person per day at 60˚C. Allowances for other losses are then applied to this initial volume in the same way as SAP 10. The SAP Conversion Tool uses the same water heating system efficiencies as SAP 10, but increases the efficiency of heat pumps by 60% relative to SAP, which results in values that are close to those calculated in PHPP 10.4a, and reported for systems in recent field trials.



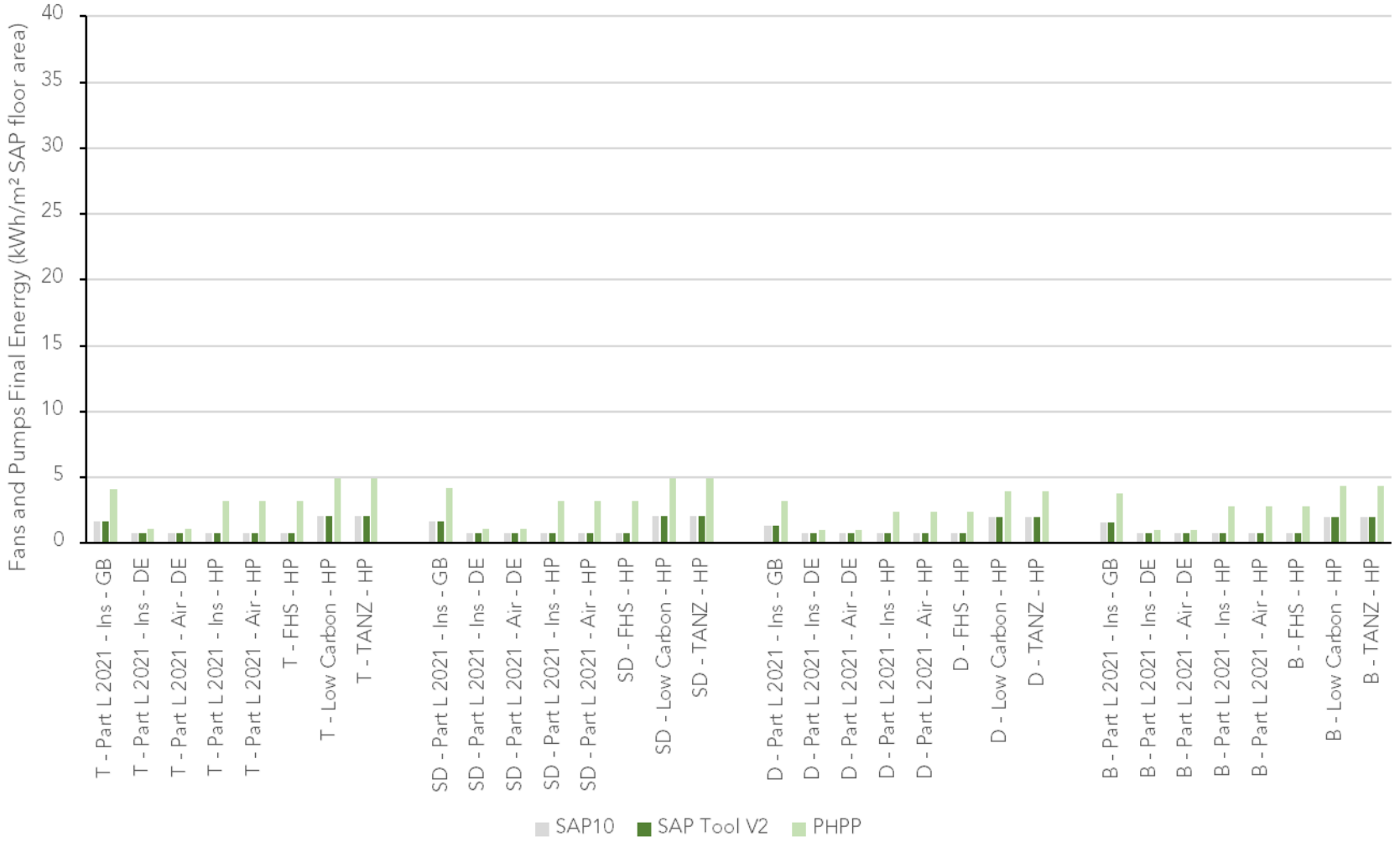
Sterilisation cycle settings for the Panasonic J series heat pump that was used for the SAP and PHPP modelling. In practice, heat pumps are expected to heat water closer to 55˚C, with a weekly sterilisation cycle to higher temperatures. They are also expected to have minimum set-back temperatures that must be reached before the heat pump reheats the hot water tank to minimise short-cycling. Together these are expected to result in higher efficiencies than calculated in SAP 10. © Panasonic

Approach to Adjusting SAP Total Energy Use | Water Heating



Water heating system efficiency calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The SAP Conversion Tool uses the same efficiencies as SAP 10, with the exception of heat pumps where the efficiency is increased by 60%. This results in similar efficiencies to PHPP 10.4a. The revised efficiencies used in the tool are in line with those reported by a range of recent field trials. Note that for air source heat pumps, a good proportion of water heating occurs during warmer months, which contributes toward relatively high annual average efficiencies, particularly when combined with modest storage temperatures enabled by sterilisation cycling.

Approach to Adjusting SAP Total Energy Use | Pumps and fans



Energy use for pumps and fans calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The SAP Conversion Tool uses the same values as SAP 10 on the basis that while the percentage difference with PHPP can be quite large, the actual amount of electricity consumption involved is relatively small. Graph scale is the same as for other end uses of electricity such as appliances, cooking and lighting to show the relatively small amount of energy use involved.

SAP 10 calculation of energy use for cooking

SAP 10 calculates energy consumption for cooking by combining a fixed annual allowance with a variable annual allowance per occupant, 'N', using the following formula:

$$E_{cook} = 138 + 28 \times N$$

$$E_{cook,m} = E_{cook} \times n_m/365$$

The second equation splits the annual consumption into a monthly figure based on the proportion of days in the month.

How reliable is the approach in SAP 10?

The approach used in SAP 10 produces similar values to PHPP 10.4a's calculation for regular electrical cooktops, and is assumed to be reasonable.

SAP Conversion Tool calculation of energy use for cooking

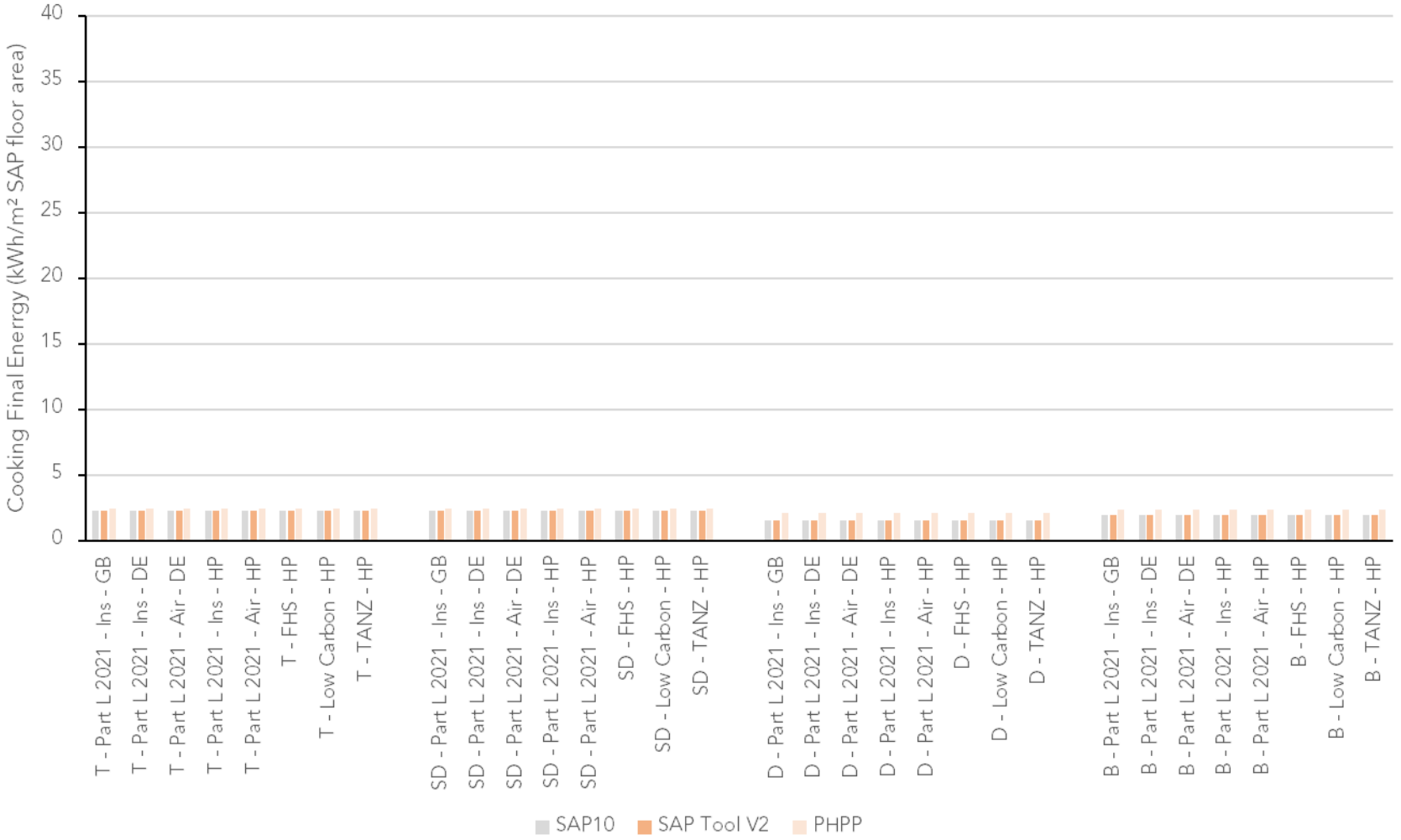
The current approach in SAP 10 has been implemented in the SAP Conversion Tool as comparisons with PHPP 10.4a indicated that energy use for cooking was very similar in both software.

