



Technical Manual



SBEM

SBEM: Simplified Building
Energy Model

*Part of the National Calculation Methodology: SBEM for
assessing the Energy Performance of Non-domestic Buildings*

A Technical Manual for SBEM

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Key changes from the previous version of the manual

- Description of calculation methodology currently applied in SBEM for transpired and non-transpired solar collectors in Section 4.13.

This manual, together with the software tools described in it, were developed by the BRE for the Department for Levelling Up, Housing, and Communities (DLUHC).

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1. Introduction

1.1. Purpose

The purpose of this document is to record the details of the various calculation procedures adopted within SBEM, generally comprising, for each:

- The input data required;
- The source of each data item;
- The assumptions made;
- The calculation algorithm(s) used;
- The source of those algorithms;
- The output data generated;
- A commentary on the strengths and weaknesses of the approach adopted.

1.2. Audience

The document is intended to be technically detailed, aimed at:

- The SBEM development team, as a reference document
- DLUHC¹ and AECOM, as a record of the SBEM project
- Developers of alternative simulation software, and of alternative interfaces
- Interested users of the tool, assumed to be building professionals, such as:
 - Architects
 - Service and M&E engineers
 - Energy surveyors
 - Building energy modellers
 - Suppliers of energy-related building components

It is not intended to be required reading for users of the tool. An overview, in the form of a BRE Information Paper², is available, but all users are expected to read and refer to the iSBEM User Guide³ if using iSBEM as the interface. That Guide contains all the information on the functioning of SBEM needed to operate the tool effectively.

¹ Department for Levelling Up, Housing, and Communities

² IP 2/07: *SBEM for non-domestic buildings*

³ Available for download from the UK-NCM website at www.uk-ncm.org.uk.

2. Background

This section of the manual looks at the requirement for a calculation methodology for the UK, which has developed into the National Calculation Methodology (NCM). It describes which draft prEN and CEN standards have been used to develop a calculation procedure, and how one particular implementation (SBEM) has been designed to satisfy these requirements.

2.1. The requirements

To promote the improvement of energy efficiency of buildings by laying down standards, the UK gave consideration to assessing the performance of buildings on a consistent basis and providing certificates for the majority of buildings so that this performance is communicated effectively. In more detail, the UK looked to:

- develop a methodology of calculation of the integrated energy performance of buildings,
- set minimum requirements for the energy performance of new and existing buildings,
- ensure that those requirements for the energy performance are met in new buildings, and that the feasibility of certain alternative energy systems is checked for new buildings,
- ensure that those requirements for the energy performance are met in existing buildings that are subject to major renovation or extension,
- develop energy certification of buildings,
- set up regular inspection of boilers and of air-conditioning systems, and of the whole heating system where the boilers are more than 15 years old,
- ensure that certification and inspections are carried out by qualified and/or accredited experts.

This Manual explains how the relevant issues above led to the National Calculation Methodology (NCM) and thence to SBEM for new construction, extensions, major refurbishment, and existing buildings. The issues which deal with inspection and the accreditation of experts are not considered here.

2.1.1. Need for methodology

The UK developed the NCM as a methodology for calculating the energy performance of buildings. SBEM is one implementation of this methodology.

Buildings are classified into different categories for the purposes of the calculation. The calculation has been based on a general framework, which includes, at least, the following factors:

- Thermal characteristics of the building (shell and internal partitions, etc.); this may include air tightness;
- Heating installation and hot water supply, including their thermal characteristics;
- Air-conditioning installation;
- Natural and mechanical ventilation;
- Built-in lighting installation (mainly in the non-residential sector);

- Position and orientation of buildings, including outdoor climate;
- Passive solar systems and solar protection;
- Indoor climatic conditions, including the designed indoor climate.

The calculation also deals with the influence of the following aspects on energy performance, where relevant:

- Active solar systems, and other heating and electricity systems based on renewable energy sources;
- Electricity produced by combined heat and power;
- District or block heating or cooling systems;
- Natural lighting.

For transparency, this manual is part an explanation on how the calculation works.

The definition of “energy performance” refers to the estimation of energy needed for the “standardised use” of the building. This estimation is intended to enable comparisons made between buildings to be on the basis of their intrinsic properties rather than being dependent on the user’s choice of operating patterns which might exist in practice. The use of CO₂ emissions as a means of comparison, rather than energy consumption, was adopted in the standard methodology, but later on, primary energy was also added as a second comparison metric.

2.2. The National Calculation Methodology (NCM)

The Building Act 1984 requires that all buildings constructed or refurbished should comply with the requirements of the current Building Regulations. As stated above, a calculation methodology for the energy performance of buildings, in the form of the NCM, was established. The UK’s Office of the Deputy Prime Minister (ODPM) - later the Ministry of Housing, Communities, and Local Government (MHCLG), and now Department for Levelling Up, Housing, and Communities (DLUHC) - stated in the 2006 Building Regulations Part L for England and Wales that:

17A - (1) The Secretary of State shall approve a methodology of calculation of the energy performance of buildings;

17B - ... The Secretary of State shall approve minimum energy performance requirements for new buildings in the form of CO₂ emission rates, which shall be based upon the methodology approved pursuant to regulation 17A.

The NCM has been developed to provide this calculation. This manual deals with the calculation methodologies and compliance checking procedures that form the NCM.

For Building Regulations compliance in England & Wales, it was decided to base compliance on CO₂ emissions, rather than on consumed energy, in order to:

- allow comparison of energy from disparate sources and of different costs;
- avoid having to set different targets where there is the option of using electricity or other fuels for a given end use;
- remind users that the overall objective for the UK is CO₂ management in order to meet international treaty obligations.

The 2006 Building Regulations called for a proposed building to be assessed by comparing its expected annual carbon dioxide emissions with a target, on a consistent, calculated basis.

This marked a change from the optional means of demonstrating compliance with previous Building Regulations which allowed either matching constructions with U-value requirements for particular elements, limits to glazing areas, etc., or achieving a calculated target. Previous calculation methods have been specified (e.g., CECM, as explained in CIBSE TM32) but there could, potentially, be difficulties in achieving consistent results.

To address these concerns, the National Calculation Methodology (NCM) was established.

However, for the 2021 revision of Part L of the Building Regulations in England, it was decided to add primary energy as a second compliance metric, alongside CO₂ emissions, and the NCM was adapted accordingly. A similar addition had already been done during the 2014 revision of the Building Regulations in Wales and was carried forward into the 2022 revision.

For the 2022 revision of Section 6 of the Building Regulations in Scotland, delivered energy was added as a second compliance metric, alongside CO₂ emissions, and the Scottish NCM was adapted accordingly.

2.2.1. Comparison rather than absolute calculation

At the core of the NCM, the calculation process compares the CO₂ emissions of the Actual building with target emissions which are based on those of a “Notional building”. Similarly, the primary energy (or delivered energy, in the case of Scotland) of the Actual building is compared to that of the Notional building. This constitutes the setting of standards.

The basis on a comparison minimises argument about how well the absolute CO₂ emissions and primary energy (or delivered energy, in the case of Scotland) are predicted by different NCM-compliant methods because both the Actual and Notional buildings are subject to the same calculation approach. Instead, it concentrates on achieving improvements compared with the previous regulations.

The NCM also requires the use of standard databases or information sources for:

- Environmental conditions and operating/occupation patterns in each part of each building
- Weather data

The reason for this is to encourage consistency between repeated evaluations of the proposals.

Standard databases are also available for

- Heating and cooling system efficiencies
- Building component parameters

These databases are described in more detail in Section 3.3.

The NCM also requires that specific construction elements in the proposed building are checked for compliance with minimum performance standards specified in Part L in England (or equivalent in Wales, Scotland, and Northern Ireland). It also requires that the output

report adopts a standard format so that building control officers will not have to interpret the way different tools present the results.

2.2.2. Basis for calculation methodology

The requirements are most readily achieved by demonstrating that the calculation method complies with the CEN standard umbrella document PG-N37, which lists a number of standards, in particular, EN ISO 13790 which deals with *Energy performance of buildings – Calculation of energy use for space heating and cooling*.

Some necessary parts of the calculation are not dealt with explicitly or completely by these CEN standards or draft prEN standards. Acceptable calculation methodologies used in SBEM to deal with the areas not covered by the standards are explained elsewhere in this document.

2.2.3. Parameters required to define a building

In the NCM, buildings for evaluation should be defined in terms of:

- the zones in which identifiable, standardised activities take place;
- the geometry of each zone: its floor area, the areas of the building fabric elements which surround it, and their location with respect to the exterior or other interior conditioned zones;
- the thermal performance characteristics of the building fabric elements surrounding each zone;
- the building services systems which serve each zone (or groups of zones);
- weather location.

2.2.4. Comparison with Target Emission Rate and Target Primary Energy Rate (or Target Delivered Energy Rate)

The performance requirement is for the proposed building to achieve a CO₂ emission rate, a “Building Emission Rate” (BER), that is no greater than a “Target Emission Rate” (TER), which is derived from the emissions of the Notional building introduced above. Similarly, for the England and Wales Building Regulations, it is also required that the proposed building achieve a “Building Primary Energy Rate” (BPER) that is no greater than the “Target Primary Energy Rate” (TPER) derived from the Notional building. On the other hand, for the Scotland Building Regulations, it is also required that the proposed building achieve a “Building Delivered Energy Rate” (BDER) that is no greater than the “Target Delivered Energy Rate” (TDER) derived from the Notional building.

Briefly, the Notional building has the following characteristics:

- The same geometry, orientation, and usage as the evaluated building;
- The amount of glazing in the Notional building is, however, not the same as that in the evaluated building. The area of glazing is a certain percentage of external walls and roofs and is dependent on the activity and building types;
- Standard operating patterns (to allow consistent comparison between buildings in the same sector);
- It is exposed to the same weather conditions as the evaluated building;

- Standardised assumptions for the building fabric, glazing type, and HVAC plant efficiencies;
- Any service not covered by Part L (e.g., emergency escape lighting, specialist process lighting, etc.) is ignored in both the Actual and Notional buildings.

While there are differences between the specifications of the Notional building, and the associated methodology for setting the target, in each of England, Wales, Scotland, and Northern Ireland, the philosophy is the same.

The NCM in each of England and Wales is used to calculate the energy consumption and, hence, the carbon dioxide emissions and primary energy of the building being evaluated (its BER and BPER, respectively) and those of the Notional building (TER and TPER, respectively). Detailed specifications of the 2021 England Notional building are in DLUHC's 2021 NCM Modelling Guide (available from the UK-NCM website⁴), and further guidance is in the England Building Regulations Approved Document Part L 2021, Volume 2, which can be accessed from <https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l>. Detailed specifications of the 2022 Welsh Notional building are in the Wales 2022 NCM Modelling Guide (available from the UK-NCM website⁴), and further guidance is in the Wales Building Regulations Approved Document Part L 2022, Volume 2, which can be accessed from <https://gov.wales/building-regulations-guidance-part-l-conservation-fuel-and-power>.

The NCM in Scotland is used to calculate the carbon dioxide emissions and delivered energy of the building being evaluated (its BER and BDER, respectively) and those of the Notional building (TER and TDER, respectively). Detailed specifications of the 2022 Scottish Notional building are in the Scotland 2022 NCM Modelling Guide, which can be accessed from <https://www.gov.scot/publications/building-standards-list-of-guidance/pages/key-supporting-technical-guidance/>, and further guidance is in the Scotland Building Regulations Section 6 for 2022, which can be accessed from <https://www.gov.scot/policies/building-standards/monitoring-improving-building-regulations/>.

For Northern Ireland, please refer to <https://www.finance-ni.gov.uk/articles/building-regulations-technical-booklets> for further information on Northern Ireland's current building regulations and published documents.

2.2.5. Compliance with minimum standards

It should be demonstrated that the minimum standard requirements applied to new and existing buildings have been met. The requirements are different for new and existing buildings (see the Approved Documents for details).

The key requirements for new buildings are effectively provided by a compliance checking module (BRUKL) which is incorporated with all implementations of the NCM, such as SBEM.

2.3. Brief from ODPM

Having established the generalised content of the NCM, ODPM (Office of the Deputy Prime Minister) sought software implementations of it. In particular, they required software which

⁴ www.uk-ncm.org.uk

would handle the majority of buildings and could be made available free to users. They commissioned BRE to develop a national calculation tool to fulfil this role.

This tool has been developed by BRE into SBEM (Simplified Building Energy Model) as the default calculation for non-domestic buildings in the UK, to enable Building Regulations compliance checks and energy ratings calculations to be carried out on a consistent basis.

The software tool comprises several modules, some of which are common with other commercial software tools for consistency:

- SBEM, the core calculation engine;
- iSBEM, an interface based on Microsoft Access®;
- BRUKL, the building regulations compliance checking module;
- EPCgen, the Energy Performance Certificate (EPC) generator;
- Standardised databases;
- Standardised report format.

This manual describes the basis of the calculation engine. Wherever possible, this has been based on European standards.

2.4. European standards (CEN) used by SBEM

The CEN umbrella document, *Standards supporting the Energy Performance of Buildings Directive (EPBD)*, PG-N37, provides an outline of a calculation procedure for assessing the energy performance of buildings. It includes a list of some thirty European standards⁵ both existing and those that are to be written, which together form a calculation methodology.

Although the UK is not bound to use these standards, except where applicable in public procurement, government policy is to adopt them generally. SBEM follows them as far as is practicable.

2.4.1. Summary of all CEN standards used by SBEM

PG-N37 Standards supporting the Energy Performance of Buildings Directive

EN 15193-1 Energy requirements for lighting – Part 1: Lighting energy estimation

EN 15217 Methods of expressing energy performance and for energy certification of buildings

EN 15243 Ventilation for buildings – Calculation of room temperatures and of load and energy for buildings with room conditioning systems

EN ISO 13786:2005 Review of standards dealing with calculation of heat transmission in buildings – Thermal performance of building components – Dynamic thermal characteristics – Calculation methods

EN ISO 13789 Thermal performance of buildings - Transmission and ventilation heat transfer coefficients — Calculation method

EN ISO 13790 Energy performance of buildings - Calculation of energy use for space heating and cooling

⁵ Published standards can be obtained online from the British Standards Institution at <https://www.bsigroup.com/en-GB/>.

EN 15316-3 Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – part 3 Domestic hot water systems

3. The calculation process

3.1. Calculation overview

SBEM takes inputs from the software user and various databases, and by calculation, produces a result in terms of the annual CO₂ emissions emanating from the energy used by the building's systems and its occupants. Some of the inputs are standardised to allow consistent comparisons for building regulations and energy ratings purposes in new and existing buildings.

SBEM calculates the energy demands of each space in the building according to the activity within it. Different activities may have different temperatures, operating periods, lighting levels, etc. SBEM calculates the heating and cooling energy demands by carrying out an energy balance based on monthly average weather conditions. This is combined with information about heating and cooling system efficiencies in order to determine the energy consumption. The energy used for lighting, ventilation, and hot water is also calculated.

Once the data has been input using the iSBEM interface, the SBEM calculation engine:

1. calculates the lighting energy requirements on a standardised basis, which takes into account the glazing area, glazing properties, light source, and lighting control systems;
2. establishes the standardised heat gains in each activity area, from the databases and input data;
3. calculates the heat energy flows between each activity area and the outside environment, where they are adjacent to each other, using CEN standard algorithms;
4. applies appropriate HVAC system efficiencies to determine the energy consumption requirements to maintain thermal conditions;
5. aggregates the consumed energy by fuel source and converts it into equivalent CO₂ emissions. This comprises the Building Emission Rate (BER);
6. similarly, converts the consumed energy into equivalent primary energy. This comprises the Building Primary Energy Rate (BPER);
7. determines, on the same basis, the CO₂ emissions and primary energy of a Notional building with the same geometry, usage, set-point temperatures, lighting, hot water, and ventilation requirements, and weather but with building component constructions, HVAC and lighting systems, as per the Notional building's specifications of the relevant building regulations;
8. derives from the Notional building's CO₂ emissions and primary energy the resulting Target Emission Rate (TER) and Target Primary Energy Rate (TPER), respectively, as per the specifications of the relevant building regulations;
9. determines, on similar basis, the CO₂ emissions of a Reference building (if applicable for the relevant building regulations), which has fixed ventilation, heating, and cooling conditions and space and water heating fuel;
10. applies a fixed improvement factor to each zone within the Reference building and derives the resulting Standard Emission Rate (SER).
11. for Scotland, calculates the Building Delivered Energy Rate (BDER) and, from the Notional building, the Target Delivered Energy Rate (TDER).

The BER, TER, BPER (or BDER for Scotland), and TPER (or TDER for Scotland) calculations are then handed over to the compliance checking module, BRUKL, to complete the assessment. Then, BRUKL:

1. compares the BER with the TER and determines a pass or fail for the CO₂ emissions criterion, based on the performance of the proposed building relative to that of the Notional building (for the Scotland Building Regulations, there are cases where the comparison of the BER with the TER is not required, as detailed in Scotland's Approved Document and NCM Modelling Guide);
2. for England and Wales, compares the BPER with the TPER and determines a pass or fail for the primary energy criterion, based on the performance of the proposed building relative to that of the Notional building;
3. for Scotland, compares the BDER with the TDER and determines a pass or fail for the delivered energy criterion, based on the performance of the proposed building relative to that of the Notional building;
4. undertakes an advisory compliance check on certain fabric and building services parameters drawn from information input using iSBEM.

Reports are generated by BRUKL to the standard format to provide:

1. comparison of BER & TER and of BPER & TPER for England and Wales, and comparison of BER & TER (if applicable) and BDER & TDER for Scotland;
2. confirmation of the elemental compliance check.

The BER and SER calculations are also handed over to the Energy Performance Certificate (EPC) generator module, EPCgen, to provide energy rating certification. Then, EPCgen:

1. calculates the asset rating of the Actual building as the normalised ratio of the BER to the SER in England, Wales, and Northern Ireland (in Scotland, the asset rating equals the BER rounded to the nearest whole number, and the Reference building is not needed), and converts it into an energy band on an A-G scale.

Reports are prepared to the standard format to provide:

1. a certificate showing the asset rating and energy band of the Actual building;
2. a report setting out recommendations for cost-effective improvements to the energy performance of the Actual building.

Intermediate results produced by SBEM are available, in electronic format, to assist in diagnostic checks on the proposed building, in the form of:

1. data reflection (to confirm data entry associated with the generated results);
2. monthly profiles of energy use (consumption) by each end use and fuel type;
3. total electricity and fossil fuel use and resulting carbon dioxide emissions and primary energy (or delivered energy for Scotland).

3.2. Inputs and information sources

The inputs to the energy calculation include:

- physical configuration of the different areas of the building (geometry);
- internal conditions to be maintained in each activity zone (area in which identifiable, standardised activities take place);
- external conditions (weather at location);

- factors affecting fabric and ventilation heat losses, including insulation levels, thermal bridges, airtightness, deliberate natural ventilation, etc.;
- expected heat gains which are determined by the occupancy pattern, installed equipment (including lighting and IT), and solar heat gains which will depend on glazing areas, properties, and orientation, and location of the building;
- information about the heating, cooling, lighting, and other building services systems.

The input module iSBEM acts as the interface between the user and the SBEM calculation engine. As far as possible, the user is guided towards appropriate databases, and then the input is formatted so that data is presented correctly to the calculation engine.

The steps involved in the input are broadly as follows:

- User defines the activities taking place and inputs the areas they occupy in the proposed/Actual building;
- Conditions in each of those areas are determined from a standard activity database;
- Durations of those conditions in each activity area are established from the activity database;
- User inputs the areas and constructions of the building components surrounding each activity area;
- User selects, from the standard weather database, a set of weather data relevant to the building location;
- User selects HVAC and lighting systems and their control systems, and indicates which activity areas they serve;
- Provided that supporting evidence is available, the user is enabled to over-write default assumptions for construction and building services parameters;
- Finally, the interface enables the user to see reports on the CO₂ emissions and primary energy (or delivered energy for Scotland) comparisons and compliance check undertaken by the BRUKL module, and/or the asset rating and energy band determined by the EPCgen module.

Hence, the user interacts with the interface module, iSBEM, and sets up a model of the building by describing its size, how it is used, how it is constructed, and how it is serviced. After the calculations are performed, the results and output reports become accessible through the interface.

When the calculation is used for building regulations compliance checking or energy performance certificate purposes, the software draws information from the sources described below.

3.2.1. User input

The user identifies the zones suitable for the analysis, according to the zoning rules (see Section 3.4.1) by examining the building and/or its drawings. The user describes the geometry of the building, i.e., areas, orientation, etc. of the building envelopes and zones, using location plans, architectural drawings, and, if necessary, measurements on site.

3.2.2. Accessible databases

By interacting with the software interface, the user can access databases for standardised construction details and for accepted performance data for heating, ventilation, and air-conditioning systems. These databases are 'accessible' in that the user can override some default parameters by supplying their own data.

Hence, the user provides the software with the U-value and thermal capacity for the building envelope elements, the HVAC systems efficiencies, and lighting data and controls by either selecting from the internal databases, using the 'inference' procedures, or inputting parameters directly (see Sections 3.3.2 and 3.3.3).

3.2.3. Locked databases

SBEM also draws information from some 'locked' databases on activity parameters and weather data. These databases are 'locked' because the user cannot alter or override their parameters as they need to be the same for similar buildings to allow fair and consistent comparison.

Hence, the selection of occupancy conditions and profiles for spaces with different activities come from a database inside the software determined by the user-selected building type and zonal activity (see Section 3.3.1). The external conditions come from the internal weather database determined by the user-selected location (see Section 3.3.4).

3.3. Databases

3.3.1. Activities

3.3.1.1. Overview of the Activity Database – purpose and contents

The NCM requires the activity definitions for a building to be defined by selecting from a set of standardised activities. For this purpose, an Activity Database has been prepared, and is available from the UK-NCM website⁴. The database contains a comprehensive list of building types (see Table 1 for the full list), and the space types that typically exist in each one (see Table 2 for the full list). Each building type has a selection of the activity types to choose from.

The NCM divides each building up into a series of zones (following the zoning rules – see Section 3.4.1), each of which may have different internal conditions or durations of operation. This enables the calculation to be more analytical about the energy consumption of a mix of uses in a particular building, rather than relying on a generic building type such as "office" or "school". For instance, an "office" building may mean anything between a set of cellular offices, meeting rooms, and circulation spaces that are only occupied during the normal working day, and a dedicated 24-hour call centre. The approach of setting up multiple activity areas allows such buildings to be defined more correctly.

In order to achieve consistency in comparisons between similar buildings, which may be used in different actual operating patterns, a number of parameters for the activity areas are fixed for each activity and building type rather than left to the discretion of users. These are mainly:

- Heating and cooling set-point temperatures;
- Lighting standards;
- Ventilation standards;
- Occupation densities and associated internal gains;

- Gains from equipment;
- Internal moisture gains in the case of swimming pools and kitchens;
- Duration when these set-points, standards, occupation densities, and gains are to be maintained;
- Set-back conditions for when they are not maintained;
- Hot water requirements.

The data are drawn from respected sources, such as CIBSE recommendations, supplemented and modified where necessary to cover activity areas not listed in such sources.

Users should bear in mind that these data are used by the calculations for the proposed/ Actual, Notional, and Reference buildings, as with the choice of weather location. The need is to ensure that comparisons with the Notional and other buildings are made on a standardised, consistent basis. For this reason, the energy and CO₂ emission calculations should not be regarded as predictions for the building in actual/real use.

Details of the parameters and schedules included in the database along with details on how they are used to calculate the values needed for SBEM, or any other energy simulation software, are described below.

As part of improving consistency of application and compliance, the activities in the NCM Activity Database were driven by the “Planning Use Class” so that the list of building types closely aligned with the Town and Country Planning (TCP) Use Classes⁶, although the class codes have now been removed from view in the NCM Activity Database and the software, considering the recent amendments to the system of use classes.

Building Type	Description
Retail and Financial/Professional services	Shops, retail warehouses, hairdressers, undertakers, travel and ticket agencies, post offices, pet shops, sandwich bars, showrooms, domestic hire shops, dry cleaners and funeral directors. Banks, building societies, estate and employment agencies, professional and financial services and betting offices. It also includes launderettes.
Restaurant and Cafes/Drinking Establishments and Hot Food takeaways	For the sale of food and drink for consumption on the premises - restaurants, snack bars and cafes. Public houses, wine bars or other drinking establishments (but not night clubs). Also premises for the sale of hot food for consumption off the premises.
Offices and Workshop businesses	Offices, research and development, light industry appropriate in a residential area.
General Industrial and Special Industrial Groups	Used for the carrying on of an industrial process other than one falling within TCP Use class B1 (Offices and Workshop businesses) and including those within TCP Use classes B3 to B7.
Storage or Distribution	Used for storage or as a distribution centre.
Hotels	Hotels, boarding and guest houses where no significant element of care is provided.
Residential Institutions - Hospitals and Care Homes	Residential care homes, hospitals and nursing homes.
Residential Institutions - Residential schools	Residential boarding schools, residential colleges and training centres. These follow a schedule of work similar to the schools schedule (with similar working days, breaks and holiday periods).

⁶Town and Country Planning (Use Classes) Order 1987 as amended. The Town and Country Planning (Use Classes) (Amendment) (England) Regulations 2020 came into force on 1st September 2020 and amended the Town and Country Planning (Use Classes) Order 1987. https://www.planningportal.co.uk/info/200130/common_projects/9/change_of_use

Residential Institutions - Universities and colleges	Universities and other residential campuses. These follow a schedule of work similar to the universities schedule (with similar working days, breaks and holiday periods).
Secure Residential Institutions	Use for a provision of secure residential accommodation, including use as a prison, young offenders institution, detention centre, secure training centre, custody centre, short term holding centre, secure hospital, secure local authority accommodation or use as a military barracks.
Non-residential Institutions - Community/Day Centre	Crèches, day nurseries and day centres.
Non-residential Institutions - Crown and County Courts	Law courts
Non-residential Institutions - Education	Non-residential education and training centres.
Non-residential Institutions - Libraries Museums and Galleries	Art galleries, museums and libraries.
Non-residential Institutions - Primary Health Care Building	Non-residential clinics and health centres.
General Assembly and Leisure plus Night Clubs and Theatres	Cinemas, music and concert halls, bingo and dance halls, swimming baths, skating rinks, gymnasiums or sports arenas (except for motor sports or where firearms are used). This type also includes night clubs and theatres.
Others - Car Parks 24 hrs	Enclosed or underground car park reserved for parking cars with 24 hrs operation.
Others - Emergency services	Includes fire stations.
Others - Miscellaneous 24hr activities	Miscellaneous 24hr activities.
Others - Passenger terminals	Airport, Bus, Train and Sea Port passenger terminals.
Others - Stand alone utility block	Modular building that just provides shower/toilet facilities.
Residential spaces	Residential spaces within non-domestic buildings not designed or altered for use as a separate dwelling (as defined in CLG's Guide to energy performance certificates for the construction, sale and let of non-dwellings, section 4.4).

Table 1: List of building types

Activity Type	Description
24 hrs Consulting/treatment areas	For all A&E consulting/treatment/work areas, occupied and conditioned 24 hours a day.
24x7 Bedroom Unit	En-suite bedrooms for patients with 24 hrs occupancy.
24x7 Circulation area (corridors and stairways)	For all 24x7 hrs circulation areas such as corridors and stairways.
24x7 Generic Office Area	Areas to perform 24 x7 hrs office work including offices and meeting rooms. It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space, areas for photocopiers and fax machines and staff lounges.
24x7 Reception	An area often containing a reception desk and reception staff with transient occupancy. It also includes patient waiting area.
24x7 Toilet	Any toilet areas. If toilets are subsidiary to changing/shower activities refer to Changing facilities with showers.
24x7 Warehouse storage	Large (warehouse sized) storage areas (unchilled) with 24 x 7 operation. If additional activities with 24x7 schedules are required (e.g. circulation, toilets) use the activities provided under building type "Others - Miscellaneous 24hr activities".
Assembly areas / halls	An area which can accommodate a large number of seated people. This could include a stage area.
Auditoria	Theatre auditoria spaces.
Bathroom	Contains a bath and/or shower and usually a basin and toilet. Also to be used for bathrooms for staff and relatives accommodation.
Bedroom	Bedroom
Bedroom Only	Guest bedroom without a bathroom.

Bedroom Unit	En-suite bedrooms with no occupancy during day time, mainly for relatives or staff. Also for nursing home bedrooms. For patient private bedroom units with 24hr occupancy use activity "24x7 Bedroom Unit".
Car Park	Area designated for parking cars (enclosed or underground)
Cell (police/prison)	A room which accommodates one or more prisoners.
Changing facilities with showers	An area used for changing, containing showers. This activity should be assigned to the shower area and all associated changing areas. For areas which can be used to for changing but which do not contain showers, such as a cloak room/locker room, use the Generic Office Space.
Changing facilities with showers - High usage	An area used for changing, containing showers - high HW usage. This activity should be assigned to the shower area and all associated changing areas. For areas which can be used to for changing but which do not contain showers, such as a cloak room/locker room, use the Generic Office Space.
Changing facilities with showers - Low usage	An area used for changing, containing showers - low HW usage. This activity should be assigned to the shower area and all associated changing areas. For areas which can be used to for changing but which do not contain showers, such as a cloak room/locker room, use the Generic Office Space.
Changing facilities with showers - Medium usage	An area used for changing, containing showers - medium HW usage. This activity should be assigned to the shower area and all associated changing areas. For areas which can be used to for changing but which do not contain showers, such as a cloak room/locker room, use the Generic Office Space.
Circulation area (corridors and stairways)	For corridors and stairways when these are separated from Office spaces, e.g. stairwells for access to other parts of the building.
Circulation area (corridors and stairways) - non public	For all non-public corridors and stairways. For public circulation spaces select Eating/drinking area.
Circulation area (corridors and stairways) - non-public/restricted	For restricted circulation areas such ward & department circulation, corridor sub-waiting, and domestic circulation (staff accommodation).
Classroom	For areas used for teaching/seminars which are not lecture theatres.
Common circulation areas	For all common circulation areas such as corridors and stairways outside the dwelling.
Computer lab	High density desk-based work space with correspondingly dense IT.
Data Centre	For data centres such as a web-hosting facilities, with 24hr high internal gains from equipment and transient occupancy.
Dept Store Sales area - chilled	A sales area in Department Stores designed to accommodate a considerable quantity of fridges/freezers such as a supermarket or food hall.
Dept Store Sales area - electrical	Sales areas in Department Stores designed to accommodate considerable electrical equipment loads such as lighting sales areas and IT/TV/Hi-fi sales areas.
Dept Store Sales area - general	All Sales areas in Department Stores which do not have a large concentration of fridges/freezers or electrical appliances.
Diagnostic Imaging	For areas which contain diagnostic imaging equipment (such as MRI and CT scanners, Bone Mineral Densitometry, Angiography, Mammography, PET, General Imaging, Linear Accelerator, Ultrasound). This category should be used for any associated plant areas where people work.
Display and Public areas	All public circulation areas where people are walking/sitting and where display items are exhibited / available normally using display lighting.
Display window	An area where display lighting is used to illuminate items with glazing onto the outside such as a shop window, but which is boxed/enclosed, separated from the main retail space.
Domestic Bathroom	An area specifically used for bathing/washing. Contains a bath and/or shower and usually a basin and toilet.
Domestic Bedroom	An area primarily used for sleep.
Domestic Circulation	For all circulation areas within the dwelling.

Domestic Dining room	An area which is primarily used for eating meals.
Domestic Kitchen	The area within the dwelling where food is prepared
Domestic Lounge	The main reception room of the home.
Domestic Toilet	An area containing a toilet and basin which is separate from the main bathroom
Dry sports hall	An area where indoor sports can be played.
Eating/drinking area	Areas where food or drink are consumed by staff and visitors, e.g. canteen or office restaurant sitting areas.
En suite bedroom	Guest bedroom unit including bedroom and on suite bathroom. Contains a bath and/or shower and usually a basin and toilet.
Fitness Studio	An area used for exercising/dance, usually with high person density but with no machines.
Fitness suite/gym	An area used for exercise containing machines.
Food preparation area	Areas where food or drinks are prepared for staff and visitors, e.g. kitchen in canteen or office restaurant.
Generic Checkin areas	Areas designated for check in, which may contain conveyer belts; security check areas, which may include equipment such as x ray machines; and baggage reclaim areas.
Generic Office Area	Areas to perform office work including offices and meeting rooms. It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space, areas for photocopiers and fax machines and staff lounges.
Generic Ward	For all areas containing beds which accommodate either single or multiple patients. It includes toilets, ward storage, staff accommodation, day patient accommodation and intensive care units.
Hall/lecture theatre/assembly area	An area which can accommodate a large number of seated people.
Heavy Plant Room	For heavy plant rooms with 24hr low-medium internal gains from equipment and transient occupancy.
Hydrotherapy pool hall	The area in which the hydrotherapy pool is contained.
Ice rink	An area which contains an ice rink.
Industrial process area	An area for industrial process work, usually involving large machinery or equipment.
Laboratory	A facility that provides controlled conditions in which scientific research, experiments, and measurement may be performed.
Laundry	An area used only for washing and/or drying clothes using washing machines and/or tumble dryers. This is not for where there is an individual washing machine within another space (e.g. a food preparation area).
Light plant room	Areas containing the main HVAC equipment for the building e.g.: boilers/air conditioning plant.
Lounges	All areas where passengers are walking/sitting which are not covered by the other space types. This includes departure lounge, corridors, stairways and gate lounges.
Office and consulting areas	Areas to perform management, office and administration work separated from standard customer/public areas. It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space and staff lounges.
Operating theatre	For the operating theatre suite, including anaesthetic, scrub & preparation rooms.
Performance area (stage)	For stages with dedicated lighting and equipment in addition to that within the remainder of the space. For stages within other activity areas which do not have specific lighting or additional electrical equipment, do not define these as separate spaces.
Physiotherapy Studio	For all physiotherapy areas, e.g., Fitness Suite/Gym, activity area, Cardiac stress test area.
Post Mortem Facility	Post-Mortem Facility (including Observation room and body preparation area)

Public circulation areas	All public circulation areas such as a foyer. For non-public spaces use "Circulation areas (corridors and stairways) - non-public"
Reception	The area in a building which is used for entry from the outside, from other building storeys or in general waiting areas containing a reception desk.
Residents common rooms	TV lounges and other common spaces for use of residents. It may contain some hot drink facilities.
Residents kitchen	Common area kitchens used by residents, e.g. in residents' halls.
Retail Warehouse Sales area - chilled	A sales area in Retail Warehouses designed to accommodate a considerable quantity of fridges/freezers such as a supermarket or food hall.
Retail Warehouse Sales area - electrical	Sales areas in Retail Warehouses designed to accommodate considerable electrical equipment loads such as lighting sales areas and IT/TV/Hi-fi sales areas.
Retail Warehouse Sales area - general	All Sales areas in Retail Warehouses which do not have a large concentration of fridges/freezers or electrical appliances.
Sales area - general	All Sales areas which do not have a large concentration of fridges/freezers or electrical appliances.
Server Room	For areas such as computer server spaces with 24hr low-medium internal gains from equipment and transient occupancy. For an area with 24hrs high gains from equipment, use the 'Data Centre' activity.
Small Shop Unit Sales area - chilled	A sales area in Small Shop Units designed to accommodate a considerable quantity of fridges/freezers such as a supermarket or food hall.
Small Shop Unit Sales area - electrical	Sales areas in Small Shop Units designed to accommodate considerable electrical equipment loads such as lighting sales areas and IT/TV/Hi-fi sales areas.
Small Shop Unit Sales area - general	All Sales areas in Small Shop Units which do not have a large concentration of fridges/freezers or electrical appliances.
Store Room	Areas for un-chilled goods storage with low transient occupancy.
Swimming pool	The area in which a swimming pool is contained. This activity should be used for the whole pool hall.
Teaching Areas	Teaching areas which include classrooms and corridors providing access to and between classrooms.
Toilet	Any toilet areas. If toilets are subsidiary to changing/shower activities refer to Changing facilities with showers.
Waiting Rooms	Enclosed waiting spaces with no through flow of people, e.g. in the transport terminal areas. For larger, more open waiting areas such as departure lounges and gate areas use "Lounges".
Warehouse storage	Large (warehouse sized) storage areas (unchilled).
Workshop - small scale	Area for sedentary light practical work, often containing some machinery, e.g. key cutting or shoe repairing. As per the definition, light industry appropriate in a residential area.

Table 2: List of Activity areas with definitions (in some cases the definition will change slightly depending on building type)

3.3.1.2. Occupation densities and associated internal gains

An occupancy density, metabolic rate, and schedule of occupancy are used to calculate the internal heat gains from people. The percentage of the metabolic gains which are sensible rather than latent (released as moisture) is also taken into account.

3.3.1.3. Heating and cooling set-points and set-back temperatures

The heating and cooling set-points define the conditions which the selected HVAC system will be assumed to maintain for the period defined by the heating and cooling schedules. For the unoccupied period, the system will be assumed to maintain the space at the set-back temperature defined in the database (set-back temperatures are not currently used by SBEM).

3.3.1.4. Lighting standards

The database contains the illuminance levels (in lux) which need to be maintained in each activity area for the period defined by the lighting schedules. This level of illumination is then provided by the lighting system selected by the user. In addition to general lighting, some activities are assumed to have display lighting. The lux levels, along with the user selected lighting system, are used to calculate the heat gains from lighting within SBEM.

3.3.1.5. Ventilation requirements

The database contains the required fresh air rate for each activity for the occupied period. This value is used along with the occupancy (as described below) to calculate the quantity of ambient air which then needs to be heated or cooled to the required heating or cooling set-point. Whether or not the activity will include high pressure filtration is also defined in the database (such as hospital operating theatres), although it is possible for the user to override this flag in the iSBEM interface.

3.3.1.6. Heat gains from equipment

Following a similar procedure to calculating heat gains from people, the database calculates the expected heat gains from equipment for each activity based on the Watts per m² and schedules of activity.

3.3.1.7. Humidity requirements

The database contains the maximum and minimum humidity requirements for each activity. This information is for dynamic simulation models and not currently used by SBEM.

3.3.1.8. Hot Water requirements

A hot water demand is defined for all occupied spaces and is determined by the activity selected for the space from the NCM Activity Database, i.e., the hot water demand is associated with the occupied spaces rather than the spaces where the hot water is accessed/drawn-off. For example, there is a demand assumed to arise from the occupants of an office for activities such as washing hands and washing-up cups. This demand is associated with the office rather than the toilet or kitchenette next door.

