Department for
Energy Security
& Net Zero

The Home Energy Model

Making the Standard Assessment Procedure fit for a net zero future

Closing date: 23:59 on 27 March 2024 (extended from 6 March)

December 2023

Any enquiries regarding this publication should be sent to us at: homeenergymodel@energysecurity.gov.uk

Executive Summary

This consultation presents the government's new Home Energy Model, a calculation methodology designed to assess the energy performance of our homes.

The Home Energy Model will replace the Standard Assessment Procedure (SAP), which was first published in 1993. Like SAP before it, the Home Energy Model will underpin a large number of government policies, making it of critical importance to the delivery of both our housing and climate objectives.

One of our aims has been to clarify and delineate between the model's different purposes and functions. The first function we have developed is for demonstrating compliance with the Future Homes Standard. In future, other functions will be added, including the production of Energy Performance Certificates. To support this, we have separated the model's core building physics from any policy-specific assumptions. This will enable users to adapt and use the model in various contexts, with different inputs and outputs suited to their needs.

The Home Energy Model is the result of a significant development process which has sought to align with modern international energy modelling standards and the best available technical evidence. The new model simulates energy performance for each half-hour of the day (as compared to each month for SAP), enabling a better representation of smart technologies and systems.

To test its ability, the Home Energy Model is being validated against other building energy models, laboratory data, and monitoring data from real homes. Validation is an iterative exercise, and we present its current status in this publication. This validation work will continue until the model goes 'live' alongside the Future Homes Standard in 2025.

Another key aim of the project has been to increase the transparency of the calculation methodology. We have therefore published the Home Energy Model codebase and aim to develop it in the open in future.

Looking ahead, we will be considering reforms to how the model will recognise new technologies and product-specific performance data, as well as how software is provided to energy assessors.

This consultation will be of interest across the built environment sector, and we look forward to engaging with stakeholders to facilitate feedback on the model and its development. Throughout the consultation period, we will be running of series of stakeholder engagement events. We encourage you to email homeenergymodel@energysecurity.gov.uk to find out more.

Contents

General information

Why we are consulting

The government is consulting on the new Home Energy Model, which will replace the Standard Assessment Procedure (SAP) for the energy rating of dwellings.

SAP is the methodology currently used by the government to estimate the energy performance of homes across the United Kingdom. This methodology is therefore of critical importance to the delivery of our housing and climate change objectives.

Following recommendations by the Climate Change Committee (CCC) and a scoping study commissioned by the then Department for Business, Energy and Industrial Strategy, we are developing a new methodology to increase its accuracy, robustness, and ensure it is fit to support the transition to net zero.

We are publishing this consultation on the Home Energy Model in order to:

- summarise the development and validation work undertaken to date; and
- facilitate feedback to enable further model development in advance of its introduction.

The Home Energy Model is still under development and its first version will be implemented alongside the Future Homes Standard in 2025.

We are publishing this consultation while the Home Energy Model is still at a formative stage to enable industry to participate in the ongoing development process.

Consultation details

Issued: 13/12/2023

Respond by: 23:59 on 27/03/2024

Enquiries to: homeenergymodel@energysecurity.gov.uk

Consultation reference: The Home Energy Model

Audiences: This consultation will be of interest to several different audiences, such as:

- SAP/RdSAP assessors and assessor accreditation schemes
- Construction industry professionals
- Product manufacturers and suppliers
- Local authorities and other building control bodies
- Academics and consultants

Given the variety of audiences, we set out which parts of the consultation might be of particular interest to specific groups in Chapter 1.

Territorial extent:

The Secretary of State has previously approved SAP as the methodology to:

- demonstrate that new dwellings in England comply with energy performance standards in the Building Regulations. See this notice of approval.
- produce Energy Performance Certificates (EPCs) in England and Wales as set out in the Energy Performance of Buildings Regulations. See this notice of approval.

The Building Regulations are devolved to Scotland, Wales, and Northern Ireland, while the Energy Performance of Building Regulations are only devolved to Scotland and Northern Ireland. However, historically, all UK Administrations have used an adapted version of SAP for both purposes. Therefore, this consultation will likely be of interest to stakeholders from all parts of the UK.

The Devolved Administrations have been involved in the development of this consultation and will determine whether they will use the Home Energy Model, or a version of it, for these devolved purposes in future.

How to respond

We strongly encourage responses via Citizen Space. Consultations receive a high-level of interest across many sectors. Using the online service greatly assists our analysis of the responses, enabling more efficient and effective consideration of the issues raised.

Respond online at: https://energygovuk.citizenspace.com/heat/home-energy-model

Or if you are unable to respond via Citizen Space:

Email to: homeenergymodel@energysecurity.gov.uk

Please do not send responses by post to the department.

When responding, please state whether you are responding as an individual or representing the views of an organisation.

Your response will be most useful if it is framed in direct response to the questions posed, though further comments and evidence are also welcome.

Confidentiality and data protection

Information you provide in response to this consultation, including personal information, may be disclosed in accordance with UK legislation (the Freedom of Information Act 2000, the Data Protection Act 2018 and the Environmental Information Regulations 2004).

If you want the information that you provide to be treated as confidential please tell us, but be aware that we cannot guarantee confidentiality in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not be regarded by us as a confidentiality request.

We will process your personal data in accordance with all applicable data protection laws. See our Privacy notice relating to consultation responses and Personal information charter for more information.

We intend to share responses to this consultation, including personal data, with our third-party contractors (the Building Research Establishment and Etude) for the purposes of analysis of consultation responses and further development of the Home Energy Model. We also intend to share anonymised responses with the Devolved Administrations for their use in policy development work.

We will summarise all responses and publish this summary on GOV.UK. The summary will include a list of names or organisations that responded, but not people's personal names, addresses or other contact details.

Quality assurance

This consultation has been carried out in accordance with the government's consultation principles. If you have any complaints about the way this consultation has been conducted, please email: bru@energysecurity.gov.uk

Chapter 1: How to use this document

This chapter gives an overview of the publication package, including where readers can find different pieces of information.

1.1 What has been published?

This consultation document is part of a wider package of material published by the government relating to the Home Energy Model and the Future Homes Standard (FHS). Depending on your interests, you may be interested in all or part of this consultation document, as well as one or more of the other publications within this package. The full list of publications is as follows:

The Home Energy Model consultation (this document)

What: This document explains the overhaul to the SAP methodology and seeks views on the approach taken by the new Home Energy Model.

Audience: This document will be of interest to those who want to understand the proposed changes to the SAP methodology and wider SAP landscape.

Please note that this consultation does not cover Energy Performance Certificate (EPC) reform and does not include a specific Home Energy Model methodology for producing EPCs.

The government is working on proposals for improving EPCs, including the performance metrics they display, and intends to consult on these separately in the coming months. The outcome of the EPC consultation will feed into the development of a Home Energy Model methodology for producing EPCs, which we aim to consult on in 2024.

The Home Energy Model: Future Homes Standard assessment consultation

What: The Home Energy Model: Future Homes Standard assessment consultation ("Home Energy Model: FHS assessment consultation") seeks views on the proposed methodology for demonstrating compliance with the Future Homes Standard (FHS).

Audience: The Home Energy Model: FHS assessment consultation will be of interest to those who want to understand the proposed standardised assumptions around occupancy, energy demand etc. to be used when assessing compliance with the FHS, as well as the methodology for the calculation of the proposed FHS compliance metrics.

The Future Homes and Buildings Standards 2023 consultation

What: The Future Homes and Buildings Standards 2023 consultation (hereafter referred to as the "FHS consultation")
ks views on proposed changes to Part L of the Building Regulations and the accompanying statutory guidance for new dwellings and non-domestic buildings. These changes will be implemented in 2025.

Audience: The FHS consultation will be of interest to those who want to understand the proposed standards for the energy performance of new dwellings under the FHS.

Home Energy Model: FHS assessment consultation tool

What: Alongside the three consultations listed above, we have published a Home Energy Model: FHS assessment consultation tool, as a browser-based application. This consultation tool gives the opportunity to interact with the model by providing a demo user interface. See the user guide for more information.

Audience: The consultation tool will be of interest to those who want to test out the Home Energy Model: FHS assessment and understand whether different dwelling designs are likely to comply with the proposed Future Homes Standard.

Home Energy Model technical documentation

What: This consultation is accompanied by several technical documents which go into further detail on the methodology and the validation exercises that have been carried out.

Audience: The technical documentation will be of interest to those who want to understand the detail of how the Home Energy Model works and how different technologies are treated.

The Home Energy Model reference code

What: The full Python source code for the Home Energy Model and the Home Energy Model: FHS assessment has been published as a Git repository. This code is identical to that sitting behind the consultation tool. We are currently considering whether the open-source code could serve as the approved methodology for regulatory uses of the Home Energy Model.

Audience: The reference code will be of interest to those who want to understand how the model has been implemented in code, and those wishing to fully clarify their understanding of the new methodology. It will also be of interest to any potential contributors to the Home Energy Model.

1.2 Where can I find information on…?

Topic	Location
Overview of the Home Energy Model and how it differs from SAP.	Chapter 2 and Chapter 4
Changes to the wider SAP landscape (e.g. how new technologies will be recognised, how software will be provided to energy assessors).	Chapter 3
Explanation of how a home's energy performance is modelled in the Home Energy Model.	Chapter 5 and the accompanying technical documentation
Information on how the Home Energy Model has been tested and validated.	Chapter 6
Assumptions used when assessing compliance with the FHS (e.g. occupancy, energy demand, weather data).	Home Energy Model: FHS assessment consultation
Calculation methodology to determine FHS compliance.	Home Energy Model: FHS assessment consultation
The proposed FHS compliance metrics.	The FHS consultation
Methodology for calculating energy performance of non-domestic buildings	The FHS consultation
EPC reform, including EPC metrics and any model calculations or assumptions specific to EPCs.	*EPC reform is not covered in any of these publications. We are developing proposals to improve EPCs and intend to consult on these in the coming months.*

Chapter 2: The need to replace SAP

The Standard Assessment Procedure (SAP) for the energy rating of dwellings is the methodology currently used by the government to estimate the energy performance of homes. In England, the methodology has two main uses:

- To demonstrate compliance of new homes with Part L of the Building Regulations
- To generate Energy Performance Certificates (EPCs) for all homes, which advise occupants, prospective buyers, landlords, and renters of the energy performance of a property.

Please note that non-domestic buildings use a different methodology, called the Simplified Building Energy Model (SBEM). See the FHS consultation for further information on proposed changes to SBEM.

SAP plays a key role in developing, implementing, and monitoring government policies on energy efficiency, fuel poverty and heat decarbonisation, and is used across the whole building industry. SAP can determine whether a property can legally be let, and whether it is eligible for various support and finance schemes to support retrofit improvements.

The government recognises that there are longstanding issues with SAP, which are not conducive to the delivery of our housing and climate change objectives. The government has therefore decided to undertake the first complete overhaul of the SAP methodology and wider ecosystem to ensure it is fit to support the transition to net zero. This publication package presents a consultation version of the new Home Energy Model, which will replace SAP from the middle of this decade.

This chapter summarises the history of SAP and the Home Energy Model project:

2.1 The history of SAP

SAP was developed by the Building Research Establishment (BRE) for the former Department of the Environment and was based on the BRE Domestic Energy Model (BREDEM). SAP was first published in 1993 and has since been updated periodically, in 1998, 2001, 2005, 2009, 2012, and most recently in 2022.

In 1994, SAP was first cited in the Building Regulations as the means of assessing the energy performance of dwellings. In 2007 it was adopted as the methodology behind Energy Performance Certificates (EPCs).

Reduced data SAP (RdSAP) was introduced in 2005 as a simpler and lower cost method for assessing existing dwellings. An RdSAP assessment will use a set of assumptions about the dwelling, reducing the volume of data an energy assessor must collect.

The current version of SAP is SAP 10.2, with the corresponding RdSAP update due for release in spring 2024.

SAP was originally designed to be completed using pen and paper (and handheld calculator) by an assessor on site. This required that the model be very simple compared to the modern industry standard. Over the course of its life, updates to SAP have improved aspects of the methodology and revised input assumptions, but the fundamental underlying workings have remained. SAP is therefore limited in its ability to model modern dwellings and technologies, and it is time to undertake a complete overhaul of the methodology.

2.2 Considering the future of SAP

Our key aim is to make a new methodology which is fit for a net zero future. Therefore, it is imperative that the methodology is transparent, directly supports industry, policy, and research, and recognises buildings that are "net zero ready".

The Climate Change Committee (CCC) has made several recommendations in the past to review and update SAP, including in their recent UK housing paper and Independent Assessment of the UK's Heat and Buildings Strategy. These include ensuring SAP drives high real-world performance and that it values the benefits of low carbon technologies.

In 2020, the SAP Industry Forum released an independent report on the likely mainstream technologies for home energy performance in the mid-2020s. This report set out how these technologies could be modelled in SAP and noted several barriers to properly representing them using the current methodology.

More recently, other recommendations have been made which bear on SAP and reinforce the need for a new approach, such as the 2023 Mission Zero review led by Chris Skidmore MP.

In response to the various issues raised, the government commissioned a scoping study in 2020 to holistically consider how the next version of SAP ("SAP 11", now known as the Home Energy Model) could be enhanced to support the transition to net zero. A consortium led by Etude[1] conducted a wide-ranging landscape and literature review, gathering feedback from

[1] Project team: CIBSE, Clarion Housing Group, Elementa, Levitt Bernstein, UCL, WSP, and Etude

over 300 industry members, and assessing energy modelling methodologies used in other countries.

The final report, "Making SAP and RdSAP 11 fit for net zero" was published in 2021. The study concluded that significant changes were needed to SAP, leading to 25 recommendations across five categories:

1. Alignment between SAP/RdSAP and its strategic objectives
2. Improvements to the methodology
3. Improvements to SAP/RdSAP and its ecosystem for net zero
4. A better evaluation of energy use
5. Support to decarbonisation of heat and electricity.

You can find the full list of 25 recommendations and how we are addressing each of them in Annex A.

In 2021, the government appointed a consortium of experts led by the BRE[2] to carry out a multi-year project to develop a replacement for SAP. Given the importance and duration of this project, the government additionally appointed a consortium led by Etude[3] to quality assure the work undertaken. This consultation and the accompanying material represent the work undertaken by this project to date.

2.3 A new name for a new methodology: the Home Energy Model

The model presented in this document and the accompanying material represents a fundamental overhaul to previous versions of SAP. The name "SAP" (Standard Assessment Procedure) implies a restricted use and single application, as well as continuity with previous versions. The new model has been developed from scratch using alternative sources to SAP and has the potential to be used in a much broader set of applications.

To express this significant change, we intend to introduce the new methodology with a new name:

The Home Energy Model

[2] Project team: BRE, AECOM, Sustenic, University of Strathclyde, Loughborough University, Kiwa, Zensar, John Tebbit, Chris Martin

[3] Project team: Levitt Bernstein, UCL, Julie Godefroy Sustainability, and Etude.

We believe this name is more intuitive and descriptive of the model's core function, which is to simulate the energy performance of a home.

1. What are your views on the choice of name for the new model? Please provide your reasoning and any supporting evidence.

We intend to call the version of the model used to demonstrate compliance with the Future Homes Standard:

The Home Energy Model: FHS assessment

Having a different name for this regulatory application will help to distinguish the underlying building physics model from this specific application with its standardised inputs and outputs. See Section 3.5 for more information on this distinction.

2. What are your views on the choice of name for the version of the model which is to be used to demonstrate compliance with the Future Homes Standard? Please provide your reasoning and any supporting evidence.

In advance of the implementation, we will consider the wider implications of this name change across all the current use cases of SAP.

3. What are your views on the potential implications of this proposed name change? Please provide your reasoning and any supporting evidence.

Note that "SAP 11" has been used as a working title for the Home Energy Model throughout the development process. There is no separate model with the name "SAP 11" and all previous references to that name should be taken to refer to the Home Energy Model.

Chapter 3: A new home energy modelling ecosystem

In order to make the Home Energy Model fit for net zero, changes are needed not just to the methodology, but to the surrounding ecosystem. The Home Energy Model incorporates a number of structural changes to enable a more open, evidence-based methodology, and increase its potential applications.

This chapter describes some of the main changes to the model ecosystem, including:

- 3.1 An open-source methodology
- 3.2 Changes to the delivery model and provision of software
- 3.3 A revised database of product characteristics
- 3.4 Recognising new technologies in the Home Energy Model
- 3.5 Using “wrappers” to distinguish different use cases

Changes to the building physics model itself are discussed in Chapter 4.

3.1 An open-source methodology

One of the aims of the Home Energy Model project has been to increase the transparency of the methodology, in line with the government’s Technology Code of Practice. We have, therefore, decided to publish the Home Energy Model codebase.

We aim to develop the Home Energy Model in the open from this point on, as we further refine and expand the model. This would mean that changes to the Home Energy Model would be visible before they are formally implemented into regulatory applications.