Future updates to the SAP Conversion Tool could consider building in a calculation for cooking energy use, which accounted for the type of cooktop that is used in the dwelling.



Induction cooktops such as the one shown above typically use less electricity than regular electric cooktops, which use less energy than gas. PHPP 10.4a allows different amounts of energy use for these three different technologies, an approach that could be considered in future versions of the SAP Conversion Tool. © Bosch

Approach to Adjusting SAP Total Energy Use | Cooking



Energy use for cooking calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The SAP Conversion Tool uses the same values as SAP 10 as it produces very similar values to the PHPP calculation. Graph scale is the same as for other end uses of electricity such as appliances, pumps and fans, and lighting to show the relatively small amount of energy use involved.

SAP 10 calculation of energy use for lighting

SAP 10 calculates energy consumption for lighting by calculating a minimum basic amount of lighting that must be provided. A contribution from daylighting is then subtracted from this value.

Remaining electrical lighting demand is then assumed to come from user-defined light fittings and associated luminous efficacies. If the user inputs insufficient lighting capacity, top-up lighting with a very low efficacy of 21.3 lumens/Watt is assumed to make up any shortfall.

How reliable is the approach in SAP 10?

The approach used in SAP 10 has the potential to be somewhat conservative as it has become quite difficult to buy low efficacy light sources due to EU lighting efficiency regulations. In practice, so long as users enter a sufficient quantity of light fittings with more typical efficacies SAP 10 should use these less conservative values.

Even if the user enters light fittings with a high efficacy, the overall amount of lighting energy use calculated by SAP 10 was still found to be significantly higher than PHPP 10.4a.

SAP Conversion Tool calculation of energy use for lighting

The SAP Conversion Tool implements a bottom-up lighting energy use calculation that is similar to PHPP 10.4a. This requires the user to input the average lighting efficacy, which is combined with the following assumptions:

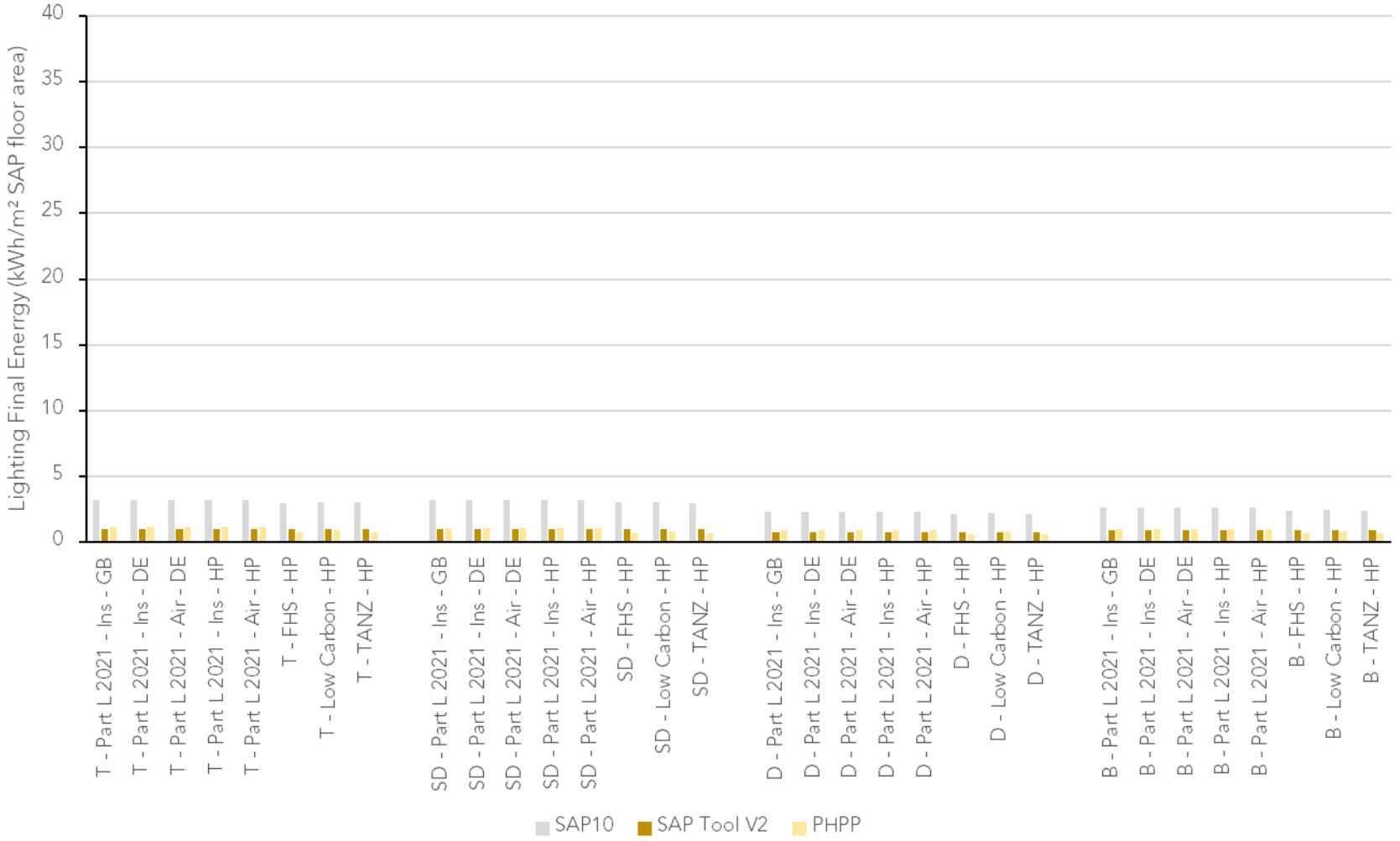
- 1,200 hours of use per lamp per occupant each year
- 5 lamps per occupant
- 800 lumens of light output per lamp, based on a standard A-type 6W LED or traditional 60W incandescent bulb

This calculation results in lighting energy use estimates that are less conservative than SAP 10.2, but more conservative than PHPP 10.4a.



A standard A-type LED bulb. The majority of lighting in new dwellings is likely to be based on LED technology, with high levels of efficacy resulting in very low amounts of annual energy use. © Philips

Approach to Adjusting SAP Total Energy Use | Lighting



Energy use for lighting calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The SAP Conversion Tool uses a similar approach to PHPP 10.4a, but with slightly more conservative assumptions in terms of the amount of lighting that is used. This results in values that are mid way between the SAP 10 and PHPP 10.4a calculations. Graph scale is the same as for other end uses of electricity such as appliances, cooking, and pumps and fans to show the relatively small amount of energy use involved.

SAP 10 calculation of total energy use

Total energy use in SAP 10 is calculated by combining the energy required by the various end uses discussed in this section together into a total annual energy requirement.

Energy use for appliances and cooking is not included in the total energy use calculated by SAP 10, as it is considered to be 'unregulated'.

How reliable is the approach in SAP 10?

The fundamental approach to summing energy use in SAP 10 is sound, however the exclusion of energy use for appliances and cooking means the total energy use numbers reported by SAP are not suitable for assessment against Greater Manchester Combined Authority total energy use policy requirements.

Other than the exclusion of these two end uses, the approach is effectively the same as that used in PHPP and other energy modelling software.