3.3.2. Constructions

The SBEM user can specify the U-value and thermal capacity information for a particular wall, door, roof, or floor (or the U-value, light transmittance, and solar transmittance for a particular window, rooflight, or glazed door) for which the construction is accurately known. Where the construction is less precisely known, the SBEM user can make use of the NCM

Construction and Glazing Databases. These databases contain a library of constructions covering different regulation periods and different generic types of construction and glazing systems.

The user may access a particular construction directly from the library by selecting first the generic type of construction and then selecting the particular construction which appears to match most closely the actual construction. Once the user has selected the construction, the database provides a U-value and thermal capacity and, in the case of glazing, a U-value and solar and light transmittance, and these values are then fed directly into the SBEM calculation.

For cases where the SBEM user has only minimal information, SBEM has an inference procedure. When using the inference procedure, the user supplies basic data such as the sector (building use), the building regulations that were in use at the time of construction, and a description of the generic type of construction. SBEM will then select the type of construction which most closely matches the description selected in the inference and will use this construction as the basis for the U-value and thermal capacity value that are to be used in the calculation.

3.3.3. HVAC system efficiencies

3.3.3.1. Definitions

The definition of “system efficiency” for HVAC systems is less straightforward than appears at first sight because of the difficulty of attributing energy for fans, pumps, and controls to the different end-uses (heating, cooling, and ventilation). The standards resolve this by separating the energy associated with these, mainly transport, components from the losses associated with the generation of heating or cooling from fuels or electricity. The energy associated with fans, pumps, and controls is treated as a separate item denoted as “auxiliary energy”. The consequent definitions for system heating and cooling efficiencies then become more straightforward - but are now different from the more familiar meanings that include the auxiliary energy.

“Auxiliary Energy”: is the energy used by the fans, pumps, and controls of a system, irrespective of whether this supports heating, cooling, or ventilation.

For heating, the “System Seasonal Efficiency”, SSEff, is the ratio of the total heating demand in spaces served by an HVAC system divided by the energy input into the heat generator(s) - typically boilers. It takes account of, for example, the efficiency of the heat generator, thermal losses from pipework and ductwork, and duct leakage. It does not include energy used by fans and pumps.

For cooling, the “System Seasonal Energy Efficiency Ratio”, SSEER, is the ratio of the total cooling demand in spaces served by a system divided by the energy input into the cold generator(s) - typically chillers. It takes account of, for example, the efficiency of the cold generator, thermal gains to pipework and ductwork, and duct leakage. It does not include energy used by fans and pumps. Since many cooling demand calculations only estimate sensible cooling, the definition may be extended to include allowances for deliberate or inadvertent latent loads.

As the demand calculations are carried out monthly, the HVAC system calculations have to be on a similar basis, i.e., explicit hourly (or more frequent) calculation would be incompatible. As a result, we need to calculate values for the three system efficiency parameters for each month.

3.3.3.2. Scope

The calculation of energy consumed by HVAC systems obviously starts with the outputs of the heating and cooling demand calculations. These produce monthly values of heating demand and sensible cooling demand for each space. These demand calculations are for idealised conditions, i.e., perfect temperature controls, uniform air temperatures, etc., so the scope of the term “HVAC system” has to be sufficiently broad to encompass some factors that relate to the spaces themselves.

EN 15243⁷ is the standard that deals with the calculation of HVAC system efficiencies. It contains a number of informative annexes that illustrate different approaches, but it does not prescribe specific calculation procedures. It permits the HVAC system performance to be calculated either monthly or hourly.

The standard identifies nearly 40 mechanisms that can affect the relationship between the cooling or heating demand of a building and the energy used by an HVAC system in meeting that demand. Heating-only systems are covered by the various parts of EN 13790. EN 15243 reflects the scope of EN 13790 where the two standards overlap. Some parts of EN 13790 require levels of detailed information that are impractical for SBEM. In these cases, simplified options addressing the same mechanisms have been used.

In EN 15243, the mechanisms are mapped against 20 or so types of HVAC systems to show which mechanisms may apply to which system types. Any compliant calculation procedure is required to declare which system types it claims to cover, and how it addresses each of the applicable mechanisms. The standard does not prescribe how each mechanism should be handled (although there are “informative” suggestions). SBEM includes all the mechanisms that were in the draft standard at the time SBEM was being developed.

3.3.3.3. Determination of system performance parameters from the mechanisms

The basic energy flow diagram of the HVAC calculation in SBEM is shown below in Figure 1. The basic philosophy is to provide a consistent set of parameters that address all the mechanisms in EN 15243. The energy flow diagram is simplified in that some of the parameters are relatively aggregated - for example, heat pickup in chilled water distribution pipework is expressed as a percentage of the cooling energy flow handled.

Putting reliable values to each mechanism for any given system would be extremely difficult, unreliable, and difficult to check, especially for existing systems. SBEM offers the user a range of system types – the system choice sets standard values for most of the mechanisms. The user is required to input (or accept a default value for) specific fan power, heat or cold generator efficiency, duct and AHU leakage, and fuel. Corrections are then applied to the standard system performance parameters.

At present, system performance parameters and the correction routines are calculated outside SBEM and inserted into look-up tables in the iSBEM interface. Internalising the calculation and providing the user with access to more of the mechanism values is a potential future upgrade.

⁷ CEN EN 15243 Ventilation for Buildings – Calculation of room temperatures and of load and energy for buildings with room conditioning systems.

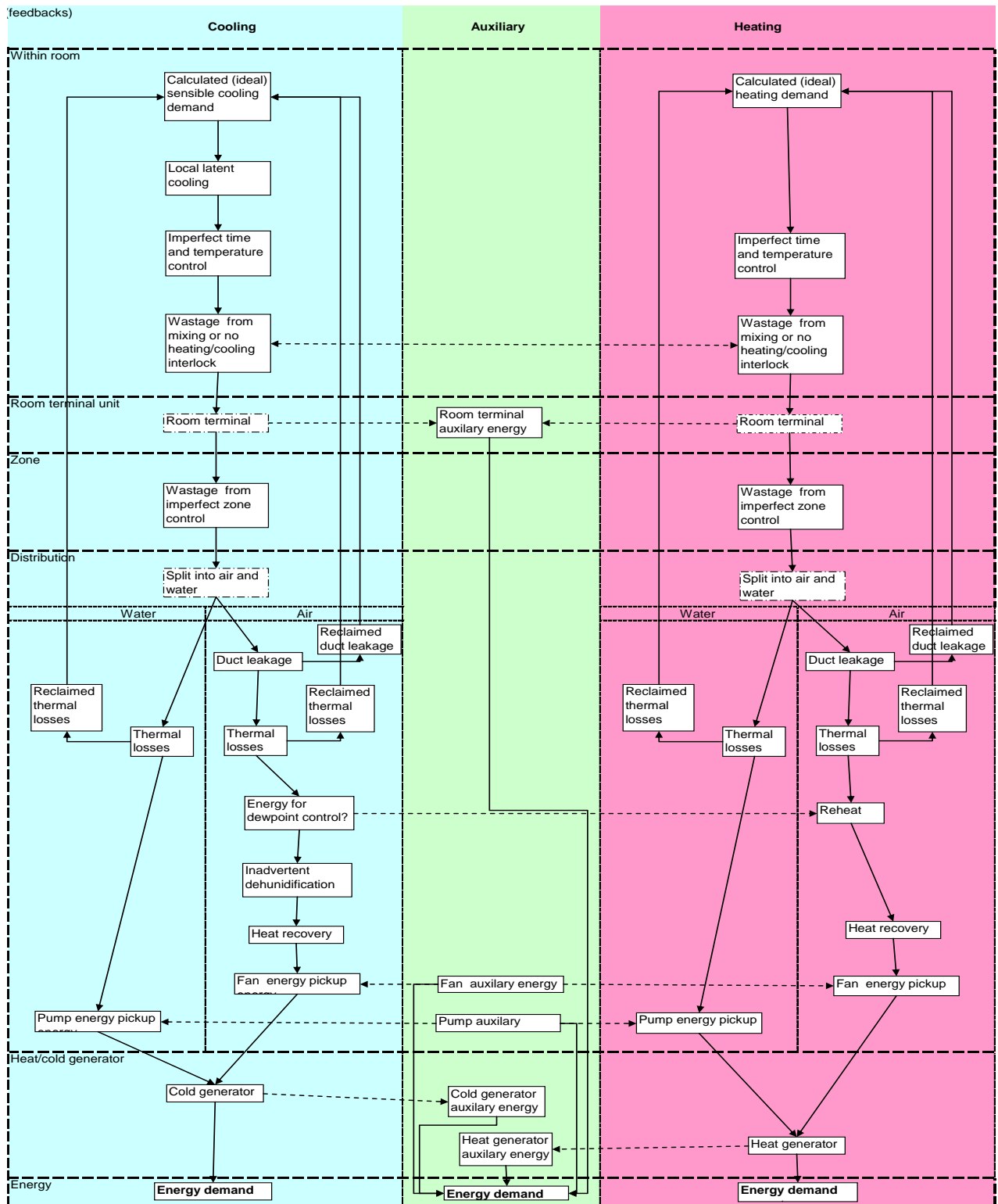


Figure 1: Basic energy flow diagram of the HVAC calculation in SBEM

3.3.3.4. The Mechanisms

The next tables, Table 3 and Table 4, list the mechanisms and summarise key points about them. Table 5 contains a complete parameter list.

HVAC parameters used in SBEM					
<i>Note: this is a subset of the longer list in Table 5a of prEN 15243. It omits, for example, change-over wastage for 2 pipe FCU</i> <i>Note: some values are arbitrary but the overall impact of all assumptions is consistent with simulation results.</i>					
Parameter	Purpose	Source of information	Likely range	Comment	User Access
Controls factor	Allows for presence or absence of time controls, metering and monitoring	ADL2A:	0.9 to 1		Separate input to iSBEM
Terminal auxiliary power parameter	Electricity demand by terminal units	TM32	0.001 to 0.005	Depends on HVAC system type and design	Currently fixed for given system type, possible to provide access in future
Local latent load	Additional demand to sensible load to allow for (local) coils sometimes operating below dewpoint.	Sensible heat ratio values in manufacturers catalogues	0 to 0.25	Depends on HVAC system type and design	Currently fixed for given system type, possible to provide access in future
Terminal Auxiliary pickup factor	Factor for the proportion of terminal fan energy that contributes to cooling load.	Cautious assumption that all fan energy contributes	0 to 1	Depends on terminal design	Currently fixed for given system type, possible to provide access in future
Allowance for imperfect local control (cooling)	Factor added to cooling demand to account for imperfect local time or temperature control	Somewhat arbitrary figures based on CEN draft prEN 15232	0 to 0.02	Depends on control sensor and system performance	Currently fixed for given system type, difficult to find meaningful values that relate to identifiable characteristics
Extra cooling load from mixing reheat etc	Factor added to both cooling and heating demands to account for some systems intentionally (and others through imperfect interlocks) allowing simultaneous heating and cooling	Mixture of factors used by NEN2916 and results of TAS and DOE2 simulations	0 to 0.4	Depends on HVAC system type and design	Currently fixed for given system type, possible to provide access in future
Extra load from imperfect zoning (cooling)	Factor added to demands for systems serving more than one space without local temperature control.	Arbitrary figure (0.05) but not applied to individual room systems.	0 to 0.2	Depends on controls zoning	Effect of different operating periods is picked up automatically from activity databases
Proportion of cooling load handled by air sub-system	Indirectly affects energy performance via assumed fan and pump power, pipe and duct heat gains and duct leakage	Obvious for all-air or all-water systems, otherwise somewhat arbitrary assumption	0 to 1	Depends on system design	Currently fixed for given system type, possible to provide access in future
Duct leakage	Factor added to air quantities. (Implicitly assuming that commissioning will result in correct airflows to spaces!).	Classes for duct and AHU leakage in prEN 15242	0 to 0.3	Depends on extent and quality of ductwork	User selection in iSBEM
Reclaimed leakage losses	Factor to allow for some of the leaked air being useful:	Cautious assumption that nothing is usefully recovered	0 to 1	Depends on location of ductwork	Currently fixed, possible to provide access in future
Duct heat pickup	Factor to allow for effect of heat transfer through duct walls	Based on Dutch standard NEN2916 and other sources	0 to 0.1	Depends on extent and insulation of ductwork	Currently fixed, possible to provide access in future
Reclaimed cold losses (cold ducts)	Factor to allow for some of the lost coolth being useful	Cautious assumption that nothing is usefully recovered	0 to 1	Depends on location of ductwork	Currently fixed, possible to provide access in future
Central latent load	Addition to sensible cooling for systems with central cooling coils.	Based on example calculations in textbooks (assumes no intentional moisture control)	0 to 0.5?	Depends on HVAC system type and design	Currently fixed for given system type, possible to provide access in future
Reheat energy	Factor added to heating demand for systems with dewpoint control	No dewpoint control assumed	0 to 0.5?	Depends on HVAC system type and design	Currently fixed, possible to provide access in future

Table 3: Mechanisms and key points

Mechanism	SBEM process
Within-room mechanisms	
Room heat balance and temperature	Monthly calculation in accordance with EN 13790
Room moisture balance and moisture content	Not addressed
Control and Zoning Issues	
Definition of zones and ability to combine room demands into zonal demands	Explicit definition of zones and ability to combine spaces into zones served by each system
Combination of room conditions into zonal return air state	Perfect mixing assumed
Contribution to room demands from separate ventilation / base cooling system	Choice of HVAC system type sets proportion of load met by sub-systems when appropriate
Contribution to room demands from heat gains or losses from pipes and ducts	Taken as zero
Impact of proportional band on energy supplied	Not explicitly included but fixed factor for imperfect control
Impact of dead band on energy supplied	Not explicitly included but fixed factor for imperfect control
Effect of open-loop control or averaging of sensors	Fixed factor when there is more than one zone.
Effect of absence of interlock between heating and cooling	For new buildings, presence is assumed. For existing buildings, a fixed penalty is applied
Distribution: terminal issues	
Energy penalties from hot/cold mixing or reheat systems	Proportional penalty according to system type
Terminal auxiliary energy.	Proportional to heat demand for unit heaters, fixed default in other cases
Effect of sensible heat ratio of terminal (<i>and risk of condensation</i>)	Fixed sensible heat ratio.
Lack of local time control	For new buildings, presence is assumed. For existing buildings, a fixed penalty is applied
Heat gains and losses from pipes and ducts <i>Includes AHUs and other air-handling components</i>	Fixed percentage loss assumed with no useful contribution to loads
Duct system air leakage <i>Includes AHUs and other air-handling components</i>	User selects class of leakage
Refrigerant pipework heat losses	Ignored
Fan and pump energy pickup	Fixed proportion of fan or pump energy
Heat recovery provision	User selects from list of options
Distribution systems: operation	
Latent demand calculation at central (zonal) plant (<i>includes dew-point control plus reheat</i>)	Fixed sensible heat ratio.
Adiabatic spray cooling	Not included
Additional demands produced by hot deck:cold deck mixing systems	Proportional penalty
Impact of mixing of return water temperature in 3-pipe systems	Ignored
Wastage due to changeover in 2-pipe systems	Ignored
Impact of variable ventilation air recirculation <i>Typically CO2 controlled – total air flow unchanged</i>	Not included explicitly but possible to approximate in input parameters
Impact of air-side free cooling	Provided as an option
Distribution systems: auxiliary energy	
Auxiliary energy use by fans and pumps (other than in terminals)	Calculated according to system type, hours of use and (for fans) SFP
Cold and Heat Generation	
Cold generator (chiller) part-load performance (including multiple installations)	Calculated externally and provided to software
Water-side free-cooling	Can be included in external calculation of seasonal performance
Thermosyphon operation	May in principle be included in external calculation of seasonal performance
Impact on chiller performance of central heat rejection equipment <i>Includes cooling towers, dry coolers etc. Included in overall performance of packaged systems</i>	May in principle be included in external calculation of seasonal performance
Auxiliary energy use by central heat rejection equipment <i>Included in overall performance of packaged systems</i>	For air-cooled equipment, included in calculation of seasonal performance. For water –cooled, fixed proportional penalty is added
Heat generator (boiler) part-load performance. (including multiple installations)	Calculated externally and provided to software
Auxiliary energy use by heat generators <i>Includes gas boosters, fuel pumps, etc. Included in overall performance of packaged systems</i>	Not included
Energy use for humidification	Not included
Bivalent systems <i>Includes boiler + CHP, condensing boiler + non-condensing boiler, heat pump + top-up, evaporative cooling + chiller.....</i>	Not included explicitly but possible to approximate in input parameters

Table 4: Summary of how SBEM deals with the HVAC mechanisms identified in EN 15243

	Cooling Demand	Cooling Demand	Intermediate calculation	Auxiliary	Intermediate calculation	Cooling Demand	Cooling Demand and heating demand	Cooling Demand	Cooling Demand	Cooling Demand	
Parameter	Peak cooling demand	Equivalent full load cooling hours	Room cooling demand	Terminal auxiliary power parameter	Terminal auxiliary energy	Local latent load	Terminal Auxiliary pickup factor	Allowance for imperfect local control	Extra cooling load from mixing reheat etc	Extra load from imperfect zoning	
Description					Fans for FCUs for example	Coils may operate below dewpoint, generating extra demand	Fans etc contribute to load: picked up as extra cooling load and reduction in heating load pro-rata to consumptions	Imperfect time or temperature control will cause extra consumption	Hot/cold mixing systems, 3-pipe systems, imperfect interlock with heating, terminal reheat all add cooling load	Different spaces may have different needs - imperfect time or temperature control will cause extra consumption	
Application	Base for calculation	Base for calculation				Factor applied to room cooling demand - but be careful with the algebra	factor applied to energy use	Factor applied to room cooling demand	Add equal amount to heating demand	Factor	
Units	kW/m2	hours pa	kWhpa/m2	kW/kW	kWhpa/kWhpa cooling	dimensionless		dimensionless	kWhpa/m2	dimensionless	
Comment	Building dependent. Expressed per unit floor area	Building dependent	Building dependent. Expressed per unit floor area	System dependent	System dependent	System dependent		Control and load dependent	System dependent	Building and system dependent	
	Cooling-air and water	Cooling-air	Cooling-air	Cooling-air	Cooling-air	Cooling-air	Heating-water	Cooling-air	Auxiliary	Cooling-air	
Parameter	Proportion of load handled by air sub-system	Duct leakage	Reclaimed leakage losses	Duct heat pickup	Reclaimed cold losses	Central latent load	Reheat energy	Heat recovery or economiser	Specific fan power	Fan energy pickup factor	
Description	Can vary from all air to no air	Can be substantial	Some of the lost coolth may be useful	Heat transfer through duct walls	Some of the lost coolth may be useful	May be inadvertent operation below dewpoint or humidity control	For dewpoint control	Airside free cooling or heat recovery wheel (etc) can reduce net loads	Used to determine fan energy. Both supply and extract	Most of fan energy is transferred to air as heat gain	
Application	factor	Leakage factor - think about the algebra when applying!	factor applied to the duct loss figure	factor	factor applied to the duct heat pickup figure	factor, but be careful with the algebra!	factor, but result is added to heating load	factor applied to room cooling demand		Proportion of fan energy - but remember that fan also runs in non-cooling modes	
Units	dimensionless	dimensionless	dimensionless	dimensionless	dimensionless	dimensionless	kWhpa/m2	dimensionless	W/s	kWhpa/m2	
Comment	system dependent	Depends on quality of ducts and AHUs	Depends on location of ductwork	Depends on extent and insulation of ductwork	Depends on location of ductwork	System dependent	System dependent	System dependent	System dependent	System dependent	
	Auxiliary	Intermediate calculation	Cooling-water	Cooling-water	Cooling-water	Intermediate calculation	Auxiliary	Cooling generation	Cooling generation		
Parameter	Fan run hours	Fan energy	Pipe heat pickup	Reclaimed cold losses	Cooling pump pickup factor	Cooling pump power	Cooling pump energy	Chiller performance	Chiller Ancillaries		
Description	All services. Same figure used for terminals	All services	Heat transfer through pipe walls	Some of the lost coolth may be useful	Most pump energy is transferred to water as heat gain		Depends on pressure drop	Seasonal value - also applied to room units	May need to add cooling towers etc		
Application	Depends on controls	Based on 10 l/s m2 for all-air systems, proportioned to % cooling by air. STP effect increased to allow for extract etc	factor	factor applied to the pipe heat pickup figure	Proportion of pump energy - but remember that pump also runs in non-cooling modes	Taken as 0.01 times wet part of peak cooling load.	Pump power times hours. Operating hours proportioned to loads.	(inverse) factor	factor added to chiller energy consumption, may be included in chiller performance		
Units	hours	kWhpa m2	dimensionless	dimensionless	kWhpa/m2		kWhpa/m2	dimensionless	dimensionless		
Comment			Depends on extent and insulation of pipework	Depends on location of pipework	System dependent		System dependent	depends on chiller, climate etc	depends on chiller, climate etc		
	Heating Demand	Heating Demand	Intermediate calculation	Intermediate calculation	Heating Demand	Heating Demand	Heating-air and water	Heating-air	Heating-air	Heating-air	Heating-air
Parameter	Heating Load	Heating EFLH	Room heating demand	Cooling proportion	Allowance for imperfect local control	Extra load from imperfect zoning	Proportion of load handled by air sub-system	Duct leakage	Reclaimed leakage losses	Duct heat loss	Reclaimed heat losses
Description	Peak heating load		Ideal annual demand	cooling energy demand divided by heating + cooling energy demand	Imperfect time or temperature control will cause extra consumption	Different spaces may have different needs - imperfect time or temperature control will cause extra consumption	Can vary from all-air to no air	Can be substantial	Some of the lost heat may be useful	Heat transfer through duct walls	Some of the lost heat may be useful
Application			Base for calculation	Rather arbitrary value used to split fan and terminal pickup between cooling and heating (and where fan etc energy has to be split between services)	Factor applied to room heating demand	Factor	factor, should this be constrained to be the same as for cooling?	set to be the same as for cooling	factor applied to the duct loss figure	factor	factor applied to the duct heat loss figure
Units	kW/m2	hours pa	kWhpa/m2		dimensionless	dimensionless	dimensionless	dimensionless	dimensionless	dimensionless	dimensionless
Comment	Building dependent	Building dependent	Building dependent		Control and load dependent	Building and system dependent	system dependent	Depends on quality of ducts and AHUs	Depends on location of ductwork	Depends on extent and insulation of ductwork	Depends on location of ductwork
	Heating-air	Heating-air	Heating-air	Heating-water	Heating-water	Heating-water	Auxiliary	Auxiliary	Heat generation	Heat generation	
Parameter	Heat recovery or economiser	Fan power	Fan energy pickup	Pipe heat losses	Reclaimed heat losses	Heating pump pickup	Heating pump power	Heating pump energy	Boiler performance	Boiler Ancillaries	
Description	Heat recovery wheel (etc) can reduce net loads	Pick up from cooling	Pick up from cooling	Heat transfer through pipe walls	Some of the lost heat may be useful	Most pump energy is transferred to water as (useful) heat gain		Depends on pressure drop	Seasonal value - also applied to room units. May be reverse cycle chiller	May need to add gas boosters etc. more relevant for reverse cycle	
Application	factor, but really needs thinking about carefully			factor	factor applied to the pipe heat loss figure	Proportion of pump energy - but remember that pump also runs in non-heating modes	Taken as 0.02 times wet part of peak heating load.	hours times power	(inverse) factor	factor added to boiler energy consumption,	
Units	dimensionless			dimensionless	dimensionless	kWhpa/m2	kW/m2	kWhpa m2	dimensionless	dimensionless	
Comment	System dependent			Depends on extent and insulation of pipework	Depends on location of pipework	System dependent	System dependent	depends on chiller, climate etc	depends on chiller, climate etc		

Table 5: Parameter list

3.3.3.5. Calibration process

As can be seen from Table 3, the likely range of values for each mechanism is known – albeit with varying degrees of reliability. Starting from a set of plausible but sometimes arbitrary figures, the values were progressively revised to provide calibrated combinations of values for each system type.

The process is illustrated in Figure 2.

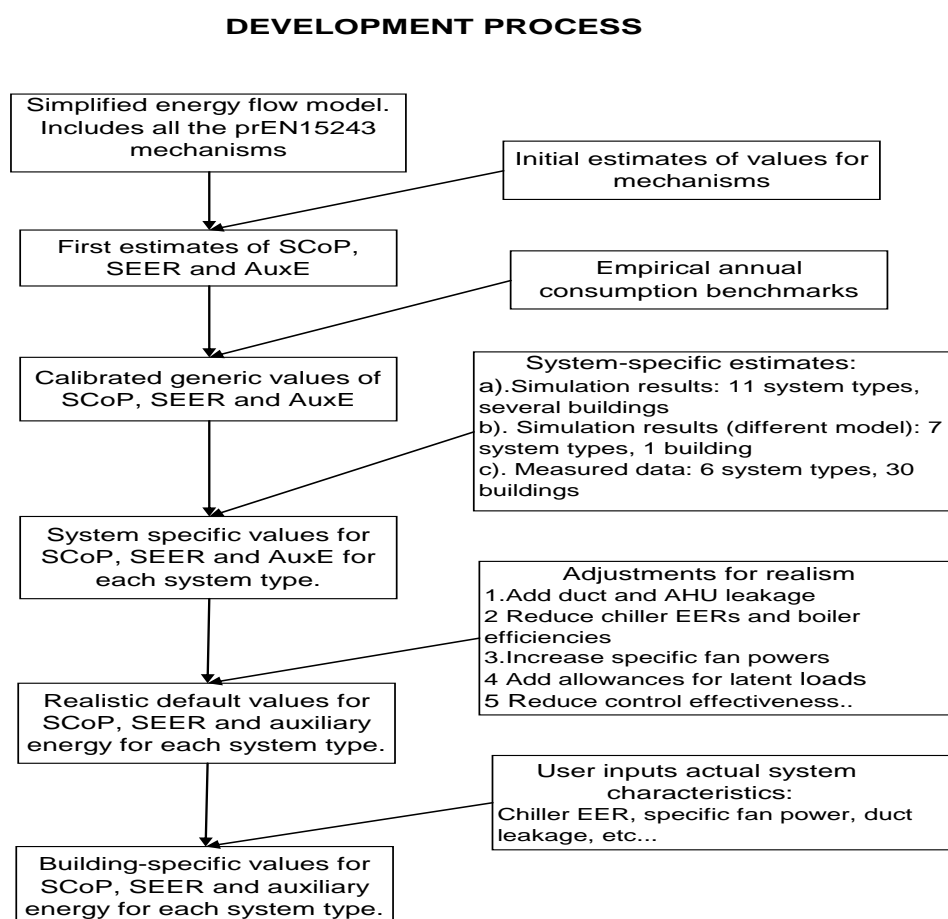


Figure 2: HVAC Model Development Process

We first produced initial estimates of typical values of the flow sheet parameters and calculated initial figures of the three performance parameters (auxiliary energy, SSEff, and SSEER). With some relatively small adjustments to the initial assumptions, the consumption figures that these implied were brought into general alignment with empirical benchmarks, notably ECG 019⁸. This provided us with calibrated generic estimates of the parameter values.

In parallel with this, we brought together several sets of existing comparisons between the energy consumptions of different types of systems in offices. These included two sets of simulation results using different models to compare different systems in identical buildings. One of the studies examined 11 different system types in a number of buildings, while the other examined 7 system types in a single building, but modelled the system components in more detail. We combined these results with measured data from 30 buildings covering 6

⁸ Energy Efficiency - Best Practice Programme (EEBPP) - Energy Consumption Guide 019: Energy Use in Offices.

system types⁹ to develop a set of system-specific values for SSEff, SSEER, and auxiliary energy. For each system type, we then adjusted the spreadsheet parameters until the spreadsheet generated the same figures.

Since the simulations assumed idealised control and other conditions, we then degraded some parameters to provide less optimistic default assumptions. In particular, we added duct and AHU leakage, reduced chiller EERs and boiler efficiencies, increased specific fan powers, added allowances for latent loads, and reduced control effectiveness.

The resulting “default” consumption levels straddle the “typical” consumption benchmarks (some systems being better than the benchmark, others worse). The idealised figures straddle the equivalent “good practice” benchmark.

3.3.3.6. Adjustments to demand figures

There are two system-related issues associated with temperature distributions within spaces that are part of the translation from heating or cooling demand to energy consumption. These are the effects of vertical temperature gradients and of radiant heating or cooling.

Temperature gradient adjustment

General Principle

Vertical temperature gradients increase the average air temperature and thus the heat loss in tall spaces. Some systems generate bigger gradients than others. De-stratification fans (and similar systems) reduce gradients but use energy for fans.

Derivation

This follows the principle summarised in the draft CEN standard (un-numbered at the time, possibly prEN 14335 section 5.1.3).

Assume that there is a linear temperature gradient, with the required comfort temperature, t_c , maintained at 1.5 m above the floor. At this height, air temperature is $t_{1.5}$.

Average air temperature is

$$t_{av} = t_{1.5} + \left[grad \times \left(\frac{h}{2} - 1.5 \right) \right]$$

where

h is the room height, in m, and

$grad$ is air temperature gradient, in K/m.

Assume that surface temperatures are unaffected.

Design operative temperature is

$$\frac{(t_r + t_{1.5})}{2}$$

where t_r is the mean radiant temperature, so nominal heat loss is

⁹ Knight IP, Dunn GN, Measured Energy Consumption and Carbon Emissions of Air-conditioning and Heat-pumps in UK Office Buildings, BSER&T, CIBSE 26(1) 2005.

$$U \times \left[\frac{(t_r + t_{1.5})}{2} - t_o \right]$$

where

U is the total conductance associated with the fabric elements enveloping the space (i.e., the sum of U -value x *envelope area* terms) and

t_o is the outdoor air temperature.

Ignoring how losses vary between floors, walls, and roof, actual heat loss is

$$U \times \left[\frac{(t_r + t_{av})}{2} - t_o \right]$$

Valuing “grad”

Actual heat loss should be based on a temperature that is higher than design value by

$$grad \times \left(\frac{h}{2} - 1.5 \right)$$

For room heights around 3 m, this correction is very small.

From GPG 303¹⁰, typical values of *grad* are:

Type of heating	<i>grad</i>
Radiant heating	0.3 K/m
Radiators	1.5 K/m
Convactor heaters	2.3 K/m

For tall spaces, the temperature adjustment can be significant - for 10 m height, they are:

Type of heating	<i>grad</i>
Radiant heating	1.1°C
Radiators	5.3°C
Convactor heaters	8.1°C

De-stratification systems (either de-stratification fans or high level downflow air heaters) gain a benefit of reducing or removing this gradient, but their fan energy use is added to the energy calculation.

¹⁰ GPG 303: The designer's guide to energy efficient buildings for industry.

3.3.3.7. Direct radiation from Heating and Cooling Systems

General Principle

Direct radiation falling on occupants allows a lower air temperature for a given level of thermal comfort. This, in turn, reduces ventilation losses.

Derivation

EN 15316-2-1 provides tabulated values of corrections based on detailed simulations of specific cases. These are difficult to capture within the structure of SBEM, and the following simplified, but more flexible process, has been derived. In practice, it gives similar corrections to those of the EN for the situations reported there.

Thermal comfort criteria are defined as a weighted mean (commonly the simple average) of the air and mean radiant temperature in a space. For practical purposes, it is usual to replace the mean radiant temperature by the mean internal surface temperature of the space and to ignore direct radiation from the heating system.

As is well-known from the use of sol-air temperatures, the effect of direct radiation is equivalent to a temperature increase of the surroundings equal to the product of the radiant intensity, I , the absorption coefficient, a , and the surface heat loss resistance, r .

Reduction in air temperature

Radiation from the heating system will also fall on the surfaces of the space. For a given indoor air temperature, this will increase the surface temperatures, and therefore the fabric heat losses. Different surfaces will be affected to different extents. However, if the air temperature is lowered to provide a constant comfort temperature, this will tend to reduce the surface temperature. As a simplification, assume that, for a given comfort level, the mean internal surface temperature is independent of the amount of direct radiation from the heating system.

With this assumption, we can calculate the air temperature reduction needed to maintain the same comfort temperature in the presence of direct radiation. If the comfort temperature t_c is expressed as the arithmetic mean of air and mean surface temperature, t_a and t_s , respectively, we have

$$t_c = (I \times a \times r) + \left(\frac{t_a + t_s}{2} \right)$$

and the reduction in air temperature due to direct radiation is

$$2 \times I \times a \times r = dt.$$

Radiant intensity

For heat emitters, such as heated floors, the proportion of heat output that is radiant can be determined from the radiant and convective heat transfer coefficients. For radiant heating systems, the radiant component is

$$Q_t \times \frac{\eta_r}{\eta_t}$$

where

Q_t is the total heat output;

η_r is the radiant efficiency;

η_t is the total efficiency of the system.

Not all the radiant energy falls on the occupied area. Denote the proportion that does as d . The occupied area will usually be the floor area of the space, A .

Therefore, the radiant intensity on the occupied area is

$$I = d \times Q_t \times \left(\frac{\eta_r}{\eta_t \times A} \right)$$

Correction factor

The heating requirement for the space is

$$Q_t = (t_i - t_o) \times (U + V) - dt \times V$$

where

t_i is the internal temperature (strictly speaking, environmental temperature, but assume comfort temperature);

t_o is the outdoor air temperature;

U is the total conductance associated with the fabric (i.e., the sum of U value \times envelope area terms), W/K;

V is the ventilation conductance, W/K.

(For purely convective heating, dt is zero, and we have the conventional formula).

However, we know that dt is proportional to Q_t .

For brevity, set $dt = k \times Q_t$.

Substituting and rearranging, we obtain

$$Q_t = \frac{(t_i - t_o) \times (U + V)}{(1 + k)}$$

That is, the conventional heat demand is multiplied by a factor $\frac{1}{(1+k)}$

Valuing “k”

V , the ventilation conductance, is $0.33 \times N \times \text{room volume}$ where N is the ventilation rate in ac/h.

So

$$k = 2 \times a \times r \times d \times 0.33 \times N \times \text{room volume} \times \left(\frac{\eta_r}{\eta_t \times A} \right)$$

And $\frac{\text{room volume}}{A}$ is equal to room height, h .

A typical value of a is 0.9, and of r , 0.123.

RADIANT HEATING SYSTEMS:

The radiant efficiency of a radiant heater is measured taking into account only the downwards radiation so, in a very large space, we might expect d to approach 1. More commonly, some radiation will fall on (the lower part of) walls.

As a default, it is proposed that d should be equal to 0.6 (for typical radiant heaters, this yields results close to those proposed by the industry using alternative reasoning).

$$k = 0.00438 \times N \times h \times \frac{\eta_r}{\eta_t}$$

k increases with increasing ventilation rate, room height, and radiant efficiency;

$\frac{\eta_r}{\eta_t}$ is a property of the radiant heater. A value of 0.5 would be reasonable as a default; rising to 0.7 for ECA-listed radiant heaters.

Note that, having calculated the heat demand, it is still necessary to divide by η_t to obtain fuel consumption.

OTHER TYPES OF SYSTEM:

The same logic applies to all heating systems that have a radiant component. For systems operating reasonably close to room temperature, the $\frac{\eta_r}{\eta_t}$ term simply represents the proportion of the output that is radiant.

The following values are suggested:

Emitter	$\frac{\eta_r}{\eta_t}$	d
Radiator	0.56	0.25 (includes 50% straight to wall behind radiator)
Heated floor	0.55	0.60
Chilled ceiling	0.55	0.40

The corrections are smaller but typically in the range 5% to 10%.

3.3.3.8. Energy Use Calculation for Hot Water in SBEM

The basic calculation scheme is straightforward:

- Hot water demand is taken from the NCM Activity Database. It is expressed per unit of floor area, but this reflects occupancy density and nominal consumption per person for the activity in question.
- Heat losses from storage and distribution are added (if they are present).
- Heat losses associated with residual hot water in distribution pipes of more than 3 metres in length are added.
- Energy consumption is calculated using the heat generation efficiency.
- CO₂ emissions and primary energy are calculated depending on the fuel source.
- Additionally, if there is a secondary circulation system, auxiliary energy and the consequent CO₂ emissions and primary energy are calculated.

The calculation does not take account of detailed draw-off patterns or of adequacy of service. Energy use by any secondary pump and heat losses from secondary pipework reflect the hours of operation defined in the NCM Activity Database.

The user can define values for the parameters below. In most cases, default (rather pessimistic) assumptions are provided.

- monthly storage losses (derived from heat loss per litre of stored hot water)
- storage volume
- insulation type and thickness on storage vessel
- length of secondary pipework
- heat loss per metre of secondary pipework
- secondary pump power

- heat generation efficiency

3.3.3.9. Heat and Cold generator seasonal efficiency

These values should be provided by the user to over-write the pessimistic default values. The calculation of the seasonal efficiency of boilers and (especially) chillers is not entirely straightforward, especially when there are multiple chillers and a degree of oversizing. Methods of handling this have been reported elsewhere^{11,12}.

3.3.4. Weather

In order to calculate the reaction of the building and systems to the variable loads imposed by the external environment, the NCM needs an input of weather data. In addition, information regarding weather data is necessary to calculate the energy yield by some renewable energy systems, such as solar and wind technologies.

Although some accredited NCM software may only require monthly figures, other software will require year-round hourly data on the following parameters for each location:

- Dry and wet bulb temperature;
- Global and diffuse solar radiation (from which radiation for any slope and orientation of surface can be calculated);
- Wind speed and direction.

In order to provide consistency of application, standard weather sets have been adopted as the only weather data sets to be used as part of the NCM. These are the 2016 CIBSE Test Reference Years¹³. The available sites are: Belfast, Birmingham, Cardiff, Edinburgh, Glasgow, Leeds, London, Manchester, Newcastle, Norwich, Nottingham, Plymouth, Southampton, and Swindon. Thus, the only option to be made available to the NCM user is to choose a weather location closest to, or most representative of, the actual site of the project.

3.4. Building geometry

There is a number of stages to defining the geometry of the building in the interface:

- Zone the building on the drawings according to the zoning rules shown in Section 3.4.1.
- After “zoning” the building, create the zones in the interface (i.e., select their building and activity types), and enter their basic dimensions, i.e., area, height, air permeability, etc.
- Define the envelopes of each zone, in terms of their type, i.e., walls, floor, ceiling/roof, areas, orientations, the conditions of the adjacent spaces, the constructions, and any thermal bridges additional to the ones defined in Section 3.4.3.