Releasing the full Home Energy Model codebase means that there is a precise and unambiguous reference version of the methodology available. The accompanying technical documents are there to provide further explanation, as well as supporting evidence, for different aspects of the model. This should significantly improve transparency and understanding among the Home Energy Model’s different audiences, as well as facilitate scrutiny and peer review.

We are currently considering whether the open-source code could serve as the approved methodology for regulatory uses of the Home Energy Model (e.g. for Building Regulations compliance purposes). This would mean that the code replaces the specification document that has served this role for previous versions of SAP, and act as the ultimate legal reference for the methodology.

The Home Energy Model is being released under the MIT Licence in line with the government’s Technology Code of Practice, and is subject to Crown Copyright. This means that all or parts of the model are freely available for use, subject to appropriate acknowledgement. We hope that this, in combination with the other changes described in this chapter, will facilitate the growth of a community of users who can adapt the Home Energy Model for their own purposes, and some of whose contributions may ultimately form part of the official version as used by government.

4. What are your views on using the open-source code as the approved methodology for regulatory uses of the Home Energy Model? Please provide your reasoning and any supporting evidence.

5. What forms of collaboration would you be interested in for future development of the Home Energy Model codebase? Please provide further details.

3.2 Changes to the delivery model and provision of software

The government is considering reforms to how the Home Energy Model software is provided to energy assessors for their use to demonstrate Part L compliance and lodge Energy Performance Certificates (EPCs).

This section describes the current delivery model and its issues, before seeking views on potential reforms.

How is SAP currently delivered?

SAP is currently delivered in a disaggregated model between the government, the SAP development contractor (currently BRE), and other private software developers.

The government owns the SAP methodology, which is publicly available as a PDF download from the SAP contractor's website. Software developers use this methodology and testing materials (including test cases) provided by the SAP contractor to design their own SAP software, which is then verified by the SAP contractor. Following successful verification, the government approves SAP software for use by energy assessors. Official SAP assessments are lodged to the Energy Performance of Buildings (EPB) register, which is a database held by the government.

Challenges with the current delivery model

The current delivery model has several issues, including:

- **Inconsistencies in results:** The specification is implemented independently by each software provider and validated to within a defined tolerance over a limited range of example cases. Therefore, there can be small differences in results depending on which software implementation is used.
- **Inertia:** The SAP methodology is slow to change as it requires several organisations to develop, test, and deploy software in a coordinated process.

- **Lack of accountability:** Working software is required for housebuilders, landlords, homeowners, and others to comply with government regulations, but no single body is responsible for delivering it.

6. What are your views on our assessment of issues with the current SAP delivery model? Please provide your reasoning and any supporting evidence.

Possible changes to the delivery model

The government is exploring alternative delivery models for regulatory uses of the Home Energy Model, including the provision of a home energy performance calculator. In this scenario, the government would provide a centralised, cloud-based version of the Home Energy Model calculation engine, which software providers could build their user interfaces around.

Having a centralised, cloud-based version of the Home Energy Model would reduce the time, resource, and financial burden on third parties to set up their own calculation engines, while ensuring all assessments use an identical calculation methodology. This should reduce barriers to market entry and thereby stimulate innovation among providers of Home Energy Model interface software. This would also enable modifications or improvements to be rolled out quickly on the central platform, without needing to propagate changes through many versions of software.

We will explore the options for how this cloud-based calculation engine could interact with the open-source reference code in the next phase of development.

7. What are your views on the concept of a centralised, cloud-based version of the Home Energy Model, to be used for regulatory purposes? Please provide your reasoning and any supporting evidence.

What are the next steps?

The government intends for these changes to the delivery model to take effect when the first version of the Home Energy Model is deployed alongside the Future Homes Standard in 2025. We will be working closely with industry, including with SAP software providers, energy assessors, and building control bodies to explore these proposed changes, and will provide further information in due course.

3.3 A revised database of product characteristics

This section discusses the use of product-specific performance data within SAP: its importance, how it is currently incorporated, and our intentions for the Home Energy Model.

The importance of product-specific performance data

When representing building service systems in a home, SAP software can either use pessimistic default values or product-specific performance data. This latter data is submitted by product manufacturers and stored within the Product Characteristics Database (PCDB). The PCDB plays a crucial role in technology markets by rewarding higher performing products.

How is product-specific performance data currently incorporated into SAP?

If a manufacturer's product falls within one of the technology categories recognised in the PCDB (e.g. boilers, heat pumps, heat networks), they can apply for their product performance data to be included in the database. Manufacturers will submit test data (usually conforming to a European Standard procedure) which is verified and audited by the government's SAP contractor. For innovative technologies which have no precedent in SAP, a new test specification is agreed through the "Appendix Q" process (see Section 3.4).

How will the new Home Energy Model recognise product-specific performance data?

The consultation version of the Home Energy Model (both the reference code and consultation tool) is not compatible with the existing PCDB format. As part of the Home Energy Model project, the database will be rebuilt from the existing underlying test data, and new classes of products will be added. A selection of dummy products is incorporated within the consultation tool to enable testing of this consultation version of the Home Energy Model.

When the Home Energy Model is 'live', we intend for all product performance data to be stored in a database that is separate from the Home Energy Model core engine. This database may include default products for certain technology types, if necessary. The interaction between this revised database and Home Energy Model software will be explored as part of changes to the delivery model (see Section 3.2).

There may be some instances where the more in-depth modelling done by the Home Energy Model provides the opportunity for manufacturers to submit more detailed data on their product. For these cases, we intend to engage with manufacturers to facilitate this data on going 'live'. Examples of this may include boiler modulation ratios and the power of back-up heaters used with heat pumps.

The collection and auditing of product-specific performance data will be reviewed as part of wider Appendix Q reform, which is discussed in the next section.

8. What are your views on revising the database of product characteristics (currently the "PCDB") for the Home Energy Model? Please provide your reasoning and any supporting evidence.

9. What changes would you recommend to the PCDB data collection procedures? Please provide your reasoning and any supporting evidence.

10. What changes would you recommend to the PCDB data requirements for particular technologies? Please provide your reasoning and any supporting evidence.

3.4 Recognising new technologies in the Home Energy Model

This section sets out the importance of recognising new technologies when modelling home energy performance, and the challenges with the current SAP process. We then describe our intentions for recognising new technologies in the Home Energy Model and seek views on our proposed principles.

How does SAP currently recognise new technologies?

In order to deliver net zero-ready homes, there will be a need for innovative solutions. Incorporating these solutions into the Home Energy Model is important to enable them to be deployed at scale.

Manufacturers can currently apply for their new technology to be recognised in SAP through a process called **"Appendix Q"**. Appendix Q enables performance information on new technologies to be used within SAP software. A product's performance is determined by testing against a specification that has been agreed by the SAP contractor, the relevant manufacturer(s), and/or industry sector representatives. As its name suggests, "Appendix Q" is an external 'bolt-on' calculation, e.g. a spreadsheet, that is appended to the SAP calculation.

Challenges with the way SAP currently recognises new technologies

Several commentaries have identified issues with the current Appendix Q process, including:

- **Lack of transparency:** industry has reported a lack of clarity around the application process (including timeframes, level of evidence required etc.)
- **Financial and commercial risk weighted against the applicant:** industry has reported that the time and cost burden of the Appendix Q process presents a barrier to innovation.
- **Long timeframes:** the Appendix Q process can take a long time and therefore prevents SAP from being more responsive to new innovative solutions.
- **Poorly integrated models:** Separate "bolt-on" calculations are awkward for assessors and prevent new technologies from interacting properly with other Appendix Q technologies and some systems in the main SAP model.

11. What are your views on our assessment of issues with the way SAP currently recognises new technologies (currently the "Appendix Q process")? Please provide your reasoning and any supporting evidence.

How will existing Appendix Q technologies be recognised in the new the Home Energy Model?

Ahead of the Home Energy Model going 'live', we intend to fully integrate all existing Appendix Q technologies into the model and product characteristics database. We plan to engage with manufacturers and industry sector representatives regarding their products' implementation.

How will technologies currently going through the Appendix Q process be recognised in the new Home Energy Model?

We intend there to be an opportunity for technologies to be integrated into the Home Energy Model before the go-live date. We encourage manufacturers to engage with the open-source reference code and test how their technology could be modelled within the Home Energy Model for consideration. The government and SAP contractor will provide more information on this process in due course.

How will the Home Energy Model recognise new technologies once it goes 'live'?

The government intends to reform the process for incorporating new technologies into the Home Energy Model (note that the name "Appendix Q" is no longer meaningful and will be replaced). It will be important for this process to strike a balance between enabling novel, innovative technologies to be recognised in the Home Energy Model, while also providing certainty of product performance for consumers.

The proposed centralised delivery model will mean there is greater flexibility for iterative updates. We expect this will enable new technologies to be recognised in the Home Energy Model core engine on a more frequent basis, removing the need for a 'bolt-on' calculation. New technologies may necessitate the creation of new Home Energy Model modules or modification of existing ones (see Section 4.3).

The approach for recognising new technologies in the Home Energy Model is still at an early development phase; however, we intend to adopt the following principles:

- **Increased transparency:** the process should be transparent, clearly defined, and easily understandable by industry.
- **Open research:** a form of the assessment and/or evidence should be published to provide transparency and demonstrate a robust process, while protecting intellectual property and commercial competitiveness.
- **Integrity:** the process should require robust evidence of the technology's performance.
- **Continuous evaluation:** the process should enable continuous evaluation of technology performance as new data is assessed.
- **Greater integration:** the process should be integrated with other similar processes that recognise innovation (e.g. ECO, Great British Insulation Scheme, PAS 2035) to avoid applicants needing to repeat evidence gathering exercises and to meet all stakeholder requirements.

We will be working closely with industry to develop this new process and will provide further information in due course.

12. What are your views on the principles for how the Home Energy Model will recognise new technologies once it is in use? Please provide your reasoning and any supporting evidence.

13. What are your suggestions for how to integrate new innovative products into the Home Energy Model? Please provide your reasoning and any supporting evidence.

3.5 Using “wrappers” to distinguish different use cases

One key aim of the Home Energy Model project has been to clarify and delineate between its different purposes and functions. This has been addressed through the use of “wrappers”.

This section explains the concept of “wrappers”, why we have chosen to use them, and demonstrates their implementation. We then look ahead and seek views on what wrappers may be developed in future and the opportunities they present.

What is a wrapper?

A wrapper in software design is a piece of code (such as a function) that wraps around other program components and calls on them as part of its operation. Wrappers can make other pieces of code easier to use, without modifying them.

In the Home Energy Model context, a wrapper will define both the standardised inputs and user inputs needed to specify the model. It will also define the outputs that the model will provide. The “core engine” of the Home Energy Model is a general-purpose tool which accepts a large range of detailed inputs, not all of which are required for a given context. Similarly, the model can output a significant amount of data, most of which is not needed by a given user. The wrapper determines what is required of the user, and what the model will assume. It processes the user’s input into the full Home Energy Model input set which is then passed to the core engine.

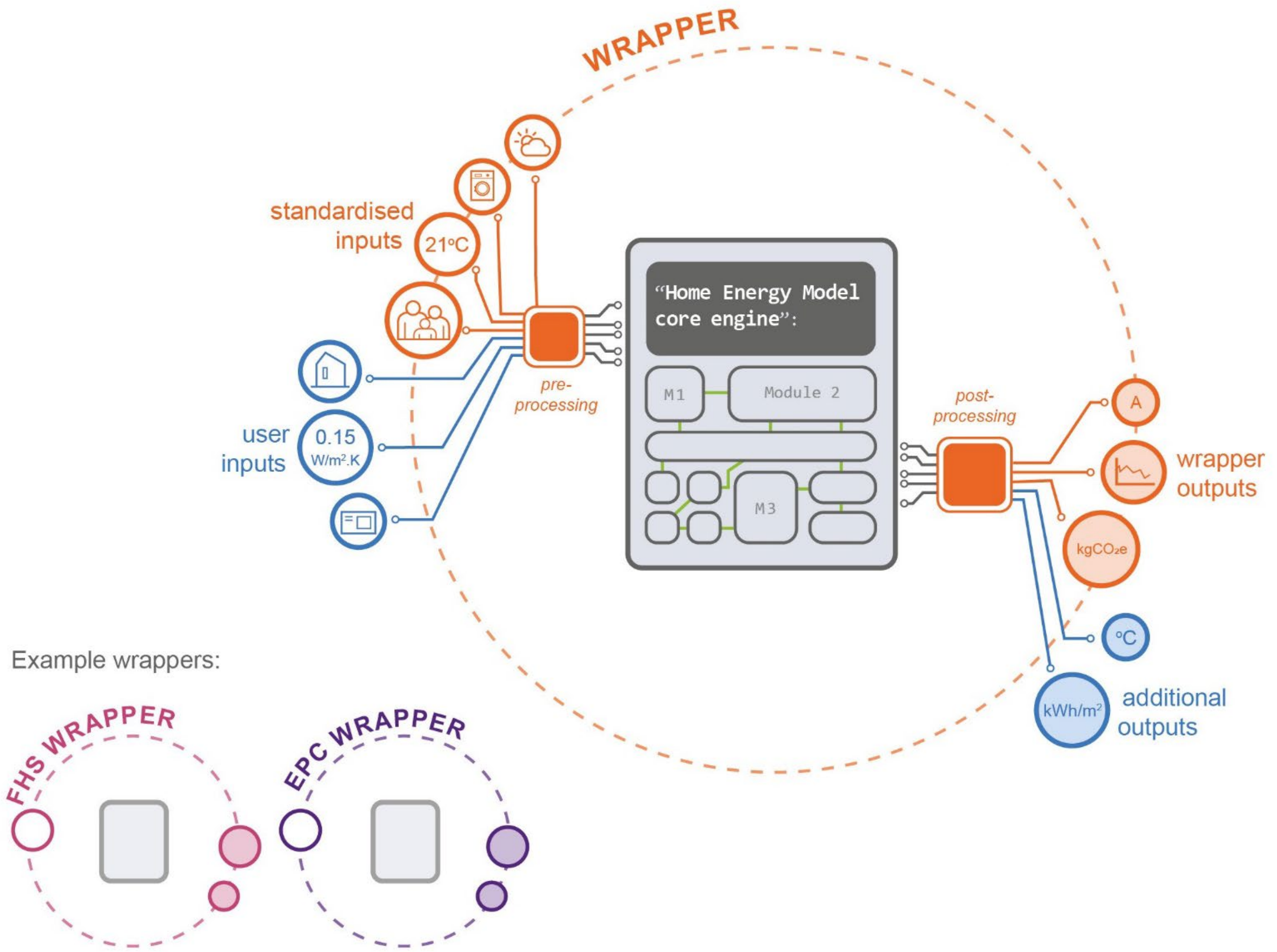


Figure 1 – Diagram of how wrappers work with the Home Energy Model

The wrapper should not be confused with the software interface, which defines how a user interacts with the model code and determines what they see (for instance, by displaying an input form to be filled in). The wrapper determines what input fields are required, and the interface displays this.

Why use wrappers?

SAP has been continuously developed over the years, and its purposes and functions have expanded over time, leading to a lack of clarity.

SAP currently has two main regulatory purposes:

1. To enable new dwellings to demonstrate compliance with Part L of the Building Regulations
2. To underpin the production of Energy Performance Certificates (EPCs)

Additionally, SAP has been used by a range of individuals and organisations for a variety of other purposes, such as:

- Estimating the real energy consumption of buildings in the UK stock (for research, policymaking and in support of planning applications)

- As a design aid for construction and building services engineering
- For assessing eligibility for government support schemes when carrying out retrofit works, independently of the EPC framework

Currently, all these use cases must make use of a common set of standardisations and assumptions, which may be more or less well-suited to each purpose.

The Home Energy Model project has provided the opportunity to start from a clean slate and rethink the structure of SAP to ensure that its different use cases are clearly delineated and separated from one another. This leads to several benefits, including:

- **User-centred design:** wrappers can be designed for a specific user need (e.g. using different standardised assumptions), rather than having to rely on something that already exists.
- **Increased flexibility:** wrappers will be able to be updated independently of one another and of the core model. This promotes continuous improvement and speeds up development.
- **Clarity and accountability:** standardised assumptions and context-specific methodology will be the clear property of their wrapper and not the core Home Energy Model.

How will the Home Energy Model be used to demonstrate compliance with the Future Homes Standard?

The Home Energy Model core engine is a software package which models the physics of a building. This includes modelling the building fabric, heating systems, electricity generation etc. The core engine is independent of the wrappers that wrap around it, and therefore does not change depending on the use case.

The Future Homes Standard assessment wrapper is a separate piece of code which specifies the inputs and outputs of the core engine to demonstrate compliance with the Future Homes Standard (FHS) (i.e. it wraps around the core engine). On the input side, this includes standardised assumptions around occupancy, weather, and setpoint temperatures. On the output side, this includes calculations to produce the FHS compliance metrics.