SAP Conversion Tool calculation of total energy use

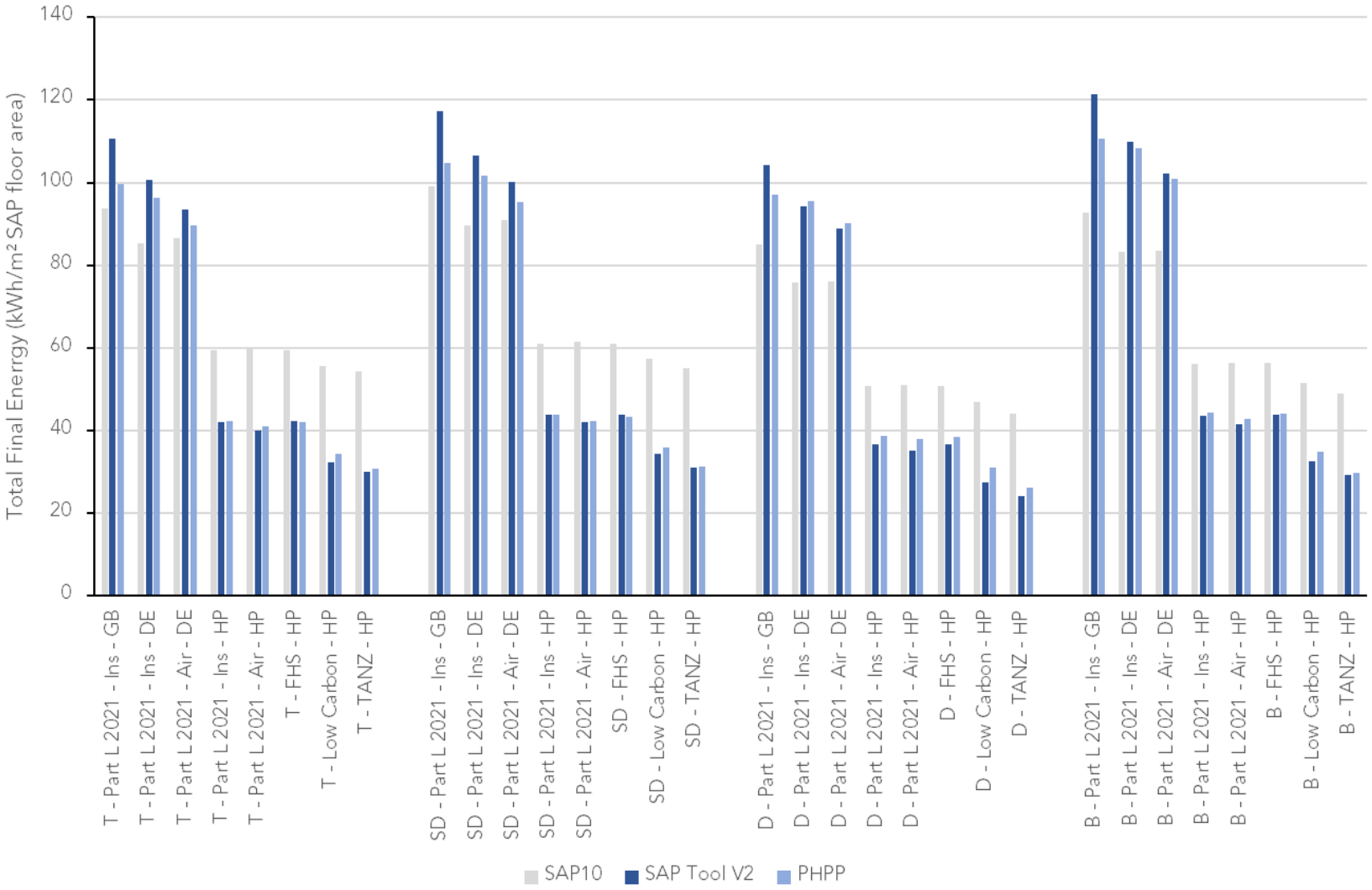
The current approach in SAP 10 has been implemented in the SAP Conversion Tool, with the addition of energy use for appliances and cooking to provide a more complete estimate of total energy use.

Comparisons with PHPP indicate that total energy use is very similar to that calculated by the SAP Conversion Tool. Due to the elemental way in which the total energy use is constructed, and the ability to check that individual elements of the total energy use all show good alignment between the tool and PHPP 10.4a, we have good confidence that the results are robust.

Annual totals	kWh/year	kWh/year	
Space heating fuel used, main system 1		(211)	
Space heating fuel used, main system 2		(213)	
Space heating fuel used, secondary		(215)	
Water heating fuel used		(219)	
Electricity for instantaneous electric shower(s)		(64a)	
Space cooling fuel used (if there is a fixed cooling system, if not enter 0)		(221)	
Electricity for pumps, fans and electric keep-hot (Table 4f):			
mechanical ventilation fans - balanced, extract or positive input from outside			(230a)
warm air heating system fans			(230b)
heating circulation pump or water pump within warm air heating unit			(230c)
oil boiler auxiliary (oil pump, flue fan, etc; excludes circulation pump)			(230d)
gas boiler auxiliary (flue fan, etc; excludes circulation pump)			(230e)
maintaining electric keep-hot facility for gas combi boiler			(230f)
pump for solar water heating			(230g)
pump for storage WWHRS (see section G3.3)			(230h)
Total electricity for the above, kWh/year	sum of (230a)...(230h) =		(231)
Electricity for lighting (calculated in Appendix L)			(232)

SAP 10 worksheet calculation for total energy use. While SAP does calculate the electricity use for appliances and cooking, it is not included in these annual totals as it is considered to be 'unregulated' energy use by Part L. The total energy use calculated by the SAP Conversion Tool includes energy use calculated for appliances and cooking. © BEIS/BRE

Approach to Adjusting SAP Total Energy Use | Total Energy Use



Total energy use calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. Energy use for appliances and cooking has been manually added to the total 'regulated' energy use from SAP 10, so the numbers are comparable with the other software. Adjustments made to the space heat demand and various end uses of energy by the SAP Conversion Tool show good alignment with PHPP 10.4a. Some residual difference is expected due to key inputs that differ between SAP and PHPP, such as the site shading, which is calculated in more detail for PHPP. Results suggest the tool should be able to differentiate with good accuracy between homes that are policy compliant and those that are not. Values from SAP 10 are heavily influenced by the underestimation of space heating demand, likely overestimation of water heating demand, and large overestimation of appliance energy use.

5.0

Approach to adjusting SAP solar generation outputs

This section explains how adjustments are applied to key SAP outputs in the SAP Conversion Tool to produce solar energy generation results that are more similar to PHPP.

SAP 10 calculation of solar energy generation

SAP 10 calculates solar energy generation using a simple formula, expressed below, which combines an annual performance factor, with the system's installed peak DC power in kW, the annual solar radiation, and an overshading factor:

$$E_{PV} = 0.8 \times kWp \times S \times Z_{PV} \quad \text{(M1)}$$

where:

S is the annual solar radiation (kWh/m²) from U3.3 in Appendix U for the applicable climate, orientation and tilt of the PV array

Z_{PV} is the overshading factor. If available, this should be the figure determined by the Microgeneration Certification Scheme (MCS) assessor, otherwise use a figure from Table M1.

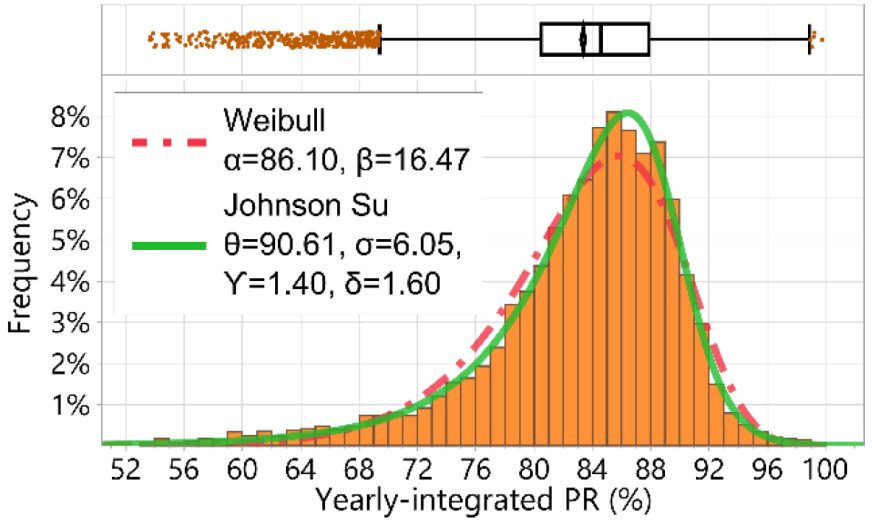
How reliable is the approach in SAP 10?

The approach used in SAP 10 is similar to most simple solar generation calculations, however the use of an 80% performance factor is conservative. This assumes that 20% of the potential power available from the solar panel is lost due to temperature losses, inverter losses, dirt build-up, mismatch losses, and wiring losses. As shown in the adjacent image, monitored data from thousands of solar systems across the UK indicates that an 85% performance factor is more typical.