¹¹ Hitchin, R. and Law, S. The Seasonal Efficiency of Multi-Boiler and Multi-Chiller Installations, Improving Energy Efficiency in Commercial Building (IEECB '06) Frankfurt, 26-27 April 2006.

¹² CEN EN 15243 Appendix I.

¹³ Weather Data provided by the Chartered Institution of Building Services Engineers. To discover more about weather data, the variables available, and Building Regulations compliance, visit: cibse.org/weatherdata.

- Within each envelope element, there may be windows/rooflights or doors. The areas, types, shading systems, and constructions of windows and doors within each envelope element need to be entered.
- Similarly, within the envelope elements or within the window/door, there may be additional thermal bridges, (other than those defined in Section 3.4.3) which need to be defined.

3.4.1. Zoning rules

The way a building is subdivided into zones will influence the predictions of energy performance. Therefore, so as to ensure consistency of application, the NCM defines zoning rules that should be applied when assessing a building for building regulations compliance or energy performance certification.

The end result of the zoning process should be a set of zones which are distinguished from all others in contact with it by differences in one or more of the following:

- The activity attached to it
- The HVAC system which serves it
- The lighting system within it
- The access to daylight (through windows or rooflights).

To this end, the suggested zoning process within a given floor plate is as follows:

1. Divide the floor into separate physical areas, bounded by physical boundaries, such as structural walls or other permanent elements.
2. If any part of an area is served by a different type of HVAC or lighting system, create a separate area bounded by the extent of those services.
3. If any part of an area has a different activity taking place in it, create a separate area for each activity.
4. Attribute just one *activity* to each resulting area.
5. Divide each resulting area into *zones* receiving significantly different amounts of daylight, defined by boundaries which are:
 - At a distance of 6 m from an external wall containing at least 20% glazing.
 - At a distance of 1.5 x room height beyond the edge of an array of rooflights whose area is at least 10% of the floor area.
 - If any resulting *zone* is less than 3 m wide, absorb it within surrounding zones.
 - If any resulting *zones* overlap, use your discretion to allocate the overlap to one or more of the *zones*.
6. Merge any contiguous areas which are served by the same HVAC and lighting systems, and which have the same activity within them (e.g., adjacent hotel rooms, cellular offices, etc.) unless there is a good reason not to.
7. Each *zone* should then have its envelopes described by the area and properties of each physical boundary. Where a *zone* boundary is virtual, e.g., between a daylight perimeter and a core *zone*, no envelope element should be defined. SBEM will then assume no transfer of heat, coolth, or light across the boundary, in either direction. In the context of

iSBEM, the building needs to be divided into separate *zones* for each activity area, subdivided where more than one HVAC system serves an activity area.

3.4.2. Envelope definitions

When the user creates a zone, envelope element, or window, what is being created is referred to in iSBEM as a 'building object'. These building objects need to be linked together correctly in order to define the geometry of a zone. When the user defines an envelope element in the *Envelopes* main tab, they will be prompted to link (or assign) it to a zone. Equally, when the user defines a window in the *Windows & Rooflights* main tab, they are prompted to link it to an envelope element. If the user creates the envelope element or window in the *Quick Envelopes* sub-tab of a particular zone, these links are established automatically.

Figure 3 is an example of a simple zone. To define the geometry of this zone, you would need to create the zone, 6 envelope elements, one window, and one door. The south wall door and window would need to be linked to the south wall, which in turn (along with the other 5 envelope elements) would need to be linked to the zone, as shown by the arrows in the diagram below.

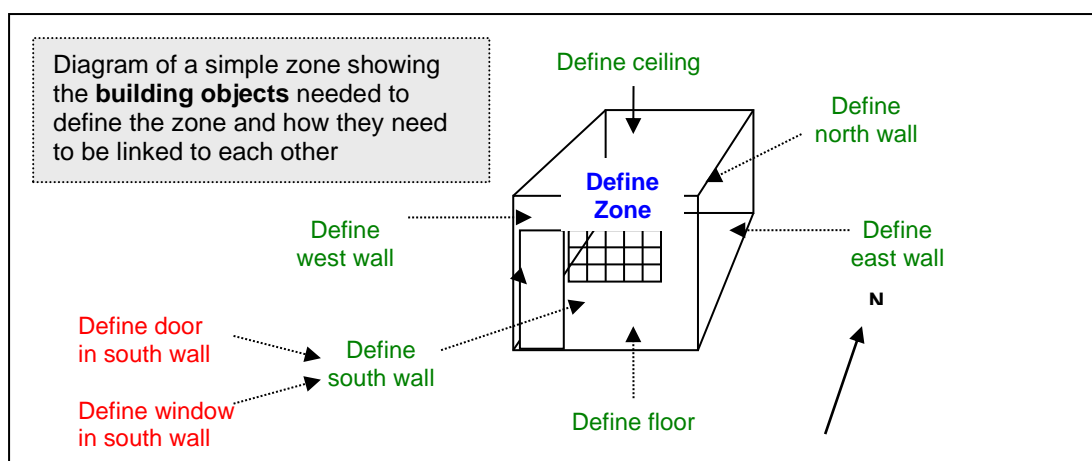


Figure 3: Diagram of building objects needed to define a simple zone

3.4.3. Thermal bridges

There are two types of thermal bridge: repeating and non-repeating. Repeating thermal bridges should be taken into account when calculating the U-value of a construction. Non-repeating thermal bridges can arise from a number of situations, but SBEM is only concerned with those arising from junctions between envelope elements, windows, and doors which are in contact with the exterior. These types of junctions fall into two categories:

- Junctions involving metal cladding
- Junctions not involving metal cladding.

At these junctions between different building elements, there can be additional loss of heat from the building which is not attributed to the U-values and areas of the adjoining elements. The additional heat loss which is attributed to the junction is expressed as a linear thermal transmittance, Ψ (Psi) value, (expressed in W/mK). SBEM contains a table of

types of junctions and default linear thermal transmittance values for each of these types of junctions, shown in Table 6, (which are used unless overwritten by the user). These default values are determined according to the method in BRE IP 1/06: *Assessing the Effects of Thermal Bridging at Junctions and around Openings* and then degraded by the greater of 0.04 W/mK or 50%, as defined in DLUHC's NCM Modelling Guide.

Type of junction	Metal cladding constructions	Non-metal cladding constructions
	Ψ (W/(m·K))	Ψ (W/(m·K))
Roof to wall	0.42	0.18
Wall to ground floor	1.73	0.24
Wall to wall (corner)	0.38	0.14
Wall to floor (not ground floor)	0.04	0.11
Lintel above window or door	1.91	0.45
Sill below window	1.91	0.08
Jamb at window or door	1.91	0.09

Table 6: SBEM's default values for the linear thermal transmittance of thermal bridges, as defined in DLUHC's NCM Modelling Guide

For each type of junction, the user can either enter an Ψ (Psi) value (W/m.K) or accept the default values.

Additional thermal bridging at junctions and around openings, which are not covered in Table 6, can be defined by the user in iSBEM in relation to the relevant building object, i.e., envelope, window, door, etc.

Note: Point thermal transmittances are ignored since point thermal bridges are normally part of plane building elements and already taken into account in their thermal transmittance, U-value.

4. The calculation algorithms

The calculation methodology can, in theory, be based on any process which evaluates the energy consumption, and hence CO₂ emissions and primary energy of a building, as long as it complies with the following NCM requirements:

- Considers the required energy uses
- Draws on standard conditions in the activity area and other databases
- Compares with a Notional building (and Reference building), defined in a standard way

The calculation method in SBEM mostly follows the CEN standard umbrella document PG-N37, which lists a number of relevant standards. The CEN umbrella document PG-N37 provides an outline of the calculation procedure for assessing the energy performance of buildings. It includes a list of the European standards, both existing and those that are to be written, which together form a calculation methodology. In particular, EN ISO 13790 deals with *Energy performance of buildings – Calculation of energy use for space heating and cooling*. Within this standard, there are several optional routes to undertaking the calculation. For instance, it includes three explicit methods – a seasonal calculation, one based on monthly heat balance, and a simplified hourly calculation, and also permits detailed simulation.

It has been decided that a seasonal calculation is unacceptable for the NCM, and that only one implementation of the monthly average calculation method will be accepted in the UK, namely that implemented in SBEM. However, some necessary parts of the calculation are not dealt with explicitly or completely by these CEN standards or draft prEN standards. Where this is the case, alternative acceptable calculation methodologies, to deal with the areas not covered by the standards, were developed. For example, parts of the following energy calculations needed to be determined:

- Fixed lighting with different control systems
- Hot water for washing

4.1. Space heating and cooling energy demand

In EN 13790, the building energy demands for heating and cooling are based on the heat balance of the building zones (Note: EN 13790 only deals with sensible cooling and heating demand in a single room). This energy demand for the building is then the input for the energy balance of the heating and cooling systems, and hence, the CO₂ emissions and primary energy for the building as a whole. The main structure of the calculation procedure is summarised in Table 7. The options chosen for SBEM from those available in the EN ISO 13790, and the resulting equations to be used, are described and/or referenced in Table 8.

1	Define the boundaries of the conditioned and unconditioned spaces, and partition them into zones according to the activities undertaken in them and the conditions required for each of those activities
2	Calculate for each period and each zone, the energy needed to heat or cool them to maintain the required set-point conditions, and the length of the heating and cooling seasons
3	Combine the results for different periods and for different zones served by the same systems and calculate the delivered energy use for heating and cooling taking into account the heat dissipated by the heating and cooling

	systems through distribution within the building or inefficiencies of heating and cooling production.
4	Combine the results for all zones and systems, to give building delivered energy totals.
5	Convert the totals into equivalent CO ₂ emissions and primary energy (this is not part of the CEN Standard – the conversion is described in ADL Vol2 and DLUHC's NCM Modelling Guide)

Table 7: Summary of CEN standard calculation

	Issues/options	Chosen route	References in CEN standard prEN ISO 13790
1	Different types of calculation method: dynamic or quasi-steady state	Quasi-steady state, calculating the heat balance over a month	5.3
2	If steady state, how to take account of dynamic effects on heating	Determine utilisation factors for internal and solar heat sources using equations 31 & 32, to allow non-utilised heat which leads to an undesired increase in temperature above set-points to be ignored. This depends on the thermal capacity of the structure	5.4.2
3	Effects of thermal inertia in case of intermittent heating	Adjust set-point temperature as described in EN ISO 13790 (i.e., thermal capacity-dependent) using information in databases	13.2
4	How to take account of dynamic effects on cooling	Using equations 35 & 36, determine utilisation factors for internal and solar heat sources, to take account of that part which takes the temperature to a certain level, so only non-utilised heat beyond that level contributes to cooling needs. This depends on the thermal capacity of the structure	12.2.1
5	Effects of thermal inertia in case of intermittent cooling	Adjust set-point temperature using information in databases.	13.2
6	Energy balance at system level	Includes energy needs at zone level; from renewables; generation, storage, distribution, emission and control losses; input to space heating and cooling systems; energy outputs e.g., from CHP; energy recovered within the system	5.5; see also figs 3a&c in the section for all energy flows
7	Relationship with unconditioned spaces	The boundary of the building is the elements between the conditioned and unconditioned spaces, including exterior. Heat transfer between conditioned spaces is ignored.	6.2
8	Dimension system for calculating areas	Internal dimensions of each zone's structural elements, so that the area	6.2, 6.3.2

		presented to heat flux from inside the building coincides with the overall internal dimensions	
9	Thermal zones	Building is partitioned into several zones, taking no account of thermal coupling between zones	6.3.1, 6.3.3.2
10	Calculation procedure for multi-zone	Regard as a series of single zone calculations, but with boundary conditions and input data coupled when zones share same heat/cooling system. Zones are aggregated when served by the same heating/cooling system.	6.3.5
11	Energy demand for heating	Equation 3; correction for holidays applied where relevant through schedules in activity area database.	7.2.1.1
12	Energy demand for cooling	Equation 4; correction for holidays applied where relevant through schedules in activity area database.	7.2.1.2
13	Length of heating season	Not calculated in SBEM – heat is available whenever monthly calculation demands it.	7.2.1.3
14	Length of cooling season	Not calculated in SBEM – cooling is available whenever monthly calculation demands it.	7.2.2
15	Calculation in two steps, to determine dissipation of heat from systems based on 1 st iteration	Not done in SBEM	7.2.5
16	Total heat transfer by transmission	Equation 11	8.2
17	Transmission heat transfer coefficients	Calculate according to EN ISO 13789:2005 taking into account other standards listed in 8.3.1	8.3.1
18	Thermal bridges	Calculate transmission heat loss according to EN ISO 13789:2005	8.3.1
19	Differences in transmission calculation between heating and cooling modes	Not implemented in SBEM - physical characteristics of building do not change	
20	Nocturnal insulation	Not implemented in SBEM	8.3.2, 8.4.2
21	Special elements	Optional; if applied, comply with 8.4.3	8.4.3
22	Total heat transfer by ventilation	Equation 13	9.2
23	Ventilation heat transfer coefficients	Determine according to section 9.3.1, using volume flow rate based on NEN 2916:1998 methodology section 6.5.2.1. Infiltration based on section 7.1.3.2 of EN 15242:2005	9.3.1
24	Differences in ventilation calculation between heating and cooling modes	The stack effect in infiltration is currently ignored during cooling calculation in SBEM.	9.3.2

25	Ventilation heat recovery	Based on section 6.5.2 of NEN 2916:1998 methodology, where according to efficiency of heat recovery system, the air flow to be heated is effectively reduced. Can be bypassed during cooling.	
26	Night-time ventilation for free cooling	Optional in cooling calculation in SBEM.	9.4.3
27	Special elements	Optional; if applied, comply with 9.4.4	9.4.4
28	Internal heat sources, including cold sources (i.e., sinks, etc.)	Calculate contribution using equations 16, 17 & 18	10.2, 10.3.1
29	Heat dissipated by system within the building	Impact on building heating/cooling needs ignored in SBEM, but heat dissipated is included in system efficiency adjustment factors	10.3.1
30	Heat gain from people and appliances	Determined from activity area database	10.3.2.1
31	Heat gain from lighting	Determined using method described in this manual	10.3.2.2
32	Heat to/from washing water and sewerage	Heat recovery from showers waste water included in SBEM	
33	Heat dissipated from or absorbed by heating, cooling and ventilation systems	Determined from efficiency factors	10.3.2.4
34	Heat from processes or goods	Determined from activity area database	10.3.2.5
35	Total solar heat sources	Equations 22 & 23 based on monthly average solar irradiance from weather data	11.2
36	Effective solar collecting area of glazed elements	Equations 24, 27 & 29. Movable shading is included. Shading factors determined from user input	11.3.2, 11.4.1, 11.4.2, 11.4.3
37	Frame fraction	Included in SBEM	11.4.4
38	Effective collecting area of opaque elements	Equations 25, 26 & equations in 11.4.5 including 30 to deal with radiation from the element to the sky.	11.3.3, 11.4.5
39	Gain utilisation factor for heating	Equations 31, 32, 33 & 34 using reference numerical parameter for monthly calculation from Table 8 based on building type and calculated building time constant (see below)	12.2.1.1
40	Loss utilisation factor for cooling	Equations 35, 36, 37, 38 & 39 using reference numerical parameter for monthly calculation from Table 9 based on building type and calculated building time constant (see below)	12.2.1.2
41	Building time constant	Equations 40 (heating) and 41 (cooling) using internal heat capacity of building	12.2.1.3
42	Internal heat capacity of building	Sum of internal capacities of all building elements, using C_m values calculated according to EN ISO 13786:2005	12.3.1

43	Internal temperatures used in energy calculations	Where heating or cooling is continuous during the whole heating period, use the set-point temperature indicated by the activity area database. If not continuous, see below.	13.1
43	Correction for holiday periods	SBEM obtains this information from the activity area database	13.4
44	Internal temperature correction for intermittent heating	As 13.2.1 – resolve mode of intermittency which is dependent on building time constant (calculated above) and difference in set-point temperature between normal and reduced heating periods	13.2.1
45	Correction for intermittent cooling	Equations 44 & 45, which need input of building time constant (calculated above) and set-point temperatures for normal cooling and intermittent periods.	13.3
46	Annual energy need for heating and cooling per building zone	Sum of heating and cooling needs in each month; as equation 47	14.1
47	Annual energy need for heating and cooling, per combination of systems	Sum of heating and cooling needs served by the same combination of systems, then sum of needs of all systems; as equation 48	14.2
48	Total system energy use, including system losses	Use option b in section 14.3.1, in order to present auxiliary energy separately from system losses, for each energy carrier.	14.3.1
49	System losses	SBEM does not require separation of total losses and system losses that are recovered in the system.	14.3.2
50	Results presentation of heating and cooling energy needs	SBEM's tabulated output reports	14.3.3
51	Additional annual energy by ventilation system	Calculated as section 14.3.4, in accordance with EN 15241. For HVAC systems involving ventilation, auxiliary energy comes from method in appendix G. Where ventilation comes from individual fans, use EN 13779.	14.3.4
52	Reporting of building and systems evaluation	Results broken down for the whole building, each zone and each month, with heating and cooling heat transfer and energy needs as in section 15.3.1. Input data reflection (as section 15.2) is available on screen but is not printed automatically, to reduce paper consumption prior to final version.	15.2, 15.3.1, 15.3.2
53	Climate related data	Hourly climatic data are needed, even though the calculation is monthly based, in order to prepare the monthly values. Data should include the parameters required in CEN standard annex A.	Annex A

54	Multi-zone calculation with thermal coupling between zones	Not implemented in SBEM	Annex B
55	Alternative formulation for monthly cooling method	Not implemented in SBEM	Annex D
56	Heat loss of special envelope elements (e.g., ventilated walls)	Not implemented in SBEM	Annex E
57	Solar gains of special elements (e.g., unconditioned sunspaces, opaque elements with transparent insulation, ventilated walls)	Not implemented in SBEM.	Annex F
58	Data for solar gains	Refer to annex G	Annex G
59	Calculation of heat use in different heating modes (e.g., if different modes have different costs)	Not implemented in SBEM	Annex H
60	Accuracy of the method	Not required for NCM	Annex I
61	Conventional input data (to be used in the absence of national data)	Not required for NCM – use activity area database	Annex J

Table 8: Options chosen in the CEN standard prEN ISO 13790:2005

4.1.1. Calculation method

SBEM adopts the quasi-steady state calculation method, calculating the heat balance over a month. The monthly calculation gives reasonable results on an annual basis, but the results for individual months close to the beginning and the end of the heating and cooling season can have errors relative to the actual profile of cooling and heating demands.

In the quasi-steady state methods, the dynamic effects are taken into account by introducing correlation factors:

For heating: a utilisation factor for the internal and solar heat sources takes account of the fact that only part of the internal and solar heat gain is utilised to decrease the energy demand for heating; the rest leading to an undesired increase of the internal temperature above the set-point. In this approach, the heat balance ignores the non-utilised heat sources, which is counterbalanced by the fact that it ignores, at the same time, the resulting extra transmission and ventilation heat transfer from the space considered due to the increased internal temperature above the set-point.

The effect of thermal inertia in case of intermittent heating or switch-off can be taken into account by introducing an adjustment to the heating set-point temperature or a correction to the calculated heat demand.

For cooling: (mirror image of the approach for heating) a utilisation factor for the transmission and ventilation heat transfer takes account of the fact that only part of the transmission and ventilation heat loss is utilised to decrease the cooling needs, the “non-

utilised” transmission and ventilation heat transfers occur during periods or moments (e.g., nights) when they have no effect on the cooling needs occurring during other periods or moments (e.g., days). In this approach, the heat balance ignores the non-utilised transmission and ventilation heat transfer. This is counterbalanced by the fact that it ignores that the cooling set-point is not always reached. With this formulation, it is explicitly shown how the heat transfer attributes to the reduction of the building energy needs for cooling.

The effect of thermal inertia in the case of intermittent cooling or switch-off can be taken into account by introducing an adjustment to the cooling set-point temperature or a correction to the calculated cooling needs.

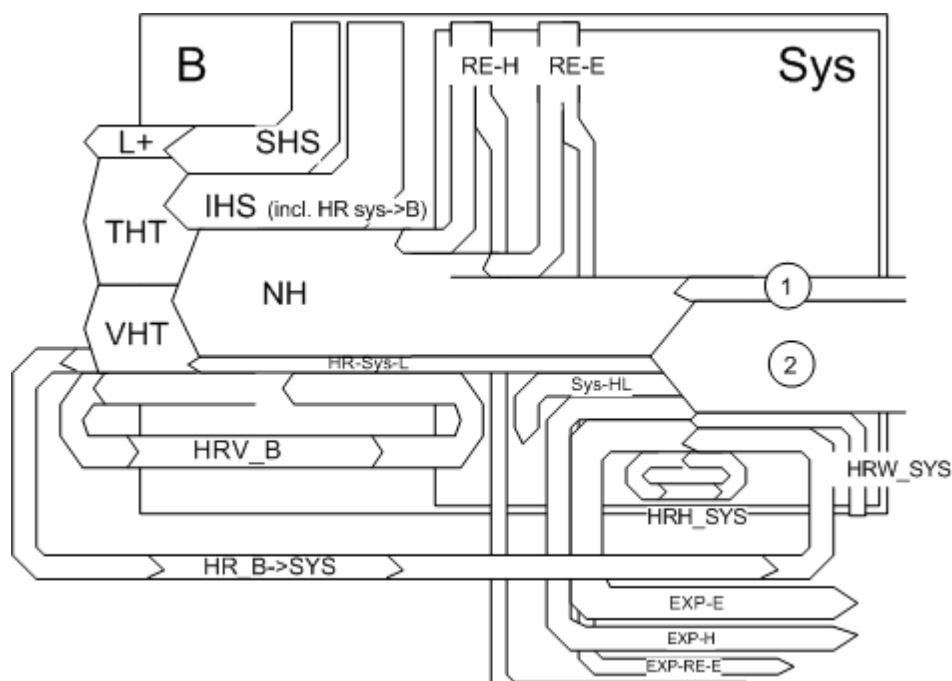
4.1.2. Overall energy balances for building and systems

The building energy demand for heating and cooling is satisfied by the energy supply from the heating and cooling systems. At the system level, the energy balance for heating and cooling, if applicable, includes:

- energy demand for heating and cooling of the building zones;
- energy from renewable energy systems;
- generation, storage, distribution, emission, and control losses of the space heating and cooling systems;
- energy input to the space heating and cooling systems;
- special energy output from the space heating or cooling systems (export; e.g., electricity from a combined heat and power installation).

The system energy balance may also include energy recovered in the system from various sources.

The main terms of the (time-average) energy balance for heating and cooling are schematically illustrated in Figure 4 and Figure 5, respectively.

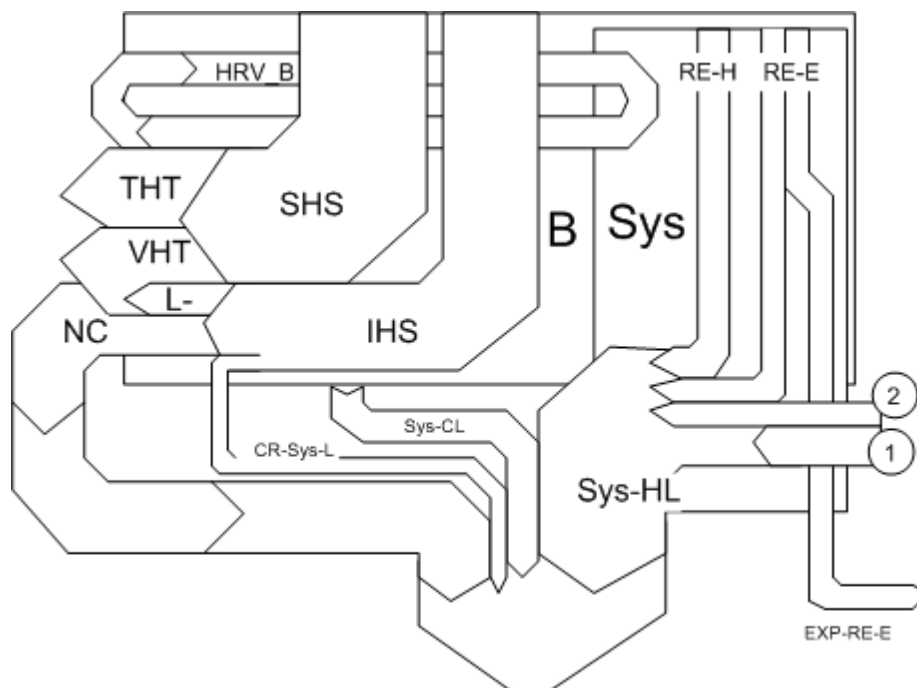


Key

B	Building	Sys	System
THT	Transmission heat transfer	Sys-HL	System heat losses, not recovered (from generation, transport, electronics, storage, distribution, emission)
VHT	Ventilation heat transfer	HRH-Sys	System heat losses, recovered in system
L	THT+VHT	HRW-Sys	Heat from waste water, recovered in system
SHS	Solar heat sources	RE-H	Renewable energy, heat e.g. solar, ground,...)
IHS	Internal heat sources (persons and appliances). Including heat recovered from hot water, heat transferred to cold water, heat from lighting and fan or pump dissipation	RE-E	Renewable energy, electric (PV)
L+	Heat from heating system: shown as separate flow: see HR-Sys-L Mismatch between transmission and ventilation heat transfer and solar and internal heat sources, leading to average internal temperature higher than required	HR-B->Sys	Heat recovered in building (into the system) e.g. ventilation exhaust air as source for heat pump; heat from building mass into vent.system,...
NH	Energy need for space heating	EXP-E	Exported electricity, non-renewable
HRV-B	Heat recovered in ventilation system (into the building)	EXP-H	Exported heat, non-renewable
HR-Sys-L	Heat recovered from system loss in building (distribution, storage, emission, etc.)	EXP-RE-E	Exported electricity, from renewable source
		EXP-RE-H	Exported heat, from renewable source
		1	Delivered energy, electricity
		2	Delivered energy, gas or coal or oil or ...

NOTE: Cross-flows between heating and cooling are not shown

Figure 4: Energy balance of a building for space heating (extracted from prEN ISO 13790:2005)



Key

B	Building	Sys	System
THT	Transmission heat transfer	Sys-HL	System energy use for cooling, including heat losses, not recovered (from generation, transport, electronics)
VHT	Ventilation heat transfer	RE-H	Renewable energy for cooling, heat e.g. solar, ground,...
L	THT+VHT	RE-E	Renewable energy for cooling, electric (PV)
SHS	Solar heat sources	CR-B->Sys	Additional heat removed from building (into the system e.g. from building mass into vent.system, ..
IHS	Internal heat sources (persons and appliances). Including heat recovered from hot water, heat transferred to cold water, heat from lighting and fan or pump dissipation	EXP-E	Exported electricity, non-renewable
L-	Heat extracted by cooling system: shown as separate flow: see CR-Sys-L	EXP-RE-E	Exported electricity, from renewable source
L-	Mismatch between transmission and ventilation heat transfer and solar and internal heat sources, leading to average internal temperature lower than required	1	Delivered energy, electricity
NC	Energy need for space cooling	2	Delivered energy, (gas, coal, oil, etc)
HRV-B	Heat recovered in ventilation system (into the building, if not by-passed during cooling period)		
CR-Sys-L	Cold recovered from system loss in building (distribution, storage, emission, etc.)		

NOTE: Cross-flows between heating and cooling are not shown

Figure 5: Energy balance of a building for space cooling (extracted from prEN ISO 13790:2005)

4.1.3. Boundary of the building

Firstly, the boundaries of the building for the calculation of energy demands for heating and cooling are defined. Secondly, the building is, if necessary, divided into calculation zones. The boundary of the building consists of all the building elements separating the conditioned space or spaces under consideration from the external environment (air, ground, or water) or from unconditioned spaces. Heat transfer between conditioned spaces is ignored in SBEM.

The floor area within the boundary of the building is the useful floor area, A_{fl} , of the building. The dimension system used to calculate A_{fl} uses the internal dimensions of each zone's structural elements (i.e., the internal horizontal dimensions between the internal

surfaces of the external zone walls and half-way through the thickness of the internal zone walls) so that the area presented to the heat flux from inside the building coincides with the overall internal dimensions.

4.1.4. Thermal zones

The building is partitioned into several zones (multi-zone calculation), taking no account of thermal coupling between the zones.

For a multi-zone calculation without thermal coupling between zones (calculation with uncoupled zones), any heat transfer by thermal conduction or by air movement is not taken into account. The calculation with uncoupled zones is regarded as an independent series of single zone calculations. However, boundary conditions and input data may be coupled, for instance, because different zones may share the same heating system or the same internal heat source.

For zones sharing the same heating and cooling system, the energy demand for heating and cooling is the sum of the energy demand calculated for the individual zones.

For zones not sharing the same heating and cooling system, the energy use for the building is the sum of the energy use calculated for the individual zones.

4.1.5. Climate data

Hourly climatic data is needed for the preparation of monthly climatic values and climate dependent coefficients. This data comprises at least:

- Hourly external air temperature, in °C;
- Hourly global and diffuse solar radiation at a horizontal plane, in W/m^2 (and indicators needed for the conversion of global solar radiation at a horizontal plane to incident radiation at vertical and tilted planes at various orientations);
- Local or meteorological wind speed, in m/s;
- Wind direction.

4.1.6. Calculation procedure for energy demand for space heating and cooling

The calculation procedure to obtain the energy demand for space heating and cooling of the building or building zone is summarised below. For each building zone and for each calculation period (month):

- calculate the characteristics for the heat transfer by transmission;
- calculate the characteristics for the heat transfer by ventilation;
- calculate the heat gains from internal heat sources and solar heat sources;
- calculate the dynamic parameters (the gain utilisation factor for heating and the loss utilisation factor for cooling);
- calculate the building energy demand for heating, Q_{NH} , and the building energy demand for cooling, Q_{NC} .

4.1.7. Energy demand for heating

For each building zone, the energy demand for space heating for each calculation period (month) is calculated according to:

$$Q_{NH} = Q_{L,H} - (\eta_{G,H} \times Q_{G,H})$$

subject to $Q_{NH} \geq 0$, $\gamma_H \leq 2.5$, and $\theta_i > \theta_e$ (otherwise, $Q_{NH} = 0.0$)

where (for each building zone, and for each month):

Q_{NH} is the building zone energy demand for heating, in MJ;

$Q_{L,H}$ is the total heat transfer (losses) for the heating mode, in MJ;

$Q_{G,H}$ is the total heat sources (gains) for the heating mode, in MJ;

$\eta_{G,H}$ is the dimensionless gain utilisation factor. It is a function of mainly the gain-loss ratio and the thermal inertia of the building zone;

γ_H is the dimensionless gain/loss ratio for the heating mode;

θ_i is the internal (indoor) temperature (the heating set-point taken from the NCM Activity Database for the activity zone), in °C;

θ_e is the external (outdoor) temperature (the monthly average temperature obtained from the hourly weather data for the location), in °C.

If applicable, corrections are applied to account for holidays, according to the occupancy schedules in the NCM Activity Database.

4.1.8. Energy demand for cooling

For each building zone, the energy demand for space cooling for each calculation period (month) is calculated according to:

$$Q_{NC} = Q_{G,C} - (\eta_{L,C} \times Q_{L,C})$$

subject to $Q_{NC} \geq 0$ and $\lambda_C \leq 2.5$ (otherwise, $Q_{NC} = 0.0$)

where (for each building zone, and for each month)

Q_{NC} is the building zone energy demand for cooling, in MJ;

$Q_{L,C}$ is the total heat transfer (losses) for the cooling mode, in MJ;

$Q_{G,C}$ is the total heat sources (gains) for the cooling mode, in MJ;

$\eta_{L,C}$ is the dimensionless utilisation factor for heat losses. It is a function of mainly the loss-gain ratio and inertia of the building zone;

λ_C is the dimensionless loss/gain ratio for the cooling mode.

If applicable, corrections are applied to account for holidays, according to the occupancy schedules in the NCM Activity Database.

4.1.9. Total heat transfer (loss) and heat sources (gain)

The total heat transfer is given by:

$$Q_L = Q_T + Q_V$$

where (for each building zone and for each month):

Q_L is the total heat transfer, in MJ;

Q_T is the total heat transfer by transmission, in MJ;

Q_V is the total heat transfer by ventilation, in MJ;

The total heat sources are given by:

$$Q_G = Q_I + Q_S$$

where (for each building zone and for each month):

Q_G is the total heat sources, in MJ;

Q_I is the sum of internal heat sources over the given period, in MJ;

Q_S is the sum of solar heat sources over the given period, in MJ.

4.1.10. Total heat transfer by transmission

The total heat transfer by transmission is calculated for each month and for each zone, z , by:

$$Q_T = H_T \times (\theta_i - \theta_e) \times t \times f$$

where (for each building zone, z , and for each month)

Q_T is the total heat transfer by transmission, in MJ;

H_T is the heat transfer coefficient by transmission of the building zone, in W/K;

θ_i is the internal temperature of the building zone, in °C, taken from the NCM Activity Database (heating set-point);

θ_e is the external (outdoor) temperature (the monthly average temperature obtained from the hourly weather data for the location) of the building zone, in °C; taken from the weather database;

t is the duration of the calculation period, i.e., number of hours in the month;

f is a factor for conversion from Wh to MJ.

NOTE: The heat transfer or part of the heat transfer may have a negative sign during a certain period.

4.1.10.1. Transmission heat transfer coefficients

The values for the heat transmission coefficient, H_T , of a zone in the building are calculated according to EN ISO 13789:2007, taking into account the standards for specific elements, such as windows (EN ISO 10077-1:2004), walls and roofs (EN ISO 6946:2005), and ground floor (EN ISO 13370:2005), for the following situations:

- Heat transmission to external environment
- Heat transmission to adjacent unconditioned space
- Heat transmission to the ground

The transmission heat transfer coefficient through the building elements separating the heated or cooled space and its surroundings is calculated by:

$$H_T = \sum_i a_i A_i U_i + \sum_k l_k \Psi_k$$

where

H_T is the heat transfer coefficient by transmission of a zone, in W/K;

a_i is a weighting factor dependent on the adjacency of the envelope i in the zone, which is currently taken in SBEM to be 1.0 if the envelope is adjacent to "Exterior", "Strongly ventilated spaces", "Unheated adjoining space", or "Underground", and taken to be 0.0 if the envelope is adjacent to a "Conditioned adjoining space" or "Same space".

A_i is the area of element i of the envelope in the zone, in m², (the dimensions of windows and doors are taken as the dimensions of the aperture in the wall);

U_i is the thermal transmittance (U-value¹⁴) of element i of the envelope in the zone, in W/(m²·K);

l_k is the length of linear thermal bridge k , in m, in the zone;

Ψ_k is the linear thermal transmittance of linear thermal bridge k , in W/(m·K), in the zone.

The summation is done over all the building components of the zone separating the internal and the external environments.

Thermal transmittance of solid ground floors in contact with the earth

If the solid ground floor U-value input to SBEM had not already been adjusted to account for insulation to counter the heat loss through contact with the ground, then SBEM adjusts the U-value (as a function of the ratio of exposed perimeter to floor area and the thermal resistance of the floor construction) following the guidance specified in section 3.5.2 of "CIBSE Guide - Vol. A - 2018" (and ISO 13370:2017 – *Thermal Performance of Buildings – Heat Transfer via the Ground – Calculation Methods*), as per the extract described below.

The U-value of a solid floor in contact with the ground depends on the 'characteristic dimension' of the floor and the 'total equivalent thickness' of the factors that, in combination, restrict the heat flow (i.e., wall thickness, surface resistances, and thermal insulation).

The characteristic dimension, B' , in m, is defined as:

$$B' = \frac{A_{fg}}{0.5 \times p_f}$$

where

A_{fg} is the area of the floor in contact with the ground, in m²,

p_f is the exposed perimeter of the floor, in m, taken as the total length of the external wall separating the heated space from the external environment or from an unheated space outside the insulated fabric.

For an infinitely long floor, B' is the width of the floor (lesser dimension), and at the other limiting case of a square floor, B' is half the length of one side.

The total equivalent thickness, d_{ef} , in m, is calculated as:

$$d_{ef} = d_w + \lambda_g \times (R_{si} + R_f + R_{se})$$

¹⁴ The U-value for solid ground floors should be adjusted to account for insulation to counter the heat loss through contact with the ground (as a function of the ratio of exposed perimeter to floor area and the thermal resistance of the floor construction) following the guidance specified in section 3.5.2 of "CIBSE Guide - Vol. A - 2007" (and ISO 13370:2007 – *Thermal Performance of Buildings – Heat Transfer via the Ground – Calculation Methods*).

where

- d_w is the thickness of the wall surrounding the ground floor, assumed to be 0.3 m;
- λ_g is the thermal conductivity of the ground, taken as 1.5 in W/mK, corresponding to a clay or silt soil which is considered most prevalent in Britain;
- R_{si} is the inside surface resistance, taken as 0.17 m²K/W;
- R_{se} is the external surface resistance, taken as 0.04 m²K/W;
- R_f is the thermal resistance of the floor, in m²K/W.

SBEM asks the user to input the un-corrected U-value for the ground floor of the Actual building as the inverse of the thermal resistance of the floor construction *only* before allowing for any ground effect (perimeter to area) or edge insulation (i.e., the user inputs $1/R_f$). For the Notional building (for compliance purposes), SBEM assumes $R_f = 0.457$ m²K/W, which is approximately the resistance of the chipboard/air gap/screed/concrete in the Notional building's ground floor construction details from the NCM Modelling Guide, and for the Reference building (for EPC purposes), SBEM assumes $R_f = 0$ m²K/W corresponding to an uninsulated floor.

The thermal transmittance of the floor, U_f , in W/m²K, is then calculated by:

If $d_{ef} < B'$, as is usually the case, then

$$U_f = \left(\frac{2 \lambda_g}{\pi B' + d_{ef}} \right) \times \ln \left(\frac{\pi B'}{d_{ef}} + 1 \right)$$

If $d_{ef} \geq B'$, as may occur for a small, well-insulated floor, then

$$U_f = \frac{\lambda_g}{(0.457 B' + d_{ef})}$$

4.1.10.2. Thermal bridges:

The default values used in SBEM for the linear thermal transmittance, Ψ , of linear thermal bridges are determined according to the method in BRE IP 1/06: *Assessing the Effects of Thermal Bridging at Junctions and around Openings* and then degraded by the greater of 0.04 W/mK or 50%, as defined in the NCM Modelling Guide. These are the values used in the calculations unless the user overrides them, as described in Section 3.4.3.

