LETI Operational Modelling Guide

How energy performance modelling helps deliver energy targets

LETI

About LETI

LETI is a voluntary network of over 1,000 built environment professionals, working together to put the UK and the planet on the path to a zero carbon future. Our vision is to understand and clarify what this means in the built environment and develop the actions needed to meet the UK climate change targets.

We do this by:

→ **Engaging with stakeholders** to develop a robust and rapid energy reduction approach, producing effective solutions to the energy trilemma of security, sustainability, and affordability.

→ **Working with local authorities** to create practicable policy to ensure the regulatory system is fit for purpose, placing verified performance at its core.

→ **Encouraging and enabling collaboration** between a large, diverse group of built environment professionals.

→ **Providing technical guidance to support exemplar development,** enabling pioneers who aspire to go beyond the current regulatory frameworks

Our volunteers are made up of developers, engineers, housing associations, architects, planners, academics, sustainability professionals, contractors and facilities managers, with support and input provided by local authorities and other organisations.

Originally the 'London Energy Transformation Initiative' (LETI) was established in 2017 to support the transition of the London's built environment to meet Net Zero Carbon. Since then, LETI has formed as a Community Interest Company and altered our name to become the 'Low Energy Transformation Initiative', but predominantly we are known as LETI. This reflects our interest in all UK zero carbon policy and regulation.

LETI has focused on providing guidance on defining what good looks like in the context of the climate emergency, publishing guidance documents, one-pagers, case studies and opinion pieces.

For more information on LETI, please see:
www.LETI.uk

LETI

Foreword

As an industry we need to rapidly upskill our literacy to deliver buildings that are aligned with our climate targets.

Core to meeting the climate emergency is to reduce energy consumption of buildings. In 2020 LETI published operational energy targets that buildings need to deliver to meet the climate emergency. Energy performance modelling must be undertaken to verify that a project is on track to meet these targets.

For too long, the majority of UK industry has only been carrying our energy modelling related to regulations and compliance. The beauty of 'energy performance modelling' is that it can be used to estimate the in-use energy consumption of our buildings, this empowers design teams, as they can understand the impact of their design decisions on the eventual meter readings of the buildings they design. It gives them the literacy needed to optimise the energy efficiency of the building. It provides data that can be used by contractors to understand the cost effectiveness of energy efficiency measures, so that more informed decisions can be made.

This guide fills a much needed gap, allowing industry to upskill. It is a must-read for everyone in the built environment industry, not just energy modellers.

If you are a developer, this guide can be used to support the procurement of the right modelling team and developing the right modelling brief as well as outlining the importance of the assumptions and inputs that go into the model. If you are an architect or engineer it tells you how you can make the most use of an energy model at each project stage, so it can inform the design in multiple ways.

If you are an energy modeller - put this at the top of your reading list, it provides a bible for energy performance modelling, sharing guidance on practical modelling protocols, which tools to use when, outputs to report, how to carry out scenario testing and a clear roadmap of what modelling needs to happen when.

As an industry we need to move away from only doing compliance modelling, and fully embrace energy performance modelling and the improved building performance it can enable. We will not meet our climate targets without this shift. Performance modelling must be carried out, so that design teams and developers and contractors have the tools to design and construct buildings that meet net zero energy targets. This will require major upskilling of energy modellers and more engagement with modelling from the wider built environment community, and this guide provides the text book for this.

Clara Bagenal George
Introba

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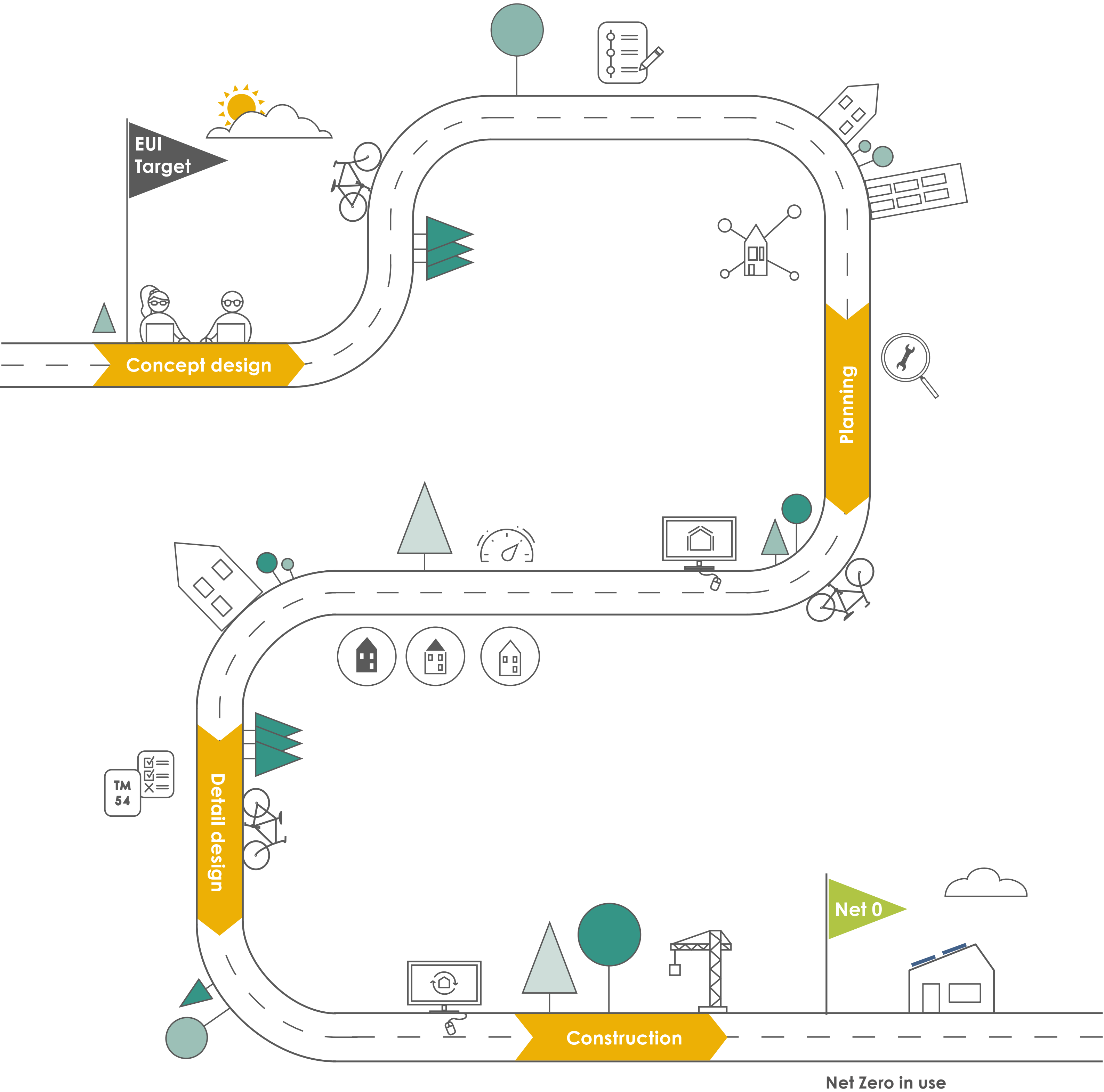
Contents


EUI Target
Concept design
Planning
TM 54
Detail design
Construction
Net 0
Net Zero in use

Welcome to the Modelling Guide

This guidance came about in response to a conversation I had with an architect friend. We were discussing the metrics within the LETI Climate Emergency Design Guide and she asked me how to find the Energy Use Intensity (EUI) on a Building Regulations UK Part L (BRUKL) report.

The truth is that a robust EUI cannot be obtained from a Part L compliance calculation, it requires a more sophisticated and nuanced modelling process. This type of modelling is not yet routinely practised in the UK, but as an industry we need to be confident that the operational energy targets we are setting can be achieved by our completed buildings in use. This guide outlines the LETI 'hive mind' best practice approach to energy performance modelling for all building types.

It is pivotal that all parties understand that modelling is only as good as the data it is based on, and that even the best models won't be omnipotent - there will always be variability in the energy actually used by a building. But understanding what factors could affect the energy performance and managing them is a vital part of closing the performance gap - modellers and their energy performance models can, and must, help!

The guide has three main chapters:

Chapter 1 sets out why we need to do energy performance modelling, what operational targets are, what is involved in this form of modelling and why compliance modelling is not the same thing.

Chapter 2 describes the 4 pieces in the modelling jigsaw: the modellers, the modelling tools, the methodology followed and the outputs obtained. It also covers the modelling timeline from early concept design through to operation.

Chapter 3 is aimed more at modellers themselves and gives advice on best practice modelling protocols as well as guidance on specific modelling tasks.

There is also a quick start guide to help you navigate the document and find the sections relevant to you whether you are a client, developer, designer, modeller or student.

LETI hopes this guide will help the industry transition smoothly to the routine delivery of in-use operational energy performance against net zero targets.

Operational energy performance modelling quick start guide

Who should focus on which parts of the guide?

Below outlines the sections of the guide that are most relevant to different audiences:

Modellers

This guide is all relevant and useful to you. We suggest you read it cover to cover.

Design teams

The following themes may be particularly interesting:

Chapter 1

- Why is energy performance modelling needed to help meet net zero operational targets?

Chapter 2

2.1 What to expect from energy modellers?

2.3 The significance of inputs and providing the modellers with robust assumptions

2.3 The usefulness of sensitivity testing analysis and how that can inform the design

2.4 What outputs to expect

2.5 The value of early stage modelling and how it can inform the design

Students

All of this guide is relevant and useful to you.

Chapter 1

- What are EUI targets?
- What is energy performance modelling?

Chapter 2

3.1 For best practice modelling advice

3.2 For detailed advice on energy modelling

Clients

The following themes may be particularly interesting:

Chapter 1

- Why energy performance modelling is needed?
- What are EUI targets?
- What is energy performance modelling?
- Why Part L compliance modelling isn't suitable?

Chapter 2

2.1 The procurement of the right modelling team and developing the right modelling brief

2.3 Importance of modelling inputs plus risks and confidence levels

2.5 Modelling timeline from early concept to post completion energy modelling

Local authorities

The following themes may be particularly interesting:

Chapter 1

- What is energy performance modelling and how does it help you deliver EUI and space heating targets?
- Why Part L compliance modelling isn't suitable?

Chapter 2

2.4 Core and additional outputs from energy performance models

2.5 Timeline – what should be modelled pre-planning

1 Use energy performance models to achieve net zero carbon outcomes

Set net zero carbon targets - use energy performance modelling to help design teams make informed choices and check the building is on track to meet the targets in-use.

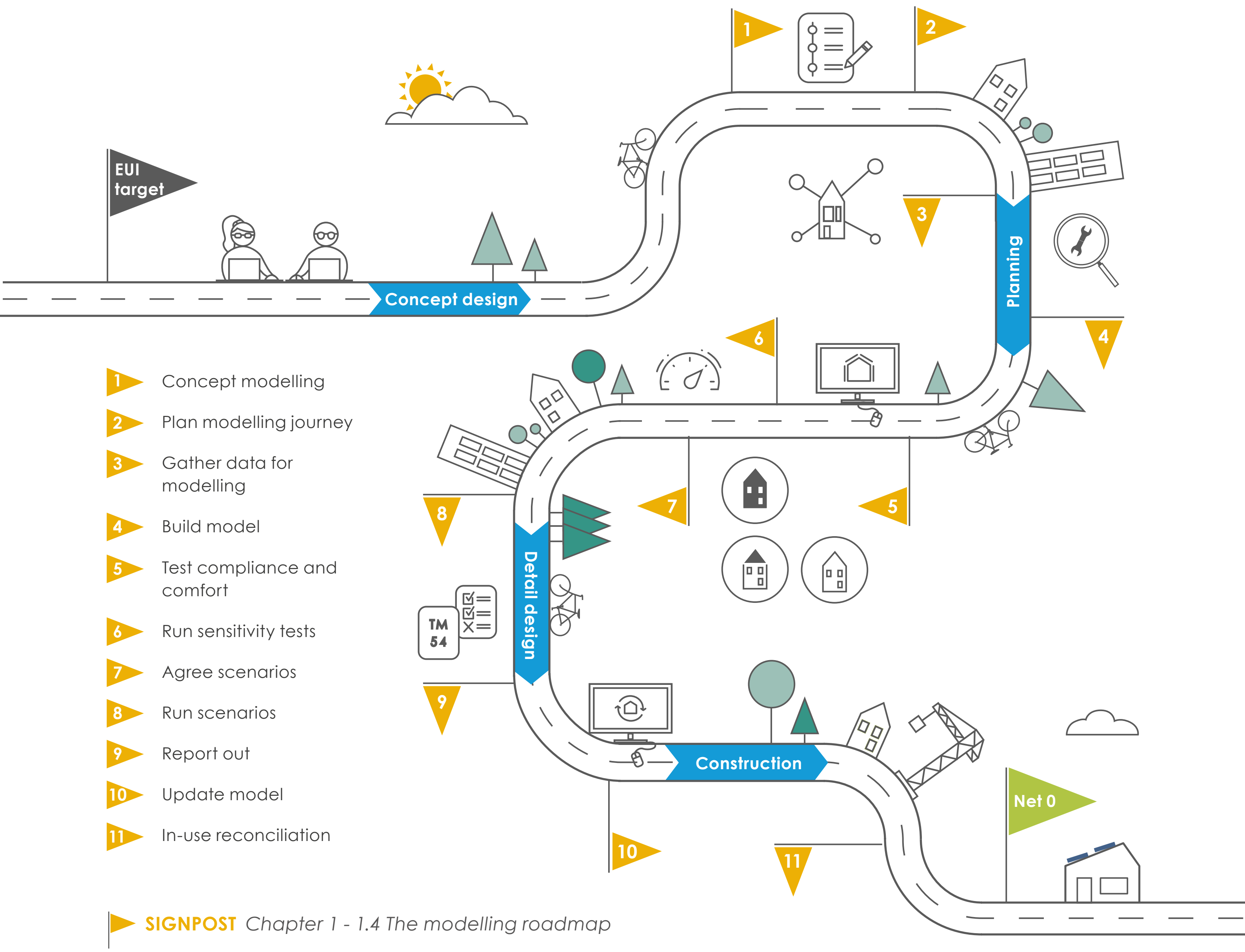
SIGNPOST *Chapter 1 - The purpose of energy performance modelling*

2 Follow LETI recommendations for EUI modelling

The seven recommendations include: using CIBSE TM54 methodology; carrying out a detailed risk management plan; preparing detailed modelling reports; and comparing metered data to the estimated EUI.

SIGNPOST *Chapter 1 - 1.3 LETI recommendations for EUI modelling*

3 Follow the LETI modelling roadmap



SIGNPOST *Chapter 1 - 1.4 The modelling roadmap*

SIGNPOST *Chapter 2 - 2.5 The modelling timeline*

Net Zero in use

4 Use the modelling jigsaw to support net zero carbon outcomes

Each piece of the jigsaw needs to work together to deliver net zero operational targets:

Modellers

Select a modeller who can create models to accurately reflect design proposals, and advise and report on the whole modelling process.

Modellers should have the following qualities:

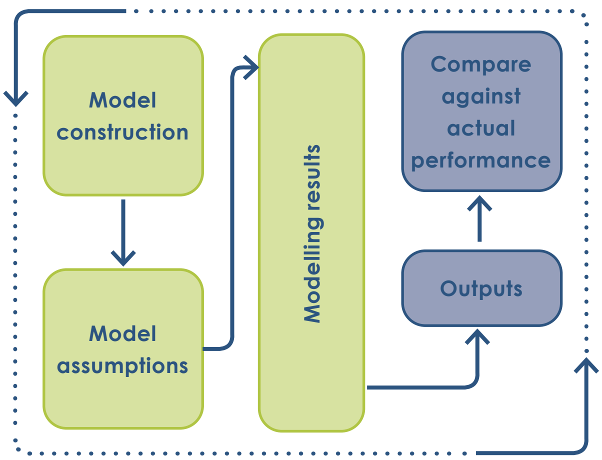
- Experience
- Efficiency
- Transparency
- Attention to detail
- Integrity
- Be collaborators
- A good modeller should be able to advise on tool selection.

SIGNPOST *Chapter 2 - 2.1 Modellers*

Methodology

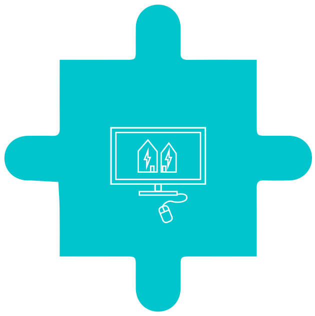
CIBSE TM54 is the backbone of EUI modelling. The methodology is thorough, flexible, and leaves room for intelligent interpretations.

1. Follow the TM54 modelling process:



2. Generate low, mid-range and high scenarios.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54*



Tools

Select the optimum modelling tool(s) to assess the project and support the design process.

Considerations when choosing the right tool:

- The effects of thermal mass or geometry
- Outputs needed and their accuracy
- The scale and complexity of systems and their controls
- Choice of steady-state or dynamic modelling tools and methods
- If system performance will vary due to load or weather

SIGNPOST *Chapter 2 - 2.2 Tools*

Outputs

Meeting net zero carbon is important, but so too is delivering a comfortable building that performs.

Minimum EUI modelling outputs should include:

- A detailed report
- Space heating demand for each scenario
- Model files with directory
- Notes on potential increases to energy use and how these can be managed
- EUI results for low, mid-range and high scenarios with comparison to the target

SIGNPOST *Chapter 2 - 2.4 Outputs*

5 Follow best practice modelling fundamentals

To support their work modellers will need to consider:

Quality assurance

→ Query input data that appears anomalous
→ Create a logical and well labelled model
→ Manage version control and iterations of the model files
→ Take responsibility for the quality of modelling work
→ Give advice on the optimum times at which to update the model.

Clear and honest reporting

→ Write a well presented and detailed modelling report
→ Include the TM54 implementation matrix in the modelling report and keep it updated
→ Regularly communicate the modelling progress with the project team.

Beyond the EUI analysis

→ Champion and assess occupant comfort
→ Use parametric modelling, where appropriate, to help inform the early design stage decisions
→ Evaluate loads not estimated by the model
→ Use energy benchmarks to provide a comparison and to fill data gaps at earlier stages in design.

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals*

6 Consider the modelling specifics

Model inputs

Geometry
Weather data
Floor area metrics
Zoning
Thermal elements
Thermal bridging
Air tightness/ infiltration
Glazing
Internal blinds
Occupants
Plug loads
Building management

Building services

Ventilation
Space heating
Domestic hot water
Lighting
Comfort cooling
Centralised HVAC

Estimating additional energy uses

Estimating additional energy uses

Including renewables

Including renewables

SIGNPOST *Chapter 3 - 3.2 Modelling specifics*

1

The purpose of energy performance modelling

1.0 The purpose of this guide

You've signed your project up to net zero operational energy targets, but how do you estimate Energy Use Intensity (EUI) and space heating demand early and often enough to help the project team make informed choices, and develop confidence that they are on track to deliver against these targets when the building is occupied?

This is a big question. We are familiar with energy modelling tools like SAP[1.1] and SBEM[1.2] being used in Building Regulations. However, estimating the actual energy performance outcomes for a building, that will be verified in operation, is a more detailed task which needs a unified project team along with a knowledgeable and experienced energy modeller steering the design. Meeting net zero EUI targets will only be fully demonstrated once a building is occupied, using the actual meter readings, but teams need to know early on if their design is capable of meeting the operational targets they have signed up to. They must also identify and manage the risks due to uncertain design information, the possible changes that could occur during construction and commissioning, and the influence of variation in building operation, all of which could affect meeting the targets in practice.

How is this done? The answer is **energy performance modelling**. This guidance describes what that is, how it works and how to get the best out of the process. The basic principles followed for energy performance modelling are the same for all projects from a single home through to a massive hospital. You will always need a modeller, a modelling software tool and for these to follow a logical methodology to output results in a useful format. This guide will help you understand and navigate this process in the most suitable way for your project.

1.1 Net zero targets

Delivering net zero buildings relies on setting absolute operational energy targets that can be readily verified in-use. What do those look like?

LETI advocates that all projects aim for both a net zero EUI (energy use intensity) target and a space heating demand target, both measured in kWh/m²/yr.

The specific operational targets set for your project might be based on the LETI Climate Emergency Design Guide, the forthcoming Net Zero Carbon Buildings Standard[1.3] or on LETI Retrofit Guide targets, but are likely to be based on an EUI metric (see next section). The operational energy ambition for a project needs to be defined from the outset and form an integral part of the brief.

Design teams, including modellers, should ideally be included in the setting of operational targets for projects alongside clients, and should be empowered and encouraged to communicate these targets and their implications throughout the design and into building operation.

The LETI Client Guide provides more information on a client's responsibilities within the design and construction of net zero buildings. Part of this responsibility includes supporting the development of the energy modelling brief and encouraging modelling teams to actively contribute throughout the design process.

Renewable energy generation targets are also a critical part of the picture and must form part of the brief for the project team.

The climate emergency necessitates all buildings to be 'net zero' as soon as possible. This includes meeting both embodied carbon targets and operational energy targets. This guide focuses on the operational energy component alone, delivering this alongside a comfortable and effective building.

SIGNPOST *LETI Climate Emergency Design Guide*

SIGNPOST *LETI Climate Emergency Retrofit Guide*

SIGNPOST *LETI Client Guide*

SIGNPOST *LETI have other resources available that consider embodied carbon*

SIGNPOST *Net Zero Carbon Buildings Standard*

Energy Use Intensity (EUI)

It is important to understand that net zero in operation doesn't mean buildings using no energy at all, but minimising the total energy consumed. This is the energy use intensity, or the EUI, and is measured in kWh per square metre of floor area (GIA) per year ($kWh/m^2/yr$). This is a metric that can be verified from meter readings when the building is in use.

The EUI includes all energy used by the building, but excludes contributions from renewable generation. This is so that energy used by the building is reduced as far as possible and only then offset by renewable generation. Renewables are a critical part of net zero buildings. Net zero targets often include a metric for renewable generation that should be tested by modelling. This guide includes advice on modelling renewable yields.

SIGNPOST *Chapter 3 - 3.2.4 Including renewables*

Designing for net zero requires an absolute target for the EUI. For example the LETI Climate Emergency Design Guide EUI target for commercial offices is $55kWh/m^2GIA/yr$ (or $70kWh/m^2NLA/yr$) and this is the main metric that office models should be seeking to demonstrate. In addition, the Climate Emergency Design Guide includes a target for space heating demand of $15kWh/m^2GIA/yr$. Space heating demand is an important target to achieve for particular types of buildings (like homes) and it should be a focus for the project team to meet both the space heating demand and EUI targets. Performance against both these metrics should be evaluated and reported on within the energy modelling scope.

Meeting EUI targets in-use needs more than just installing masses of insulation, it takes a project team making good decisions on topics like form factor, glazing ratios, building orientation and system specification. Many of these are decisions made at early design stages, so the modelling team needed to help evaluate and optimise them needs to be appointed early.

In some buildings - particularly homes - the amount of energy used by elements that are connected to occupant behaviour can have a big impact on the overall energy use and be difficult to accurately predict. Occupant behaviour can influence everything from the thermostat set points, to hot water usage, to use of appliances, so understanding the role that occupancy plays in meeting the EUI is a critical step for the modelling team. It is usual to aggregate in-use metered data for homes over several properties to smooth out some of the variance from different lifestyle choices, and to protect privacy for occupants.

Alongside operational energy targets, a net zero building must also assess and optimise how it performs in terms of comfort for occupants; and demand management - how the building mitigates the peak of energy use.

SIGNPOST *LETI Climate Emergency Design Guide - LETI targets, how these were developed and design advice on how to meet them.*

SIGNPOST *Net Zero Carbon Buildings Standard*

SIGNPOST *Chapter 2 - 2.4 Outputs, Comfort assessments*

SIGNPOST *Chapter 2 - 2.4 Outputs, Energy flexibility*

LETI net zero targets

LETI's net zero targets for each archetype are as follows:

	Energy Use Intensity	Space Heating
Residential	35 kWh/m^2.yr	15 kWh/m^2.yr
Office	55 kWh/m^2.yr	15 kWh/m^2.yr
School	65 kWh/m^2.yr	15 kWh/m^2.yr

Figure 1.1 - LETI EUI targets

Space heating demand

The space heating demand metric is distinct from the EUI as it is based on how much heat a building needs in order to stay at a comfortable temperature (referred to as energy demand), rather than how much energy is used to deliver that heat, by the heating system (referred to as energy consumption or energy use).

LETI has set targets for space heating demand due to its impact on:

Building

Having a space heating demand target will allow the project team to understand whether the building envelope (an element which the design team has the most control over, has a service life of around 30 years or longer, which is difficult, expensive, disruptive and carbon intensive to change) is efficient. This encourages a sufficient 'fabric first' approach, which is embedded in LETI guidance on particular elements of the building fabric.

Infrastructure

As we shift to a grid powered predominantly by renewable energy, seasonal and daily fluctuations become more important, particularly providing heating in winter when demand is high. Peak load has a significant impact on the wider infrastructure of the electricity grid, so measures that help limit this peak demand are important for a future that uses almost exclusively renewable energy.

In buildings that use mechanical cooling LETI recommend that space cooling demand is also estimated and reported on. Passive design measures to reduce overheating and cooling demands can significantly affect operational energy savings.

Energy Use Intensity

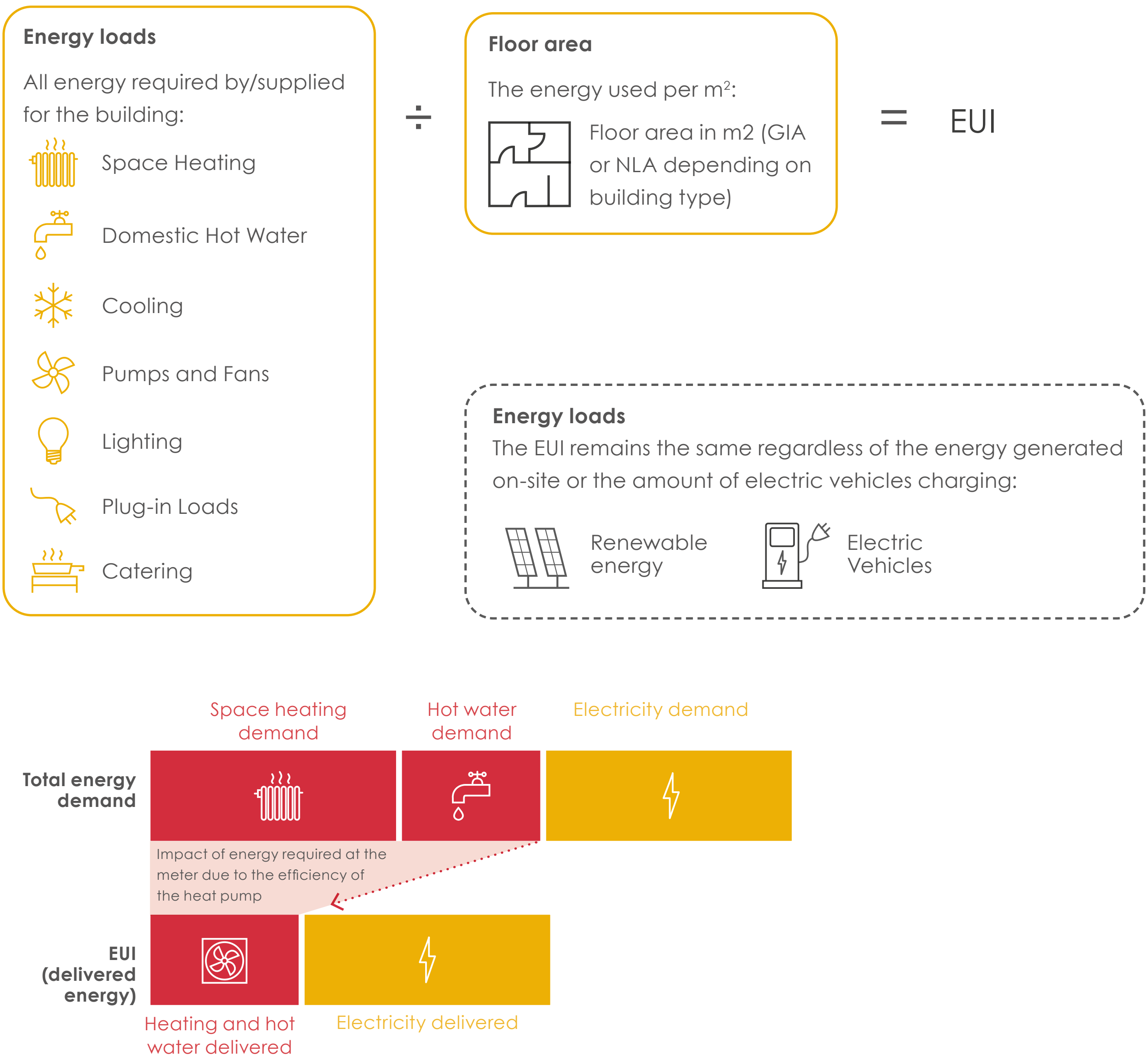


Figure 1.2 - LETI EUI definition

Minimising the performance gap

Minimising the 'performance gap' (the often huge divide between design intent and how real buildings perform in practice) is pivotal for enabling net zero operational targets to be achieved in practice. The performance gap usually has several contributory factors, the most common of which include:

Unsuitable modelling tools - regulatory tools are not suitable for accurately estimating operational energy use in buildings. The modeller should use tools that are proven in the context of energy performance modelling and follow a thorough and well-planned methodology.