SAP Conversion Tool calculation of solar energy generation

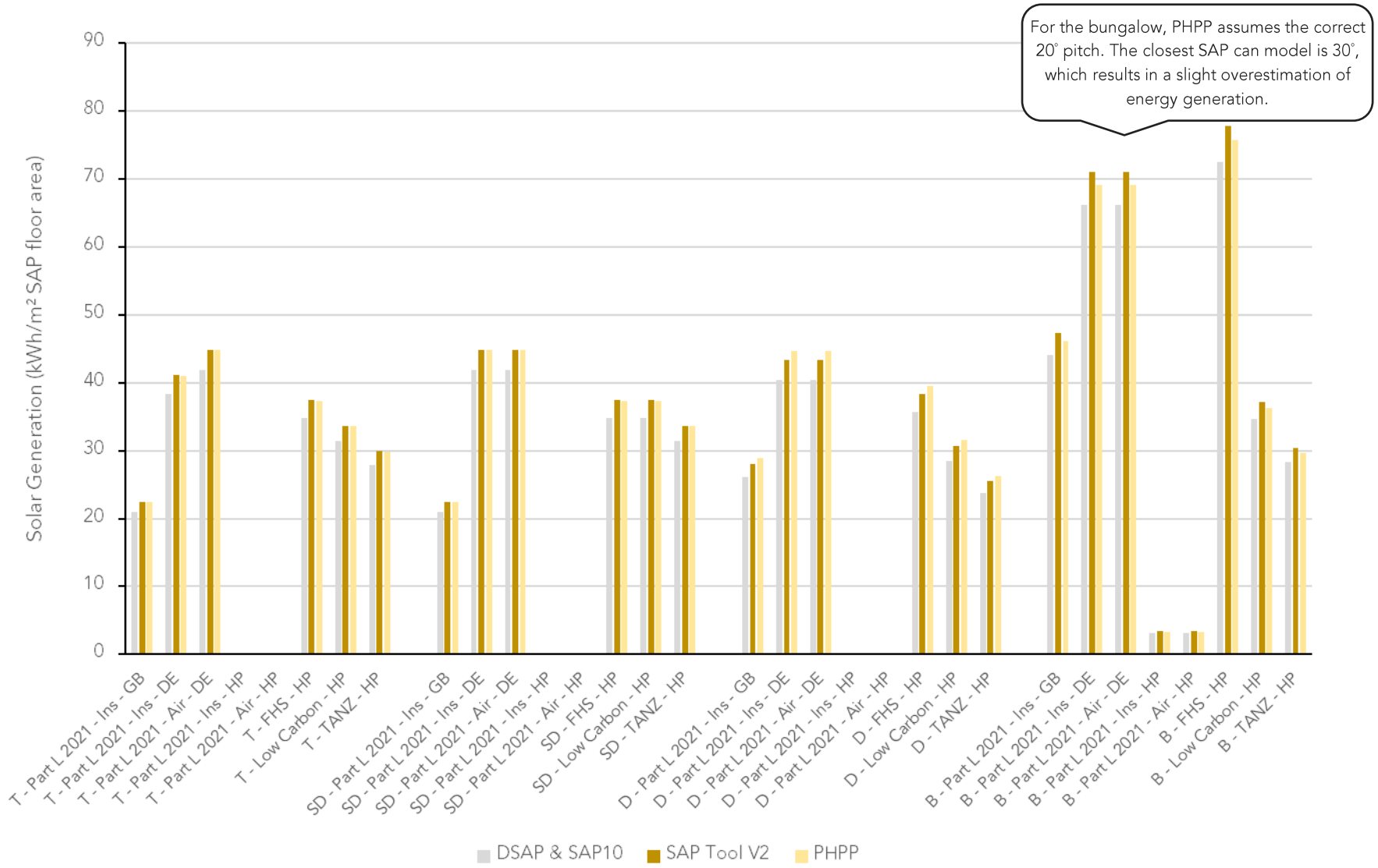
The SAP Conversion Tool takes the solar generation value calculated in SAP 10, removes the 80% performance factor and then reapplies an 85% performance factor. This results in a modest increase to predicted solar energy generation, which is expected to be more realistic.

An additional bespoke correction factor is applied to solar generation calculated in both PHPP and the SAP Conversion Tool to better align solar generation with values calculated by the PVGIS tool. For example, solar generation is increased by 1% in the SAP Conversion Tool for the West Pennines climate region, which applies to Greater Manchester Combined Authority. This correction should reduce the need for applicants to oversize systems.



Histogram of yearly-integrated performance factor across years of data for thousands of solar systems in the UK. The median performance factor was found to be 85%, therefore this value is assumed in the SAP Conversion Tool. © Taylor et al, University of Sheffield

Approach to Adjusting SAP Solar Generation | Solar Irradiation



Solar energy generation calculated by DesignSAP 10.2, the SAP Conversion Tool V2, and PHPP 10.4a for each scenario. Modelled in the West Pennines climate region. The SAP Conversion Tool applies a performance factor of 85%, which is less conservative than the value of 80% assumed in SAP 10. This results in slightly increased energy generation that is closer to PHPP. An additional bespoke increase of 1% is also applied to West Pennines to account for differences in values calculated between SAP 10 and PHPP 10.4 (based on calibration with PVGIS). Part L scenarios may or may not have solar, depending on whether it was required for the dwelling primary energy rate to comply with the target primary energy rate under Part L 2021.

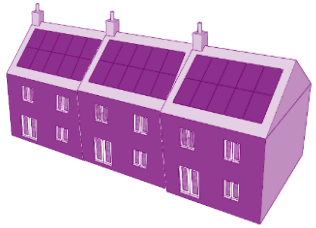
6.0

Technical specifications

This section presents each building type and the specifications for each performance scenario.

Terraced House

This section contains the specifications and assumptions for a 3-bedroom terraced house.



Energy modelling | Terraced House

A 3-bedroom terraced home was selected from publicly available documents submitted in support of a planning application for a new housing development.

Building fabric

The property has a gross internal floor area of 93m². The main entrance faces the street to the North East, while the rear of the house faces to the South West and features a small garden. The property has typical glazing proportions and layout for this type of home. The form heat loss factor of 2.20 is within the expected range for a terraced home. Although the property has chimneys fitted, these are not assumed to be functional as this would prevent adequate airtightness being achieved.

Heating

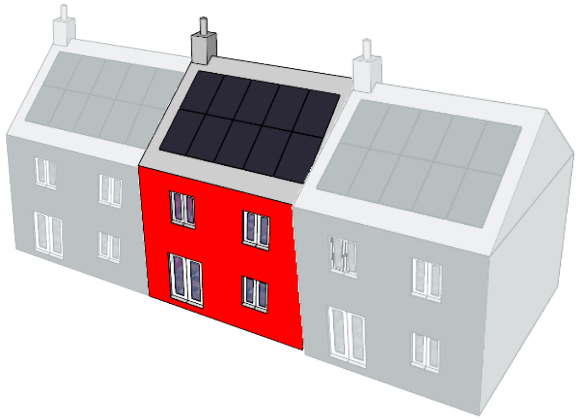
The baseline Part L 2021 scenario assumes use of a combi boiler, although this is not compliant with net zero planning policies. Two additional Part L 2021 scenarios assume use of direct electric heating, while the remaining scenarios assume use of an air-water heat pump. A cheaper air-air heat pump, or a ground source heat pump could also be used. Suitable heat emitters include radiators, or underfloor heating for scenarios with poorer fabric efficiency.

Solar PV

The property has more than enough space to achieve a net zero energy balance on-site in any orientation. As presented on plans, the South West roof has space for up to 15 solar panels, and if the property faced East-West, this could be doubled.



A typical 3 bedroom terraced house was selected



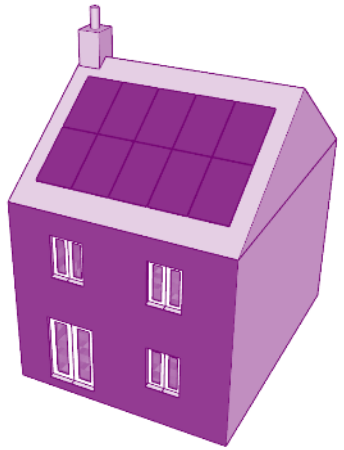
A 3D model of the house and surrounding features was created in DesignPH 2.1.15 and used to calculate solar gains and shading for PHPP.