4.1.11. Total heat transfer by ventilation

The total heat transfer by ventilation Q_v is calculated for each month and for each zone z as described in Section 4.2.

4.1.12. Heat gains

Heat gains result from a contribution from internal heat sources Q_i in the building, consisting of occupants, lighting, appliances, and a contribution from solar heat through transparent constructions $Q_{sun,t}$ and through opaque constructions $Q_{sun,nt}$.

The heat gains are calculated by

$$Q_{gain} = Q_i + Q_{sun,t} + Q_{sun,nt}$$

where:

Q_{gain} is the heat gain per month, in MJ;

Q_i is the internal heat production, in MJ;

$Q_{sun,t}$ is the solar heat gain through transparent construction parts of the external envelope, in MJ;

$Q_{sun,nt}$ is the solar heat gain through opaque construction parts of the external envelope, in MJ.

4.1.12.1. Internal heat sources

Internal heat sources, including cold sources (sinks, sources with a negative contribution), consist of any heat generated in the conditioned space by internal sources other than the energy intentionally utilised for space heating, space cooling, or hot water preparation.

The heat gain from internal heat sources is calculated from:

$$Q_i = Q_{i,occ} + Q_{i,app} + Q_{i,li}$$

where

Q_i is the sum of internal heat production from internal heat sources, in MJ;

$Q_{i,occ}$ is the internal heat production from occupants, in MJ; determined from the NCM Activity Database, according to the building and activity types selected for the zone.

$Q_{i,app}$ is the internal heat production from appliances, in MJ; determined from the NCM Activity Database, according to the building and activity types selected for the zone.

$Q_{i,li}$ is the internal heat production from lighting, in MJ.

Dissipated heat from lighting devices is determined from the lighting energy consumption calculated for the zone.

The value for the internal heat production from lighting, $Q_{i,li}$, is calculated from:

$$Q_{i,li} = W_{light} \times A \times 3.6 \times f_{li,gain}$$

where

$Q_{i,li}$ is the internal heat production from lighting, in MJ;

W_{light} is the energy consumption by lighting, in kWh/m², as determined in Section 4.4;

A is the area of the zone, in m²;

3.6 is the conversion factor from kWh to MJ;

$f_{li,gain}$ is a gain factor that is dependent on whether there are air-extracting luminaires in the zone. It has a value of 0.9 if there are air-extracting luminaires and 1 if there are no air-extracting luminaires in the zone.

4.1.12.2. Solar heat gain through transparent constructions

The solar heat gain per month through transparent construction parts of the external envelope is determined as:

$$Q_{sun,t} = \sum_j [q_{sun,j} \times f_{sh,j} \times f_{sun,j} \times g_j \times (1.0 - f_f) \times A_j]$$

where

$Q_{sun,t}$ is the solar heat gain through transparent constructions, in MJ;

$q_{sun,j}$ is the quantity of solar radiation per month on the plane in MJ/m², for weather location and orientation of window j ;

$f_{sh,j}$ is the shading correction factor for window j ;

$f_{sun,j}$ is the reduction factor for moveable solar protection for window j , as calculated in Section 4.1.12.2.1;

g_j is the total solar energy transmittance, for window j ;

A_j is the area of window j , in m², including the frame;

f_f is the computational value for the frame factor (proportion of window area that is occupied by the frame), i.e., $(1.0 - f_f)$ = proportion of window area that is occupied by the glazing.

The external shading correction factor, $f_{sh,j}$, which is in the range 0 to 1, represents the reduction in the incident solar radiation due to permanent shading of the surface concerned resulting from overhangs and fins.

The shading correction factor can be calculated from:

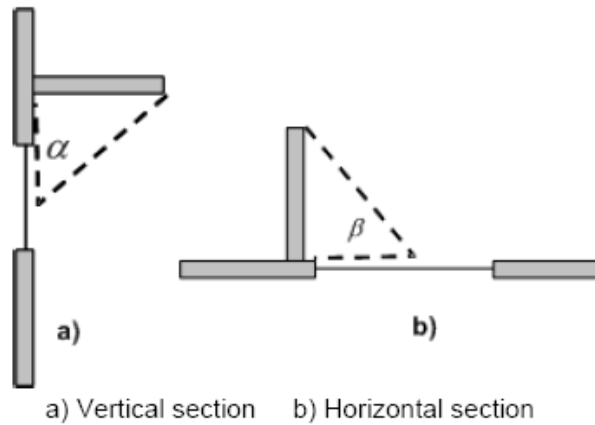
$$f_{sh,j} = F_o \times F_f$$

where

F_o is the partial shading correction factor for overhangs;

F_f is the partial shading correction factor for fins.

The shading from overhangs and fins depends on the overhang or fin angle, latitude, orientation, and local climate. Seasonal shading correction factors for typical climates are given in Table 9 and Table 10.



Key

α overhang angle

β fin angle

Figure 6: Overhang and fin: a) Vertical section b) Horizontal section¹⁵

NB: For the purposes of this calculation, the angles α and β , indicated by the dashed lines in Figure 6, are taken between the plane of the window and the overhang or fin shadow line at mid-window.

Overhang angle	45°N latitude			55°N latitude			65°N latitude		
	S	E/W	N	S	E/W	N	S	E/W	N
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30°	0.90	0.89	0.91	0.93	0.91	0.91	0.95	0.92	0.90
45°	0.74	0.76	0.80	0.80	0.79	0.80	0.85	0.81	0.80
60°	0.50	0.58	0.66	0.60	0.61	0.65	0.66	0.65	0.66

Table 9: Partial shading correction factor for overhangs, F_o ¹⁵

Fin angle	45°N latitude			55°N latitude			65°N latitude		
	S	E/W	N	S	E/W	N	S	E/W	N
0°	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30°	0.94	0.92	1.00	0.94	0.91	0.99	0.94	0.90	0.98
45°	0.84	0.84	1.00	0.86	0.83	0.99	0.85	0.82	0.98
60°	0.72	0.75	1.00	0.74	0.75	0.99	0.73	0.73	0.98

Table 10: Partial shading correction factor for fins, F_f ¹⁵

If the overhang accounted for by the shading correction factor above is in fact a brise-soleil, then the factor is applied to the calculation only during the summer months (May to September). **NB:** For the purposes of the calculation, a brise-soleil has strips, louvres, holes, etc., as opposed to a solid overhang.

¹⁵ Extracted from BS EN ISO 13790:2008 - *Energy performance of buildings — Calculation of energy use for space heating and cooling*

The total solar energy transmittance, g , is the time-averaged ratio of energy passing through the unshaded element to that incident upon it. For windows or other glazed envelope elements with non-scattering glazing, ISO 9050 or EN 410 provides a method to obtain the solar energy transmittance for radiation perpendicular to the glazing. This value, g_{\perp} , is somewhat higher than the time-averaged transmittance, and a correction factor, F_W , is used:

$$g = F_W \times g_{\perp}$$

The factor F_W is taken from Table 11 as the value corresponding to the orientation of the glazing and its tilt from the horizontal.

Tilt	Orientation								
	S	SE	E	NE	N	NW	W	SW	H
0°	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
10°	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
15°	1.28	1.27	1.35	1.52	1.68	1.52	1.36	1.29	0.87
20°	1.28	1.27	1.35	1.52	1.68	1.52	1.36	1.29	0.87
25°	1.28	1.27	1.34	1.50	1.64	1.49	1.35	1.29	0.87
30°	1.28	1.27	1.32	1.45	1.55	1.44	1.33	1.28	0.87
35°	1.29	1.26	1.31	1.40	1.46	1.39	1.31	1.28	0.87
40°	1.29	1.26	1.29	1.35	1.38	1.34	1.29	1.27	0.87
45°	1.29	1.26	1.27	1.30	1.29	1.29	1.27	1.27	0.87
50°	1.26	1.23	1.24	1.25	1.24	1.25	1.23	1.24	0.87
55°	1.23	1.20	1.20	1.21	1.19	1.20	1.20	1.21	0.87
60°	1.20	1.17	1.17	1.16	1.14	1.16	1.16	1.18	0.87
65°	1.17	1.14	1.14	1.11	1.09	1.11	1.13	1.15	0.87
70°	1.12	1.11	1.10	1.07	1.04	1.07	1.09	1.10	0.87
90°	0.89	0.91	0.91	0.89	0.88	0.88	0.90	0.90	0.87

Table 11: Correction factor F_W for g-value of non-scattering glazing

4.1.12.2.1. Calculation of the reduction factor for moveable solar protection

Using the methodologies described in BS EN 13363-1:2003+A1:2007 and BS EN ISO 13790:2008, the shading reduction factor for moveable shading provisions, $f_{sun,j}$ for window j is derived using the following equation:

$$f_{sun,j} = \frac{[(1 - f_{sh,with}) \times g_{gl} + (f_{sh,with} \times g_{gl+sh})]}{g_{gl}}$$

where

g_{gl} is the total solar energy transmittance of the window when the solar shading is not in use (i.e., glazing only);

g_{gl+sh} is the total solar energy transmittance of the window when the solar shading is in use (i.e., glazing plus shading device);

$f_{sh,with}$ is the weighted fraction of the time with the solar shading in use, e.g., as a function of the intensity of incident solar radiation.

Calculation of the weighted fraction of the time with the solar shading in use

The weighted fraction of the time during which the solar shading device is in use or not in use depends on the climate and the season or month. For the purposes of the SBEM

calculations, for each climate, a table has been produced with values for $f_{sh,with}$ for a variety of orientations of the window. The values have been derived as the sum of the hourly values of the intensity of incident solar radiation for all hours in the month with intensity higher than 300 W/m^2 , $I_{sol>300}$, divided by the sum of the hourly values of the intensity of incident solar radiation for all hours in the month, I_{sol} , i.e.,

$$f_{sh,with} = \frac{I_{sol>300}}{I_{sol}}$$

Calculation of the total solar energy transmittance of the window when the solar shading is in use

This method applies to all types of movable solar protection devices parallel to the glazing, such as, louvre, Venetian, or roller blinds. The position of the solar protection device can be interior or exterior. It is assumed that for external solar protection devices, the space between the solar protection devices and the glazing is unventilated and for internal solar protection devices, this space is ventilated. Venetian or louvre blinds are assumed to be adjusted so that there is no direct solar penetration.

This method is based on the normal incidence of radiation. It is applicable when the total solar energy transmittance of the glazing is between 0.15 and 0.85, the solar transmittance of the solar protection devices is between 0 and 0.5, and the solar reflectance of the solar protection devices is between 0.1 and 0.8.

The resulting total solar energy transmittance is solely used for calculating the shading reduction factor for moveable shading provisions, f_{sun} . It is not intended to be used for calculating beneficial solar gains or thermal comfort criteria.

External solar protection device (Figure 7)

The total solar energy transmittance for glazing and an external solar protection device, g_{gl+sh} , is given by:

$$g_{gl+sh} = (\tau_{e,B} \times g_{gl}) + \left(\alpha_{e,B} \times \frac{G}{G_2} \right) + \left[\tau_{e,B} \times (1 - g_{gl}) \times \frac{G}{G_1} \right]$$

where

$\tau_{e,B}$ is the solar transmittance of the solar protection device, which is obtained from Table 12 for typical solar protection devices;

g_{gl} is the total solar energy transmittance of the window when the solar shading is not in use (i.e., glazing only);

$\alpha_{e,B}$ is the absorptance of the solar protection device, which is calculated as

$$\alpha_{e,B} = 1 - \tau_{e,B} - \rho_{e,B}$$

where $\rho_{e,B}$ is the solar reflectance of the solar protection device, which is obtained from Table 12 for typical solar protection devices;

$$G_1 = 5 \text{ W/m}^2\text{K};$$

$$G_2 = 10 \text{ W/m}^2\text{K};$$

$$G = \frac{1}{\left(\frac{1}{U_g} + \frac{1}{G_1} + \frac{1}{G_2} \right)}$$

where U_g is the thermal transmittance of the window, in $\text{W/m}^2\text{K}$.

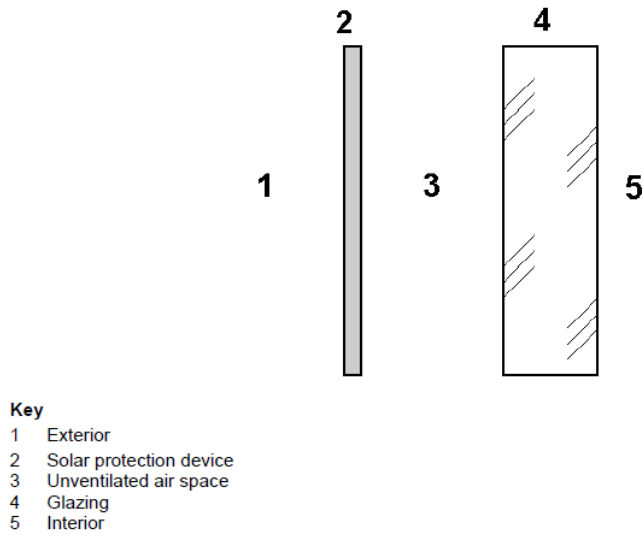


Figure 7: Characteristic position of external solar protection device¹⁶

Transmittance $\tau_{e,B}$		Reflectance $\rho_{e,B}$			
		white	pastel	dark	black
Opaque	0.0	0.7	0.5	0.3	0.1
Medium translucent	0.2	0.6	0.4	0.2	0.1
High translucent	0.4	0.4	0.3	0.2	0.1

Table 12: Data for typical solar protection devices¹⁶

Internal solar protection device (Figure 8)

The total solar energy transmittance for glazing and an internal solar protection device, g_{gl+sh} , is given by:

$$g_{gl+sh} = g_{gl} \times \left[1 - (g_{gl} \times \rho_{e,B}) - \left(\alpha_{e,B} \times \frac{G}{G_3} \right) \right]$$

where

g_{gl} is the total solar energy transmittance of the window when the solar shading is not in use (i.e., glazing only);

$\rho_{e,B}$ is the solar reflectance of the solar protection device, which is obtained from Table 12 for typical solar protection devices;

$\alpha_{e,B}$ is the absorptance of the solar protection device, which is calculated as

$$\alpha_{e,B} = 1 - \tau_{e,B} - \rho_{e,B}$$

where $\tau_{e,B}$ is the solar transmittance of the solar protection device, which is obtained from Table 12 for typical solar protection devices;

$$G_3 = 30 \text{ W/m}^2\text{K};$$

¹⁶ Extracted from BS EN 13363-1:2003+A1:2007 - Solar protection devices combined with glazing - Calculation of solar and light transmittance - Part 1: Simplified method.

$$G = \frac{1}{\left(\frac{1}{U_g} + \frac{1}{G_3}\right)}$$

where U_g is the thermal transmittance of the window, in W/m²K.

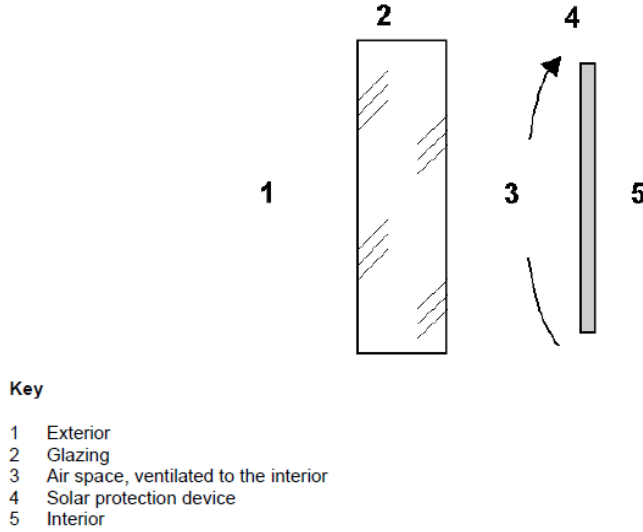


Figure 8: Characteristic position of internal solar protection device¹⁶

4.1.12.3. Solar heat gain through opaque constructions

The solar heat gain per month through opaque construction parts of the external envelope is determined as:

$$Q_{sun,nt} = \sum_j (f_{ab} \times q_{sun,j} \times U_{c,j} \times A_{c,j})$$

where

$Q_{sun,nt}$ is the solar heat gain through opaque constructions, in MJ;

f_{ab} is a factor 0.045 which consists of an assumed value of 0.9 for the dimensionless absorption coefficient for solar radiation of the opaque construction multiplied by the external surface heat resistance which is taken as 0.05 m²K/W.

$q_{sun,j}$ is the quantity of solar radiation per month on the plane in MJ/m², for weather location and orientation of construction part j ;

$U_{c,j}$ is the thermal transmittance of construction part j , in W/m²K;

$A_{c,j}$ is the area of construction part j , in m².

4.1.13. Gain utilisation factor for heating

The gain utilisation factor indicates the capability of the building of utilising the solar heat and the internal heat in such a way that this will lead to a reduction of the heating demand which, without these sources, would have to be supplied by the heating installation. The gain utilisation factor for heating, $\eta_{G,H}$ is a function of the gain/loss ratio, γ_H , and a numerical

parameter, a_H , that depends on the building zone's inertia, according to the following equation:

$$\text{if } \gamma_H > 0 \text{ and } \gamma_H \neq 1: \quad \eta_{G,H} = \frac{1 - \gamma_H^{a_H}}{1 - \gamma_H^{a_H+1}}$$

$$\text{if } \gamma_H = 1: \quad \eta_{G,H} = \frac{a_H}{a_H + 1}$$

$$\text{if } \gamma_H < 0: \quad \eta_{G,H} = \frac{1}{\gamma_H}$$

with

$$\gamma_H = \frac{Q_{G,H}}{Q_{L,H}}$$

where (for each month and for each building zone)

$\eta_{G,H}$ is the dimensionless gain utilisation factor for heating;

γ_H is the dimensionless gain/loss ratio for the heating mode;

$Q_{G,H}$ is the total heat gains for the heating mode, in MJ;

$Q_{L,H}$ is the total heat losses for the heating mode, in MJ;

a_H is a dimensionless numerical parameter depending on the time constant, τ_H , defined by:

$$a_H = a_{0,H} + \frac{\tau_H}{\tau_{0,H}}$$

where

$a_{0,H}$ is a dimensionless reference numerical parameter, determined according to Table 13;

τ_H is the time constant for heating of the building zone, in hours, determined according to Section 4.1.15;

$\tau_{0,H}$ is a reference time constant, from Table 13, in hours.

$a_{0,H}$	$\tau_{0,H}$
1.0	15

Table 13: Values of the numerical parameter $a_{0,H}$ and reference time constant $\tau_{0,H}$ for heating for a monthly calculation method

NOTE: The gain utilisation factor is defined independently of the heating system characteristics, assuming perfect temperature control and infinite flexibility. A slowly responding heating system and a less-than-perfect control system can significantly affect the use of gains.

4.1.14. Loss utilisation factor for cooling

The loss utilisation factor for cooling, $\eta_{L,C}$, is a function of the loss/gain ratio, λ_C , and a numerical parameter, a_C , that depends on the building thermal inertia, according to the following equation:

$$\text{if } \lambda_C > 0 \text{ and } \lambda_C \neq 1: \quad \eta_{L,C} = \frac{1 - \lambda_C^{a_C}}{1 - \lambda_C^{a_C+1}}$$

$$\text{if } \lambda_C = 1: \quad \eta_{L,C} = \frac{a_C}{a_C + 1}$$

$$\text{if } \lambda_C < 0: \quad \eta_{L,C} = 1$$

with

$$\lambda_C = \frac{Q_{L,C}}{Q_{G,C}}$$

where (for each month and each building zone)

$\eta_{L,C}$ is the dimensionless utilisation factor for heat losses;

λ_C is the dimensionless loss/gain ratio for the cooling mode;

$Q_{L,C}$ is the total heat losses for the cooling mode, in MJ;

$Q_{G,C}$ is the total heat gains for the cooling mode, in MJ;

a_C is a dimensionless numerical parameter depending on the time constant, τ_C , defined by:

$$a_C = a_{0,C} + \frac{\tau_C}{\tau_{0,C}}$$

where

$a_{0,C}$ is a dimensionless reference numerical parameter, determined according to Table 14;

τ_C is the time constant for cooling of the building zone, in hours; determined according to Section 4.1.15.

$\tau_{0,C}$ is a reference time constant, from Table 14, in hours.

$a_{0,C}$	$\tau_{0,C}$
1.0	15

Table 14: Values of the numerical parameter $a_{0,C}$ and reference time constant $\tau_{0,C}$ for cooling for a monthly calculation method

NOTE: The loss utilisation factor is defined independently of the cooling system characteristics, assuming perfect temperature control and infinite flexibility. A slowly responding cooling system and a less-than-perfect control system may significantly affect the utilisation of the losses.

4.1.15. Building time constant for heating and cooling mode

The time constant for the heating mode, τ_H , characterises the internal thermal inertia of the heated space during the heating period. It is calculated from:

$$\tau_H = \frac{C_m / 3.6}{H_{L,H}}$$

where

τ_H is the time constant of the building zone for the heating mode, in hours;

C_m is the effective thermal capacity of the building zone, in kJ/K, determined according to Section 4.1.15.1;

$H_{L,H}$ is the heat loss coefficient of the building zone for the heating mode, in W/K.

3.6 is introduced to convert the effective thermal capacity from kJ to Wh.

Similarly, the time constant for the cooling mode, τ_C , characterises the internal thermal inertia of the cooled space during the cooling period. It is calculated from:

$$\tau_C = \frac{C_m / 3.6}{H_{L,C}}$$

where

τ_C is the time constant of the building zone for the cooling mode, in hours;

C_m is the effective thermal capacity of the building zone, in kJ/K, determined according to Section 4.1.15.1;

$H_{L,C}$ is the heat loss coefficient of the building zone for the cooling mode, in W/K;

3.6 is introduced to convert the effective thermal capacity from kJ to Wh.

4.1.15.1. Effective thermal capacity of the building zone

The effective thermal capacity of the building zone, C_m , is calculated by summing the heat capacities of all the building elements in direct thermal contact with the internal air of the zone under consideration:

$$C_m = \sum_j \kappa_j A_j = \sum_j \sum_i \rho_{ij} c_{ij} d_{ij} A_j$$

where

C_m is the effective thermal capacity, in kJ/K;

κ_j is the internal heat capacity per area of the building element j , in kJ/(m²·K);

A_j is the area of the element j , in m²;

ρ_{ij} is the density of the material of the layer i in element j , in kg/m³;

c_{ij} is the specific heat capacity of the material of layer i in element j , in kJ/(kg·K);

d_{ij} is the thickness of the layer i in element j , in m.

The sum is done for all layers of each element, starting from the internal surface and stopping at the first insulating layer, the maximum thickness given in Table 15, or the middle of the building element; whichever comes first.

Application	Maximum thickness, in m
Determination of the gain or loss utilisation factor	0.10

Table 15: Maximum thickness to be considered for internal heat capacity¹⁵

4.1.16. Continuous and quasi-continuous heating or cooling mode, monthly method

4.1.16.1. Continuous heating and/or cooling

For continuous heating during the whole heating period, $\theta_{set,H}$, the heating set-point temperature (°C) from the NCM Activity Database is used as the internal temperature of the building zone.

For continuous cooling during the whole cooling period, $\theta_{set,C}$, the cooling set-point temperature (°C) from the NCM Activity Database is used as the internal temperature of the building zone.

NOTE: For the monthly method, the actual mean internal temperature may be higher in the heating mode due to instantaneous overheating. However, this is taken into account by the gain utilisation factor. Similarly, for the cooling mode, the actual mean internal temperature may be lower due to instantaneous high heat losses.

4.1.16.2. Quasi-continuous heating

Intermittent heating is considered as continuous heating with adjusted set-point temperatures if mode A or mode B applies:

Mode A:

- If the set-point temperature variations between normal heating and reduced heating periods are less than 3°K and/or
- If the time constant of the building zone is less than 0.2 times the duration of the shortest reduced heating period (for heating),

then the set-point temperature for the heating calculation is the time average of the set-point temperatures. See illustration in a) and b) of Figure 9.

Mode B:

- If the time constant of the building zone is greater than 3 times the duration of the longest reduced heating period, then the set-point temperature for the heating calculation is the set-point temperature for the normal heating mode. See illustration in c) of Figure 9.

4.1.17. Corrections for intermittency, monthly method

4.1.17.1. Heating

In the case of intermittent heating which does not fulfil the conditions in Section 4.1.16.2, the energy demand for heating, $Q_{H,interm}$, in MJ, is calculated by using the following equation; **NB:** this is the condition currently assumed in SBEM.

$$Q_{H,interm} = a_{H,red} \times Q_{H,cont}$$

where

$Q_{H,cont}$ is the energy demand for continuous heating, in MJ, calculated in accordance with Section 4.1.7.

$a_{H,red}$ is the dimensionless reduction factor for intermittent heating, determined according to the following equation:

$$a_{H,red} = 1 - \left[b_{H,red} \times \left(\frac{\tau_{0,H}}{\tau_H} \right) \times \gamma_H \times (1 - f_{H,hr}) \right]$$

with minimum value: $a_{H,red} = f_{H,hr}$ and maximum value: $a_{H,red} = 1$

and where

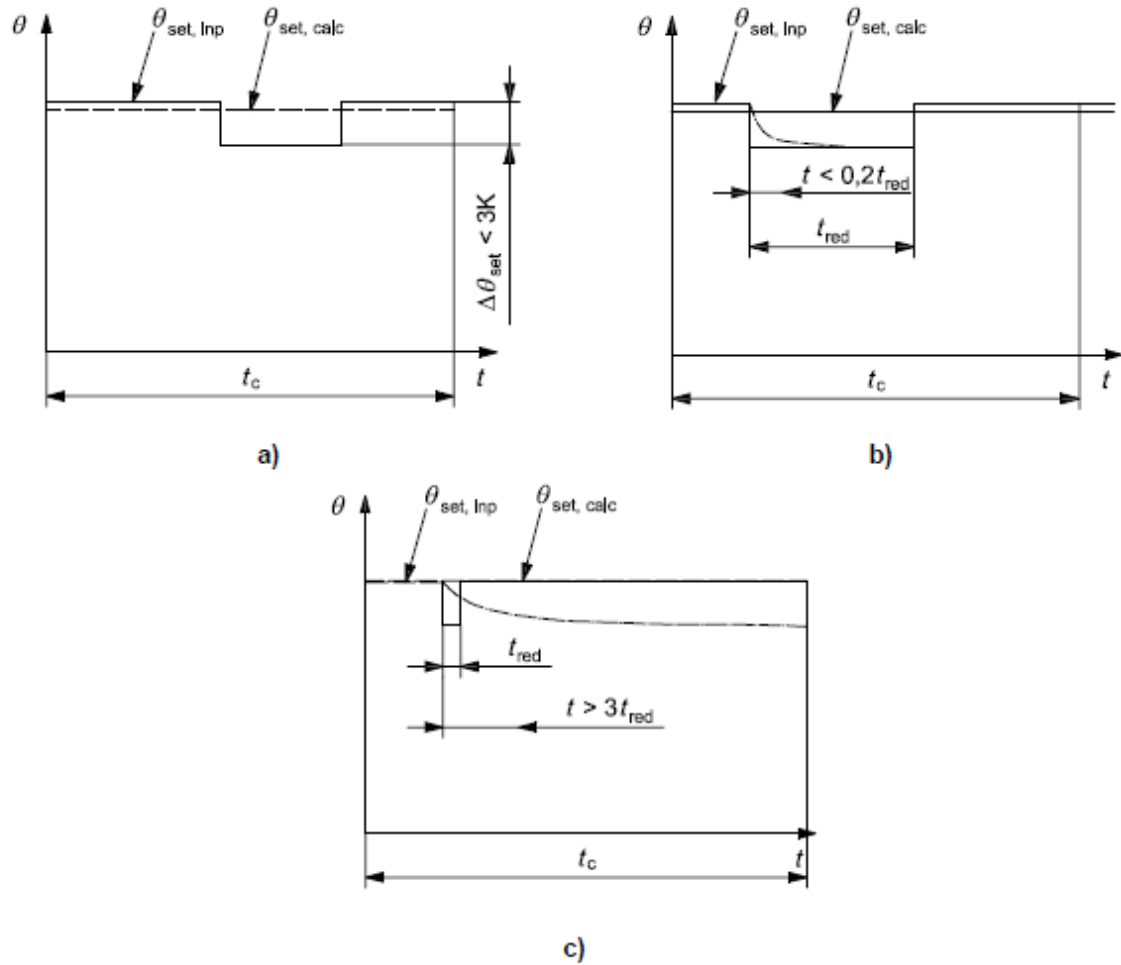
$f_{H,hr}$ is the fraction of the number of hours in the month with a normal heating set-point (no reduced set-point or switch-off);

$b_{H,red}$ is an empirical correlation factor of value = 3;

$\tau_{0,H}$ is the reference time constant for the heating mode, in hours;

τ_H is the time constant of the building zone for heating, in hours;

γ_H is the dimensionless gain/loss ratio for the heating mode.



Key

The cases a, b and c represent different situations as described in the text.

$\theta_{\text{set,inp}}$	set-point temperature provided as input
$\theta_{\text{set,calc}}$	set-point temperature for the calculation
t	time
t_c	representative part of the calculation period

Figure 9: Example of quasi-continuous heating¹⁵

4.1.17.2. Cooling

Due to the diurnal pattern of the weather, and the effect of the building thermal inertia, an evening/night thermostat set-back or switch-off has, in general, a much smaller effect on the energy demand for cooling than a thermostat set-back or switch-off has on the heating energy demand. This implies that a thermostat set-back or switch-off during the evening/night will result in only a small or no decrease in the energy demand for cooling, except during warm months or in the case of high internal gains, in combination with small heat losses. Therefore, the time fraction for intermittency in the cooling mode, $f_{C,day}$ (see next), is based on the number of days in the month with cooling, instead of number of hours in the month as for the heating mode, $f_{H,hr}$ (in Section 4.1.17.1).

In the case of intermittent cooling, the energy demand for cooling, $Q_{C,interm}$, in MJ, is calculated by using the following equation:

$$Q_{C,interm} = a_{C,red} \times Q_{C,cont}$$

where

$Q_{C,cont}$ is the energy demand for continuous cooling, in MJ, calculated in accordance with Section 4.1.8.

$a_{C,red}$ is the dimensionless reduction factor for intermittent cooling, determined according to the following equation:

$$a_{C,red} = 1 - \left[b_{C,red} \times \left(\frac{\tau_{0,C}}{\tau_C} \right) \times \frac{1}{\lambda_C} \times (1 - f_{C,day}) \right]$$

with minimum value: $a_{C,red} = f_{C,day}$ and maximum value: $a_{C,red} = 1$

and where

$f_{C,day}$ is the fraction of the number of days in the month with, at least during daytime, a normal cooling set-point (no reduced set-point or switch-off);

$b_{C,red}$ is an empirical correlation factor of value = 3;

$\tau_{0,C}$ is the reference time constant for the cooling mode, in hours;

τ_C is the time constant of the building zone for cooling, in hours;

λ_C is the dimensionless loss/gain ratio for the cooling mode.

4.1.18. Annual energy demand for heating and cooling, per building zone

The annual energy demand for heating and cooling for a given building zone is calculated by summing the calculated energy demand per period, taking into account possible weighting for different heating or cooling modes.

$$Q_{NH,yr} = \sum_i Q_{NH,i}$$

and

$$Q_{NC,yr} = \sum_j Q_{NC,j}$$

where

$Q_{NH,yr}$ is the annual energy demand for heating of the considered zone, in MJ;

$Q_{NH,i}$ is the energy demand for heating of the considered zone per month i , in MJ (adjusted for intermittence following section 4.1.17, if applicable);

$Q_{NC,yr}$ is the annual energy demand for cooling of the considered zone, in MJ;

$Q_{NC,j}$ is the energy demand for cooling of the considered zone per month j , in MJ (adjusted for intermittence following section 4.1.17, if applicable).

4.1.19. Annual energy demand for heating and cooling, per combination of systems

In case of a multi-zone calculation (with or without thermal interaction between zones), the annual energy demand for heating and cooling for a given combination of heating, cooling, and ventilation systems servicing different zones is the sum of the energy demands over the zones, zs , that are serviced by the same combination of systems:

$$Q_{NH,yr,zs} = \sum_z Q_{NH,yr,z}$$

and

$$Q_{NC,yr,zs} = \sum_{jz} Q_{NC,yr,z}$$

where

$Q_{NH,yr,zs}$ is the annual energy demand for heating for all building zones, zs , serviced by the same combination of systems, in MJ;

$Q_{NH,yr,z}$ is the annual energy demand for heating of zone, z , serviced by the same combination of systems, in MJ;

$Q_{NC,yr,zs}$ is the annual energy demand for cooling for all building zones, zs , serviced by the same combination of systems in MJ;

$Q_{NC,yr,z}$ is the annual energy demand for cooling of zone, z , serviced by the same combination of systems, in MJ.

4.1.20. Total system energy use for space heating and cooling and ventilation systems

In case of a single combination of heating, cooling, and ventilation systems in the building, or per combination of systems, the annual energy consumption (use) for heating and the annual energy consumption (use) for cooling, including system losses, are determined as a function of the energy demands for heating and cooling in the ways described in sections 4.5 and 4.6, respectively, expressed in MJ. The auxiliary energy consumption (use) is calculated separately as described in section 4.7.

4.1.21. Reporting results

For each building zone and each month, the following results are reported:

For heating mode:

- Total heat transfer by transmission;
- Total heat transfer by ventilation;
- Total internal heat sources;
- Total solar heat sources;
- Energy demand for heating.

For cooling mode:

- Total heat transfer by transmission;
- Total heat transfer by ventilation;
- Total internal heat sources;
- Total solar heat sources;
- Energy demand for cooling.

For each HVAC system, the monthly and annual heating and cooling energy demand is reported.

For the whole building, the monthly and annual energy used for heating and cooling is reported.

4.2. Ventilation demand

4.2.1. Heat transfer by ventilation, heating mode

For every month, the heat transfer by ventilation, Q_{V-heat} , is calculated as

$$Q_{V-heat} = H_{V-heat} \times (\theta_i - \theta_e) \times n \times 0.0864$$

where

Q_{V-heat} is the heat transfer by ventilation, in MJ;

H_{V-heat} is the ventilation heat loss coefficient, in W/K;

θ_i is the internal (indoor) temperature (the heating set-point taken from the NCM Activity Database for the activity zone), in °C;

θ_e is the external (outdoor) temperature (the monthly average temperature obtained from the hourly weather data for the location), in °C;

n is the number of days within a month;

0.0864 is a conversion factor from W.days to MJ.

4.2.1.1. Ventilation heat loss coefficient

$$H_{V-heat} = \rho_a \times c_a \times u_{v-heat} \times A$$

where

H_{V-heat} is the ventilation heat loss coefficient for heating, in W/K;

$\rho_a \times c_a$ is the air heat capacity per volume ~ 1.2 kJ/m³K (product of the air density, in kg/m³, and the air specific heat capacity, in kJ/kgK);

u_{v-heat} is the air flow rate through the conditioned space, in l/sm² floor area;

A is the zone floor area, in m².

4.2.1.2. Ventilation air flow rate

$$u_{v-heat} = \left(\frac{u_{v-inf}}{3.6} \right) + [(1 - \eta_{HR}) \times u_{v,m,heat}] + u_{v,n,heat}$$

where

u_{v-heat} is the air flow rate through the conditioned space, in l/sm² floor area;

u_{v-inf} is the air flow rate through the conditioned space due to infiltration, converted by dividing by 3.6 from m³/hm² to l/sm² floor area;

η_{HR} is the efficiency of the heat recovery system. The default values are shown in Table 16, which can be over-ridden by the user.

$u_{v,m,heat}$ is the air flow rate through the conditioned space resulting from mechanical ventilation during operation time, in l/sm² floor area. This value is obtained using the ventilation requirements as established in the NCM Activity Database for each type of activity.

$u_{v,n,heat}$ is the air flow rate through the conditioned space resulting from natural ventilation, in l/sm² floor area. This value is obtained using the ventilation requirements as established in the NCM Activity Database for each type of activity.

Heat recovery system	Efficiency
Plate heat exchanger (Recuperator)	0.65
Heat-pipes	0.6
Thermal wheel	0.65
Run around coil	0.5

Table 16: Default efficiencies of the heat recovery systems

4.2.2. Heat transfer by ventilation, cooling mode

For every month, the heat transfer by ventilation Q_{V-cool} is calculated as

$$Q_{V-cool} = H_{V-cool} \times (\theta_i - \theta'_e) \times n \times 0.0864$$

where

Q_{V-cool} is the heat transfer by ventilation, in MJ;

H_{V-cool} is the ventilation heat loss coefficient, in W/K;

θ_i is the internal (indoor) temperature (the cooling set-point taken from the NCM Activity Database for the activity zone);

θ'_e is the modified external air temperature as appearing in Table 17;

n are the number of days within a month, in days;

0.0864 is a conversion factor from W.days to MJ.

Month	θ'_e (°C)
January	16.0
February	16.0
March	16.0
April	16.0
May	16.0
June	17.0
July	18.5
August	18.3
September	16.0
October	16.0
November	16.0
December	16.0

Table 17: Values¹⁷ used for the temperature of the supply air for the calculation of monthly ventilation losses for cooling demand

4.2.2.1. Ventilation heat loss coefficient

$$H_{V-cool} = \rho_a \times c_a \times u_{v-cool} \times A$$

where

H_{V-cool} is the ventilation heat loss coefficient for cooling, in W/K

¹⁷ Taken from NEN 2916:1998: *Energy performance of non-residential buildings - Determination method*.

$\rho_a \times c_a$ is the air heat capacity per volume $\sim 1.2 \text{ kJ/m}^3\text{K}$ (product of the air density, in kg/m^3 , and the air specific heat capacity, in kJ/kgK , respectively);

u_{v-cool} is the air flow rate through the conditioned space, in l/sm^2 floor area;

A is the zone floor area, in m^2 .