Over-idealised models - design teams are used to emphasising the positive in building design and will tend to present a 'perfect' idealised version of the proposals. Models such as PHPP (Passive House Planning Package)[1.4] and CIBSE TM54 (Energy Performance Technical Memorandum)[1.5] both buck this trend by introducing margins and caution on every variable. The TM54 methodology also addresses this by testing a range of scenarios, rather than just a single one.

Construction or commissioning issues - the quality of construction and commissioning will heavily influence building performance compared to design intent. Every value engineering decisions and fix for an issue that arises during construction could impact on the ultimate energy performance. These risks should be monitored and managed.

Occupants and operational management - the way designers anticipate a building will be used is almost always different to the real occupation which will usually vary day to day and hour to hour. Modellers need to consider a range of possible occupancy scenarios and report on the impact these could have on energy performance.

Energy performance modelling has a valuable part to play in closing the performance gap. To do so it needs to be carried out accurately, transparently, using the right tools and following a well organised methodology. The risks raised by the modelling exercise will inform the key areas that should be monitored and managed to avoid them impacting on the in-use performance.

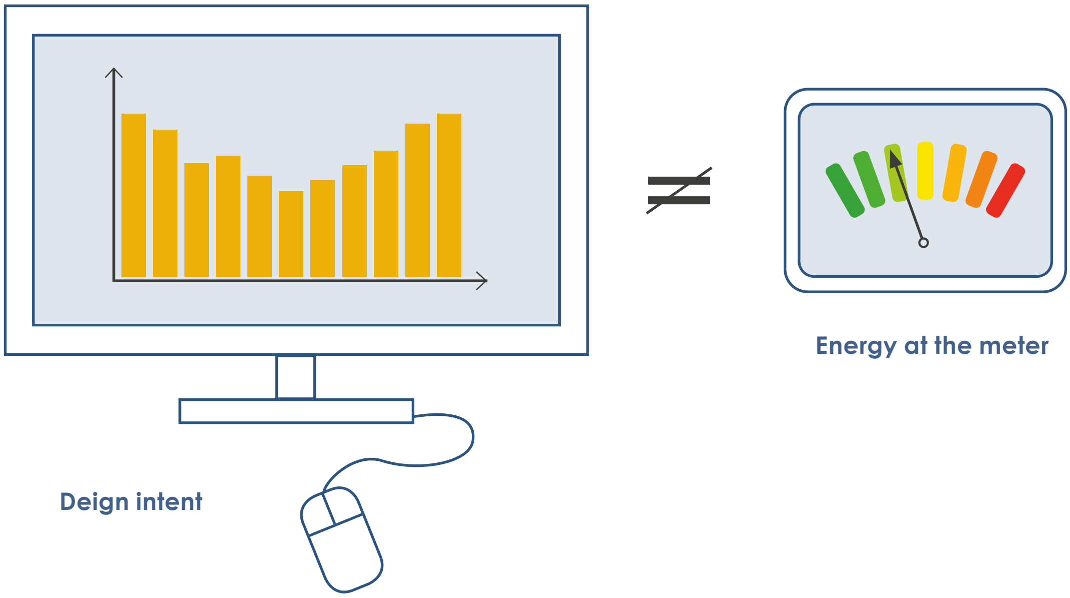


Figure 1.3 - The performance gap between the design intent and the performance of buildings in-use

1.2 What is energy performance modelling?

Meeting EUI targets in operation requires the ability to estimate the operational energy performance outcome from a design. The reality is that a purposeful and well-planned modelling exercise that evolves with the project is needed. This might at first appear to be a lot of work to derive a few numbers - mainly the EUI (and its subdivision into different energy sources) and the space heating demand - but there is a lot more value that can (and should) be harnessed from this work. By putting the design under the scrutiny of a thorough modelling exercise, the project team can be precise about how materials and products are used (helping to save money) as well as create a building that works better for the people who will use and operate it in the future.

The targets represent a few significant metrics which summarise a building's energy performance characteristics. The art of energy performance modelling is to show how these targets might be achieved under a variety of potential scenarios, providing a more robust understanding of how the building will work in real life. By doing so the work will be able to highlight the key risks that could prevent targets from being met.

Models estimating performance against operational energy targets need to be as accurate as possible, but also include allowances and margins that represent the real-world construction industry and operation of buildings. Life isn't perfect and modelling should reflect this.

The energy performance modelling exercise is a process that will add most value when started at the very earliest design stages and then returned to regularly up until the building is completed, occupied, and beyond.

Terminology

This guide describes the benefits and process of delivering energy performance modelling. The EUI (kWh/m²/yr) estimated by these models can be directly compared with meter readings in a completed and occupied building.

This type of modelling can be described using a number of terms: predictive energy modelling, net zero modelling, EUI modelling, operational energy modelling etc. We have settled on the term **energy performance modelling** for this guidance as this is what is used in CIBSE TM54 (which is heavily referenced), and is a good descriptor for the exercise.

This guide assumes that energy performance modelling is being performed in order to support the delivery of net zero operational performance targets.

Note that this document is not a design guide. LETI and other sources have provided plenty of advice on the key features of a net zero building. This guide is written to support clients, project teams and modellers to work together on the critical analysis that will monitor and inform progress towards a net zero building in operation.

This guide sets out how project teams should model the energy performance of buildings to achieve EUI and space heating demand targets. Net zero buildings must do more than just these two metrics and other forms of modelling should be used to inform this.

The diagram below highlights which of the main objectives of the LETI Climate Emergency Design Guide this modelling guide covers. Other guidance from LETI and the wider industry demonstrate how to model for the other objectives.

The modelling guide

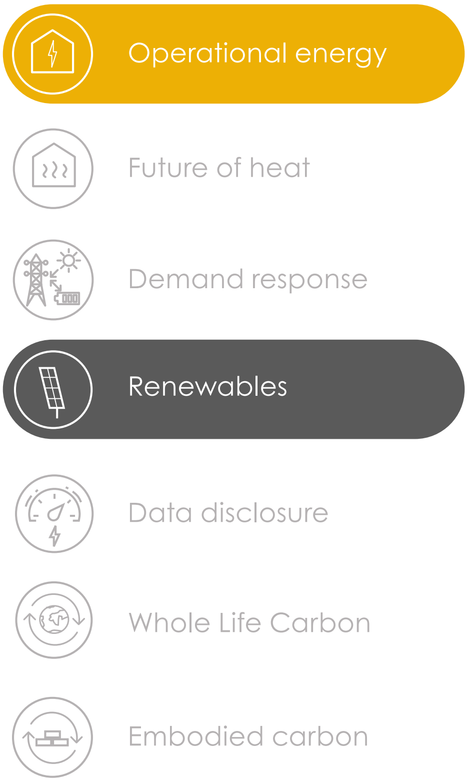


Figure 1.4 - Focus for the LETI operational energy modelling guide

How does energy performance modelling add value?

Energy performance modelling is a significantly more complex exercise than a typical Part L[1.6] calculation for Building Regulations compliance. You should expect both the time taken and the professional fees to be higher than for a Part L assessment. Your modelling team will need to be more engaged, involved, detailed and accurate in everything they do.

In return, the project will benefit substantially and should expect to see:

→ A better design, future-proofed from any changes in regulation or policy

→ Demonstrably meeting best practice operational energy performance, aligned with EUI targets and delivered in practice

→ A clearer picture of how each design factor impacts on operational energy use, and hence a more robust energy strategy

→ An understanding of the key project risks and how each could affect delivery of the targeted energy performance in practice

→ A roadmap to manage these performance risks and close the performance gap

→ A precise understanding of how to meet net zero targets for buildings that can help with a more efficient use of materials, products, and energy.

→ Additional modelling outputs including early concept analysis helping optimise form and passive design measures and thermal comfort assessments identifying any risk of overheating or significant hours when space heating or cooling won't reach setpoints.

→ A level of understanding that goes beyond one project and can set you and your team up for future developments.

The caveat: "All models are wrong, but some are useful" *(George Box)*

Operational energy models can be invaluable tools for supporting net zero designs, but modelling requires planning and the engagement of modellers from start to finish on a project. The way we use buildings and how they respond to this and their environment is inherently imprecise and models can only be as good as the information they are based on, the tools used, and the skill of the modellers. Alongside this construction is not a linear process, modellers must try to capture the evolving picture of how a building will be constructed, commissioned and operated through each design stage, which is why they must become an integral part of the design and construction team. A good model (and its associated modelling reports) will be transparent about the strengths and weaknesses therein, and the modelling process should include consideration of these, and other risks that will need managing to avoid adversely impacting on in-use energy use.

Modelling offers a powerful role in interrogating and questioning the proposed building design, but it will never be able to guarantee outcomes for energy use or thermal comfort. The model should be used to inform the design at various stages, by answering relevant questions and allowing the design to be stress tested under a number of different scenarios.

Fortunately there is good advice out there and this guidance will help you navigate your modelling journey.

Why regulatory compliance tools are not suitable here

Although Part L is a Building Regulations compliance requirement for almost all projects, LETI strongly cautions against the use of compliance tools such as SAP 2021 and SBEM 2021 (not the dynamic modelling tools which can also be used to demonstrate non-domestic Part L compliance) when estimating EUIs for a number of reasons:

1. **Different objectives** - The purpose of compliance modelling tools is to demonstrate compliance with Part L of the Building Regulations. The regulation endeavours to provide a flexible and cost effective approach to compliance. The key premise for compliance is that the 'actual' building (the proposed building) demonstrates carbon emissions no greater than the 'notional' building (that matches the geometry and meets prescribed values for fabric performance and system efficiencies).

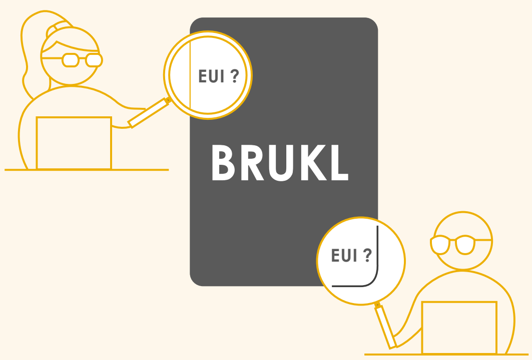
2. **Regulatory compliance is based on a comparison against a baseline model** as such some passive design features such as form and orientation don't affect the comparison result (since they will affect the notional building and actual building equally).

3. **Regulatory compliance draws an artificial divide between energy uses** - often referred to as regulated and unregulated energy. Regulated energy is the energy associated with fixed services in a building. When the regulations were developed it was thought more practical to regulate fabric thermal efficiency than to regulate the size of fridge a homeowner may purchase. However, to meet the climate emergency we need to reduce all energy use in all buildings. EUIs represent a whole building energy use target, inclusive of both regulated and unregulated sources as this captures all emissions.

4. **Regulatory compliance tools use fixed internal gain profiles for occupancy and "plug loads"** to allow like-for-like comparison across sites and between buildings. These profiles might represent an industry-wide "average" but don't give the flexibility to reflect what is known about the project at design stage or to explore the range of possible occupancy outcomes.

The outputs from regulatory models are often far removed from the real in-use performance of buildings. This highlights why these tools cannot and should not be used for informing net zero designs. It is hoped that SAP 11, which will support the Future Homes Standard[1.7], will improve on previous iterations and become a more useful predictor for in-use energy performance.

The absolute EUI metric requires a very different, more accurate and more involved modelling approach, which when carried out well, should give a more accurate approximation for the energy a building design will use in practice.



The Energy Use Intensity (EUI) cannot be found on the BRUKL document!

Figure 1.5 - Limitations for BRUKL documents

SIGNPOST *Appendix 1 - The problem with compliance modelling*

SIGNPOST [NCM Call for Evidence] - Submission by CIBSE and LETI gives a background on weaknesses with compliance tools

1.3 LETI Recommendations for EUI modelling

Within this guide LETI make some specific recommendations for EUI modelling, these are summarised here:

1 That CIBSE TM54 is followed as the central methodology for all energy performance assessments, including energy performance modelling, in all building types. The guidance in this document is intended to augment and support project teams in following TM54 when designing for EUI targets.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54*

2 That the CIBSE TM54 implementation matrix is used as a tool for monitoring the confidence and possible variance within the input data. The confidence levels should gradually improve as the project progresses, with most steps reaching a high level of confidence by detailed design.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Risks and confidence levels*

3 That by detailed design the confidence level attached to most of the key modelling inputs reach 'high', and that a detailed risk management plan has been discussed and agreed with the project team. This plan plays an important role in monitoring and managing the risks that could take the energy use of the building over the target, and should include advice on how each risk is being mitigated.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Risks and confidence levels*

4 That all projects look at thermal comfort and specifically overheating risk, and complete an assessment relevant to the type of building and the level of risk.

SIGNPOST *Chapter 2 - 2.4 Outputs, Comfort assessments*

5 That the construction industry becomes more open to the simple sharing of energy model files through the design process in the same way that drawings or specifications allow the transfer of design information between existing and new team members.

SIGNPOST *Chapter 2 - 2.1 Modellers, facilitating the handover of energy models*

6 That detailed modelling reports are prepared and presented on by modellers, and checked by project teams to reduce the risk of any design elements, or occupancy scenarios being misinterpreted within the model, and to enable communication of the estimated EUI and the basis of the result, and the key risks that might impact on meeting it. Ideally it should be possible to replicate a model from the modelling report.

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Clear and honest reporting*

7 That once metered data has been collected from the building, this is compared against the estimated EUI / energy consumption of the building. This is essential to close the performance gap.

SIGNPOST *Chapter 2 - 2.5 The modelling timeline*

1.4 The modelling roadmap

1. **Concept modelling**
   Develop simple models to explore very early design decisions and help optimise passive solutions around form, orientation, glazing ratios etc.

2. **Plan modelling journey**
   Think through what modelling will be needed and when.

3. **Gather data for modelling**
   Models are as good as the information they are based on.

4. **Build model**
   Modeller creates Initial model with best information available.

5. **Test compliance and comfort**
   Make the model work hard providing additional outputs to support the design process.

6. **Run sensitivity tests**
   Use the model to test the impact of less certain inputs using the implementation matrix.

7. **Agree scenarios**
   Use sensitivity analysis to inform the high, mid-range and low EUI scenarios.

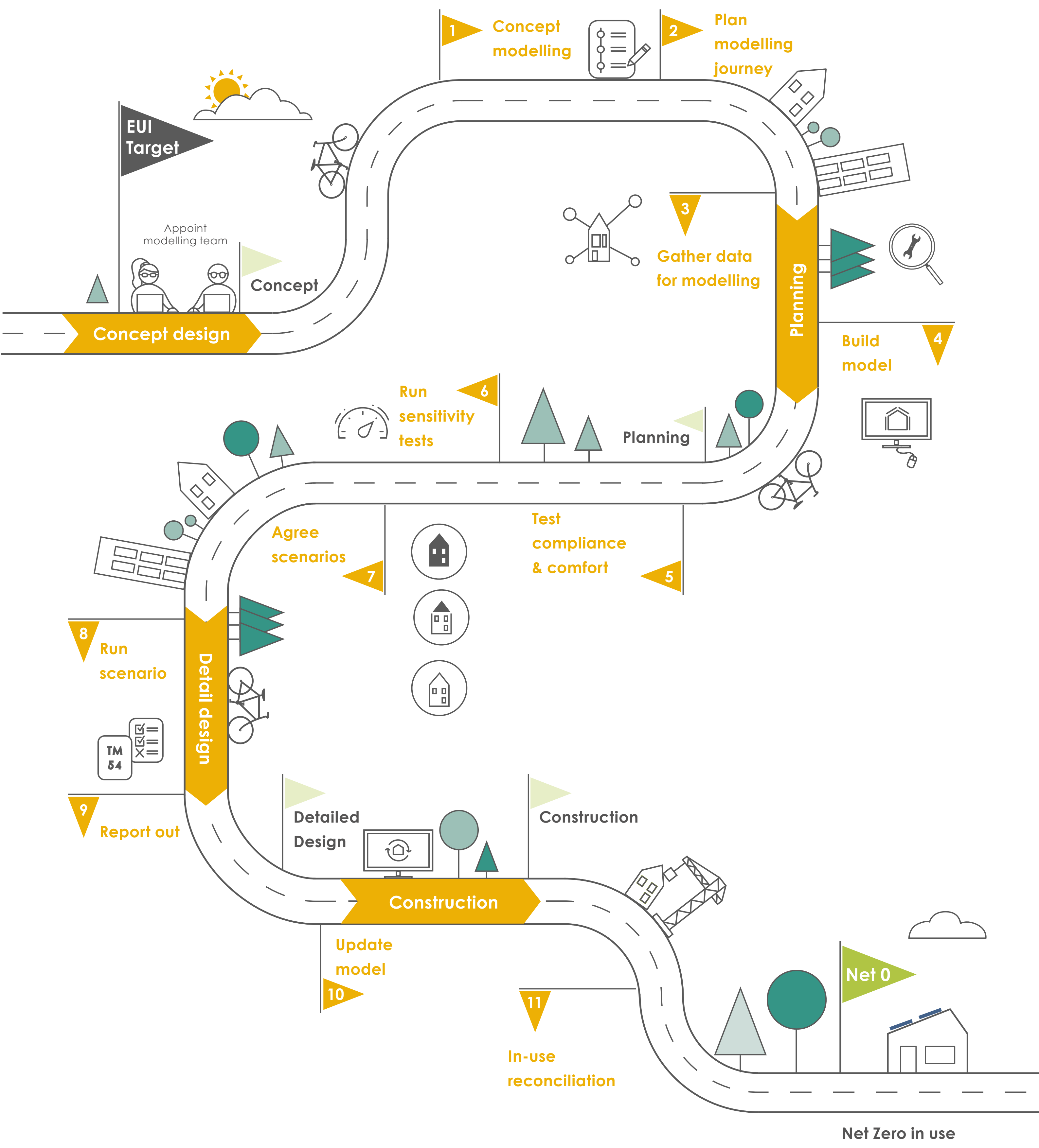
8. **Run scenarios**
   Modeller runs all 3 scenarios through model adds additional energy uses and establishes draft EUIs.

9. **Report out**
   Modellers write a clear account of the modelling done and the design team QA check it and on board the risks within the high scenario that might cause targets to be exceeded.

10. **Update model**
    The model needs to keep pace with the design in a timely way so that changes that will impact on performance are picked up and mitigated.

11. **In-use reconciliation**
    Update the model following commissioning to producing outputs that can then be directly compared with the in-use meter monitoring.

SIGNPOST *Chapter 2 - 2.5 The modelling timeline*


EUI Target
Appoint modelling team
Concept
Concept design
1
Concept modelling
2
Plan modelling journey
3
Gather data for modelling
Planning
4
Build model
Planning
5
Test compliance & comfort
6
Run sensitivity tests
7
Agree scenarios
8
Run scenario
TM 54
Detail design
9
Report out
Detailed Design
Construction
Construction
10
Update model
11
In-use reconciliation
Net 0
Net Zero in use

2

The modelling jigsaw

2.0 The modelling jigsaw

This guide is focused on the objective of delivering buildings that meet net zero operational energy targets in practice and long into the future. It is important to keep sight of this objective as it's easily lost. The modelling infrastructure needed to support this includes **modellers** (humans), **modelling tools** (software within which the virtual models are created), **modelling methodology** (defining modelling approach, inputs and results) and the **modelling output** (software files that store all the model inputs and results and modelling reports that present the process followed and results in a transparent format). Each piece of the jigsaw needs to work together to deliver net zero operational targets.

The structure of this section

This chapter is set out to align with the four key aspects of the modelling jigsaw:

→ Section 2.1 - **Modellers**

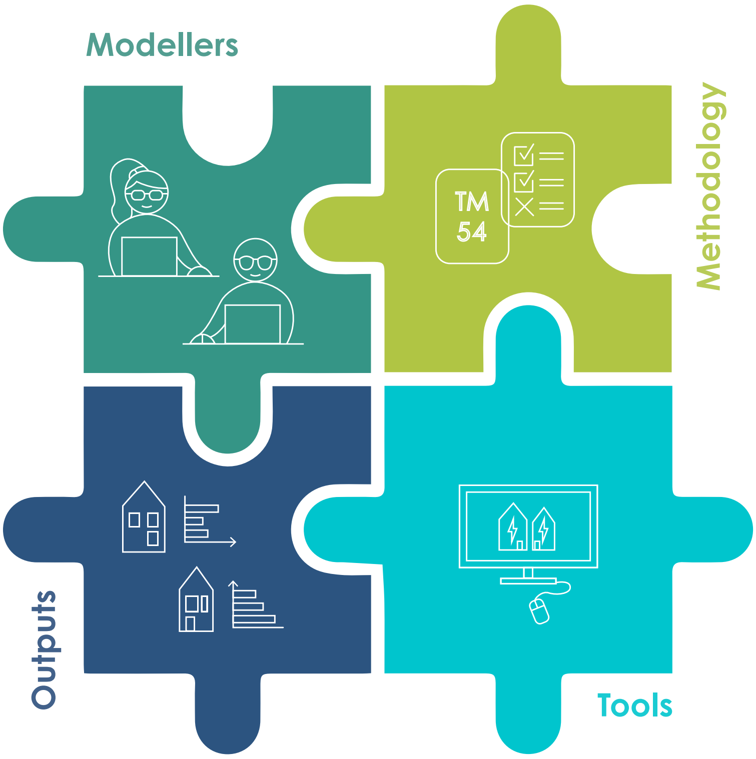
→ Section 2.2 - **Tools**

→ Section 2.3 - **Methodology**

→ Section 2.4 - **Outputs**

The final section discusses the modelling timeline from early concept modelling through to using models to pace building performance in operation:

→ Section 2.5 - The modelling timeline



Modellers

Responsibility for creating models that accurately reflect design proposals, advising and reporting on the whole modelling process.

Outputs

Meeting an EUI target in practice is important, but so too is delivering a comfortable building that performs. Models can usefully support the design process in various ways.

Methodology

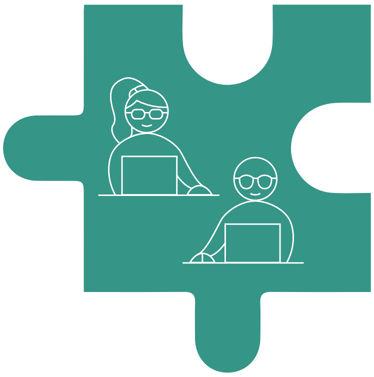
CIBSE TM54 forms the backbone for EUI modelling. The methodology is thorough and flexible, leaving room for the modeller to make intelligent interpretations.

Tools

Selecting the optimum modelling tool(s) to assess the project and support the design process.

Figure 2.1 - The modelling jigsaw

2.1 Modellers



Modellers are a vital piece of the jigsaw, as they carry responsibility for taking decisions on all the other pieces. Modellers must build models that accurately reflect design proposals and keep them up to date through the design and construction process. They are responsible for reporting on the assumptions and outputs, advising on the whole modelling process, and highlighting and tracking the risks that could impact on meeting the targets.

Whether you appoint an individual modeller or a modelling team, an independent consultant or a team within an existing appointment, there are important considerations to bear in mind to help you get the best for your project.

When to involve the modeller(s)

The type and extent of energy performance modelling needed on a project will depend on its scale, building type and complexity. Thinking through what might be needed and when is an important early consideration so that the right tools are selected, sufficient budget is allocated, and positive decisions are encouraged throughout the design process.

In general, try to appoint an energy modeller before the beginning of the concept design stage (RIBA Stage 2) starts. They can then help with early concept analysis and planning out the modelling exercise throughout the rest of the project. The early concept design stage is a crucial moment for many buildings, getting advice from the modeller or modelling team on the building form, orientation and glazing proportions before they are fixed will be the simplest and cheapest way to achieve net zero operational targets. Being too early is better than being too late, the modeller can (and should) always let you know if they feel their input is not needed straight away.

How the model is used at each stage will vary depending on the specific needs of the project and should be discussed between the client, project team and modeller. This should then be reflected in the modelling appointment, and sufficient time and budget allocated. It's important for the modelling team to be ready to test potential changes in the design or changes to the project construction or systems (substantial enough to impact on energy performance). Planning out the number of likely iterations and describing what they will cover early on is useful to give a clear scope to the modelling team and the Client. The earlier the modelling team is appointed in the process the better. This can often lead to fewer model iterations as they can help steer the design away from poor choices.

Who is right for the job?

Different modellers or modelling teams will bring different qualities. Here are some points to consider when choosing who to appoint:

1. **Experience**
Modellers should be competent and experienced with the tools they use, and

knowledgeable about the design process and design options. They should be able to answer questions about the models they create and drill into the results to explain and justify them. The level of skill and experience needed for energy performance modelling should not be underestimated. Modelling tools are complex and powerful, with a great many parameters and settings, and they need to be well understood and applied for a model's findings to be robust. Modellers are an intrinsic part of the design team and should bring their experience and knowledge from previous schemes to each project. This is especially true during the earlier design stages when the building is less fixed and the project team need more guidance on what good looks like.

2 Transparency

Modellers should provide clear reporting on the status of modelling work, what has been done, what information has been used, where there is uncertainty and what the results indicate. Modelling reports should be detailed enough enable a smooth handover if the modelling team changes and a rebuild of the model if necessary.

3 Integrity

Modellers need to create an honest picture of how designs are expected to perform, not idealising to show more pleasing results. Models can become very complex, and mistakes are possible, it is important that these are picked up and corrected rather than hidden or disguised. To err is human, so it's important that QA procedures are in place to look for possible errors. Both spot checking inputs and establishing confidence that all result sets seem plausible. A good internal audit from alternate modellers or an external peer review appointment is recommended.

4 Efficient

Modellers need to offer good value for the time they spend on projects. A good modelling scope and appointment should be thorough and robust but not excessive.

5 Attention to detail

Modellers must take responsibility for their work, labelling all model elements in a clear and logical way, reporting on their modelling approach, highlighting where all information came from and what was used by the modeller to fill any gaps, including highlighting any software defaults. They need to communicate clearly what the findings and recommendations are and highlight areas of weakness or risk in the modelling, and how this will feed into the scenario analysis and confidence reporting.