Energy modelling | Terraced House Specifications

	Part L 2021 Gas Boiler	Part L 2021 Insulation Direct Electric	Part L 2021 Airtightness Direct Electric	Part L 2021 Insulation Heat Pump	Part L 2021 Airtightness Heat Pump	Future Homes Standard	Low Carbon	Truly Affordable Net Zero
Building fabric strategy	Part L 2021 compliant fabric, developer spec	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	FHS notional building specification	To achieve space heat demand of 30 kWh/m²/yr	To achieve space heat demand of 15-20 kWh/m²/yr
Floor (W/m^{2}K, SAP adjusted)	0.100	0.100	0.130	0.100	0.130	0.100	0.150	0.100
Walls (W/m^{2}K)	0.160	0.160	0.180	0.160	0.180	0.160	0.150	0.120
Roof (W/m^{2}K)	0.100	0.100	0.100	0.100	0.100	0.100	0.120	0.090
Windows (W/m^{2}K)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	0.8 (triple-glazed)
Doors (W/m^{2}K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Air Permeability (m^3/m^2/hr)	5	5	3	5	3	5	1	0.60
Ventilation	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s
Space Heating	Gas combi boiler Radiators at <60˚C Weather comp	Direct electric	Direct electric	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <35˚C Weather comp
Domestic Hot Water	Gas combi boiler WWHR 36%	150l direct electric tank at 60˚C 1.1kWh/day loss	150l direct electric tank at 60˚C 1.1kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss
Solar PV	2.52 kW	4.62 kW	5.04 kW	0 kW	0 kW	4.20 kW	3.78 kW	3.36 kW

Semi-detached House

This section contains the specifications and assumptions for a 3-bedroom semi-detached house.



Energy modelling | Semi-detached House

A 3-bedroom semi-detached home was selected from publicly available documents submitted in support of a planning application for a new housing development.

Building fabric

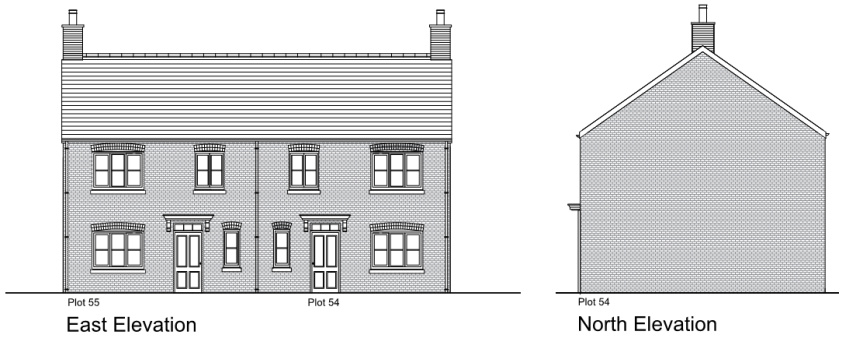
The property has a gross internal floor area of 93m². The main entrance faces the street to the North East, while the rear of the house faces to the South West and features a small garden. The property has typical glazing proportions and layout for this type of home. The form heat loss factor of 2.8 is within the expected range for a semi-detached home. Although the property has chimneys fitted, these are not assumed to be functional as this would prevent adequate airtightness being achieved.

Heating

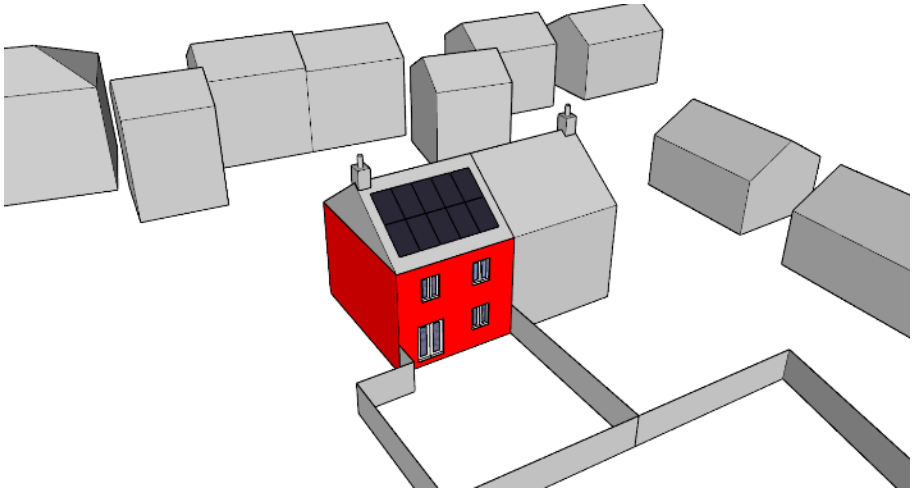
The baseline Part L 2021 scenario assumes use of a combi boiler, although this is not compliant with net zero planning policies. Two additional Part L 2021 scenarios assume use of direct electric heating, while the remaining scenarios assume use of an air-water heat pump. A cheaper air-air heat pump, or a ground source heat pump could also be used. Suitable heat emitters include radiators, or underfloor heating for scenarios with poorer fabric efficiency.

Solar PV

The property has more than enough space to achieve a net zero energy balance on-site in any orientation. As presented on plans, the South West roof has space for up to 15 solar panels, and if the property faced East-West, this could be doubled.



A typical 3 bedroom semi-detached house was selected



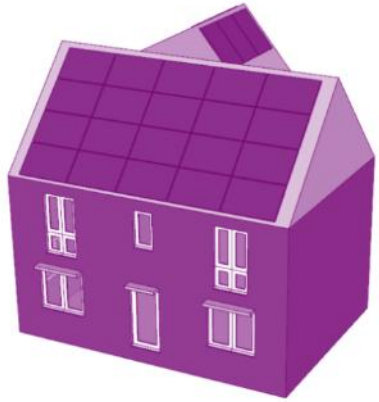
A 3D model of the house and surrounding features was created in DesignPH 2.1.15 and used to calculate solar gains and shading for PHPP.

Energy modelling | Semi-detached House Specifications

	Part L 2021 Gas Boiler	Part L 2021 Insulation Direct Electric	Part L 2021 Airtightness Direct Electric	Part L 2021 Insulation Heat Pump	Part L 2021 Airtightness Heat Pump	Future Homes Standard	Low Carbon	Truly Affordable Net Zero
Building fabric strategy	Part L 2021 compliant fabric, developer spec	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	FHS notional building specification	To achieve space heat demand of 30 kWh/m²/yr	To achieve space heat demand of 15-20 kWh/m²/yr
Floor (W/m^{2}K, SAP adjusted)	0.110	0.110	0.130	0.110	0.130	0.110	0.150	0.090
Walls (W/m^{2}K)	0.160	0.160	0.180	0.16	0.180	0.160	0.190	0.130
Roof (W/m^{2}K)	0.100	0.100	0.110	0.100	0.110	0.100	0.110	0.090
Windows (W/m^{2}K)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	0.8 (triple-glazed)
Doors (W/m^{2}K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Air Permeability (m^3/m^2/hr)	5	5	3	5	3	5	1	0.60
Ventilation	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s
Space Heating	Gas combi boiler Radiators at <60˚C Weather comp	Direct electric	Direct electric	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <35˚C Weather comp
Domestic Hot Water	Gas combi boiler WWHR 36%	150l direct electric tank at 60˚C 1.1kWh/day loss	150l direct electric tank at 60˚C 1.1kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss
Solar PV	2.52 kW	5.04 kW	5.04 kW	0 kW	0 kW	4.20 kW	4.20 kW	3.78 kW

Detached House

This section contains the specifications and assumptions for a detached 4-bedroom house.



A 4-bedroom detached home designed by McBains Architecture was selected from a publicly available Barrett Homes catalogue submitted in support of a planning application.

Building fabric

The property has a gross internal floor area of 142m². The main entrance faces the street to the South, while the rear of the house faces to the North and features a small garden. The property is a typical developer spec detached house, with reasonable glazing proportions and layout. The form heat loss factor of 3.0 is fairly poor but is as expected for a small detached home. As a result, good levels of insulation are required to achieve the required space heating demand.

