Technical Manual



SBEM: Simplified Building Energy Model

Part of the National Calculation Methodology : SBEM for assessing the Energy Performance of Buildings

A Technical Manual for SBEM

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Key changes from the previous version of the manual

- Correction of typing error to include window area in first equation in section 4.1.12.2.
- Clarification on calculation in case there is no time switch on HW secondary circulation in section 4.3.2.

This manual, together with the software tools described in it, were developed by the BRE for the Department for Communities and Local Government (DCLG).

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1. Introduction

1.1. Purpose

The purpose of this document is to record the detail 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
- DCLG¹ 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:
 - o Architects
 - Service and M&E engineers
 - o Energy surveyors
 - o Building energy modellers
 - o 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 Communities and Local Government

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

³ Available for download from <u>http://www.ncm.bre.co.uk</u>.

2. Background

This section of the manual looks at the requirement for a calculation methodology for the UK that complies with Article 3 of the EPBD, 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. Requirements of the EPBD

The Energy Performance of Buildings Directive (EPBD) 2002/91/EC of the European Parliament and Council (dated 16 December 2002) calls on each EU Member State to promote the improvement of energy efficiency of buildings, by laying down standards, assessing performance on a consistent basis, and providing certificates for the majority of buildings so that this performance is communicated effectively.

In more detail, the EPBD calls on Member States to:

- develop a methodology of calculation of the integrated energy performance of buildings (Article 3)
- set minimum requirements for the energy performance of new and existing buildings (Article 4)
- 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 (Article 5)
- ensure that those requirements for the energy performance are met in existing buildings that are subject to major renovation or extension (Article 6)
- develop energy certification of buildings (Article 7)
- 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 (Articles 8 & 9)
- ensure that certification and inspections required by articles 7, 8 & 9 are carried out by qualified and/or accredited experts (Article 10)

This Manual explains how the relevant parts of Articles 3, 4, 5, 6 & 7 led to the National Calculation Methodology (NCM) and thence to SBEM for new construction, extensions, major refurbishment and existing buildings. The issues addressed by EPBD Articles 8 - 10, which deal with inspection and the accreditation of experts, are not considered here.

2.1.1. Need for methodology

Article 3 of the EPBD calls for a methodology for calculating the energy performance of buildings, to be applied at a National or Regional level. The UK response to this has been to develop the NCM; SBEM is one implementation of this methodology.

An annex to the EPBD states that the calculation must be 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 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 should also deal 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

Buildings should be classified into different categories for the purposes of the calculation. Article 3 of the EPBD calls for the calculation to be transparent, that is, the way it works should be explained. This manual is part of that explanation.

The definition of "energy performance" in Article 2 of the EPBD 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. Article 3 permits the use of CO_2 emissions as a means of comparison, rather than energy consumption, in the standard methodology.

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, the EPBD calls for a calculation methodology on the energy performance of buildings to be established. The response to this by the UK Office of the Deputy Prime Minister (ODPM) - now the Department for Communities and Local Government (DCLG) - was to state in the 2006 Building Regulations Part L for England and Wales:

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

(2) The methodology shall comply with the requirements of the Directive. 17B - The Secretary of State shall approve minimum energy performance requirements for new buildings in the form of CO_2 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.

The EPBD permits the inclusion of a CO_2 emission factor in the standard methodology. For Building Regulations compliance in the UK, it has been decided to base compliance on CO_2 emissions, rather than on delivered or primary energy, in order to:

- avoid confusion over definitions of delivered and primary energy
- 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 carbon management in order to meet international treaty obligations.

Following on from the Article 3 requirement of the EPBD, 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 marks 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 these are not compliant with all the requirements of the EPBD, and there could potentially be difficulties in achieving consistent results.

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

2.2.1. Comparison rather than absolute calculation

At the core of the NCM, the calculation process compares the carbon emissions of the proposed building with target emissions which are based on those of a "notional building". This constitutes setting the standards in order to satisfy the requirements of Article 4 of the EPBD.

The basis on a comparison minimises argument about how well the absolute carbon emissions are predicted by different NCM-compliant methods, because both the proposed 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
- Heating and cooling generator efficiencies

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 of the EPBD are most readily achieved by demonstrating that the calculation method complies with the CEN standard umbrella document PG-N37, which lists standards relevant to the implementation of the EPBD. In particular EN ISO 13790 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 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

The performance requirement is for the proposed building to achieve carbon emissions less than a "Target Emissions Rate" (TER). This is derived from those of the notional building introduced above.

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 type.
- 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 building fabric, glazing type, and HVAC plant efficiencies.
- Any service not covered by Part L (e.g. emergency escape lighting, specialist process lighting) is ignored in both the actual and notional building

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

The NCM is used to calculate the energy consumption and hence carbon dioxide emissions of both the building being evaluated (its "Building Emissions Rate" or BER) and those of the notional building.

Detailed specifications of the 2013 England notional building are in DCLG's 2013 NCM Modelling Guide (available from <u>www.ncm.bre.co.uk</u>), and further guidance is in the Building Regulations Approved Document Part L 2013 in England, which can be accessed from <u>www.planningportal.gov.uk/uploads/br/BR_PDF_AD_L2A_2013.pdf</u>. Further information on the limiting standards for building services is available in the 2013 Non-Domestic Building Services Compliance Guide, which can be accessed from <u>http://www.planningportal.gov.uk/uploads/br/pon_domestic_building_services_compliance</u>

http://www.planningportal.gov.uk/uploads/br/non_domestic_building_services_compliance_guide.pdf

Detailed specifications of the 2014 Welsh notional building are in the Wales 2014 NCM Modelling Guide (available from <u>www.ncm.bre.co.uk</u>), and further guidance is in the Building Regulations Approved Document Part L 2014 Wales, which can be accessed from <u>www.wales.gov.uk/docs/desh/publications/140326building-regs-approved-document-l2afuel-power-en.pdf</u>.

Detailed specifications of the 2015 Scottish notional building are in the Scotland 2015 NCM Modelling Guide, which can be accessed from <u>http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/techhandbooks/ncmg2015</u>), and further guidance is in the Scotland Building Regulations Section 6 for 2015, which can be accessed from <u>http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/techhandbooks/ncmg2015</u>, which can be accessed from <u>http://www.gov.scot/Topics/Built-Environment/Building/Building-standards/techbooks/te</u>

For Northern Ireland, please refer to <u>http://www.dfpni.gov.uk/index/buildings-energy-</u><u>efficiency-buildings.htm</u> for further information on Northern Ireland's building regulations and published documents.

2.2.5. Compliance with Articles 5 & 6

EPBD Articles 5 & 6 require that 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; for instance for new buildings over 1000m² it must be shown that the technical, environmental, and economic feasibility of alternative systems such as heat pumps or CHP has been considered before construction starts.

The articles 5 & 6 requirements for new buildings and refurbishments are effectively provided by a compliance checking module (BRUKL) which is incorporated into all implementations of the NCM, such as SBEM.

2.3. Brief from DCLG

Having established the generalised content of the NCM, the DCLG (Department of Communities and Local Government) sought software implementations of it. In particular, they required software which would handle the majority of buildings and could be made available free to users. They commissioned BRE to write a national calculation tool to fulfil this role.

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

It 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 standards⁴ 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 Review of standards dealing with calculation of heat transmission in buildings – Thermal performance of buildings – Transmission and ventilation heat transfer coefficients – Calculation methods

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

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

⁴ Published standards can be obtained online from the British Standards Institution at <u>http://www.bsonline.bsi-global.com/server/index.jsp</u>.

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 resulting from the energy used by the building and its occupants. Some of the inputs are standardised to allow consistent comparisons for building regulation and energy rating 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 system efficiencies in order to determine the energy consumption. The energy used for lighting and hot water is also calculated.

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

- 1. calculates lighting energy requirements on a standardised basis, which takes into account the glazing area, shading, light source, and lighting control systems
- 2. establishes the standardised heat and moisture gains in each activity area, from the database
- 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 delivered energy requirements to maintain thermal conditions
- 5. aggregates the delivered energy by source, and converts it into equivalent CO₂ emissions. This comprises the Building Emission Rate (BER).
- determines, on the same basis, the CO₂ emissions of a notional building with the same geometry, usage, heat gains, temperature, lighting and ventilation conditions, and weather but with building component construction, HVAC and lighting systems, as per the specifications of the relevant building regulations.
- derives from the notional building's CO₂ emissions the resulting Target Emission Rate (TER), as per the specifications of the relevant building regulations.
- 8. determines, on similar basis, the CO₂ emissions of a reference building, which has fixed ventilation and cooling conditions and space and water heating fuel.
- 9. applies a fixed improvement factor to each zone within the reference building and derives the resulting Standard Emission Rate (SER).

The BER and TER calculations are then handed over to the compliance checking module, BRUKL, to complete the assessment. BRUKL:

- 1. compares the BER with the TER, and determines a pass or fail for the CO₂ emissions criterion, based on the relative performance of the proposed building
- 2. undertakes a compliance check on certain fabric and building services parameters drawn from information input using iSBEM.