These inputs and outputs are specific to demonstration of compliance with the FHS and are therefore summarised in the corresponding Home Energy Model: FHS assessment consultation document.

How will the Home Energy Model work with EPCs?

The government will be developing an Energy Performance Certificate (EPC) wrapper for the Home Energy Model. Similar to the FHS assessment wrapper, this will be a separate software package, which will wrap around the Home Energy Model core engine.

The EPC wrapper will specify the inputs to the core engine that are needed for an EPC assessment. For existing buildings, this will take on the function that Reduced data SAP

(RdSAP) has performed in the past; for example, by specifying what assumptions are to be used if detailed design information is unavailable.

The EPC wrapper will also process the outputs of the core engine into the form needed for the certificate. This will include calculations to produce the metrics and recommendations displayed on EPCs. The government is currently working on proposals for improving EPCs, including the performance metrics they display, and intends to consult on these in the coming months. The outcome of the EPC consultation will feed into the development of the EPC wrapper.

Work on the EPC wrapper for the Home Energy Model will start in the next phase of model development, following this consultation. The government intends to consult on the EPC wrapper in 2024 to invite feedback from stakeholders.

What other wrappers could be developed in future?

The Home Energy Model project is focused on Building Regulations compliance and EPCs as the two main regulatory use cases for the model. However, we acknowledge that there are many other potential use cases that could be facilitated. The wrapper/core separation, in combination with the open-source publication of the Home Energy Model reference code, means that wrappers can be developed for each of these use cases as needed, either by government, industry, academia, or other parties.

At this stage, the government is not committing to the development of any further wrappers. However, other examples of potential wrappers (to be developed by government or others) could include:

- Self-assessment of energy use, taking account of occupant-specific information.
- Stock-level assessment of retrofit measures.
- PAS 2035 energy assessments.
- Interface with Building Information Modelling (BIM).
- Whole-life carbon assessment (possibly through interface with other tools).

Devolved Administrations will determine if there is a case to develop new or variant wrappers for their own devolved regulatory purposes.

14. What are your suggestions for other wrappers that could be developed for the Home Energy Model in future? Please provide your reasoning and any supporting evidence.

Chapter 4: The new Home Energy Model – an overhaul

In addition to its new ecosystem (see Chapter 3), the Home Energy Model also represents a step change in the calculation methodology as compared to SAP 10.2. This chapter describes some of the key changes, including:

4.1 Increasing the time resolution

4.2 Building strong foundations on international standards

4.3 A modular architecture

4.4 Modelling energy flexibility and smart technologies

4.1 Increasing the time resolution

The current version of SAP, SAP 10.2, undertakes calculations at a monthly timestep. This means that energy demand and building services performance are evaluated at 12 snapshots (one representing each month), while overall performance is considered for the complete year (with average exterior conditions). This reflects the age and intended simplicity of SAP but has notable drawbacks.

One such drawback is that the performance of heat pumps can vary over time depending on several factors. In order to capture this variation, heat pumps are currently simulated at a higher time resolution, but outside the main SAP model. This prevents them from interacting properly with other technologies or systems present in the model.

By comparison, the new Home Energy Model is able to simulate homes at a 30-minute time resolution. This means that every half-hour of the simulated year is evaluated, with specific exterior conditions and a memory of the situation in the previous timestep.

Increasing the time resolution of the model has several benefits, including:

- **Fewer constraints:** Enabling half-hourly simulation gives the flexibility to choose the level of detail in which to model each element of the building.
- **Improved representation of heat pumps:** Heat pumps are now simulated in a home's specific context, rather than as a generic test simulation.
- **Smart technologies and storage:** Increasing the time resolution means the Home Energy Model is better able to model the benefits of smart technologies, energy storage, and load-shifting. A reduced timestep also improves the treatment of energy generation

(e.g. solar PV panels) and will enable the Home Energy Model to accommodate a wider range of energy tariffs. Peak demand can also be considered more accurately.

- **Supporting different use cases:** Increasing the time resolution will help support all possible use-cases of the Home Energy Model.
- **Validation against dynamic simulation and monitoring data:** Increasing the time resolution enables detailed, meaningful comparison between the Home Energy Model and more advanced dynamic simulation models of building physics, as well as between real-time monitoring data from specific buildings. This helps to further improve confidence in the accuracy and flexibility of the model. Some such validation exercises have already been undertaken (see Chapter 6).

An increase in time resolution (along with other improvements) increases the complexity of the Home Energy Model and hence the model takes longer to complete a run. At this stage of development, the code has not been fully optimised and so both the reference code and the consultation tool will evaluate relatively slowly.

On balance, however, we believe that the benefits of increasing the time resolution outweigh the potential negative consequences. We understand that fast runtimes are very important for SAP users. We will be looking at limiting this potential drawback in the next phase of the project.

15. What are your views on the increased time resolution offered by the Home Energy Model? Please provide your reasoning and any supporting evidence.

4.2 Building strong foundations on international standards

Since its inception in 1993, SAP has been based on the BRE Domestic Energy Model (BREDEM). BREDEM has been in development since the 1980s and the current version is BREDEM 2012. BREDEM is intended to be compliant with BS EN ISO 13790:2008, which was at that time the European Standard covering the calculation of the energy performance of buildings.

BS EN ISO 13790:2008 has since been withdrawn and replaced by BS EN ISO 52016-1:2017. This standard covers the specification of calculation methods to assess demand for space heating and cooling, with a more detailed treatment of thermal zoning. In addition to monthly simulation, the standard fully supports a half-hourly simulation, and we have therefore chosen to use it as the basis for the Home Energy Model. BS EN ISO 52016-1:2017 also works consistently with other current international standards, which can then be used to model particular features (e.g. BS EN 15316-4-2:2017, which is the basis of the Home Energy Model heat pump simulation).

Alignment with current British and European Standards was chosen as the most effective method to quickly develop a new model which could achieve a high level of confidence and quality assurance, while retaining the required level of ambition. In combination with the decision to increase the time-resolution, this has necessitated a move away from BREDEM, which is no longer the basis for the Home Energy Model.

We have reserved the option to deviate from the European Standards in places where we have evidence or a basis for doing so (for example, from our lab testing data). See Chapter 5 for further detail on the methodological approach taken for individual technologies and systems within the Home Energy Model.

16. What are your views on the choice of BS EN ISO 52016-1:2017 (in its half-hourly form) as the basis for the Home Energy Model? Please provide your reasoning and any supporting evidence.

4.3 A modular architecture

SAP has been continuously developed and its functions have expanded over time, leading to a lack of structural clarity. The Home Energy Model project has provided the opportunity to start from a clean slate and redesign the structure of SAP using wrappers (see Section 3.5) and a modular architecture.

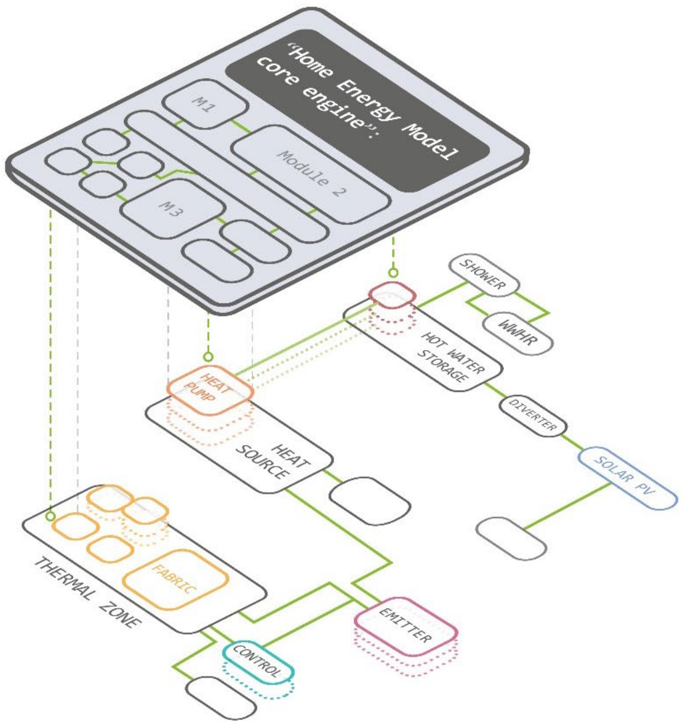


Figure 2 – Conceptual diagram of the Home Energy Model's modular architecture

The Home Energy Model reference code is constructed of a modular framework. The boundary of a module is defined by a fixed set of inputs and outputs that are exchanged with other modules, which should not typically vary when the inner workings of the module change. Therefore, one e.g. heating system could be switched for another without the rest of the code having to change, because the two systems share a common format despite their internal calculations and parameters being different.

There are several benefits to adopting this approach:

- **Ease of use:** having clearly delineated modules within the Home Energy Model simplifies the model and helps remove barriers to understanding. It also becomes easier to identify and isolate errors.
- **Flexibility and continuous improvement:** new features can be added within modules or as new modules, without needing to update the rest of the code. It may be that different organisations could develop different modules in parallel in the future, as discussed in the section on reforms of Appendix Q (Section 3.4).

The model's architecture will continue to expand and evolve throughout its development (see Section 5.5 for more information on future features development).

4.4 Modelling energy flexibility and smart technologies

What is energy flexibility and why is it important?

Energy flexibility is the ability to adapt and regulate energy use, generation, and/or storage in response to signals from the home or wider energy system.

Enabling energy flexibility will empower consumers and reduce costs. Smart meters, technologies, and tariffs will enable consumers to change their consumption patterns to match times of cheap low carbon electricity and give consumers greater control over their energy use. Energy flexibility will reduce costs for people who engage with smart products and services and reduce system costs for everyone by reducing the amount of electricity generation and network capacity needed. In the joint Government and Ofgem 2021 Smart Systems and Flexibility Plan, we committed to consider how smart technologies could be modelled within SAP.

How is energy flexibility modelled in the Home Energy Model? How does this compare to SAP 10.2?

As a monthly simulation, SAP 10.2 has limited ability to evaluate overlapping profiles for energy demand, weather, and fuel prices in order to assess the benefits of energy storage technologies or renewable electricity generation.

In comparison, the Home Energy Model can run as a half-hourly simulation and can accept varying profiles, which potentially take unique values for every half-hour of the year. This permits realistic modelling of the interactions between variable supply and demand and enables the quantification of benefits from storage and load shifting technologies and behaviours.

For example, the likely reduction in (daily or annual) peak electricity demand can be assessed, as can potential energy savings when switching to a time-of-use electricity tariff in combination with a solar PV diverter.

17. What are your views on the ability of the Home Energy Model to model energy flexibility and smart technologies? Please provide your reasoning and any supporting evidence.

Chapter 5: What is inside the Home Energy Model?

This chapter gives an overview of how some key areas are treated in the Home Energy Model. For each topic, we provide:

A link to the relevant technical document, which provides further explanation and supporting evidence.

- The methodological approach in SAP 10.2
- The methodological approach in the new Home Energy Model (e.g. standards followed)

Key take-aways

This chapter and the accompanying technical documents are intended to highlight key aspects of the model and are not intended to be a comprehensive model specification. The published Home Energy Model codebase acts as the full reference for the methodology during this consultation and can be referred to if in doubt. We intend to continue to supplement this with further technical documentation throughout the development process.

Please note that methodology to demonstrate compliance with the FHS is described in the separate Home Energy Model: FHS assessment consultation document, to maintain the distinction between the different use cases of the Home Energy Model.

Overall calculation structure

Technical Paper: HEM-TP-01 General summary of core calculation

The Home Energy Model core engine runs a calculation loop for each timestep. At a very basic level, this calculation loop can be divided into the following stages:

1. Calculation of hot water demand and energy supplied to meet demand (including energy consumed by the heating system in meeting this demand)
2. Calculation of space heating/cooling demand and energy supplied to meet demand (including energy consumed by the heating/cooling system in meeting this demand)
3. Additional calculations for systems that provide multiple services (e.g. combi boiler that provides both hot water and space heating)
4. Calculation of electricity generation, self-consumption, and storage

This loop is then repeated for the next timestep, and so on, for the whole calculation period. At the end of the whole calculation, results are returned to the wrapper for post-processing and generation of outputs.

The timestep and calculation period are model inputs, specified by the user or wrapper. For FHS assessment purposes, the FHS assessment wrapper specifies a 30-minute timestep and a 1-year calculation period.

This chapter is divided into the following sections:

5.1 Space heating and cooling demand

5.2 Domestic Hot Water (DHW) demand

5.3 Heating and cooling systems

5.4 Electricity generation, self-consumption, and storage

At the end of this chapter, we discuss future features development in Section 5.5.

5.1 Space heating and cooling demand

Space heating and cooling demand describes the amount of energy needed within a home to maintain the rooms at the desired temperature during desired periods of time.

This section describes the key aspects of calculating space heating and cooling demand within the Home Energy Model:

5.1.1 Overview of space heating and cooling demand

5.1.2 Fabric heat loss

5.1.3 Thermal bridges

5.1.4 Heat loss through infiltration and controlled ventilation

5.1.5 Thermal mass

5.1.6 Solar gains and solar absorption

5.1.7 Shading

5.1.1 Overview of space heating and cooling demand

Technical Paper: HEM-TP-04 Space heating and cooling demand

In SAP 10.2, space heating demand is determined by using the calculated heat loss rate, internal gains, and solar gains to estimate how much energy is needed to reach the desired mean internal temperature. Cooling demand is calculated in a similar way. SAP 10.2 defines two heating zones, distinguishing the main living area from the rest of the dwelling, and allowing these to have different heating times and setpoint temperatures.

The Home Energy Model uses a different approach to calculate space heating and cooling demand. The new methodology sets up and solves a set of heat balance equations based on BS EN ISO 52016-1:2017 (see Section 4.2). The ability to run a half-hourly simulation means that short-term variations in internal temperature can be explicitly represented.

In the Home Energy Model, the building can be divided into any number of thermal zones, each of which can have their own heating and cooling setpoints. A heating setback temperature (i.e. the temperature, outside of normal heating hours, that you do not want your home to fall below) and cooling setback temperature can also be provided in the same way. The Home Energy Model calculates and controls on operative temperature, rather than air temperature as in SAP 10.2.

At each timestep, the engine calculates if the internal temperature would fall below the heating setpoint (e.g. the temperature set on the thermostat) if the heating systems were switched off. If the temperature would drop below the setpoint, then the engine calculates the heating demand, output of the heating system and resulting temperature. Unlike in SAP 10.2, the building takes time to warm up to its setpoint, which is important to consider when sizing the heating system and setting controls.

For cooling, the Home Energy Model can receive separate window opening (e.g. 22°C) and active cooling (e.g. 24°C) setpoint temperatures. If opening the windows is not sufficient to cool the building below the active cooling setpoint, then the model will calculate the active cooling demand and resulting temperature, assuming the windows are now closed (to keep the cooled air inside).

If the heating/cooling demand within a timestep exceeds the capacity of the system, the shortfall is reported, and the internal temperature remains below/above the setpoint. This is in contrast to SAP 10.2, which assumes that the heating and cooling demand is always met.

The heating demand in a thermal zone is influenced by the amount of incidental heat gain coming from occupant activities and the use of appliances etc. which release heat as a byproduct of their operation. These incidental heat gains are determined by the user or wrapper, to ensure the model remains flexible in its assumptions about how the dwelling is used.

Overview of space heating and cooling demand

- Based on BS EN ISO 52016-1:2017.
- Can represent half-hourly temperature variations.
- No limit on number of (uncoupled) thermal zones.
- Ability to specify half-hourly setpoints and setback temperatures.
- Calculates and controls using operative temperature (not air temperature).
- Includes building warm-up time.
- Heating and cooling demands can remain unmet.
- Incidental heat gains are model inputs.

18a. What are your views on the methodological approach for calculating space heating and cooling demand? Please provide your reasoning and any supporting evidence.

5.1.2 Fabric heat loss

Technical Paper: HEM-TP-05 Fabric heat loss

In SAP 10.2, fabric heat loss is summed across all building elements using the product of each element's area and U-value, with thermal bridges added separately. This gives a single value for total fabric heat loss which feeds into the overall heat transfer coefficient and heat loss parameter.

In the Home Energy Model, the calculation of fabric heat loss forms part of the core heat balance equations, as described in BS EN ISO 52016-1:2017. The heat losses for each zone are calculated independently, with no heat flow assumed between them. We may consider introducing thermal coupling between zones in future.

Building fabric elements adjacent to a heated space (e.g. another dwelling, or zone) are assumed to have no heat loss to this adjacent heated space. Building fabric elements adjacent to an unheated exterior space (e.g. an unheated corridor) are assumed to lose heat to this unheated space, which is modelled by adding a thermal resistance to the external surface of the building element.