Heating

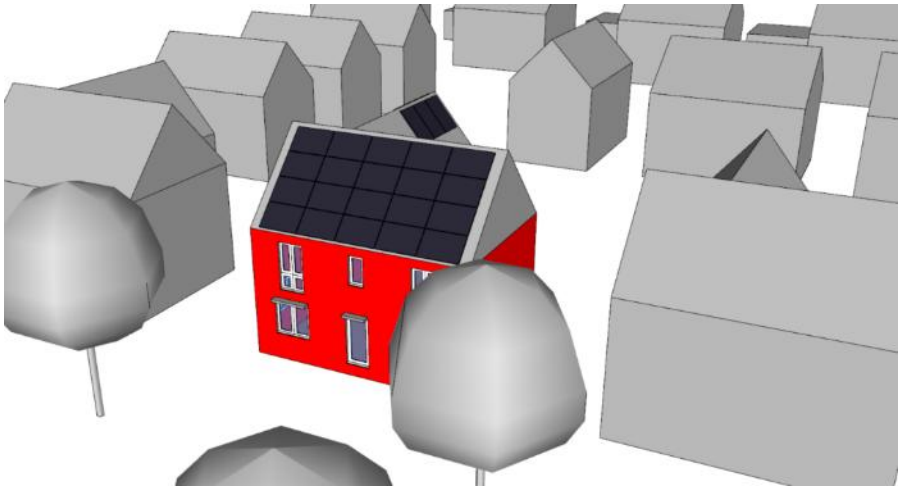
The baseline Part L 2021 scenario assumes use of a combi boiler, although this is not compliant with net zero planning policies. Two additional Part L 2021 scenarios assume use of direct electric heating, while the remaining scenarios assume use of an air-water heat pump. A cheaper air-air heat pump, or a ground source heat pump could also be used. Suitable heat emitters include radiators, or underfloor heating for scenarios with poorer fabric efficiency.

Solar PV

The property has more than enough space to achieve a net zero energy balance on-site in any orientation. As presented on plans, the property has sufficient space for 22 solar panels. This includes allowance for 2 panels on the smaller rear roof section. If the property faced East or West, it would be possible to install more panels on the rear plane of the main roof.



A typical 4 bedroom detached house was selected from a Barrett Homes planning application.



A 3D model of the house and surrounding features was created in DesignPH 2.1.15 and used to calculate solar gains and shading for PHPP.

Energy modelling | Detached House Specifications

	Part L 2021 Gas Boiler	Part L 2021 Insulation Direct Electric	Part L 2021 Airtightness Direct Electric	Part L 2021 Insulation Heat Pump	Part L 2021 Airtightness Heat Pump	Future Homes Standard	Low Carbon	Truly Affordable Net Zero
Building fabric strategy	Part L 2021 compliant fabric, developer spec	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	FHS notional building specification	To achieve space heat demand of 30 kWh/m²/yr	To achieve space heat demand of 15-20 kWh/m²/yr
Floor (W/m^2K, SAP adjusted)	0.120	0.120	0.130	0.120	0.130	0.120	0.150	0.090
Walls (W/m^2K)	0.150	0.150	0.180	0.150	0.180	0.150	0.150	0.100
Roof (W/m^2K)	0.110	0.110	0.110	0.110	0.110	0.110	0.100	0.090
Windows (W/m^2K)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	0.8 (triple-glazed)
Doors (W/m^2K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Air Permeability ($m^3/m^2/hr$)	5	5	3	5	3	5	1	0.60
Ventilation	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s
Space Heating	Gas combi boiler Radiators at <60˚C Weather comp	Direct electric	Direct electric	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <35˚C Weather comp
Domestic Hot Water	Gas combi boiler WWHR 36%	150l direct electric tank at 60˚C 1.1kWh/day loss	150l direct electric tank at 60˚C 1.1kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss
Solar PV	4.62 kW	7.14 kW	7.14 kW	0 kW	0 kW	6.31 kW	5.04 kW	4.20 kW

Bungalow

This section contains the specifications and assumptions for a detached 3-bedroom bungalow.



Energy modelling | Bungalow

A 3-bedroom home was selected, which had been developed as a new build property.

Building fabric

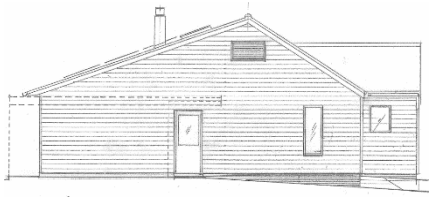
The property has a gross internal floor area of 108m². The main entrance faces the street to the South, while the rear of the house faces to the North and features a small garden. The property has typical glazing proportions and layout. The form heat loss factor of 4.4 is poor but is expected for a detached bungalow. As a result, even with high levels of insulation, the space heating demand is higher than the other house types. In practice, we would expect developers to reduce heat loss by optimising the design of the building, as this would be cheaper than using high levels of insulation. For example, glazing ratios could be reduced.

Heating

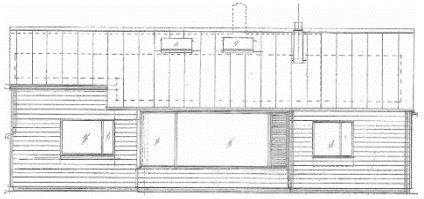
The baseline Part L 2021 scenario assumes use of a combi boiler, although this is not compliant with net zero planning policies. Two additional Part L 2021 scenarios assume use of direct electric heating, while the remaining scenarios assume use of an air-water heat pump. A cheaper air-air heat pump, or a ground source heat pump could also be used. Suitable heat emitters include radiators, or underfloor heating for scenarios with poorer fabric efficiency.

Solar PV

The property has more than enough space to achieve a net zero energy balance on-site in any orientation. As presented on plans, the property has sufficient space for 36 solar panels. There is additional space for 2 panels on the smaller roof section to the rear of the property. If the property faced East or West, it would be possible to install more panels on the rear plane of the main roof.

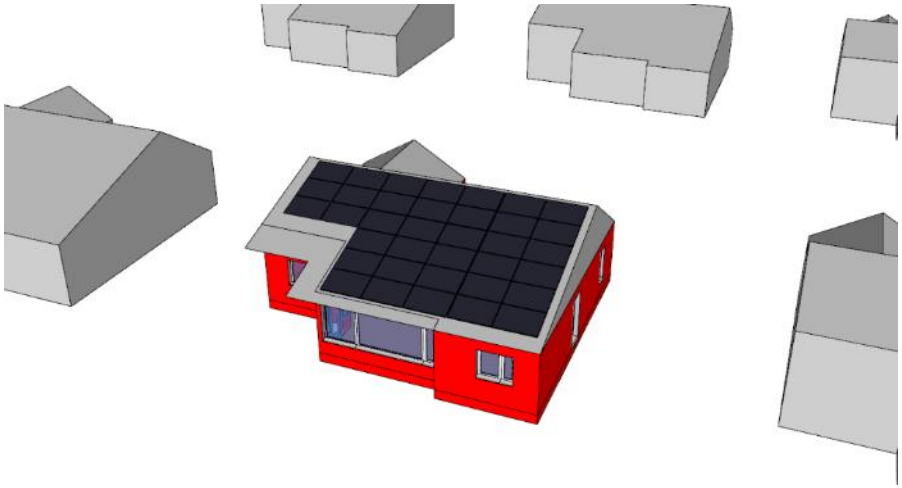


East Elevation



South Elevation

A typical 3 bedroom bungalow was selected



A 3D model of the house and surrounding features was created in DesignPH 2.1.15 and used to calculate solar gains and shading for PHPP.

Energy modelling | Bungalow Specifications

	Part L 2021 Gas Boiler	Part L 2021 Insulation Direct Electric	Part L 2021 Airtightness Direct Electric	Part L 2021 Insulation Heat Pump	Part L 2021 Airtightness Heat Pump	Future Homes Standard	Low Carbon	Truly Affordable Net Zero
Building fabric strategy	Part L 2021 compliant fabric, developer spec	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	Part L 2021 compliant fabric, insulation led	Part L 2021 compliant fabric, airtightness led	FHS notional building specification	To achieve space heat demand of 30 kWh/m²/yr	To achieve space heat demand of 15-20 kWh/m²/yr
Floor (W/m^{2}K, SAP adjusted)	0.130	0.130	0.130	0.130	0.130	0.130	0.150	0.090
Walls (W/m^{2}K)	0.160	0.160	0.200	0.160	0.200	0.160	0.100	0.090
Roof (W/m^{2}K)	0.100	0.100	0.110	0.100	0.110	0.100	0.100	0.080
Windows (W/m^{2}K)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	1.2 (double-glazed)	0.8 (triple-glazed)
Doors (W/m^{2}K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Air Permeability (m^3/m^2/hr)	5	5	3	5	3	5	1	0.60
Ventilation	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	0% heat recovery 0.08 Wh/m^3 0.18 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s	88% HR. 2m duct 25mm insulation 0.24 Wh/m^3 0.60 W/l/s
Space Heating	Gas combi boiler Radiators at <60˚C Weather comp	Direct electric	Direct electric	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <45˚C Weather comp	5kW ASHP Radiators at <35˚C Weather comp
Domestic Hot Water	Gas combi boiler WWHR 36%	150l direct electric tank at 60˚C 1.1kWh/day loss	150l direct electric tank at 60˚C 1.1kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss	200l heat pump tank at 55˚C 1.4kWh/day loss
Solar PV	5.88 kW	8.82 kW	8.82 kW	0.42 kW	0.42 kW	9.66 kW	4.62 kW	3.78 kW

6.0

Appendices

Appendix A | Approach to thermal bridging

Causes of thermal bridging

Thermal bridging often occurs at junctions in the building envelope due to:

1. Structural thermal bridging, which result from additional structural materials required in these locations.
2. Geometrical thermal bridging, which results from the under or over counting of heat loss areas. In SAP, heat loss areas are typically under counted, while in PHPP they are usually over counted.