6 Collaboration

The output from a model is only as good as the assumptions it is based on. Clients and project teams need to allow time to communicate effectively and provide the modeller with the best information and a good understanding of the design intent at each point in the timeline when modelling is initiated or updated. The modeller in turn should take a proactive approach, making clear requests for the information they need and flagging gaps and anomalies. The objective is a constructive, respectful and collaborative relationship between the modeller and the project team, where all sides can ask questions of each other and the model can be used to inform the design process, test scenarios and check progress against targets.

Qualifications for energy modellers in the UK are limited and should not be relied on as a judge of the right candidate. Picking the right team for the job will depend on the type and scale of the project. LETI recommends seeking out people with experience of working on Passivhaus projects, especially for domestic projects; these people would be referred to as a Passivhaus Designer or Consultant[2.1] (see logos below). For commercial buildings, someone who has attended the CIBSE Advanced Simulation Modelling for Design for Performance[2.2] course is a good indicator.

In the US the ASHRAE BEMP (Building Energy Modelling Professional) certification scheme[2.3] is a measure of competency to model new and existing building and systems with the full range of physics; and to evaluate, select, use, calibrate and interpret the results of energy modelling software where applied to building and systems energy performance and economics. It is not yet widely adopted in the UK.

Being able to demonstrate experience and knowledge of performance modelling, ideally in a similar project type and with onerous targets, should be the main driver as not all modellers will seek out these accreditations.

Passivhaus designer

ASHRAE Building Energy Modelling Professional

Figure 2.2 - Accredited modelling schemes

Optimising the modelling appointment

How energy modelling services are procured can make a big difference to the project. The modelling scope should always be considered as a separate service with as much importance as other consultants appointed on the project.

Given the pivotal nature of the modelling, consider appointing an independent peer review of the modelling work to add confidence that it is robust, and that the project is on track to meet its targets. Knowing their work will be reviewed can be a good motivator for modelling teams and the second perspective can help spot errors, inconsistencies, or missed opportunities.

For example:

→ The NABERS UK[2.4] scheme requires that simulation reports are reviewed at stage 4 by an Independent Design Review (IDR) panel member to help ensure that the assumptions used, methodology followed and results declared are robust.

→ In Passivhaus, a Certifier would complete their own energy model and check the evidence at design and construction stages. Having this oversight through design and construction offers quality assurance that reduces the performance gap in Passivhaus projects.

There are two key decisions when making the main modelling team appointment:

→ Whether to appoint an **independent modelling specialist**, or an **embedded modelling team** within a larger consultant organisation, typically within the M&E or architecture organisation.

→ Whether to **retain the same modelling team** throughout all project stages, or make **new appointments at each stage**.

Some benefits to each option are set out in the table below.

Independent modelling consultant

+ Independent consultant working for you, without actual or perceived conflict of interest

+ Ability to retain single consultant even if MEP/architecture team changes

Embedded modelling team

+ Potential for quicker response times to changes made by their colleagues

+ More natural information flows, less external coordination needed

+ Efficient re-use of models for other design tasks such as daylight studies, or plant sizing

New appointments at each stage

+ Independent review of the work from the previous stage, benefiting from fresh eyes and new ideas

+ Potential to benefit from additional specialisation

Retaining the same modelling team

+ Consistency of information flows and approach: reduced on boarding time at each stage.

+ More holistic understanding of the design and decision making, better opportunity to learn the ins and outs of your approach which can lead to upskilling for future projects

Figure 2.3 - Benefits to different modelling and team approaches

Facilitating the handover of energy models

It is not uncommon in the UK for different models to be developed from scratch for the same building by different modelling teams at different stages, which can be a waste of modelling resources. For this reason LETI recommend that the construction industry becomes more open to the simple sharing of energy models through the design process in the same way that drawings or specifications allow the transfer of design information between existing and new team members. There is often resistance to sharing model files with some valid reasoning around efficient handover and liability, but these issues should be surmountable. One solution might be to explore 'project' based professional indemnity (PI) insurance, rather than individual consultant PI cover.

Some suggestions to encourage the successful sharing of models:

1. **Include model files and modelling reports in the list of deliverables** - prior to engaging modellers, specify that you will need the model files and associated report to be handed over. This can be a good way to emphasise that model quality is paramount for the project and that the modelling work (including reporting, as well as the model itself) will be subject to the highest levels of scrutiny.

2. **Expect an honest approach to assumptions or simplifications** - it's important to recognise that an individual model is done at a specific point in time, for a specific purpose. Often simplifications are made within the model, assumptions made around unknown data, or workarounds are employed to meet specific project constraints. Taking over a model will almost always involve a degree of review, updating and reconfiguring for the latest design stage.

3. **Make sure scenario testing is in the brief and shared as well** - there should be multiple iterations of a model providing sensitivity and scenario testing - these files should be clearly labelled and documented.

4. **The client should mediate the exchange of models** - when handing over models, the model files should come from the client directly and be supplemented with the simulation model report. Ideally both modelling teams should agree to (and be paid for) two handover sessions e.g. an initial handover session for the original modeller to take the new modeller through the model, and a 2nd session to go through detailed questions if needed after a short period. Any further questions should be limited and directed via the client.

5. **Provide the modelling report in any future contract bids** - when appointing a new modelling team, include the modelling report (and ideally also the model files) from the previous team in the bid documents so that the bidders can review whether the existing model is fit for the proposed purpose.

6. **Be pragmatic** - there may be circumstances where it is more efficient to start a new model from scratch if there are significant changes or if the modeller uses a different software package, but the previous model and report may still offer valuable insights into assumptions and methods used and result previously obtained.

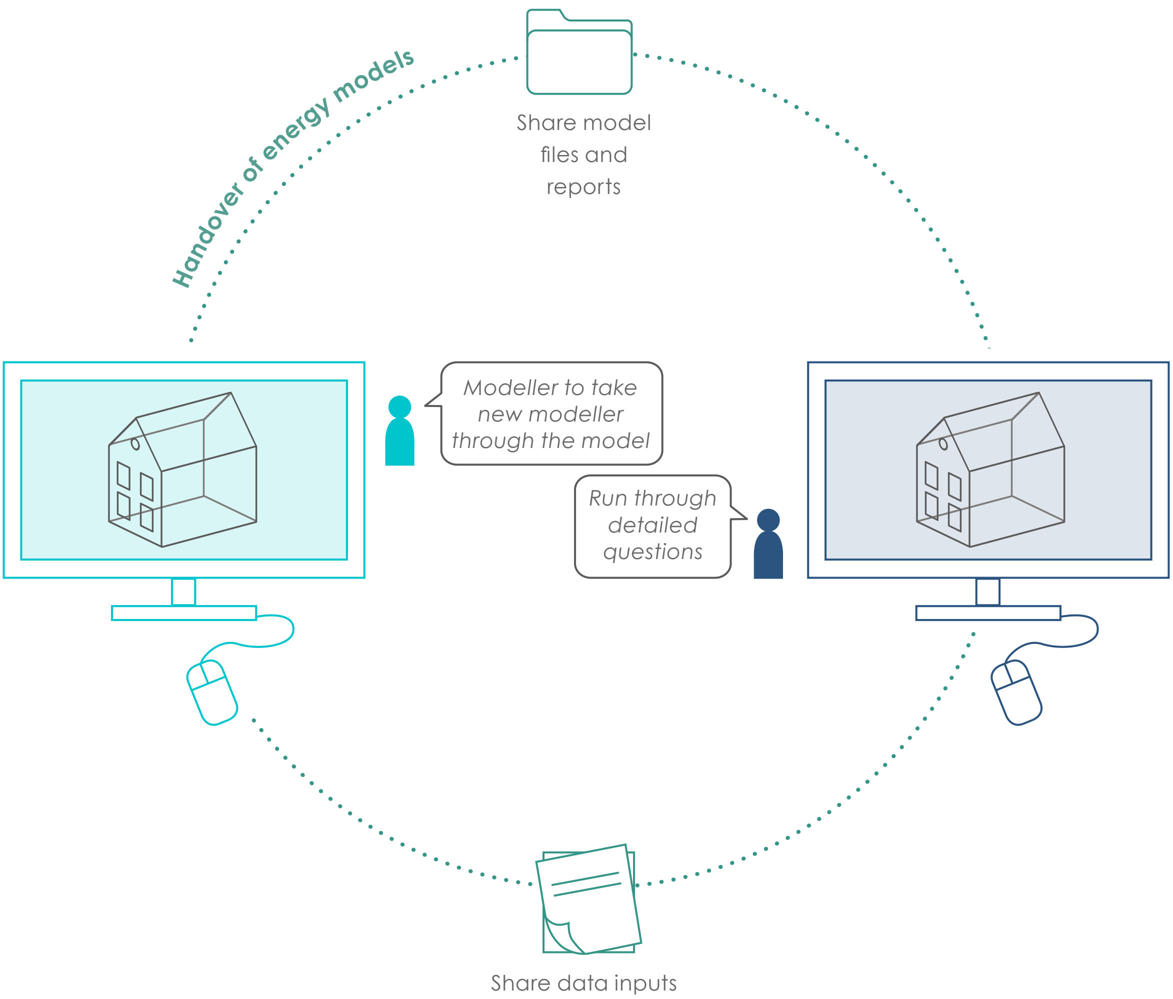
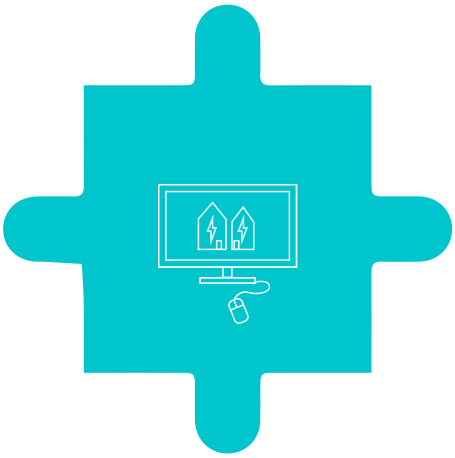


Figure 2.4 - Facilitating the handover of energy performance models

2.2 Tools



Energy models create virtual representations of a building, its operation and subsequent energy consumption and generation. Modelling tools vary in their scope and sophistication and should be selected to best suit and support the project.

The main modelling tools used to estimate energy performance fall into two categories, quasi-steady state models and dynamic simulation models:

Quasi-steady state models (Passivhaus PHPP, also SAP and SBEM) are the simplest and quickest to run. Detailed information can still be needed about the building, but this information is often averaged over larger periods of time (months or years) or space (less zoning) compared to dynamic models. They are also good when a building has simple controls i.e. not reliant on complex interdependent systems or controls to maintain the environmental conditions (often homes fall into this category but also plenty of non-domestic buildings).

Dynamic simulation models (EDSL TAS[2.5], IES Virtual Environment[2.6], Energy+[2.7] and Design Builder[2.8]) can present a very detailed hour by hour representation of a building and its usage. Because they model the building behaviour at a granular level, they can explore the performance, and interactions between occupancy and more complicated heating, cooling and ventilation systems.

Both approaches have an important role to play in delivering net zero buildings and it is possible for both types of tool to be used for different assessments on the same project. The team should consult with their modelling team early on in the design process about what type of model might be used, at each stage, and for what purpose.

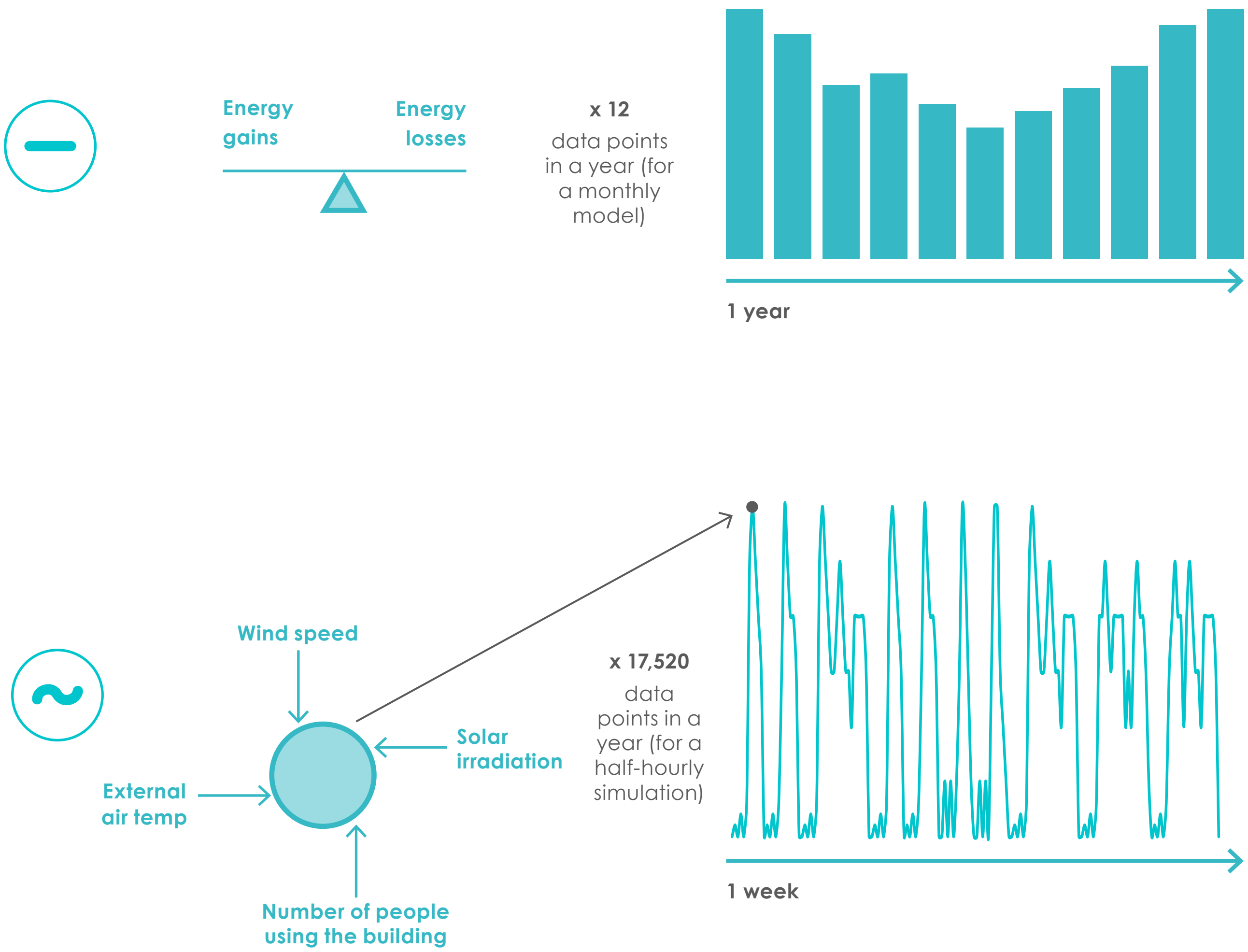


Figure 2.5 - Indicative demand profile differences between dynamic and quasi-steady state. A dynamic simulation model needs a much larger amount of input data compared to a quasi-steady state model. Dynamic simulations analyse buildings at intervals typically of less than an hour, this may mean thousands of calculation points which all need input data. This means they have the potential to be very accurate and precise, but this accuracy is dependent on the quality of the inputs. Quasi-steady state models average their inputs over longer time periods, often a month or year. Sourcing this amount of data is often a straight forward exercise.

Choosing the right tool

In general dynamic simulation models are good for analysing the detailed performance of a building at small time intervals. Quasi steady state models tend to average information across space and time, but because of this are quicker to create and simpler to run. Dynamic models can give the impression of accuracy given the amount of data they can output and the clever graphics they produce, however they rely on numerous input data points. This means that the modeller will need to know in detail about their building and its operation to produce an accurate simulation. A high quality steady state model still requires a good level of detail, but the amount of information needed is less than dynamic models. Despite this they can still produce an accurate assessment of energy performance for simpler buildings and would give enough accuracy to produce an EUI or annual space heating demand.

Energy performance modelling must evaluate the annual operational needs (demands) for the building, how those needs will be met (building services plant i.e. heating and hot water services) and the control logic that will enable this process to function efficiently. In practice this can be achieved in a range of ways from a spreadsheet through to a detailed dynamic HVAC model.

A modeller should understand the limitations of the tool they are using and make recommendations for other types of analysis where they believe it is helpful for the project objectives. An example of this would be completing a model in PHPP and using the overheating analysis to test for the risk of high internal temperatures. If PHPP does find a risk (even a low level one) then analysis in a dynamic tool should be used to confirm the risk and identify mitigation options. This assessment should follow CIBSE TM52[2.9] for non-domestic buildings, or CIBSE TM59[2.10] for homes. The modeller should also bear in mind the implication of Part O[2.11] of the building regulations.

SIGNPOST *Chapter 1 - 1.2 Why regulatory compliance tools are not suitable here*

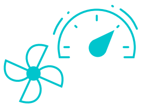
SIGNPOST *Appendix 1 - The problem with compliance modelling*

SIGNPOST *CIBSE TM54 (2022) section 4.4 and 7.1 includes some useful advice on choosing a suitable approach.*

Considerations when choosing the right tool

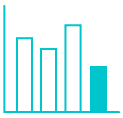
It is useful to think about the following when choosing a modelling tool:

The effects of thermal mass or complex geometry on the energy performance

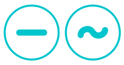


The complexity of building systems and their controls, and if they contribute significantly to the overall energy use

If building systems' performance will vary significantly due to load or weather



What outputs are needed from the model and their accuracy. Many performance metrics are annual but if the energy model is needed to test against in-use performance, more accuracy may be required



How the considerations above can be modelled accurately through steady-state or dynamic modelling tools and methods

A good modeller should be able to advise on tool selection, but bear in mind that they may have a bias towards the tools they are most familiar with.

Figure 2.6 - Considerations for tool choices

Quasi-steady state

Steady state models are based on an energy 'balance' methodology, where calculations are made at a daily, monthly or annual time frame. These tools are quick to run and need less data or background assumptions than dynamic models. This means that the results are often more transparent, easier to interpret, and less susceptible to input error. For this reason they are well suited to early design stage testing where the building form, orientation and scale is still in flux, or simpler buildings that don't have complex HVAC systems and controls.

Examples of commonly used steady state tools include PassivHaus Planning Package (PHPP), SAP and SBEM. LETI do not recommend the use of the current (2021) versions of SAP and SBEM for energy performance modelling. Instead PHPP is recommended for simple buildings, modelling with a detailed consideration for how occupancy may impact on the results. Note that the PHPP tool is recommended for assessments regardless of whether the building is targeting the Passivhaus standard.

Recommended steady-state modelling methodologies by LETI

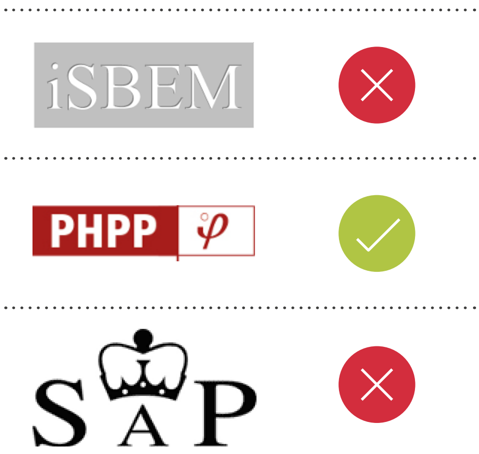


Figure 2.7 - Recommended methodologies for steady-state modelling

Passivhaus Planning Package (PHPP)

Passivhaus provides a way of designing and delivering low operational energy buildings with high levels of thermal comfort. It provides a set of performance targets, modelling tools, and a quality control process, including independent third-party certification. They are modelled using the Passivhaus energy tool, PHPP[2.12].

PHPP offers a flexible, robust and useful energy calculation. When compared to in-use monitoring of buildings it closely matches the average performance, especially in low energy buildings. This accuracy at a 'stock' level has been arrived at through decades of testing and refinement of the steady state calculation, alongside a robust quality assurance process carried out during construction and at completion.

More care and understanding is needed if it is to be used in existing buildings that can be susceptible to more variable internal temperatures. The spreadsheet format means that the calculation is fully transparent, allowing the user to interrogate results, openly and honestly modify important assumptions, and be able to quickly create scenarios and stress test models. Importantly, PHPP analyses all energy uses within a building, allowing the results to easily align with EUI targets.

PHPP is good at predicting space heating demand, particularly as an average over large samples, and can be used to provide these figures as part of a larger TM54 assessment in domestic and non-domestic buildings. All of the assumptions are editable, although many will need to be fixed for the certification. Despite this, the flexibility allows a modeller to test and alter parameters of building performance or occupant behaviour, which can prove to be a powerful design tool. A change log is recommended as an important record of what has been altered, for what reason, and what impact it had.

Being able to manipulate many of the parameters of the model allows a user to alter the standard occupancy assumption by manually adjusting the internal gains. In this way its approach to plug loads can be tailored more closely to what will be installed in the building and how the occupants are expected to use it.

Because PHPP is open source, various plug-ins and add ons have been developed over the years. DesignPH is especially useful as it allows modellers to use SketchUp to recreate a building geometry and its surroundings. This then imports the 3D information into a standard PHPP spreadsheet. One of the main benefits of this is the accuracy of the shading analysis.

SIGNPOST *More information on PHPP is available on Passipedia.*

Dynamic simulation modelling (DSM) tools

DSM (also known as Dynamic Thermal Modelling (DTM)) tools create a detailed representation of an operational building for every hour in a full year. Each room can be represented by a separate modelling zone; sometimes several zones are used in a large space to capture higher heat losses or gains in perimeter spaces or stratification in very high spaces. Occupancy patterns and gains can be specified down to an hourly level throughout a year. Natural ventilation can be estimated based on opening windows and wind characteristics from the weather file, and mechanical ventilation supply and extract rates can be specified by zone, and controlled by timeclock or on CO_2 sensors. Lighting can be specified by zone and controlled by timeclock, or linked to daylight levels or occupancy. All HVAC equipment can be included and operational controls applied. Models are simulated against weather files for locations appropriate to the site which include hourly values for a full year.

Examples of commonly used DSM tools include Design Builder, EDSL TAS, Energy+ and IES Virtual Environment.

Hourly results are available for every zone and include a very wide range of parameters from air and operative temperatures to individual wall surface temperatures, air flow through each window, solar gains, and whole building totals such as annual space heating demand and peak chiller loads etc.

Dynamic modelling tools

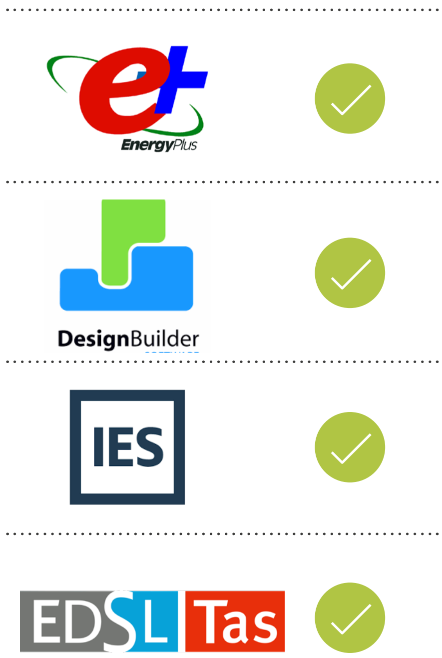


Figure 2.8 - Dynamics modelling tools

HVAC modelling

Template HVAC modelling enables a range of standard HVAC systems to be applied to meet modelled demands. These templates are often based on the systems allowed within the NCM. This form of HVAC modelling is quicker and requires less experience to implement, and can be effective at early stages where HVAC systems are not fully designed or where proposed systems are a good match for one of the templates.

Where a building features multiple heat generators, chillers, air handling plant or a BMS then simple estimates or template HVAC systems lose accuracy and detailed HVAC modelling that can better capture the inter-relationships and controls is advisable.

Detailed HVAC modelling allows both the proposed HVAC (Heating, Ventilation and Cooling) systems and their control algorithms to be tried out against realistic operational patterns and weather. This process can help with optimising and sizing the HVAC design, pre-empting problems that otherwise might not surface until commissioning is taking place on site.

This form of detailed HVAC modelling is not currently routine in the UK but is rapidly gaining interest following successful adoption in other parts of the world in connection with ASHRAE 90.1 modelling through LEED assessment, and also the Australian NABERS scheme that is now active in the UK.

Benefits of detailed HVAC modelling

The key benefits of detailed HVAC modelling:

→ ‘Granular’ understanding of a significant part of building energy consumption in non-domestic buildings at the design stage, leading to optimised designs

→ Testing the impact of HVAC design or specification decisions

→ Enables the operation of heat pumps to be tested to optimise flow and return temperatures and sizing - this is especially helpful as the industry adapts to routine specification of heat pumps instead of boilers

→ Early development and testing of controls strategy including for mixed-mode systems

→ ‘Dress rehearsing’ proposed HVAC and control algorithms against realistic operational patterns and weather to help pre-empt issues that otherwise might not surface until commissioning is taking place

→ Allows HVAC equipment to be more accurately sized

→ Enables a test of the whole HVAC design and how it will work together hour by hour, rather than separate elements in isolation

→ Enabling modelled performance to be compared against in-use performance to optimise and help diagnose any faults

2.3 Methodology: TM54

CIBSE TM54 'Evaluating operational energy performance of buildings at the design stage' (2022) forms the backbone for EUI modelling. It provides an industry approved protocol for all in-use energy performance modelling, whether steady-state or dynamic. It is referenced heavily in this guidance. The methodology sets out a thorough and flexible approach, leaving room for the modeller to make intelligent interpretations.

LETI recommend that TM54 is followed as the central methodology for all EUI assessments in all building types. The guidance in this document is intended to augment and support project teams in following TM54 when designing for EUI targets.

TM54 requires modellers to build a comprehensive model of all energy uses within a building using the right tools, either steady state or dynamic, explore the key unknowns that could impact on energy performance, and create a matrix of risks that need to be managed to enable the project target to be reached. The results are presented using three scenarios: low, mid-range (best estimate), and high energy consumption. These help to give context to the results and the potential risks and variance on the outcome.

Delivering on EUI targets in practice requires the performance gap to be minimised. Modelling must play its part in this by developing realistic models that consider design and operational risks, using sensitivity testing and scenario analysis to present the range of possible outcomes, and highlight the route needed to achieve the targets set.

TM54 can be applied to any building type, including homes. There is advice on how to select an appropriate modelling approach and tool i.e. steady state, template HVAC modelling, and detailed HVAC modelling. Energy modelling tools are good at simulating the potential behaviour and interaction of materials, systems and environmental conditions. People may use a building in a way that was not anticipated, or construct it or commission it in a way that was not intended, so models need to take account of a range of possible scenarios and highlight the impact that each might have on the building performance. TM54 provides a framework in which to do this.

Clients and project teams should understand the inherent uncertainty in model predictions, and assist modellers in developing ranges and scenarios to test, allowing suitable performance margins, and manage the risks identified in order to meet the targets in practice.

TM54 sets out an approach based on risk assessment, sensitivity analysis, low, medium, and high energy-use scenario testing leading to a range of probable performance. It also includes reporting requirements including an implementation matrix that records and tracks uncertainty and potential variance on all modelling input data. It emphasises that accurate outcomes rely on good quality modelling and good information sharing between the project team and modeller.

17 Steps

The TM54 methodology comprises 17 steps. Simpler buildings including individual homes will be able to skip some steps.

TM54 has the requirement to fill out an 'implementation matrix' in the modelling report (step 16). This matrix is a table for modellers to set out how each of the TM54 steps have been addressed for the project, the likely range of input parameters, and the level of confidence in the data used. This importantly allows an early stage or 'light touch' TM54 assessment to be differentiated from a more detailed assessment carried out at a later design stage. It also helps the whole team to be conscious of the strengths and weaknesses within the model, to track the risks that could affect in-use energy consumption, and to focus on reducing the gaps and margins as the design evolves.