The increased granularity of the Home Energy Model enables fabric heat loss to be calculated for each building element at half-hourly timesteps.

Although the heat transfer coefficient and related parameters (Boxes 37-40 in the SAP 10.2 worksheet) are no longer used within the Home Energy Model calculation, these values can be outputted using the same definitions as in SAP 10.2, to facilitate comparisons with previous versions of SAP and with other tools.

Fabric heat loss

- Based on BS EN ISO 52016-1:2017.
- Calculated independently for each zone.
- Accounts for whether adjacent zones are heated or unheated.
- Can be calculated for each building element at half-hourly timesteps.
- Can calculate the heat transfer coefficient and heat loss parameter, if needed.

18b. What are your views on the methodological approach for calculating fabric heat loss? Please provide your reasoning and any supporting evidence.

5.1.3 Thermal bridges

A thermal bridge is an area of a building's construction that has significantly higher heat transfer than the surrounding materials.

In SAP 10.2:

- Linear thermal bridges are accounted for using their length and linear thermal transmittance.
- Point thermal bridges are accounted for using a point thermal transmittance.

This then feeds into the total fabric heat loss and in turn the overall heat transfer coefficient for the dwelling.

In the Home Energy Model, thermal bridges are defined in a similar way. The effect of thermal bridges is then combined for each zone and fed directly into the heat balance equations. This allows the heat loss due to thermal bridges to be accounted for at each timestep.

Thermal bridges

- Combined to form a term in the heat balance equations.
- Can be modelled at half-hourly timesteps.

18c. What are your views on the methodological approach for calculating thermal bridges? Please provide your reasoning and any supporting evidence.

5.1.4 Heat loss through infiltration and controlled ventilation

Technical Paper: HEM-TP-06 Ventilation and Infiltration

The movement of air into and out of a home, both through infiltration and controlled ventilation, will affect its heat loss.

Infiltration

Infiltration (unintentional or uncontrolled air flow, generally due to holes and cracks in the building fabric) varies significantly with a home's construction and levels of shelter, as well as wind and temperature conditions.

In SAP 10.2, the infiltration rate is derived from a dwelling's air tightness measurement, defined as air permeability during a 50Pa blower-door test. This measurement is divided by 20 as a 'rule of thumb' to give an average infiltration rate over the course of a year in typical circumstances, which is then adjusted to allow for sheltering and monthly wind speed. If using a low-pressure (4Pa) pulse test in place of the blower-door test, an equation converts between the two results.

In the Home Energy Model, the air tightness measurement is used in the same way; however, the "rule of thumb" has been replaced using parts of CIBSE Guide A: Environmental Design to give a variable divisor which takes into account the home's built-form and level of shelter. The dwelling infiltration rate is then calculated by adjusting this value for each hour using the wind speed from the weather input data.

Other contributing factors, such as the prevailing wind direction and the "stack effect" are not fully addressed by the Home Energy Model. We will consider further development of this area in the model in future.

Infiltration

- Based on measurement of air tightness (either 50Pa blower-door or 4Pa pulse test).
- Divide by 20 "rule of thumb" replaced using figures from CIBSE Guide A.
- Accounts for the home's built-form, level of shelter, and wind speed.

Controlled ventilation

Controlled ventilation refers to both:

- Intermittent Mechanical Extract Ventilation with background ventilators
- Continuous mechanical ventilation systems (i.e. Mechanical Ventilation with Heat Recovery (MVHR) or Continuous Mechanical Extract Ventilation with background ventilators)

In SAP 10.2, controlled ventilation systems are assumed to have a fixed minimum dwelling ventilation rate. As the dwelling's infiltration rate increases, a series of curves are used to reduce the ventilation rate for some types of ventilation systems (e.g. intermittent mechanical extract ventilation with background ventilators). The contribution of intermittent extract fans and purpose-built openings (e.g. chimney flues) is also included. For MVHR systems a heat recovery efficiency is used.

In the Home Energy Model, this basic approach is retained except for the minimum ventilation rate, which is now a user or wrapper input. For MVHR systems, the Home Energy Model also considers losses from ductwork.

We will be prioritising further development of this area in the next phase of model development. We would therefore welcome feedback on the approach taken, and particularly the interaction between the infiltration rate and controlled ventilation. We are also considering what ventilation control systems or arrangements could be included in future.

Controlled ventilation

- Minimum ventilation rate is now a user or wrapper input.
- Accounts for MVHR ductwork losses.

18d. What are your comments on the methodological approach for calculating infiltration and/or controlled ventilation? Please provide your reasoning and any supporting evidence.

5.1.5 Thermal mass

Technical Paper: HEM-TP-07 Thermal mass

SAP 10.2 calculates thermal mass using the internal effective heat capacities (or "kappa values") of individual fabric elements such as walls and floors. The thermal mass calculation only includes the fraction of the construction build-up that is estimated to be significantly involved in storing and releasing heat over time.

In the Home Energy Model, each building element (excluding glazed elements) is given an "areal heat capacity" (i.e. heat capacity per unit area) as a model input. In contrast to SAP 10.2, this includes the full construction build-up.

The influence of thermal mass on heat storage depends on where the thermal mass is distributed in each construction layer. To represent this, the Home Energy Model simplifies the construction into layers (exterior face, interior face, internal/middle), and uses a mass distribution class to describe how mass is distributed among the layers, as described in BS EN ISO 52016-1:2017.

Unlike SAP 10.2, the Home Energy Model also incorporates the thermal mass of the air and furniture in the dwelling, again using assumptions from BS EN ISO 52016-1:2017.

The thermal mass determines the warm-up and cool-down rates of each zone (see also Section 5.1.1), and so is a key component of the heat balance equations. These equations are used to calculate the operative temperature of each zone which dictates the space heating or cooling demand for a given timestep. Thermal mass therefore influences the amount of heating required and also the hours of operation for the heating system.

Thermal mass

- Based on BS EN ISO 52016-1:2017.
- Model input for the areal heat capacity of each building element.
- Model input for the mass distribution class of each building element.
- Incorporates the thermal mass of the air and (assumed) furniture in the home.

18e. What are your views on the methodological approach for calculating thermal mass? Please provide your reasoning and any supporting evidence.

5.1.6 Solar gains and solar absorption

Technical Paper: HEM-TP-08 Solar gains and solar absorption

Solar gains and solar absorption describe how the habitable space is heated by the sun, either directly through an opening such as a window, or indirectly through the building fabric.

In SAP 10.2, solar gains are calculated using monthly solar radiation figures, which are adjusted for window size and orientation. SAP 10.2 does not account for solar absorption through opaque elements of the building fabric.

The Home Energy Model follows the methodology described in BS EN ISO 52010-1:2017, calculating the position of the sun in hourly steps based on weather input data. The model calculates the individual components of solar radiation (diffuse and direct) and combines them to give the total solar irradiance for each individual building element, accounting for the orientation and pitch of each.

Solar gains and solar absorption

- Based on BS EN ISO 52010-1:2017.
- Calculates the position of the sun at hourly timesteps.

- Accounts for solar energy absorption by opaque elements.

18f. What are your views on the methodological approach for calculating solar gains and solar absorption? Please provide your reasoning and any supporting evidence.

5.1.7 Shading

Technical Paper: HEM-TP-08 Solar gains and shading

Energy gain from the sun is moderated by shading, where external obstacles or parts of the dwelling itself prevent sunlight from falling on the windows or surfaces.

SAP 10.2 takes a simplified approach to shading of a dwelling, categorising it as either heavy, more than average, average, or very little.

The Home Energy Model uses the methodologies described in BS EN ISO 52016-1:2017 and PD CEN ISO/TR 52016-2:2017 to calculate the reduction in solar gains and solar absorption due to direct and diffuse solar shading. The model calculates the position of the sun each hour from the hourly weather input data. This is then combined with the orientation of the building elements and shading objects to determine how much shade is received.

In comparison to SAP 10.2, the Home Energy Model has two types of shading:

1. Shading from distant objects, such as other buildings. These shade parts of the home (walls, roofs, windows etc.), and reduce the solar absorption or solar gains of the affected building elements.
2. Window overshading, e.g. from overhangs and reveals. These shade the affected window or glazed door, reducing solar gains.

Movable shutters, blinds, curtains etc. are not included in the consultation version of the Home Energy Model. We will consider whether to implement this in the methodology in future.

Shading

- Calculations from BS EN ISO 52016-1:2017 and PD CEN ISO/TR 52016-2:2017.
- Based on position of the sun at hourly timesteps.
- Differentiates shading from distant objects vs window overshading.

18g. What are your views on the methodological approach for calculating shading? Please provide your reasoning and any supporting evidence.

5.2 Domestic Hot Water (DHW) demand

Technical Paper: HEM-TP-09 Energy for domestic hot water

Domestic Hot Water (DHW) demand describes the energy needed to heat water from taps, including baths and showers (it does not include water heating within appliances such as kettles or washing machines).

In SAP 10.2, the monthly demand for hot water is estimated based on the floor area and bathing facilities in the home.

In the Home Energy Model, the DHW energy demand is calculated from the hot water demand schedule. This schedule is specified by the user or wrapper, and consists of a series of shower, bath, and/or other tapping events. The amount of water used in a bath event is dependent on the bath's volume, while the amount of water used by any other outlet is dependent on its flow rate and the duration of each tapping event.

The main difference between SAP 10.2 and the Home Energy Model is the increase in time resolution, meaning that each hot water event can now be defined individually. With this comes the ability to record when a sequence of events has exhausted the hot water cylinder (if present) and estimate the peak load on the hot water system, neither of which was previously possible. If the hot water cylinder has been exhausted, the model reports that the DHW demand is unmet. Systems that provide instantaneous hot water (e.g. combi boilers, point-of-use water heaters) are assumed to have sufficient capacity for any realistic DHW demand.

Defining each hot water event individually means that the efficiency of related systems (e.g. wastewater heat recovery) can be based on calculated flow rates rather than averages.

Domestic Hot Water (DHW) demand

- Calculated from a schedule of hot water events (e.g. showers, baths).
- Ability to record when hot water cylinder is exhausted.

19a. What are your views on the methodological approach for calculating Domestic Hot Water demand? Please provide your reasoning and any supporting evidence.

5.2.1 Heat losses from domestic hot water pipework

Technical Paper: HEM-TP-10 Ductwork and Pipework losses

SAP 10.2 uses a standardised assumption that hot water loses 15% of its energy while running through DHW pipework, contributing to internal heat gains.

Pipework losses in the Home Energy Model are calculated according to BS EN ISO 12241:2022. Unlike SAP 10.2, the Home Energy Model takes account of properties of the pipework such as the volume, length and level of insulation. The heat losses are based on the temperature differential between the water within the pipe and the surrounding air, as well as the duration of the tapping event. The main component of pipework losses is from hot water left standing in the pipework once DHW demand is met. The losses from pipework inside the conditioned part of the dwelling then contribute to internal heat gains.

Heat losses from DHW pipework

- Based on BS EN ISO 12241:2022.
- Calculated using information on the pipe's volume, length, and level of insulation.

19b. What are your views on the methodological approach for calculating heat losses from Domestic Hot Water pipework? Please provide your reasoning and any supporting evidence.

5.2.2 Heat losses from hot water cylinders

Technical Paper: HEM-TP-11 Hot water storage tanks

SAP 10.2 uses manufacturer data (if available) to determine the standing losses for water storage according to BS EN 1566 or BS EN 12897. If product specific data is not provided, then a default heat loss rate is attributed based on cylinder volume and insulation thickness. Temperature factors are applied to account for the average temperature under typical operating conditions.

In the Home Energy Model, hot water cylinders are modelled explicitly using a four-layered model based on BS EN 15316-5:2017, which assumes the water is stratified by temperature. Standing losses are based on the same manufacturer's data as in SAP 10.2, with an additional adjustment to account for the conditions calculated at each timestep. The Home Energy Model enables the definition of a setpoint temperature for hot water cylinders, and a minimum hot water temperature, enabling greater flexibility in the modelling of the water heating system.

Heat losses from hot water cylinders

- Based on BS EN 15316-5:2017.
- Stratifies water by temperature.
- Can define setpoint temperature for hot water cylinders.
- Can define a minimum temperature for the hot water provided.

19c. What are your views on the methodological approach for calculating heat losses from hot water cylinders? Please provide your reasoning and any supporting evidence.

5.2.3 Heat gains from domestic hot water

In SAP 10.2, a quarter of the available heat in the water run from taps, showers, and baths is assumed to contribute as an incidental gain to space heating. The remainder is available for waste water heat recovery systems or lost to the plughole. No change to this assumption is proposed for the Home Energy Model

19d. What are your views on the methodological approach for calculating incidental gains from domestic hot water? Please provide your reasoning and any supporting evidence.

5.3 Heating and cooling systems

Once the space heating/cooling and DHW demands have been calculated (see Sections 5.1 and 5.2 respectively), the model determines how that demand can be met through the heating and cooling systems within the dwelling.

This section covers the modelling methodology for the following:

- 5.3.1 Heat pumps
- 5.3.2 Electric resistive heaters
- 5.3.3 Electric storage heaters
- 5.3.4 Heat networks
- 5.3.5 Boilers
- 5.3.6 Heat batteries
- 5.3.7 Mechanical cooling
- 5.3.8 Other DHW heating (e.g. immersion heaters, point-of-use, solar thermal)
- 5.3.9 Emitters, pumps, fans, and controls

The systems listed above represent those which are most fully developed in the consultation version of the Home Energy Model. Please see Section 5.5 for information on future features development.

5.3.1 Heat pumps

Technical Paper: HEM-TP-12 Heat pump methodology

SAP 10.2 represents heat pumps using a simulation methodology called Domestic Annual Heat Pump System Efficiency (DAHPSE), which itself is based on BS EN 15316-4-2:2017 (Path B). The DAHPSE simulation was included as a pre-calculation when generating heat pump records in the Product Characteristics Database (PCDB) and therefore had to make generic assumptions about the likely space and water heating demand profiles.

In the Home Energy Model, this simulation has moved into the core engine and is based on a combination of DAHPSE and BS EN 15316-4-2:2017 directly.

Heat pump performance is calculated by combining standardised test data with the specific characteristics of the building being modelled. For example, external temperatures are combined with space and water heating demand for each hourly timestep to calculate the heat pump's heat output, electricity draw, and coefficient of performance.

The Home Energy Model only assumes use of back-up heating if specified by the user or the wrapper (or potentially by the product record in a reformed PCDB). This is different to SAP 10.2, which assumed that all heat pumps had back-up electric heating (either integrated or separate) of unlimited capacity. This was a by-product of the assumption that space heating/cooling demand was always met (see Section 5.1.1).

The reformed PCDB (see Section 3.3) may take advantage of additional data that could improve the accuracy of heat pump characterisation (e.g. the actual power of any back-up heaters packaged within heat pumps), and we will engage with industry on this in due course.

The consultation version of the Home Energy Model can represent:

- Air source heat pumps
- Exhaust air heat pumps
- Ground source heat pumps

We aim to develop a methodology for packaged hybrid heat pumps and other varieties in the next phase of model development.

Heat pumps

- Modelled using DAHPSE and BS EN 15316-4-2:2017.
- Simulated in-situ rather than as an off-model calculation.
- Takes account of hourly external temperatures.
- Takes account of hourly heating and hot water demand unique to the dwelling.

- No assumed back-up heating.

20a. What are your views on the modelling of heat pumps in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.2 Electric resistive heaters

In SAP 10.2, electric resistive heaters are assumed to be 100% efficient and responsive.

The Home Energy Model remains unchanged from SAP 10.2, with the addition of new inputs for capacity and a convective fraction. The capacity affects the calculation of building warm-up time, achieved internal temperature and unmet demand. The convective fraction affects how much of the energy output from the heater is assumed to be absorbed by the internal air vs. the internal surfaces.

Electric resistive heaters

- Same basis as SAP 10.2.
- New inputs for capacity and convective fraction.

20b. What are your views on the modelling of electric resistive heaters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.3 Electric storage heaters

The SAP 10.2 methodology for electric storage heaters is very basic, assuming a 100% efficiency and poor responsiveness.

In comparison, the modelling of electric storage heaters within the Home Energy Model is underpinned by a combination of physical modelling of heat transfer and empirically derived product performance data.

The Home Energy Model considers two components of storage heaters: the core where energy is stored and the case which prevents the stored energy from leaking out too quickly. The temperature variations in these two components are modelled differently.

To model storage heaters, the Home Energy Model calculates three heat transfers:

- Heat transfer from the core to the room is calculated based on the temperature difference between the core and the air passing through the storage heater (where the air flow is controlled based on heating demand).

- Heat transfer from the case to the room is modelled like a normal emitter (see Section 5.3.9).
- Heat transfer from the core to the case is calculated based on the properties of the insulation material and the temperature difference between them.

The electrical input into the storage heater is calculated based on the temperature of the core and a control schedule (e.g. which only allows electrical input during an off-peak electricity charging period). The storage heater has a maximum output and can run out of heat if undersized or undercharged.