Reports are prepared to the standard format to provide:

- 1. comparison of BER & TER
- 2. confirmation of the elemental compliance check

The BER and SER calculations are also handed over to the energy performance certificate generator module, EPCgen, to provide energy rating certification. EPCgen:

 calculates the asset rating of the actual building as the ratio of the BER to the SER in England, Wales, and Northern Ireland (the asset rating equals the BER in Scotland), 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 any diagnostic checks on the proposed building:

- 1. data reflection (to confirm entry associated with results)
- 2. monthly profiles of energy use by each end use and fuel type
- 3. total electricity and fossil fuel use, and resulting carbon dioxide emissions

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
- factors affecting fabric and ventilation heat losses, including insulation levels, airtightness, deliberate natural ventilation, and the geometry of the building
- 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, thermal mass, geometry, and orientation
- 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. 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 and compliance checking module.

The steps involved in the input are 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 database
- Durations of those conditions in each activity area are established from the database
- User inputs the areas and constructions of the building components surrounding each activity area

- User selects, from the standard 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 comparison 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 should draw 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 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 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 NCM website. The database contains a comprehensive list of building types (see Table 1 for the full list), and the space types that might 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), 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 type such as "office" or "school". For instance, an "office" 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:

- Heating and cooling temperature and humidity set-points
- 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 demand

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 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 have been driven by the "Planning Use Class" so that the list of building types closely aligns with the Town and Country Planning (TCP) Use Classes⁵.

| Building Type | Description |
|---|--|
| A1/A2 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. |
| A3/A4/A5 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. |
| B1 Offices and Workshop businesses | Offices, research and development, light industry appropriate in a residential area. |
| B2 to B7 General Industrial and Special Industrial Groups | Use for the carrying on of an industrial process other than one falling within TCP Use class B1 and including those within TCP Use classes B3 to B7. |
| B8 Storage or Distribution | Use for storage or as a distribution centre. |
| C1 Hotels | Hotels, boarding and guest houses where no significant element of care is provided. |
| C2 Residential Institutions - Hospitals and Care Homes | Residential care homes, hospitals and nursing homes. |
| C2 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). |
| C2 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). |
| C2A 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. |
| D1 Non-residential Institutions - Community/Day Centre | Crèches, day nurseries and day centres. |
| D1 Non-residential Institutions - Crown and County Courts | Law courts |
| D1 Non-residential Institutions - Education | Non-residential education and training centres. |
| D1 Non-residential Institutions - Libraries Museums and Galleries | Art galleries, museums and libraries. |
| D1 Non-residential Institutions - Primary Health Care Building | Non-residential clinics and health centres. |
| D2 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 nor designed |

⁵http://www.planningportal.gov.uk/england/public/planning/smallbusiness/bg13commontypesofapplic ation/bg138changeofuse/useclassorder.

| | or altered for use as a separate dwelling (as defined in DCLG'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 |
| 24x7 Generic Office Area | conditioned 24 hours a day. 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 Warehouse storage | Large (warehouse sized) storage areas (unchilled) with 24 x 7 operation. |
| 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. |
| Bedroom | Bedroom |
| Bedroom unit | Guest bedroom unit including bedroom and on suite bathroom. Contains a bath and/or shower and usually a basin and toilet. |
| Car Park | Area designated for parking cars (enclosed or underground) |
| Cell (police/prison) | A room which accommodates one or more residents/inmates. |
| 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. |
| Circulation area (corridors and stairways) | For all circulation areas such as corridors and stairways. |
| Circulation area (corridors and stairways) - non public | For all non-public corridors and stairways. |
| 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 corresponding dense IT. |
| Cupboard | Areas for un-chilled storage with low transient occupancy. |
| 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. |

| glazing onto the outside such as a shop window, but which boxed/enclosed, separated from the main retail space. Domestic Bathroom An area spocifically used for bathing/washing. Contains a bath and/or shower and usually a basin and toilet. Domestic Circulation For all circulation areas within the dwelling. Domestic Circulation An area within is primarily used for sting meals. Domestic Circulation An area within is primarily used for eating meals. Domestic Conge The area within the dwelling where food is prepared Domestic Toilet An area primarily used for eating and drinking. Diry sports hall An area specifically designed for eating and drinking. Fitness Studio An area specifically designed for eating and drinking. Fitness Studio An area specifically designed for eating and drinking. Fitness suite/gym An area where food is prepared. Generic Checkin areas Areas designated for check in, which may include equipment such as x ray machines. and bagagae reclaim areas. Generic Office Area Areas to perform office work including offices and meeting rooms. It can include internal corridors providing access to office spaces, tea making facilities or kitcheneties within th office space, areas for photocopiers and fax machines and staff lounges. Generic Ward For ala reas containing beds which accommodate either single or multip | Display area | An area where display lighting is used to illuminate items. |
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| Eating/drinking area An area specifically designed for eating and drinking. 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 An area where food is prepared. Generic Checkin areas Areas designated for check in, 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 coridors providing access to office spaces, tea making facilities or kitchneettes within th 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 containes and/or truble dryers. Laboratory A rarea where provides controlled conditions in which scient research, experiments, and measurement may be perform the same where passengers are waking facilities or kitchenettes within the office space, an exitra sy and gate lounges. | | the main bathroom |
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| | 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 |

| Post Mortem Facility | Post-Mortem Facility (including Observation room and body |
|--|--|
| 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. |
| 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 sales area - chilled | All warehouse sized sales areas designed to accommodate a considerable quantity of fridges/freezers such as a hypermarket. |
| Warehouse sales area - electrical | All warehouse sized sales areas designed to accommodate considerable electrical equipment loads such as IT sales. |
| Warehouse sales area - general | All warehouse sized sales area which do not contain a large concentration of freezers/fridges or electrical appliances. |
| Warehouse storage | Large (warehouse sized) storage areas (unchilled). Lux = 300; Equip = 2; Heat Set Point = 18 |
| Workshop - small scale | An area for sedentary-light practical work. Often containing some machinery. |

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 setback temperature defined in the database.

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.

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 commercial kitchens and hospital operating theatres).

3.3.1.6. Heat gains from equipment

Following a similar procedure as for calculating heat gains from people and lighting, the database calculates the expected heat gains from equipment for each activity based on the Watts per square meter 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.

3.3.1.8. Hot Water requirements

A hot water demand is defined for all occupied spaces. The hot water demand is associated with the occupied spaces rather than the spaces where the hot water is accessed, i.e., there is a demand for hot water associated with an office rather than a toilet or tea room.

3.3.2. Constructions

The SBEM user can specify the U-value and thermal capacity information for a particular wall, window, roof, or floor for which the construction is accurately known. Where the construction is less precisely known, the SBEM user can make use of SBEM's construction and glazing databases. These databases contain a library of constructions covering different regulation periods and different generic types of construction.

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, solar factors, 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 EPBD 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 for heating", 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. <u>Scope</u>

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 15243⁶ is the EPBD 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 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 iSBEM. Internalising the calculation and providing the user with access to more of the mechanism values is a future upgrade.

⁶ CEN EN 15243 Ventilation for Buildings – Calculation of room temperatures and of load and energy for buildings with room conditioning systems.

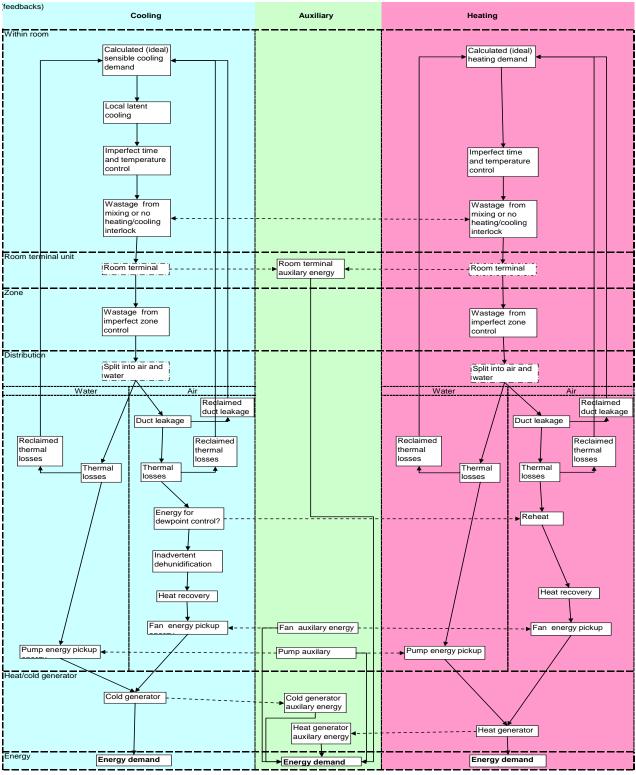


Figure 1: Basic energy flow diagram of the HVAC calculation in SBEM

3.3.3.4. The Mechanisms

The tables below, 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 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 Note:some values are arbitrary but the overall impact of all assumptions is consistent with simulation results. | | | | | | |
|---|---|---|-------------------|---|--|--|--|
| 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 commissioining 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 | | | |
| 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 | | |