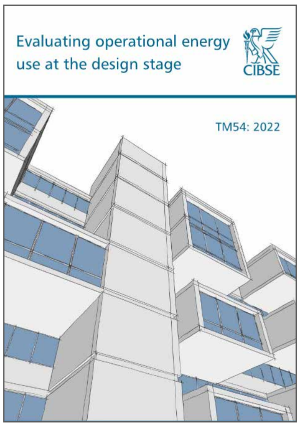


Figure 2.9 - CIBSE TM54

TM54 is based on the following principles:

→ Set project targets for operational energy performance.

→ Use the right tool for the project.

→ Be mindful and record where there are gaps or weaknesses in the input data.

→ Consider how the building will be run in practice, what variance there might be on this and how that might affect the energy use.

→ Include additional building energy uses not calculated by the model.

→ Carry out sensitivity analysis to explore the most influential and least certain parameters on the estimated energy performance.

→ Carry out scenario testing that looks at a mid-range (best estimate) plus high and low energy use scenarios to frame the result or quantify uncertainty.

→ Report clearly on how the modelling was carried out, all the input data and confidence levels, plus results from all the sensitivity tests and scenarios run with comparison against targets.

→ Monitor in-use performance and compare measured data to the model outputs; exploring any discrepancies between the two to help diagnose and fix performance issues.

SIGNPOST *CIBSE TM54 can be downloaded from the CIBSE website (free for CIBSE members).NB TM54 has recently been updated and it is the new revision (2022) that we refer to in this guide.*

TM54 Modelling Process

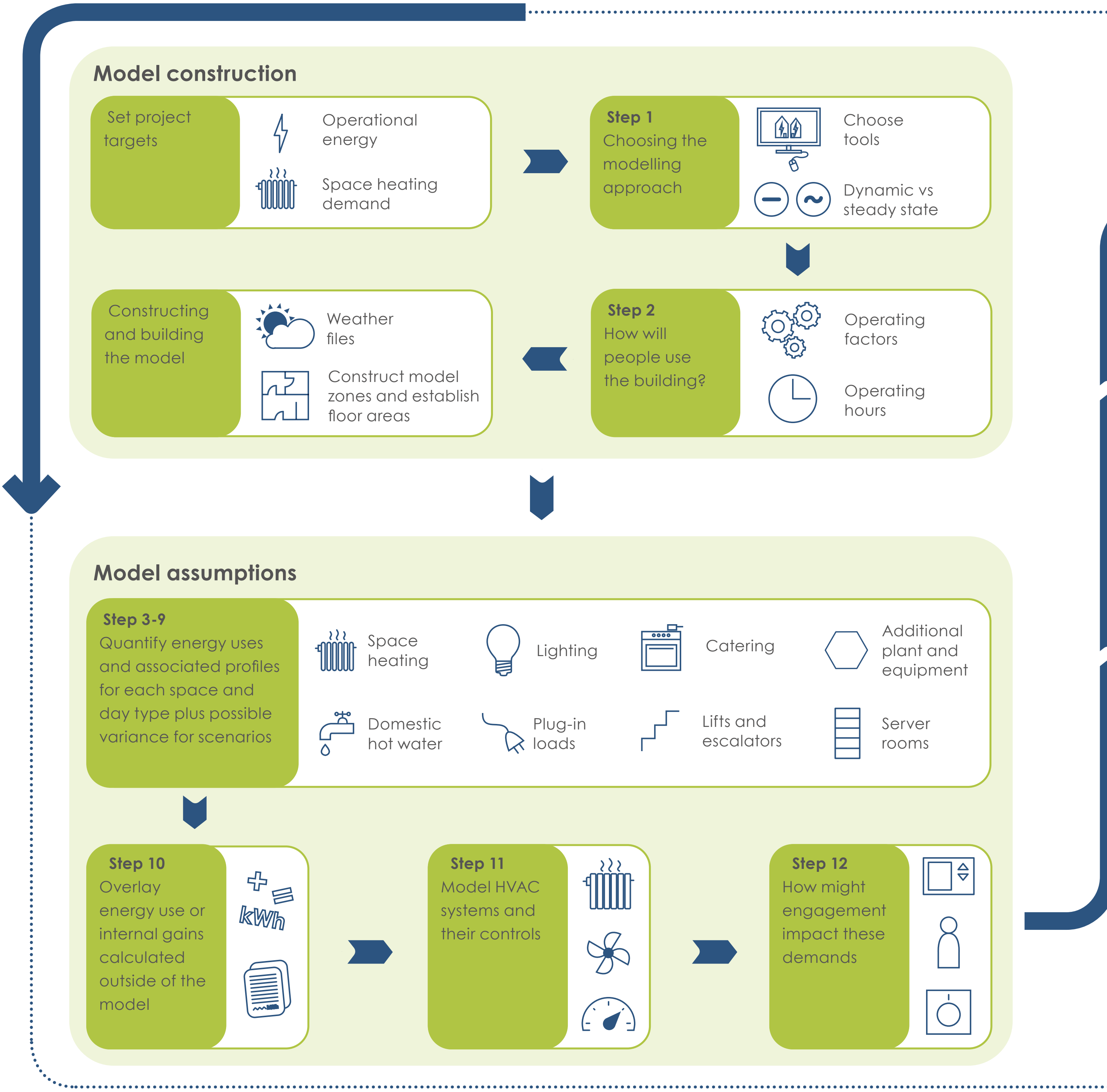
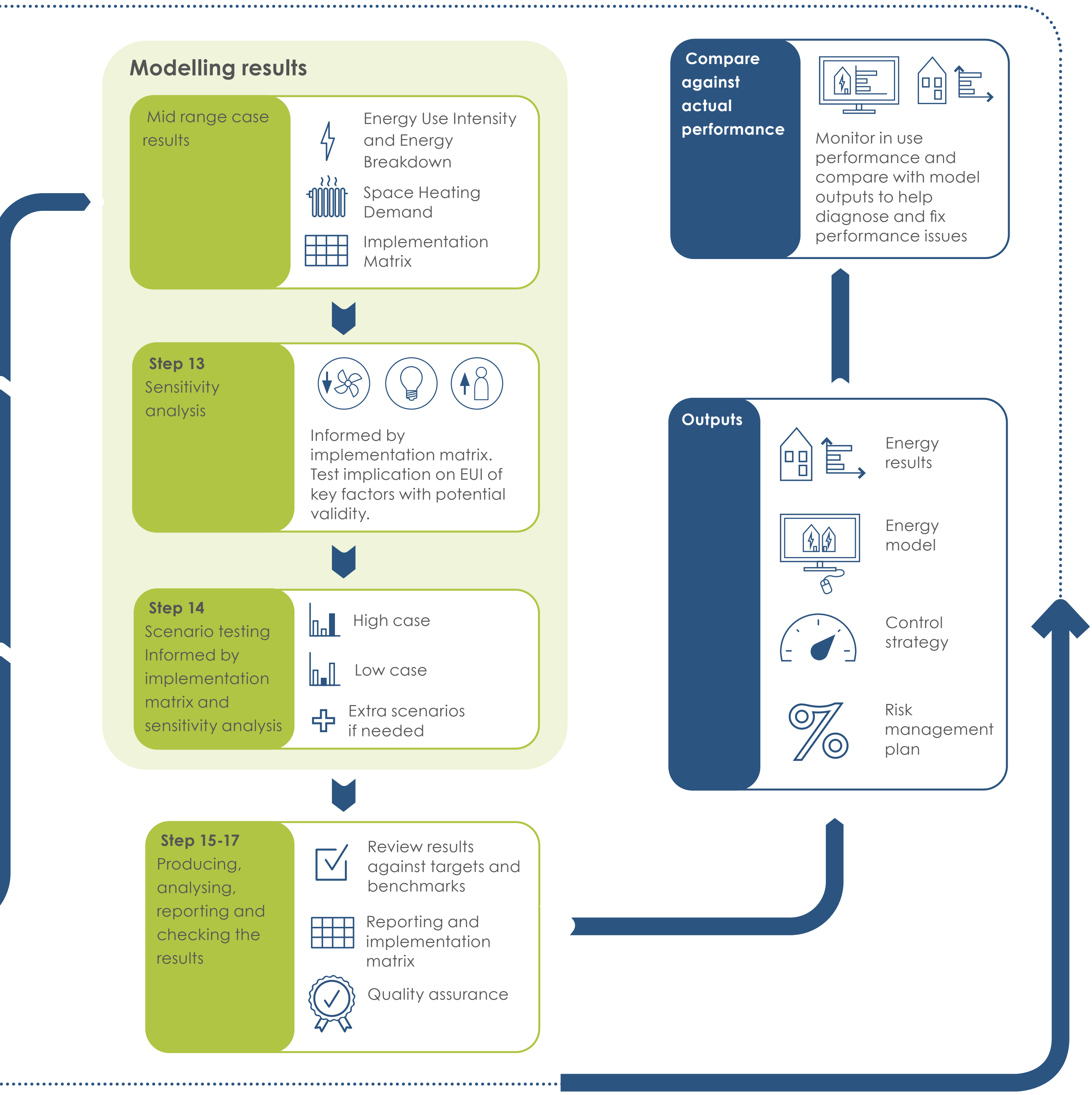


Figure 2.10 - TM54 modelling process


Modelling results
Mid range case results
Energy Use Intensity and Energy Breakdown
Space Heating Demand
Implementation Matrix
Step 13
Sensitivity analysis
Informed by implementation matrix. Test implication on EUI of key factors with potential validity.
Step 14
Scenario testing Informed by implementation matrix and sensitivity analysis
High case
Low case
Extra scenarios if needed
Step 15-17
Producing, analysing, reporting and checking the results
Review results against targets and benchmarks
Reporting and implementation matrix
Quality assurance
Compare against actual performance
Monitor in use performance and compare with model outputs to help diagnose and fix performance issues
Outputs
Energy results
Energy model
Control strategy
Risk management plan

Risk and confidence levels

All models are only as good as the assumptions they are built from. Project teams need to work closely with modellers to give them the most accurate input data to model at each design stage or model update, but there will always be uncertainty in the analyses. An important part of the process is evaluating these uncertainties and communicating them and the impact they might have on meeting the EUI target.

The TM54 implementation matrix allows the source and confidence levels of key inputs to be tracked. These variances on inputs are explored using sensitivity testing and used to produce the low, mid-range and high energy use scenarios that are the key output from the modelling. Any potential variance that could lead to the project missing its EUI target should be logged and tracked so as to keep focus on managing these risks.

In addition the design should include sufficient margin to accommodate some variance and still meet the EUI target.

In practice, managing these risks and margins can be a tricky balancing act that requires transparent collaboration and collective focus amongst the whole project team.

One question to ask is whether it is practical for the building occupiers to operate the building as intended. It is easy to make design stage assumptions, but unless the operating principles are discussed and agreed with building operators, there may be unforeseen conflicts or difficulties that could impact on energy performance.

TM54 includes example entries for the implementation matrix (table 13) which indicate the level of information, probable range and confidence levels that might be provided against each step.

LETI recommend that by the detailed design stage, the confidence level attached to most of the key modelling inputs has reached 'high', and that a detailed risk management plan has been discussed and agreed with the project team. This plan plays an important role in monitoring and managing the risks that could take the energy use of the building over the target, and should include advice on how each risk is being mitigated.

Firstly sensitivity testing, then scenario analysis helps modellers to quantify what impact these unknowns will have.

Developing scenario analysis

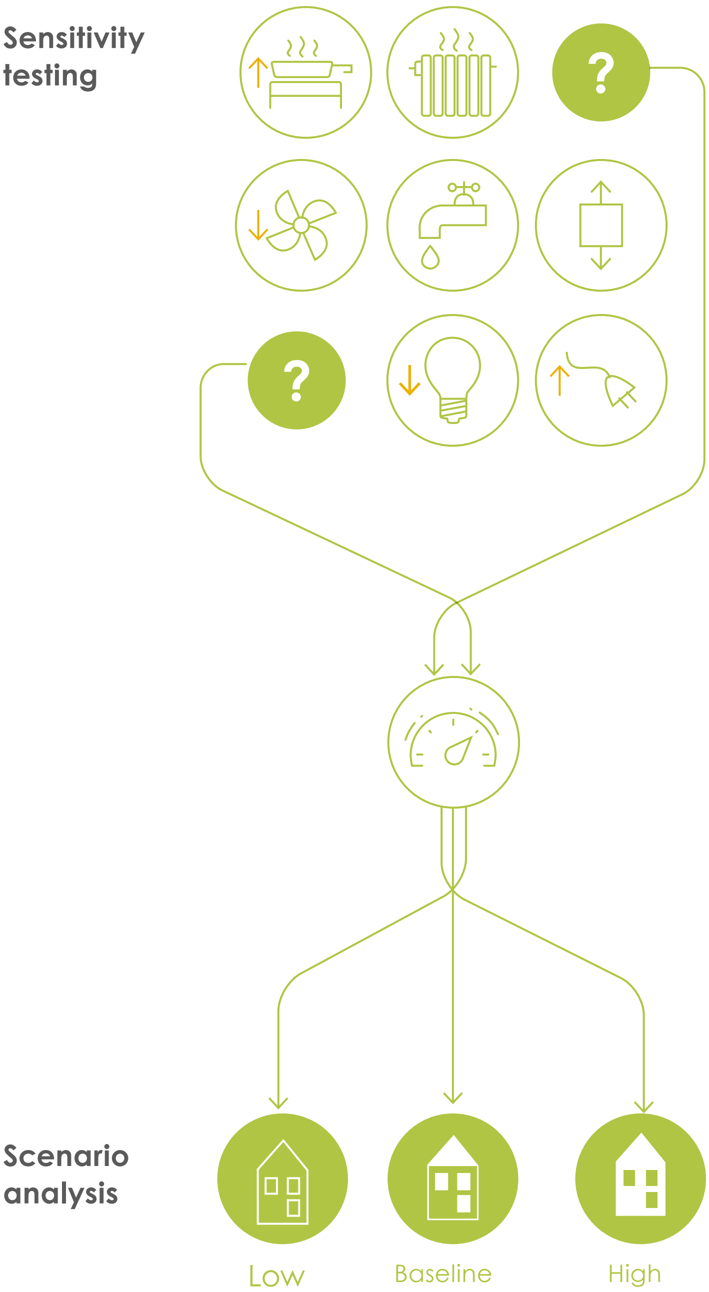


Figure 2.11 - Scenario Analysis

Sensitivity testing

The TM54 implementation matrix should be used to build a picture of which model inputs and design variables are most or least certain and which have the greatest possible range on their values. Where it is not immediately apparent what impact changing an individual input might have on annual energy consumption, sensitivity testing will allow inputs to be varied one at a time to explore whether they increase or decrease total energy use and to what extent. This analysis will then help inform the basis for low, mid-range and high scenarios that will be modelled to produce the central EUI estimate (mid-range) and low and high results that will frame this and put a range on the possible in-use energy use.

LETI recommend that models are tested against current and future TRY (Test Reference year) weather scenarios as part of the sensitivity analysis.

Some projects will not need much sensitivity analysis as it will be clear which variables will put the EUI up or down. More complex projects including those with heating and comfort cooling, can be harder to predict as higher internal gains can reduce space heating demand but increase cooling loads, so the impact on annual energy consumption will be less predictable.

Creating scenarios

TM54 describes the creation of low, mid-range and high energy use scenarios:

"The modelling results should be presented as a range to demonstrate the level of uncertainty:

→ *A mid-range scenario is the best estimate of energy use, based on the occupancy estimates from the prospective occupants (if possible, or otherwise the client) and the most reasonable assumptions for the building's systems efficiencies, controls and management regimes.*

→ *A high and low-end scenario should be generated by taking into account uncertainties for key parameters."*

The low-end scenario may be the least useful in practice as it is very rare for buildings to out-perform their mid-range estimates in operation, but it can help give context as well as identify potential improvements to implement at future design stages.

LETI require that energy performance modelling demonstrates that buildings should hit their EUI targets (and space heating demand) for the mid-range scenario.

In buildings where occupant dependent energy uses (appliances, cooking, specialist equipment, hot water, etc.) are expected to be particularly high, it might be very difficult to show compliance with an EUI target using the mid-range (best estimate) scenario. In these cases it is recommended to run a scenario with more conventional occupancy to demonstrate that the EUI target can be met where this is the case. This would help to communicate the influence of occupancy on energy demands and to show that all possible design measures have been taken to reduce them.

There is an argument that the 'high energy use' case modelled should also meet the EUI target in order to allow a safe margin, BUT the concern with this approach is that it can put pressure on teams to include less severe options in the high case in order to meet this target, or that it can make targets appear unattainable. LETI believe the high case should be an opportunity to compound uncertainties and risks as a warning to project teams how easy it would be for performance to slide. Also required is a risk management exercise to communicate, monitor and mitigate the risk of performance not meeting the target.

It is important to consider a wide range of 'what if's' when formulating the three scenarios, and also to check, as far as possible, that the changes in inputs do not cancel each other out in the combined scenarios. For example a reduction in occupancy would reduce electricity use associated with appliances but potentially increase space heating demand, as the occupancy gains would be lower.

Some 'what ifs' may be outside the control of the project team as they relate to how the building is run and managed in use, but still need to be thought about and factored into scenarios. TM54 table 13 includes a useful list of considerations and how these might feed into the scenarios run.

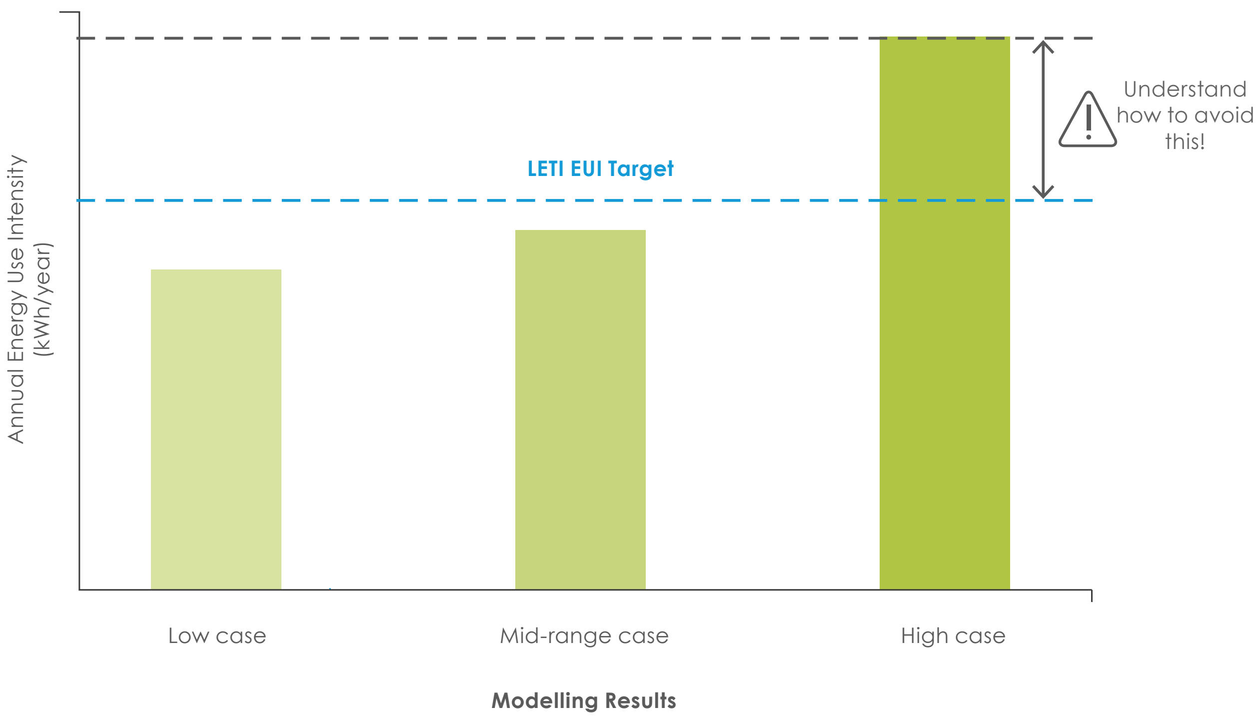


Figure 2.12 - The importance of low, baseline and high scenario cases

The whole project team should help with the process of thinking through what to include in the scenarios and how, but the modeller will be expected to lead on this. It is important to involve the client and the future building management team (often referred to as facilities management) or occupants (if possible or relevant) as early as possible within the project, as these are the people who will determine how the building is used.

It is also important that the model references the proposed sub-metering strategy so that outputs from the model can be grouped in the same way as the meters. This will help facilitate like-for-like comparison. The modelling team should engage others to align their models with the proposed meters.

See also the following suite of CIBSE documents that cover different aspects around establishing and improving the operation performance of buildings once they are up and running.

SIGNPOST *CIBSE TM61: Operational performance of buildings*[2.13]

SIGNPOST *CIBSE TM62: Operational performance: Surveying occupant satisfaction*[2.14]

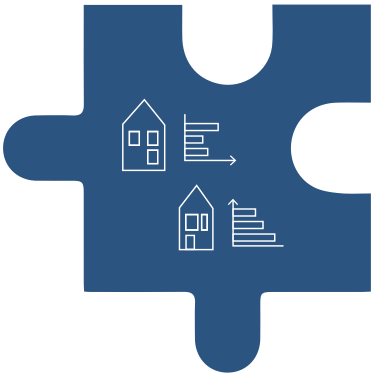
SIGNPOST *CIBSE TM63: Operational performance: Building performance modelling and calibration for evaluation of energy in-use*[2.15]

SIGNPOST *CIBSE TM64: Operational performance: Indoor air quality — emissions sources and mitigation measures*[2.16]

	Low	Mid Range	High
Lighting efficiency (lm/w)	115	105	95
Space heating set point (*C)	19	21	22
Occupied hours	9 - 5	8 - 6	7 - 8
Air permeability ($m^3/m^2/hr$)	1	3	5
DHW distribution Efficiency (%)	15	90	85

Figure 2.13 - Low, baseline and high scenarios dependent on weather

2.4 Outputs



Creating a model that provides a good estimate for the EUI a building can achieve in use is the core focus of this guidance. Meeting an EUI target in practice is important, but so too is delivering a comfortable building that performs in all aspects. Modelling can additionally help indoor environmental quality, including overheating risk, daylight access, and internal air quality. It can also help size and 'dress rehearse' the plant and equipment, reducing over-sizing, and explore energy flexibility including how to reduce peak loads across the systems.

Core outputs

Core energy performance modelling outputs should include:

→ A detailed modelling report.

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Clear and honest reporting*

→ The EUI results estimated by the model for the low, mid-range and high scenarios and how these compare to the EUI target.

→ The space heating demand and space cooling demand estimated by the model for each scenario plus the assumed DHW demand.

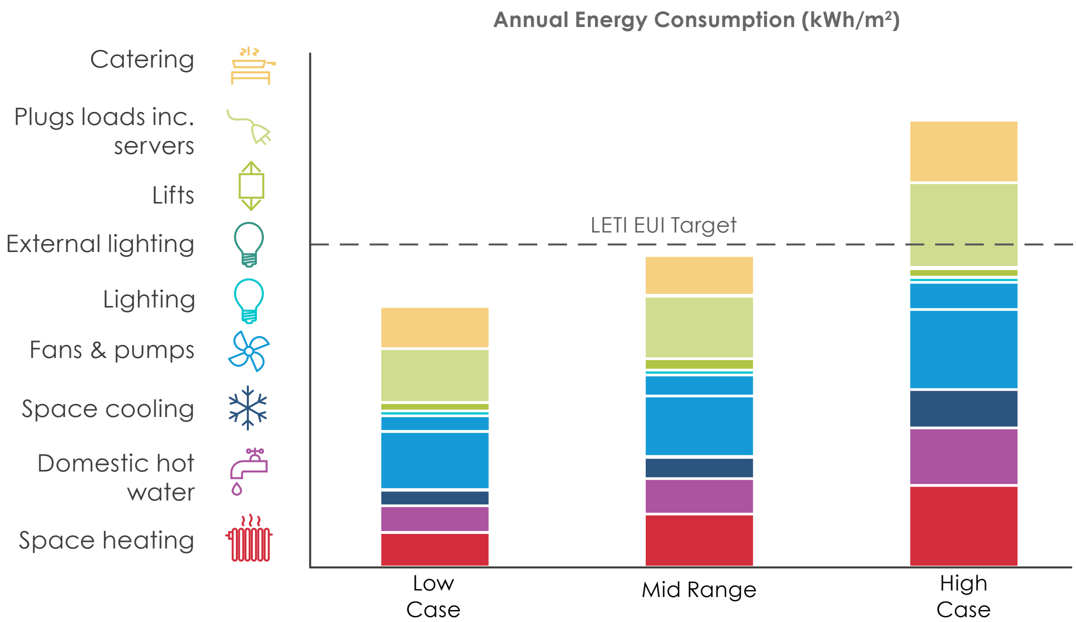
→ Exploration of factors affecting the buildings in-use energy performance and identification of the design, construction, commissioning and management risks that might impact on this performance so they can be monitored and managed.

→ The model files with a directory outlining which files relate to each case and scenario.

Modellers should be available to present these outputs and answer any questions from the client and project team.

Minimum EUI modelling should include:

- A detailed report
- The space heating demand estimated by the model for each scenario
- The model files with a directory outlining which files relate to each case and scenario
- Discussion of key notes that could increase energy used and how these will be managed.
- The EUI results estimated by the model for the low, mid- range and high scenarios and how these compare to the EUI target.



Modellers should be available to present on these outputs and answer any questions from the client and design team.

Figure 2.14 - Modelling Outputs

Additional modelling outputs

Alongside modelling for the EUI target, the models can be re-purposed and extrapolated to provide other benefits, including assisting building professionals to:

→ Check that the building is designed to be comfortable to occupy as well as energy efficient to operate. This includes checking for significant overheating risk or undersized space heating systems

→ Assess whether daylight access has been optimised

→ Estimate what the peak loads are likely to be and how the demand might vary to assess energy flexibility and how these demands can be managed and balanced with storage options and connected renewable generation

→ Communicate the key design elements and design intent regarding operational energy performance, and how building operators can readily monitor whether this is being met for different energy uses.

→ Test that the HVAC approach proposed is appropriate for the project and can work efficiently

→ Check that plant sizing can meet demands throughout a typical year and into the future

→ Check that the controls strategy will work as intended

→ Check building regulations compliance (Part L/ Part O)

→ Post completion, energy models can serve as a platform for testing future plant replacement, building upgrades, alterations etc.

Producing these extra outputs may require more work and input from the modelling team but can employ the same core model.