The reformed PCDB (see Section 3.3) may need additional test data to characterise electric storage heaters using this new methodology. We will engage with the industry on this in due course.

Electric storage heaters

- Brand new methodology.
- Based on a comprehensive physical description of the system.
- Explicit equations for heat transfer and energy balance.

20c. What are your views on the modelling of electric storage heaters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.4 Heat networks

In SAP 10.2, heat networks can be represented by the heat interface unit (HIU), which connects the home to the heat network. Where an HIU is present, the HIU is modelled as though it were any other heat source. The heat provided by the network is then treated as a “fuel” with equivalent associated parameters.

In the Home Energy Model heat networks are modelled in a similar way and are always represented by an HIU within the dwelling. The model takes account of the HIU’s maximum power limit and heat loss through its components such as heat exchangers and pipework.

In SAP 10.2, information on a heat network is either provided through the PCDB or through direct data entry into SAP software. This includes information on heat generator efficiencies and distribution losses. In the Home Energy Model, we anticipate that this information will only be able to be provided through the reformed PCDB.

Modern heat networks, known as fifth generation or ambient loop heat networks, operate at low temperatures. Dwellings connected to these heat networks will typically have a heat pump which can raise the temperature of the heat supplied. In this scenario, the Home Energy Model models the amount of energy the heat pump draws from the network, and the effect of the heat network distribution temperature on the performance of the heat pump.

The Home Energy Model does not calculate or account for distribution losses in the heat network or the performance of heat generators on the network. It is assumed that these will be accounted for outside of the core model by applying appropriate factors to the heat drawn from the network by the systems in the dwelling.

Heat networks

- Heat networks represented by the Heat Interface Unit (HIU).
- Accounts for the HIU's maximum power limit and loss factor.
- Can model the use of heat pumps on low temperature heat networks.

20d. What are your views on the modelling of heat networks in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.5 Boilers

Technical Paper: HEM-TP-14 Boiler methodology

In SAP 10.2, the efficiency of a boiler's space heating and hot water production is derived from information on their winter and summer seasonal efficiencies. These seasonal efficiencies are estimated using a weighted average of full- and part-load test data from BS EN 15502-1, adjusted for boiler type. The resulting efficiency is applied independently of the building heat load. For combi boilers, an additional loss is included to account for unacceptable water temperatures during warm-up. This combi loss is estimated using test data from EN 13203-2.

In the Home Energy Model, boiler efficiency is calculated for each timestep based on space heating and DHW demand. The boiler methodology builds on work developed in SAP 10.2 to explore the sub-annual variation in boiler return temperature and its effect on heating efficiency. This in turn was based on a combination of the DAHPSE model (see Section 5.3.1) and the Energy Balance Validation method from SAP 2009.

The model retains the adjustment of full- and part-load efficiency from SAP 10.2. This is used to adjust the theoretical efficiency-vs-return-temperature curves. When the dwelling heat load for a given timestep is above the minimum modulation[4] of the boiler, this is sufficient to calculate efficiency. When the building heat load is less than the boiler minimum modulation level then the boiler is likely to cycle on and off. This is now accounted for in the Home Energy Model by reducing efficiency based on lab testing of boilers at low loads (see Section 6.2.3).

[4] Note that the minimum modulation level has been set to 30% of maximum load while further testing and development is carried out.

When the heat load is greater than the maximum output of the boiler, then the efficiency at maximum output will be used, and some demand will remain unmet.

For combi boilers, the combi loss methodology is the same as in SAP 10.2.

The consultation version of the Home Energy Model can model regular and combi boilers which use mains gas or LPG as a fuel. We aim to develop a methodology for other types of boilers (e.g. oil and solid fuel boilers) in the next phase of development.

Boilers

- Boiler efficiency is estimated dependent on load and return temperature.
- Takes account of cycling of the boiler when below minimum modulation.

20e. What are your views on the modelling of boilers in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.6 Heat batteries

Technical Paper: HEM-TP-15 Heat batteries

Heat batteries store/release thermal energy by heating/cooling a storage medium with a heat transfer fluid passing through a coil or heat exchanger in the heat battery.

SAP 10.2 does not include heat batteries and therefore this is a new technology to be included within the Home Energy Model.

The Home Energy Model heat battery methodology is underpinned by a combination of fundamental physical principles and empirically derived performance data. The module will use manufacturer data to encapsulate the physical properties and behaviours of heat batteries, including their thermal characteristics, energy storage capacity, charging and discharging behaviour, and energy losses. This laboratory test data will then be interpolated to enable the heat battery to be modelled under different conditions.

The heat battery methodology consists of four main processes, most of which are modelled at each timestep:

- System initialisation (this is executed at the start of the run to determine the initial state of the system and parameterise the control strategy)
- Electric charging for conversion to stored heat (considering current charge level and time for charging)
- Energy output (considering charge level and energy demand)

- Auxiliary energy consumption (energy used during standby mode and for the operation of internal systems e.g. circulation pumps)

In the consultation version of the Home Energy Model, heat batteries are simulated as a heat source, in the same way as e.g. a boiler. The model does not currently simulate heat batteries as a substitute for hot water cylinders. This is something we will consider for the next phase of model development.

Heat batteries

- Based on a combination of fundamental physical principles and performance data.
- Simulated as a heat source. Not currently simulated as a substitute for hot water cylinders.

20f. What are your views on the modelling of heat batteries in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.7 Mechanical cooling

In SAP 10.2, mechanical cooling is modelled using a single efficiency which is applied to the cooling demand.

The Home Energy Model follows the same principles as SAP 10.2, with the addition of new inputs for cooling capacity and convective fraction. The convective fraction may vary depending on the type of cooling system (cool-air, cool-surface etc.).

It is likely that there will be further development of this area of the model in future.

Mechanical cooling

- Same basis as SAP 10.2
- New inputs for cooling capacity and convective fraction

20g. What are your views on the modelling of air conditioning in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.8 Other DHW heating (e.g. immersion heaters, point-of-use, solar thermal)

Immersion heaters: In the Home Energy Model, immersion heaters are modelled with an efficiency of 100% and a maximum capacity. The explicit modelling of hot water cylinders (see Section 5.2.2) means that users can input the positions of both the thermostat and immersion heater(s) within the cylinder, which will affect the control behaviour for the heater.

Point-of-use water heaters: The current implementation of point-of-use water heaters within the Home Energy Model is mostly the same as in SAP 10.2, apart from the addition of a user input on efficiency.

In the consultation version of the model, point-of-use water heaters are assumed to be installed on a whole-dwelling basis rather than for specific outlets and cannot co-exist with hot water cylinders or any other DHW heating system. We will consider enabling greater flexibility in the next phase of model development.

Solar thermal: Both SAP 10.2 and the Home Energy Model implement solar thermal based on BS EN 15316-4-3. Unlike SAP 10.2, the Home Energy Model uses the hourly version of the calculation in the standard, and so accounts for the effects of weather variation on performance.

Other DHW heating (e.g. immersion heaters, point-of-use, solar thermal)

- Can input the position of the thermostat and immersion heater(s) within the hot water cylinder.
- Point-of-use water heaters now have a user input for efficiency.
- Hourly modelling of solar thermal systems.

20h. What are your views on the modelling of other Domestic Hot Water heating (e.g. immersion heaters, point-of-use, solar thermal) in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.3.9 Emitters, pumps, fans, and controls

This section covers the modelling methodology for how heat is distributed around the home, including ancillary equipment such as pumps and controls:

Heat emitters (radiators, underfloor heating etc.)

Technical Paper: HEM-TP-16 Heat emitters

Some of the heating systems described above (e.g. heat pumps, heat networks, boilers) heat the building via emitters.

In SAP 10.2, heat emitters are assumed to be properly sized, and are modelled using broad categories of responsiveness.

In comparison, the Home Energy Model does not assume that emitters are properly sized, but instead enables their characteristics to be defined through model inputs. The emitter calculation is primarily based on an equation from the ASHRAE handbook and a simple heat balance.

In the Home Energy Model, heat emitters are modelled at each timestep to determine the amount of energy required to bring them up to a sufficient temperature to meet the space heating demand.

When calculating the amount of energy required and emitted, the model takes account of the flow temperature settings (including any weather compensation[5]), as well as the energy required to warm up the emitters themselves (and subsequently the energy released during their cool-down). Accounting for the thermal mass of the emitters at each timestep means that the Home Energy Model provides a more granular representation of the responsiveness of the heating system.

Heat emitters

- Not assumed to be properly sized.
- Parameterised in detail.
- Modelled at each timestep.
- Takes account of the thermal mass of the emitters.

20i. What are your views on the modelling of heat emitters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

Pumps’ and fans’ energy consumption

The Home Energy Model accounts for the energy consumed by pumps and fans that run as part of the heating or ventilation system.

SAP 10.2 does not attempt to model the energy used by pumps and fans in detail but uses fixed assumptions of annual consumption figures based on the heating system type. In the case of a warm air system, SAP 10.2 makes additional allowance for the specific fan power and volume of the dwelling.

In the Home Energy Model, the running hours of a heating system’s pumps and fans are determined by the system’s calculated operating hours. The power for each state (e.g. standby, full load) comes from the PCDB The total energy consumed by the pumps and fans depends on the amount of time spent in each state.

In the case of mechanical ventilation systems, fans are generally assumed to run all the time at a single energy consumption rate determined by their specific fan power. In some cases, such

[5] Weather compensation is a type of control which changes the flow temperature of the system depending on the temperature outside.

as exhaust air heat pumps, overventilation may be required under some conditions to give sufficient heat output.

The main difference between SAP 10.2 and the Home Energy Model is the explicit modelling of the run-time of pumps and fans as well as the utilisation of more detailed inputs on their associated power.

Pumps' and fans' energy consumption

- Models pumps and fans' run-time.
- More detailed model inputs on pumps and fans' power consumption.
- Modelled at each timestep.

20j. What are your views on the methodological approach for calculating pumps and fans energy consumption in the Home Energy Model? Please provide your reasoning and any supporting evidence.

Controls for heating and/or hot water

In SAP 10.2, controls are not explicitly modelled. Instead, fixed values are used to adjust the mean internal temperature of the dwelling and/or the efficiency of the heating system, depending on the heating controls present. For some water heating controls, the presence of the control also impacts the assumed losses from hot water storage.

In the Home Energy Model, space heating/cooling and hot water systems can refer to one or more control objects. These control objects require an input schedule defining whether a system is on or off during a particular timestep and, in the case of space heating and cooling systems, also the temperature points at which the thermostat has been set. In this context, “on” means the system is ready to provide heating or cooling but actual operation will also depend on demand.

Controls for space heating/cooling systems can also have an enforced setback temperature. If provided, the model checks the control schedule against this setback in every timestep and will override the schedule with the appropriate setback turning the system on if necessary. Additionally, the control object can be set to have an advanced start facility to account for warm-up time.

The Home Energy Model also models simple cost-minimising controls. For example, a control connected to an electric immersion heater may pick the cheapest times to purchase electricity to heat water.

Further system-specific controls can be defined as part of the system parameters in some cases, such as weather compensation and modulating controls for heat pumps.

We are considering what additional heating control systems or arrangements could be included in future.

Controls for heating and/or hot water

- Controls explicitly modelled at each timestep using control schedules.
- Can define whether a system is on or off.
- Can define setpoint and setback temperatures and advanced start periods.

20k. What are your views on the modelling of controls for heating and/or hot water in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.4 Electricity generation, self-consumption, and storage

The last stage of each calculation loop within the Home Energy Model is the calculation of electricity generation, self-consumption, and storage.

The amount of electricity used by heating, cooling, and ventilation systems is calculated in previous stages of the calculation loop (see overall calculation structure). Electricity use by lighting, appliances, and cooking is an input into the core model and therefore provided by the wrapper or user.

In the consultation version of the Home Energy Model, there is a fixed priority order for allocating electricity supply and demand.

The priority order for allocating electricity generated within the home (e.g. through solar PV) is:

1. Instantaneous use (or “self-consumption”)
2. Electric battery storage
3. PV diverter to a hot water cylinder
4. Grid export

The priority order for meeting any electricity demand within the home is:

1. Self-generation (e.g. solar PV, wind turbines)
2. Electric battery storage
3. Mains electricity (grid import)

This fixed ordering within the Home Energy Model could be made more flexible in future; for example, to account for time-of-use import or export tariffs.

The next section provides further detail on solar PV, PV diverters, and electric batteries. These aspects of electricity generation and storage are the most fully developed in the consultation version of the Home Energy Model. Please see Section 5.5 for information on future features development.

21a. What are your views on the current priority order for allocating electricity supply and demand in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.4.1 Solar PV

Technical Paper: HEM-TP-18 PV generation and self-consumption

In SAP 10.2, the performance of solar PV depends on the average solar irradiance (adjusted for orientation, pitch, and overshading).

The Home Energy Model follows the hourly procedure method described in BS EN 15316-4-3:2017 to calculate the energy output of a PV system installed within a dwelling. PV output within the Home Energy Model is calculated using the solar radiation from the input weather data file (see Section 5.1.6 for a description of the solar radiation calculation), as well as the orientation, pitch, and shading of the panels (follows same calculation as for window shading, see Section 5.1.7).

The calculated performance is then adjusted depending on the solar panel's level of ventilation, replacing generic performance factors from the BS EN standard with a set of national performance factors for UK-based systems. This is in contrast to SAP 10.2, which does not consider how well-ventilated the panels are.

In the next phase of development, we may look to include inverter types, tracking systems, and the modelling of module-level power electronics to mitigate the effect of shading of panels.

Solar PV

- Solar PV methodology follows BS EN 15316-4-3:2017 hourly methodology.
- Solar PV performance varies based on system location, orientation, pitch, and shading.
- Solar PV performance is adjusted to account for panel's level of ventilation.

21b. What are your views on the modelling of solar PV in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.4.2 Electric batteries

In SAP 10.2, battery storage is only permitted alongside solar PV. The methodology is based on an off-model simulation and is therefore only very approximate.

In the Home Energy Model, electric batteries are fully integrated into the electricity generation and consumption calculations. However, the model of the battery itself remains fairly simple within this consultation version. Some of the key aspects of the battery module include modelling its charging/discharging efficiency based on user input and the ability for charging and discharging to happen within the same timestep.

In the next phase of model development, we may look to further develop the battery module by adding aspects such as a maximum dis/charging rates, variations in behaviour based on temperature, and the ability to charge from the grid. We are also considering what control systems or arrangements for electric batteries could be included in future.

Electric batteries

- Fully integrated into electricity generation and consumption calculations.
- Allows for charging and discharging within the same timestep.

21c. What are your views on the modelling of electric batteries in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.4.3 PV diverters

Technical Paper: HEM-TP-18 PV generation and self-consumption

In the Home Energy Model, PV diverters can send electricity generated by solar PV to immersion heaters in hot water cylinders.

The greater resolution of hot water cylinder setpoints and temperatures in the Home Energy Model means that utilisation and storage loss factors required to model PV diverter performance in SAP 10.2 are no longer needed. In the next phase of development, we may look at the ability to divert PV generation to other features, such as a heat pump providing water heating for a storage tank in place of an immersion heater. We are also considering what control systems or arrangements for PV diverters could be included in future.

PV diverters

- Dynamic effects of PV diverters can be modelled due to increased time resolution.

21d. What are your views on the modelling of PV diverters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

5.5 Future features development

This chapter has described the key aspects of the consultation version of the Home Energy Model. Given that the Home Energy Model is still under development, we have prioritised the development of a core list of features for this consultation. Ahead of implementation in 2025, the government intends to develop further features, including all technologies currently featured in SAP 10.2, and all existing Appendix Q technologies (see Section 3.4).

We aim to develop these features in the open (see Section 3.1) and will engage with industry as part of the ongoing development process.

Please note that future development will be visible in the open-source code, but not in the consultation tool, which we do not intend to maintain beyond the consultation.

22. What are your views on future features development for the Home Energy Model? Please make suggestions, explaining your reasoning.

23. What data or evidence do you have which could support the future development of features within the Home Energy Model? Please provide further details.

Chapter 6: Validating the Home Energy Model

Validation is the process of checking how well a model meets its goals and user needs. Our intent is for the Home Energy Model to simulate building energy use as realistically as possible. Therefore, we have undertaken a series of validation exercises to check whether this is the case, assessing the model's performance against:

1. Comparable modelling tools,
2. Monitoring data from real dwellings, and
3. Laboratory test data.

These exercises represent a significant increase in the rigour of the development process as compared to SAP. We hope that by demonstrating a robust and transparent validation process, we can give users confidence in the new Home Energy Model and demonstrate an improvement over SAP 10.2.

This chapter describes the approach taken to validate the Home Energy Model to date and summarises the results of those validation exercises. We then seek views and call for evidence to support ongoing validation as development continues.