4.2.2.2. Ventilation air flow rate

$$u_{v-cool} = \left(\frac{u_{v-inf}}{3.6} \right) + [(1 - \eta_{HR}) \times u_{v,m,cool}] + u_{v,n,cool}$$

where

u_{v-cool} is the air flow rate through the conditioned space, in l/sm^2 floor area;

u_{v-inf} is the air flow rate through the conditioned space due to infiltration, converted by dividing by 3.6 from m^3/hm^2 to l/sm^2 floor area;

η_{HR} is the efficiency of the heat recovery system. The default values are shown in Table 16, which can be over-ridden by the user. This parameter is set to 0 if heat recovery can be bypassed or switched off in summer (referred to as variable heat recovery efficiency in SBEM).

$u_{v,m,cool}$ is the air flow rate through the conditioned space resulting from mechanical ventilation during operation time, in l/sm^2 floor area. This value is given by the ventilation requirements as established in the NCM Activity Database for each type of activity.

$u_{v,n,cool}$ is the air flow rate through the conditioned space resulting from natural ventilation, in l/sm^2 floor area. This value is obtained using the ventilation requirements as established in the NCM Activity Database for each type of activity.

4.2.3. Demand-controlled ventilation

The Actual building includes the ability to model demand-controlled ventilation for zones with mechanical ventilation while, for naturally ventilated zones, there is the option of enhanced ventilation control, which refers to natural ventilation with BMS control (i.e., modifying the ventilation flow rate provided by natural means in the space based on some form of control). The details for implementing demand-controlled ventilation are outlined below (taken from NCM Modelling Guide).

For zones whose ventilation is defined as mechanical, the following options are available in iSBEM:

1. No demand-controlled ventilation (*default option*)
2. Demand control dependent on number of occupants
3. Demand control dependent on gas sensors

If the option selected is either 2 or 3 from above, then the parameter “air flow regulation type” will become active with the following available options:

1. Damper control (*default option*)
2. Speed control

For zones whose ventilation is defined as natural, the options available in iSBEM are:

1. No demand-controlled ventilation (*default option*)
2. Enhanced ventilation

Depending on the user inputs, a modified demand control fresh air rate (FAR_{dc}) is determined from the NCM fresh air rate (FAR_{max}) as follows:

$$FAR_{dc} = [C_{dc} \times FAR_{lower}] + [(1 - C_{dc}) \times FAR_{max}]$$

where

FAR_{max} is the ventilation rate per person from the NCM Activity Database multiplied by the peak occupancy density during the occupied period (i.e., l/s.m²);

FAR_{lower} is the greater of either: FAR_{min} or $(0.6 \times FAR_{max})$.

where FAR_{min} is the ventilation rate per person from the NCM Activity Database multiplied by the minimum occupancy density during the occupied period (i.e., this can be zero for some activities).

C_{dc} is a demand control coefficient and is determined based on the data in Table 18.

Type of demand control	Demand control coefficient (C_{dc})
None	0
Control based on occupancy number of occupants	0.85
Control based on gas sensor	0.95
Enhanced natural ventilation	0.5

Table 18: Values for demand control coefficient

4.2.4. Infiltration air flow rate (heating and cooling)

This methodology has been extracted from the CEN standards EN 15242. When it can be assumed that there is no interaction between the ventilation system (e.g., mechanical system) and the leakages impact, a simplified approach can be used to calculate the infiltrated and exfiltrated values as follows.

Calculate the air flow through the envelope due to the stack effect, $u_{v-inf-stack}$, and the wind effect, $u_{v-inf-wind}$, without considering mechanical or combustion air flows.

Calculate infiltration due to the stack effect ($u_{v-inf-stack}$) for heating mode

For each external envelope, the air flow due to the stack effect is calculated using the following equation:

$$u_{v-inf-stack} = 0.0146 \times Q_{4pa} \times [h_{stack} \times abs(\theta_e - \theta_i)]^{0.667} \quad [\text{m}^3/\text{h}\text{m}^2 \text{ outer envelope}]$$

where

Q_{4pa} is the air leakage characteristics for a pressure difference of 4 Pa, in m³/h m² of outer envelope, i.e., the average volume of air (in m³/h) that passes through unit area of the building envelope (in m²) when subject to an internal to external pressure difference of 4 Pascals. The value input by the user is the air flow for a pressure difference of 50 Pa and is converted to air flow for a pressure difference of 4 Pa using the information in Table 19, before being used in the above equation. The outer envelope area of the building is defined as the total area of the floor, walls, and roof separating the interior volume from the outside environment.

The conventional value of h_{stack} is 70% of the zone height H_z .

abs is the absolute value.

θ_e is the external (outdoor) temperature (the monthly average obtained from the hourly weather data for the location), in °C

θ_i is the internal (indoor) temperature (the heating set-point taken from the NCM Activity Database for the activity zone where the envelope belongs), in °C.

		m ³ /h per m ² of outer envelope (exp n = 0.667)		
leakages level		Q_{4pa}	Q_{10pa}	Q_{50pa}
single family	low	0.5	1.0	2.5
	average	1.0	2.0	5.0
	high	2.0	3.5	10.0
multi family; non-residential except industrial	low	0.5	1.0	2.5
	average	1.0	2.0	5.0
	high	2.0	3.5	10.0
industrial	low	1.0	2.0	5.0
	average	2.0	3.5	10.0
	high	4.0	7.0	20.0

		n (vol.h) (exp n=0.667)			outer area/vol 1/m
leakages level		n _{4Pa}	n _{10Pa}	n _{50Pa}	
single family	low	0.4	0.8	1.9	0.75
	average	0.8	1.5	3.8	0.75
	high	1.5	2.6	7.5	0.75
multi family; non- residential except industrial	low	0.2	0.4	1	0.4
	average	0.4	0.8	2	0.4
	high	0.8	1.4	4	0.4
industrial	low	0.3	0.6	1.5	0.3
	average	0.6	1.1	3	0.3
	high	1.2	2.1	6	0.3

		m ³ /h per m ² of floor area (exp n = 0.667)			outer area/floor area
leakages level		Q_{4pa}	Q_{10pa}	Q_{50pa}	
single family	low	0.9	1.8	4.5	1.8
	average	1.8	3.6	9.0	1.8
	high	3.6	6.3	18.0	1.8
multi family; non- residential except industrial	low	0.6	1.1	2.8	1.1
	average	1.1	2.2	5.5	1.1
	high	2.2	3.9	11.0	1.1
industrial	low	1.5	3.0	7.5	1.5
	average	3.0	5.3	15.0	1.5
	high	6.0	10.5	30.0	1.5

Table 19: Examples of leakages characteristics¹⁸

¹⁸ Extracted from BS EN 15242:2007 - Ventilation for buildings — Calculation methods for the determination of air flow rates in buildings including infiltration

Calculate infiltration due to the wind impact ($u_{v-inf-wind}$) for heating and cooling modes

For each external envelope, the air flow due to the wind impact is calculated as

$$u_{v-inf-wind} = 0.0769 \times Q_{4pa} \times (\Delta C_p \times V_{site}^2)^{0.667} \quad [\text{m}^3/\text{hm}^2 \text{ outer envelope}]$$

where

Q_{4pa} is the same as defined above.

ΔC_p is the wind pressure coefficient defined as:

- for vertical walls: the wind pressure coefficient difference between the windward and leeward sides for a given wind direction. The conventional value of ΔC_p is 0.75.
- for roofs: the wind pressure coefficient at the roof surface.
 - flat roof: ΔC_p is averaged to 0.55
 - pitched roof: ΔC_p is averaged to 0.35

V_{site} is the wind speed at the building in m/s defined as:

- for vertical walls: average wind speed for a wind sector of $\pm 60^\circ$ to the external wall axis (orientation)
- for roofs: wind speed considering all wind sectors

Then, for each zone, the air flow contributions of all its external envelopes due to the wind impact are totalled.

Calculate the resulting air flow from stack and wind, u_{v-sw}

For each zone, the air flow due to stack and wind effects is calculated as:

$$u_{v-sw} = \max(u_{v-inf-stack}, u_{v-inf-wind}) + \frac{0.14 \times u_{v-inf-stack} \times u_{v-inf-wind}}{Q_{4pa}} \quad [\text{m}^3/\text{hm}^2 \text{ outer envelope}]$$

where

$u_{v-inf-stack}$ is the air flow contributions of all external envelopes due to the stack impact totalled for the zone, in m^3/hm^2

$u_{v-inf-wind}$ is the air flow contributions of all external envelopes due to the wind impact totalled for the zone, in m^3/hm^2

Q_{4pa} is the same as defined above

\max is the maximum value, i.e., greater of

As an approximation, the infiltrated part, u_{v-inf} , can be defined using the following equation:

$$u_{v-inf} = \max(0, u_{v-diff}) + u_{v-sw} \quad [\text{m}^3/\text{hm}^2 \text{ outer envelope}]$$

where

u_{v-diff} is the difference between supply and exhaust air flows (calculated without wind or stack effect).

\max is the maximum value, i.e., greater of

However, this simplified approach does not take into account the fact that if there is a difference between supply and exhaust, the zone is under-pressurised or over-pressurised. Therefore:

$$u_{v-inf} = u_{v-sw} \quad [\text{m}^3/\text{hm}^2 \text{ outer envelope}]$$

At the same time, the resulting air flow is converted to be per unit floor area.

$$u_{v-inf} = u_{v-sw} \times \frac{A_{env}}{A_{zone}} \quad [\text{m}^3/\text{hm}^2 \text{ floor area}]$$

where:

A_{env} is the total area of the outer envelopes defined as the total area of the floor, walls, and roof separating the interior volume of the specific zone from the outside environment, in m^2 .

A_{zone} is the floor area of the zone, in m^2 .

4.2.5. Outputs produced

Q_{V-heat} : heat transfer by ventilation for the heating requirements calculations.

Q_{V-cool} : heat transfer by ventilation for the cooling requirements calculations.

4.3. Hot water demand

Energy demand for each zone (MJ/month) is calculated as:

$$Q_{HWz} = Demand_{db} \times \frac{4.18}{1000} \times A_z \times \Delta T$$

where

Q_{HWz} is the hot water energy demand for each zone, in MJ/month;

$Demand_{db}$ is the hot water demand from the NCM Activity Database (see APPENDIX A:), in l/m² per month;

ΔT is the temperature difference (°C that water is heated up), taken as 50°C (the energy is required to raise the water temperature from 10°C to 60°C);

$\frac{4.18}{1000}$ is the specific heat capacity of water, in MJ/kgK;

A_z is the area of zone z , in m².

Calculate distribution loss for each zone for each month (MJ/month):

If the dead leg length in the zone is greater than 3 m, then distribution losses are calculated as:

$$Loss_{HWz} = 0.17 \times Q_{HWz}$$

where

$Loss_{HWz}$ is the hot water distribution heat loss for zone z , in MJ/month;

0.17 is the default monthly hot water system distribution loss (MJ/month) per monthly hot water energy demand (MJ/ month).

For each Hot Water System (HWS):

- Carry out calculations for each solar energy system (SES) serving the HWS, if applicable, to calculate the SES contribution to HWS, used to reduce hot water demand;
- Evaluate hot water demand, area served, and distribution losses for HWS using:
 - Sum monthly demand for all zones served by HWS (identifying the proportion of the HW demand that is attributed to showers, and baths if present);
 - Sum monthly distribution losses for all zones served by HWS;
 - Sum area of all zones served by HWS;
- Evaluate earliest start time and latest end time for any zone served by HWS;
- Account for contribution from solar energy system, Section 4.9, if applicable;
- Account for contribution from CHP, if applicable.

4.3.1. HW Demand for Showers

In principle, the hot water energy demand for each HWS, Q_{HWS} , in MJ/month, is the summation of the demand of all the zones the system serves, i.e.,

$$Q_{HWS} = \sum_{z=0}^n Q_{HWz}$$

where

Q_{HWS} is the hot water energy demand for each HWS, in MJ/month;

Q_{HWz} is the hot water energy demand for each zone, in MJ/month.

This HW demand is assumed to consist of the demand for showering and bathing, $Q_{HWS_{SH+B}}$, where applicable, and other activities, e.g., washing hands, $Q_{HWS_{Other}}$, which is calculated as follows:

$$Q_{HWS_{SH+B}} = \sum_{z=0}^n (Q_{HWz} \times f_{SHz})$$

$$Q_{HWS_{Other}} = \sum_{z=0}^n [Q_{HWz} \times (1 - f_{SHz})]$$

where

$Q_{HWS_{SH+B}}$ is the hot water energy demand dedicated to showers and baths from each HWS, in MJ/month;

Q_{HWz} is the hot water energy demand, in MJ/month, for each zone, z , served by the HWS;

f_{SHz} is a fraction (a value from 0 to 1) retrieved from the NCM Activity Database denoting the proportion of the zone's activity's hot water demand that is attributed to showers (and baths if present);

$Q_{HWS_{Other}}$ is the hot water energy demand dedicated to uses other than showers and baths from each HWS, in MJ/month.

Further, the hot water energy demand dedicated to showers might need adjustments due to the flow type of the showers. Therefore, depending on the number and type of showers (and baths) served by each HWS, the hot water energy demand dedicated to showers from each HWS is adjusted as:

$$Q_{HWS_{SH}} = \sum_{S=0}^n \frac{Q_{HWS_{SH+B}} \times N_S \times (1 - f_{bath_S}) \times flow_S}{N_{total}}$$

where

$Q_{HWS_{SH}}$ is the hot water energy demand dedicated to showers from each HWS adjusted by shower flow type, in MJ/month;

N_S is the number of showers of type S served by the HWS;

f_{bath_S} is the fraction of the hot water demand attributed to shower type S that is actually diverted to the bath underneath that shower. This fraction is assumed to be 0.22 (i.e., the remaining 0.78 will be used in the shower) if shower type S is above a bath, and 0 otherwise;

$flow_S$ is the flow factor for shower type S depending on its flow type as shown in Table 20;

N_{total} is the total number of showers (of all types) served by the HWS.

Type of shower	$flow_s$	Flow rate [litres/min]
Standard flow	1	7 - 9
High flow*	1.6	> 9
Low flow!	0.6	< 7
* including power showers		
! or electric instantaneous		

Table 20: Flow factor for shower types

Depending on the number and type of showers and baths served by each HWS, the hot water energy demand dedicated to baths from each HWS is calculated as:

$$Q_{HWS_B} = \sum_{S=0}^n \frac{Q_{HWS_{SH+B}} \times N_S \times f_{bath_S}}{N_{total}}$$

where

Q_{HWS_B} is the hot water energy demand dedicated to baths, if available, from each HWS, in MJ/month;

Therefore, the hot water energy demand presented to the HWS is actually calculated as:

$$Q_{HWS}^* = Q_{HWS_{SH}} + Q_{HWS_B} + Q_{HWS_{Other}}$$

Distribution losses

In a similar method, rather than being calculated as:

$$Loss_{HWS} = \sum_{z=0}^n Loss_{HWz}$$

the distribution losses for the HWS which serves the zones can also be split into its components for showering and bathing, $L_{HWS_{SH+B}}$, and other activities, $L_{HWS_{Other}}$, as follows:

$$Loss_{HWS_{SH+B}} = \sum_{z=0}^n (Q_{HWz} \times f_{loss} \times f_{SHz})$$

$$Loss_{HWS_{Other}} = \sum_{z=0}^n [Q_{HWz} \times f_{loss} \times (1 - f_{SHz})]$$

where

$Loss_{HWS_{SH+B}}$ is the distribution losses associated with hot water energy demand dedicated to showers and baths from each HWS, in MJ/month;

Q_{HWz} is the hot water energy demand for each zone, in MJ/month;

f_{loss} is the default monthly hot water system distribution loss (MJ/month) per monthly hot water energy demand (MJ/month), taken to be 0.17 if the dead leg length in the zone is greater than 3 m, and 0 otherwise.

f_{SHz} is a fraction (a value from 0 to 1) retrieved from the NCM Activity Database denoting the proportion of the zone's activity's hot water demand that is attributed to showers (and baths if present);

$Loss_{HWS_{Other}}$ is the distribution losses associated with hot water energy demand dedicated to uses other than showers and baths from each HWS, in MJ/month.

The distribution losses associated with baths alone can be isolated proportional to the corresponding energy demand as follows:

$$Loss_{HWS_B} = Loss_{HWS_{SH+B}} \times \frac{Q_{HWS_B}}{Q_{HWS_{SH+B}}}$$

where

$Loss_{HWS_B}$ is the distribution losses associated with hot water energy demand dedicated to baths from each HWS, in MJ/month;

Q_{HWS_B} is the hot water energy demand dedicated to baths, if available, from each HWS, in MJ/month;

$Q_{HWS_{SH+B}}$ is the hot water energy demand dedicated to showers and baths from each HWS, in MJ/month.

The distribution losses associated with showers, adjusted due to the flow type of the showers, can be calculated proportional to the corresponding energy demand as follows:

$$Loss_{HWS_{SH}} = (Loss_{HWS_{SH+B}} - Loss_{HWS_B}) \times \frac{Q_{HWS_{SH}}}{(Q_{HWS_{SH+B}} - Q_{HWS_B})}$$

where

$Loss_{HWS_{SH}}$ is the distribution losses associated with hot water energy demand dedicated to showers, adjusted due to the flow types, from each HWS, in MJ/month;

$Q_{HWS_{SH}}$ is the hot water energy demand dedicated to showers from each HWS adjusted by shower flow type, in MJ/month;

$Q_{HWS_{SH+B}}$ is the hot water energy demand dedicated to showers and baths from each HWS, in MJ/month.

The adjusted distribution losses for the HWS can then be calculated as:

$$Loss_{HWS}^* = Loss_{HWS_{SH}} + Loss_{HWS_B} + Loss_{HWS_{Other}}$$

where

$Loss_{HWS}^*$ is the distribution losses for the HWS, in MJ/month.

4.3.2. Waste Water Heat Recovery from Showers

If the hot water system serves showers fitted with WWHRS, then the energy demand for the HWS is adjusted as described below.

The volume of water used in showers provided by the HWS at 60°C, is calculated as:

$$V_{60} = Q_{HWS_{SH}} \times \frac{1000}{4.18 \times (60 - 10)}$$

where

V_{60} is the volume of hot water (litres/month) at 60°C, in litres/month;

$Q_{HWS_{SH}}$ is the hot water energy demand dedicated to showers from each HWS adjusted by shower flow type, in MJ/month;

$(60 - 10)$ is the temperature difference (the HWS heats the water temperature from 10°C to 60°C);

$\frac{4.18}{1000}$ is the specific heat capacity of water, in MJ/kgK.

It is assumed that hot water at 60°C is mixed with cold water at 10°C to produce water at 41°C for use in showers. Therefore, the volume of hot water (litres/month) at 41°C is calculated as:

$$V_{41} = \frac{(60 - 10)}{(41 - 10)} \times V_{60}$$

where

V_{41} is the volume of hot water (litres/month) at 41°C, in litres/month;

V_{60} is the volume of hot water (litres/month) at 60°C, in litres/month.

Calculate the energy recovered (MJ/month) by a WWHRS fitted to showers as:

$$Q_{WWHRS_{rec}} = \sum_{S=0}^n \frac{N_S \times HR_S \times V_{41} \times (35 - 10) \times 4.18}{N_{total} \times 1000}$$

where

$Q_{WWHRS_{rec}}$ is the energy recovered by WWHRS fitted to showers, in MJ/month;

N_S is the number of showers of type S served by the HWS;

HR_S is the heat recovery efficiency of the WWHRS fitted to shower type S if applicable (0 if no WWHRS fitted);

V_{41} is the volume of hot water (litres/month) at 41°C, in litres/month;

N_{total} is the total number of showers (of all types) served by the HWS;

$(35 - 10)$ is the temperature difference, assuming the waste water is at 35°C and cold water is at 10°C, and the volume of water passing through the WWHRS is the same volume of water passing through the shower at 41°C;

$\frac{4.18}{1000}$ is the specific heat capacity of water, in MJ/kgK.

NB: This methodology is for an instantaneous WWHRS so the hot water used in baths is excluded from the WWHRS calculation.

NB: An electric instantaneous shower can be included in this configuration only if it includes appropriate thermostatic control options.

Therefore, the hot water energy demand presented to the HWS in case it serves showers with WWHRS is calculated as:

$$Q_{HWS_{WWHRS}} = Q_{HWS_{SH}} + Q_{HWS_B} + Q_{HWS_{Other}} - Q_{WWHRS_{rec}}$$

where

$Q_{HWS_{WWHRS}}$ is the adjusted energy demand presented to the HWS after heat is recovered by WWHRS, in MJ/month;

$Q_{HWS_{SH}}$ is the hot water energy demand dedicated to showers from each HWS adjusted by shower flow type, in MJ/month;

Q_{HWS_B} is the hot water energy demand dedicated to baths, if available, from each HWS, in MJ/month;

$Q_{HWS_{Other}}$ is the hot water energy demand dedicated to uses other than showers and baths from each HWS, in MJ/month;

$Q_{WWHRS_{rec}}$ is the energy recovered by WWHRS fitted to showers, in MJ/month;

Adjust the distribution losses due to heat recovered by WWHRS:

The distribution losses associated with showers if WWHRS is fitted can be calculated as follows:

$$Loss_{HWS_{SH_{WWHRS}}} = Loss_{HWS_{SH}} \times \frac{(Q_{HWS_{SH}} - Q_{HWS_{WWHRS}})}{Q_{HWS_{SH}}}$$

where

$Loss_{HWS_{SH_{WWHRS}}}$ is the distribution losses associated with hot water energy demand dedicated to showers, taking into account any fitted WWHRS, from each HWS, in MJ/month;

$Loss_{HWS_{SH}}$ is the distribution losses associated with hot water energy demand dedicated to showers, adjusted due to the flow types, from each HWS, in MJ/month;

$Q_{HWS_{SH}}$ is the hot water energy demand dedicated to showers from each HWS adjusted by shower flow type, in MJ/month;

The adjusted distribution losses for the HWS if any WWHRS are fitted to showers can then be calculated as:

$$Loss_{HWS_{WWHRS}} = Loss_{HWS_{SH_{WWHRS}}} + Loss_{HWS_B} + Loss_{HWS_{Other}}$$

where

$Loss_{HWS_{WWHRS}}$ is the distribution losses for the HWS if it serves showers fitted with WWHRS, in MJ/month;

$Loss_{HWS_B}$ is the distribution losses associated with hot water energy demand dedicated to baths from each HWS, in MJ/month;

$Loss_{HWS_{Other}}$ is the distribution losses associated with hot water energy demand dedicated to uses other than showers and baths from each HWS, in MJ/month;

Calculate pump energy:

If the WWHRS uses a pump, then the associated energy needs to be calculated and included in the auxiliary energy of the building. The energy used by the WWHRS pump is calculated as described below.

A standard assumption is that each shower use consumes 66 litres of water and lasts for 8 minutes. Therefore, the number of shower uses per month, N_{uses} , is calculated as:

$$N_{uses} = \frac{V_{41}}{66}$$

where

V_{41} is the volume of hot water (litres/month) at 41°C, in litres/month, assuming the volume of water passing through the WWHRS at 35°C is the same volume of water passing through the shower at 41°C.

Further, the duration of shower uses, T_{uses} , in hours per month is calculated as:

$$T_{uses} = N_{uses} \times \frac{8}{60}$$

where

60 is a factor to convert minutes to hours

The WWHRS pump operating time, T_{pump} , in hours per month, is calculated as:

$$T_{pump} = T_{uses} \times \frac{1 + (1.4 \times N_{total}^{0.5})}{2}$$

where

$\frac{1 + (1.4 \times N_{total}^{0.5})}{2}$ is a simultaneity term for shower usage;

N_{total} is the total number of showers (of all types) served by the HWS.

The auxiliary energy consumption by the pump during operating time, Q_{pump} , in kWh per month, is calculated as:

$$Q_{pump} = \sum_{s=0}^n \frac{T_{pump} \times N_s \times Power_s}{N_{total} \times 1000}$$

where

N_s is the number of showers of type S served by the HWS;

$Power_s$ is the nominal power, in W, of the WWHRS pump which is connected to shower type S ;

N_{total} is the total number of showers (of all types) served by the HWS;

1000 is a factor to convert W to kW.

4.3.3. Hot Water storage

If the hot water system includes storage, and the storage volume has not been input by the user, then the storage volume (litres) is calculated as:

$$V_{store} = Q_{day} \times 18$$

where

V_{store} is the storage volume, in litres,

Q_{day} , is the daily HW energy demand, in MJ/day, is calculated by:

$$Q_{day} = \frac{Q_{month_max}}{N_{days}}$$

where

Q_{month_max} is the maximum monthly demand, in MJ;

N_{days} is the number of days in the month;

18 is a computational value – storage volume is 18 litres per MJ of daily demand.

If the storage losses (MJ/month) have not been input by the user, then storage losses are calculated as:

$$Loss_{store} = Loss_{day} \times (V_{store_s})^{1/3} \times \frac{365}{12} \times (V_{store})^{2/3} \times 3.6$$

where

$Loss_{store}$ is the HW storage losses, in MJ/month;

$Loss_{day}$ is the HW storage losses per day in kWh per litre of storage and is calculated as follows:

- for an uninsulated storage vessel: 0.1425 kWh/day per litre of storage
- for a vessel with loose jacket of insulation thickness t mm: $0.005 + \frac{1.76}{(t+12.8)}$
- for a vessel with factory fitted insulation of thickness t mm: $0.005 + \frac{0.55}{(t+4)}$

V_{store_s} is the storage volume, in litres, if the annual hot water demand were 5 MJ/m², i.e., it is calculated as $= \frac{5}{365} \times 18 \times A_{HWS}$

where

18 is the same computational value described above;

A_{HWS} is the total area served by the HWS, in m²;

$\frac{365}{12}$ is multiplication by the number of days in the year and division by the number of months in order to obtain the monthly storage losses;

V_{store} is the hot water storage volume, in litres, as calculated above or as input by the user;

3.6 is a factor to convert the storage losses from kWh to MJ.

4.3.4. Secondary circulation

If the HWS includes a secondary circulation, then, if not input by the user, the secondary circulation loop length (m) is calculated as:

$$loop_{SC} = \sqrt{A_{HWS}} \times 4.0$$

where

$loop_{SC}$ is the secondary circulation loop length, in m;

A_{HWS} is the total area served by the HWS, in m²;

4.0 is a computational value.

The secondary circulation losses (MJ/month) are calculated as:

$$Loss_{SC_m} = l_m \times loop_{SC} \times h_{SC} \times N_m \times \frac{3.6}{1000}$$

where

$Loss_{SC_m}$ is the secondary circulation losses, in MJ, for month m ;

l_m is the secondary circulation losses per metre, taken as 15 W/m of secondary circulation loop length, if it is not input by the user;

$loop_{SC}$ is the secondary circulation loop length in m;

h_{SC} is the number of daily hours of operation of the secondary circulation (or 24 hours if there is no time switch on the secondary circulation);

N_m is the number of days in month m ;

$\frac{3.6}{1000}$ is a factor to convert W to kWh and then kWh to MJ.

The secondary circulation pump power (kW), if not input by the user, is calculated as:

$$P_{SC} = \frac{(0.25 \times loop_{SC}) + 42}{500}$$

where

P_{SC} is the secondary circulation pump power, in kW;

$loop_{SC}$ is the secondary circulation loop length, in m;

0.25, 42, and 500 are computational values.

The secondary circulation pump energy is then calculated by multiplying the pump power by the hours of operation as above. This is then included in the auxiliary energy calculated for the building.

4.4. Lighting energy use

Lighting energy is calculated according to CEN EN 15193-1. Inputs to this calculation include lighting power, duration of operation including the impact of occupancy, and terms to deal with the contribution of daylight under different control regimes.

Energy for lighting, W_{light} , in kWh/m².year, is calculated as:

$$W_{light} = \sum_{j=1}^{12} \left\{ N_j \times \left[\sum_{i=1}^{24} (P_j \times F_{Dji} \times F_{Oji}) + \sum_{i=1}^{24} (P_{dj} \times F_{Od}) + (24 \times P_p) \right] \right\} \div 1000$$

where:

N_j is number of days in month j

P_j is lighting power density in W/m² for each hour of month j

P_{dj} is display lighting power density in W/m² for each hour of month j

P_p is parasitic power density in W/m²

F_{Dji} is daylight correction factor (utilisation factor) for hour i of month j

F_{Oji} is occupancy correction factor for hour i of month j

F_{Od} is occupancy correction factor for display lighting throughout the year

1000 is conversion from W to kW

4.4.1. Calculate lighting power density in the Actual and Notional buildings, P_j

The lighting power density for the Actual and Notional buildings are calculated as specified in the NCM Modelling Guide of the relevant building regulations for England, Wales, Scotland, and Northern Ireland.

Where the user selects a lamp type for each zone in the Actual building, the default luminous efficacy values in Table 21 will be used in the calculation by SBEM.

If the Actual building includes constant illuminance control, then the general lighting power density is reduced by 10%.

Lamp Type	Luminaire lumens per circuit Watt			
	For all buildings except those specified in the next column		For modular or portable "distress purchase" buildings with a planned time of use in a single location ≤ 2 years	
	Side-lit and not daylight activities	Top-lit activities	Side-lit and not daylight activities	Top-lit activities
LED	50.0	50.0	55.0	55.0
Tungsten and Halogen	7.5	9.0	7.5	9.0
Fluorescent - compact	22.5	27.0	22.5	27.0
T12 Fluorescent - halophosphate - low frequency ballast	25.0	30.0	25.0	30.0

T8 Fluorescent - halophosphate - low frequency ballast	27.5	33.0	55.0	55.0
T8 Fluorescent - halophosphate - high frequency ballast	32.5	39.0	55.0	58.5
T8 Fluorescent - triphosphor - high frequency ballast	36.3	43.5	55.0	65.3
Metal Halide	25.0	39.0	25.0	39.0
High Pressure Mercury	22.5	27.0	22.5	27.0
High Pressure Sodium	35.0	42.0	35.0	42.0
T5 Fluorescent - triphosphor-coated - high frequency ballast	37.5	45.0	56.3	67.5
Fluorescent (no details)	22.5	27.0	22.5	27.0

Table 21: Luminous efficacies used by SBEM in correspondence to the lamp types selected (from England's 2021 NCM Modelling Guide)

4.4.2. Calculate display lighting power density, P_{dj}

For the Actual building, the display lighting will be defined in terms of the average display lighting lamp (light source) efficacy for each zone, which will be pro-rated against an efficacy of 15 light source lumens per circuit-watt to adjust the NCM display lighting power density value associated with the activity in the NCM Activity Database.

Daylight harvesting and local manual switching do not apply to display lighting in the Actual or Notional building (i.e., they only affect general lighting).

4.4.3. Calculate parasitic power, P_p

The parasitic power density, P_p , is assumed to be:

- For manual switching: 0 W/m²
- For photoelectric control (dimming or switching) or constant illuminance control: default for digitally-addressable systems = 0.57 W/m², default for stand-alone sensors = 0.3 W/m², or the user can specify the value for the system used.
- For occupancy sensing: default = 0.3 W/m², or the user can specify the value for the system used.

4.4.4. Calculate daylight correction factor, F_{Dji}

The daylight impact factor (utilization factor), F_D , is the lighting use in a space, expressed as a fraction of that with no daylight contribution.

4.4.4.1. Daylight penetration

This is expressed in terms of the average daylight factor (DF). It can also be used with rooflights. The average daylight factor in SBEM is assumed to be:

- For side windows: $DF = DF_1 = 45 \times \frac{W_{win}}{A}$
- For spaces with horizontal or shed type rooflights: $DF = DF_2 = 90 \times \frac{W_{roof}}{A}$
- For both side windows and rooflights: $DF = DF_1 + DF_2$

Where W_{win} is the total window area including the frame (adjusted for the frame factor of each window), W_{roof} is the total rooflight area including the frame (adjusted for the frame factor of each rooflight), and A is the area of all room surfaces (ceiling/roof, floor, walls, windows, and rooflights).

These figures are for clear low-e double glazing. If tinted glazing is used, multiply by the manufacturer's normal incidence light transmittance and divide by 0.76.

Calculate the daylight factor for front, middle, and back of zone:

DF_F is the average daylight factor (%) in the front part of zone within the first 3 m from the facade:

$$DF_F = (1.75 \times DF_1) + DF_2$$

DF_M is average daylight factor (%) in the middle part of zone within the second 3 m from the facade:

$$DF_M = (0.25 \times DF_1) + DF_2$$

DF_B is average daylight factor (%) in the back part of zone beyond the first 6 m from the facade:

$$DF_B = DF_2$$

4.4.4.2. Photoelectric control

Calculate the utilisation factor:

For zones that are daylight by windows in only one orientation, the utilisation factor, F_D , should take account of the difference in control between the front and back of the zone as follows:

If the photo sensor is in the front of the zone only, then:

$$F_D = \left[\text{fraction area daylight by windows} \times \frac{(F_{D,F} + 1)}{2} \right] + [(1 - \text{fraction area daylight by windows}) \times 1.0]$$

If the photo sensor is in the front and back, then:

$$F_D = \left[\text{fraction area daylight by windows} \times \frac{(F_{D,F} + F_{D,M})}{2} \right] + [(1 - \text{fraction area daylight by windows}) \times F_{D,B}]$$

For zones with rooflights or with windows in opposite orientations, where the difference in azimuth is 175° or more, and the ratio of the daylight contribution between the opposite sides is less than 3:1, then the utilisation factor is calculated as:

$$F_D = \left[\text{fraction area daylight by windows} \times \frac{(F_{D,F} + F_{D,M})}{2} \right] + [(1 - \text{fraction area daylight by windows}) \times F_{D,B}]$$

where

$F_{D,F}$ is the utilisation factor for the front part of the room

$F_{D,M}$ is the utilisation factor for the middle part of the room

$F_{D,B}$ is the utilisation factor for the back part of the room

and they are calculated according to the type of lighting control as follows:

Photoelectric switching:

E_{ext} is the external illuminance (in kLux) – from the illuminance data for the particular weather location similar to that for Kew shown, as an example, in Table 22.

E_{design} is the design illuminance (in Lux)

Front part of room:

$$\begin{aligned} \text{if } (E_{ext} \times DF_F \times 10) > E_{design} \quad & \text{then } F_{D,F} = 0 \\ \text{else if } (E_{ext} \times DF_F \times 10) > (0.5 \times E_{design}) \quad & \text{then } F_{D,F} = 0.5 \\ \text{else } & F_{D,F} = 1 \end{aligned}$$

Middle part of room:

$$\begin{aligned} \text{if } (E_{ext} \times DF_M \times 10) > E_{design} \quad & \text{then } F_{D,M} = 0 \\ \text{else if } (E_{ext} \times DF_M \times 10) > (0.5 \times E_{design}) \quad & \text{then } F_{D,M} = 0.5 \\ \text{else } & F_{D,M} = 1 \end{aligned}$$

Back part of room:

$$\begin{aligned} \text{if } (E_{ext} \times DF_B \times 10) > E_{design} \quad & \text{then } F_{D,B} = 0 \\ \text{else if } (E_{ext} \times DF_B \times 10) > (0.5 \times E_{design}) \quad & \text{then } F_{D,B} = 0.5 \\ \text{else } & F_{D,B} = 1 \end{aligned}$$

Photoelectric dimming

Front part of room:

$$\begin{aligned} \text{if } (E_{ext} \times DF_F \times 10) > E_{design} \quad & \text{then } F_{D,F} = 0 \\ \text{else } F_{D,F} &= \frac{E_{design} - (E_{ext} \times DF_F \times 10)}{E_{design}} \end{aligned}$$

Middle part of room:

$$\begin{aligned} \text{if } (E_{ext} \times DF_M \times 10) > E_{design} \quad & \text{then } F_{D,M} = 0 \\ \text{else } F_{D,M} &= \frac{E_{design} - (E_{ext} \times DF_M \times 10)}{E_{design}} \end{aligned}$$

Back part of room:

$$\begin{aligned} \text{if } (E_{ext} \times DF_B \times 10) > E_{design} \quad & \text{then } F_{D,B} = 0 \\ \text{else } F_{D,B} &= \frac{E_{design} - (E_{ext} \times DF_B \times 10)}{E_{design}} \end{aligned}$$

NB: In normal operation, the residual light output and power consumption of dimmed lights will occur throughout working hours unless (potential future modifications to SBEM) the circuit is switched off by the occupants, an occupancy sensor, or a time switch.

4.4.4.3. Manual switching

This only applies where there is local manual switching, i.e.,

- maximum distance from a switch to the luminaire it controls is 6 m or twice the luminaire mounting height if this is greater
- or if the area of the room is less than 30 m²
- It does not apply in corridors or other circulation areas, dry sports/fitness, ice rinks, changing rooms, swimming pools, sales areas, baggage reclaim areas, security check areas, eating/drinking areas, halls, lecture theatres, cold stores, display areas, A&E, industrial process areas, warehouse storage, and performance areas (stages), for all of which, $F_D = 1$.

A manual switching choice is only assumed to occur when either:

- the building is occupied for the first time in the day
- (not currently included in SBEM) a period when the lighting is required follows a period when the lighting is not required
- (not currently included in SBEM) following a period when the space has been completely unoccupied for at least an hour; or
- (not currently included in SBEM) an overriding time switch has switched off the lighting.]

Following such an event, F_D is calculated as follows:

$$\text{if } (E_{ext} \times DF_F \times 10) > E_{design} \quad \text{then } F_D = 0.5$$

and if there are side windows in one orientation only, then:

$$F_D = [\text{area daylit by windows} \times 0.5] + [(1 - \text{area daylit by windows}) \times 0.5]$$

$$\text{else } F_D = 1$$

4.4.4.4. Manual plus photoelectric control

F_D is calculated for each control separately. Then the minimum of the two F_D values is taken.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Time												
630	0.0	0.2	2.2	2.1	6.8	9.0	7.4	3.7	0.7	0.0	0.0	0.0
730	0.3	2.0	7.3	7.3	13.0	15.1	13.9	9.9	4.5	0.7	0.7	0.1
830	2.2	6.5	12.5	12.6	19.3	20.9	20.0	16.6	11.0	4.2	3.8	1.6
930	5.8	10.6	17.1	18.2	24.7	26.0	26.1	22.6	16.9	9.4	7.8	4.7
1030	8.7	14.0	20.7	22.7	28.7	30.6	31.1	26.9	22.2	13.8	10.9	7.6
1130	10.2	15.3	22.5	26.1	31.0	32.6	34.9	30.6	25.0	17.1	12.6	9.0
1230	10.1	15.9	22.4	27.7	33.6	34.8	36.3	32.9	25.9	18.7	12.6	9.1
1330	8.9	13.7	20.4	27.6	33.8	35.4	35.9	33.1	25.4	19.0	11.0	7.7
1430	6.0	10.9	16.8	26.6	32.6	34.0	34.2	31.8	24.5	17.1	8.2	4.9
1530	2.5	6.7	12.5	24.0	29.1	30.2	31.1	28.3	21.1	14.0	3.9	1.6

1630	0.3	2.0	7.4	18.7	24.4	25.6	26.6	23.1	16.2	9.8	0.6	0.1
1730	0.0	0.2	2.3	13.4	18.9	20.5	20.7	17.0	10.5	4.2	0.0	0.0
1830	0.0	0.0	0.3	7.6	13.2	14.8	14.6	10.5	4.3	0.7	0.0	0.0
1930	0.0	0.0	0.0	2.1	6.8	9.1	8.1	3.8	0.7	0.0	0.0	0.0

Table 22: External illuminances in Kew in kilolux. Outside these times the external illuminance is assumed to be zero

4.4.5. Occupancy correction, F_{Oji}

If the building is occupied, but there is no requirement for lighting (e.g., a hotel room or hospital ward at night), $F_O = 0$.