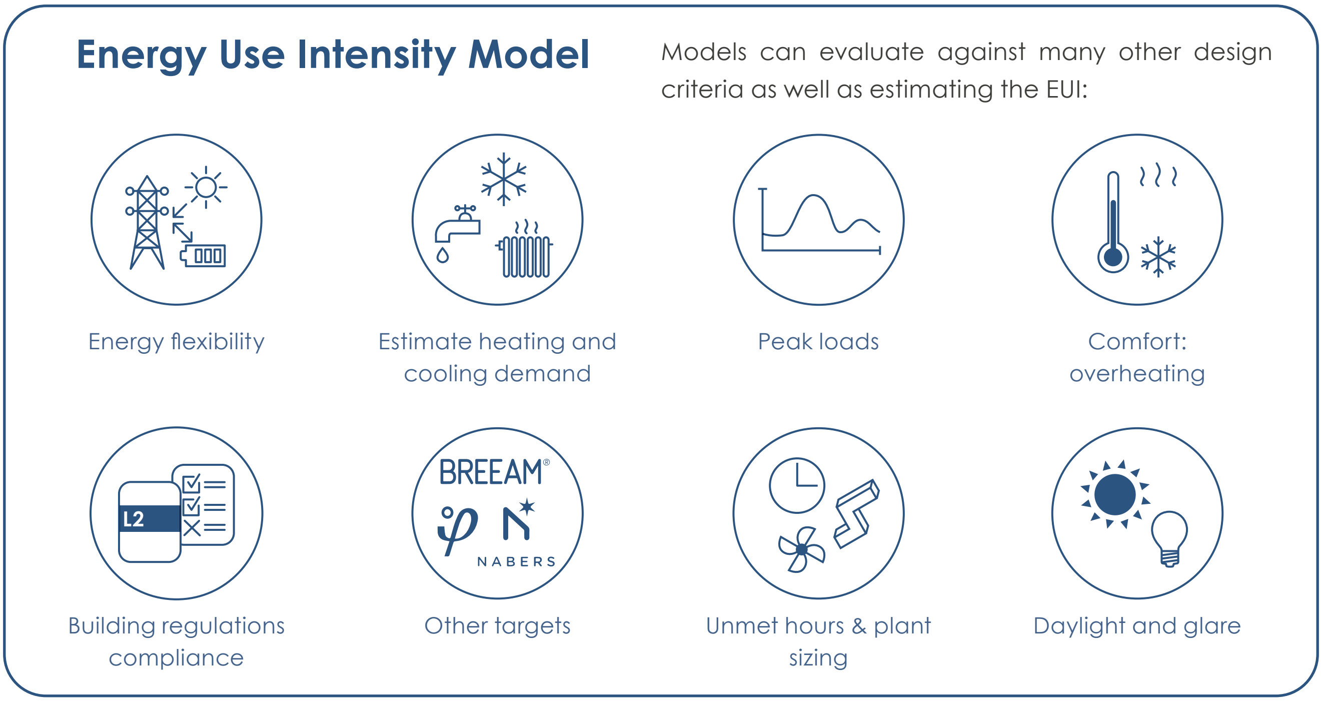


Figure 2.15 - Additional benefits to modelling

Comfort assessments

The primary purpose of any building is as a place of shelter. We spend almost 90% of our time indoors and we rely on buildings to protect us from the elements and provide a comfortable environment for our activities - keeping us warm in winter, cool in summer, with fresh air and good lighting. It would be easy to design a net zero building if you were unconcerned about the comfort of the occupants!

Meeting net zero operational energy targets alongside delivering a comfortable and healthy indoor environment is imperative.

There are several aspects to human comfort:

→ Thermal comfort - not being too hot or too cold

→ Acoustic comfort - not being in too noisy an environment

→ Air quality - provision of fresh air free from unpleasant smells, allergens and pollutants

→ Visual comfort - free from glare and flickering lights and with sufficient lighting to see clearly (depending on task), and a view out of the window

While these aspects are all subjective with different humans having different preferences, there is CIBSE guidance on how to deliver on each of these for the majority of occupants, and modelling can help. Considering all comfort criteria at very early design stages helps inform the most effective design for the building envelope alongside considerations of spatial planning, orientation and form factor.

How comfort requirements are met will impact on the energy consumed by the building. Failure to achieve comfort will often result in additional energy use to resolve these comfort issues for example by retrofitting additional capacity, altering set-points or extending plant operating hours.

The building envelope design has a big influence on comfort. Glazing is one example where careful consideration is needed to balance competing objectives. Windows should provide good daylight, a view out, fresh air and cooling in summer, as well as thermal comfort in winter by being well insulated and draught-free. Too much glass can increase overheating risk in summer and space heating demand in winter, whereas too little could increase lighting loads, reduce views out and limit natural ventilation provision. With detailed energy models, it is possible to tailor the glazing proportions to the light available. In denser town and city environments this may mean varying the glazing on each storey and each façade.

Where different models and tools are used to evaluate different performance aspects it is essential that all assumptions are aligned to avoid inconsistencies. Examples include ensuring the same glazing parameters and frame factors are used for overheating and daylight assessments, and the same window opening assumptions (free areas and hours of use) in overheating and acoustic assessments.

Overheating risk

A building that gets too hot is not performing well. Cooling loads could be excessive (where mechanical cooling is provided), and complaints are likely.

The early design stage Overheating in New Homes tool and guidance[2.17] available for free from the

Good Homes Alliance (GHA) website is a good place to start for advice on the key features that can increase or help mitigate overheating risk. Although this guidance is aimed at new homes, most of the principles are relevant for all building types. There is also now a retrofit overheating risk tool available from the GHA, also aimed at homes but with potentially wider applicability.

Dynamic models can be adapted or developed to test overheating risk against CIBSE TM52 or TM59 criteria for naturally ventilated spaces, and follow CIBSE Guide A[2.18] criteria (operative temperatures and PMV/PPD) for mechanically ventilated and/or cooled spaces.

PHPP also contains an overheating check, although not as stringent as a TM59 assessment it is still a good starting point for testing the likely risk. PHPP also includes an overheating stress testing element that allows users to vary elements of building performance (such as occupancy or weather) to see how these would impact on the overheating risk.

Part O of the Building Regulations now applies to all new homes and forms an overheating risk assessment that uses either CIBSE TM59 (see above) or a simplified method that sets maximum glazing area and minimum ventilation free areas.

Note that comfort criteria are more onerous for vulnerable occupants (care homes, sheltered accommodation, hospitals, etc.).

LETI recommend that all projects consider overheating risk and complete an assessment relevant to the type of building and the level of risk i.e. projects in London and the South-East are more likely to need a dynamic simulation modelling assessment than something modestly glazed in the North East.

SIGNPOST Good Homes Alliance Overheating Guidance and Tool

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Beyond the EUI analysis, Modelling overheating risk*

Daylight access

Daylight is an important consideration, and can be improved by locating windows higher in façades. Low level glazing can increase overheating risk without improving daylight so should be limited to where it is essential for accessibility (views from seated).

Good daylight levels can improve occupants' connection to outside, reduce reliance on artificial lighting, and reduce energy demand, especially where daylight linking and dimming is specified.

The Climate Emergency Design Guide recommends that windows make up no more than 35% of facade area to be enough to maintain daylight levels without increasing overheating risk. It also gives suggested glazing proportions by facade for different building types with a clear directive to balance daylight and overheating risk.

SIGNPOST *Chapter 3 - 3.2 Modelling specifics, Lighting*

Plant sizing and unmet hours checks

Part of achieving thermal comfort is making sure systems are sized to meet comfort set points all year, without being oversized which can reduce efficiency. Although energy models should not be the complete basis for sizing of systems, they offer an opportunity to double check the M&E design and can be used as a platform for asking questions about oversized systems.

Steady state models do not contain enough detail to provide this analysis in full, but in PHPP the space heating load calculation can be used to help verify that the proposed size of the space heating system is justified. If the modeller uses PHPP for this then be careful to check assumptions around weather, gains and losses.

Dynamic modelling tools can help with the sizing process by providing peak load assessments, and/or by simulating with the proposed equipment specifications and sizes and checking for 'unmet hours'.

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Beyond the EUI analysis, Checking unmet hours*

Energy flexibility

In the past, energy supply was scheduled to meet demand. As we transition to intermittent sources of renewable energy, demand will increasingly need to be scheduled to meet supply. As one of the largest end-users of energy (and in many cases also as the interface between electric vehicles and the electricity grid), buildings will increasingly need the ability to flex when they use energy to make best use of both on-site and off-site renewables. As the smart metering roll-out completes, time of use pricing is likely to increasingly reward buildings that can use energy when it is windy and sunny, and penalise buildings that need grid energy when renewable resources are low and grid demand is high. The need for energy flexibility is therefore expected to become a key part of future building regulations.

Energy performance modelling plays an important role in quantifying the main long-term characteristics of a building that contribute to its energy storage capacity. The thermal mass of the building in combination with its heat loss parameter affects how long the heating and cooling systems can be turned down, or even off, while maintaining a comfortable indoor environment. In net zero compliant buildings, this could be many hours or even days. Hot water storage capacity provides another important form of thermal energy storage, for which a range of control options are already available. Finally, battery storage can also be added to further increase storage capacity.

While there is not yet agreement on how electric vehicles should be considered in relation to buildings, it is likely to be increasingly difficult to maintain separation between the two. Vehicle to grid and vehicle to home capabilities are forecast to expand, meaning electric vehicles will become another storage resource available to many buildings (battery capacities can be large enough to meet anywhere from several days to a week or more of domestic electricity consumption in a net zero compliant home). While not yet relevant to Part L modelling, the ability to forecast demand for vehicle charging and model how this will interact with building mounted renewable energy systems is already a useful skill for many projects - however, EVs are not currently included in the EUI metric.

NABERS UK

Design, construction and operation process - for more complex non-domestic buildings

NABERS UK allows design teams to commit to project specific energy performance targets based on a star rating scheme. These commitments are made at the design stage using a similar modelling process to that advocated in this guidance.

Design for Performance requires detailed modelling of the building, including the HVAC systems and controls, in order to assess whether the building could, in theory, meet the project-specific energy target. At least four off-axis scenarios plus one compound scenario must be modelled in order to understand the potential risks that may lead to the target not being achieved. The target energy performance is decided by the applicant when the NABERS UK Design for Performance agreement is signed and the rating scale is expressed as a number of stars from 1 to 6 stars. The Design for Performance process involves identifying non-technical barriers to achieving the rating through the inclusion of a project Rating Achievement Plan, which demonstrates how the applicant will maintain sufficient control of the building design, construction and operation such that the target rating can be achieved. The Stage 4 building design documents, 'Rating Achievement Plan' and Simulation Report are reviewed by a member of the NABERS UK Independent Design Review panel to help manage the risks involved in achieving the rating. The NABERS process is well documented including reporting requirements. Once the building has been occupied for 12 months, an in-use rating is carried out. It is this in-use measurement that the building star rating is ultimately based on, and if the rating committed to during design does not match this there can be significant contractual repercussions.

Though currently NABERS UK only applies to 'Base Building' energy, if the modeller includes a detailed assessment of tenant energy use in the model, the modelling principles are broadly the same so the same modelling could support both EUI targets and NABERS star rating estimation. Tenant and whole building NABERS UK schemes are due to be released by BRE in early to mid 2023.

The LETI Office EUI target of 55kWh/m²/yr has been estimated to be approximately equivalent to a 6 star NABERS rating.

Figure 2.16 - NABERS star scoring systems

SIGNPOST NABERS

2.5 The modelling timeline

It is normal for models to be completed and updated several times during the design process, to monitor progress and give confidence that targets are still in range. Early assessments are usually lighter touch with broader assumptions made, and gradually refined and enhanced as the design evolves. How frequently models are reviewed and updated will be up to the client and project team and will be influenced by the complexity of the project, how much the design changes over time and by how easily the EUI and other targets are met.

The following spreads suggest an overview for a modelling timeline. The modelling scope should respond to client and planning requirements as well as energy performance targets; it is worth drafting out an agile scope as project requirements and constraints vary, and can evolve with the design.

Each stage should consider to some extent the three core requirements of net zero buildings while delivering a comfortable environment for occupants: energy, fabric efficiency and low carbon heat and renewable energy[2.19].

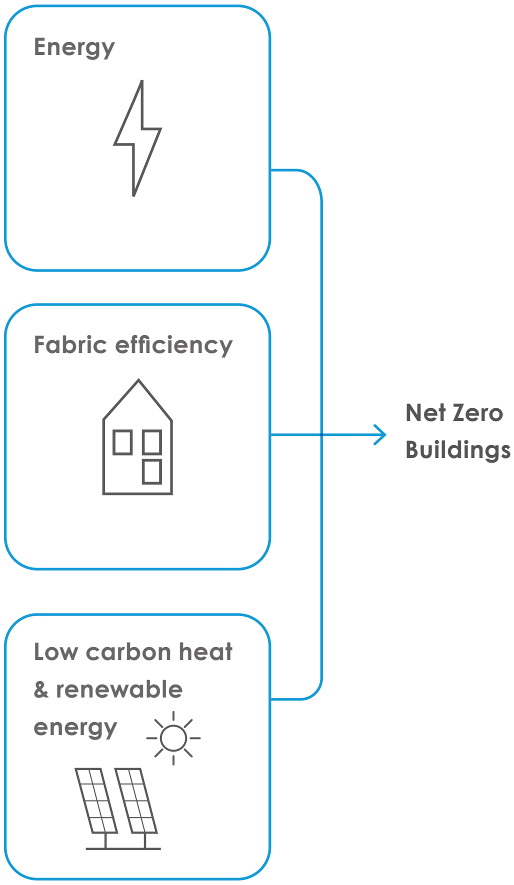


Figure 2.17 - Inputs for net zero carbon buildings

Concept stage modelling

Early concept stage modelling can have significant benefits for optimising designs. It is of most benefit when informing an architect's choices before they draw up their first architectural layouts. These choices might include putting certain room uses on certain facade orientations, indicative window area sizing, thermal mass options, how passive cooling can be sufficient, which room uses can be naturally ventilated, indicative window opening areas, how an appropriate fit-out IT strategy or task lighting strategy could eliminate mechanical AC entirely, etc.

A modeller should be invited to participate in early design discussions; an experienced modeller can bring their knowledge of building physics and modelling techniques to advise on likely outcomes and devise modelling exercises that would test the impact of competing options. This concept design input comes before the architectural model has been created, so models need to be built from scratch as simply as possible. Such exercises would typically only include a small portion of the building such as one classroom, a single floor or an individual apartment in order to explore the impact of specific decisions.

Experienced modellers and project teams should be able to whittle down the range of options to be tested, but parametric analysis can be a useful option for efficiently testing a wide range of incremental changes to find the 'sweet spots'

Some schemes (tried and tested designs) may benefit less from modelling at a very early stage, whilst others may employ numerous small studies. Modellers should endeavour to be proactive in their involvement, providing useful feedback on the questions raised using simple studies and not overcomplicating models too soon to avoid unnecessary cost.

The key route into helpful modelling at early stages is to focus on the specific questions that the project team needs feedback on in order to inform their decisions. These questions could include almost anything, but some examples might be:

→ "How much glazing do we need to meet classroom daylight targets if we arrange it like this or this?";

→ "How should we vary the facade treatment between the different orientations?";

→ "How would the annual space heating load vary if we used a smaller footprint with more storeys?";

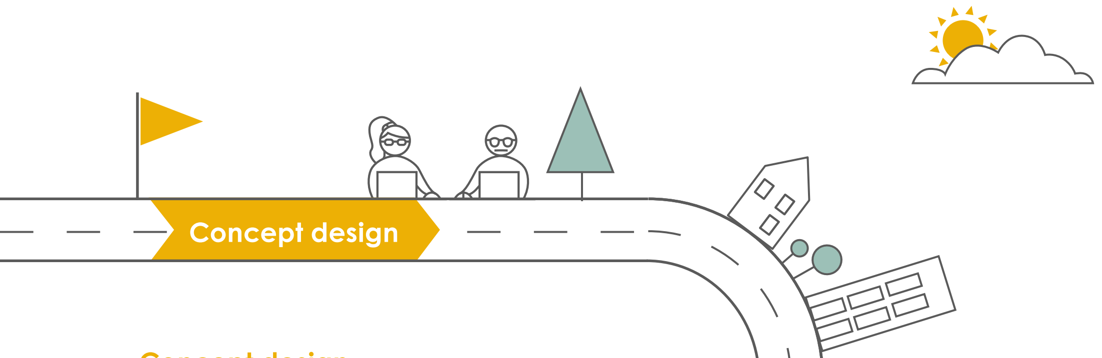
→ "How should we treat the SW corner zones to mitigate against higher overheating risk/cooling loads?".

The aim being to identify what combinations would allow a step change in systems design – be it allowing full natural ventilation, enhanced natural ventilation, low capacity systems like activated thermal mass, etc., compared with a 'business as usual' approach.

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Beyond the EUI analysis, Parametric modelling*

Modelling Timeline

This shows suggested modelling priorities at each design stage.

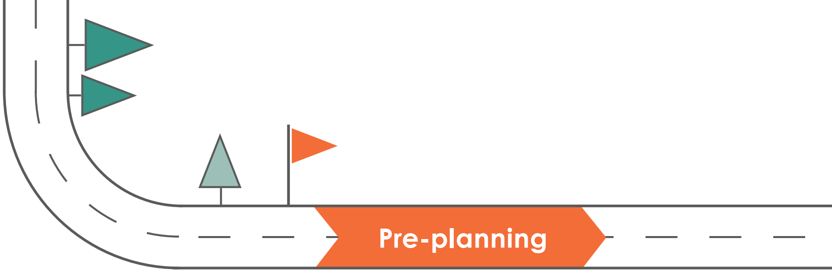


Concept design

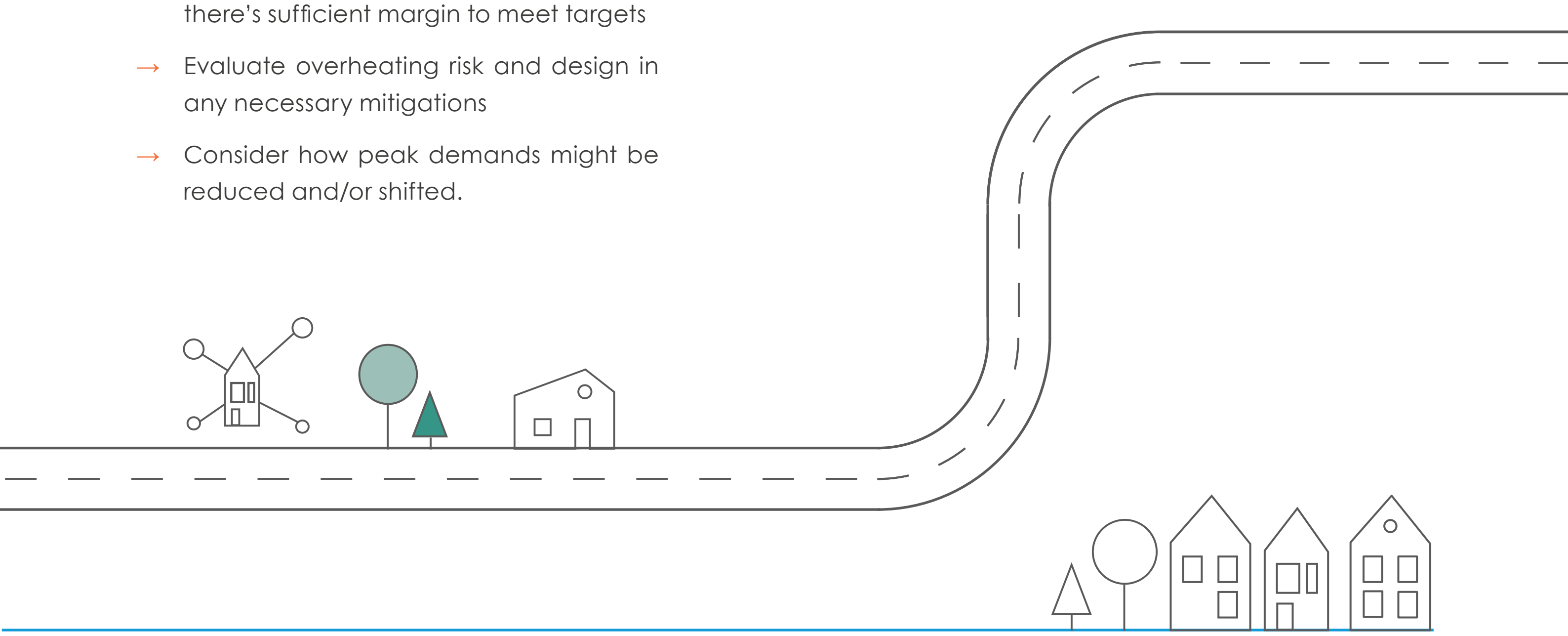
- → Optimise:
  - → Orientation for capturing useful solar gains whilst limiting overheating risk and optimising PV generation
  - → Fabric for thermal performance, proportions of glazing, shading approach, natural ventilation openings
  - → Form factor to reduce thermal bridging and fabric heat losses
- → Identify type and space requirements for low carbon heating/cooling systems
- → Identify and flag significant thermal bridges, can they be improved?
- → Influence final project brief i.e. Can adaptive comfort standards be applied? Can the project meet even tougher targets? Can passive cooling allow dedicated mechanical cooling systems to be omitted?

Pre-planning

- → Define glazing for each facade and ability to naturally ventilate (resolving tension between ventilation, overheating risk/limiting cooling loads, daylight access and acoustics)
- → Evaluate the possible range of internal gain profiles (occupants, lighting and equipment)
- → Ask about any additional equipment that might be installed within the building
- → Evaluate ventilation supply rates and method for each space and day type and how these will be controlled for occupancy
- → Estimate the impact of thermal bridging on heat losses

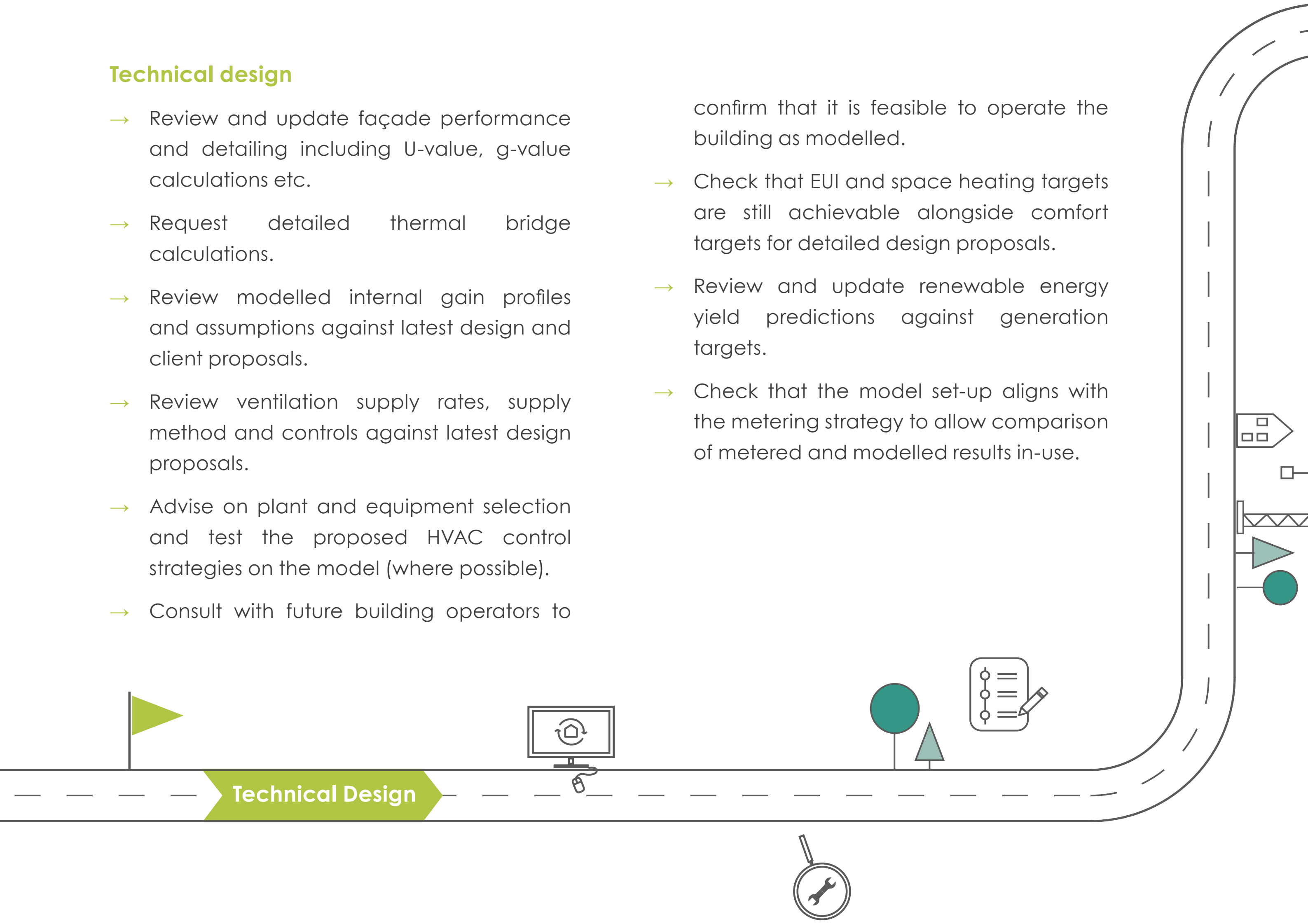


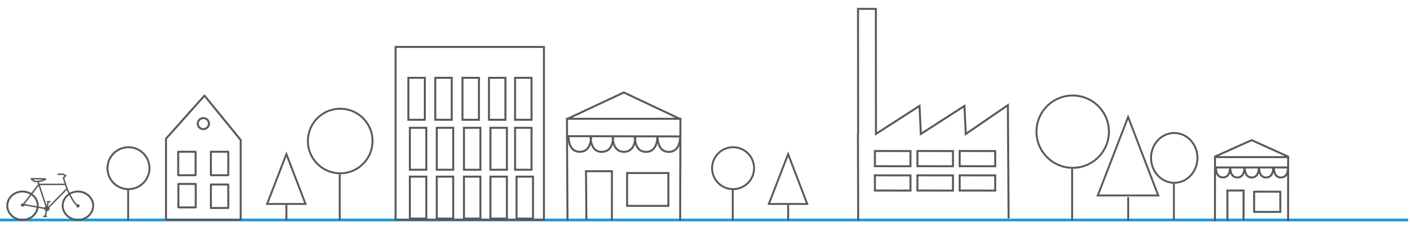
- Optimise HVAC systems selection to meet building demands using lowest energy
- Check plant space allowance and location
- Identify any unconditioned spaces and locate outside thermal line
- Identify any additional loads to be included e.g. catering, lifts, external lighting, process loads
- Provide initial EUI and space heating demand results and discuss whether there's sufficient margin to meet targets
- Evaluate overheating risk and design in any necessary mitigations
- Consider how peak demands might be reduced and/or shifted.
- Assess yield from any on-site renewable energy generation. Consider measures to align demand with generation as these may affect floor plans, e.g. DHW storage.
- Identify the 'big hitters' for energy consumption and plan how to manage them going forward.



Technical design

- → Review and update façade performance and detailing including U-value, g-value calculations etc.
- → Request detailed thermal bridge calculations.
- → Review modelled internal gain profiles and assumptions against latest design and client proposals.
- → Review ventilation supply rates, supply method and controls against latest design proposals.
- → Advise on plant and equipment selection and test the proposed HVAC control strategies on the model (where possible).
- → Consult with future building operators to confirm that it is feasible to operate the building as modelled.
- → Check that EUI and space heating targets are still achievable alongside comfort targets for detailed design proposals.
- → Review and update renewable energy yield predictions against generation targets.
- → Check that the model set-up aligns with the metering strategy to allow comparison of metered and modelled results in-use.





Construction

→ Go to (or get updates from) site and assess implications of any value engineering proposals or item changes made on site for meeting the targets in the model.

SIGNPOST *Scottish Governments new 'Net Zero Public Sector Buildings Standard' Dynamic Simulation Modelling Guide Appendix 1* - *Workflow which sets out a detailed plan suggesting what to do when.*

Handover

→ Prepare estimates for energy use aligned to the sub-metering strategy so they can be tracked in use.

→ Flag other useful parameters for monitoring e.g. heat pump flow temperature and night/weekend base loads.

→ Communicate renewable generation targets and how this will be monitored.

In-use

→ Calibrate the model to reflect actual operation e.g. more occupants, longer hours, actual equipment loads.

→ Try to obtain 'live' local weather data or look at normalising for the actual weather using degree days or similar.