In the development of the SAP Conversion Tool, it was necessary to calculate the expected thermal bridging in SAP and PHPP to ensure the tool's fabric heat loss calculations could be properly calibrated.

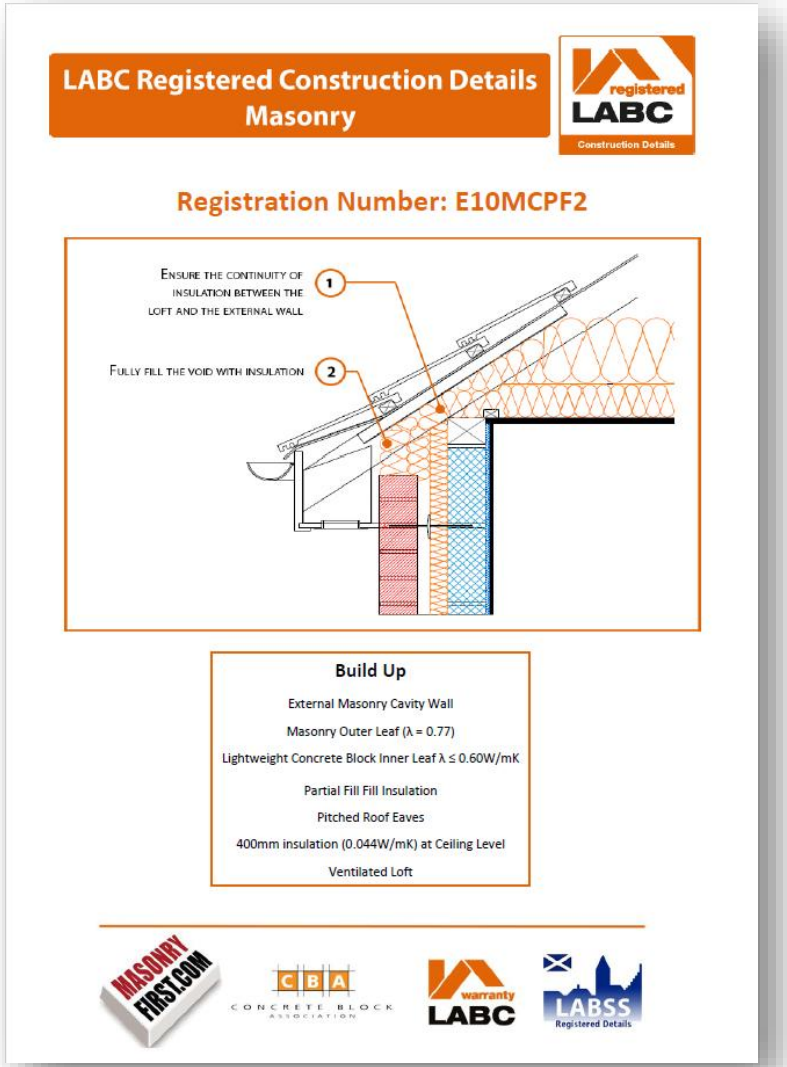
Thermal bridging locations

Thermal bridging may be expected at the following junctions for the buildings modelled:

- Window/door sills/thresholds, jambs and lintels
- External wall to ground floor
- Eaves
- Gable
- Vertical wall corners (both normal and inverted)
- Vertical party wall junctions
- Party wall to ground floor
- Party wall to ceiling

Junction Designs

LABC details for most of these junctions were used as the basis for thermal bridge modelling to create a full set of values that could be used for all the dwellings. The details assumed beam and block floors with masonry cavity wall construction and insulation at ceiling level.



Example of an LABC detail that was used for thermal bridge modelling of the eaves junction. Insulation depths were varied according to scenario. © LABC

Internal vs External

Thermal bridging for most junctions is measured as the amount of Watts of heat loss per linear meter of junction. This is called a PSI-value. When PSI-values are calculated, the way the heat loss areas are measured in the thermal bridge model must be the same as the way they are modelled in the main SAP or PHPP energy model for which they will be used.

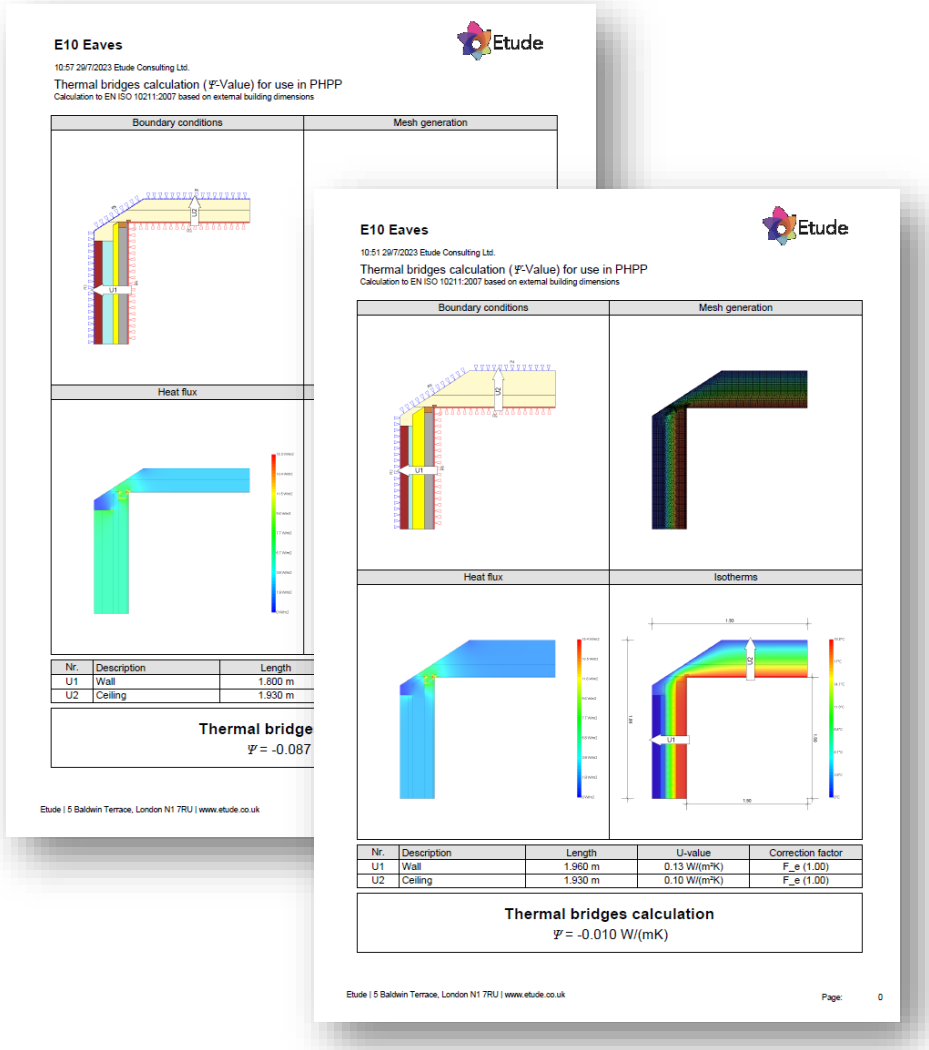
In SAP, the heat loss areas are measured based on the internal dimensions of the building, this means the thermal bridge calculations must also use the internal dimensions. In PHPP, the heat loss areas are measured based on the external dimensions of the building's thermal envelope, this means the thermal bridge calculations must also use the external dimensions.

For each junction, two sets of thermal bridge calculations were carried out, one based on the internal dimensions of the junction and one based on the external dimensions.

Insulation Depth

The amount of thermal bridging present in a junction, and therefore the PSI-value, vary depending on the amount of insulation present in the adjacent building elements. As different amounts of insulation were assumed for each dwelling and performance scenario, this meant it would not be accurate to use a single set of PSI-values.

To address this, for each junction two thermal bridge calculations were done, with different U-values for the adjacent floors/walls/roofs. One calculation assumed the best U-values that were expected, and one assumed the worst U-values permitted under Part L 2021. This provided an upper and lower PSI-value for each junction. For any specific combination of U-values that were assumed in the main energy model, a bespoke PSI-value could then be determined by interpolating between the best and worst cases. This assumes a linear relationship between the U-values of adjacent elements and the junction's PSI-value, which is unlikely to be the case in practice, however the approach is expected to be accurate enough for the purposes of calibrating the SAP Conversion Tool.