| 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 | pondity to appriod |
| 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 (and risk of condensation) | 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 Includes AHUs and other air- handling components | Fixed percentage loss assumed with no useful contribution to loads |
| Duct system air leakage | User selects class of leakage |
| Includes AHUs and other air-handling components | |
| 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 (includes dew-point control plus reheat) | 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 Impact of variable ventilation air recirculation <i>Typically CO2 controlled – total</i> air flow unchanged | Ignored 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) Cold and Heat Generation | Calculated according to system type, hours of use and (for fans) SFP |
| | Coloulated automally and provided to cofficers |
| Cold generator (chiller) part-load performance (including multiple installations) | Calculated externally and provided to software |
| Water-side free-cooling Thermosyphon operation | Can be included in external calculation of seasonal performance May in principle be included in external calculation of seasonal |
| have a first shift and a start of a sector back of the start of the st | performance |
| Impact on chiller performance of central heat rejection equipment <i>Includes</i> cooling towers, dry coolers etc. Included in overall performance of packaged systems | May in principle be included in external calculation of seasonal performance |
| Auxiliary energy use by central heat rejection equipment | For air-cooled equipment, included in calculation of seasonal |
| Included in overall performance of packaged systems | 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 Includes gas boosters, fuel pumps, | Not included |
| etc. Included in overall performance of packaged systems | |
| | |
| Energy use for humidification Bivalent systems Includes boiler + CHP, condensing boiler + non-condensing | Not included 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

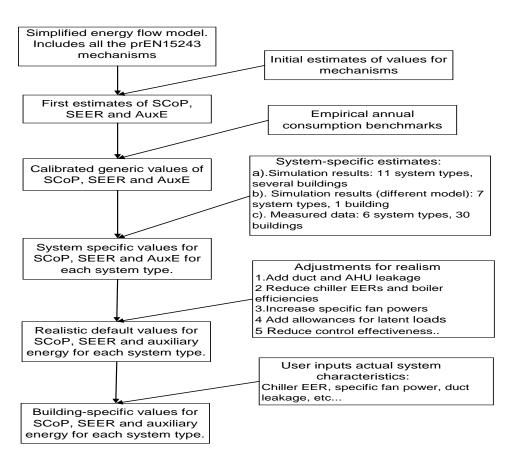
| | | | | | | | Cooling Demand | | | | |
|--------------------------|--|---|---|--|--|---|---|--|---|---|--|
| | Cooling Demand | Cooling Demand | Intermediate calculation | Auxiliary | Intermediate calculation | Cooling Demand | and heating demand | Cooling Demand | Cooling Demand | Cooling Demand | |
| Parameter | Peak cooling demand | Equivalent full load cooling hours | Room cooling demand | auxiliary power | Terminal auxiliary energy | Local latent load | Terminal Auxiliary pickup factor | Allowance for imperfect local control | Extra cooling load from mixing reheat | Extra load from imperfect zoning | |
| Description | | | | parameter | 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 | etc 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 toenergy use | Factor applied to room cooling demand | Add equal amount to heating demand | Factor | |
| Units Comment | Kw/m2 Building dependent. Expressed per unit floor area | hours pa Building dependent | kWhpa/m2 Building dependent. Expressed per unit floor area | kW/kW System dependent | kWhpa/kWhpa cooling System dependent | dimensionless System dependent | | dimensionless Control and load dependent | kWhpa/m2 system dependent | dimensionless Building and sytem dependent | |
| Parameter | Cooling-air and wa Proportion of load handled by air sub-system | Cooling-air Duct leakage | Cooling-air Reclaimed leakage losses | Cooling-air Duct heat pickup | Cooling-air Reclaimed cold losses | Cooling-air Central latent Ioad | Heating-water Reheat energy | Cooling-air Heat recovery or economiser | Auxiliary Specific fan power | Cooling-air Fan energy pickup factor | |
| Description | Can vary from all- air to no air factor | 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 factor, but be | 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 | lactor | Leakage factor - think about the algebra when applying! | factor applied to the duct loss figure | lactor | factor applied to the duct heat pickup figure | careful with the algebra! | added to <i>heating</i> 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 | kWhpa/m2 | dimensionless | W/I/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 | |
| Deservator | Auxiliary | Intermediate calc | Cooling-water | Cooling-water | Cooling-water | Intermediate calc | Auxiliary | Cooling generation Chiller | Cooling generation | | |
| Parameter Description | Fan run hours All services. Same figure used | Fan energy All services | Pipe heat pickup Heat transfer through pipe walls | Reclaimed cold losses Some of the lost coolth may | Cooling pump pickup factor Most pump energy is transferred to water as | Cooling pump power | Cooling pump energy Depends on pressure drop | performance Seasonal value - also applied to | Chiller Ancillaries May need to add cooling towers | | |
| | for terminals | | | be useful | heat gain | | - | room units | etc | | |
| Application | Depends on controls | Based on 10 l/s m2 for all-air systems, proportioned to % cooling by air. SFP 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 | | |
| Parameter | Heating Demand Heating Load | Heating Demand Heating EFLH | Intermediate calculation Room heating demand | Intermediate ca Cooling | Heating Demand Allowance for | Heating Demand Extra load from | Heating-air and wa Proportion of | Heating-air Duct leakage | Heating-air Reclaimed | Heating-air Duct heat loss | Heating-air Reclaimed heat |
| | | | - | proportion | imperfect local control | imperfect zoning | load handled by air sub-system | - | leakage losses | | 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 s for cooling | factor applied to the duct loss figure | factor | factor applied to the duct heat loss figure |
| Units Comment | kW/m2 Building | hours pa Building | kWhpa/m2 Building dependent | | dimensionless Control and load | dimensionless Building and | dimensionless system dependent | dimensionless Depends on | dimensionless Depends on | dimensionless Depends on | dimensionless Depends on location |
| | dependent | dependent | | | dependent | sytem dependent | | quality of ducts and AHUs | location of ductwork | extent and insulation of ductwork | of ductwork |
| Parameter | Heating-air Heat recovery | Heating-air Fan power | Heating-air Fan energy pickup | Heating-water Pipe heat | Heating-water Reclaimed heat losses | Heating-water Heating pump | Auxiliary Heating pump | Auxiliary Heating pump | Heat generation Boiler | Heat generation Boiler | |
| Description | or economiser Heat recovery wheel (etc) can reduce net loads | Pick up from cooling | Pick up from cooling | losses Heat transfer through pipe walls | Some of the lost heat may be useful | pickup Most pump energy is transferred to water as(useful) heat gain | power | energy Depends on pressure drop | performance Seasonal value - also applied to room units. May be reverse cycle chiller | Ancillaries 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- | Taken as 0.02 times wet part of peak heating load. | hours times power | (inverse) factor | factor added to boiler energy consumption, | |
| | | | | | | heating modes | | | | | |
| Units | dimensionless | | | dimensionless | dimensionless | heating modes kWhpa/m2 | kW/m2 | kWhpa m2 | dimensionless | dimensionless | |

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.



DEVELOPMENT PROCESS

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 019. 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

system types⁷ 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, 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 $t_{av} = t_{1.5} + grad^*(h/2-1.5)$ where *h* is room height and grad is air temperature gradient in K/m
- Assume that surface temperatures are unaffected
- Design operative temperature is $(t_r + t_{1.5})/2$ so nominal heat loss is $U^*((t_r + t_{1.5})/2 t_0)$
- Ignoring how losses vary between floors, walls, and roof, actual heat loss is $U^*((t_r + t_{av})/2 t_o)$

Valuing grad

Actual heat loss should be based on a temperature that is higher than design value by $grad^*(h/2-1.5)$. For room heights around 3 m, this correction is very small.

From GPG 303, typical values of grad are:

| Radiant heating | 0.3 K/m |
|-----------------|---------|
| Radiators | 1.5 K/m |

⁷ 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.

Convector heaters 2.3 K/m

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

| Radiant heating | 1.1⁰C |
|-------------------|-------|
| Radiators | 5.3⁰C |
| Convector heaters | 8.1⁰C |

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.

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

$t_c = I^* a^* r + (t_a + t_s)/2$

And the reduction in air temperature due to direct radiation is $2^{t} a^{t} r = dt$

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

$Q_t^* \eta_r / \eta_t$

where Q_t is the total heat output, η_r is the radiant efficiency, and 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*.

So the radiant intensity on the occupied area is

$$I = d^*Qt^* \eta_r / (\eta_t^*A).$$

Correction factor

The heating requirement for the space is

 $Q_t = (t_i - t_o)^* (U + V) - dt^* V$

where t_i is the internal temperature (strictly speaking environmental temperature, but say comfort temperature),

to is the outdoor air temperature

U is the total conductance associated with the fabric (that is the sum of U^*A terms)

V is the ventilation conductance

(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 $dt = k^*Q_t$.