At other times, $F_O = 1$ if the lighting is switched on 'centrally' (this is assumed in SBEM if there is no manual switching or photoelectric control).

In specific activity areas, such as corridors or other circulation areas, dry sports/fitness, ice rinks, changing rooms, swimming pools, sales areas, baggage reclaim areas, security check areas, eating/drinking areas, halls, lecture theatres, cold stores, display areas, A&E, industrial process areas, warehouse storage, performance areas (stages), etc., $F_O = 1$ even if occupancy sensing or manual control is provided, unless an automatic time switch dims or switches off the lighting (i.e., the options "Auto On / Dimmed" or "Auto On / Auto Off" in Table 23).

4.4.5.1. Local occupancy sensing

$$F_{Oji} = F_{OC} \quad (\text{for each hour } i \text{ in the calculation})$$

In these expressions, F_{OC} is given in Table 23. System types are defined in the CEN standard EN 15193: *Energy performance of buildings — Energy requirements for lighting*.

Occupancy Sensing	F_{OC}
Systems without automatic presence or absence detection	
Manual On/Off Switch	1.00
Manual On/Off Switch + additional automatic sweeping extinction signal	0.95
Systems with automatic presence and/or absence detection	
Auto On / Dimmed	0.95
Auto On / Auto Off	0.90
Manual On / Dimmed	0.90
Manual On / Auto Off	0.82

Table 23: F_{OC} values

4.4.6. Time switching – used for display lighting only – calculate F_{Od}

Automatic time switch:

If there is an automatic time-switch for display lighting, then

$$F_{Od} = 1 - f$$

where $f = 0.2$ to represent a reduction of 20% in the power density of display lighting.

If there is no time-switch for display lighting, then $f = 0$.

4.4.7. Correction for Metering

Apply metering correction of 5% reduction to the lighting energy calculated, if applicable.

4.5. Heating energy use

Heating energy use is determined on a monthly basis for each HVAC system defined in the building. Having calculated the energy demand for heating in each zone of the building (Q_{NH}) as described in section 4.1.7 and 4.1.17.1, the heating energy demand (H_d) for the HVAC system h_i will be the addition of the demand of all the zones attached to that HVAC system. The heating energy use (H_e) for the HVAC system is then calculated by:

$$H_e = \frac{H_d}{SSEff}$$

where $SSEff$ is the seasonal efficiency of the heating system as discussed in section 3.3.3.

The building heating energy use will be the addition of the heating energy use of all the HVAC systems included in the building.

4.5.1. Correction for Metering

Apply metering correction of 5% reduction to the heating energy calculated, if applicable.

4.6. Cooling energy use

Cooling energy use is determined on a monthly basis for each HVAC system defined in the building. Having calculated the energy demand for cooling in each zone of the building (Q_{NC}) as described in section 4.1.8 and 4.1.17.2, the cooling energy demand (C_d) for the HVAC system h_i will be the addition of the demand of all the zones attached to that HVAC system. The cooling energy use (C_e) for the HVAC system is then calculated by:

$$C_e = \frac{C_d}{SSEER}$$

where $SSEER$ is the seasonal energy efficiency ratio of the cooling system as discussed in section 3.3.3.

The building cooling energy use will be the addition of the cooling energy use of all the HVAC systems included in the building.

4.6.1. Correction for Metering

Apply metering correction of 5% reduction to the cooling energy calculated, if applicable.

4.7. Auxiliary energy use

Auxiliary energy use is calculated on a monthly basis for each zone, depending on its servicing strategy, defined in the building.

4.7.1. Data requirements

Ventilation rate:

- For mechanical ventilation, SBEM uses outside fresh air rates from the NCM Activity Database (for the chosen activity in zone).
- For mechanical exhaust, users need to enter air flow rate.

Specific fan power (SFP):

- Users need to enter the SFP where there is mechanical ventilation, either at zone level or HVAC level.
- Users must also enter the SFP at zone level where there is zonal mechanical exhaust.

4.7.2. Definition of algorithms

The auxiliary energy for each zone is calculated monthly as shown below (in kWh/m²) and then multiplied by the area of the zone (in m²), and, if applicable, also corrected for metering.

The auxiliary energy is the product of the auxiliary power density and annual hours of operation of the HVAC system from the NCM Activity Database (e.g., the hours when the heating set-point is above the set-back temperature based on the daily/weekly/annual schedules from the NCM Activity Database).

The zone's auxiliary power density is the sum of the pump and fan power density.

4.7.2.1. Pump power

The pump power density for the Actual building will depend on the type of HVAC system and whether the pump has variable speed control. Table 24 determines which HVAC system types need to account for pump power and whether the option of specifying variable speed pumping is available to the user. Table 25 gives the pump power densities for constant speed pumping as well as variable speed pumping.

HVAC system type	Pump power	Variable speed pumping allowed
Central heating using water: radiators	LTHW ¹⁹ only	Yes
Central heating using water: convectors	LTHW only	Yes
Central heating using water: floor heating	LTHW only	Yes
Central heating with air distribution	None	No
Other local room heater - fanned	None	No
Other local room heater - unfanned	None	No
Unflued radiant heater	None	No
Flued radiant heater	None	No

¹⁹ Low temperature hot water

Multiburner radiant heaters	None	No
Flued forced-convection air heaters	None	No
Unflued forced-convection air heaters	None	No
Single-duct VAV	Both LTHW and CHW ²⁰	No
Dual-duct VAV	Both LTHW and CHW	No
Indoor packaged cabinet (VAV)	Both LTHW and CHW	Yes
Fan coil systems	Both LTHW and CHW	Yes
Induction system	Both LTHW and CHW	Yes
Constant volume system (fixed fresh air rate)	Both LTHW and CHW	No
Constant volume system (variable fresh air rate)	Both LTHW and CHW	No
Multizone (hot deck/cold deck)	Both LTHW and CHW	No
Terminal reheat (constant volume)	Both LTHW and CHW	No
Dual duct (constant volume)	Both LTHW and CHW	No
Chilled ceilings or passive chilled beams and displacement ventilation	Both LTHW and CHW	Yes
Chilled ceilings or passive chilled beams and mixing ventilation	Both LTHW and CHW	Yes
Active chilled beams	Both LTHW and CHW	Yes
Water loop heat pump	Both LTHW and CHW	No
Split or multi-split system	None	No
Single room cooling system	None	No
Variable refrigerant flow	None	No

Table 24: Assigning pump power to HVAC systems (from 2021 NCM Modelling Guide)

Pump configuration	Pump power density (W/m ²)	
	LTHW only	Both LTHW and CHW
Constant speed pumping	0.6	1.8
Variable speed pumping with differential sensor across pump	0.5	1.5
Variable speed pumping with differential sensor in the system	0.4	1.1
Variable speed pumping with multiple pressure sensors in the system	0.3	0.9

Table 25: Pump power density for Actual building (from 2021 NCM Modelling Guide)

4.7.2.2. Fan power

For zones whose servicing strategy is mechanical ventilation as well as heating and/or cooling, the fan power density is determined for each zone using one of the following equations as determined by Table 26:

$$FPS_1 = (FAR_{max} \times SFP_{central}) + (SCR \times SFP_{terminal})$$

$$FPS_2 = \text{greater of } (FAR_{max}, SCR) \times SFP_{central}$$

$$FPS_3 = \text{greater of } \left(\frac{SCR}{5}, FAR_{max} \right) \times SFP_{central}$$

$$FPS_4 = FAR_{max} \times SFP_{central}$$

$$FPS_5 = 0.85 \times FAR_{max} \times SFP_{central}$$

where

²⁰ Chilled water

FAR_{max} is the peak fresh air supply rate (l/s.m²) that is set by the NCM activity type;

SCR is the space conditioning supply rate (i.e., the air flow rate needed to condition the space, in l/s.m²), which is calculated as follows:

$$SCR = \frac{\text{greater of } (PSH, PSC)}{\rho \times C_p \times \Delta T}$$

where

$\rho = 1.2$ kg/m³ is the air density;

$C_p = 1.018$ kJ/kgK is the air specific heat capacity;

$\Delta T = 8^\circ\text{K}$, PSH is the peak space heating load;

PSC is the peak space cooling load (i.e., in W/m² of floor area for each zone);

$SFP_{central}$ is the central unit specific fan power, in W/(l/s);

$SFP_{terminal}$ is the terminal unit specific fan power, in W/(l/s), if applicable.

HVAC system type	Fan power density
Central heating using water: radiators	-
Central heating using water: convectors	-
Central heating using water: floor heating	-
Central heating with air distribution	FPS_2
Other local room heater - fanned	-
Other local room heater - unfanned	-
Unflued radiant heater	-
Flued radiant heater	-
Multiburner radiant heaters	-
Flued forced-convection air heaters	-
Unflued forced-convection air heaters	-
Single-duct VAV	FPS_2
Dual-duct VAV	FPS_2
Indoor packaged cabinet (VAV)	FPS_1
Fan coil systems	FPS_1
Induction system	FPS_3
Constant volume system (fixed fresh air rate)	FPS_2
Constant volume system (variable fresh air rate)	FPS_2
Multizone (hot deck/cold deck)	FPS_2
Terminal reheat (constant volume)	FPS_2
Dual duct (constant volume)	FPS_2
Chilled ceilings or passive chilled beams and mixing ventilation	FPS_4
Active chilled beams	FPS_3
Water loop heat pump	FPS_2
Split or multi-split system	-
Single room cooling system	-
Variable refrigerant flow	FPS_4
Chilled ceilings or passive chilled beams and displacement ventilation ²¹	FPS_5

Table 26: Assigning fan power equations to HVAC systems (from 2021 NCM Modelling Guide)

²¹ Displacement ventilation is assumed to reduce the required airflow by 15% compared to mixing ventilation.

For zones whose servicing strategy is mechanical ventilation (which might include heat recovery) but no heating or cooling, the fan power density is the product of the fresh air supply rate from the NCM Activity Database and the specific fan power defined by the user at zone level.

For zones with mechanical exhaust, the fan power density is the product of the user defined exhaust rate and the specific fan power defined by the user. The exhaust fan energy will be an addition to the fan energy for supply & extract ventilation, if available.

For zones served by the HVAC systems listed in Table 27, additional fan energy is included to account for integral fans using the ratio (to be input by the user) of associated fan power, in W per kW of heat output (delivered) by the heating system.

HVAC system type
Central heating using water: convectors (<i>but only in case the system utilises fanned convectors</i>)
Other local room heater - fanned

Table 27: Additional fan power for HVAC systems (from 2021 NCM Modelling Guide)

For zones with de-stratification fans, the following is added to the monthly auxiliary energy calculation:

$$\frac{1}{3.6} \text{ kWh/m}^2 \text{ (i.e., 1 MJ/m}^2\text{)}$$

Energy for other ancillary services in the building, such as secondary hot water circulation (Section 4.3.4), forced circulation for solar water heating systems (Section 4.9), night cooling, etc., will be an addition to the fan and pump energy in order to form the total auxiliary energy for the building.

4.7.2.3. Demand-controlled ventilation

In addition to affecting the fresh air load (i.e., energy to heat and cool the fresh air), demand control of ventilation can also affect the auxiliary energy. Where there is demand control of ventilation, as per the 2021 NCM Modelling Guide, the auxiliary energy calculation will use FAR_{max} pro-rated by a value obtained from Table 28, depending on the type of control for air regulation and the ratio of modified fresh air rate to maximum fresh air rate (i.e.,

$$\frac{FAR_{dc}}{FAR_{max}}).$$

Proportion of maximum fan power in case of demand control of ventilation						
$\frac{FAR_{dc}}{FAR_{max}}$	0	0.2	0.4	0.6	0.8	1
Air flow regulation type						
Damper control*	0	0.525	0.65	0.8	1	1
Speed control	0	0.1	0.18	0.35	0.65	1
*Average of forward and backward blades.						
Use linear interpolation for intermediate values of $\frac{FAR_{dc}}{FAR_{max}}$						

Table 28: Fan power for demand-controlled ventilation (from 2021 NCM Modelling Guide and based on BS EN 15241:2007 - Ventilation for buildings)

4.8. Hot water energy use

As described in section 4.3, for each HWS, calculate:

- hot water demand, in MJ/month
- distribution losses, in MJ/month
- storage losses, in MJ/month
- secondary circulation losses, in MJ/month
- secondary circulation pump energy (added to auxiliary energy)

Distribution efficiency

The monthly HWS distribution efficiency is calculated as:

$$Eff_{dist} = \frac{Q_{HWS}}{(Q_{HWS} + Loss_{dist} + Loss_{stor} + Loss_{sec})}$$

where

- Eff_{dist} is the monthly hot water distribution efficiency for the HWS;
- Q_{HWS} is the water heating energy demand for the HWS, in MJ/month;
- $Loss_{dist}$ is the hot water distribution losses for the HWS, in MJ/month, if applicable;
- $Loss_{stor}$ is the hot water storage losses for the HWS, in MJ/month, if applicable;
- $Loss_{sec}$ is the hot water secondary circulation losses for the HWS, in MJ/month, if applicable.

Hot Water energy consumption

The hot water energy consumption, in MJ/month, for the HWS is calculated as:

$$E_{HWS} = \frac{\left(\frac{Q_{HWS}}{Eff_{dist}} \right)}{Eff_{gen}}$$

where

- E_{HWS} is the water heating energy consumption for the HWS, in MJ/month;
- Q_{HWS} is the water heating energy demand for the HWS, in MJ/month;
- Eff_{dist} is the monthly hot water distribution efficiency for the HWS;
- Eff_{gen} is the hot water generator efficiency for the HWS.

If the hot water system is connected to a solar water heating system and/or a CHP generator, the water heating energy consumption is calculated as:

$$E_{HWS} = \frac{\left[\left(\frac{Q_{HWS}}{Eff_{dist}} \right) - C_{CHP} - C_{SES} \right]}{Eff_{gen}}$$

where

- E_{HWS} is the water heating energy consumption, in MJ/month;
- Q_{HWS} is the water heating energy demand for the HWS, in MJ/month;

Eff_{dist} is the monthly hot water distribution efficiency for the HWS;

C_{CHP} is the water heating contribution to this HWS from a CHP, in MJ/month, if applicable;

C_{SES} is the water heating contribution to this HWS from a SES, in MJ/month, if applicable;

Eff_{gen} is the hot water generator efficiency for the HWS.

Note: If the hot water is provided by the HVAC system's heat generator, rather than by an independent generator, the efficiency of the heat generator is reduced by 5% for the water heating calculation in order to take account of the reduction in the efficiency at part-load operation (since the generator would have been sized to accommodate both the space and water heating loads).

4.9. Solar thermal energy systems

The energy yield given by the solar thermal energy system is calculated according to the collector orientation and inclination. In order to calculate the radiation at the collector plane, the hourly radiation data is processed to yield values of monthly global solar radiation for the orientations and inclinations shown in Table 29 and Table 30, respectively.

For the purposes of SBEM calculations, solar hot water is used to displace some (or all) of the hot water demand presented to the hot water system in the building, and hence, reduce the fuel that would otherwise be used by the hot water generator in order to meet the whole demand.

4.9.1. Data requirements

General

- HWS which the solar energy system is serving: specifies the name given by the user for the hot water system (HWS) to which the solar energy system (SES) is connected. This parameter is needed for the software to know the demand of the zones served by the hot water system and that is being displaced by the solar energy system;
- Area: specifies the solar collector maximum projected area through which un-concentrated solar radiation enters the collector, in m²;
- Orientation: specifies the orientation of the solar collector;
- Inclination: specifies the inclination of the solar collector in degrees from the horizontal where 0° stands for a horizontal surface and 90° for a vertical surface.

Orientations
N
NE
E
SE
S
SW
W
NW

Table 29: Orientations for which the monthly solar radiation has been calculated for SBEM

Inclinations
0
15
30
45
60
75
90

Table 30: Inclinations for which the monthly solar radiation has been calculated for SBEM

Collector parameters

If the collector parameters are known, they should be entered by the user into iSBEM. Otherwise, the default values in Table 31 will be used by the software. The collector parameters are as follows:

- η_0 : (sigma-zero) is the zero-loss collector efficiency factor from the collector test standards EN 12975-2 and related to the aperture area;
- a_1 : is the linear heat loss coefficient from the collector test standards EN 12975-2 and related to the aperture area, in W/m^2K ;
- a_2 : is the temperature dependence of the heat loss coefficient from the collector test standards EN 12975-2 and related to the aperture area, in W/m^2K^2 ;
- IAM : is the Incidence Angle Modifier of the collector from the collector test standard EN 12975-2 when the test angle of incidence between the collector and the direct solar radiation for the test condition is 50° .

Collector type	η_0	a_1	a_2	IAM
Unglazed collector	0.9	20	0	1
Flat plate collector	0.75	6	0	0.94
Evacuated tube collector	0.65	3	0	0.97

Table 31: Default solar collector parameters

Solar storage

The solar storage parameters are as follows:

- Solar pre-heating type: specifies the arrangements for solar pre-heating as one of the following options:
 - dedicated solar pre-heating storage: when there is one or more dedicated solar storage vessel that are heated with the solar collectors only and that do not contain any other heating sources.
 - combined cylinder: the solar storage is combined in a hot water cylinder with one or more back-up heating sources, i.e., the solar energy system shares the same storage vessel with the hot water system.

- Solar storage volume, V_{sol} : this refers to the dedicated solar storage volume, and it should be calculated according to the arrangements for solar pre-heating as indicated in the schematics in Figure 10:
 - in the case of one or more separate pre-heat tank(s), such as arrangements a) or c) in Figure 10, the solar storage volume is the volume of the pre-heat tank(s)
 - in the case of a combined cylinder, such as arrangement b) in Figure 10, the solar storage volume is the volume between the bottom of the lowest back up element (electric element or heat exchanger) to the lowest element of the solar primary.
 - in the case of a thermal store (hot water only) where (only) the solar coil is within the thermal store, i.e., no back-up heating, the solar storage volume is the volume of the dedicated thermal storage
 - in the case of a direct system, such as arrangement d) in Figure 10, the solar volume should be calculated as 0.3 times the volume of the cylinder. See also Note 2 below.

Note 1

The schematic examples reflected in the Figure 10 are unlikely to represent all types of commercial solar thermal installations. Where necessary, and for more complex systems, an accredited dynamic simulation tool can be used.

Note 2

The dedicated solar volume of a solar thermal installation varies depending on the control and timing strategy of the back-up system. To optimise the performance of the solar thermal system, the back-up system should be prevented from operating during and prior to the period of the day where the solar radiation is strong enough to contribute to the hot water requirements. Where it can be demonstrated that the dedicated solar volume should be calculated following a different approach to the guidelines given here, alternative calculations can be used as long as they are in agreement with the UK Micro Certification Scheme standards in effect at that time. The detail and justifications of the calculations undertaken will need to be submitted to the Building Control officer.

- Insulation type and thickness: specifies the type and thickness of the insulation of the solar storage tank.

If the hot water storage vessel is shared between the solar energy system and the back-up hot water system, then the storage losses are already accounted for in Section 4.3.3. If the solar system has a dedicated hot water storage vessel, then the storage losses are calculated using the same procedure as in Section 4.3.3.

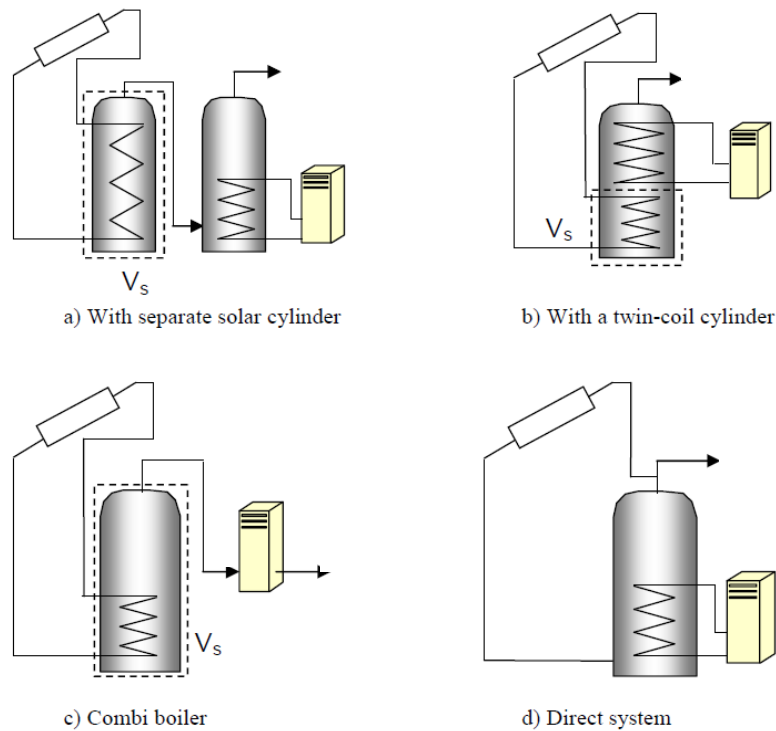


Figure 10: Arrangements for solar pre-heating (these schematics are not intended to show safety measures and devices needed to make the systems safe - Adapted from SAP 2005).

Collector loop

The solar loop refers to all elements located between the solar collector and the point where the back-up heating source supplies the hot water system with energy. The collector loop parameters are as follows:

- Heat transfer rate of the heat exchanger(s) in the solar loop, in W/K, $(U_{st})_{hx}$:
 - For solar thermal direct systems in which the solar primary transmission fluid and the consumed water are the same (arrangement d) in Figure 10), the option *there is no heat exchanger* should be chosen in iSBEM.
 - For indirect systems where the primary circuit fluid is different to that of the secondary side of the system, there will be one or more heat exchangers in the storage vessel.

In order to calculate the drop in system efficiency induced by the heat exchanger(s) in the solar loop, the heat transfer rate of the heat exchanger(s) needs to be entered by the user. If this value is not known, the default option should be used.

- For small systems, the heat transfer rate of the heat exchanger in the solar loop value can be obtained from test results according to the standards *EN 12975-3 - Performance characterisation of stores for solar heating systems*.
- For large systems, the value is taken from the heat exchanger performance data sheet provided by the manufacturer.
- For systems with more than one heat exchanger, using an intermediary or tertiary arrangement, such as with a thermal store, an equivalent heat

transfer rate should be entered by the user (alternatively, dynamic simulation tools can be used).

- Overall heat loss coefficient of all pipes in the solar loop, $U_{loop,p}$, including pipes between collectors and array pipes and between collector array and the solar storage tank(s), in W/K
- If the pipe and insulation for the solar loop are known, the overall heat loss coefficient of all pipes in the solar loop can be calculated accordingly - see for instance, *John A. Duffie and William A. Beckman: Solar Engineering of Thermal Process. Wiley-Interscience ed., 1991.*
- If the pipe and insulation for the solar loop are not known, default values should be used.

Distribution losses

If there are pipes between the solar thermal system and the back-up heating system, the user needs to specify whether the distribution pipes between the solar energy system and the back-up heating source are insulated. This is used to estimate the thermal losses of the distribution between the thermal solar system and the back-up heater.

Auxiliary energy

The auxiliary energy parameters are as follows:

- Circulation system: specifies the type of circulation system that the solar thermal system uses, i.e., either thermosiphon systems, forced circulation systems assisted with photovoltaics, or forced circulation systems using grid electricity for the circulation pump.
- Nominal power of pump(s): specifies the nominal input power, in W, of the circulation pump(s) in the solar loop, i.e., the power stated on the pump(s) label.

For a multi-stage pump, the power corresponding to the typical operation mode is chosen.

4.9.2. Definition of algorithms

Useful solar thermal output: $Q_{W,sol,us,mi}$

The (monthly) useful contribution of the solar thermal system to the hot water requirements of the building, in kWh, is calculated as:

$$Q_{W,sol,us,mi} = Q_{W,sol,out,mi} - Q_{sol,ls,mi}$$

where

$Q_{W,sol,out,mi}$ is the heat output of the solar thermal system in month i , in kWh

$Q_{sol,ls,mi}$ is the thermal losses of the solar thermal system in month i , in kWh

Solar thermal output system: $Q_{W,sol,out,mi}$

The output of the solar thermal system, in kWh, is calculated as:

$$Q_{W,sol,out,mi} = f_{sol,mi} \times Q_{W,sol,us,mi}$$

where

$Q_{W,sol,us,mi}$ is the hot water requirements in month i , in kWh

$f_{sol,mi}$ is the fraction of the hot water covered by the thermal solar system in month i , calculated as:

$$f_{sol,mi} = (a \times Y_{W,mi}) + (b \times X_{W,mi}) + (c \times Y_{W,mi}^2) + (d \times X_{W,mi}^2) + (e \times Y_{W,mi}^3) + (f \times X_{W,mi}^3)$$

where

$X_{W,mi}$ is a value that depends on the collector loop heat loss coefficient and the temperature difference, but also on the storage tank volume by taking into account the storage tank capacity correction factor. It is calculated as:

$$X_{W,mi} = \frac{A \times U_{loop} \times \eta_{loop} \times \Delta T_{mi} \times f_{st} \times t_{mi}}{Q_{W,sol,us,mi} \times 1000}$$

where

A is the collector area, in m^2 .

U_{loop} is the heat loss coefficient of the collector loop and is determined by the collector characteristics and the insulation of the pipes, in W/m^2K . It is calculated as:

$$U_{loop} = a_1 + (a_2 \times 40) + \left(\frac{U_{loop,p}}{A} \right)$$

where

$U_{loop,p}$ is the overall heat loss coefficient of all pipes in the solar loop, including pipes between collectors and array, and pipes between collector array and solar storage tank(s), in W/K

- If pipe and insulation for the collector are known, formulas for insulated pipes can be used, or
- If collector characteristics are not known, a default calculation is undertaken using $U_{loop,p} = 5 + (0.5 \times A)$

η_{loop} is the efficiency factor of the collector taking into account the influence of the heat exchanger calculated as:

- if the heat exchanger characteristics in the collector loop are known, then:

$$\eta_{loop} = 1 - \Delta\eta$$

where

$$\Delta\eta = \frac{(\eta_0 \times A \times a_1)}{(U_{st})_{hx}}$$

and $(U_{st})_{hx}$ is the heat transfer rate of the heat exchanger(s) in the solar loop, in W/K

For direct systems, $\Delta\eta = 0$

- if the heat exchanger characteristics in the collector loop are not known, then:

$$\eta_{loop} = 0.85$$

ΔT_{mi} is the reference temperature difference in month i calculated as:

$$\Delta T_{mi} = T_{ref,mi} - T_{e,avg,mi}$$

where

$T_{ref,mi}$ is the reference temperature in month i , in °C, calculated as:

$$T_{ref,mi} = 11.6 + (1.18 \times T_w) + (3.86 \times T_{cw}) - (1.32 \times T_{e,avg,mi})$$

where

T_w is the desired hot water temperature, taken as 40°C

T_{cw} is the mains water supply temperature, taken as 10°C

$T_{e,avg,mi}$ is the monthly average outside temperature for each location

f_{st} is the storage tank capacity correction factor, calculated as

$$f_{st} = \left(\frac{V_{ref}}{V_{sol}} \right)^{0.25}$$

where

V_{ref} is the reference volume equal to 75 litres per m² of collector

V_{sol} is the solar storage tank volume, in litres

t_{mi} is the length of month i , in hours

$Y_{W.mi}$ is a value that depends on the collector data (zero-loss collector efficiency) and the solar irradiance on the collector plane. It is calculated as:

$$Y_{W.mi} = \frac{A \times IAM \times \eta_0 \times \eta_{loop} \times I_{mi} \times t_{mi}}{Q_{W,sol,us,mi} \times 1000}$$

where

I_{mi} is the average solar irradiance on the collector plane during the month i , in W/m²

a, b, c, d, e, f are the correlation factors depending on the storage tank type as shown in Table 32. The values used are those calculated in the f-chart method (*John A. Duffie and William A. Beckman: Solar Engineering of Thermal Process. Wiley-Interscience ed., 1991*).

Correlation factors for collector arrays connected to hot water storage tanks	
a	1.029
b	-0.065
c	-0.245
d	0.0018
e	0.0215
f	0

Table 32: Correlation factors - Adapted from EN 15316-4-4:2007

Calculation of auxiliary energy consumption: $W_{sol,aux,mi}$

The auxiliary energy consumption (electricity required by the circulation pumps) of the solar thermal system, in kWh, is calculated according to:

- For thermosiphon systems or forced circulation systems assisted with photovoltaics,
 $W_{sol,aux,mi} = 0$
- For forced circulation systems using grid electricity,

$$W_{sol,aux,mi} = \frac{P_{aux,nom} \times t_{aux,mi}}{1000}$$

where

$P_{aux,nom}$ is the nominal power of the circulation pumps, input by the user, in W. If it is not known, then it calculated as:

$$P_{aux,nom} = 25 + (2 \times A)$$

$t_{aux,mi}$ is the operation time of the pump in month i , in hours

The annual operation time of the circulation pump is assumed to be 2000 hours. The monthly operation time of the pump is determined by the distribution of the annual operation time corresponding to the monthly distribution of the solar irradiance (e.g., if January irradiation is 5% of annual irradiation, then January operation time of the pump is assumed to be 5% of the annual operation time of the pump).

Thermal losses of the solar system: $Q_{sol,ls,mi}$

The thermal losses of the solar thermal system, in kWh, calculated as:

$$Q_{sol,ls,mi} = Q_{W,sol,st,ls,mi} + Q_{bu,dis,ls,mi}$$

where

$Q_{W,sol,st,ls,mi}$ is the solar storage tank heat losses, in kWh

- For combined cylinders, the solar storage tank heat losses are calculated as part of the hot water module calculations (Section 4.3.3).
- For separate solar cylinder installations, the losses are calculated depending on the type and thickness of the insulation following the same calculation methodology as described for hot water cylinders of the back-up systems (Section 4.3.3).

$Q_{bu,dis,ls,mi}$ is the heat distribution losses between the thermal solar system and the back-up heater, in kWh. If there are pipes between the SES and the back-up system, the losses are determined based on whether the distribution pipes between the solar energy system and back-up heating source are insulated as follows:

- If the pipes are insulated:

$$Q_{bu,dis,ls,mi} = 0.02 \times Q_{W,sol,us,mi} \times \frac{Q_{W,sol,out,mi}}{Q_{W,sol,us,mi}}$$

- If the pipes are not insulated:

$$Q_{bu,dis,ls,mi} = 0.05 \times Q_{W,sol,us,mi} \times \frac{Q_{W,sol,out,mi}}{Q_{W,sol,us,mi}}$$

4.9.3. Outputs produced

SBEM deducts the useful hot water produced by the solar thermal energy system from the requirements intended to be met by the HWS to which the solar energy system is connected.

4.10. Photovoltaics

The energy yield given by the photovoltaic system (PV) is calculated according to the collector orientation and inclination. In order to calculate the radiation at the PV module, the hourly radiation data is processed to yield values of monthly global solar radiation for the orientations and inclinations shown in Table 29 and Table 30, respectively. The algorithms used in SBEM follow the standards BS EN 15316-4-3:2017.

4.10.1. Definition of algorithms

Photovoltaic electricity generation

The monthly electricity produced by the photovoltaic modules, $E_{el,PV,out}$, in kWh, is calculated as:

$$E_{el,PV,out} = \frac{P_{pk} \times E_{sol} \times f_{shading} \times f_{per}}{I_{ref}}$$

where

P_{pk} is the PV array installed peak power, in kW_p, obtained under standard test conditions²². If it is not included in the input, it is calculated as:

$$P_{pk} = K_{pk} \times A$$

where

K_{pk} is the default peak power coefficient, in kW_p/m², depending on the type of the photovoltaic modules as given in Table 33.

A is the area of the photovoltaic panels, excluding the supporting construction (without the frame), in m²

E_{sol} is the monthly solar radiation on the PV system, in kWh/m²

$f_{shading}$ is the over-shading factor taken from the Table 34 according to the level of over-shading of the PV array. The over-shading level refers to the percentage of the sky that is blocked by obstacles. It should be assessed taking into account the inclination of the panels.

f_{per} is a system performance factor taken from Table 35 according to the ventilation strategy and module type of the PV array (definitions in Table 36). This factor takes into account the system performance of the building-integrated PV installation depending on the conversion system from direct current to alternating current, actual operation temperature of the PV modules, and building integration of the PV modules (according to the type of ventilation of the PV modules).

I_{ref} is the reference solar irradiance equal to 1 kW/m²

²² Reference testing values of cell temperature $\theta=25^{\circ}\text{C}$, in plane irradiance $I_{ref}=1 \text{ kW/m}^2$, air mass solar reference spectrum AM=1.5 for a PV module or a PV cell testing – EN 6182.9

Module type	Peak power coefficient in kW _p /m ²
Mono crystalline silicon*	0.15
Multi crystalline silicon*	0.12
Multi layer thin film amorphous silicon	0.04
Other thin film layers	0.035
Thin film copper-indium-gallium-diselenide	0.105
Thin film cadmium-telluride	0.095
* With a minimum package density of 80%	

Table 33: Default peak power coefficient, K_{pk} , adapted from BS EN 15316-4-3:2017

Level of over-shading	Mono crystalline silicon	Multi crystalline silicon	Multi layer thin film amorphous silicon	Other thin film layers	Thin film copper-indium-gallium-diselenide	Thin film cadmium-telluride
None or very little <20%	1	1	1	1	1	1
Modest [20-60%]	0.7	0.7	0.8	0.8	0.8	0.8
Significant [60-80%]	0.5	0.5	0.6	0.6	0.6	0.6
Heavy >80%	0.3	0.3	0.4	0.4	0.4	0.4

Table 34: Shading factor, $f_{shading}$, (adapted from SAP 2012 but modified to reflect different performance sensitivity to shading of different PV technologies)

Ventilation Strategy	Mono crystalline silicon	Multi crystalline silicon	Multi layer thin film amorphous silicon	Other thin film layers	Thin film copper-indium-gallium-diselenide	Thin film cadmium-telluride
Strongly ventilated or forced ventilated modules	0.82	0.82	0.82	0.82	0.82	0.82
Moderately ventilated modules	0.8	0.8	0.81	0.81	0.81	0.81
Unventilated modules	0.76	0.76	0.78	0.78	0.78	0.78

Table 35: System performance factor, f_{per} , (adapted from BS EN 15316-4-3:2017 to reflect different performance sensitivity to ventilation levels of different PV technologies)

Ventilation Strategy	Definition
Strongly ventilated or forced ventilated modules	It refers to those situations where there is no thermal interaction between the PV modules and the surface where they are mounted. This could apply for instance to stand-alone system mounted on a flat roof.
Moderately ventilated modules	There is an air gap between the PV modules and the surface where they are mounted. This would apply to roof slope systems where a suitable air gap between the PV module and the roof has been allowed for.
Unventilated modules	There is no air gap between the PV modules and the surface where they are mounted

Table 36: PV array ventilation strategy definitions

Carbon dioxide displaced by photovoltaic electricity

$$C_{PV} = E_{el,PV,out} \times c_D$$

where

C_{PV} is the monthly carbon dioxide emissions displaced by the electricity generated by the PV modules, in kgCO₂

c_D is the amount of carbon dioxide displaced by each unit of electricity produced by the PV modules, in kgCO₂ per kWh, i.e., the emission factor for electricity.

Primary energy displaced by photovoltaic electricity

The monthly primary energy displaced by the electricity generated by the PV modules are calculated using the same approach described above for emissions but substituting the primary energy factor for the emission factor.

4.10.2. Outputs produced

- Monthly electricity produced by the photovoltaic system.
- Carbon dioxide emissions and primary energy displaced due to the electricity generated by the photovoltaic system.

4.11. Wind generators

The methodology followed to calculate the electricity generated by wind turbines in SBEM is based on the Average Power Density Method. Electricity produced by the wind turbine is obtained by estimating the average power density of the wind throughout a year using the hourly weather data and by applying a turbine efficiency of conversion. Correction of the wind resource due to turbine height and terrain type is allowed for.

4.11.1. Data requirements

- Terrain type: specifies the type of terrain where the wind generator is installed from smooth flat country (no obstacles) to urban with average building height bigger than 15 m, as shown in Table 37;
- Diameter: specifies the wind turbine rotor diameter, in m;
- Hub height: specifies the wind turbine hub height, in m;
- Power: specifies the wind turbine rated power (electrical power at rated wind speed), in kW. This information is used to assign an efficiency of conversion to the wind turbine. For SBEM purposes, this efficiency is considered to change with the monthly wind speed and turbine rated power according to Table 38.

Terrain type	K_R terrain factor	z_o roughness length (m)
Open Flat Country	0.17	0.01
Farm Land with boundary hedges, occasional small farm structures, houses or trees	0.19	0.05
Suburban, industrial areas and permanent forests	0.22	0.3
Urban areas in which at least 15% of surface is covered with buildings of average height exceeding 15m	0.24	1

Table 37: Terrain categories and related parameters (CIBSE, 2002)

Product of mean monthly wind speed (m/s) and $C_R(z)$ coefficient	Small turbines (<80 kW)	Medium turbines (>80 kW)
[0,3]	0 %	0 %
[3,4]	20%	36%
[4,5]	20%	35%
[5,6]	19%	33%
[6,7]	16%	29%
[7,8]	15%	26%
[8,9]	14%	23%
>9	14%	23%

Table 38: Wind turbine efficiencies of conversion, K_{WT}

4.11.2. Definition of algorithms

Wind turbine electricity generation

The monthly electricity produced by the wind turbine, in kWh, is calculated as:

$$E_{WT} = \frac{0.5 \times \rho \times (C_R(z) \times V_0)^3 \times A \times EPF \times K_{WT} \times 24 \times N}{1000}$$

where

ρ is the air density $\sim 1.225 \text{ kg/m}^3$

$C_R(z)$ is the roughness coefficient at height z and is calculated as:

$$C_R(z) = K_R \times \ln\left(\frac{z}{z_o}\right)$$

where

K_R is the terrain factor (Table 37)

z_o is the roughness length (Table 37)

z is the wind turbine hub height, in m.