Example of separate thermal bridge calculations for the best (foreground) and worst (background) case U-values expected for the wall and ceiling adjacent to the eaves junction. These calculations provided a range of PSI-values, from which a bespoke value could be interpolated, depending on the U-values of the adjacent wall and ceiling in each scenario.

Appendix A | Approach to thermal bridging

			Terraced								Semi-Detached							
			Part L 2021 - Insulation - Gas Boiler	Part L 2021 - Insulation - Direct Electric	Part L 2021 - Airtightness - Direct Electric	Part L 2021 - Insulation - Heat Pump	Part L 2021 - Airtightness - Heat Pump	FHS - Heat Pump	Low Carbon - Heat Pump	TANZ - Heat Pump	Part L 2021 - Insulation - Gas Boiler	Part L 2021 - Insulation - Direct Electric	Part L 2021 - Airtightness - Direct Electric	Part L 2021 - Insulation - Heat Pump	Part L 2021 - Airtightness - Heat Pump	FHS - Heat Pump	Low Carbon - Heat Pump	TANZ - Heat Pump
		8	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SAP	E2 Lintel	0.050	0.05	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E3 Sill	0.050	0.05	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E4 Jamb	0.050	0.05	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E5 Ground Floor Perimeter	0.163	0.16	0.161	0.159	0.161	0.159	0.161	0.160	0.163	0.161	0.161	0.159	0.161	0.159	0.161	0.158	0.163
	E10 Eaves	0.097	0.09	0.087	0.082	0.087	0.082	0.087	0.084	0.097	0.087	0.087	0.080	0.087	0.080	0.087	0.078	0.095
	E12 Gable	0.106	0.11	0.114	0.117	0.114	0.117	0.114	0.116	0.106	0.114	0.114	0.119	0.114	0.119	0.114	0.120	0.108
	E16 Corner	0.038	0.05	0.046	0.050	0.046	0.050	0.046	0.044	0.038	0.046	0.046	0.050	0.046	0.050	0.046	0.052	0.040
	E17 Inverted Corner	-0.062	-0.07	-0.075	-0.082	-0.075	-0.082	-0.075	-0.072	-0.062	-0.075	-0.075	-0.082	-0.075	-0.082	-0.075	-0.085	-0.065
	E18 Party Wall	0.035	0.04	0.038	0.040	0.038	0.040	0.038	0.037	0.035	0.038	0.038	0.040	0.038	0.040	0.038	0.041	0.036
	P1 Party Wall-Ground Floor	0.134	0.14	0.140	0.148	0.140	0.148	0.140	0.146	0.134	0.142	0.142	0.148	0.142	0.148	0.142	0.152	0.134
	P4 Party Wall-Roof	0.096	0.11	0.105	0.109	0.105	0.109	0.105	0.107	0.096	0.105	0.105	0.111	0.105	0.111	0.105	0.113	0.098
			0.00															
PHPP	E2 Lintel	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E3 Sill	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E4 Jamb	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E5 Ground Floor Perimeter	0.077	0.064	0.064	0.048	0.064	0.048	0.064	0.051	0.077	0.061	0.061	0.048	0.061	0.048	0.061	0.038	0.077
	E10 Eaves	0.000	-0.022	-0.022	-0.030	-0.022	-0.030	-0.022	-0.026	0.000	-0.022	-0.022	-0.034	-0.022	-0.034	-0.022	-0.039	-0.005
	E12 Gable	0.009	0.006	0.006	0.005	0.006	0.005	0.006	0.005	0.009	0.006	0.006	0.004	0.006	0.004	0.006	0.004	0.008
	E16 Corner	-0.065	-0.091	-0.091	-0.105	-0.091	-0.105	-0.091	-0.085	-0.065	-0.091	-0.091	-0.105	-0.091	-0.105	-0.091	-0.111	-0.071
	E17 Inverted Corner	0.041	0.062	0.062	0.073	0.062	0.073	0.062	0.057	0.041	0.062	0.062	0.073	0.062	0.073	0.062	0.078	0.046
	E18 Party Wall	0.011	0.006	0.006	0.004	0.006	0.004	0.006	0.008	0.011	0.006	0.006	0.004	0.006	0.004	0.006	0.003	0.010
	P1 Party Wall-Ground Floor	0.114	0.117	0.117	0.122	0.117	0.122	0.117	0.121	0.114	0.118	0.118	0.122	0.118	0.122	0.118	0.124	0.114
	P4 Party Wall-Roof	0.078	0.084	0.084	0.087	0.084	0.087	0.084	0.086	0.078	0.084	0.084	0.088	0.084	0.088	0.084	0.089	0.079

			Detached								Bungalow							
			Part L 2021 - Insulation - Gas Boiler	Part L 2021 - Insulation - Direct Electric	Part L 2021 - Airtightness - Direct Electric	Part L 2021 - Insulation - Heat Pump	Part L 2021 - Airtightness - Heat Pump	FHS - Heat Pump	Low Carbon - Heat Pump	TANZ - Heat Pump	Part L 2021 - Insulation - Gas Boiler	Part L 2021 - Insulation - Direct Electric	Part L 2021 - Airtightness - Direct Electric	Part L 2021 - Insulation - Heat Pump	Part L 2021 - Airtightness - Heat Pump	FHS - Heat Pump	Low Carbon - Heat Pump	TANZ - Heat Pump
		8	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
SAP	E2 Lintel	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E3 Sill	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E4 Jamb	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E5 Ground Floor Perimeter	0.163	0.161	0.161	0.159	0.161	0.159	0.161	0.160	0.165	0.160	0.160	0.158	0.160	0.158	0.160	0.162	0.165
	E10 Eaves	0.097	0.087	0.087	0.080	0.087	0.080	0.087	0.089	0.101	0.087	0.087	0.076	0.087	0.076	0.087	0.099	0.106
	E12 Gable	0.106	0.114	0.114	0.119	0.114	0.119	0.114	0.113	0.103	0.114	0.114	0.122	0.114	0.122	0.114	0.105	0.100
	E16 Corner	0.038	0.044	0.044	0.050	0.044	0.050	0.044	0.044	0.034	0.046	0.046	0.054	0.046	0.054	0.046	0.034	0.032
	E17 Inverted Corner	-0.062	-0.072	-0.072	-0.082	-0.072	-0.082	-0.072	-0.072	-0.055	-0.075	-0.075	-0.088	-0.075	-0.088	-0.075	-0.055	-0.052
	E18 Party Wall	0.035	0.037	0.037	0.040	0.037	0.040	0.037	0.037	0.033	0.038	0.038	0.042	0.038	0.042	0.038	0.033	0.032
	P1 Party Wall-Ground Floor	0.134	0.142	0.142	0.148	0.142	0.148	0.142	0.146	0.129	0.145	0.145	0.151	0.145	0.151	0.145	0.138	0.128
	P4 Party Wall-Roof	0.096	0.105	0.105	0.111	0.105	0.111	0.105	0.103	0.092	0.105	0.105	0.114	0.105	0.114	0.105	0.094	0.089
PHPP	E2 Lintel	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E3 Sill	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E4 Jamb	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	E5 Ground Floor Perimeter	0.077	0.061	0.061	0.048	0.061	0.048	0.061	0.051	0.087	0.054	0.054	0.041	0.054	0.041	0.054	0.067	0.090
	E10 Eaves	0.000	-0.022	-0.022	-0.034	-0.022	-0.034	-0.022	-0.017	0.008	-0.022	-0.022	-0.043	-0.022	-0.043	-0.022	0.004	0.017
	E12 Gable	0.009	0.006	0.006	0.004	0.006	0.004	0.006	0.007	0.010	0.006	0.006	0.003	0.006	0.003	0.006	0.009	0.011
	E16 Corner	-0.065	-0.085	-0.085	-0.105	-0.085	-0.105	-0.085	-0.085	-0.051	-0.091	-0.091	-0.118	-0.091	-0.118	-0.091	-0.051	-0.045
	E17 Inverted Corner	0.041	0.057	0.057	0.073	0.057	0.073	0.057	0.057	0.031	0.062	0.062	0.083	0.062	0.083	0.062	0.031	0.025
	E18 Party Wall	0.011	0.008	0.008	0.004	0.008	0.004	0.008	0.008	0.013	0.006	0.006	0.002	0.006	0.002	0.006	0.013	0.015
	P1 Party Wall-Ground Floor	0.114	0.118	0.118	0.122	0.118	0.122	0.118	0.121	0.112	0.120	0.120	0.123	0.120	0.123	0.120	0.117	0.111
	P4 Party Wall-Roof	0.078	0.084	0.084	0.088	0.084	0.088	0.084	0.083	0.075	0.084	0.084	0.091	0.084	0.091	0.084	0.077	0.073

The full set of PSI-values assumed in both SAP and PHPP for all dwellings and performance scenarios. Use of a complete set was necessary to ensure accurate calibration of the SAP Conversion Tool.