Substituting and rearranging, we obtain

 $Q_t = (t_i - t_o)^* (U+V)/(1+k)$

That is, the conventional heat demand is multiplied by a factor 1/(1+k)

Valuing k

V, the ventilation conductance is $0.33^*N^*room volume$, where *N* is the ventilation rate in ac/h.

So $k = 2*a*r*d*0.33*N*room volume*\eta_r / (\eta_t*A)$

And 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).

 $k = 0.00438 N^{h} \eta_{r} / \eta_{t}$

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

 η_r / η_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 η_r / η_t term simply represents the proportion of the output that is radiant.

The following values are suggested:

| Emitter | η_r / η_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 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 (as in SAP).
- Energy consumption is calculated using the heat generation efficiency.
- CO₂ emissions are calculated depending on the fuel source.
- Additionally, if there is a secondary circulation system, auxiliary energy and the consequent CO₂ emissions 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 Activity database.

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

- storage volume
- heat loss per litre of stored hot water
- insulation type and thickness on storage vessel
- length of secondary pipework
- heat loss per metre of 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^{8,9}.

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 only requires 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 equate to the 2006 CIBSE Test Reference Years. 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 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.

⁸ 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.
⁹ CEN EN 15243 Appendix I.

- 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 room heights 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 <u>virtual</u>, e.g., between a daylit 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, he will be prompted to link (or assign) it to a zone. Equally, when he defines a window in the *Windows & Rooflights* main tab, he is 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 below 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.

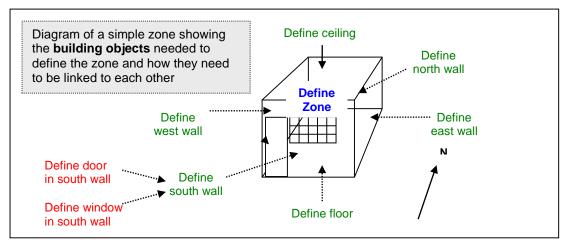


Figure 3: Diagram of building objects needed to define a simple zone

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, 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%.

| Type of junction | Metal cladding constructions Ψ (W/(m⋅K)) | Non-metal cladding constructions 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

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

<u>Note:</u> Point thermal transmittances are ignored as 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 CO_2 emissions of a building, as long as it complies with the following NCM requirements:

- Considers the energy uses required by article 3 of the EPBD
- 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 standards relevant to the implementation of the EPBD. 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 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 CO_2 emissions 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 (this is not part of the CEN Standard – the conversion is described in ADL2A) |

Table 7: Summary of CEN standard calculation

| | Issues/options | Chosen route | References in CEN standard EN ISO13790 |
|---|--|---|---|
| 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 presented to heat flux from inside the building coincides with the overall | 6.2, 6.3.2 |

| | | internal dimensions | |
|----------|---|--|----------------|
| 9 | Thermal zones | Building is partitioned into several | 6.3.1, 6.3.3.2 |
| | | zones, taking no account of thermal | , |
| | | coupling between zones | |
| 10 | Calculation procedure | Regard as a series of single zone | 6.3.5 |
| | for multi-zone | calculations, but with boundary | |
| | | conditions and input data coupled when | |
| | | zones share same heat/cooling system. | |
| | | Zones are aggregated when served by | |
| 11 | Energy demand for | the same heating/cooling system. | 7011 |
| 11 | Energy demand for heating | Equation 3; correction for holidays applied where relevant through | 7.2.1.1 |
| | neating | schedules in activity area database. | |
| 12 | Energy demand for | Equation 4; correction for holidays | 7.2.1.2 |
| 12 | cooling | applied where relevant through | 7.2.1.2 |
| | coomig | schedules in activity area database. | |
| 13 | Length of heating | Not calculated in SBEM – heat is | 7.2.1.3 |
| | season | available whenever monthly calculation | |
| | | demands it. | |
| 14 | Length of cooling | Not calculated in SBEM – cooling is | 7.2.2 |
| | season | available whenever monthly calculation | |
| | | demands it. | |
| 15 | Calculation in two | Not done in SBEM | 7.2.5 |
| | steps, to determine | | |
| | dissipation of heat from | | |
| | systems based on 1 st iteration | | |
| 16 | Total heat transfer by | Equation 11 | 8.2 |
| | transmission | | 0.2 |
| 17 | Transmission heat | Calculate according to EN ISO | 8.3.1 |
| | transfer coefficients | 13789:2005 taking into account other | |
| | | standards listed in 8.3.1 | |
| 18 | Thermal bridges | Calculate transmission heat loss | 8.3.1 |
| 10 | | according to EN ISO 13789:2005 | |
| 19 | Differences in | Not implemented in SBEM - physical | |
| | transmission calculation | characteristics of building do not change | |
| | between heating and cooling modes | | |
| 20 | Nocturnal insulation | Not implemented in SBEM | 8.3.2, 8.4.2 |
| 20 | Special elements | Optional; if applied, comply with 8.4.3 | 8.4.3 |
| 22 | Total heat transfer by | Equation 13 | 9.2 |
| | ventilation | | |
| 23 | Ventilation heat transfer | Determine according to section 9.3.1, | 9.3.1 |
| | coefficients | using volume flow rate based on NEN | |
| | | 2916:1998 methodology section 6.5.2.1. | |
| | | Infiltration based on section 7.1.3.2 of | |
| <u> </u> | Difference i | EN 15242:2005 | |
| 24 | Differences in | Infiltration and heat recovery are | 9.3.2 |
| | ventilation calculation | currently ignored during cooling | |
| | between heating and | | |
| 25 | cooling modes Ventilation heat | Only during heating. Based on section | |
| 20 | recovery | 6.5.2 of NEN 2916:1998 methodology, | |
| | 10000019 | where according to efficiency of heat | |
| | | | |

| | | recovery eveters the cirthout to be | |
|----|---|---|----------------|
| | | recovery system, the air flow to be | |
| 26 | Night-time ventilation | heated is effectively reduced. Not implemented in SBEM | 9.4.3 |
| 20 | for free cooling | | 5.4.5 |
| 27 | Special elements | Optional; if applied, comply with 9.4.4 | 9.4.4 |
| 28 | Internal heat sources, | Calculate contribution using equations | 10.2, 10.3.1 |
| 20 | including cold sources | 16, 17 & 18 | 10.2, 10.0.1 |
| | (i.e., sinks, etc.) | | |
| 29 | Heat dissipated by | Impact on building heating/cooling | 10.3.1 |
| | system within the | needs ignored in SBEM, but heat | |
| | building | dissipated is included in system | |
| | | efficiency adjustment factors | |
| 30 | Heat gain from people | Determined from activity area database | 10.3.2.1 |
| | and appliances | | |
| 31 | Heat gain from lighting | Determined using method described in | 10.3.2.2 |
| | | this manual | |
| 32 | Heat to/from washing | Ignored in SBEM | 10.3.2.3 |
| 22 | water and sewerage | Determined from officiares fosters | 10 2 2 4 |
| 33 | Heat dissipated from or | Determined from efficiency factors | 10.3.2.4 |
| | absorbed by heating, cooling and ventilation | | |
| | systems | | |
| 34 | Heat from processes or | Determined from activity area database | 10.3.2.5 |
| | goods | | 10.0.2.0 |
| 35 | Total solar heat sources | Equations 22 & 23 based on monthly | 11.2 |
| | | average solar irradiance from weather | |
| | | data, including the effect of gains in | |
| | | adjacent unconditioned spaces | |
| 36 | Effective solar | Equations 24, 27 & 29. Movable shading | 11.3.2, |
| | collecting area of | is included. Shading factors determined | 11.4.1, |
| | glazed elements | from user input | 11.4.2, 11.4.3 |
| 37 | Frame fraction | Included in SBEM | 11.4.4 |
| 38 | Effective collecting area | Equations 25, 26 & equations in 11.4.5 | 11.3.3, 11.4.5 |
| | of opaque elements | including 30 to deal with radiation from | |
| | | the element to the sky. Sky temperature taken from weather data | |
| 39 | Gain utilisation factor | Equations 31, 32, 33 & 34 using | 12.2.1.1 |
| 00 | for heating | reference numerical parameter for | · <u> </u> |
| | ion nouting | monthly calculation from table 8 based | |
| | | on building type and calculated building | |
| | | time constant (see below) | |
| 40 | Loss utilisation factor | Equations 35, 36, 37, 38 & 39 using | 12.2.1.2 |
| | for cooling | reference numerical parameter for | |
| | | monthly calculation from table 9 based | |
| | | on building type and calculated building | |
| | D H H | time constant (see below) | 10.0.1.5 |
| 41 | Building time constant | Equations 40 (heating) and 41 (cooling) | 12.2.1.3 |
| 40 | Internal boot conseils of | using internal heat capacity of building | 10.2.1 |
| 42 | Internal heat capacity of | Sum of internal capacities of all building | 12.3.1 |
| | building | elements, using C _m values calculated according to EN ISO 13786:2005 | |
| 43 | Internal temperatures | Where heating or cooling is continuous | 13.1 |
| | used in energy | during the whole heating period, use the | 10.1 |
| | calculations | set-point temperature indicated by the | |
| L | | | L] |

| | | activity area database. If not continue |] |
|----|--|---|-------------------------|
| | | activity area database. If not continuous, see below. | |
| 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 | Not implemented in SBEM | Annex D |

| | for monthly cooling method | | |
|----|--|---|---------|
| 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 EN ISO 13790:2004

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 sources 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 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 transfer 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 on the set-point temperature or an adjustment on the calculated cooling needs.