The validation exercises are described fully in the accompanying technical documentation. This chapter is best read in conjunction with that material.

Note that the outputs of the Home Energy Model are sensitive to the assumptions which are applied. Wrappers introduce a range of standardised assumptions which could lead to departures from the most realistic estimates of energy use, and so validation of such standardised assumptions has been considered separately.

Please see the Home Energy Model: FHS assessment consultation *for commentary on the validation of the FHS assessment wrapper.*

6.1 Validation Approach

The Home Energy Model has been validated using different approaches.

1. Validation against benchmark building energy models

We have modelled a set of archetype homes using both the Home Energy Model and well-validated existing models and then compared the results. Validation against other models is very valuable as it enables comparison on a detailed component-by-component basis, rather than comparing only "headline" outputs such as overall heating demand. This helps spot errors and allows us to judge the significance and relative strengths of different approaches. When identifying and explaining points of difference, none of the models is necessarily assumed to be giving the "correct answer"; however, the comparator models chosen are well-validated and established tools.

2. Validation against real-world case studies

We have modelled real-world buildings using the Home Energy Model and compared the results to monitoring data collected from the same buildings in use. There are two types of case studies:

- **Occupied homes:** These case studies are good for taking account of real occupant behaviour. However, the uncontrolled operating conditions, often paired with more limited data collection, can bring considerable uncertainty and limit the ability to validate the physical accuracy of the model.
- **Unoccupied test houses:** These homes are set up as if they are occupied, but under strictly controlled conditions, typically with a high number of monitoring sensors. This allows much higher precision on validation of the physical accuracy of the model.

A close match between predicted and monitored energy use is the gold standard for demonstrating a realistic representation of real-world homes. So far, the number of dwellings tested is limited, and there is less scope to determine the precise causes of differences than when validating against other benchmark building energy models.

3. Validation against lab tests

We have conducted lab tests on specific technologies (e.g. boilers, heat pumps), and compared the data against the relevant module in the Home Energy Model. This allows for detailed examination of the module methodology under both normal and relatively extreme conditions, with a focus on known gaps in the existing evidence base.

4. Sensitivity analysis

We conducted a series of sensitivity analyses to understand how varying individual model inputs can affect the model outputs. This sensitivity analysis has been used to validate the model by demonstrating that the model responds to variations in a sensible and realistic way.

6.2 Validation Results

In this section we discuss the first three validation approaches in turn, giving a summary of the purpose, method, results, conclusion, and recommendations of each.

These validation exercises have taken place throughout the development of the Home Energy Model, and the results been used to understand which areas need further improvement. See the technical papers for details on the model version used in each exercise.

6.2.1 Validation against benchmark building energy models

Validation Paper: HEM-VAL-01 Inter-modal validation

In this validation exercise, we compared the Home Energy Model against:

- The Passivhaus Planning Package (PHPP), a building energy model which is regarded as demonstrably accurate for modelling of high-performance homes in the field.
- Environmental Systems Performance - Research (ESP-r), a building energy model which offers a high time resolution and is known to have good building physics accuracy.

In addition, we compared the Home Energy Model to SAP 10.2 to understand how and where it offers improvements.

Method

We ran five archetype homes through the models and compared the results. The archetypes used were:

- A detached house,
- A semi-detached house,
- A terrace house,
- A deck access flat (mid-floor),
- A Victorian-era flat (mid-floor).

These archetypes are fictional but realistic dwellings chosen to encompass a range of build types. The Victorian flat archetype was chosen to have relatively poor fabric quality, with the other archetypes specified at current new build fabric standards, to ensure relevance to the Future Homes Standard.

In addition to the above, a simple ‘shoebox’ model was used when detailed analysis was required to identify trends between the models’ core building physics algorithms.

We analysed and compared the following key metrics:

- space heating demand
- internal temperature
- dwelling annual energy balance

As necessary, we also looked more deeply into e.g. the components of solar gain and other details of the heat balance methodology. Closeness of alignment between the models was assessed[6] using methodology taken from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Guideline 14 (AG14).

It is important to note that, in the validation of Home Energy Model itself (i.e. the core engine), the intention was to isolate the underlying building physics from the models' differing standardised assumptions and input conventions. All models therefore underwent an alignment process to ensure like-for-like comparison. This alignment was progressively relaxed as the testing went on, to examine the effects of key standardisations (like the choice of heating setpoint temperature).

Hence, the model results being compared and summarised here ("Phase 1" of the comparison) are not what they would produce if used normally in the field (except in the final runs, which specifically look at the impact of FHS assessment wrapper assumptions, and are discussed in the Home Energy Model: FHS assessment consultation).

In the early stages of the exercise, ESP-r was the primary comparator model. Notably, only ESP-r and the Home Energy Model can simulate an unheated, "free-floating" dwelling. As standard assumptions were introduced, PHPP took a more prominent role.

Results and conclusions

The comparison exercise highlighted various points of strength and weakness across the different models, and we are confident that the variations in outputs have been explained by known methodology differences, following detailed analysis.

The general conclusion is that the Home Energy Model is visibly capturing effects which SAP 10.2 does not, and that this sometimes improves its alignment with either PHPP or ESP-r, as compared to SAP (though there are exceptions[7]). The Home Energy Model has been shown to partly agree with its comparators. It is within the threshold values recommended by AG14 for many of the statistical indices that were calculated. See Figure 3 for an example of the comparison output.

The two half-hourly models (the Home Energy Model and ESP-r) produce very similar half-hourly time profiles of internal temperatures across all archetypes under a range of conditions, with heating both on and off. Where differences occur, such as ESP-r's frequently higher summer temperatures, these are largely explained by differences in the treatment of solar gains, which are very influential on the overall heat balance in all the models.

In cases where window overshading was significant, SAP 10.2 was generally the outlier result with by far the simplest treatment of the effect of window overshading. This demonstrates a significant improvement over SAP 10.2 in the Home Energy Model's building physics and functionality.

[6] This assessment adopted the indicators and criteria used in AG14. As AG14's criteria are intended for comparison with in-use data rather than models, meeting its criteria cannot be taken as evidence of validation.
[7] The deck access flat has SAP 10.2 as the (low) outlier in annual space heat demand, with the Home Energy Model closer to both PHPP and ESP-r. Elsewhere the Home Energy Model tends to predict the highest space heat demand, by a small margin.

Table 1B_DE Annual Energy Demand

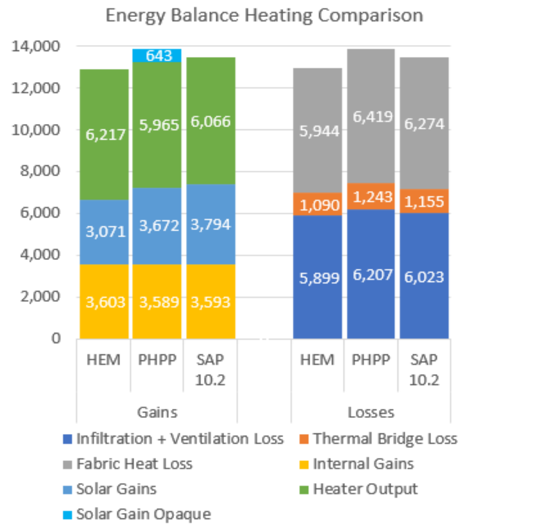
		1B_DE			
		ESP-r	PHPP	SAP10.2	HEM
Annual Energy Demand (kWh/yr)	Space Heating	5,311	6,052	5,967	6,036
	Hot Water				
	Cooling				
	Lighting				
	Ventilation				

Table 1B_DE Monthly Space Heating Demand

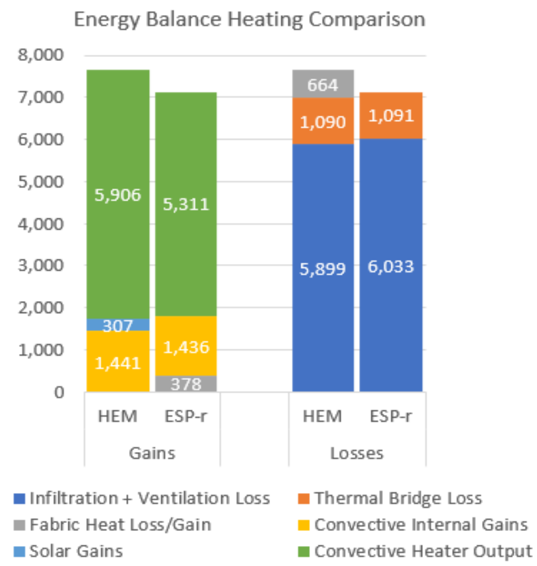
		1B_DE			
		ESP-r	PHPP	SAP10.2	HEM
Monthly Space Heating Demand (kWh)	January	1055.0	1071.0	1110.4	1086.7
	February	776.0	815.0	865.9	834.2
	March	572.0	659.0	731.1	666.5
	April	393.0	487.0	443.2	510.3
	May	163.0	261.0	218.4	272.8
	June	5.0	87.0	67.5	22.8
	July	0.0	34.0	18.7	0.4
	August	0.0	29.0	26.0	0.0
	September	54.0	191.0	119.1	133.4
	October	390.0	469.0	428.6	491.6
	November	818.0	846.0	798.6	885.9
	December	1086.0	1102.0	1139.8	1131.6

Table 1B_DE Operative and Internal Air Temperatures

		1B_DE			
		ESP-r	PHPP	SAP10.2	HEM
Annual Internal Air (dry bulb) Temperature [average for whole dwelling] (°C)		22.3	21.0	21.0	21.9
Half-Hourly Operative Temperature	Zone 1: Winter Week] (oC)	21.2	21.0	21.0	21.2
	Zone 2: [Winter Week] (oC)	21.0	21.0	21.0	21.0
	Zone 1: [Summer Week] (oC)	25.1	21.0	21.0	23.7
	Zone 2: [Summer Week] (oC)	25.6	21.0	21.0	24.0



Phase 1B - DE - Energy Balance Comparison Graphs at the External Boundary



Phase 1B - DE - Air Node Energy Balance Comparison Graphs

Figure 3 – Example dashboard of outputs presenting comparison of the Home Energy Model and other comparator models. Detached house archetype, Phase 1B (aligned inputs with continuous heating profile).

Where there was a large unshaded glazed area, ESP-r tended to be the outlier (with lower heat demand) due to a number of more subtle effects not captured in the other models. We will consider these for future inclusion in the Home Energy Model.

The inter-model comparison report notes some areas for improvement and further validation which we will consider in the next phase of development. For example:

- Better alignment with ESP-r could be achieved by altering the input parameterisation of thermal mass for building elements. This would be a departure from the BS EN 52016-1:2017 approach, with a number of alternatives available.
- Closer alignment with ESP-r's solar gain calculations could be achieved by more accurately accounting for variation in reflectivity of windows, depending on the incident angle of sunlight. This also means going beyond the methodology in BS EN 52016-1:2017. The static reflectivity value taken from the Standard is lower than that used in PHPP and the time-average derived from the varying ESP-r values, leading to higher solar gains overall.
- Accounting for inter-zone heat transfers would potentially improve alignment of heat demand with both ESP-r and PHPP. BS EN 52016-1:2017 does provide a methodology to account for this effect.
- Undertaking further validation of the heat transfer coefficient values applied within the Home Energy Model and considering the appropriateness of dynamically calculated heat transfer coefficients (HTCs), as used in ESP-r.
- So far, most of the focus has been on space heating demand, internal temperature and building physics. While some validation of systems has been carried out, this is more limited. More interrogation of systems, especially heat pumps, is needed.
- Alignment of the models when differing levels of air tightness was applied reflected a difference in the core algorithms. The current Home Energy Model approach may reduce the estimated benefit of an MVHR system compared to a natural ventilation or decentralised mechanical extract solution.
- Further work is needed to develop the Home Energy Model's treatment of infiltration and ventilation, to improve alignment and internal consistency with the heat loss calculations.

Note that recommendations were also produced, from the inter-modelling validation exercise, which relate to the FHS assessment wrapper standardisation, and which are considered in the corresponding consultation. An incidental finding of this work is that the widely publicised differences in output between SAP 10.2 and PHPP derive largely from differences in conventions and standardised input assumptions, rather than the underlying building physics models. This further makes the case for close attention to the content of FHS assessment wrapper assumptions when considering the final energy use estimates.

We will continue to validate the Home Energy Model against established models throughout its development to improve its accuracy, including further examination of older building typologies.

24. What are your views on the inter-model validation work that has been carried out (i.e. comparison against SAP 10.2 and validation against PHPP and ESP-r)? Please provide your reasoning and any supporting evidence.

6.2.2 Validation against real-world case studies

We have validated the Home Energy Model against the following real-world case studies:

- Two test houses from the International Energy Agency Annex 58 research project.
- The Camden Passivhaus, designed by Bere Architects.
- Three homes from the Marmalade Lane development in Cambridge, which were monitored during construction and used as part of the Building For 2050 research project.

IEA Annex 58 Test Houses

Validation Paper: HEM-VAL-02 In-use validation - IEA Annex 58

In 2013-14, the International Energy Agency's Annex 58 research project collected in situ monitoring data from two test houses to support the validation of building energy models. The project conducted experiments using two identical all-electric bungalows situated at the Fraunhofer Institute for Building Physics in Holzkirchen, Germany.

These test houses do not have occupants and therefore provide a good opportunity to test the building physics of the Home Energy Model under a wide range of experimental conditions.

This validation exercise particularly compared the following aspects of the Home Energy Model against hourly data from the test houses:

- Internal temperatures
- Space heating energy consumption

The validation results show that the Home Energy Model demonstrated a good prediction of both internal temperatures and space heating energy consumption. Differences identified could reflect both limited information on some inputs to the Home Energy Model and measurement error in the test houses.

The Home Energy Model predicted space heating energy consumption generally aligned well with the measured data, both in aggregate (e.g. weekly average) and at high time resolutions, when fed detailed input data calibrated to the specific dwelling. An example is given in Figure 4. See the HEM-VAL-02 for more results from this validation exercise, including further graphics.

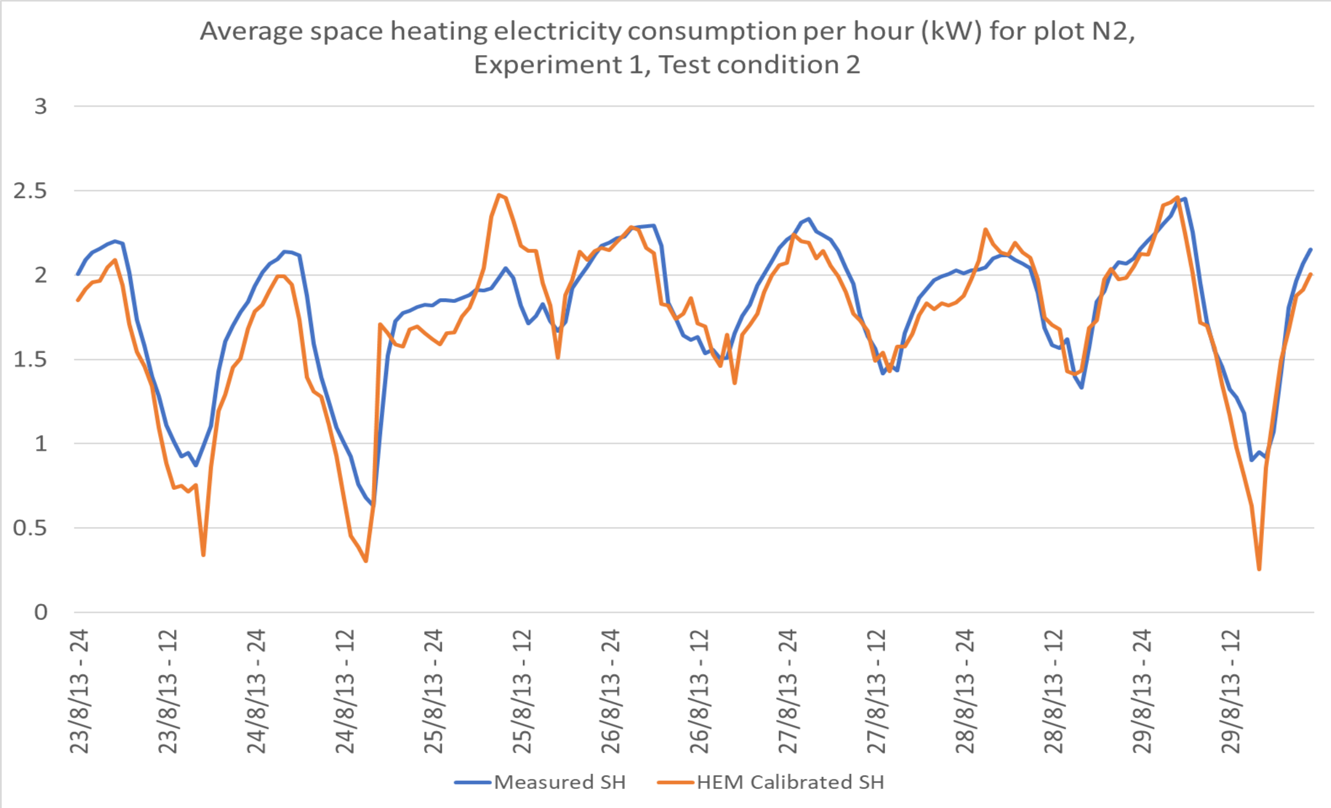


Figure 4 – A comparison of Home Energy Model predicted vs measured data for space heating energy consumption for an IEA Annex 58 test house.