→ Compare measured energy use against model results and explore where there are divergences, what might be causing them and how they might be fixed.

Modelling for refurbishment

Energy performance modelling for refurbishment projects is much the same as for new builds.

The key differences are:

1. Net zero targets can be more challenging to achieve in existing buildings depending on the age, building type, condition and any listed or other heritage status - the LETI Climate Emergency Retrofit Guide provides some retrofit targets that account for the constraints on particular buildings.
2. The useful opportunity to calibrate the model against measured performance and occupancy pre-retrofit

Unless a previous design model or design information still exists and is available, it can be challenging to get good data about the detailed construction of existing buildings. Surveys can drill exploratory holes and make good estimates for construction build-ups; assumptions can be made based on the common practice or building regulations requirements at the time of construction, but the older the building the more likely it is to have been upgraded, altered or repaired over the years, which could have impacted on the thermal performance and air tightness levels. Air tightness testing, thermal imaging and co-heating tests can also be valuable tools for understanding elements of the existing building performance and informing the model.

Measured energy performance data for the building (meter readings) can be valuable for helping to calibrate the 'before' model. The calibrated model can then be used to explore the impact of passive improvements before any significant retrofit intervention (e.g. better controls and operation), as well as helping target retrofit works for the largest impact on energy consumption.

SIGNPOST *LETI Climate Emergency Retrofit Guide*

Using models to optimise buildings during operation

A good quality energy performance model can continue to offer value through construction and into occupancy. It can communicate the design intent in a very specific way and allow deviations in performance between this 'as designed' model and the measured building performance to be explored and diagnosed.

The performance gap has varied contributory factors, but closing it is vital if EUI targets are to be delivered on in practice. The energy performance model, the risk management exercise developed from the implementation matrix and the modelling report can all be valuable tools for spotting where there is divergence between design intent and actual performance, diagnosing what might be causing this variance and what remedial actions should be taken.

This process of regularly running a model against recent weather data with updates to actual operational patterns is sometimes known as continuous **data driven commissioning**, or **digital twins** and can be a powerful tool to assist fine-tuning and performance optimisation.

SIGNPOST *Chapter 1 - 1.1 Net Zero Targets, Minimising the performance gap*

Normalising for weather

In order to allow for a fair comparison between modelled and measured data it can be necessary to allow for variations in the weather between that used in the model and what occurred in reality.

Try to obtain local weather data that covers the monitored period; if that is not possible, try to run the model with a weather file showing reasonably similar weather patterns to those in the monitoring period - at least in terms of heating and cooling degree days. If that is not possible, carry out a degree day analysis to review modelled and actual heating (or cooling) energy use against the modelled and actual heating (or cooling) degree days[2.20].

SIGNPOST *CIBSE TM54 includes advice at the in-use stage too (see section 8 from page 57)*

SIGNPOST *CIBSE TM63 Operational performance: Building performance modelling (2020) provides further advice on comparing operational performance with model outputs also has guidance on weather calibration*

SIGNPOST *CIBSE TM41 (2006) has advice on utilising degree days*

3

Modelling advice

3.0 Modelling advice

This section provides detailed advice on the practicalities of delivering high quality energy performance modelling and is aimed largely at modellers.

Modelling operational energy performance to the level needed to support net zero targets requires modellers to be detailed and thorough in their approach, whilst being completely open and transparent with the rest of the project team.

This chapter is divided into two sections:

3.1 Best practice modelling fundamentals addresses the detailed parts of the modeller's role with guidance on how to have a thorough modelling approach, as well as being clear and rigorous in reporting.

3.2 Modelling specifics highlights some key aspects of modelling operational energy to support net zero targets, taking a deeper dive into **specifics** that might be encountered on projects.

3.1 Best practice modelling fundamentals

When undertaking energy performance modelling it is crucial not to over 'idealise' the scheme. Even though it is understood that there are multiple reasons behind the performance gap - many of which can and should be eliminated, but some are related to over-optimistic predictions that don't account for building operation in reality. If net zero design promises are to be delivered, then we need to ensure our modelling is focused on reflecting actual operation (slightly messier than in our sparkly model environment).

To increase the value of the exercise, modellers need to be rigorous and transparent in their approach. Many of the concepts needed to help plan the modelling journey for a project are presented in the timeline section.

SIGNPOST *Chapter 2 - 2.5 The modelling timeline*

To support their work modellers will need to consider:

Quality assurance

→ Query input data received that appears anomalous or is significantly wide of the recommendations in the LETI Climate Emergency Design Guide

→ Create a logical and well labelled model which could be understood by other modellers

→ Manage version control for the model files, keeping records of each iteration

→ Take responsibility for the quality of modelling work: interrogating results for potential errors, using best practice QA procedures and asking for additional review when needed

→ Give advice on the optimum points at which to update the model taking account of pertinent design changes while keeping the modelling efficient and cost effective.

Clear and honest reporting

→ Write a well presented and detailed modelling report which documents all the modelling inputs and sources, the process followed and the results obtained with helpful commentary on areas of risk or uncertainty and any recommendations (use LETI reporting template as starting point)

→ Include the TM54 implementation matrix in the modelling report and keep it updated

→ Regularly communicate the modelling progress with the project team and answer their questions.

Beyond the EUI analysis

→ Champion (and assess) occupant comfort making sure that a suitable level of modelling provision has been allocated

→ Parametric modelling studies, where appropriate, to help inform the early design stage decisions

→ Evaluate loads not estimated by the model e.g. catering, lifts, external lighting

→ Use energy benchmarks in an informed way to provide a comparison for the building and also to fill data gaps at earlier stages in design

SIGNPOST *Appendix 3 - LETI Operational energy performance template*

Quality assurance and data management

To err is human, and it is wrong to assume that any model is robust without sense checking results and performing good quality assurance.

Key quality control recommendations include:

1. Create a model tracker or change log document so it's easy to see what updates have been made to the model between each new version or export of results
2. Keep a record of the building measurements and/or design drawing versions that you can easily cross reference with the model
3. Review the model results with another competent person to check for 'silly answers' or anomalous behaviour
4. Check input data and the results against benchmarks from similar projects or industry data. If this can't be found, reach out to other consultants or modellers to see if they have results or data for a similar building, our industry should be supporting each other in this way
5. Check that input data is consistent across the models created for different purposes e.g. overheating risk assessment and daylight models
6. Create annotated sets of 2D or 3D plans or model images highlighting key elements such as wall types, windows, or thermal bridges.
7. Have a quality assurance checklist of common errors to look out for - see opposite.

Quality assurance checklist

- ◻ North angle is set correctly
- ◻ Significant adjacent buildings and other objects are included for their shading effects
- ◻ Check the energy base load at times where the building should be unoccupied. Is this high or low and how could this be validated?
- ◻ Conflicting set points that could cause simultaneous heating and cooling
- ◻ Unmet hours - are comfort targets being met consistently within the model in all occupied rooms?
- ◻ Occupancy - what has been assumed for the number of occupants and occupancy profile through a day? Is this based on standard values for compliance calculations or real-world values?
- ◻ Check that the total number of occupants within all zones doesn't exceed total design occupancy for the building (easy to do, especially in schools, as design occupancy for each room will rarely be met consistently as people move about through the day)
- ◻ Internal equipment and lighting heat gains - are model parameters clear and appropriate?
- ◻ U-value calculations - are repeating thermal bridging elements accurately accounted for including double or triple studs, for example in timber and steel framed walls?
- ◻ Thermal bridging - has a reasonable and justifiable allowance been made?
- ◻ Windows and doors - are the dimensions and thermal properties of glazing and frames correctly entered with consistent performance values used between heat loss, overheating, and daylighting models?
- ◻ Are natural ventilation openings accurately accounted for including the impact of deep reveals, shading mechanisms (including blinds), restrictors or limits on opening reach, and appropriate discharge coefficients applied?
- ◻ Ventilation - are ventilation rates a realistic reflection of the MEP design and controls? Sense check that the building is not excessively ventilated, which leads to excessive heat loss, or under-ventilated which could cause moisture problems or increase summer overheating risk.
- ◻ Space heating and DHW distribution and storage losses - is the model of the distribution system realistic, and aligned with the proposed design? Distribution energy losses can exceed space heating and/or DHW energy demand in net zero compliant buildings, and contribute significantly to overheating risk.
- ◻ Heat pump COP - has accurate performance data been used for heat pumps? Ideally use manufacturer's test data for specified products and check that flow temperature is accounted for. Many rule of thumb SCOP values for heat pumps are inaccurate. Modelling should be of sufficient quality to quantify the value of low flow temperatures.

Clear and honest reporting

Provide a clear record of the model that includes all input parameters within the model. Include a record of sources of data. Detail the modelling methodology followed, and the results obtained. This might feel like a tiresome chore, but there are multiple advantages:

→ Provides a clear record of the model that can be checked against the design as it evolves enabling changes to be identified.

→ Helps the modeller keep track of what has been done and why. One may return to the project several times with lengthy intervals between, and a good report will make it easier to pick up again where you left off

→ Transparency encourages trust and confidence with the client and project team.

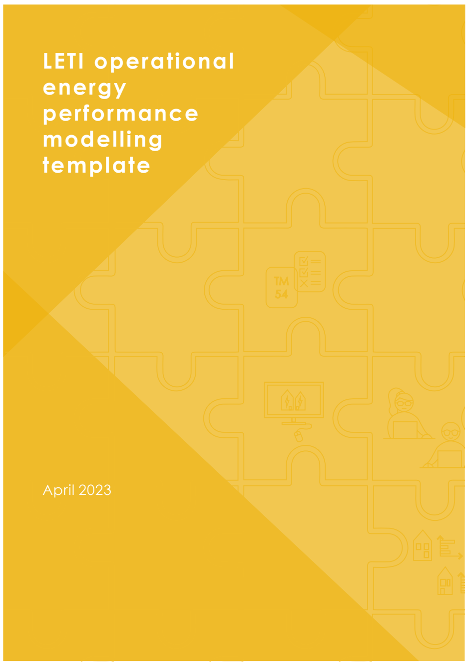
→ Makes it possible for the project team to help pick up any errors, changes or misinterpretations of the design.

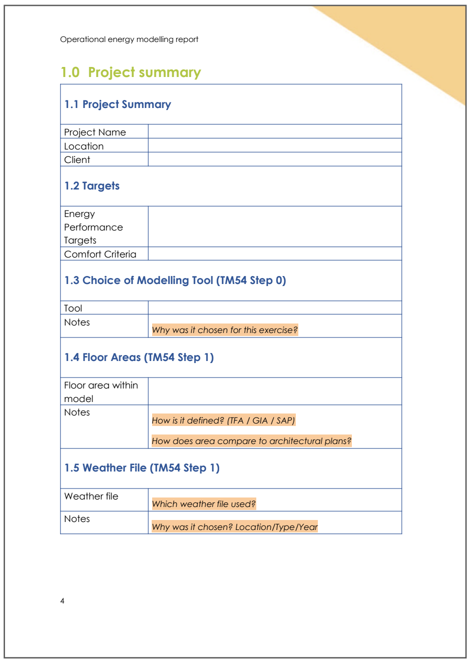
→ Makes it easier to handover models if/when required.

Ideally it should be possible to replicate a model based solely on the modelling report (and the design drawings).

Modellers should be prepared to present the contents of the report to the rest of the project team to help them engage with it and understand the findings - expect questions. It's important that the report is clear on the short, medium and long term actions for the rest of the project team.

SIGNPOST *Appendix 3 - LETI Operational energy performance template*





Operational energy modelling report

1.0 Project summary

1.1 Project Summary	
Project Name	
Location	
Client	
1.2 Targets	
Energy Performance Targets	
Comfort Criteria	
1.3 Choice of Modelling Tool (TM54 Step 0)	
Tool	
Notes	*Why was it chosen for this exercise?*
1.4 Floor Areas (TM54 Step 1)	
Floor area within model	
Notes	*How is it defined? (TFA / GIA / SAP)* *How does area compare to architectural plans?*
1.5 Weather File (TM54 Step 1)	
Weather file	*Which weather file used?*
Notes	*Why was it chosen? Location/Type/Year*

4

Figure 3.0 - Modelling Report Template

Reporting against EUI target

A key aspect of the reporting is against the target(s) specified - see section 12 in the LETI Operational energy performance modelling report template.

Modelling results should be presented as a range including the low, mid-range and high case result sets. A strict net zero operational target demands that modelling results are conservative to minimise any performance gap. The mid-range scenario result should fall below the EUI target or the alarm should be raised.

When presenting results remember to add in energy uses that are not calculated within the model such as for appliances, cooking, lifts and external lighting - see Additional energy uses.

Also report on estimated renewable generation, but the EUI itself should exclude contributions from renewable energy.

Remember to divide the total energy consumption by the GIA rather than the total modelled area to calculate the kWh/m² as these can vary significantly. See section Floor area.

Performance against the targeted EUI should be demonstrated using the 'mid-range' energy use TM54 scenario. It is possible that the 'high' scenario will exceed the EUI target by a significant margin. This is an opportunity to draw attention to what is included in the high scenario and the significant risk factors that could result in the target being missed.

Include a breakdown of the EUI into the different energy uses. Ideally this should also refer to the sub-metering strategy enabling straightforward comparison between the model results and the meter readings once the building is in use.

At the early design stage the EUI derived from the energy model can work as a useful 'energy budget' to focus minds and quantify different elements of the building. Providing the design or construction team with a breakdown of the energy demands associated with particular building components is a good way of articulating both their individual impact and their contribution to meeting the project targets. It also allows the allocation of responsibility to particular members of the team for delivering the overall EUI.

As an example, in homes it is useful to draw attention to the impact of particular thermal bridges as a proportion of the overall space heating demand. This can help identify particularly poorly performing junctions and prevent value engineering that impacts energy performance at a later stage.

SIGNPOST *Appendix 3 - LETI Operational energy performance template*

SIGNPOST *Chapter 3 - 3.2.1 Floor area*

SIGNPOST *Chapter 3 - 3.2.3 Estimating additional energy uses*

Reporting risk and confidence levels

At each key stage complete the TM54 implementation matrix including a discussion on probable range (variance) and confidence levels for input data against each of the steps. This is an opportunity for modellers to be transparent about the information the model is based on, and whether it is detailed and bespoke to the project, or educated estimates. Where detailed information is available there may still be a range on the potential in-use outcome e.g. a classroom designed for 30 occupants might end up used by more or fewer depending on whether the school is under or over-subscribed, and the average through the day may be lower as a classroom might be empty for a period or two during the day when those students have PE, lunch or are taught in the library.

The confidence levels within the implementation matrix should improve as the project progresses, with most steps reaching high by detailed design. Those areas that still have significant uncertainty either in the design info or in what will occur in practice should be used to define the sensitivity scenarios tested and their range applied across the low, mid-range and high scenarios. They should also be included in the project risk management plan with thought and attention paid to how these risks might be minimised.

TM54 steps	Recommendation	Modelling approach (summary)	Probable range	Confidence level (L/M/H)	QA check
Step 2: Estimating operating hours and occupancy factors	Request anticipated operational profiles from the client, for example through structured interview.	*PHPP defaults used. Actual values unknowable until post-occupancy.*	±50%	*L*	*Recommend further discussions with clients, and if defaults continue to be used, this should be included in sensitivity tests, and in scenario testing if sensitivity is high.*

Figure 3.1 - Excerpt from TM54 Table 13 to show how confidence levels should be considered in the implementation matrix.

SIGNPOST CIBSE TM54, Table 13 Implementation matrix

Beyond the EUI analysis

A modeller should always be thinking about how the building designs they are modelling may be used and might perform in real life. The energy performance models created can help the design team understand more than the energy consumption and space heating demand as they simulate many aspects of internal environmental conditions. This wider functionality should be used to inform design decisions that will impact on occupant comfort and help the project team make better choices.

Early concept stage modelling

Use the skills and experience gained from being a modeller to help inform early design decisions such as orientation, form factor, glazing ratios and layouts. Simple models that might only take a small portion of a building, one floor or a single room can be used to compare a range of design options against each other to see the resulting effects on the energy consumption.

Modellers should be able to simplify and optimise these studies to offer a cost-effective way to explore the design questions raised by the project team. It is not usually appropriate to model a whole building in any detail at the very early design stage, as the design will still be in significant flux.

Models should be appropriate to the design stage and able to respond to the specific questions being raised by the project team.

Modelling overheating risk

CIBSE TM52 and TM59 provide protocols for assessing overheating risk for non-domestic and domestic projects respectively using dynamic simulation modelling. Building Regulations now require a Part O overheating assessment (with the option of using TM59) on all new build homes.

Overheating is more common in warmer parts of the country (e.g the south east) and in rooms with higher areas of solar exposed glazing or limited natural ventilation. See the list of references at the end of this section for guidance on where overheating risk comes from and suitable mitigations. Models should include perimeter zones for each facade in larger rooms to pick up solar gains accurately, and help explore design measures to reduce them passively where possible. This helps to improve occupant comfort and to reduce any mechanical cooling loads.

Modelled overheating risk assessments require a CIBSE 2020 DSY1 50th percentile high emissions (Design Summer Year) weather file, as opposed to the Test Reference Year (TRY) weather files recommended for energy performance modelling. Assessments also take account of the vulnerability of occupants (e.g. for hospitals and care homes) by switching from category II occupants (default) to category I (more vulnerable), with more onerous criteria.

Most dynamic modelling tools have now introduced the ability to include the cooling effects of ceiling fans on operative temperatures based on the air speeds generated. This effect is approximated by bringing the operative temperature results closer to the air temperature results. The impact on overheating risk results can be relatively modest compared to the experienced comfort benefits of installed ceiling fans.

In the UK, buildings are rarely mechanically humidified due to the energy required and low perceived benefit achieved. However, high air movement coupled with very low humidity in winter can negatively impact occupant comfort due to increased evaporation from the skin. This can result in complaints leading to increasing heating setpoints and higher energy consumption. The design of air systems needs to consider how air is delivered with low velocities to achieve optimum comfort in the occupant zone.

PHPP also includes an overheating calculation. Although this is simpler and less precise than a dynamic assessment, it can be used to identify whether a building is particularly prone to high internal temperatures. PHPP does not break the building into zones, so if individual rooms are at higher risk of overheating this may be missed.

The Passivhaus Trust published good practice guidance for buildings for overheating, this includes several question the modeller should ask when deciding whether a more detailed dynamic modelling assessment is required:

→ Is there an area which has a higher glazing proportion than the overall façade?

→ Is there an area where window opening is restricted compared to the rest of the building? E.g. for noise or security reasons.

→ Is there an area which is not subject to the same shading objects as the majority of the façade?

→ Is there an area in which only single aspect ventilation is possible?

→ Is there an area which is adjacent to a particular internal heat source? E.g. plant room.

→ Are any bedrooms at risk of overheating? – typically people are less tolerant of higher temperatures when sleeping. Specific risk factors could include west facing rooms with no cross ventilation.

→ Is there an area which will have higher internal gains for short periods? E.g. Bunsen burners in a school classroom.

It is good practice to 'stress test' an overheating model, in essence making sure that sensitivity analysis and scenario testing are included within the overheating assessment. It is important to understand what are the key factors in the overheating strategy and what would happen if they changed. Testing future weather scenarios is one of these, but also think about occupancy changes (more people in the building), windows not being opened due to external noise or a problem with the ventilation system. Discuss what these stress tests might be with the rest of the project team and how these risks might be managed.

SIGNPOST *CIBSE TM52 The Limits of Thermal Comfort for non-domestic projects*

SIGNPOST *CIBSE TM59 Design Methodology for the assessment of overheating for home*

SIGNPOST *CIBSE AM11 Building Performance Modelling* [3.1]

SIGNPOST *CIBSE provides weather files for the assessment of overheating for current and future weather scenarios' as well as TM49 Design summer years for London*[3.2]

SIGNPOST *The Good Homes Alliance have useful early stage tools for identifying the key risk factors for overheating, suitable mitigation measurements and when a detailed modelling assessment might be needed.*[3.3]

SIGNPOST *The Passivhaus Trust have produced an 'Avoiding summer overheating' guide and plug-in for PHPP both downloadable for free.*[3.4]

Checking unmet hours

Dynamic simulation modelling tools provide the facility to check the unmet hours for a building model. These are the annual hours in each zone where the specified HVAC capacity was unable to deliver the selected setpoints. This can happen if central plant or room emitters are undersized, or if morning start up controls are not set to come on early enough. A few hours unmet is unlikely to be a major issue but significant unmet hours should be investigated. Zero unmet hours could indicate oversized plant or problems with the model and should also be investigated.

The unmet hours assessment should not be run using auto-sizing (where the model automatically sizes the plant to meet the peak room demands), and only once the size of centralised building services and room emitters have been calculated and entered into the model.

The unmet hours should be assessed for the assumed occupied hours as opposed to the plant operational hours.

This assessment is distinct from evaluating occupant comfort as it is undertaken using air temperature, the same metric as the thermostats controlling the model (and the actual building in-use). Thermal comfort is assessed using resultant or operative temperatures which include radiant effects and are closer to the temperatures that would be perceived by occupants, and can deviate from air temperature by several degrees. Refer to section Centralised HVAC systems and controls for more information on controls, and section Comfort assessments and Modelling overheating risk for more information on assessing comfort.

In addition to thermal comfort it is worth using the model to check CO_2 levels calculated for occupied zones to test that sufficient ventilation (natural or mechanical) provision is being made throughout the year. Under-modelling of ventilation rates can lead to significant under-prediction of space heating loads and AHU energy consumption.

The assessment should be undertaken and reviewed with the client and M&E designers to check acceptable tolerances and plant sizing.

SIGNPOST *Chapter 2 - 2.2 Tools, HVAC modelling*

SIGNPOST *Chapter 2 - 2.4 Outputs, Comfort assessments*

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Beyond the EUI analysis, Modelling overheating risk*

SIGNPOST *Chapter 3 - 3.2.2 Centralised HVAC*

Parametric modelling

Parametric modelling is a process where building attributes can be created or modified based on a series of inputs (known in this context as parameters). This technique can be used to run multiple model scenarios using optimisation algorithms, with the aim to arrive at or identify an optimised solution. This technique has gained prominence with increased computing speeds along with greater access to the underlying functions and parameters within software. The key to effective parametric optimisation is defining the problem you are trying to solve and then selecting an effective set of variables to allow 'the best' solution to be found.

Parametric modelling can be useful in early concept stage modelling, when less of a building's design has been decided upon and many of its attributes are still being discussed amongst the project team. Parametric modelling can be used in this instance to navigate the design in the optimum direction from a conflicting and/or complementary set of factors.

Parametric analysis techniques can also help automate the early stage sensitivity analysis, allowing more inputs to be varied and assessed to explore their individual and combined impact on the modelled energy performance.

Whilst a potentially powerful tool, parametric analysis can run hundreds of models with thousands (if not more) inputs and assumptions. Care should be taken to check that automated studies are carefully controlled and the background data understood to prevent misleading or incorrect conclusions being drawn.

Software tools are constantly evolving and providing improved functionality and automation. Modellers should stay abreast of the features offered by their software tools and how these might add value to projects.

Using benchmarks

Benchmark data can be valuable for filling gaps in input data that won't be available until more detailed design stages, or for presenting modelling outputs against for comparison.

Benchmark data should however be used with caution as it may reflect a wide range of building ages, styles and operation across the category. Where available 'best practice' benchmarks are generally more pertinent to net zero targets. Benchmark data is not always available in any detail for all building types and is inherently backward looking and therefore tends to be outdated and less reflective of recent trends e.g. towards LED lighting or heat pump usage.

Specifically benchmarks can be useful for:

→ Giving context to targets and modelling results

→ Filling gaps in input data at earlier design stages e.g. catering loads, lift loads, DHW demands etc.

→ Providing sanity checks for the modelling results both for the total EUI range and for the breakdown of separate uses.

Wherever benchmark data is used this should be clearly communicated including the source, and justification given for why the data used is suitable and the best available for the context in which it is applied.

SIGNPOST *CIBSE TM54 has some useful advice on the use of benchmarks in section 6.2 on page 13.*

3.2 Modelling specifics

The following sections give specific advice for approaching different aspects of energy performance modelling. Some advice may be more or less relevant depending on the type of building being modelled and the software tool being used.

This section is arranged in four sections:

→ 3.21 Modelling inputs

→ 3.22 Building services

→ 3.23 Additional energy uses

→ 3.24 Renewables

Modelling specifics considered within each section are presented on the following page.

The best approach for building a particular model will depend on the specifics of the project being modelled, and the tools being used. If in doubt refer to relevant software manuals or the guidance referenced at the end of this document.

Summary of modelling specifics

3.2.1 Model inputs

- Geometry
- Weather data
- Floor area metrics
- Zoning
- Thermal elements (walls, floors, roofs etc.)
- Thermal bridging
- Air tightness/infiltration
- Glazing
- Internal blinds
- Occupants
- Plug loads (equipment gains/ unregulated loads)
- Building management

3.2.2 Building services

- Ventilation
- Space heating
- Domestic hot water
- Lighting
- Comfort cooling
- Centralised HVAC systems and controls

3.2.3 Estimating additional energy uses

- Estimating additional energy uses

3.2.4 Including renewables

- Including renewables

3.2.1 Model inputs

Geometry

Best practice for constructing model geometry depends on the software being used and is outside the scope of this document.

QA on geometry should include the following list of prompts:

→ Use the latest drawings

→ Double-check the North angle against the site using google maps satellite view as this can be shown incorrectly on drawings

→ Model all windows accurately. Focus on correctly representing glazing areas, frame factors and natural ventilation openings

→ Check floor to ceiling heights and apply any double height spaces

→ Include a vertical air path in stairwells and risers

→ Approximate sloping roofs and external shading features as closely as possible

→ Include (in outline) any significant surrounding buildings that might impact on shading

→ Check any surfaces adjacent to heated or unheated spaces (rather than external) have been accurately entered in the model

→ Keep a record of evidence used for modelling, e.g. drawing numbers and revisions, window schedules

In some cases it is possible to accurately import model geometry from architectural files e.g. SketchUp or Revit. This is an area where software is constantly improving but many tools still struggle to bring in geometry reliably so check carefully. When it works, this route can be a helpful time saver.

Weather data

Choose suitable weather data for the site location to reflect the current and future climate scenarios.

Because EUI's look at energy use for a full year it is recommended that TRY (Test Reference Year) weather files are used for dynamic models rather than Design Summer Year (DSY) files which are specifically developed for overheating risk assessments.

SIGNPOST *CIBSE TM54 gives advice on selecting weather data - see section 7.2.3.*

Floor area

Understand the difference between gross internal floor area (GIA), net internal floor area (NIA) and treated floor area TFA (for PHPP) as metrics use different ones. LETI's EUI targets are referenced against GIA whereas RIBA and UKGBC provide metrics for NIA too. When using PHPP convert the metrics into GIA for comparison. It is helpful to include these metrics in modelling reports.

GIA is essentially the whole enclosed floor area within the external walls, taking all floors into account. Many models give the total modelled area as the sum of each zone area, which is smaller than the GIA. The model measures zone area from the internal surface of each wall. It is important to use the right area as the total energy use will be divided by it to establish the EUI. RICS publishes guidance on measuring standard floor area metrics[3.5].

SIGNPOST *RICS Code of measuring practice*

Zoning

Models should reflect the internal layouts proposed, and be zoned accordingly. Additional zones may be needed to subdivide very large rooms or double/triple height spaces. Perimeter zones (4-6m) should be applied in large open plan spaces to pick up the higher solar gains, daylight availability and heat losses in perimeter areas and corners.

It may be possible to combine some smaller and repetitive rooms (such as cellular offices) where they are all on the same facade, have the same construction, the same usage patterns applied, and the same HVAC servicing strategy.

In larger models it is helpful to create groups of zones according to hours of use, HVAC strategy and sub-metering strategy, so that servicing can be applied to them consistently, and results can be grouped for easier comparison with sub-meter readings.