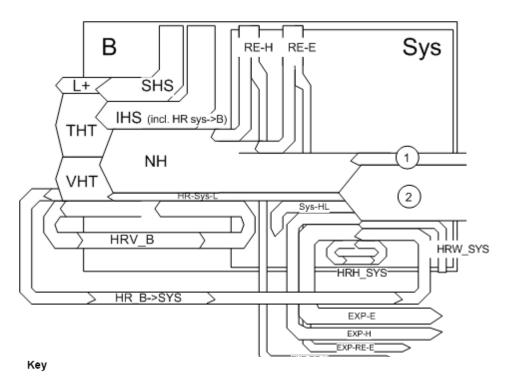
4.1.2. Overall energy balances for building and systems

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.

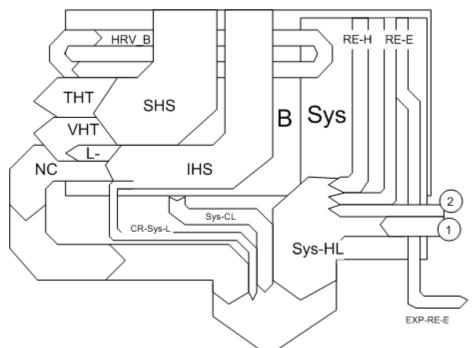
The main terms of the (time-average) energy balance for heating and cooling are schematically illustrated in Figure 4 and Figure 5, respectively.



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



| В | Building | Sys | System |
|----------|---|-----------|---|
| ТНТ | 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 | | |
| IHS | Internal heat sources (persons and appliances). Including heat recovered from hot water, heat | CR-B->Sys | Additional heat removed from building (into the system |
| | transferred to cold water, heat from lighting and fan or pump dissipation Heat extracted by cooling system: shown as separate flow: see HR-Svs-L | | e.g. from building mass into vent.system, |
| L- | Mismatch between transmission and ventilation heat transfer and solar and internal heat sources, leading to average internal temperature lower than required | EXP-E | Exported electricity, non-renewable |
| NC | Energy need for space cooling | EXP-RE-E | Exported electricity, from renewable source |
| HRV-B | Heat recovered in ventilation system (into the | 1 | Delivered energy, electricity |
| | building, if not by-passed during cooling period) | | 22. 2 |
| CR-Sys-L | Cold recovered from system loss in building (distribution, storage, emission, etc.) | 2 | Delivered energy, (gas, coal, oil, etc) |

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

Figure 5: Energy balance of a building for space cooling

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 adjacent buildings or 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 $A_{\rm fl}$ of the building. The dimension system used to calculate $A_{\rm fl}$ 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/m² (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:

- 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:

$$Q_{\rm NH} = Q_{\rm L,H} - \eta_{\rm G,H} \cdot Q_{\rm G,H}$$

subject to $Q_{\rm NH} \ge 0$

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

 $Q_{\rm NH}$ 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;

 $Q_{G,H}$ are 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.

If applicable, corrections are applied to account for holidays, according to the occupancy schedules in the 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:

 $Q_{\rm NC} = Q_{\rm G,C} \cdot \eta_{\rm L,C} \cdot Q_{\rm L,C}$

subject to $Q_{\rm NC} \ge 0$

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

 $Q_{\rm NC}$ 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;

 $Q_{G,C}$ are 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.

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

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

The total heat transfer, Q_L , is given by:

 $Q_{\rm L} = Q_{\rm T} + Q_{\rm V}$

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

 $Q_{\rm L}$ 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, Q_G , of the building zone for a given calculation period, are:

 $Q_{\rm G} = Q_{\rm i} + Q_{\rm s}$

where (for each building zone and for each calculation period):

 $Q_{\rm G}$ are the total heat sources, in MJ;

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

 $Q_{\rm S}$ 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:

$$Q_{T} = \sum_{k} \left\{ H_{T,k} \cdot \left(\theta_{i} - \theta_{e,k} \right) \right\} \cdot t \cdot f$$

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

 Q_{T} is the total heat transfer by transmission, in MJ;

 $H_{T,k}$ is the heat transfer coefficient by transmission of element *k* to adjacent space(s), environment, or zone(s) with temperature $\theta_{e,k}$, in W/K;

 θ_i is the internal temperature of the building zone, in degrees Celsius; taken from the Activity database (heating set-point);

 $\theta_{e,k}$ is the external (outdoor) temperature (the monthly average temperature obtained from the hourly weather data for the location) of element *k*, in degrees Celsius; taken from the Weather database;

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

f is a factor for conversion from Wh to MJ.

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

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, $H_{T,k}$, of element *k* are calculated according to EN ISO 13789:2005, 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).

The value for temperature $\theta_{e,k}$ is the value for the temperature of the external environment of element *k*, 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 the external air is calculated by:

$$H_{\mathsf{T}} = \sum_{i} A_{i} U_{i} + \sum_{k} l_{k} \Psi_{k}$$

where

 H_{T} is the heat transfer coefficient by transmission of building envelope, in W/K;

 A_i is the area of element *i* of the building envelope, 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-value¹⁰) of element *i* of the building envelope, in W/(m²·K);

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

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

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. 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} and through opaque constructions $Q_{sun,nt}$.

The heat gains are calculated by

 $Q_{\text{gain}} = Q_{\text{i}} + Q_{\text{sun,t}} + Q_{\text{sun,nt}}$

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;

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

¹⁰ The U-value for 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).

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 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 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:

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

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 m^2 ;

3.6 is the conversion factor from kWh to MJ;

 $f_{\text{li,gain}}$ 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:

$$Q_{sun,t} = \sum_{j} \left(q_{sun,j} \times f_{sh,j} \times f_{sun,j} \times g_{j} \times (1.0 - f_{f}) \times A_{j} \right)$$

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:

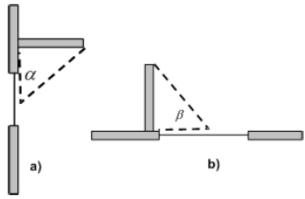
 $f_{sh;i} = F_o x F_f$

where

 F_{o} is the partial shading correction factor for overhangs;

 $F_{\rm f}$ is the partial shading correction factor for fins.

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



a) Vertical section b) Horizontal section

Key

 α overhang angle β fin angle

Figure 6: Overhang and fin: a) Vertical section b) Horizontal section¹¹

<u>NB:</u> 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.

¹¹ Extracted from BS EN ISO 13790:2008 - Energy performance of buildings — Calculation of energy use for space heating and cooling

| Overhang | 45° N lat. | | | 55° N lat. | | | 65° N lat. | | |
|----------|------------|------|------|------------|------|------|------------|------|------|
| angle | s | E/W | N | s | E/W | N | s | E/W | Ν |
| 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 overhang, Fo¹¹

| Fin angle | 45° N lat. | | | angle 45° N lat. 55° N lat. | | | 65° N lat. | | |
|-----------|------------|------|------|-----------------------------|------|------|------------|------|------|
| | S | E/W | Ν | 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}^{11}

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). <u>NB:</u> For the purposes of the calculation, a brise-soleil has strips, louvres, holes, etc., as opposed to a solid overhang.

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 provide 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:

$$g = F_W g_\perp$$

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 | | | | | | | | |
|-------------|-------------|------|------|------|------|------|------|------|------|
| 1 III | S | SE | E | NE | Ν | NW | W | SW | Н |
| 0 ° | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 |
| 10º | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 |
| 15º | 1.28 | 1.27 | 1.35 | 1.52 | 1.68 | 1.52 | 1.36 | 1.29 | 0.87 |
| 20º | 1.28 | 1.27 | 1.35 | 1.52 | 1.68 | 1.52 | 1.36 | 1.29 | 0.87 |
| 25º | 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 |
| 35º | 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 |

| 65º | 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:

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

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 this calculation,

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/m², $I_{sd>300}$, 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 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:

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

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);

 α_{eB} 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 W/m²K.