Camden Passivhaus

Validation Paper: HEM-VAL-03 In-use validation - Camden Passivhaus

The Camden Passivhaus is a house in London designed by Bere Architects to Passivhaus standards. Its performance has been studied in detail as part of the Technology Strategy Board (now Innovate UK) Building Performance Evaluation Programme. The house has mechanical ventilation with heat recovery, a high standard of insulation and airtightness, high performance glazing, and (apart from two heated towel rails) heating via the ventilation supply air.

This validation exercise particularly compared the following aspects of the Home Energy Model against the monitored data:

- Internal temperatures
- Space heating energy consumption

The monitoring data used was from a period in 2012-2013, during which the home was occupied. We calibrated the weather, occupancy, and space heating regime assumptions in the Home Energy Model so that they better represented the actual conditions.

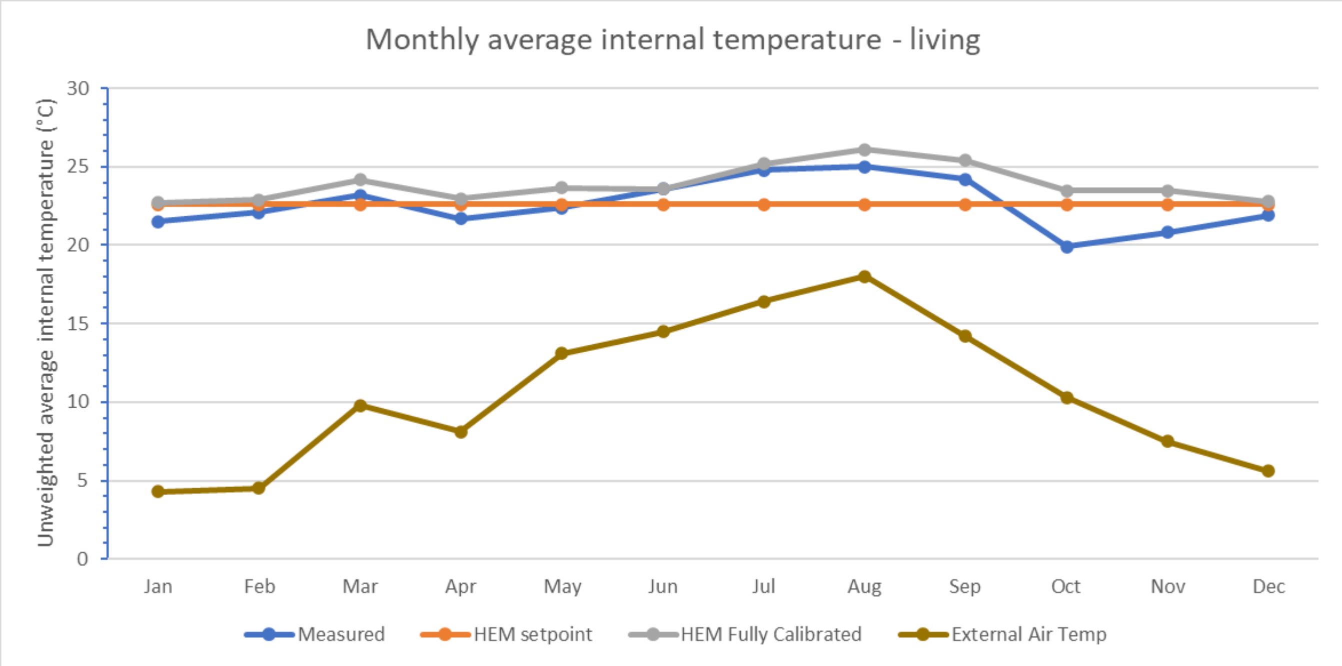


Figure 5 – A comparison of Home Energy Model predicted vs measured internal temperatures for each month in the living area of the Camden Passivhaus

The Home Energy Model produced results that are broadly consistent with the measured data. As an example, the graph above shows that the predicted internal temperatures (grey line) generally show good alignment with the measured data (blue line). The differences identified can plausibly be explained by uncertainties inherent in the case study data.

Alignment of the annual energy consumption for space heating was also close for the calibrated comparison, though at monthly level the variation was greater. As the space heating demand (predicted and measured) was very low for this dwelling, the sensitivity of the total to variations in solar and internal gains due to varying occupant behaviour is high.

A major uncertainty in this validation exercise is the limited data available on the behaviour of the residents. Further information on the residents' use of solar shading and their use of heating controls would have been beneficial in validating the variations over the course of a year.

This case study noted that a more detailed treatment of window shading (from curtains, blinds etc.) in the Home Energy Model may lead to more accurate results in some circumstances.

Building for 2050 – Marmalade Lane development

Validation Paper: HEM-VAL-03 In-use validation - Building for 2050

The Building For 2050 project was a study of the construction of low-cost, low-carbon homes, funded by the then Department for Business, Energy & Industrial Strategy. In this validation exercise, we have used monitoring data from three homes from the project's Marmalade Lane housing development in Cambridge. These homes have air-source heat pumps and mechanical ventilation with heat recovery.

This validation exercise particularly compared the following aspects of the Home Energy Model against the monitored data:

- Internal temperatures
- Space heating energy consumption

The validation results show that the Home Energy Model, when calibrated:

- provided a reasonable fit to the internal temperature data (see Figure 5, below)
- provided annual space heating electricity consumption that was within 20% of the monitored data.

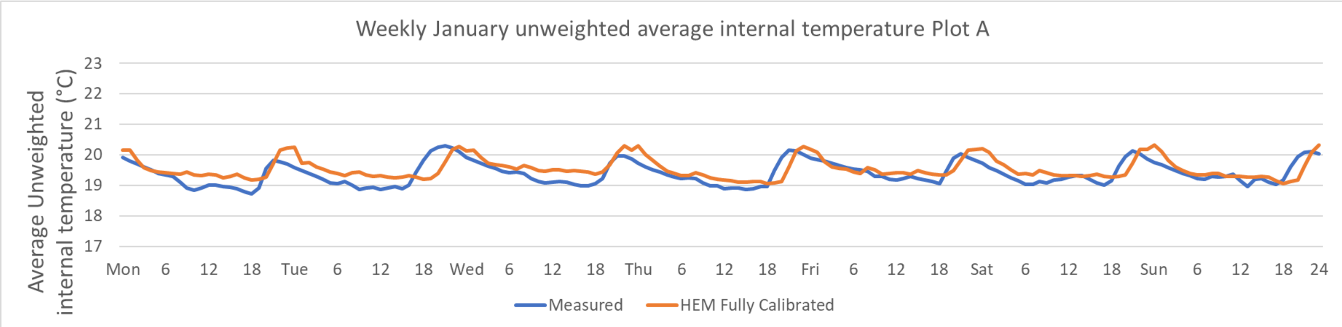


Figure 6 – A comparison of Home Energy Model predicted vs measured internal temperatures for an average week in January in one of the Marmalade Lane homes.

The monitoring data used was from a period in 2019-2020, when the homes were occupied. In order to compare the monitored data to the Home Energy Model, we calibrated the weather, occupancy, and space heating regime assumptions in the two models, so that they better represented the actual conditions.

In this case study SAP 10.2 runs (both calibrated and uncalibrated) were carried out alongside the Home Energy Model runs. SAP 10.2 could not be calibrated to the specific dwelling data as closely as the Home Energy Model, but the calibrations used were the same as far as possible. The alignment of the Home Energy Model to the measured data was consistently better than that of SAP 10.2.

A major uncertainty is the limited data available on the behaviour of the residents. Other uncertainties include the accuracy of the input data entered into the model, such as whether the data entered on the building fabric and building services performance accurately represented the actual performance, and the accuracy of the measured data. It was also not possible to separate energy use by different end uses, notably space heating and hot water consumption could not be distinguished and so the split was estimated.

The level of agreement observed between the calibrated Home Energy Model and the measured data should therefore be viewed with caution. However, since common calibration was used between the Home Energy Model and SAP 10.2 as far as possible, the conclusion that the Home Energy Model can better reflect these dwellings compared to SAP would appear to be comparatively robust.

25. What are your views on the validation work that has been carried out against real-world case studies (i.e. IEA Annex 58, Camden Passivhaus, and Marmalade Lane)? Please provide your reasoning and any supporting evidence.

6.2.3 Validation against lab tests

Lab testing enables us to collect high-resolution data on the performance of specific technologies. Given that the Home Energy Model can run simulations at half-hourly timesteps, we are able to use these lab test results to validate the model to a much higher degree of resolution than was previously possible with SAP 10.2.

We have undertaken two sets of lab tests to enable validation of the methodologies for boilers and for heat pumps.

Lab testing of boiler cycling

Validation Paper: HEM-VAL-05 Lab testing – boiler cycling

The sub-hourly modelling of boilers within the Home Energy Model (see Section 5.3.5) enables the explicit representation of boiler cycling, which SAP had only previously captured through aggregate correction factors. Boiler cycling occurs when the energy demand falls below the boiler’s minimum output, meaning the boiler switches on and off to maintain temperature. This leads to a decrease in the boiler’s efficiency.

Lab tests were carried out on boilers at low outputs, and the results compared against the Home Energy Model. The Home Energy Model showed a good alignment with the lab results when the boiler operated at 30% of full output; however, testing indicates the model currently still overestimates boiler efficiencies at outputs lower than this. The consultation version of Home Energy Model therefore does not permit boiler modulation lower than 30%.

To supplement the lab results, the Home Energy Model was also compared against field trial data, which showed the model’s boiler cycling behaviour was consistently within the range observed in the field.

These results show that the Home Energy Model is a reliable tool for capturing the impact of boiler cycling on efficiency. We will consider further validation of the boiler methodology in the next phase of development.

Lab testing of heat pumps providing DHW

Validation Paper: HEM-VAL-06 Lab testing – heat pumps DHW

Unlike SAP 10.2, the Home Energy Model includes an explicit representation of hot water cylinders. This provides the opportunity to validate the performance of heat pumps providing DHW through lab testing.

Lab testing was carried out to analyse the sensitivity of heat pump performance when providing DHW. The tests were conducted using a 5 kW Monoblock heat pump with inverter-controlled compressor and variable speed water pump that is currently available on the UK market.

The lab tests assessed the effects of varying the following:

Variable	Results
Outside air temperature	The lab and modelling values followed a similar trend; however, the modelling predicted better heat pump performance than shown by the lab tests at the lowest external temperature (2°C).
DHW tapping profile	The lab and modelling values followed a similar trend; with differences arising again at low external temperatures.
Maximum flow temperature	The lab and modelling values followed a similar trend, but the Home Energy Model is slightly less sensitive to this than the lab data indicates.
Cylinder volume	The Home Energy Model was not able to fully capture the difference in performance of a change in cylinder size, with similar performance at 150 vs 210 litres. The lab data indicates a moderate drop in COP.
Thermostat location in cylinder	The Home Energy Model shows a smaller variation in performance when the thermostat moves between the top and bottom of the cylinder than the lab data, for both cylinder sizes tested. However, the majority of the variation observed is captured.

These results show that the Home Energy Model predicts similar trends to the lab tests across a range of variables. However, the model tended to somewhat overestimate the performance of heat pumps providing DHW under certain circumstances – notably for smaller cylinders and low exterior temperatures.

We will consider undertaking another round of heat pump testing to investigate how the Home Energy Model could be further improved.

26. What are your views on the lab testing validation work that has been carried out (i.e. on boiler cycling and heat pumps providing DHW)? Please provide your reasoning and any supporting evidence.

6.3 What further validation will there be?

The Home Energy Model is still under development and its first 'live' version will be implemented alongside the Future Homes Standard in 2025. In advance of this, we will undertake further validation to ensure the model is as robust as possible. This will likely include:

- Running additional archetypes through the Home Energy Model, PHPP, and ESP-r, and comparing the results.
- Additional validation against real-world case studies, including two low carbon houses inside Energy House 2.0 (a large-scale research facility at the University of Salford[8]).
- Validation against field trial data, including from the government's Electrification of Heat Demonstration Project and forthcoming Homes for Net Zero project.
- Further lab tests on the effect of different controls, modulation rates, and fuels on boiler efficiency.
- Further lab tests to validate the space heating efficiency and DHW performance of both of heat pumps and hybrid heat pumps.

We encourage consultees to engage with the open-source code and conduct their own validation exercises.

27. What examples of real-world case studies, or other data, do you suggest be used to further validate the Home Energy Model? Please provide further information.

28. What suggestions do you have for further validation exercises that could be undertaken to refine the Home Energy Model? Please make suggestions, explaining your reasoning, and providing any supporting evidence.

[8] The Energy House 2.0 project is a partnership between the University of Salford, Barratt Developments, Bellway Homes, and Saint-Gobain.

Public Sector Equality Duty

The government must consider how policies and decisions affect people who are protected under the Equality Act 2010. The protected characteristics are: age, disability, gender reassignment, marriage or civil partnership, pregnancy and maternity, race, religion or belief, sex, and sexual orientation.

The Home Energy Model core engine models the physics of a building, and therefore does not include any assumptions relating to people or their behaviour. The model has been validated against monitoring data from a limited set of real-world homes. In the next phase of development, we will be undertaking further validation using a wider variety of home archetypes.

We will consider how the proposed changes to the surrounding modelling ecosystem (see Chapter 3) may impact those with protected characteristics. These changes include how the model recognises new technologies and product-specific performance data, and how software is provided to energy assessors.

We will consider the possible equality impacts of these proposals during policy development and will undertake an equality assessment in advance of implementation.

29. What are your views on the impact of proposed changes to the modelling ecosystem on those with protected characteristics? Please provide your reasoning and any supporting evidence.

Environmental Principles Policy Statement

The Environment Act 2021 places a duty on the government to consider the environmental principles policy statement (EPPS) when making policy, to help protect and enhance the environment whilst supporting innovation and economic growth. The statement sets out how to interpret and proportionately apply the five environmental principles:

1. The integration principle – policy-makers should look for opportunities to embed environmental protection in other fields of policy that have impacts of the environment
2. The prevention principle – government policy should aim to prevent environmental harm
3. The rectification at source – if damage to the environment cannot be prevented it should be tackled at its origin
4. The polluter pays principle – those who cause pollution or damage to the environment should be responsible for mitigation or compensation
5. The precautionary principle – where there are threats of serious or irreversible damage, a lack of full scientific certainty shall not be used a reason for postponing cost-effective measures to prevent environmental degradation

The Home Energy Model is a calculation methodology designed to assess the energy performance of a home. As a stand-alone methodology, the Home Energy Model has a minimal impact on the environment. However, the model will have an indirect impact on the environment through the policies that it supports.

This consultation sets out how we have responded to recommendations from the Climate Change Committee and others to create a methodology that is fit for a net zero future. Our intent is for the Home Energy Model to simulate building energy use as realistically as possible and thereby avoid biases towards certain types of technologies or systems. We have undertaken a series of validation exercises to check whether this is the case (see Chapter 6).

We will consider the possible environmental impacts of the Home Energy Model during the next phase of development.

30. What are your views on the possible environmental impacts of the Home Energy Model core engine itself? Please provide your reasoning and any supporting evidence.

Next steps

This consultation presents the new Home Energy Model, which will replace the Standard Assessment Procedure (SAP) for the energy rating of dwellings.

The Home Energy Model is still under development and its first 'live' version will be implemented alongside the Future Homes Standard in 2025. Responses to this consultation will provide valuable feedback and recommendations for further model development in advance of its introduction.

In 2022, the government appointed a consortium led by Etude[9] to quality assure the Home Energy Model throughout its development. For this publication, Etude have produced an evaluation of the consultation version of the Home Energy Model against key success criteria (see the evaluation report on the Home Energy Model consultation page). This evaluation, alongside the responses to this consultation, will be used to plan the next phase of model development.

We aim to be as transparent as possible with our next phase of model development, developing code in the open, and with close links to industry. Through this, we hope to ensure a smooth implementation of the Home Energy Model.