V_0 is the mean monthly wind speed as derived from the hourly weather data for each location, in m/s

A is the turbine swept area, in m^2 , calculated as:

$$A = \frac{\pi \times D^2}{4}$$

where

D is the wind turbine diameter, in m

EPF is the energy pattern factor calculated using the hourly wind speed data from the weather data set as:

$$EPF = \frac{APD}{0.5 \times \rho \times V_0^3}$$

where

APD is the average power density, in W/m^2 , calculated as:

$$APD = \left[\sum_{i=1}^{8760} (0.5 \times \rho \times V_i^3) \right] \div 8760$$

where

V_i is the wind speed at hour i , as given by the weather data, in m/s

8760 is the number of hours in a year

K_{WT} is the wind turbine efficiency of conversion, in %, as given in Table 38.

N is the number of days in the month

Note for vertical axis wind turbines

In order to define a vertical axis wind turbine, an equivalent turbine diameter, D_e , needs to be defined such that:

$$A_{VAWT} = \frac{\pi \times D_e^2}{4}$$

where

A_{VAWT} is the swept area of the vertical axis wind turbine, in m²

D_e is the vertical axis wind turbine equivalent diameter used for the calculations, in m.

Carbon dioxide displaced by wind turbines

$$C_{WT} = E_{WT} \times c_D$$

C_{WT} is the monthly carbon dioxide emissions displaced by the electricity generated by the wind turbine, in kgCO₂

c_D is the amount of carbon dioxide displaced by each unit of electricity produced by the wind turbine for the displaced electricity, in kgCO₂ per kWh, i.e., emission factor for electricity.

Primary energy displaced by wind turbines

The monthly primary energy displaced by the electricity generated by the wind turbines are calculated using the same approach described above for emissions but substituting the primary energy factor for the emission factor.

4.11.3. Outputs produced

- Monthly electricity produced by the wind turbine.
- Carbon dioxide emissions and primary energy displaced by the electricity generated by the wind turbine.

4.11.4. Commentary on accuracy

Wind speed is taken from the CIBSE test reference years. Variations in the local wind resource from the one used by SBEM are unavoidable.

Generic wind turbine efficiencies have been assumed, which means that turbines with the same diameter will yield the same energy yield over a year without allowing for differences among different turbine makes.

4.12. CHP generators

4.12.1. Data requirements

- Fuel type: specifies the fuel type used for the CHP generator;
- Heat seasonal efficiency: is the total useful heat supplied by the CHP plant divided by the total fuel energy input (using the gross calorific value);
- Electrical (power) seasonal efficiency: is the total electrical power generated by the CHP plant divided by the total fuel energy input (using the gross calorific value);
- Building space heating supplied: specifies the percentage of the building's space heating demand supplied by the CHP generator (if the building is served by more than one HVAC system, then the percentage supplied refers to the space heating demand of the HVAC system to which the CHP plant is connected);
- Building hot water supplied: specifies the percentage of the building's hot water demand supplied by the CHP generator (the percentage supplied refers to the hot water demand of the HWS which is served by the HVAC system to which the CHP plant is connected);
- Building space cooling supplied: specifies the percentage of the building's space cooling demand supplied by the tri-generation plant (if the building is served by more than one HVAC system, then the percentage supplied refers to the space cooling demand of the HVAC system to which the tri-generation plant is connected);
- Chiller seasonal energy efficiency ratio: is the seasonal efficiency of the heat-fired chiller (typically an absorption chiller), calculated as the ratio of the useful cooling output to the energy input over the cooling season.

Note: the CHPQA Quality index is input in SBEM for reporting purposes only in order to inform the compliance checking process by Building Control for new builds. This value is not used in the calculations.

4.12.2. Definition of algorithms

Energy consumption by the CHP plant

Amount of monthly energy, Q , used by the CHP plant, in kWh, is calculated as:

$$Q = \frac{(H_{SH} \times p_{SH}) + \left(\frac{H_{SC} \times p_{SC}}{SEER_{SC}} \right)}{\eta_{THSH}} + \frac{(H_{HW} \times p_{HW})}{\eta_{TH}}$$

where

- H_{SH} is the monthly space heating demand of the building, in kWh;
- p_{SH} is the proportion (fraction) of the space heating demand supplied by the CHP plant;
- H_{HW} is the monthly hot water demand of the building, in kWh;
- p_{HW} is the proportion (fraction) of the hot water demand supplied by the CHP plant;
- H_{SC} is the monthly space cooling demand of the building, in kWh;
- p_{SC} is the proportion (fraction) of the space cooling demand supplied by the heat-fired chillers of the CHP plant;

$SEER_{SC}$ is the heat-fired chiller seasonal energy efficiency ratio of the CHP plant, taking into account any system losses associated with provision of cooling to the served spaces by the HVAC system to which the CHP is connected;

η_{THSH} is the seasonal thermal efficiency of the CHP plant (defined as the total useful heat supplied divided by the total fuel energy input, using the gross calorific value), taking into account any system losses associated with provision of heating to the served spaces by the HVAC system to which the CHP is connected;

η_{TH} is the seasonal thermal efficiency of the CHP plant (defined as the total useful heat supplied divided by the total fuel energy input, using the gross calorific value). If the CHP provides proportions of both space heating and water heating, the thermal efficiency is reduced by 5% for the water heating calculation in order to take account of the reduction in the efficiency at part-load operation.

Carbon dioxide generated by the CHP plant fuel requirements

$$F_C = Q \times c$$

where

F_C is the monthly CO₂ emissions due to the fuel used by the CHP plant, in kg;

Q is the energy consumed by the CHP plant, i.e., its fuel requirements, in kWh;

c is the CO₂ rate of the fuel used by the CHP plant, in kgCO₂/kWh, i.e., emission rate of the fuel.

Primary energy consumed by the CHP plant fuel requirements

The monthly primary energy consumed by the CHP plant are calculated using the same approach described above for emissions but substituting the primary energy factor for the emission factor.

Electricity generated by the CHP plant

The monthly electricity produced by the CHP plant, in kWh, is calculated as:

$$E_{CHP} = Q \times \eta_E$$

where

E_{CHP} is the electricity generated by the CHP plant, in kWh;

η_E is the seasonal electrical (power) efficiency of the CHP plant.

Carbon dioxide displaced by the CHP plant

$$C_{CHP} = E_{CHP} \times c_D$$

C_{CHP} is the monthly carbon dioxide emissions displaced by the electricity generated by the CHP plant, in kgCO₂;

c_D is the amount of carbon dioxide displaced by each unit of electricity produced by the CHP plant for the displaced electricity, in kgCO₂ per kWh.

Primary energy displaced by the CHP plant

The monthly primary energy displaced by the electricity generated by the CHP plant are calculated using the same approach described above for emissions but substituting the primary energy factor for the emission factor.

4.12.3. Outputs produced

- Carbon dioxide emissions generated and primary energy consumed by the CHP plant fuel requirements
- Electricity produced by the CHP plant
- Carbon dioxide emissions and primary energy displaced due to the electricity generated by the CHP plant

4.13. Transpired and non-transpired solar air collectors

4.13.1. Transpired solar air collectors

A transpired solar collector (TSC) is a solar thermal air heater system which uses a perforated solar collector, mounted on the external façade of the building, to preheat the ventilation air supply to the building using the solar radiation incident on the collector.

The calculation method for transpired solar collectors in SBEM is based on work carried out within the IEA Implementing Agreement SHC.T14.Air.1. SBEM contains default values for the system parameters which are designed to produce cautious estimates of energy savings. Product-specific information from manufacturers should be used to over-write these defaults.

The calculation of the collector efficiency depends on whether the type of operation of air flow rate through the TSC system is “Constant flow” or “Variable flow”.

Collector efficiency if the air flow rate through the collector is constant

The monthly solar radiation incident on the solar collector is calculated as:

$$G_{sun} = \frac{I \times 1000000}{h_{sun} \times n_{days} \times 3600}$$

where

G_{sun} is the solar radiation incident per month on the collector, in W/m², taking account of collector's orientation and inclination, and any shading if applicable;

I is the solar radiation incident per month on the collector, in MJ/m², taking account of the collector's orientation and inclination, and any shading if applicable, multiplied by 1000000 to convert MJ to J;

h_{sun} is the number of sunlight hours in the day, taken from Table 39;

n_{days} is the number of days in the month;

3600 is a factor to convert hours to seconds.

Month	h_{sun}
January	9
February	10
March	11
April	12
May	12
June	12
July	12
August	12
September	12
October	11
November	9
December	8

Table 39: Number of sunlight hours in the day

The monthly suction face velocity is calculated as:

where

$$V_s = \frac{q}{A}$$

V_s is the monthly suction face velocity, in m/s;

q is the design air flow rate for the collector, in m³/s, whose default value is taken from Table 40 unless over-written by the user;

A is the area of the collector, in m².

Design type	q [m ³ /s]
Standard operation	1.8
High temperature rise	0.9
High air volume	2.7

Table 40: Default design air flow rate for transpired solar collector

The monthly heat exchange effectiveness (ratio of suction air temperature rise to maximum possible temperature rise) is calculated as:

$$\varepsilon_{hx} = 1.0 - (5.0 \times V_s)$$

where

ε_{hx} is the monthly heat exchange effectiveness;

V_s is the monthly suction face velocity, in m/s.

The monthly convective heat transfer coefficient is calculated as:

$$h_c = 6.0 + (4.0 \times V_\infty) - (76 \times V_s)$$

where

h_c is the monthly convective heat transfer coefficient, in W/m²K;

V_∞ is the monthly wind speed at face of the collector, in m/s;

V_s is the monthly suction face velocity, in m/s.

The monthly radiation heat loss coefficient is calculated as:

$$h_r = (4 \times \varepsilon \times \sigma_{sb} \times T_{amb}^2) \times (T_{amb} + (1.6 \times t))$$

where

h_r is the monthly radiation heat loss coefficient, in W/m²K;

ε is the thermal emittance of the collector, taken = 0.9;

σ_{sb} is the Stefan–Boltzmann constant = 5.67×10^{-8} W/m²K⁴;

T_{amb} is the monthly average ambient temperature, in K;

t is calculated as:

$$t = \frac{\alpha \times G_{sun}}{(\rho \times C_p \times V_s \times \varepsilon_{hx}) + (4 \times \varepsilon \times \sigma_{sb} \times T_{amb}^3) + h_c}$$

where

- α is the absorptivity of the collector, taken from Table 41;
- G_{sun} is the solar radiation incident per month on the collector, in W/m^2 , taking account of the collector's orientation and inclination, and any shading if applicable;
- ρ is the air density = 1.23 kg/m^3 ;
- C_p is the specific heat capacity of air = 1006 J/kgK ;
- V_s is the monthly suction face velocity, in m/s ;
- ε_{hx} is the monthly heat exchange effectiveness;
- ε is the thermal emittance of the collector, taken = 0.9 ;
- σ_{sb} is the Stefan–Boltzmann constant = $5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$;
- T_{amb} is the monthly average ambient temperature, in K ;
- h_c is monthly convective heat transfer coefficient, in $\text{W/m}^2\text{K}$.

The monthly collector efficiency is calculated as:

$$\eta = \frac{\alpha}{1 + \left(\frac{h_r + h_c}{\rho \times C_p \times V_s \times \varepsilon_{hx}} \right)}$$

where

- η is the monthly efficiency of the collector;
- α is the absorptivity of the collector, taken from Table 41;
- h_r is the monthly radiation heat loss coefficient, in $\text{W/m}^2\text{K}$;
- h_c is the monthly convective heat transfer coefficient, in $\text{W/m}^2\text{K}$;
- ρ is the air density = 1.23 kg/m^3 ;
- C_p is the specific heat capacity of air = 1006 J/kgK ;
- V_s is the monthly suction face velocity, in m/s ;
- ε_{hx} is the monthly heat exchange effectiveness.

Absorptivity	α
Very high	0.95
High	0.85
Good	0.75
Moderate	0.65
Low	0.45

Table 41: Absorptivity of transpired solar collectors

Useful heat

The useful energy or the heat delivered by the collector to the building each month is calculated as:

$$Q_{TSC} = \eta \times G_{sun} \times A$$

where

Q_{TSC} is the monthly useful heat delivered by the transpired solar collector, in W/m²;
 η is the monthly efficiency of the collector;
 G_{sun} is the solar radiation incident per month on the collector, in W/m², taking account of its orientation and inclination, and any shading if applicable;
 A is the area of the collector, in m².

Temperature rise

The monthly actual temperature rise is calculated as:

$$T_{act} = \frac{\eta \times G_{sun} \times A}{q \times \rho \times C_p}$$

where

T_{act} is the monthly actual temperature rise, in K;
 η is the monthly efficiency of the collector;
 G_{sun} is the solar radiation incident per month on the collector, in W/m², taking account of the collector's orientation and inclination, and any shading if applicable;
 A is the area of the collector, in m²;
 q is the design air flow rate for the collector, in m³/s, whose default value is taken from Table 40 unless over-written by the user;
 ρ is the air density = 1.23 kg/m³;
 C_p is the specific heat capacity of air = 1006 J/kgK.

The monthly delivered air temperature is calculated as:

$$T_{del} = T_{amb} + \Delta T_{offset} + T_{act}$$

where

T_{del} is the monthly delivered air temperature, in K;
 T_{amb} is the monthly average ambient temperature, in K;
 ΔT_{offset} is a temperature offset = 3 K added to the ambient temperature as it is assumed that the daytime temperature is higher than the average temperature;
 T_{act} is the monthly actual temperature rise, in K.

Collector efficiency if the air flow rate through the collector is variable

If the operation of the air flow rate is variable, an iterative process is applied in order to calculate the collector efficiency. An initial efficiency is first calculated following the above process for constant flow using the design air flow rate, i.e.,

$$q_{(1)} = q$$

$$\eta_{(1)} = \eta$$

$$T_{act(1)} = T_{act}$$

$$T_{del(1)} = T_{del}$$

Then 3 more iterations are carried out as described below so that:

In a 2nd run of the calculation, the monthly values of $\eta_{(2)}$, $T_{act(2)}$, and $T_{del(2)}$ are calculated using the monthly air flow rate $q_{(2)}$ which is itself calculated as:

$$q_{(2)} = q_{(1)} \times \left(\frac{T_{rec} - T_{del(1)}}{T_{rec} - T_{act(1)}} \right)$$

where

T_{rec} is the monthly recirculation temperature, in K, taken as the average heat set point temperature of the zones which receive the pre-heated air from the solar collector (weighted by the percentage of the pre-heated air each zone receives) + 276.

In a 3rd run of the calculation, the monthly values of $\eta_{(3)}$, $T_{act(3)}$, and $T_{del(3)}$ are calculated using the monthly air flow rate $q_{(3)}$ which is itself calculated as:

$$q_{(3)} = q_{(2)} \times \left(\frac{T_{rec} - T_{del(2)}}{T_{rec} - T_{act(2)}} \right)$$

In a 4th and final run of the calculation, the monthly values of $\eta_{(4)}$, $T_{act(4)}$, and $T_{del(4)}$ are calculated using the monthly air flow rate $q_{(4)}$ which is itself calculated as:

$$q_{(4)} = q_{(3)} \times \left(\frac{T_{rec} - T_{del(3)}}{T_{rec} - T_{act(3)}} \right)$$

Useful heat

The useful energy or the heat delivered by the collector to the building each month is calculated as:

$$Q_{TSC} = \eta_{(4)} \times G_{sun} \times A$$

where

Q_{TSC} is the monthly useful heat delivered by the transpired solar collector, in W/m²;

$\eta_{(4)}$ is the monthly efficiency of the collector after the 4th run of calculation;

G_{sun} is the solar radiation incident per month on the collector, in W/m², taking account of the collector's orientation and inclination, and any shading if applicable;

A is the area of the collector, in m².

4.13.2. Non-transpired solar air collectors

Non-transpired solar collector are structural elements, rather than “add-on” elements like transpired solar collectors. The calculation method implemented in SBEM is based on an integrated solar air pre-heating system. SBEM contains default values for the system parameters which are designed to produce cautious estimates of energy savings. Product-specific information from manufacturers should be used to over-write these defaults.

The integrated solar air heating system is designed to provide pre-heated air into a building. As the air rises in the collector, its temperature increases. In an infinitely high collector, it

would eventually reach a limiting temperature: the “stagnation temperature”. This depends on three physical characteristics of the collector, its height, the air flow rate, and the incident solar radiation. The exit temperature is below this value (though with suitable configurations it may be very close to it).

Temperature rise at exit

The performance of the collector is determined by the temperature rise of the exit temperature above ambient. From experimental data and modelling of the collector, the temperature rise at exit (relative to ambient) per unit incident radiation can be calculated to define the basic thermal model of the collector as:

$$\Delta T = \Delta T_s \times \left(1 - e^{-\frac{h \times coef}{q}}\right)$$

At zero height of the collector, i.e., if $h = 0$, then $\Delta T = 0$

At max height or zero flow rate, i.e., if $h = \infty$ or $q = 0$, then $\Delta T = \Delta T_s$

where:

ΔT is the temperature rise at exit per unit incident radiation, in K per W/m²;

h is the collector height, in m;

q is the design air flow rate, in m³/s per unit collector width;

ΔT_s is the air temperature coefficient, in K per W/m² - the stagnation temperature rise per unit incident radiation, i.e., the limiting value of ΔT for an infinitely high collector;

coef is the air flow rate coefficient - exponential parameter per unit flow rate. This captures the way in which the temperature changes with collector height and flow rate.

The collector is characterised by the values of the two parameters: ΔT_s and *coef*.

Useful heat

The useful energy or the heat delivered by the collector to the building each month is calculated as:

$$Q_{NTSC} = q \times \rho \times C_p \times \Delta T \times I$$

where:

Q_{NTSC} is the monthly useful heat delivered by the non-transpired solar collector, in MJ;

q is the air flow rate through the collector, in m³/s;

ρ is the air density = 1.23 kg/m³;

C_p is the specific heat capacity of air = 1006 J/kgK;

I is the solar radiation incident per month on the collector, in MJ/m², taking account of the collector's orientation and inclination, and any shading if applicable.

4.13.3. Fan energy

If the solar air collector system, whether transpired or non-transpired, is provided with an independent fan, then the associated fan energy needs to be accounted for. This energy will

contribute some additional heat gains to zones served by the solar air system, as well as add to the auxiliary energy of the building (for pumps, fans, etc.).

The fan energy in each month is calculated as:

$$E_{fan} = q \times SFP \times h_{sun} \times n_{days} \times f_{use}$$

where:

E_{fan} is the fan energy, in kWh;

q is the monthly air flow rate through the collector, in m³/s;

SFP is the specific fan power, in W/(l/s);

h_{sun} is the number of sunlight hours in the day, taken from Table 39;

n_{days} is the number of days in the month;

f_{use} is the in-use factor for the month, taken from Table 42.

Month	f_{use}
January	1
February	1
March	1
April	1
May	0.8
June	0.05
July	0.05
August	0.05
September	0.8
October	1
November	1
December	1

Table 42: In-use factor for independent fan for solar air collector system

4.13.4. Total energy

The total monthly heat gains by the solar collectors (transpired and non-transpired) can be calculated as below.

During the summer months from May to September:

$$Q_{total} = Q_{SC} + (E_{fan} \times 3.6)$$

$$Q_{direct} = 0$$

During October to April:

$$Q_{total} = Q_{SC}$$

$$Q_{direct} = E_{fan} \times 3.6$$

where

Q_{total} is the total heat delivered by the solar collector, in MJ;

Q_{SC} is the useful heat from the solar collector, in MJ;

Q_{direct} is the direct heat delivered by the solar collector, in MJ;

E_{fan} is the fan energy, in kWh;

3.6 is a factor to convert kWh to MJ.

4.13.5. Internal heat gains

For each zone which receives pre-heated air from a solar air collector, the corresponding monthly internal heat gains, in heating mode, can be calculated as:

$$Q_{heat,SC} = Q_{total} \times f_{use} \times f_{supply}$$

where

$Q_{heat,SC}$ is the heat gains to the zone from the solar collector for the heating demand calculation of the zone, in MJ;

Q_{total} is the total heat delivered by the solar collector, in MJ;

f_{use} is the in-use factor for the month, taken from Table 42 if the solar air collector system has an independent fan, and taken as 1.0 if it does not;

f_{supply} is the fraction of the total air pre-heated by the solar collector system which is supplied to the zone.

For each zone which receives pre-heated air from a solar air collector, the corresponding monthly direct heat gains, in heating mode can be calculated as:

$$Q_{heat,direct,SC} = Q_{direct} \times f_{use} \times f_{supply}$$

where

$Q_{heat,direct,SC}$ is the direct heat gains to the zone from the solar collector for the heating demand calculation of the zone, in MJ;

Q_{direct} is the direct heat delivered by the solar collector, in MJ;

f_{use} is the in-use factor for the month, taken from Table 42 if the solar air collector system has an independent fan, and taken as 1.0 if it does not;

f_{supply} is the fraction of the total air pre-heated by the solar collector system which is supplied to the zone.

For each zone which receives pre-heated air from a solar air collector, the corresponding monthly internal heat gains, in cooling mode, can be calculated as:

$$Q_{cool,SC} = (Q_{total} + Q_{direct}) \times f_{ctrl} \times f_{use} \times f_{supply}$$

where

$Q_{cool,SC}$ is the heat gains to the zone from the solar collector for the cooling demand calculation of the zone, in MJ;

Q_{total} is the total heat delivered by the solar collector, in MJ;

Q_{direct} is the direct heat delivered by the solar collector, in MJ;

f_{ctrl} is the control factor determined by the control type of the solar collector system, and it is taken as 0.5 if the control type is "Only manual" and 0 if the control is "Automatic";

f_{use} is the in-use factor for the month, taken from Table 42 if the solar air collector system has an independent fan, and taken as 1.0 if it does not;

f_{supply} is the fraction of the total air pre-heated by the solar collector system which is supplied to the zone.

The solar collector heat gains can then be included with heat gains from other sources (see Section 4.1.12) when calculating the zone's energy demand for space heating for each month (see Section 4.1.7) and when calculating the zone's energy demand for space cooling for each month (see Section 4.1.8).

5. Options for interfacing to SBEM

SBEM requires data to be presented in a standard format through an input interface. iSBEM (interface to SBEM) was commissioned by DLUHC to fulfil the role of the default interface. However, other approved interfaces to SBEM are available. These other interfaces are not discussed in this document.

5.1. iSBEM

The iSBEM input module acts as the interface between the user and the SBEM calculation engine. The user is guided towards appropriate databases as described earlier in this document, and the input is formatted so that data is presented correctly to the calculation engine, compliance checking modules, and the EPC modules.

5.1.1. Logic behind iSBEM structure

iSBEM is structured as a series of forms in Microsoft Access®. This software was chosen at the time of development as the platform for speed and convenience with programming in order to enable delivery within a limited timescale.

During the development of iSBEM, BRE has had extensive experience with operating the software and explaining it to users. This has enabled them to develop a detailed user guide with terms that most potential users can understand and follow.

5.1.2. How iSBEM collects the data for SBEM

The information gathering is arranged under a series of forms, tabs, and sub-tabs in order to structure the way the user collects and inputs the data. This structure is dealt with in full detail in the *iSBEM User Guide*²³, but, in summary, the forms deal with the following:

- General
 - Project and assessor details
 - File handling
- Project database - setting up the constructions used in the building
 - Walls
 - Roofs
 - Floors
 - Doors
 - Glazing
- Geometry - definition for each building element surrounding every zone:
 - Size
 - Orientation

²³ Available from the UK-NCM website www.uk-ncm.org.uk

- Construction
- Thermal bridges
- Links between elements
- Building services - setting up the systems used in the building
 - HVAC systems
 - Hot water generators including solar hot water
 - Photovoltaic systems
 - Wind generators
 - Combined heat and power
 - Lighting and its control
 - General issues relating to ventilation, power factor correction, etc.
 - Allocation of systems to each zone
- Ratings - deals with the results in terms of energy consumption, CO₂ emissions, primary energy, delivered energy, and ratings for the building
- Building Navigation – used to review entered data

Information is entered into the first four of these forms by the user, and once the building description is complete, the calculation can be run. Results are then displayed in the Ratings form.

6. Applications for SBEM

SBEM calculates the energy consumption and consequent CO₂ emissions and primary energy for the heating, cooling, ventilation, lighting, and hot water systems which serve a particular building. This can be used in a number of applications.

6.1. Building Regulations compliance

The call for minimum energy performance standards to be met for new buildings is being answered in the UK by the requirement to comply with the Building Regulations relevant to each part of the UK (England, Wales, Scotland, and Northern Ireland). The regulations also distinguish between domestic and non-domestic buildings, and new and refurbished buildings. For England and Wales, the relevant documents for new build non-domestic buildings are the respective Approved Document Part L, volume 2, to which the reader should refer for definitive statements on how to achieve compliance (Section 2). Similar formats apply for Scotland and Northern Ireland.

As outlined in Section 2, the performance requirement in the UK is for the proposed building to achieve CO₂ emissions of a “Building Emission Rate” (BER) no worse than a “Target Emission Rate” (TER) and, in England and Wales, to achieve a “Building Primary Energy Rate” (BPER) no worse than a “Target Primary Energy Rate” (TPER). In Scotland, the proposed building is also required to achieve a “Building Delivered Energy Rate” (BDER) no worse than a “Target Delivered Energy Rate” (TDER).

The check can be undertaken when the building design is first submitted for outline Building Regulations approval, although this is not obligatory. However, the check must be undertaken when the “as built” parameters are confirmed prior to final Building Regulations approval. This allows for changes, and remedial actions if needed, between the original conceptual and construction stages, and confirmation that parameters such as air tightness (which cannot be checked until the building is actually constructed) have been achieved. The result then provides the basis for the “Asset Rating” (see next section).

DLUHC have commissioned SBEM, with its interface iSBEM, to be the default application to implement this Building Regulations compliance check for non-domestic buildings, including the generation of the Notional building and TER, and the comparison between BER and TER. This application also contains the rules for zoning the building consistently.

The Building Regulations tab on the Ratings form of iSBEM reports on the comparison between BER and TER, and whether the proposed building meets the CO₂ compliance check at each stage, i.e., the BER does not exceed the TER. Other checks are carried out in parallel by the compliance module, BRUKL, which draws on data recorded for SBEM to establish whether various elemental values meet the minimum standards in the Approved Documents.

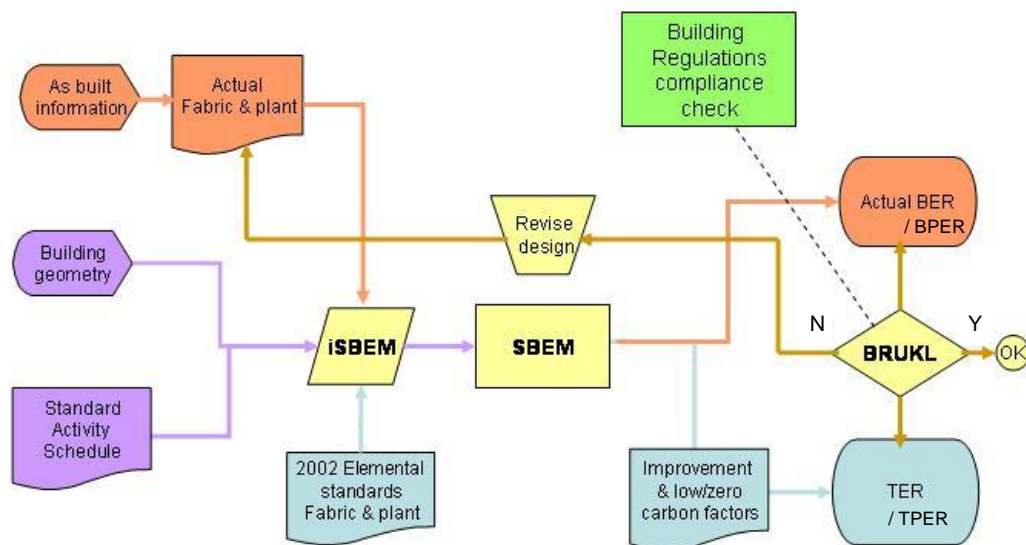


Figure 11: Inputs, calculations and comparisons involved in Building Regulations compliance checking procedures in SBEM for England

Further buttons on this tab provide intermediate results from the SBEM calculation, and data reflection reports to allow auditing against information on the proposed building.

BRE have collaborated with other software providers to enable them to develop alternative interfaces to SBEM, and links with other design software (dynamic simulation models) so that they interact with the compliance and certifications modules.

6.2. Asset rating

There was a call for new and existing buildings to have an energy performance certificate available after construction and whenever they change hands through sale or let. The certificate should report on the intrinsic, as-built energy performance based on standardised operating patterns and internal conditions for the mix of activities taking place in the building. This is called the “asset rating” in the UK. This rating enables buildings with similar uses to be compared on a like-for-like basis in order for their potential to be operated efficiently. The asset rating is presented in the form of an “Energy Performance Certificate (EPC)” to help non-technical buyers and tenants to understand the relative performance of buildings.

The formal EPCs are issued, by an accredited energy assessor, on the basis of calculations carried out using SBEM or an alternative approved dynamic simulation model. A central register of building ratings is maintained so that government can report to the EU on the CO₂ efficiency of the building stock. In addition to the certificate, a list of recommendations

for improvement will be generated and given to the building user or potential purchaser/tenant.

The asset rating in England is based on a comparison between the standardised emissions of the building (the BER as calculated for Building Regulations compliance) and those of a “Reference” building (the same approach applies in both Wales and Northern Ireland but is different in Scotland). The description of the Reference building and the EPC rating scale are defined in the NCM Modelling Guide for the respective building regulations and devolved administration. The EPC also displays the corresponding energy band which is based on the rating.

SBEM is capable of working out the intrinsic energy and CO₂ performance of buildings against the standardised operating patterns required for the asset rating. This process is similar to that required for checking Building Regulations compliance.

For a new building, producing the EPC would be undertaken using the same data collected for the compliance check, by selecting another assessment option in the software.

For an existing building which has not gone through the compliance check, the actual construction and system parameters are input. It is appreciated that some of this information may be difficult to acquire for existing buildings as, for instance, drawings and schedules of the current constructions may no longer be available. Default values for constructions, HVAC, HWS, and lighting system parameters based on age, generic appearance, etc., are provided in the software for selection by the user.

7. Planned developments

The initial versions of SBEM and iSBEM did not include all the features that users would find valuable or helpful, but the versions have evolved significantly since then. The many possible areas for extension and improvement include new options for energy systems and controls, and more diagnostic and error-checking information. The pace of, and priorities for, development will depend on the funding available and feedback from users and other stakeholders (including suppliers of systems and components).

Some upgrades are already under development and others have been agreed, in principle, as desirable. Several of these are currently being implemented. The following technical enhancements had been identified and agreed with DLUHC and are on the “waiting list” for funding:

First priority

- Add night ventilation strategies **(Done)**
- Add systems that provide enhanced thermal coupling to structure
- Add demand-controlled ventilation **(Done)**
- Add additional HVAC controls
- Add automatic blind controls **(Done)**
- Add multi-boiler and chiller seasonal efficiency calculation

Second Priority

- Provide daylight data for 14 sites **(Done)**
- Add explicit dehumidification calculation
- Provide user access to default HVAC parameters
- Develop better shading model
- Improve handling of air-handling luminaires
- Improve pump energy calculation **(Done)**
- Provide more chiller options
- Add embedded heat emitters
- Include provision for bivalent heating **(Done)**
- Add hot water conservation features (spray taps, etc.)
- Add provision for trace heating
- Improve duct leakage correction to be non-linear
- Add provision for energy piles
- Include ventilation efficiency correction

Third Priority

- Provide heating and cooling load indicators

- Provide more diagnostic information
- Explore more sophisticated inference rules for existing buildings
- Migrate to web-based implementation

Subsequent requests by users

- Add low-temperature heat emitters
- Distinguish heating systems by responsiveness
- Provide a route for highly simplified data input

8. References

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International Energy Agency, IEA Solar Heating and Cooling Report No. SHC.T14.Air.1, Low Cost, High Performance Solar Air-Heating Systems Using Perforated Absorbers

APPENDIX A: Guidance on HW demand calculation from data in the NCM Activity Database

The calculation of the monthly HW demand is produced as follows:

$$HWS_i = \frac{HWS \times HP_m}{HPF}$$

where:

HWS_i is the monthly HW demand (l/m² per month i);

HWS is the nominal HW demand value for the specific activity (l/m² per day); Field 'HWS' in the 'activity' table of the NCM Activity Database.

HP_m is the sum of the hourly values in the occupancy schedule for the specific activity for the month i ;

HPF is the factor containing the approximation of the sum of the hourly values in the occupancy schedule for the specific activity for an average weekday; Field 'HWS_HP_FACTOR' in the 'activity' table of the NCM Activity Database.

Therefore, for hourly calculations, the hourly HWS demand could be calculated as:

$$HWS_h = \frac{HWS \times HP_h}{HPF}$$

where:

HWS_h is the hourly HW demand (l/m² per hour h);

HWS is the nominal HW demand value for the specific activity (l/m² per day); Field 'HWS' in the 'activity' table of the NCM Activity Database.

HP_h is the activity's relevant hourly value from the occupancy schedule; Field 'hxx' from the 'daily_schedules' table for the relevant occupancy schedule of the NCM Activity Database.

HPF is the factor containing the approximation of the sum of the hourly values in the occupancy schedule for the specific activity for an average weekday; Field 'HWS_HP_FACTOR' in the 'activity' table of the NCM Activity Database.

APPENDIX B: Basic Logic for Filtering Recommendations for EPCs

This appendix is a record of the structure and process of the filtering logic used to make an initial selection of recommendations to accompany EPCs.

Content with a clear background describes the logic that is mandatory for the production of the formal Recommendations Report in England and Wales.

Sections that have grey background are NOT a required element of the Recommendations Report in England and Wales. They are used in iSBEM to provide extra information to assessors. Other software may make also use them, but this is not mandatory. Accreditation bodies may require additional information to be provided to assist auditing.

B1.0 Schematic logic of filtering process

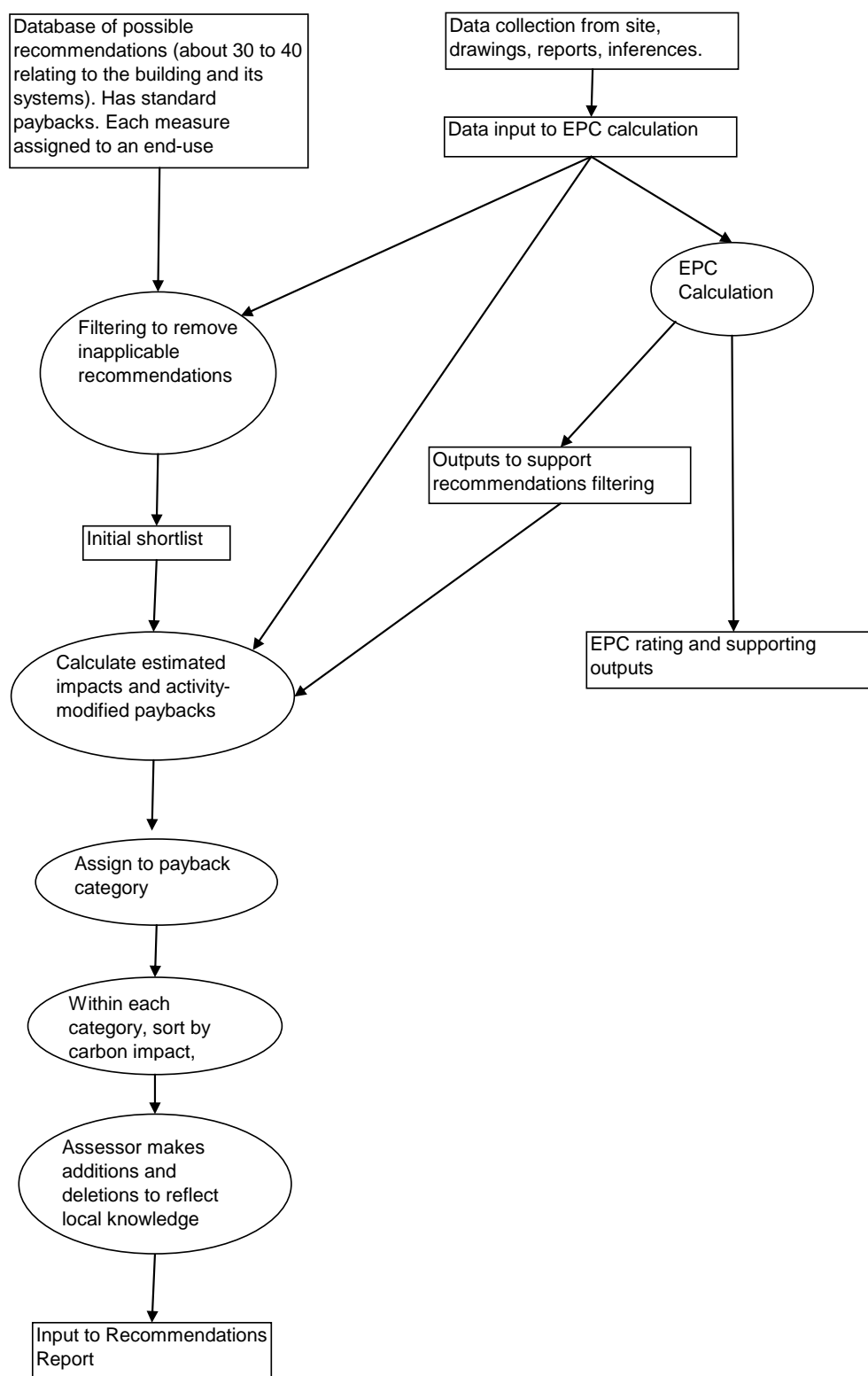


Figure 12: Schematic logic of recommendations filtering process

The initial list of potential recommendations is a subset of those collected by AECOM for use with Display Energy Certificates in the UK. Since the EPC calculation contains no information on operation or maintenance, potential recommendations relating to these

aspects of energy efficiency have been omitted. On the other hand, the more detailed information available for the calculation has, in some cases, allowed the DEC recommendations to be refined. The basic payback information has also been taken from the DEC source. To retain some consistency over as wide a range of recommendations as possible, the paybacks for office applications have been used. (This application contains the largest number of recommendations). However, the paybacks are adjusted within the following logic to reflect the intensity and duration of use of the building being assessed.