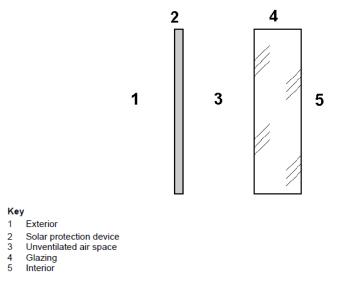


Figure 7: Characteristic position of external solar protection device¹²

¹² 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.

| Transmittanc | Reflectance | | | | | |
|--------------------|------------------|-------|--------|------|-------|--|
| $	au_{e,B}$ | ρ _{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 sola | r protection devices ¹² |
|---------------------------------|------------------------------------|
|---------------------------------|------------------------------------|

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

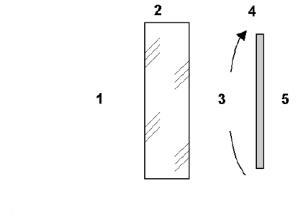
$$\alpha_{e,B} = 1 - \tau_{e,B} - \rho_{e,B}$$

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

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

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

where U_{g} is the thermal transmittance of the window, in W/m²K.



Key

- 1 Exterior 2 Glazing
- Glazing
 Air space, ventilated to the interior
- 4 Solar protection device
- 5 Interior

Figure 8: Characteristic position of internal solar protection device¹²

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:

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

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 utilizing 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, $\eta_{\rm H}$ is a function of the gain/loss ratio, $\gamma_{\rm H}$ and a numerical parameter, $a_{\rm H}$ that depends on the building inertia, according to the following equation:

$$\begin{array}{ll} \text{if } \gamma_{\text{H}} > 0 \text{ and } \gamma_{\text{H}} \neq 1; & \eta_{\text{H,gn}} = \frac{1 - \gamma_{\text{H}}^{a_{\text{H}}}}{1 - \gamma_{\text{H}}^{a_{\text{H}}+1}} \\ \\ \text{if } \gamma_{\text{H}} = 1; & \eta_{\text{H,gn}} = \frac{a_{\text{H}}}{a_{\text{H}}+1} \\ \\ \text{if } \gamma_{\text{H}} < 0; & \eta_{\text{H,gn}} = 1/\gamma_{\text{H}} \end{array}$$

with

$$\gamma_{\rm H} = \frac{Q_{\rm G,H}}{Q_{\rm L,H}}$$

where (for each month and for each building zone)

 η_{GH} is the dimensionless gain utilisation factor for heating;

 $\gamma_{\rm H}$ is the dimensionless gain/loss ratio for the heating mode;

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

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

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

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

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.

| <i>a</i> _{0,H} | τ _{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

<u>NOTE:</u> 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, η_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:

if
$$\lambda_{\rm C} > 0$$
 and $\lambda_{\rm C} \neq 1$: $\eta_{\rm L,C} = \frac{1 - \lambda_{\rm C}^{a_{\rm C}}}{1 - \lambda_{\rm C}^{a_{\rm C}+1}}$
if $\lambda_{\rm C} = 1$: $\eta_{\rm L,C} = \frac{a_{\rm C}}{a_{\rm C}+1}$

if
$$\lambda_{\rm C} < 0$$
: $\eta_{\rm L,C} = 1$

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;

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

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

 $a_{\rm C}$ is a dimensionless numerical parameter depending on the time constant, $\tau_{\rm C}$, defined by:

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

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.

| <i>a</i> _{0,C} | τ _{0,C} |
|-------------------------|------------------|
| 1.0 | 15 |

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

<u>NOTE:</u> 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

This 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:

$$\tau_{\rm H} = \frac{C_{\rm m}/3.6}{H_{\rm L,H}}$$

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:

$$\tau_C = \frac{C_{\rm m}/3.6}{H_C}$$

where

 τ_{C} is the time constant of the building or building zone for the cooling mode, in hours;

 $C_{\rm m}$ is the effective thermal capacity of the building zone, in kJ/K, determined according to Section 4.1.15.1;

 $H_{\rm C}$ 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:

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

where

 $C_{\rm m}$ 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 m |
|--|------------------------|
| Determination of the gain or loss utilization factor (period of variations: 1 d) | 0,10 |

Table 15: Maximum thickness to be considered for internal heat capacity¹¹

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

<u>NOTE:</u> 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:

$$Q_{H,interm} = a_{H,red} Q_{H,con}$$

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:

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

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

and where

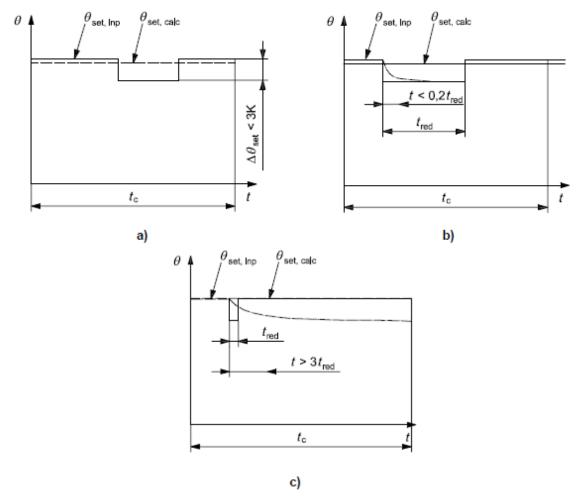
 $f_{H,hr}$ is the fraction of the number of hours in the month with a normal heating set-point (no reduced set-point or switch-off);

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

 τ_{H} is the time constant of the building zone for heating, in hours;

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

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

Figure 9: Example of quasi-continuous heating¹¹

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 below), 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:

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

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:

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

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;

 τ_{c} is the time constant of the building zone for cooling, in hours;

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

$$Q_{\text{NH,yr}} = \sum_{i} Q_{\text{NH,}i}$$
 and $Q_{\text{NC,yr}} = \sum_{j} Q_{\text{NC,}j}$

where

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

 $Q_{\text{NH},i}$ is the energy demand for heating of the considered zone per month, in MJ;

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

 $Q_{\text{NC},j}$ is the energy demand for cooling of the considered zone per month, in MJ.

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:

$$Q_{\text{NH,yr,zs}} = \sum_{z} Q_{\text{NH,yr,z}}$$
 and $Q_{\text{NC,yr,zs}} = \sum_{z} Q_{\text{NC,yr,z}}$

where

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

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

 $Q_{\text{NC},\text{yr},zs}$ 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

$$Q_{v-heat} = H_{v-heat} \bullet (\theta_i - \theta_e) \bullet n \bullet 0.0864$$

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 where the envelope belongs)

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

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

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

where

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

 $\rho_{a\bullet}c_a$ 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 I/sm² floor area

A is the zone floor area, in m²

4.2.1.2. Ventilation air flow rate

 $u_{v-heat} = u_{v-inf} / 3.6 + (1 - \eta_{HR}) \bullet u_{v,m,heat} + u_{v,n,heat}$

where

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

 $u_{\nu-inf}$ 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

 $\eta_{\rm HR}$ 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 I/sm² floor area. This value has been 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 I/sm² floor area. This value has been 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

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

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 where the envelope belongs)

 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 |
| Мау | 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: Values 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

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

where

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

 $\rho_{a\bullet}c_a$ 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-cool} is the air flow rate through the conditioned space, in I/sm² floor area

A is the zone floor area, in m^2

4.2.2.2. Ventilation air flow rate

 $u_{v-cool} = u_{v-inf} / 3.6 + (1 - \eta_{HR}) \bullet u_{v,m}$

where

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

 $u_{\nu-inf}$ 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

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

 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).

4.2.3. Demand-controlled ventilation

The actual building includes the ability to model demand control 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.

For zones whose ventilation is defined as <u>mechanical</u>, 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 <u>natural</u>, 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., $I/s.m^2$),

 FAR_{lower} is the greater of either: FAR_{min} or (0.6 × 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 (<i>C</i> _{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 impact, $u_{v-inf-stack}$, and the wind impact, $u_{v-inf-wind}$, without considering mechanical or combustion air flows.

Calculate infiltration due to the stack effect (uv-inf-stack)

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

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

where:

 Q_{4Pa} is the air leakage characteristics for a pressure difference of 4 Pa, in m³/hm² 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).