The zoning of energy models is not relevant to all modelling approaches (e.g. PHPP by default does not zone the building), but it is necessary where different parts of the building are used or serviced in different ways.

Thermal Element (walls, floors, roofs etc.)

All building elements should be reflected as accurately as possible in energy models, following the relevant standards, such as BS EN ISO 6946, 10211-1, 13370, and 10077, BR 443, 465, and 497 (BRE publications), and BS EN 673.

Calculations and models should take the following into account for proposed construction materials:

→ dimensions,

→ orientation,

→ thermal mass,

→ thermal conductivity,

→ surface resistivity,

→ repeating thermal bridges (including from mechanical fastenings),

→ solar and light transmittance properties for transparent materials

SIGNPOST *Chapter 3 - 3.2 Modelling specifics, 3.2.1 Glazing*

Detailed U-value calculations should be performed for representative sections of build-up, which include effects from multiple timber or steel elements around windows, doors and load paths. Note that U-values for rooflights should be adjusted depending on their tilt angle.

Approaches to calculating heat losses through elements adjacent to the ground vary depending on the software used. This means U-values for ground elements usually differ between Part L (which include perimeter/area effects) and PHPP calculations. Insulation manufacturers often provide U-value calculations that follow the Part L methodology.

Curtain walling

Note that it is not usually possible to meet very high thermal performance targets using large areas of curtain walling. Even with triple glazing, a well designed curtain wall with approximately 50% transparent/opaque ratio can achieve approx 0.65W/m²K compared to LETI's recommended combined opaque & glazed external wall U-value target of 0.34-0.57W/m²K (for commercial offices).

Thermal bridging

Thermal bridges not only increase heat loss, these localised cool spots are often linked to mould growth and poor quality construction standards. Thermal bridges may or may not have a significant impact on the building's overall energy consumption but the project team are responsible for identifying all of them and evaluating the risk to the project energy performance targets. It's important to clearly identify each and every thermal bridge, sometimes they can be accounted for in other thermal elements such as U-values or ignored.

Repeated thermal bridging in timber and steel framed walls can contribute significantly to the overall heat flow. For lightweight steel framing, this may include sections where insulation is omitted entirely, for example between two or more frames that are fastened to one another.

Interfaces between any curtain wall elements and opaque fabric (concrete, etc.) are of especial interest for thermal bridging and should be accounted for adequately from the project's onset (prior to planning) to avoid overestimating the fabric performance (or to avoid underestimating it, resulting in oversized conditioning system).

Accounting for thermal bridging

A critical aspect to correctly estimating heat loss is including thermal bridges. The level of detail to which thermal bridging is accounted for in the various modelling softwares varies considerably:

→ SAP has a building y-value calculation tool which prompts the user to include non-repeating thermal bridges from a non-exhaustive list of potential bridges. This tool still misses some bridge types such as 3D point bridges arising from structural penetrations.

→ PHPP includes the facility to input the detail for each and every thermal bridge in a building giving a clear quantification of its impact. Because of this clarity and the importance of thermal bridging to meet Passivhaus targets, the y-value is of less use in PHPP. Instead users should look at the impact on the space heating demand and the EUI. For domestic buildings a target of around 1-3kWh/m^2/yr for single homes or 4-7kWh/m^2/yr in multi-residential buildings would be appropriate.

→ Most dynamic simulation modelling software follows the convention of not explicitly modelling building linear thermal bridges but rather applying a catch all factor to the U-values to account for non-repeating thermal bridging. Although there is often an option to be more specific. The 2021 NCM modelling guide assumes the thermal bridging factor is 25% of the U-value in non-domestic buildings. This adjustment to U-values takes place in the code and is generally not reported in a transparent way. The building y-value can be assessed via thermal bridging calculations carried out following BS EN ISO 10211 and measurement of all bridges before being converted to a fraction of the U-value and used to adjust the software inherent assumption.

There are three main categories to consider when accounting for thermal bridges:

1. **Clear field transmittance** is the heat flow from the wall, floor or roof assembly. This transmittance includes the effects of uniformly distributed thermal bridging components, like brick ties, structural framing like studs, and structural cladding attachments that would not be practical to account for on an individual basis. The clear field transmittance is a heat flow per area, and is represented by a U-value denoted as the clear field (Uo).

2. **Linear transmittance** is the additional heat flow caused by details that are linear. This includes slab edges, window sills, parapets, and transitions between assemblies. The linear transmittance is a heat flow per length, and is represented by psi (Ψ).
3. **Point transmittance** is the heat flow caused by thermal bridges that occur only at single, infrequent locations. This includes building components such as structural beam penetrations and intersections between linear details. The point transmittance is a single additive amount of heat, represented by chi (χ).

Calculating thermal bridges

Calculating thermal bridges is not straightforward. Pre-prepared calculations are available for standard details and these are useful earlier on in a project to understand the rough heat loss for the fabric specification being used. However, as the project progresses any variation from the pre-prepared calculation will need to be tested as even small changes to the connecting elements or how they are constructed can dramatically impact on the heat loss through the junction. Specialist help should always be sought for complex details.

There are specific tools for calculating thermal bridging (HEAT2, HEAT3, BISCO, TRISCO, THERM, etc.)[3.6]. These require detailed knowledge of the construction and expertise in the software to accurately calculate the resulting heat loss. Usually the discipline who designs the junction should be responsible for providing the ψ and χ values to the energy modeller to either input in the model or to provide a U-value that already accounts for these.

Air tightness

The air tightness of a building is represented via the infiltration rate in models which is usually expressed in air changes per hour (ACH).

Air tightness is later tested by pressurising the constructed building to 50Pa using fans (blower door tests) and measuring how quickly the air escapes) measured as m^3 per m^2 -of building envelope- per hr). New pulse tests are now available for some buildings that use shorter pulses at 4Pa to provide a quicker test.

It is important to understand that the air that leaks from a pressurised building is significantly higher than that from an unpressurised building. CIBSE Guide A section 4.6 gives advice on relating air tightness (measured @50Pa pressure) to infiltration rates at atmospheric pressure (with 3m/s external wind speed). This guidance includes a number of tables that give values for different building archetypes (Tables 4.16-4.24). Note that these values represent ‘normally exposed sites in winter’ and are intended to calculate winter heat loss conservatively.

Infiltration can have a significant impact on energy performance as leakier buildings demand higher heating loads.

Air tightness is also often taken as a proxy for build quality which has implications for other aspects of building thermal performance.

Pay attention to:

→ Infiltration introduced by building services penetrations, as these are commonly blocked during air tightness testing

→ The impact of pressurisation from mechanical ventilation systems supplying more air than they extract; in practice this can reduce infiltration (or result in exfiltration) when the ventilation plant is operating

→ Localised impacts, for example adjacent to entrance doors; this can be very significant in frequently used doors.

In most cases infiltration is poorly estimated due to unpredictable impacts of building layout, wind direction and the effects of surrounding building and topology. Spaces on the leeward side of buildings can experience exfiltration rather than infiltration as air is pulled through the building from the windward side. In well designed and constructed airtight buildings this should be less of an issue, as overall infiltration is minimised.

It is not always possible for modellers to take account of all these nuances in air permeability, but they should be aware that the values they use in models are approximations and factor this into the scenarios used.

Where modelling tools allow it (e.g. in EDSL TAS), set the infiltration to modulate with external wind speed which should improve accuracy, also modelling softwares increasingly offer the ability to assign facade-specific external wind exposure.

An alternative method for modelling infiltration more accurately using dynamic modelling tools is to apply it as an opening in all window frames. This is more time-consuming to apply than specifying a fixed value as it requires evaluating the total infiltration rate for the whole building and dividing it across total frame areas. It assumes that windows are evenly distributed across exposed façades, but allows for infiltration and exfiltration to be calculated based on external wind speed and pressure balances, focuses infiltration in the perimeter spaces where it will happen in practice, and has anecdotally been demonstrated to provide a much better correlation with measured performance. Care should be taken if employing this method, as any errors could significantly undermine the potential improvement in accuracy.

Glazing

Glazing is a very influential building component. It allows in natural daylight reducing the need for electric lighting, beneficial solar gains in winter and less beneficial solar gains in summer, which can increase overheating risk or cooling loads. Windows are often additionally utilised as openings for natural ventilation. Used well, glazing has many architectural benefits, but used carelessly it can be an obstacle to achieving net zero. The design aspects of glazing are important to consider early in the design process as glazing areas and positioning are harder to change post-planning.

Models can be incredibly useful for testing different glazing options and optimising the use and specification of glazing for daylighting, solar heat gains, thermal heat loss and ventilation.

The following factors should be considered in the modelling:

1. **Window position**
   the positioning of a window within the facade so that recesses, reveals, overhangs or other factors contributing to shading are correctly accounted for in the model both thermally and for daylight.

2. **Framing area**
   Default frame factors are often around 10% or 50mm in many softwares (which is low for smaller or openable windows) so this should be

reviewed and updated once the architectural details become available. The percentage of frame affects the overall window unit U-value (and therefore heat loss) which means in the same project different sized windows may have different overall U-values.

3. U-values

Make sure that whole window U-values (which include glazing size and framing) are specified and used in the model as opposed to centre-pane values.

4. Glass solar transmission

A key parameter for modelling glazing performance is the solar transmission (centre pane g-value), this is commonly reported next to the light transmittance properties. The g-value is particularly important as this will influence both the energy performance of the building and the thermal comfort (higher solar gains increase overheating risk). The g-value of glazing comprises three components of transmission; direct transmission, reflection and absorption. Depending on the proportions of these components it is possible for two glass types to have the same g-value but differing performances. This is particularly relevant with regards to thermal comfort, where for example, a body tinted glass and a solar control glass have the same g-value but with the body tinted glazing some of the solar control is coming from the higher absorption of the body tint. This higher absorption can result in higher surface temperatures, and more radiant energy raising the operative temperature of the room. Recommendations on solar transmission (g-value) should always be assessed in parallel with light transmission and achieving good levels of natural daylighting. Note that some window manufacturers supply 'whole window g-values' which include the shading from frames - make sure you use centre pane values for modelling.

5. Window openings for natural ventilation

How windows open (top hung, sash, side hung etc.), which panes are openable and how wide, obstacles to air flow e.g. cills or reveals, and any barriers to opening these windows (noise, security, pollution, health and safety) will affect the efficacy of natural ventilation. Insufficient ventilation can increase overheating risk. The modeller should make sure to understand how the software tool models openings and applies discharge coefficients. The 'equivalent areas' and discharge coefficients that should be used to represent each natural ventilation opening areas can be calculated using the discharge coefficient calculator spreadsheet free to download here.

Remember also to factor in any restrictors, deep reveals and limits on opening reach. Thought should also be given to whether window openings could clash with the operation of internal blinds.

6. External shading impacts

Building features (overhangs, articulations and shading features) surrounding landscape, buildings and vegetation can all impact on the solar gain and daylight levels within a building. It is important for modellers to understand this and fully consider the impacts of shading on glazing. Shading from vegetation can be seasonal or temporary, so should only be factored in where there are long term plans to maintain it, and the software has the capability. Note that Part O/ TM59 assessments do not allow shading from vegetation to be included.

To check glass performance many glass manufacturers now have online tools which will give the correct performance of all their glass products. Below are links to some of these calculation tools. All are free to use but may require the user to register for an account.

SIGNPOST Discharge Coefficient Calculation

SIGNPOST *Examples of glazing manufacturers*

Guardian Glass
Saint Gobain
AGC
Pilkington Glass

If these links don't have the information needed, all manufacturers have technical teams who could be contacted for further assistance.

Internal blinds

When modelling any type of internal blinds, consider how they will operate: occupants, often have control, and can override the blind settings in order to promote access to daylight and views. If blinds are used more frequently than anticipated this can increase lighting loads.

Blinds with lighter coloured or reflective backings are most effective at reducing solar gains. The characteristics of any blinds included in models should be well communicated so that they are correctly specified and purchased.

Blinds should be designed so as not to clash with window opening mechanisms. Interstitial blinds (where a venetian blind is located between two of the glass panes) can be a good choice, but care should be taken to model the blind in the correct cavity.

Consult software providers for advice on modelling more complex blind systems or active façades.

Do not include blinds in a model where they are not going to be installed as part of the base build as there is no guarantee they will be fitted in the future.

Overheating assessments for homes following TM59 under Part O of the Building Regulations should not include blinds in the model even if they will be installed, as per the methodology requirements within the Approved Document.

SIGNPOST *CIBSE has recently published technical guidance on modelling blinds in CIBSE TM69 2022* [3.7]

Occupants

People significantly impact the energy performance of the spaces they inhabit through their metabolic heat gains (which depend on their size, ambient temperature, activity and clothing level), and through their behavioural patterns, driven by comfort, activities and preferences (e.g. opening windows, use of lighting and equipment etc.).

The hours during which people will occupy any given space will vary. Primary information obtained directly from the project team and building owner/operator on the expected operational conditions should be sought as early as possible within a project. Where this is not possible, benchmark heat gains can be found in industry guidance, such as CIBSE Guide A and the references below. It should be remembered that, in the case of occupancy gains, these figures represent typical levels and are generally based on an assumed mix of age and gender, so may require further interrogation. All assumptions used should be discussed with the project team in detail, using 'layman's terms' (such as % of people at their desk rather than W/m^2) to agree that the figures represent the best possible representation of likely (mid-range) operational conditions. The potential range, low to high, on both occupancy numbers and occupancy hours should be factored into scenario testing.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios*

The NCM internal conditions database provides standardised occupancy, temperature set-points and heat gain profiles for space types within various building planning use classes. These can make a useful starting point for early stage assessments, but include some anomalies and oddities so should be reviewed in detail and updated to better match the actual project including out-of -hours usage.

The occupancy of adjacent buildings (with party walls) might need to be considered and accounted for. For example if a residential building is adjacent to a commercial space it is likely that heating regimes will differ and therefore more heat will be lost through party walls than when two residential properties are connected.

Workspaces

Workspace occupancies are often easier to predict as they follow consistent working hours, although some workspaces will have greater variation as people move around the building, travel to meetings, work flexible hours or from home at times. Buildings are often open and available to occupants far longer than the standard working day, and maintenance and cleaning teams can work shifts outside of core hours. If buildings are assumed to be densely populated for long hours then they are likely to see lower space heating loads, higher cooling loads (if cooling is used), higher plug loads and probably greater water and DHW use. Where these buildings are more sparsely occupied the opposite is expected.

Homes

Occupancy patterns within homes are notoriously hard to predict as we all live different lifestyles, and it is equally reasonable for a person to be at home 24/7, or to work outside the home for long hours and only be at home to sleep at night. Ensuring that homes are built to be energy efficient regardless of the lifestyle patterns of their inhabitants is essential. The large variation in occupation should be a fundamental consideration of the sensitivity analysis and scenario testing for domestic buildings. For instance, modellers should be aware of what happens if a home has many more people living in it than perhaps considered 'normal' during design and flag this to the project team.

As the space heating demand is reduced in thermally efficient homes, the appliances and hot water use will have an increasing impact on the EUI. Modellers should be thorough in modelling the consumption from these energy uses and, where possible, avoid 'defaults' or benchmarks that often rely on historical data.

CIBSE TM59 includes occupancy and equipment gain profiles intended to represent an upper level of domestic occupancy for the purposes of overheating risk assessments. These profiles might be useful to start from for homes where occupant data is unknown but should be reviewed in detail as they may be a bit high for use in energy performance modelling.

PHPP normally takes standard occupancy assumptions for homes to allow comparison between projects. For non-domestic buildings it includes suggestions for occupancy patterns for different spaces in the typical building typologies, although data can be entered from another source if available. It's worth bearing in mind that for Passivhaus certification particular assumptions for internal heat gains in homes and schools will need to be used instead of bespoke data.

Factor in variance in the occupancy numbers and profiles assumed within scenario testing.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios*

SIGNPOST NCM Call for Evidence - Submission by CIBSE and LETI gives examples of anomalies/points to watch out for in NCM profiles e.g. for schools and offices.

SIGNPOST CIBSE Guide A chapter 6 for advice on internal heat gain assumptions

Equipment gains (plug loads and other unregulated loads)

Initially benchmarks or template profiles such as those listed for occupancy gains above may need to be used as a way of understanding likely small power consumption and heat loads. As the design develops, clients/project teams should be able to provide more specific loads for each space, and advice on possible variance in peak loads and profiles for the scenario analysis.

Be wary of using standardised profiles from SAP or the NCM as these tend to be based on outdated assumptions. It's important to understand the difference between a top down and bottom up assumption. Often SAP or NCM approaches use top down data based on large surveys, these will show the average of hundreds of buildings and may not be relevant to the proposed building. This might be okay for very initial assumptions but should always be heavily caveated and ring fenced for updates as soon as possible. A bottom up calculation (i.e. understanding the likely type and number of pieces of equipment and calculating a rough usage pattern) will help to give more accurate values for the equipment loads and profiles.

For homes, PHPP has a 'bottom-up' calculation that picks out the major appliances and quantifies the likely energy use by providing details from the appliance and how many times it is likely to be used. This is a useful tool to start to build up a more accurate unregulated energy profile for a home and will provide far more accurate figures than generic 'top down' multipliers that rely on floor area or occupancy.

Compare the modelled 'mid-range' plug loads against the LETI Climate Emergency Design Guide recommendations for context as to whether these values are high or low.

Be aware that the rated energy use of any appliance is not necessarily the power they use at all times. the rated power is likely to be the peak, with many devices showing significant diversity from this with much lower 'stand-by' power.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance in the plug-loads assumed within scenario testing)*

Building management

Work with the project team to understand how the building might be managed and whether specific management decisions could significantly impact on the in-use energy performance.

Ask questions about how the building might be used outside of core hours (e.g. during early mornings, evenings and weekends) and how HVAC services will be controlled for these hours. When will cleaning and maintenance be carried out? What is the unoccupied base load predicted to be? How will this be managed i.e. who will turn equipment off at the end of the day?

Factor these considerations into the low, mid-range and high energy use scenarios.

Blanket factors to account for management factors should not be used as TM54 (2022) now requires a more considered approach.

In domestic buildings, the building managers will be the inhabitants. Predicting their behaviour accurately is not possible, but it is possible to test extremes to see how this will impact performance, e.g. what happens if residents turn the heating set point up to 25°C or they turn off the mechanical ventilation systems?

Building services and their controls should be represented as accurately as possible within models. Modellers should use their skill and experience to model systems in a robust way that does not overcomplicate (incurring additional risk of error), but does endeavour to provide a realistic evaluation of energy consumption. Where possible detailed HVAC modelling should be used to accurately represent the systems and their controls.

SIGNPOST *CIBSE TM54 (2022) Step 12: Taking management considerations into account (page 40)*

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance in how the building might be managed within scenario testing)*

3.2.2 Modelling building services

Ventilation

It is important that all forms of ventilation are factored into energy performance models. Good ventilation is vital for indoor air quality, and is often the means of purging summer heat gains and mitigating overheating risk. Ventilation can have a significant impact on energy consumption depending on how it is delivered. Energy models can help explore the relative impact of different options to help optimise this decision.

The model should be constructed to reflect how ventilation air is to be provided and controlled, in order to accurately estimate the heating and cooling loads associated with that ventilation.

Estimating the energy that will be consumed in delivering the ventilation can be done manually using spreadsheets in simple scenarios, considering the ventilation supply rates, supply temperatures, heat recovery efficiencies and specific fan powers. Detailed HVAC modelling offers a much more detailed approach that can factor in aspects such as demand controlled ventilation, simultaneous heating and cooling, fan heat pickup and the proposed control algorithms.

SIGNPOST *Chapter 2 - 2.2 Tools, HVAC modelling*

There are 3 aspects to think about and model when it comes to building ventilation:

1. **Infiltration** - Uncontrolled ventilation through perforations in the building fabric should be minimised as far as possible.

SIGNPOST *Chapter 3 - 3.2.1 Airtightness/infiltration*

2. **Background ventilation** - The year round ventilation needed to maintain good air quality and prevent moisture build-up and damp and mould forming. When designing for net zero this will be provided by some form of mechanical ventilation with heat recovery, as natural ventilation systems using trickle vents or similar cannot recover heat and therefore waste significant space heating energy. Part F of the Building Regulations sets minimum requirements on background ventilation provision.
3. **Summer purge ventilation** - The additional ventilation needed in summer to mitigate overheating risk. In mechanically ventilated buildings fans might run at higher flow rates and/or for extra hours to provide night cooling or 'free cooling' (when outside air is cool enough to provide cooling instead of running a chiller). In buildings without mechanical ventilation or in mixed mode buildings, summer purge ventilation is commonly provided using openable windows. This natural ventilation provision needs to be designed and controlled to maintain summer comfort within the building.

SIGNPOST *Chapter 2 - 2.4 Outputs, Comfort assessments*

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Beyond the EUI analysis, Modelling overheating risk*

Ventilation impacts on energy performance in a number of ways:

→ **Heating loads -** incoming fresh air will need to be heated to room set points. The energy needed to do this will depend on the supply rates, set points, room gains, weather data, heat recovery efficiency, heat generation efficiency, distribution losses and any preconditioning applied.

→ **Cooling loads (where applicable) -** incoming fresh air will need to be cooled to room set points or room supply temperature. The energy needed to do this will depend on the supply rates, set points, room gains, weather data, coolth recovery efficiency, chiller efficiency and any distribution losses.

→ **Humidity control (where applicable) -** energy used for humidification/dehumidification cycles will depend on the set points, weather data, and plant efficiency. Often dehumidification in commercial buildings is achieved through cooling of the incoming air below the dew point and then reheating via heating coils. Care should be taken not to over-cool the air below the temperature required to provide the required level of dehumidification.

→ **Ventilation fan energy -** the energy used for fans will depend on factors such as the pressure drop in the Air Handling or Heat Recovery unit and related ductwork, fan motor efficiencies and system controls.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance in the ventilation supply rates and heat recovery efficiency within scenario testing)*

Space heating

Space heating demand is a dynamic outcome of the balance between heat gains and losses, and will take account of a large number of the model input parameters including the building fabric performance, external weather, internal occupancy patterns and gains, ventilation rates, heating set-points (including out-of hours set-backs for frost protection) and heat emitter types.

The LETI Climate Emergency Design Guide recommends reducing space heating demand to below 15 kWh/m²/yr for all building types included.

Note that space heating demand is different to space heating energy consumption; the demand is how much thermal heat is required, whereas the consumption is how much fuel is required to generate that heat. Space heating demand is thus a property of the building fabric, form and internal conditions rather than of the selected heating system.

Net zero buildings must use all electric systems.

Include model estimates for the annual space heating demand (kWh/m²/yr (GIA)) in the modelling results.

Heat pumps

Accurate modelling of heat pump energy consumption depends on correct calculation of the heat pump's efficiency, or Coefficient of Performance (COP). The COP varies depending on the source and sink temperatures experienced by the heat pump. In practice, the source temperature is usually the same as the outdoor air, ground, or in some cases a water source. The sink temperature is effectively the flow temperature of the heat distribution system and should be as low as possible to maximise efficiency. Heat pump capacity is also important, as undersized units will have to use direct electricity during periods where demand exceeds their capacity, and oversized units will operate at lower efficiencies and may excessively cycle on and off.

Heat pump manufacturers publish data tables showing the COP and heat output of their units at different temperature pairings, usually based on BS EN 14825 (or other) test data. This data can be combined with information on the source and sink temperatures experienced by the building throughout the year to estimate the electricity consumption of the heat pump.

Tools such as SAP 10 connect to heat pump performance data outside of the main calculation engine in something called the Products Characteristic Database (PCDB) to provide a single annual average seasonal coefficient of performance (SCOP). This allows for a simpler calculation, however may fail to account for differences in buildings, such as how their space heating demand fluctuates monthly or hourly.

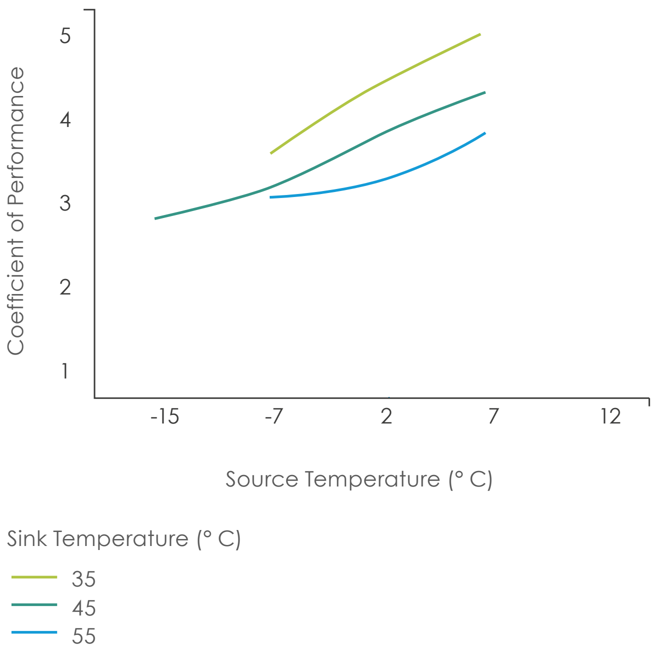


Figure 3.2 - Typical manufacturer test data for an 8kW air source heat pump showing efficiency at different source and sink temperatures.

PHPP calculates the impact of the external conditions on heat pump performance within the main calculation engine for each month, and does separate calculations for space heating and DHW, achieving a fairly good resolution for the variation in efficiency. Dynamic software can perform these calculations at a much higher resolution, so use of correct manufacturer data is particularly important. The COP can vary for part load conditions, and this should be accounted for where software permits.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance in the heating set-points , generation efficiency and heat recovery with in scenario testing)*

Domestic Hot Water

Dynamic simulation modelling tools are not especially talented at estimating Domestic Hot Water (DHW) usage. The demand tends to be based on a litres per person per day rates and assumed occupancy. These tools are better at modelling how efficiently these demands are met using the building services. DHW demand should be estimated using advice from the client and CIBSE benchmarks as a backstop. This demand should be applied in the model along with the generation plant efficiency and sizing, supply temperatures, controls, and storage and distribution losses. Legionella cycles should also be considered.

Modelling and comparing the DHW system options reasonably accurately for net zero buildings is valuable to inform decisions around whether to opt for a centralised or distributed DHW generation and the extent of DHW storage. DHW storage is generally beneficial for reducing peak loads and providing durable long-term demand side management capacity, but may have reduced benefits where DHW demand is low.

SIGNPOST *Chapter 2 - 2.4 Outputs, Energy flexibility (minimising peak demand/ demand management)*

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance in the DHW demand assumed within scenario testing)*

In some buildings DHW demand may equal or greatly exceed space heat demand. Distribution and/or storage losses can contribute toward overheating risk because DHW, unlike space heating, is also used during the summer months. DHW flow temperatures often drive communal heating system flow temperatures, which affects heat pump efficiency and system losses. Buildings with traditional 60-70°C flow temperature communal heating systems modelled in PHPP have shown DHW losses that exceed space heat demand. In some commercial buildings, storage and related circulation losses may be so large relative to demand that storage is not justified and point of use systems are a more efficient choice.

The DHW demand and the energy used to deliver it can alternatively be calculated outside of the model using simplified spreadsheet methods. In this case it is important to ensure that any storage and distribution losses are included, plus the benefits of any Waste Water Heat Recovery (WWHR) systems. Be careful with this separation as in smaller, energy efficient homes the DHW system and storage will add heat gains into the home. These should always be calculated and included in the general space heating demand calculation and any overheating risk analysis.

In the absence of a DHW distribution design for the project (or a similar previous project), even at concept design stage, the project Public Health engineer should be able to provide guidance on the pipework distribution route and pipework diameters. The maximum permissible pipework heat losses in Part L can then be applied as a starting point for inclusion of distribution losses in the model.