The filtered and prioritised recommendations are intended to guide assessors, who have the final responsibility for them. Assessors are able to remove or add recommendations. With some software (for e.g., iSBEM), they may also comment on recommendations and provide justification for additions and removals.

B2.0 The logic, Step by Step

Note: It is important that all default values are set (or overwritten by the assessor, either directly or via the inference procedures).

B2.1 Basic whole-building information

- From calculations already carried out for EPC rating, record Notional building's
 - Heating kWh/m², Cooling kWh/m², Lighting kWh/m², Hot water kWh/m², Auxiliary kWh/m²
 - Heating kgCO₂/m², Cooling kgCO₂/m², Lighting kgCO₂/m², Hot water kgCO₂/m², Auxiliary kgCO₂/m²
 - Identify which of these services are actually present in the building
 - Calculate % of CO₂ emissions attributable to each end-use
- From calculations already carried out for EPC rating, record Actual building's
 - Heating kWh/m², Cooling kWh/m², Lighting kWh/m², Hot water kWh/m², Auxiliary kWh/m²
 - Heating kgCO₂/m², Cooling kgCO₂/m², Lighting kgCO₂/m², Hot water kgCO₂/m², Auxiliary kgCO₂/m²
 - Calculate % of "energy" (price-weighted?) attributable to each end-use
 - Calculate % of CO₂ emissions attributable to each end-use
- From calculations already carried out for EPC rating, record Typical building's
 - Heating kWh/m², Cooling kWh/m², Lighting kWh/m², Hot water kWh/m², Auxiliary kWh/m²
 - Heating kgCO₂/m², Cooling kgCO₂/m², Lighting kgCO₂/m², Hot water kgCO₂/m², Auxiliary kgCO₂/m²

B2.2 Categorise end-uses as good/fair/poor

B2.2.1 Heating

- **For heating**, compare Actual kWh/m² with that for Notional and Typical
 - If **Actual < Notional**, classify heating energy efficiency as "good"
 - If **Notional ≤ Actual < Typical**, classify heating energy efficiency as "fair"
 - **Otherwise**, classify heating energy efficiency as "poor"

- **For heating**, compare Actual kgCO_2/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify heating CO₂ efficiency as “good”
 - If **Notional ≤ Actual < Typical**, classify heating CO₂ efficiency as “fair”
 - **Otherwise**, classify heating CO₂ efficiency as “poor”

B2.2.2 Cooling

- **For cooling**, compare Actual kWh/m^2 with that for Notional
 Note – We cannot use the Reference building as it uses mixed-mode cooling. Criteria are based on system efficiencies relative to that of the Notional building, bearing in mind that the Notional building system is assumed to be a fairly run-of-the-mill FC system.
 - If **Actual < 0.85 x Notional**, classify cooling energy efficiency as “good”
 - If **0.85 x Notional ≤ Actual < 1.5 x Notional**, classify cooling energy efficiency as “fair”
 - **Otherwise**, classify cooling energy efficiency as “poor”
- **For cooling**, compare Actual kgCO_2/m^2 with that for Notional
 - But ignore virtual cooling (overheating is captured later)
 - If **Actual < 0.85 x Notional**, classify cooling CO₂ efficiency as “good”
 - If **0.85 x Notional ≤ Actual < 1.5 x Notional**, classify cooling CO₂ efficiency as “fair”
 - **Otherwise**, classify cooling CO₂ efficiency as “poor”

B2.2.3 Lighting

- **For lighting**, compare Actual kWh/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify lighting energy efficiency as “good”
 - If **Notional ≤ Actual < Typical**, classify lighting energy efficiency as “fair”
 - **Otherwise**, classify lighting energy efficiency as “poor”
- **For lighting**, compare Actual kgCO_2/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify lighting CO₂ efficiency as “good”
 - If **Notional ≤ Actual < Typical**, classify lighting CO₂ efficiency as “fair”
 - **Otherwise**, classify lighting CO₂ efficiency as “poor”

B2.2.4 Domestic Hot Water

- **For hot water**, compare Actual kWh/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify hot water energy efficiency as “good”
 - If **Notional ≤ Actual < Typical**, classify hot water energy efficiency as “fair”
 - **Otherwise**, classify hot water energy efficiency as “poor”
- **For hot water**, compare Actual kgCO_2/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify hot water CO₂ efficiency as “good”
 - If **Notional ≤ Actual < Typical**, classify hot water CO₂ efficiency as “fair”
 - **Otherwise**, classify hot water CO₂ efficiency as “poor”

B2.2.5 Auxiliary (includes Mechanical Ventilation)

- **For Auxiliary**, compare Actual kWh/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify Auxiliary energy efficiency as “good”
 - If **Notional ≤ Actual < Typical**, classify Auxiliary energy efficiency as “fair”

- **Otherwise**, classify Auxiliary energy efficiency as “poor”
- **For Auxiliary**, compare Actual kgCO_2/m^2 with that for Notional and Typical
 - If **Actual < Notional**, classify Auxiliary energy efficiency as “good”
 - If **Notional \leq Actual < Typical**, classify Auxiliary energy efficiency as “fair”
 - **Otherwise**, classify Auxiliary energy efficiency as “poor”

B2.3 Recommendation triggered by system components

Notes:

- Boiler criterion is set to 0.7 rather than 0.65 in order to classify default boilers as poor
- “Potential impact” criteria have been pre-calculated using boiler efficiencies and rules taken from draft DEC thresholds of 4% and 0.5% of total building value.
- These are generally applied **both** at project and individual component level (there may be exceptions where only one is meaningful)
- Where recommendations are applied at project level, the assessment of impact assumes that for all systems components which trigger the recommendation, the recommendation is applied. The overall building energy (and CO_2) is then compared to the original building energy (and CO_2).

B2.3.1 Heating

B2.3.1.1 Heating efficiency

- **Check if using default heating efficiency – if yes, trigger EPC-H4**

Note: Assessing impact of recommendation **EPC-H4** is done similarly to that for recommendation **EPC-H1** shown overleaf.

- If **heat generator efficiency > 0.88**, classify heat generator efficiency as “good”.
- If **0.88 \geq heat generator efficiency > 0.70**, classify heat generator efficiency as “fair”.
 - If fuel is gas, oil or LPG, trigger recommendation **EPC-H3** (condensing boiler)

Note: If hot water is provided by the space heating boiler, hot water is included in the energy and CO_2 proportions below.

Fuel	Price Factor (with respect to gas)
gas	1
LPG	2.74
Biogas	1.48
oil	1.72
coal	0.61
Anthracite	1.07
Smokeless fuel (inc coke)	0.61
Dual fuel appliances (mineral + wood)	1.48
biomass	1.48
electricity	3.43
Waste heat	0.2

Table 43: Fuel Price factors

- Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate new heating (and, if appropriate, HWS) energy as ratio between actual efficiency and **0.89**. Determine % change in total building energy
 - If change in total energy is > 4%, potential impact is “high”
 - If $4\% \geq$ change in total energy > 0.5%, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate new heating (and, if appropriate HWS) CO₂ emissions as ratio between actual efficiency and **0.89**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is > 4%, potential impact is “high”
 - If $4\% \geq$ change in total CO₂ > 0.5%, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”
 - If **0.70 ≥ heat generator efficiency**, classify heat generator efficiency as “poor”
 - Trigger recommendation **EPC-H1** (high efficiency boiler), and if fuel is gas, oil or LPG, trigger **EPC-H3** (condensing boiler) - assessed as above
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate new heating (and, if appropriate, HWS) energy as ratio between actual efficiency and **0.81**. Determine % change in total building energy
 - If change in total energy is > 4%, potential impact is “high”
 - If $4\% \geq$ change in total energy > 0.5%, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate new heating (and, if appropriate HWS) CO₂ emissions as ratio between actual efficiency and **0.81**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is > 4%, potential impact is “high”
 - If $4\% \geq$ change in total CO₂ > 0.5%, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”
 - If heating fuel is electricity, and if **heat generator efficiency < 2**, trigger recommendation **EPC-R1** (consider GSHP) and **EPC-R5** (consider ASHP)
- Note: CoP of 2 is the worst allowable in the Building Services Guide, but the air-source's default in iSBEM is 2.2, which is used below.*
- **For EPCR5:**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate new heating (and, if appropriate, HWS) energy as ratio between actual efficiency and **2.2**. Determine % change in total building energy
 - If change in total energy is > 4%, potential impact is “high”
 - If $4\% \geq$ change in total energy > 0.5%, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate new heating (and, if appropriate HWS) CO₂ emissions as ratio between actual efficiency and **2.2**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is > 4%, potential impact is “high”
 - If $4\% \geq$ change in total CO₂ > 0.5%, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”

- **For EPCR1**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate new heating (and, if appropriate, HWS) energy as ratio between actual efficiency and 3.1. Determine % change in total building energy
 - If change in total energy is > 4%, potential impact is “high”
 - If 4% ≥ change in total energy > 0.5%, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate new heating (and, if appropriate, HWS) CO₂ emissions as ratio between actual efficiency and 3.1. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is > 4%, potential impact is “high”
 - If 4% ≥ change in total CO₂ > 0.5%, potential impact is “medium”
 - Otherwise, change in total CO₂, potential impact is “low”

B2.3.1.2 Heating controls

- **Does the heating system have centralised time control?** If not, and there is also no room by room time control and there is no optimum start and stop control, then trigger recommendation **EPC-H2**
 - Improve heating efficiency by 1 percentage point and
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43),
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- **Does the heating system have room by room time control?** If not, trigger recommendation **EPC-H5**
 - Improve heating efficiency by 1 percentage point and
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43),
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- **Does the heating system have room by room temperature control?** If not, trigger recommendation **EPC-H6**
 - Improve heating efficiency by 2 percentage points and
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43),

- If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Assess likely scale of CO₂ impact from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- **Does the heating system have optimum start and stop control?** If not, trigger recommendation **EPC-H7**
 - Improve heating efficiency by 2 percentage points and
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43),
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- **Does the heating system have weather compensation controls?** If not, trigger recommendation **EPC-H8**
 - Improve heating efficiency by 1.5 percentage points and
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43),
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”

B2.3.2 Cooling

B2.3.2.1 Cooling Efficiency

- **Check if using default cooling efficiency – if yes, trigger EPC-C1**

Note: Assessing impact of recommendation **EPC-C1** is done similarly to that for recommendation **EPC-C2** shown below.

- If cold generator efficiency > 2.4, classify cold generator efficiency as “good”
- If 2.4 ≥ cold generator efficiency > 2.0, classify cold generator efficiency as “fair”
 - Trigger recommendation **EPC-C2**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate new cooling energy as ratio between actual efficiency and 2.5. Determine % change in total building energy

- If change in total energy is $> 4\%$, potential impact is “high”
 - If $4\% \geq$ change in total energy $> 0.5\%$, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
- Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate new cooling CO₂ emissions as ratio between actual efficiency and **2.5**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is $> 4\%$, potential impact is “high”
 - If $4\% \geq$ change in total CO₂ $> 0.5\%$, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”
- If **2.0 > cold generator efficiency**, classify cold generator efficiency as “poor”
 - Trigger recommendation **EPC-C2** as above

B2.3.2.2 Duct and AHU leakage

- If the HVAC system is VAV (including packaged cabinet), fan coil, induction, constant volume, multizone, terminal reheat, dual duct, chilled ceiling or chilled beam (with displacement ventilation), or active chilled beams,
- Extract duct and AHU leakage for Actual Building
 - If **duct and AHU leakage $< 5\%$** , classify duct leakage as “good”
 - If **$5\% \leq$ duct and AHU leakage $< 10\%$** , classify duct leakage as “fair”
 - Trigger recommendation **EPC-C3** and calculate impact
 - Reduce cooling energy by P where P is:
 - For VAV, constant volume, multizone, terminal reheat, dual duct, **P=5%**
 - For fan coil, induction, **P=2%**
 - For chilled ceiling, chilled beam, **P=0.5%**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43),
 - If total energy cost for building changes $> 4\%$, impact is “high”
 - If $4\% \geq$ total energy cost for building changes $> 0.5\%$, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂
 - If total CO₂ emissions from the building change $> 4\%$, impact is “high”
 - If $4\% \geq$ total CO₂ emissions from the building change $> 0.5\%$, impact is “medium”
 - Otherwise, impact is “low”
 - If **$10\% \leq$ duct and AHU leakage**, classify duct leakage as “poor”
 - Trigger recommendation **EPC-C3 – as above** and calculate impact - this time, reducing cooling energy by P where P is:
 - For VAV, constant volume, multizone, terminal reheat, dual duct, **P=10%**
 - For fan coil, induction, **P=4%**
 - For chilled ceiling, chilled beam, **P=1%**

B2.3.3 Hot Water

B2.3.3.1 Hot water generator efficiency

- If hot water is NOT provided by the space heating heat generator
 - If **heat generator efficiency > 0.79** , classify heat generator efficiency as “good”

- If $0.79 \geq \text{heat generator efficiency} > 0.7$, classify heat generator efficiency as “fair”
 - And trigger recommendation **EPC-W1**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate new hot water energy as ratio between actual efficiency and **0.8**. Determine % change in total building energy
 - If change in total energy is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total energy} > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate new hot water CO₂ emissions as ratio between actual efficiency and **0.8**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total CO}_2 > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”
- If $0.7 \geq \text{heat generator efficiency}$, classify heat generator efficiency as “poor”
 - And trigger recommendation **EPC-W1 – as above**
 - Assess likely scale of impact as above
- If HWS efficiency is “poor”,
 - Trigger recommendation **EPC-W2**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate reduction in hot water energy as ratio between actual HWS efficiency and **0.75**. Determine % change in total building energy
 - If change in total energy is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total energy} > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate reduction in hot water emissions as ratio between actual HWS efficiency and **0.75**. Determine % change in total building CO₂ emissions.
 - If change in total CO₂ is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total CO}_2 > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”

B2.3.3.2 Hot water storage

- Check whether there is hot water storage
 - If **storage heat loss $> (\text{default value} \times 0.9)$** , trigger recommendation **EPC-W3**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate reduction in hot water energy as **50% of storage losses**. Determine % change in total building energy
 - If change in total energy is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total energy} > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate reduction in hot water energy as **50% of storage losses**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is $> 4\%$, potential impact is “high”

- If $4\% \geq \text{change in total CO}_2 > 0.5\%$, potential impact is “medium”
- Otherwise, change in total CO₂ potential impact is “low”

B2.3.3.3 Secondary HWS circulation

- If there is secondary HWS circulation and there is no time control,
 - Trigger recommendation **EPC-W4**
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43). Calculate reduction in hot water energy as **30% of total hot water energy**. Determine % change in total building energy
 - If change in total energy is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total energy} > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total energy potential impact is “low”
 - Assess likely scale of CO₂ impact from proportion of total CO₂. Calculate reduction in hot water energy as **30% of total hot water energy**. Determine % change in total building CO₂ emissions
 - If change in total CO₂ is $> 4\%$, potential impact is “high”
 - If $4\% \geq \text{change in total CO}_2 > 0.5\%$, potential impact is “medium”
 - Otherwise, change in total CO₂ potential impact is “low”

B2.3.4 Fuel Switching

Note: The potential impact calculations are the same process for each of the fuel-switching recommendations – only the fuel CO₂ contents and prices differ.

- If coal, trigger recommendations **EPC-F2**, **EPC-F3**, and **EPC-F6**
 If hot water is provided by the space heating boiler, include hot water in energy and CO₂ proportions below

- Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43), for **EPC-F2** (coal to gas)

Note: For simplicity assume no change in boiler efficiency – savings are due to fuel price only

- If total energy cost for building changes $> 4\%$, impact is “high”
- If $4\% \geq \text{total energy cost for building changes} > 0.5\%$, impact is “medium”
- Otherwise, impact is “low”
- Assess likely scale of CO₂ impact for **EPC-F2** from proportion of total CO₂
 - If total CO₂ emissions from the building change $> 4\%$, impact is “high”
 - If $4\% \geq \text{total CO}_2 \text{ emissions from the building change} > 0.5\%$, impact is “medium”
 - Otherwise, impact is “low”

- Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43), for **EPC-F3** (coal to biomass)

Note: For simplicity assume no change in boiler efficiency – savings are due to fuel price only

- If total energy cost for building changes $> 4\%$, impact is “high”
- If $4\% \geq \text{total energy cost for building changes} > 0.5\%$, impact is “medium”
- Otherwise, impact is “low”
- Assess likely scale of CO₂ impact for **EPC-F3** (from proportion of total CO₂)

- If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43), for **EPC-F6** (coal to oil)
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Note: For simplicity assume no change in boiler efficiency – savings are due to fuel price only*
- If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Assess likely scale of CO₂ impact for **EPC-F6** from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- If heating fuel is oil or LPG, trigger recommendations **EPC-F1** and **EPC-F4**
- If hot water is provided by the space heating boiler, include hot water in energy and CO₂ proportions below*
- Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43), for **EPC-F1** (oil to gas)
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Note: For simplicity assume no change in boiler efficiency – savings are due to fuel price only*
- If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Assess likely scale of CO₂ impact for **EPC-F1** from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43), for **EPC-F4** (oil to biomass)
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Note: For simplicity assume no change in boiler efficiency – savings are due to fuel price only*
- If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Assess likely scale of CO₂ impact for **EPC-F4** from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”

- If 4% \geq total CO₂ emissions from the building change > 0.5%, impact is “medium”
- Otherwise, impact is “low”
- If heating fuel is gas, trigger recommendation **EPC-F5** (gas to biomass)
 - Assess likely scale of energy impact from proportion of total “energy” (assumed to be price-weighted using factor from Table 43), for **EPC-F5** (gas to biomass)
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% \geq total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely scale of CO₂ impact for **EPC-F5** from proportion of total CO₂
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% \geq total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”

Note: For simplicity assume no change in boiler efficiency – savings are due to fuel price only

B2.3.5 Lighting

Note: Survey should require lamp type to be completed or inferred

- Check whether any spaces have T12 lamps
 - If they do, trigger recommendation **EPC-L1**
 - Assess likely impact on energy (assumed price weighted)
 - Impact is assessed by changing all T12 lamps to T8 lamps and assessing the % change in energy for the project
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% \geq total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely impact on CO₂
 - Impact is assessed by changing all T12 lamps to T8 lamps and assessing the % change in CO₂ for the project
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% \geq total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Check whether any spaces have T8 lamps
 - If they do, trigger recommendation **EPC-L5**
 - Assess likely impact on energy (assumed price weighted)
 - Impact is assessed by changing all T8 lamps to T5 lamps and assessing the % change in energy for the project
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% \geq total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely impact on CO₂

- Impact is assessed by changing all T8 lamps to T5 lamps and assessing the % change in CO₂ for the project
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Check whether any spaces have GLS lamps
 - If they do, trigger recommendations **EPC-L2**
 - Assess likely impact on energy (assumed price weighted)
 - Impact is assessed by changing all GLS lamps to CFL and assessing the % change in energy for the project
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely impact on CO₂
 - Impact is assessed by changing all GLS lamps to CFL and assessing the % change in CO₂ for the project
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Check whether any spaces (with fluorescent lamps) have mains frequency ballasts
 - If they do, trigger recommendation **EPC-L7**
 - Assess likely impact on energy (assumed price weighted)
 - Impact is assessed by changing all T8 lamps with mains frequency ballast to T8 lamps with high frequency ballast and assessing the % change in energy for the project
 - If total energy cost for building changes > 4%, impact is “high”
 - If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
 - Assess likely impact on CO₂
 - Impact is assessed by changing all T8 lamps with mains frequency ballast to T8 lamps with high frequency ballast and assessing the % change in CO₂ for the project
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”
- Check whether any spaces have high-pressure mercury discharge lamps
 - If they do, trigger recommendations **EPC-L3** and **EPC-L6**
 - Assess likely impact on energy (assumed price weighted)
 - Impact is assessed by changing all HP mercury to SON replacements (HP sodium) and assessing the % change in energy for the project. *Note that the paybacks will be different for EPC-L3 and EPC-L6 although the energy impact will be the same.*

- If total energy cost for building changes > 4%, impact is “high”
- If 4% ≥ total energy cost for building changes > 0.5%, impact is “medium”
- Otherwise, impact is “low”
- Assess likely impact on CO₂
 - Impact is assessed by changing all HP mercury to SON replacements (HP sodium) and assessing the % change in CO₂ for the project. *Note that the paybacks will be different for EPC-L3 and EPC-L6 although the CO₂ impact will be the same.*
 - If total CO₂ emissions from the building change > 4%, impact is “high”
 - If 4% ≥ total CO₂ emissions from the building change > 0.5%, impact is “medium”
 - Otherwise, impact is “low”

B2.3.6 Renewables

- Is a wind turbine installed? If not trigger recommendation **EPC-R2**
 - Energy impact is (currently always) low
 - CO₂ impact is (currently always) low
- Is solar thermal water heating installed? If not trigger recommendation **EPC-R3**
 - Energy impact is (currently always) low
 - CO₂ impact is (currently always) low
- Is a photovoltaic system installed? If not trigger recommendation **EPC-R4**
 - Energy impact is (currently always) low
 - CO₂ impact is (currently always) low

Note: Ideally we need a proper calculation to estimate impact, but, generally, the absolute impacts are likely to be low. The assessor can over-write this if the building merits special consideration.

B2.3.7 Envelope

Note: For envelope (and lighting) recommendations, guidance on impact is often very general. We can improve this in future - maybe looking at the gain/loss ratio, etc.

Scale of Potential Impact			
Proportion of total energy or CO ₂ accounted for by end-use	Overall consumption for end-use		
	Good efficiency	Fair efficiency	Poor efficiency
20% + energy or CO ₂	Medium	Medium	High
5% to 20% energy or CO ₂	Low	Medium	High
5% - energy or CO ₂	Low	Low	Medium

Table 44: Scale of potential impact

Roofs

For pitched roofs with lofts

- If any have **U-value > 1.0**, trigger recommendation **EPC-E6**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂

- Use Table 44 applied to heating CO₂

For flat roofs

- If any have **U-value > 1.0**, trigger recommendation **EPC-E2**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂

Walls

For solid walls

- If any have **U-value > 1.0**, trigger recommendation **EPC-E3**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂

For cavity walls

- If any have **U-value > 1.0**, trigger recommendation **EPC-E4**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂

Glazing

For all glazing

- If any have **U-value > 3.5** (assumed single glazed), trigger recommendation **EPC-E5**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂
- And trigger recommendation **EPC-E8**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂

Floors

- If any have **U-value > 1.0**, trigger recommendation **EPC-E1**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂

Airtightness

- If **permeability > 14**, trigger recommendation **EPC-E7**
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 44 applied to heating energy
 - Assess likely impact on CO₂
 - Use Table 44 applied to heating CO₂

Overheating

- Check whether any space in the building overheats

This is done by assessing if the solar gain limit defined in the NCM is exceeded in any zone in the building

- If yes, trigger recommendation **EPC-V1**
 - Energy impact is (currently always) medium
 - CO₂ impact is (currently always) medium

B2.4 Next step: “Triggered” recommendations now need prioritising

To calculate **PAYBACK** for each recommendation, adjust standard paybacks (from Table 47) for building activities using the following:

- **For heating measures**
 - Multiply payback by **140** and divide by **TYPICAL** building heating consumption (kWh/m².year)
- **For lighting measures**
 - Multiply payback by **30** and divide by **TYPICAL** building lighting consumption (kWh/m².year)
- **For cooling measures relating to cold generators**
 - Multiply payback by **30** and divide by **1.2 x NOTIONAL** building cooling consumption (kWh/m².year)
- **For cooling measures relating to mechanical ventilation**
 - Multiply payback by **60** and divide by **NOTIONAL** building auxiliary energy consumption (kWh/m².year)
- **For hot water measures**
 - Multiply payback by **10** and divide by **NOTIONAL** building hot water energy consumption (kWh/m².year)

*Note: Standard paybacks are for offices and are derived by AECOM from an analysis of reported (expected) paybacks by CT surveys (in this case, in offices). (These surveys presumably are mostly in larger buildings). The adjustment scales the payback according to the ratio of **typical** building consumption to ECG 019⁸ (average of types 1 and 2, except cooling type 3). (Note: need to choose suitable air-con adjustment). Actual values are of secondary importance as the results are primarily used to rank measures.*

B2.5 Calculate supporting information

To calculate **POUND PER CARBON SAVING** for each recommendation, use the following:

Apply financial payback adjustment

This adjusts the financial payback for existing fuels other than gas (or electricity). It is based on the relative prices of fuels. Multiply the payback by the value from Table 45.

Fuel	Factor
Natural gas	1
LPG	0.36
Biogas	0.68
Oil	0.58
Coal	1.64
Anthracite	1.64
Smokeless fuel (inc coke)	1.64
Dual fuel appliances (mineral + wood)	0.68

Biomass	0.68
Grid supplied electricity	1.22
Grid displaced electricity	0
Waste heat	0.1

Table 45: Financial payback adjustment

Label in terms of £ spent per carbon saving

Good [index < 3], Fair [3 ≤ index < 5] or Poor [index ≥ 5]

Note: Based on DEC draft guidance advice – subsequently not used - that more than 4% of site energy is “high”, less than 0.5% is “low”, between these limits is “medium”. The current note assumes that energy is weighted by cost. It also uses information from an early DEC draft that suggests a rough indicator based on proportion of energy accounted for by end use: more than 20% “high”, less than 5% “low”, in between “medium”. This is extended in the table to reflect the “as found” performance. All these criteria will need to be reviewed in the light of early experience.

For fuel switching recommendations only

Adjust for the CO₂ content of different fuels by multiplying the financial payback by the relative CO₂ contents. (The financial payback has already been adjusted for fuel prices if the initial fuel is not gas). The adjustment depends on both existing and recommended fuel.

Multiply POUND PER CARBON SAVING value calculated above by relevant value from Table 46.

To	From									
	biomass	coal	LPG	oil	gas	biogas	anthracite	smokeless fuel	dual fuel	waste heat
biomass	1	0.09	0.11	0.09	0.13	1	0.08	0.06	0.13	1.39
coal	11.64	1	1.24	1.1	1.5	11.64	0.92	0.74	1.56	16.17
LPG	9.36	0.8	1	0.88	1.21	9.36	0.74	0.6	1.25	13
oil	10.6	0.91	1.13	1	1.37	10.6	0.84	0.68	1.42	14.72
gas	7.76	0.67	0.83	0.73	1	7.76	0.61	0.49	1.04	10.78
biogas	1	0.09	0.11	0.09	0.13	1	0.08	0.06	0.13	1.39
anthracite	12.68	1.09	1.35	1.2	1.63	12.68	1	0.81	1.7	17.61
smokeless fuel	15.68	1.35	1.68	1.48	2.02	15.68	1.24	1	2.1	21.78
dual fuel	7.48	0.64	0.8	0.71	0.96	7.48	0.59	0.48	1	10.39
waste heat	0.72	0.06	0.08	0.07	0.09	0.72	0.06	0.05	0.1	1

Table 46: Fuel switching recommendations adjustment to calculate POUND PER CARBON SAVING

- Sort “triggered” measures into rank order (lowest paybacks first)
- Offer this list to the assessor
 - Assessor can accept or reject selected recommendations, but must give reasons for rejection
- Select all recommendations with **payback < 3 years**
 - Sort these by decreasing magnitude of CO₂ saving
 - If there are more than **15**, select the first **15**
 - These are the “recommendations with a **short** payback”

- Select all recommendations with **$3 \leq \text{payback} < 7$ years**
 - Sort these by decreasing magnitude of CO₂ saving
 - If there are more than **10**, select the first **10**
 - These are the “recommendations with a **medium** payback”
- Select all recommendations with **$\text{payback} \geq 7$ years**
 - Sort these by decreasing magnitude of CO₂ saving
 - If there are more than **5**, select the first **5**
 - These are the “recommendations with a **long** payback”
- Select recommendations added by assessor
 - Sort these by decreasing magnitude of CO₂ saving
 - If there are more than **10**, select the first **10**
 - These are the “other recommendations”

B3.0 Some caveats

These recommendations have been generated for the building and its energy systems operated according to standard schedules that are appropriate to the general activities in the building. The assessor should use their knowledge to remove inappropriate ones and possibly to add additional ones.

It is strongly recommended that more detailed assessments are carried out to quantify the benefits before making final decisions on implementation.

If the Energy Performance Rating calculation has made extensive use of default values, some of the recommendations may be based on uncertain assumptions.

The replacement of systems or building elements when they reach the end of their useful life, or during refurbishment, offers economic opportunities beyond those listed here. Where this list of recommendations has identified a system, building element, or end-use energy or CO₂ performance as being “poor”, the opportunities for improvement will be especially high. In most cases, new elements and systems will also need to comply with Building Regulations performance standards.

These recommendations do not cover the quality of operation or maintenance of the building and its systems. There are frequently significant opportunities for energy and CO₂ savings in these areas, and a full “energy audit” to identify them is strongly recommended.

B4.0 Report Formats

The format of the Recommendations Report is described in a separate template.

According to the information provided, for this building:	Typical payback	Carbon saved per £ spent	Potential impact on energy use	Potential impact on carbon emissions
Heating accounts for 35% of the carbon emissions				
The overall energy efficiency for heating is <i>fair</i>				
The carbon efficiency for heating is <i>fair</i>				
The heating system efficiency is <i>good</i>				
The heat generator efficiency is <i>good</i>				
The worst insulation level of some windows is <i>poor</i>				
* Recommendation: Replace/improve glazing i.e. install double glazing	<i>Medium</i>	<i>Medium</i>	<i>Medium</i>	<i>Medium</i>
The worst insulation level of walls is <i>fair</i>				
The worst insulation level of roofs is <i>poor</i>				
* Recommendation: Install/improve roof insulation	<i>Poor</i>	<i>Poor</i>	<i>High</i>	<i>High</i>
The worst insulation level of floors is <i>fair</i>				
Cooling accounts for 30% of the carbon emissions				
The overall energy performance for cooling is <i>poor</i>				
The carbon efficiency for cooling is <i>poor</i>				
The cooling system efficiency is <i>poor</i>				
* Recommendation: pressure test and seal ductwork	<i>Good</i>	<i>Good</i>	<i>Medium</i>	<i>Medium</i>
The cold generator efficiency is <i>fair</i>				
* Recommendation: when next replacing the chiller, select a high performance model	<i>Good</i>	<i>Good</i>	<i>Medium</i>	<i>High</i>
The demand for cooling is <i>poor</i>				
* Recommendation: reduce solar gain by use of shading devices or reflective film	<i>Good</i>	<i>Good</i>	<i>Low</i>	<i>Medium</i>
(If no cooling system is installed in a space, the overheating risk can be checked and reported:				
Some spaces in this building have a significant risk of overheating				
* Recommendation: reduce solar gain by use of shading devices or reflective film	<i>Good</i>	<i>Good</i>	<i>Low</i>	<i>Medium</i>
Lighting accounts for 25% of carbon emissions				
The overall energy performance of lighting is <i>good</i>				
The carbon efficiency of lighting is <i>good</i>				
The energy efficiency of the worst lighting systems in this building is <i>poor</i>				
* Recommendation: replace tungsten GLS lamps with CFLs	<i>Good</i>	<i>Good</i>	<i>Potentially medium but requires more assessment</i>	<i>Potentially medium but requires more assessment</i>
Hot water provision accounts for 10% of carbon emissions				
The energy performance of hot water provision is <i>fair</i>				
The carbon efficiency of hot water provision is <i>poor</i>				
Mechanical ventilation accounts for 5% of carbon emissions				
The energy efficiency of mechanical ventilation is <i>poor</i>				
The carbon efficiency of mechanical ventilation is <i>poor</i>				
* Recommendation: consider replacing extract fans	<i>Medium</i>	<i>Good</i>	<i>Medium</i>	<i>Good</i>

Figure 13: Example format for optional additional information

B5.0 Working list of EPC recommendations

Note: Wording of recommendations to be reviewed

CODE	DESCRIPTION	CATEGORY	PAYBACK Currently using an average of FAIR and POOR values
EPC-C1	default chiller efficiency	COOLING	3
EPC-C2	install high efficiency chiller	COOLING	3.5
EPC-C3	Inspect and seal ductwork	COOLING	7.5
EPC-W1	High efficiency water heater	HOT-WATER	4.15
EPC-W3	DHW storage insulation	HOT-WATER	3.8
EPC-W4	DHW secondary circulation time control	HOT-WATER	4.5
EPC-W2	DHW point of use system	HOT-WATER	8
EPC-E1	insulate floor	ENVELOPE	15
EPC-E2	insulate roof	ENVELOPE	25
EPC-E3	insulate solid walls	ENVELOPE	6.5
EPC-E4	cavity wall insulation	ENVELOPE	3.7
EPC-E5	secondary glazing	ENVELOPE	4.6
EPC-E6	insulate loft	ENVELOPE	5.6
EPC-E7	pressure test	ENVELOPE	7
EPC-E8	improve glazing	ENVELOPE	9.3
EPC-F1	Oil or LPG to natural gas (heating)	FUEL-SWITCHING	1.08
EPC-F2	Coal to natural gas (heating)	FUEL-SWITCHING	3.75
EPC-F3	Coal to biomass (heating)	FUEL-SWITCHING	3.81
EPC-F4	Oil or LPG to biomass (heating)	FUEL-SWITCHING	6.7
EPC-F5	gas to biomass (heating)	FUEL-SWITCHING	6.72
EPC-F6	Coal to oil (heating)	FUEL-SWITCHING	8.4
EPC-H2	heating central time control	HEATING	1.8
EPC-H5	local time control	HEATING	5.8
EPC-H6	Room temperature control	HEATING	4.8
EPC-H7	Heating optimum start and stop control	HEATING	2.5
EPC-H8	heating weather compensation controls	HEATING	5
EPC-H1	install high efficiency boiler	HEATING	2.3
EPC-H3	install condensing boiler	HEATING	6.6
EPC-H4	default heat generator efficiency	HEATING	3
EPC-L1	T12 to T8	LIGHTING	0.6
EPC-L2	GLS to CFL	LIGHTING	0.85
EPC-L3	HP mercury to SON replacements	LIGHTING	1.8
EPC-L5	T8 to T5	LIGHTING	2.8
EPC-L6	HP mercury to SON	LIGHTING	3.5
EPC-L7	Mains to HF ballast	LIGHTING	5.7
EPC-V1	overheating	OVERHEATING	1.7
EPC-R1	consider GSHP	RENEWABLES	11.7
EPC-R2	install wind turbine	RENEWABLES	15.9
EPC-R3	install solar thermal water heating	RENEWABLES	20.2
EPC-R4	install PV system	RENEWABLES	44.7
EPC-R5	consider ASHP	RENEWABLES	9.8

Table 47: Working list of EPC recommendations

CODE	TEXT
EPC-C1	The default chiller efficiency is chosen. It is recommended that the chiller system be investigated to gain an understanding of its efficiency and possible improvements.
EPC-C2	Chiller efficiency is low. Consider upgrading chiller plant.
EPC-C3	Ductwork leakage is high. Inspect and seal ductwork
EPC-W1	Install more efficient water heater
EPC-W3	Improve insulation on DHW storage
EPC-W4	Add time control to DHW secondary circulation
EPC-W2	Consider replacing DHW system with point of use system
EPC-E1	Some floors are poorly insulated – introduce/improve insulation. Add insulation to the exposed surfaces of floors adjacent to underground, unheated spaces or exterior.
EPC-E2	Roof is poorly insulated. Install/improve insulation of roof.
EPC-E3	Some solid walls are poorly insulated – introduce/improve internal wall insulation.
EPC-E4	Some walls have uninsulated cavities - introduce cavity wall insulation.
EPC-E5	Some windows have high U-values - consider installing secondary glazing
EPC-E6	Some loft spaces are poorly insulated - install/improve insulation.
EPC-E7	Carry out a pressure test, identify and treat identified air leakage. Enter result in EPC calculation
EPC-E8	Some glazing is poorly insulated. Replace/improve glazing and/or frames.
EPC-F1	Consider switching from oil or LPG to natural gas
EPC-F2	Consider converting the existing boiler from coal to natural gas
EPC-F3	Consider switching from coal to biomass
EPC-F4	Consider switching from oil or LPG to biomass
EPC-F5	Consider switching from gas to biomass
EPC-F6	Consider switching from coal to oil
EPC-H2	Add time control to heating system
EPC-H5	Add local time control to heating system
EPC-H6	Add local temperature control to the heating system
EPC-H7	Add optimum start/stop to the heating system
EPC-H8	Add weather compensation controls to heating system
EPC-H1	Consider replacing heating boiler plant with high efficiency type
EPC-H3	Consider replacing heating boiler plant with a condensing type
EPC-H4	The default heat generator efficiency is chosen. It is recommended that the heat generator system be investigated to gain an understanding of its efficiency and possible improvements.
EPC-L1	Replace 38mm diameter (T12) fluorescent tubes on failure with 26mm (T8) tubes
EPC-L2	Replace tungsten GLS lamps with CFLs: Payback period dependent on hours of use
EPC-L3	Replace high-pressure mercury discharge lamps with plug-in SON replacements
EPC-L5	Consider replacing T8 lamps with retrofit T5 conversion kit.
EPC-L6	Replace high-pressure mercury discharge lamps with complete new lamp/gear SON (DL)
EPC-L7	Introduce HF (high frequency) ballasts for fluorescent tubes: Reduced number of fittings required
EPC-V1	In some spaces, the solar gain limit defined in the NCM is exceeded, which might cause overheating. Consider solar control measures such as the application of reflective coating or shading devices to windows.
EPC-R1	Consider installing a ground source heat pump
EPC-R2	Consider installing building mounted wind turbine(s)
EPC-R3	Consider installing solar water heating
EPC-R4	Consider installing PV
EPC-R5	Consider installing an air source heat pump

Table 48: Text for EPC recommendations