The next phase of the project will have several workstreams, including:

- **Government Response:** we will publish a Government Response to this consultation in 2024. This response will present our plans for the next phase of model development, including how feedback and recommendations will be addressed.
- **EPC wrapper:** The government is currently working on proposals for improving EPCs, including the performance metrics they display, and intends to consult on these separately in the coming months. The outcome of the EPC consultation will feed into the development of a Home Energy Model methodology for producing EPCs (an "EPC wrapper"). We intend to consult on the EPC wrapper methodology in 2024. See Section 3.5 for more information.
- **Further features development:** The Home Energy Model does not yet contain the full complement of technologies covered by SAP 10.2. These features will be added in the next phase of development, alongside other improvements to the model methodology as needed. We will take account of feedback to this consultation when planning ongoing development. See Section 5.5 for further information.
- **Product-specific performance data:** As part of the Home Energy Model project, the existing Product Characteristics Database (PCDB) will be fully rebuilt. There may be some instances where the more in-depth modelling done by the Home Energy Model provides the opportunity for manufacturers to submit more detailed data on their product. In the next phase of the project, we intend to engage with manufacturers to facilitate this data

[9] Project team: Levitt Bernstein, UCL, Julie Godefroy Sustainability, and Etude.

provision so that their products can be best represented in the model. See Section 3.3 for more information.

- **Recognising new technologies:** the government intends to reform the process for incorporating new technologies into the Home Energy Model (process previously known as “Appendix Q”). We will be working closely with industry to develop this new process and will provide further information in due course. See Section 3.4 for more information.
- **Further validation:** In advance of implementation, we will undertake further validation of the Home Energy Model to ensure it is as robust as possible. We also encourage consultees to engage with the published source code and undertake their own validation exercises. See Chapter 6 for more information.
- **Delivery model:** Section 3.2 sets out possible changes to how software is provided to energy assessors to demonstrate Part L compliance and lodge Energy Performance Certificates (EPCs). We intend for these changes to take effect when the first ‘live’ version of the Home Energy Model is implemented in 2025. We will be working closely with industry to explore these proposed changes and will provide further information in due course.

Consultation questions

Chapter 2: The need to replace SAP

1. What are your views on the choice of name for the new model? Please provide your reasoning and any supporting evidence.

2. What are your views on the choice of name for the version of the model which is to be used to demonstrate compliance with the Future Homes Standard? Please provide your reasoning and any supporting evidence.

3. What are your views on the potential implications of this proposed name change? Please provide your reasoning and any supporting evidence.

Chapter 3: A new home energy modelling ecosystem

An open-source methodology

4. What are your views on using the open-source code as the approved methodology for regulatory uses of the Home Energy Model? Please provide your reasoning and any supporting evidence.

5. What forms of collaboration would you be interested in for future development of the Home Energy Model codebase? Please provide further details.

Changes to the delivery model and provision of software

6. What are your views on our assessment of issues with the current SAP delivery model? Please provide your reasoning and any supporting evidence.

7. What are your views on the concept of a centralised, cloud-based version of the Home Energy Model, to be used for regulatory purposes? Please provide your reasoning and any supporting evidence.

A revised database of product characteristics

8. What are your views on revising the database of product characteristics (currently the “PCDB”) for the Home Energy Model? Please provide your reasoning and any supporting evidence.

9. What changes would you recommend to the PCDB data collection procedures? Please provide your reasoning and any supporting evidence.

10. What changes would you recommend to the PCDB data requirements for particular technologies? Please provide your reasoning and any supporting evidence.

Recognising new technologies in the Home Energy Model

11. What are your views on our assessment of issues with the way SAP currently recognises new technologies (currently the "Appendix Q process")? Please provide your reasoning and any supporting evidence.

12. What are your views on the principles for how the Home Energy Model will recognise new technologies once it is in use? Please provide your reasoning and any supporting evidence.

13. What are your suggestions for how to integrate new innovative products into the Home Energy Model? Please provide your reasoning and any supporting evidence.

Using "wrappers" to distinguish different use cases

14. What are your suggestions for other wrappers that could be developed for the Home Energy Model in future? Please provide your reasoning and any supporting evidence.

Chapter 4: The new Home Energy Model – an overhaul

15. What are your views on the increased time resolution offered by the Home Energy Model? Please provide your reasoning and any supporting evidence.

16. What are your views on the choice of BS EN ISO 52016-1:2017 (in its half-hourly form) as the basis for the Home Energy Model? Please provide your reasoning and any supporting evidence.

17. What are your views on the ability of the Home Energy Model to model energy flexibility and smart technologies? Please provide your reasoning and any supporting evidence.

Chapter 5: What is inside the Home Energy Model?

Space heating and cooling demand

18a. What are your views on the methodological approach for calculating space heating and cooling demand? Please provide your reasoning and any supporting evidence.

18b. What are your views on the methodological approach for calculating fabric heat loss? Please provide your reasoning and any supporting evidence.

18c. What are your views on the methodological approach for calculating thermal bridges? Please provide your reasoning and any supporting evidence.

18d. What are your comments on the methodological approach for calculating infiltration and/or controlled ventilation? Please provide your reasoning and any supporting evidence.

18e. What are your views on the methodological approach for calculating thermal mass? Please provide your reasoning and any supporting evidence.

18f. What are your views on the methodological approach for calculating solar gains and solar absorption? Please provide your reasoning and any supporting evidence.

18g. What are your views on the methodological approach for calculating shading? Please provide your reasoning and any supporting evidence.

Domestic Hot Water (DHW) demand

19a. What are your views on the methodological approach for calculating Domestic Hot Water demand? Please provide your reasoning and any supporting evidence.

19b. What are your views on the methodological approach for calculating heat losses from Domestic Hot Water pipework? Please provide your reasoning and any supporting evidence.

19c. What are your views on the methodological approach for calculating heat losses from hot water cylinders? Please provide your reasoning and any supporting evidence.

19d. What are your views on the methodological approach for calculating incidental gains from domestic hot water? Please provide your reasoning and any supporting evidence.

Heating and cooling systems

20a. What are your views on the modelling of heat pumps in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20b. What are your views on the modelling of electric resistive heaters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20c. What are your views on the modelling of electric storage heaters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20d. What are your views on the modelling of heat networks in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20e. What are your views on the modelling of boilers in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20f. What are your views on the modelling of heat batteries in the Home Energy Model? Please provide your reasoning and any supporting evidence

20g. What are your views on the modelling of air conditioning in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20h. What are your views on the modelling of other Domestic Hot Water heating (e.g. immersion heaters, point-of-use, solar thermal) in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20i. What are your views on the modelling of heat emitters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20j. What are your views on the methodological approach for calculating pumps' and fans' energy consumption in the Home Energy Model? Please provide your reasoning and any supporting evidence.

20k. What are your views on the modelling of controls for heating and/or hot water in the Home Energy Model? Please provide your reasoning and any supporting evidence.

Electricity generation, self-consumption, and storage

21a. What are your views on the current priority order for allocating electricity supply and demand in the Home Energy Model? Please provide your reasoning and any supporting evidence.

21b What are your views on the modelling of solar PV in the Home Energy Model? Please provide your reasoning and any supporting evidence.

21c. What are your views on the modelling of electric batteries in the Home Energy Model? Please provide your reasoning and any supporting evidence

21d. What are your views on the modelling of PV diverters in the Home Energy Model? Please provide your reasoning and any supporting evidence.

Future features development

22. What are your views on future features development for the Home Energy Model? Please make suggestions, explaining your reasoning.

23. What data or evidence do you have which could support the future development of features within the Home Energy Model? Please provide further details.

Chapter 6: Validating the Home Energy Model

24. What are your views on the inter-model validation work that has been carried out (i.e. comparison against SAP 10.2 and validation against PHPP, and ESP-r)? Please provide your reasoning and any supporting evidence.

25. What are your views on the validation work that has been carried out against real-world case studies (i.e. IEA Annex 58, Camden Passivhaus, and Marmalade Lane)? Please provide your reasoning and any supporting evidence.

26. What are your views on the lab testing validation work that has been carried out (i.e. on boiler cycling and heat pumps providing DHW)? Please provide your reasoning and any supporting evidence.

27. What examples of real-world case studies do you suggest be used to further validate the Home Energy Model? Please provide further information.

28. What suggestions do you have for further validation exercises that could be undertaken to refine the Home Energy Model? Please make suggestions, explaining your reasoning, and providing any supporting evidence.

Public Sector Equality Duty

29. What are your views on the impact of proposed changes to the modelling ecosystem on those with protected characteristics? Please provide your reasoning and any supporting evidence.

Environmental Principles Policy Statement

30. What are your views on the possible environmental impacts of the Home Energy Model core engine itself? Please provide your reasoning and any supporting evidence.

Annex A – Recommendations from the Scoping Study

In 2020, the government commissioned a scoping study to holistically consider how the next version of SAP could be enhanced to support net zero. The final report, "Making SAP and RdSAP 11 fit for net zero", was published in 2021. The study concluded that significant changes were needed to SAP, leading to 25 recommendations across five categories:

1. Alignment between SAP/RdSAP and its strategic objectives
2. Improvements to the methodology
3. Improvements to SAP/RdSAP and its ecosystem for net zero
4. A better evaluation of energy use
5. Support to decarbonisation of heat and electricity.

This Annex lists the 25 recommendations and sets out how they are being addressed across both the Home Energy Model and Home Energy Model: FHS assessment:

Category 1: Alignment between SAP/RdSAP and its strategic objectives

	Recommendation	*We are addressing this recommendation by…*
1	SAP can and must become a tool for net zero Carbon ready new buildings	As the Home Energy Model's first role is to support the Future Homes Standard, we have prioritised validation against low-carbon new build homes with high fabric standards and heat pumps.
2	SAP/RdSAP can and must become a better tool for whole house retrofit	This is the overarching recommendation for assessing existing buildings. Much of the development work of the Home Energy Model will benefit both new and existing dwellings. In addition, while validation has focused on new dwellings (as per recommendation 1), it has also been undertaken against typical existing dwellings and this will continue in the next phase of the project. The application of the Home Energy Model to retrofit will be considered in the development of the EPC wrapper (including the equivalent of RdSAP) in 2023-24.

3	SAP/RdSAP can and must become better at evaluating energy use	This has been the main objective of development so far, supported by extensive validation (including against in-use case studies) (see Chapter 6). The treatment of all energy uses within the core calculation has been improved (see Recommendation 7).
4	Homes need to become smart ready and SAP/RdSAP needs to help with this	This was a key determinant of the move to a half-hourly simulation (see Recommendation 7). All smart systems noted by the report have either already been included in the Home Energy Model or are intended to be. Addressing this recommendation also meets the government commitment in the 2021 Smart Systems and Flexibility Plan to support industry to incorporate flexibility and smart technologies.
5	SAP can and must play a bigger role in reducing the performance gap	This is partially addressed by the efforts to make SAP better at evaluating energy use – see Recommendation 3. Beyond this, this recommendation covers points for the wider delivery model which are out of scope for this development, but under consideration by the government.

Category 2: Improvements to the methodology

	Recommendation	*We are addressing the recommendation by…*
6	Carbon factors: replace the short term with long term factors (e.g. 25-year average)	The carbon intensity of fuels will be set within the different wrappers and not the core model. The factors used in SAP 10.2 have been revised for use with the Future Homes Standard (see the Home Energy Model: FHS assessment consultation).
7	SAP should remain a steady-state monthly tool, but with a new module for flexibility	We decided to take the more ambitious approach and develop a half-hourly "steady state" model, in accordance with BS EN ISO 52016-1:2017. Validation comparisons with dynamic simulation modelling have shown good initial results (see Chapter 6). Further testing of the representation of energy flexibility and associated technologies will be needed.

8	SAP should 'tell the truth', and enable bespoke non-regulatory uses	This has been addressed by the separation of the core Home Energy Model and the wrappers (see Section 3.5). The Home Energy Model will not contain any deviations from the best available understanding of building physics, with simplifications only applied for usability, where they have been assessed not to have a significant impact. All standardised assumptions for regulatory assessments (e.g. Building Regulations compliance, EPCs) are confined to the wrappers. Non-regulatory wrappers may be developed in future, and an open version will be available for users to enter freely any range of inputs.
9	A significant improvement of Appendix Q and the PCDB process is required	As part of the Home Energy Model project, the existing Product Characteristics Database (PCDB) will be fully rebuilt. See Section 3.3. The government intends to reform the process for incorporating new technologies into the Home Energy Model (the process previously known as “Appendix Q”). See Section 3.4.
10	Overheating: towards simplified flagging system	SAP Appendix P will not be retained in its current form. Cooling and ventilation demand has been revised as part of the Future Homes Standard work, but a separate overheating assessment has not been developed.
11	SAP/RdSAP outputs need to be compatible with disclosure and data analysis goals	The Home Energy Model will support data analysis by allowing comparisons between results calibrated to in-use conditions (e.g. weather, occupancy) and measured in-use energy data.

Category 3: Improvements to SAP/RdSAP and its ecosystem for net zero

	Recommendation	*We are addressing the recommendation by…*
12	No more Notional Building: the introduction of absolute energy use targets	The use of a Notional Building is specific to assessments of compliance with Part L of the Building Regulations. See the Future Homes Standard consultation for more information.

13	New metrics for net zero Carbon (and not primary energy)	The Home Energy Model is able to produce a large number of outputs which can support the production of different metrics relevant for net zero. The choice of output metrics for the Home Energy Model: FHS assessment is specific to assessing compliance with the Future Homes Standard. See the Future Homes Standard consultation for the rationale and proposed options relating to FHS compliance metrics.
14	Better governance: a modular architecture and an evidence-based culture	The Home Energy Model follows a modular architecture (see Section 4.3) which should facilitate future development by allowing separate modules to be updated quickly and easily. Open-source development (see Section 3.1) is the basis for an evidence-based culture. All documentation will be published (including documentation of the evidence base, validation testing and off-model derivation of assumptions).
15	New EPC ratings from SAP/RdSAP to support net zero and fuel poverty	This will be considered in the government's upcoming consultation on EPC reform, in the coming months.
16	SAP should be fully integrated in the digital age	The Home Energy Model is being published as open-source Python code (see Section 3.1). This opens the door to innovation through third party applications, including the integration and analysis of large input and/or output data sets. See also Recommendation 11.

Category 4: A better evaluation of energy use

	Recommendation	*We are addressing the recommendation by…*
17	Location should be taken into account and not normalised as it is now	The Home Energy Model will be able to accept different weather data for different locations. The choice of weather data for regulatory purposes is now made within the wrapper rather than the core Home Energy Model calculation and can be modified for a given context.

		The government is consulting on the use of regional weather data for FHS assessments as part of the Future Homes Standard consultation.
18	Domestic hot water should be modelled more accurately	All the detailed recommendations under this heading in the scoping study have been addressed in the Home Energy Model, including a review of hot water usage and associated energy use, and updated modelling of hot water systems including heat pumps.
19	SAP/RdSAP should better model the energy performance of ventilation systems	The methodology for infiltration rates and accounting for pressure test results has been improved, but further research and development is anticipated in this area. MVHR ductwork losses are also modelled in more detail. See Chapter 5. Further improvements will be considered as part of PCDB reform.
20	Thermal bridges: good practice should be rewarded (and bad practice penalised)	The treatment of thermal bridges in the Home Energy Model is not significantly different to that in SAP 10.2. However, the engine requires a full set of thermal bridge lengths and thermal transmittance values. The FHS assessment wrapper currently places the onus on the user to enter these, without use of defaults or y-values.
21	SAP needs to better reflect all energy uses, including cooking and white goods	The Home Energy Model is likely to enable individual inputs of appliance energy data. Whether these energy uses are in scope for output metrics, and what user input data is required to specify them, is determined within the wrapper for individual regulatory purposes, rather than the core engine. All energy demands may now be profiled at half-hourly resolution.
22	Occupancy: the standardised assumptions should be re-validated	Occupancy is now determined within the wrapper rather than the core engine and need not be standardised in all cases. The standardised assumptions used for Part L assessments have been re-derived from English Housing Survey 2017-2020 data. They now depend more on the number of bedrooms than on floor area, better matching the way homes are used in England.

		See the Home Energy Model: FHS assessment consultation for the new approach.

Category 5: Support to decarbonisation of heat and electricity

	Recommendation	*We are addressing the recommendation by…*
23	SAP/RdSAP needs to model all heat pump systems accurately to reward efficiency	The heat pump simulation has been moved into the core model and is now evaluated in context, rather than off-model within the PCDB. This brings the Home Energy Model into close alignment with BS EN 15316-4-2:2017. See the section on heat pumps in Chapter 5.
24	Heat networks: SAP/RdSAP should evaluate distribution losses more accurately	The representation of individual heat networks will be determined as part of the ongoing PCDB overhaul.
25	Solar Photovoltaics require better modelling and a prominent SAP/RdSAP output	The modelling of solar PV has been brought in line with current ISO standards. We plan to address the more detailed recommendations from the scoping study (such as Module Level Power Electronics) in the next phase of development. The prominence of solar PV within outputs is determined in each wrapper. This will be considered for EPCs as part of the upcoming consultation on EPC reform.