Lighting

Follow CIBSE TM54 guidance (Step 3) on evaluating lighting loads.

→ Where internal blinds are provided for glare control, factor into the scenario testing that they could be left down longer than anticipated which may increase electrical lighting loads.

→ Where daylight linking and dimming or presence detection systems are proposed these should be accurately reflected in the model

→ Ask questions about the hours that lighting might be used in the building, e.g. when cleaning will take place, or if security patrols might continue through the night, or if any lights will be left on all night for security. Extended evening and weekend use of lighting systems can dramatically increase the energy used.

→ Flag up to the project team if the lighting power density values supplied for the modelling exceed the LETI Climate Emergency Design Guide recommendations.

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance on the lighting power density and hours of use assumed within scenario testing)*

Comfort cooling

For many buildings the most energy efficient cooling mechanism is openable windows.

Mechanical cooling should be reduced or avoided where possible due to the embodied and operational carbon it uses, the impact the heat rejected from chillers can have on the local microclimate (exacerbating the problem for neighbouring buildings), and the financial cost (capital and running).

Ceiling fans can provide a much lower energy cooling solution than mechanical cooling. Fans generate useful air movement and can reduce the temperature experienced by occupants as the breeze generated increases the evaporation of moisture from skin, increasing adiabatic cooling. Dynamic simulation tools are able to roughly approximate this cooling effect based on the air speeds generated.

It is worth noting that ceiling fans require minimum ceiling heights and should be specified to operate quietly - especially in bedrooms.

Where passive servicing solutions are ruled out (possibly due to acoustic or air quality constraints or high internal gains), the modelling should be used to help the design team minimise the cooling demand by demonstrating the benefit of passive design elements. The modelling can also be used to help designers optimise the efficiency with which mechanical cooling is delivered. Modern chillers can deliver very high efficiencies, which combined with efficient distribution and reasonable cooling set points (i.e. 25-26°C) plus use of ‘free cooling’ (see section on ventilation) when feasible, can minimise the energy consumed for mechanical cooling considerably.

Make sure mechanical cooling is accurately represented in HVAC modelling including the size and part load performance of the chiller and the heat rejection plant. Avoid using the simplified SEER (Seasonal Energy Efficiency Ratio) metric beyond the technical design stage as detailed manufacturer data should be available once units are specified.

SIGNPOST *Chapter 3 - 3.2.2 Ventilation*

SIGNPOST *Chapter 2 - 2.3 Methodology: TM54, Creating scenarios (Factor in variance on the cooling set points and chiller seasonal efficiency within scenario testing.)*

Centralised HVAC systems and controls

Detailed HVAC modelling tools should be used where a project utilises centralised plant and a Building Management System (BMS) that controls the HVAC systems.

The HVAC modelling should include:

→ All key HVAC components including heating and cooling plant, any humidification or dehumidification systems, heat recovery, fans, pumps, preheat coils, frost protection.

→ Properties, such as sizes, part load performance curves, pump and fan curves and heat recovery effectiveness.

→ The proposed control logic

Detailed HVAC modelling offers an opportunity to dress-rehearse the control logic and if a system can be made to work effectively using the simpler control logic available within a model then that should be a good sign that it will be practicable within the real building. This dress-rehearsal opportunity can help iron out errors and enable the write up and communication of the control strategy in an intelligible way.

Note: Any models originally based on NCM models/templates should re-work the HVAC systems to accurately reflect the proposed design.

Dynamic simulation modelling tools do not always have the same sophistication of control algorithms as full BMS systems. BMS can have fail safe routines that mean they keep operating despite faults where models will not and may fall into cycling (repeatedly switching equipment on and off) modes where control bands are too tight. In practice overcomplicated control logic can do more harm than good to energy performance as systems get over-ridden when they appear to misbehave in practice. Mixed mode buildings need particular attention to ensure that controls prevent mechanical heating and cooling while the windows are open.

Quality Assurance is important here. Start by understanding and documenting what each part of the HVAC is doing, and how that relates to the design intent. The software tools enable you to interrogate the temperatures and flow rates of each component for each hour of operation which can help confirm whether systems are operating as expected.

Discuss with the design team what variance there might be in the HVAC controls and operation that should be explored through the sensitivity analysis and factored into the TM54 scenarios.

The controls used must be detailed within the modelling report.

Advice for learning HVAC modelling

HVAC modelling is a complex discipline, but it's essential that the UK industry upskill to meet the Climate Emergency. Our top tips to learning HVAC modelling are:

→ Make sure to be informed on the basic principles of efficient HVAC system design and controls

→ Sign up and attend HVAC modelling training offered by your modelling software provider

→ Start with complete Stage 4 designs and learn how to replicate them in the software before applying the techniques to less evidenced early stage modelling

→ Think about the controls logic using sketches before trying to implement controls in the model

→ Check: is every significant piece of equipment from the mechanical design in the model?

→ Check: look at the hourly air temperature and flow values on each node, is this what should be happening?

→ Check: talk your model and results through with the mechanical engineer

→ Be realistic about the time it can take to truly develop all the skills needed: experience is not built overnight

CIBSE plan to offer HVAC modelling training sessions - check their website for details.

SIGNPOST *Chapter 3 - 3.1 Best practice modelling fundamentals, Beyond the EUI analysis, Checking unmet hours*

SIGNPOST *Chapter 2 - 2.2 Tools, HVAC modelling*

3.2.3 Estimating additional energy uses

Additional energy uses

It is vital that all energy uses are factored into the analysis. Energy uses that are often not considered in models but should be included in EUI assessments include:

→ Lifts and escalators
→ Catering
→ Server rooms and related cooling
→ External lighting and electric car charging points
→ Car park ventilation and lighting
→ Emergency generator use
→ Trace heating of pipework
→ Cold water pumping
→ Security
→ Over door air curtains
→ Generator sump heaters

Follow CIBSE TM54 (2022) advice on evaluating any of these loads that are applicable.

The calculations used, and the sensitivity and scenarios they are included in should be included in the report and clearly added into the final energy use analysis.

SIGNPOST *CIBSE TM54 (2022) Step 12: Taking management considerations into account (page 40)*

3.2.4 Including renewables

Including renewables

This section focuses on solar photovoltaic technology as it is the main renewable technology now deployed on buildings in the UK.

When reporting against EUI targets, generation from renewables should NOT be included in the total energy used. This generation should be evaluated separately and then used to offset the energy used on site.

The accuracy of energy modelling tools at predicting the energy generation from solar photovoltaic (PV) systems varies. The most basic calculations should account for system installed capacity, location, orientation, tilt, shading, and include some allowance for system losses (which are typically around 14% for systems with a central inverter). More advanced calculations should include allowances for the use of microinverters or DC optimisers, and bifaciality of solar modules.

The core calculations in SAP (2021) do not account for system location and should be disregarded. However it's important to note that current SAP (10.2) EPC cost outputs do account for location and provide a basic prediction of annual energy generation.

PHPP's core PV calculations also account for system location and provide a monthly breakdown of predicted generation, but experience has shown they tend to underestimate generation by around 10%. Both SAP (2021) and PHPP use coarse solar irradiation data for a large climate zone, which does not account for what can be quite large differences in irradiation between different locations within the same climate zone.

SAP (2021) and PHPP calculations can be sense-checked using the freely available PVGIS tool, which allows for a precise location to be entered. It is recommended that losses are left at the standard value of 14%, or reduced to 10% if microinverters or DC optimisers are used, as a conservative improvement. Increases in energy generation resulting from bifaciality of modules are more complicated to calculate, but can increase energy production from 5%- 25% so should be considered. This is beyond the scope of this guidance, but module manufacturers have published their own methodologies.

Dynamic simulation models simulate applied renewables against hourly weather data enabling the link between sunnier weather hours, and the resulting and higher PV yield and increased cooling loads to be explored for example.

Solar installers usually have access to higher quality solar modelling software such as Helioscope, Opensolar, Pylon, PVSyst, SolarGIS, Solarplus, and Solar Pro [3.8]. These packages typically model location and technology specific solar generation and battery systems in detail.

Rates of residential solar self-consumption (where electricity generated is used immediately by the inhabitants rather than being exported to the grid) can be estimated using the Microgeneration Certification Schemes guidance document "Determining the electrical self-consumption of domestic solar photovoltaic installations with and without electrical energy storage". However, this may not cover all available technologies, such as solar diverters for multi-residential buildings. In these cases, manufacturer data may be the only resource available.

Although electric vehicle (EV) charging is also outside the scope of the EUI target, it is worth considering the impact that these have on energy use and compensating with additional renewable provision. As an indication a typical private car, travelling 7,400 miles a year might consume around 2,000 - 2,500kWh of electricity - equivalent to the average home's annual domestic hot water demand.

A

Appendix

A1: The problem with compliance modelling

There are many reasons why Part L compliance calculations are different and produce different results to energy performance models. It is important to understand this as it is tempting (but misguided) to see them as similar.

SIGNPOST *Chapter 1 - 1.2 Why regulatory compliance tools are not suitable here*

1. Validating performance against the targets

Current planning policy is often based on a required improvement over compliance with building regulations, determined using a baseline target: the 'notional building'. The notional building has the same shape, orientation and, up to a point, the same glazing proportions as the actual proposed building design. However, the notional building is fictional and is created by the compliance software solely for building regulations purposes. Consequently, the % improvement cannot be measured in-use. This demonstrates the importance of an absolute EUI target, which can be checked against metered energy in the occupied building. This makes post-construction verification and learning from a feedback loop easier with the EUI target

2. Incentivising better design

Essential components of an energy efficient design involve creating a building that has the right form, orientation and glazing proportions. However, comparing a development to its own notional building essentially neutralises the benefit of good design and fails to penalise building designs that are inefficient in these aspects. With an absolute EUI target, the benefits (or penalty) of changes to the building form and design are assessed and good design practice is rewarded.

3. Additional issues with changing carbon and primary energy factors

Current targets in Part L (2021) focus on carbon emission factors and primary energy factors. The carbon factor for electricity has changed very significantly over the last 10 years as the national grid has decarbonised, and in fact varies hour to hour (often minute to minute) so it is not feasible to accurately estimate the true carbon emissions from a buildings operation. Using fixed carbon factors impacts on the assessed % improvement and penalises PVs which inherently operate most when it is sunny and therefore renewable generation within the grid is likely to be higher.

We need design metrics that only change in response to changes to the building design (rather than improvements in carbon factors that are outside the developers control)

4. Not skewed by renewables contribution

EUI metrics do not include (i.e. are not reduced by) renewable generation on site (usually PV). This is not to disincentivise the inclusion of PV, but to make sure that this is not allowed to offset a very poorly performing building.

Part L assessments do include PV generation and they exclude 'unregulated energy' which includes all equipment plugged into the wall and all process loads such as catering kitchens and server rooms. This again distorts the picture of the energy that will actually be used by the building.

5. Standardised profiles

Regulatory compliance tools use fixed profiles for the number of people in a building and how they behave. This creates a generic assumption for the internal gains and "plug loads" to allow like-for-like comparison across sites and between buildings of the same category. These profiles might represent an industry-wide "average" but do not give the flexibility required to reflect what is known about the project at design stage or to explore the range of possible occupancy and usage profile outcomes.

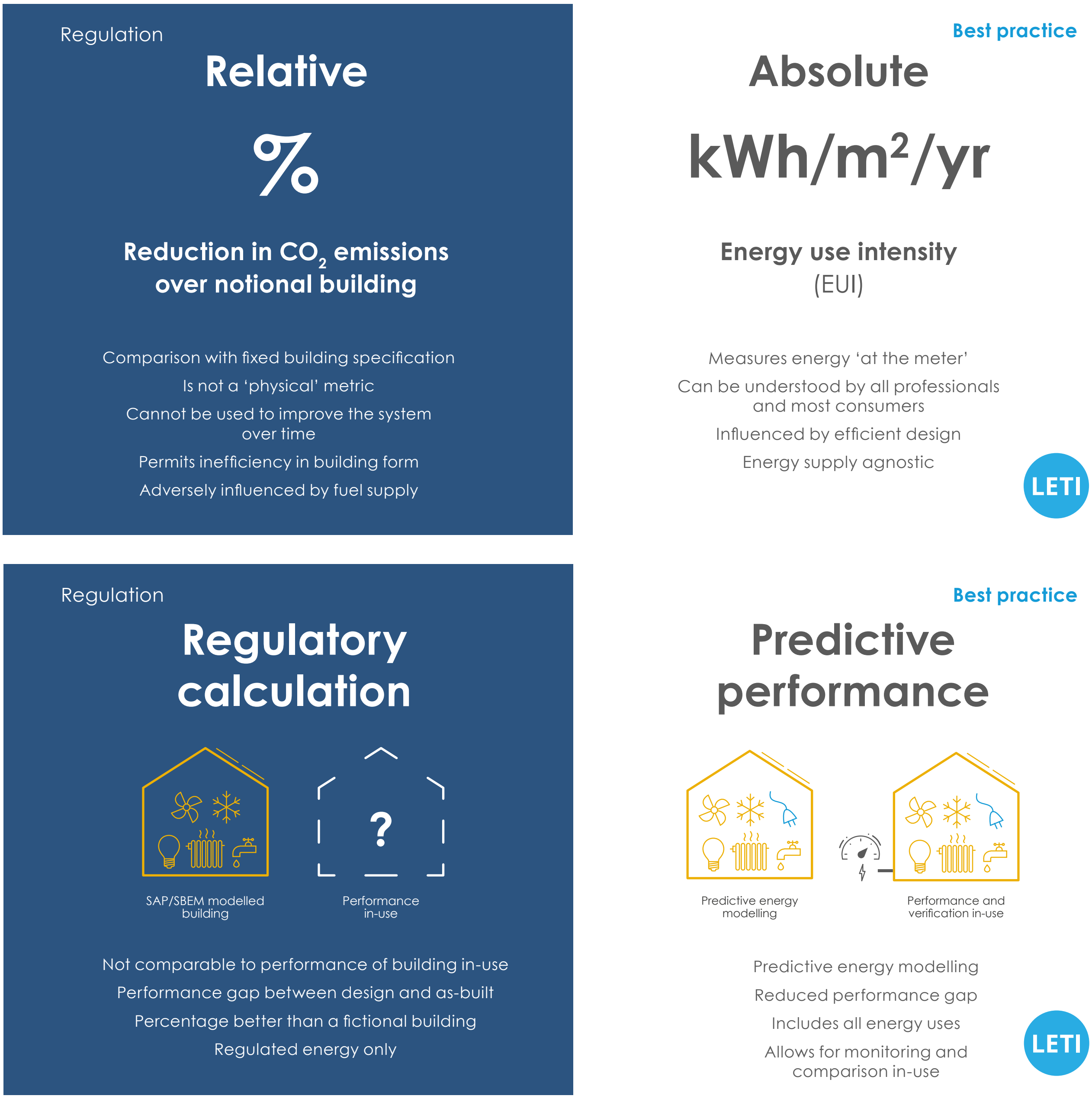


Figure A1.1- The differences between Part L compliance modelling and energy performance modelling

A2: Useful reference documents

When reading this reference material it is important to make a distinction between models carried out for compliance and assessments performed for absolute energy performance modelling. Some simplifications reasonable for a comparative modelling exercise would not be appropriate for energy performance modelling.

The climate emergency necessitates modelling to be aimed at reliably estimating absolute performance in use, and the modeller must, by all means necessary, create a model that anticipates how much energy the building is likely to use in real life operation. While many of the guides referenced below contain useful information that can be applied into models used for energy performance modelling, it's important for each modeller to check that they only use assumptions and simplifications that represent the anticipated use of their particular building.

Literature, publications and standards

Publications on the impact of building occupants:

→ *"Understanding the impact of occupancy toward integration of building performance simulation in early-stage design"* - Picco et al, 2020

→ ISO 17772-1 - specifies requirements for indoor environmental parameters for thermal environment, indoor air quality, lighting and acoustics and specifies how to establish these parameters for building system design and energy performance calculations.

→ EN 16798-1 - provides you with design criteria for the local thermal discomfort factors, draught, radiant temperature asymmetry, vertical air temperature differences and floor surface temperature.

→ *"Data for occupancy internal heat gain calculation in main building categories"* - Ahmed et al, 2017

→ ASHRAE Standard 90.1-2016 User Manual Appendix G & Chapter 5.6

→ NABERS UK Guide to Design for Performance Appendix A – Defaults for Simulations

These datasets have been found to vary substantially, so all figures and underlying assumptions should be considered carefully prior to adoption. Furthermore, the datasets vary in terms of the building types covered.

Publications on the performance gap

→ OBeime, S. (2015, 08 26). The energy performance gap. FMJ - Facilities Management Journal

→ Mitchell, R., & Natarajan, S. (2020, 06 01). UK Passivhaus and the energy performance gap. Energy and Buildings, 224. 10.1016/j.enbuild.2020.110240

Guidance and technical manuals

Chartered Institute of Building Services Engineers (CIBSE)

CIBSE publish guidance for modellers and building engineers considering impacts on energy use. Several of the documents form the framework of assessing buildings through planning policy or regulation. It is a UK based organisation and focuses its content on that market.

→ **CIBSE AM11: Building performance modelling (2015) -** in this Application Manual a wide range of building performance modelling tools are considered. The aim is to offer the user useful guidance on the application of different types of simulation tools, best practice approach, and quality assurance procedures in applying these tools. The target readerships of this Manual are building services engineering practices but the Manual should also be of interest to architects, developers, facility managers and building users. Includes a review of modelling standards in different countries (including US and Australia) and various approaches to thermal simulation.

→ **CIBSE TM61: Operational Performance Of Buildings (2020) -** The aim of this document is to provide insights into the problem of the performance gap following an integrated approach to energy and indoor quality. This document references TM54 for energy analysis.

→ **CIBSE TM63: Operational performance: Building performance modelling and calibration for evaluation of energy in-use (2020) -** The aim of this document is to provide a methodological framework to undertake Measurement and Verification of building performance in use. It sets out modelling approaches and potential impact on performance gap, and guidance on the development and validation of calibrated energy simulation models. This document references TM54 for energy analysis.

National Australian Built Environment Rating System (NABERS)

NABERS, the National Australian Built Environment Rating System, is an initiative by the government of Australia to measure and compare the environmental performance of Australian buildings and tenancies. NABERS is also used in New Zealand, South Africa and the UK.

→ **Office of Environment and Heritage, NSW - Handbook for Estimating - NABERS,** which outlines how a building, tenancy or data centre's energy consumption, and therefore its NABERS star rating, can be estimated prior to operation. This document is to be used as a guide whenever a computer simulation is used to estimate base building or whole building energy use under NABERS Energy. This document is structured to allow its use in a prescriptive manner. A compliance checklist is provided to check that the building energy estimate complies with key elements.

→ **NABERS UK**

NABERS UK is an adaptation of the Australian NABERS rating scheme for rating the energy efficiency of office buildings across England, Wales, Scotland and Northern Ireland. The current scheme only rates the Base Building energy efficiency of an office, excluding the tenancies.

→ **NABERS UK Guide to Design for Performance (2021)**

This guide sets out the minimum steps and processes required for a project implementing the NABERS UK Design for Performance (DfP) process.

→ **NABERS UK Rules -** split into 2 documents: NABERS UK The Rules - Energy for Offices and NABERS UK The Rules - Metering and Consumption. These documents explain in detail how NABERS UK ratings are to be calculated are key reference documents for Accredited Assessors.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)

CIBSE publish guidance for modellers and building engineers considering impacts on energy use. Although focussed in the US several documents are used and referenced internationally.

→ **ASHRAE 90.1** has been a benchmark for commercial building energy codes in the United States and a key basis for codes and standards internationally for more than 40 years. This standard provides the minimum requirements for energy-efficient design of most buildings, except low-rise residential buildings*. It offers, in detail, the minimum energy efficiency requirements for design and construction of new buildings and their systems, new portions of buildings and their systems, and new systems and equipment in existing buildings, as well as criteria for determining compliance with these requirements. It is an indispensable reference for HVAC engineers and other professionals involved in design of buildings and building systems.

*Also refer to ASHRAE 90.2 for Low-rise buildings.

→ **ASHRAE 90.1: Appendix G** uses a more independent baseline where many of the characteristics of the baseline design are based on standard practice, meaning credit is available not only for exceeding prescriptive requirements in the code, but also for exceeding standard practice that is not regulated by the code. The proposed building energy performance needs to exceed that of the baseline by an amount commensurate with the code year being evaluated.

HVAC users should be aware of the different versions of ASHRAE 90.1 and their applicability to Building rating systems:

→ 2010 in LEED v4

→ 2013 for BREEAM International

→ 2016 for LEED v4.1

For LEED Projects modellers should refer to the Advanced Energy modelling for LEED Technical manual - https://www.usgbc.org/resources/advanced-energy-modeling-leed-technical-manual-v10

→ **ASHRAE 90.1 User Manual** provides sample calculations, application examples, useful tools, forms to demonstrate compliance with 90.1 and references to resources and websites.

The 90.1 standard is written in mandatory language and not intended as a design specification or an instruction manual, the User's Manual was developed to minimise multiple interpretations of Standard 90.1-2016 that may occur. This manual is intended for architects, engineers, contractors, code officials, educational programs and other building professionals and provides sample calculations, application examples, useful tools, forms to demonstrate compliance and references to resources and websites.

→ **ASHRAE 62.1 - Ventilation for Acceptable Indoor Quality** provides tables for ventilation and exhaust rates for different zones and usages. The standard specifies minimum ventilation rates and other measures for new and existing buildings that are intended to provide IAQ that is acceptable to human occupants and that minimises adverse health effects. It also defines the roles of and minimum requirements for mechanical and natural ventilation systems and the building envelope intended to provide acceptable indoor air quality in residential buildings along with explanations for calculating system ventilation efficiency and zone air distribution effectiveness. It is also useful when zone occupancy is unknown as default ASHRAE occupancy density can be used for the calculation.

→ **ASHRAE Standard 55 - Thermal Environmental Conditions for Human Occupancy** specifies conditions for acceptable thermal environments and is intended for use in design, operation, and commissioning of buildings and other occupied spaces. The standard addresses the four primary environmental factors (temperature, thermal radiation, humidity, and air speed) and two personal factors (activity and clothing) that affect thermal comfort. It is applicable for air conditioned, mechanically ventilated and naturally ventilated buildings.

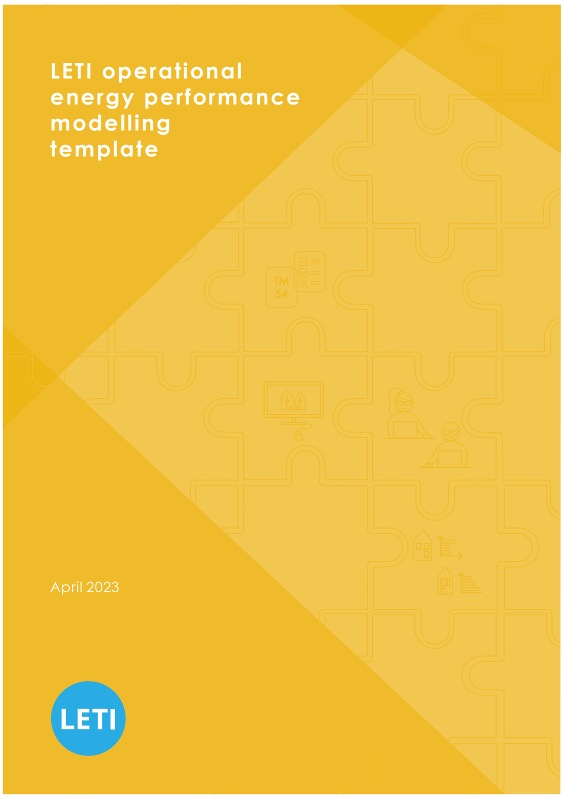
U.S. Department of Energy (DOE) reference buildings contain commercial reference building models for new construction, organized by building type and location. These U.S. Department of Energy (DOE) reference buildings are complete descriptions for whole building energy analysis. They provide the accompanying spreadsheet of inputs which could be included when approaching HVAC modelling.

→ 2020 ASHRAE Handbook - HVAC Systems and equipment discusses various systems and the equipment (components or assemblies) they comprise, and then in addition describes their features and differences. This information helps system designers and operators to select and use equipment that is the best fit for a particular application or scenario. Subject matter experts on ASHRAE Technical Committees in each subject area have reviewed all chapters and revised them as needed for current technology and practice.

→ ASHRAE Advanced Energy Design Guide Series. This includes guidance on achieving a 50% energy savings against ASHRAE 90.1 2004 for 5 building types as well as guidance for achieving zero energy use for 2 building types.

A3: LETI Operational energy performance modelling report template

A formatted report template with a suggested layout and headings for operational energy performance modelling reports is provided as a word document here:



A4: Definitions

Tools and methodologies

SAP: Standard Assessment Procedure - a methodology used for assessing the energy use of domestic buildings. Part L1 of the Building Regulations uses the SAP methodology to assess and compare performance against the notional dwelling.

NCM: National Calculation Methodology - a methodology used for assessing the energy use of non-domestic buildings. Part L2 of the Building Regulations uses the NCM methodology to assess and compare performance against the notional building.

SBEM: Simplified Building Energy Model - a tool used that implements the methodology outlined in the NCM. Part L2 of the Building Regulations uses the SBEM tool to assess and compare performance against the notional dwelling.

PHPP: Passivhaus Planning Package - a spreadsheet based tool used to design and demonstrate the energy performance of buildings. The tool can be used both as a 'design tool', where parameters can be customised to a building's likely performance to reflect real life as much as possible, or as a certification tool, where several of the parameters are fixed and the output can be used to demonstrate compliance with the Passivhaus standard.

DesignPH: DesignPH is a tool that works alongside PHPP which allows users to model their buildings in 3D before the results are processed in the spreadsheet based PHPP.

EDSL TAS: Environmental Design Solutions Limited Thermal Analysis Software - a building modelling and simulation tool capable of performing hourly dynamic thermal simulation.

Modelling specifics and metrics

DTM: Dynamic thermal modelling (this is the same as DSM)

DSM: Dynamic simulation modelling (this is the same as DTM)

EUI: Energy use intensity

DHW: Domestic hot water

HVAC: Heating, ventilation and air conditioning

COP: Coefficient of performance

Organisations and schemes

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers - source of methodology and guidance documents.

BREEAM: Building Research Establishment Environmental Assessment Method - an international green building rating certification scheme.

CIBSE: Chartered Institute of Building Services Engineers

GLA: Greater London Authority.

LEED: Leadership in Energy and Environmental Design - an international green building rating certification scheme.

NABERS: National Australian Built Environment Rating System - also exists in the UK now under NABERS UK, a scheme for rating the energy efficiency of buildings and providing guidance documents.

PHI: Passivhaus Institute - a research institute responsible for developing the Passivhaus standard.

RIBA: Royal Institute of British Architects

UKGBC: UK Green Building Council

Measurement

GEA: Gross external area - the floor area of a building which accounts for the whole area of the enclosed building including wall thicknesses.

GIA: Gross internal area - the floor area of a building which accounts for the whole area of the enclosed building but excludes the thickness of the external wall.

NIA: Net internal area - the usable floor area of a building measured to the internal finish of the perimeter or party walls.

NLA: Net lettable area. The floor area that is to be leased and in respect of which a rent is payable, which generally excludes common areas (such as corridors, public atrium and toilets) and areas used to accommodate building and property management facilities and services. Often equivalent to NIA.

TFA: Treated floor area - defined differently for SAP and PHPP, this is a measure of the amount of usable floor space within the thermal envelope.

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Operational Modelling Guide

This Operational Modelling Guide explores how a building's meter readings can be estimated at design stages, and how this understanding can be used to inform and improve designs - providing more confidence that operational energy targets can be achieved. LETI has produced this document to support project teams to design buildings that will deliver EUI and space heating demand targets.

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