 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)

| | | | m3/h per m2 of outer envelope (exp n = 0.667 | | |
|-------------------|-------------------|------|---|-------|--|
| | leakages level | Q4Pa | Q10Pa | Q50Pa | |
| single family | low | 0.5 | 1 | 2.5 | |
| | average | 1 | 2 | 5 | |
| | high | 2 | 3.5 | 10 | |
| multi family ; | low | 0.5 | 1 | 2.5 | |
| non residential | average | 1 | 2 | 5 | |
| except industrial | high | 2 | 3.5 | 10 | |
| industrial | low | 1 | 2 | 5 | |
| | average | 2 | 3.5 | 10 | |
| | high | 4 | 7 | 20 | |

| | | | n (vol.h) (exp n=0.667) | | | | | |
|-------------------|-------------------|------|----------------------------|-------|----------|--|--|--|
| | leakages level | n4Pa | n10Pa | n50Pa | area/vol | | | |
| 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 ; | low | 0.2 | 0.4 | 1.0 | 0.4 | | | |
| non residential | average | 0.4 | 0.8 | 2.0 | 0.4 | | | |
| except industrial | high | 0.8 | 1.4 | 4.0 | 0.4 | | | |
| industrial | low | 0.3 | 0.6 | 1.5 | 0.3 | | | |
| | average | 0.6 | 1.1 | 3.0 | 0.3 | | | |
| | high | 1.2 | 2.1 | 6.0 | 0.3 | | | |

| | | | m3/h per m2 of n = 0 | floor area (exp .667) | outer area / |
|-------------------|-------------------|------|-------------------------|--------------------------|--------------|
| | leakages level | Q4Pa | Q10Pa | Q50Pa | floor area |
| 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 ; | low | 0.6 | 1.1 | 2.8 | 1.1 |
| non residential | average | 1.1 | 2.2 | 5.5 | 1.1 |
| except industrial | 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 characteristics¹³

Calculate infiltration due to the wind impact (uv-inf-wind)

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

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

where:

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

 ΔC_n 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 ±60° 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, u_{v-sw} , for each zone using the following equation:

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

where:

¹³ Extracted from BS EN 15242:2007 - Ventilation for buildings — Calculation methods for the determination of air flow rates in buildings including infiltration

 $u_{v-inf-stack}$ is the air flow contributions of all external envelopes due to the stack impact totalled for the zone, in m³/hm².

 $u_{v-inf-wind}$ is the air flow contributions of all external envelopes due to the wind impact totalled for the zone, in m³/hm².

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

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

 $u_{v-inf} = \max(0, u_{v-diff}) + u_{v-sw}$ [m³/hm² outer envelope]

where:

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

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:

$$u_{v-inf} = u_{v-sw}$$
 [m³/hm² outer envelope]

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

$$u_{v-\inf} = u_{v-sw} \bullet \frac{A_{env}}{A_{zone}}$$

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 m².

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

Demand for each zone is calculated as:

Hot water Demand (MJ/month) = Database demand * 4.18 /1000 * zone AREA * ΔT

where

Database demand is the hot water demand from the Activity database (see APPENDIX A:), in I/m² per month.

| ∆ <i>T</i> as 50°K. | is the temperature difference (deg K that water is heated up), taken |
|------------------------|--|
| 4.18/1000 | is the specific heat capacity of water in MJ/kgK |
| zone AREA | in m ² |

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

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

Distribution loss = 0.17^* Hot water demand

where

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 serving the HWS to calculate 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;
 - 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 HWS;
- Account for contribution from solar energy system, Section 4.9, if applicable;
- Account for contribution from CHP, if applicable.

4.3.1. 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 is calculated as:

Storage volume (litres) = Daily demand (MJ/day) * 18

where

Daily demand = Maximum monthly demand / Number of days in the month

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

If the storage losses have not been input by the user, then storage losses are calculated as:

Storage losses (MJ/month) = Daily storage loss (kWh/litre of storage)*(Storage volume5)^{1/3} *(365/12)*(Storage volume)^{2/3} * 3.6

where

Daily storage loss is the 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 + 1.76/(t+12.8)
- for a vessel with factory fitted insulation of thickness t mm: 0.005 + 0.55/(t + 4)

Storage volume5 is the storage volume, in litres, if the annual hot water demand were 5 MJ/m^2 , i.e., it is calculated as = (5/365)*18*Area served, with 18 being the same computational value described above.

365/12 is multiplication by the number of days and division by the number of months in order to obtain the monthly storage losses.

Storage volume 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.

4.3.2. Secondary circulation

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

Loop length = $sqrt(Area served)^* 4.0$

where

Area served is the total area served by the HWS, in m².

4.0 is a computational value.

The secondary circulation losses are calculated as:

Secondary circulation losses (MJ/month) = Losses per metre (W/m) * Loop length (m) * Hours of operation * Numbers of days in month * 3.6/1000

where

Losses per metre 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 length is the secondary circulation loop length in m;

Hours of operation number of hours of daily operation of the HWS (or 24 hours if there is no time switch);

3.6/1000 to convert W to kWh and then kWh to MJ;

The secondary circulation pump power, if not input by the user, is calculated as: Secondary circulation pump power (kW) = (0.25 * Loop length + 42) / 500where Loop length 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 of the HWS.

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.

Equation for lighting:

$$W_{light} = \frac{\sum_{j=1}^{12} \left[N_j \times \left(\sum_{i=1}^{24} \left[P_j \left(F_{Dji} \times F_{Oji} \right) \right] + \sum_{i=1}^{24} \left(P_{dj} \times F_{Od} \right) + (24 \times P_P) \right) \right]_{kWh/m^2 year}$$

With:

 N_{i} = [31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31]. Number of days in each month

 P_j = Lighting power in W/m² for each hour of month j

 P_{p} = Parasitic power in W/m² hour

 P_{di} = Display lighting power in W/m² for each hour of month *j*

 F_{Dii} = Daylight correction factor (utilisation factor) for hour *i* of month *j*

 F_{Oii} = Occupancy correction factor for hour *i* of month *j*

 F_{Od} = Occupancy correction factor for display lighting throughout the year

4.4.1. Calculate lighting power 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 20 will be used in the calculation by SBEM.

| | Luminaire lumens per circuit Watt | | | | | | |
|-----------------------------------|--|-----------------------|--|-----------------------|--|--|--|
| Lamp Type | For all build those spec next c | ified in the | For modular or portable "distress purchase" buildings with a planned time of use less than 2 years | | | | |
| | Side-lit and not daylit activities | Top-lit activities | Side-lit and not daylit activities | Top-lit activities | | | |
| LED | 27.5 | 33.0 | 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 - | 25.0 | 30.0 | 25.0 | 30.0 | | | |

| low frequency ballast | | | | |
|--|------|------|------|------|
| 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 20: Luminous efficacies used by SBEM in correspondence to the lamp types selected

4.4.2. Calculate display lighting power in the actual and notional buildings, Pdj

For the actual building

1. The display lighting will be defined in terms of the average display lighting lamp efficacy for each zone, which will be pro-rated against an efficacy of 15 lamp lumens per circuit-watt to adjust the NCM display lighting value associated with the activity.

For the notional building

1. The display lighting in the notional building is based on the display lighting power density from the NCM activity database multiplied by 0.682 (i.e., adjustment between lamp efficacy of 22 and 15).

Daylight harvesting and local manual switching do not apply to display lighting in the notional building (i.e., they only affect general lighting).

4.4.3. Calculate parasitic power, Pp

Unless actual data are supplied, the parasitic power loading P_p is assumed to be:

- Manual switching: 0 W/m²
- Photocell control: default for digitally addressable systems = 0.57 W/m², default for stand-alone sensors = 0.3 W/m², or user can specify value for system used.
- Occupancy sensing: default = 0.3 W/m^2 , or user can specify value for 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: $DF = DF_1 = 45 W_{win}/A$
- For spaces with horizontal or shed type rooflights: $DF = DF_2 = 90 W_{roof}/A$
- For both side windows and rooflights: $DF = DF_1 + DF_2$

Where W_{win} is the total window area including frame, W_{roof} is the total rooflight area including frame, and A is the area of all room surfaces (ceiling, floor, walls and windows).

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 room:

 DF_F is average daylight factor in front part of room within the first 3 m (%) $DF_F = (1.75 * DF_1) + DF_2$

 DF_M is average daylight factor in middle part of room within the second 3 m (%) $DF_M = (0.25 * DF_1) + DF_2$

 DF_B is average daylight factor in back part of room beyond the first 6 m (%) $DF_B = DF_2$

4.4.4.2. Photoelectric control

Calculate the utilisation factor:

For zones that are daylit by windows in only one orientation, the utilisation factor 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 only, then:

$$F_D = (area \, daylit \, by side \, windows) * \frac{(F_{D,F} + 1)}{2} + (1 - area \, daylit \, by side \, windows) * 1$$

If the photo sensor is in the front and back, then:

$$F_D = (area \, daylit \, by side \, windows) * \frac{(F_{D,F} + F_{D,M})}{2} + (1 - area \, daylit \, by side \, windows) * F_{D,B}$$

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:

$$F_D = (area \, daylit \, by side \, windows) * \frac{(F_{D,F} + F_{D,M})}{2} + (1 - area \, daylit \, by side \, windows) * F_{D,B}$$

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 21. E_{design} is the design illuminance (in Lux)

Front part of room:

If $E_{ext} \times DF_F \times 10 > E_{design}$ then $F_{D,F} = 0$

Elseif: $E_{ext} \times DF_F \times 10 > 0.5 \times E_{design}$ then $F_{D,F} = 0.5$ Else: $F_{D,F} = 1$

Middle part of room:

If $E_{ext} \times DF_M \times 10 > E_{design}$ then $F_{D,M} = 0$

Elseif: $E_{ext} \times DF_M \times 10 > 0.5 \times E_{design}$ then $F_{D,M} = 0.5$

Else: $F_{D,M} = 1$

Back part of room:

IF: $E_{ext} \times DF_B \times 10 > E_{design}$ then $F_{D,B} = 0$

Elseif: $E_{ext} \times DF_B \times 10 > 0.5 \times E_{design}$ then $F_{D,B} = 0.5$

Else: $F_{D,B} = 1$

Photoelectric dimming

Front part of room:

If: $E_{ext} \times DF_F \times 10 > E_{design}$ then $F_{D,F} = 0$ Else: $F_{D,F} = (E_{design} - E_{ext} \times DF_F \times 10) / E_{design}$

Middle part of room:

If: $E_{ext} \times DF_M \times 10 > E_{design}$ then $F_{D,M} = 0$ Else: $F_{D,M} = (E_{design} - E_{ext} \times DF_M \times 10) / E_{design}$

Back part of room:

If: $E_{ext} \times DF_B \times 10 > E_{design}$ then $F_{D,B} = 0$

Else: $F_{D,B} = (E_{design} - E_{ext} \times DF_B \times 10) / E_{design}$

[In normal operation, their residual light output and power consumption will occur throughout working hours unless (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 6m or twice the luminaire mounting height if this is greater
- or if the area of the room is less than 30m²
- 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 and E, industrial process areas, warehouse storage, and performance areas (stages) for 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:

If: $E_{ext} \times DF \times 10 > E_{design}$ then $F_D = 0.5$

and if there are side windows in one orientation only, then:

 F_D = (area daylit by side windows) * 0.5 + (1 - area daylit by side windows) * 0.5

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 21: External illuminances in Kew in kilolux. Outside these times the external illuminance |
|---|
| is assumed to be zero |

4.4.5. Occupancy correction, Foji

If the building is occupied but there is no requirement for lighting (e.g., a hotel room or hospital ward at night), $F_0 = 0$

At other times, F_0 equals 1 if the lighting is switched on 'centrally' (this is assumed in SBEM if there is no manual switching or photoelectric control).

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 and E, industrial process areas, warehouse storage, and performance areas (stages), F_0 equals 1 even if occupancy sensing or manual control is provided, unless an automatic time switch dims or switches off the lighting (the options "Auto On / Dimmed" or "Auto On / Auto Off" in Table 22).

4.4.5.1. Local occupancy sensing

 $F_{Oi} = F_{OC}$ (i means for each hour in the calculation)

In these expressions *F*_{oc} is given in Table 22. System types are defined in the CEN standard PrEN 15193: *Energy performance of buildings* — *Energy requirements for lighting*.

| Occupancy Sensing | Foc |
|---|------|
| Systems without automatic presence or absence detection | |
| Manual On/Off Switch | 1.00 |
| Manual On/Off Switch + additional automatic sweeping extinction | 0.95 |
| signal | |
| 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 22: Foc values

4.4.6. Time switching – used for display lighting only – calculate Fod

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, the heating energy demand for the HVAC system h_i will be the addition of the demand of all the zones attached to that HVAC system (H_d) . The heating energy use for the HVAC system h_i (H_e) is then calculated by:

$H_e = H_d / SSEFF$

where *SSEFF* is the system 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 $(Q_{\rm NC})$ as described in section 4.1.8, the cooling energy demand for the HVAC system h_i will be the addition of the demand of all the zones attached to that HVAC system (C_d) . The cooling energy use for the HVAC system h_i (C_e) is then calculated by:

$C_e = C_d / SSEER$

where *SSEER* is the system 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 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/m^2) and then multiplied by the area of the zone in (m^2) , and if applicable, also corrected for the electrical power factor of the building:

The auxiliary energy is the product of the auxiliary power density and annual hours of operation of the heating system from the activity database (i.e., 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 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 23 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 24 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 ¹⁴ 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 |

¹⁴ Low temperature hot water

| Flued radiant heater | None | No |
|--|---------------------------------|-----|
| 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 ¹⁵ | 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 |
| 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 |

Table 23: Assigning pump power to HVAC systems

| 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 24: Pump power density for actual building

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 25:

$$FPS_{1} = (FAR_{max} \times SFP_{central}) + (SCR \times SFP_{terminal})$$
$$FPS_{2} = Greater of (FAR_{max}, SCR) \times SFP_{central}$$
$$FPS_{3} = Greater of \left(\frac{SCR}{5}, FAR_{max}\right) \times SFP_{central}$$

¹⁵ Chilled water

$$FPS_4 = FAR_{max} \times SFP_{central}$$

where FAR_{max} is the peak fresh air supply rate (l/s.m²) that is set by the NCM activity type, and "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:

$$SCR = \frac{Greater of (PSH, PSC)}{\left(\rho \times C_p \times \Delta T\right)}$$

where $\rho = 1.2 \text{ kg/m}^3$, $C_{\rho} = 1.018 \text{ kJ/kgK}$, $\Delta T = 8\text{K}$, *PSH* is the peak space heating load, and *PSC* is the peak space cooling load (i.e., in W/m² of floor area for each zone).

| 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 | FPS₁ |
| 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 displacement ventilation | FPS ₄ |
| Active chilled beams | FPS ₃ |
| Water loop heat pump | FPS ₂ |
| Split or multi-split system | - |
| Single room cooling system | - |

Table 25: Assigning fan power equations to HVAC systems

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 extract fan energy will be an addition to the fan energy for supply/extract ventilation, if available.

For zones with de-stratification fans, the following is added to the monthly auxiliary energy calculation:

1/3.6 kWh/m² (i.e., 1 MJ/m²)

Energy for other ancillary services in the building, such as secondary hot water circulation (Section 4.3.2) and forced circulation for solar water heating systems (Section 4.9), etc., will be an addition to the fan and pump energy.

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-controlled ventilation can also affect the auxiliary energy. Where the air flow regulation uses fan speed control (i.e., using variable speed fans), the auxiliary energy calculation will use FAR_{dc} instead of FAR_{max} , but if the air flow regulation uses damper control then the auxiliary energy calculation will not be affected.

4.8. Hot water energy use

As described in section 4.3, for each HWS, calculate:

- storage losses
- secondary circulation losses
- secondary circulation pump energy (added to auxiliary energy)

The monthly HWS distribution efficiency is calculated as:

Distribution efficiency

Distribution efficiency = Hot water demand (MJ/month) Hot water demand (MJ/month) + Distribution losses (MJ/month) + Storage losses (MJ/month) + Secondary circulation losses (MJ/month)

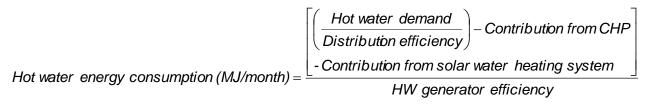
Calculate hot water energy consumption for the HWS as:

Hot Water energy consumption

| | Hot water demand | |
|---|-------------------------|--|
| Hot water energy consumption (MJ/month) = | Distribution efficiency | |
| | HW generator efficiency | |

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:

Hot Water energy consumption



<u>Note:</u> 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 (since the generator has 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 was processed to yield values of global solar radiation for the orientations and inclinations shown in Table 26 and Table 27, respectively.

For the purposes of SBEM calculations, solar hot water is used to displace the fuel that would otherwise be used by the hot water generator.

4.9.1. Data requirements

<u>General</u>

- 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 primary fuel that is being displaced by the solar energy system.
- Area: specifies the solar collector maximum projected area through which unconcentrated solar radiation enters the collector, in m²
- Orientation: specifies the orientation of the solar collectors
- Inclination: specifies the inclination of the solar collectors in degrees from the horizontal where 0° stands for a horizontal surface and 90° for a vertical surface.

| Orientations |
|--------------|
| Ν |
| NE |
| Е |
| SE |
| S |
| SW |
| W |
| NW |

Table 26: Orientations for which the solar radiation has been calculated

| Inclinations |
|--------------|
| 0 |
| 15 |
| 30 |
| 45 |
| 60 |
| 75 |
| 90 |

Table 27: Inclinations for which the solar radiation has been calculated

Collector parameters

If the collector parameters are known, they should be entered by the user. Otherwise, the default values in Table 28 will be used. The collector parameters are as follows:

- η_o: (sigma-zero) is the zero-loss collector efficiency factor from the collector test standards EN 12975-2 and related to the aperture area.
- a1: is the linear heat loss coefficient from the collector test standards EN 12975-2 and related to the aperture area, in W/m²K.
- a₂: 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/m²K²
- 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_o | a1 | a2 | 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 28: Default 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

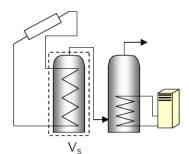
The schematic examples reflected in the Figure 10 are unlikely to represent all types of commercial solar thermal installations. Where necessary, and for more complex systems, an accredited dynamic simulation tool can be used.

Note 2

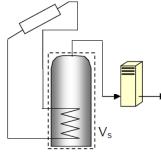
The dedicated solar volume of a solar thermal installation varies depending on the control and timing strategy of the of the back-up system. To optimise the performance of the solar thermal system, the back-up system should be prevented from operating during and prior to the period of the day where the 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.

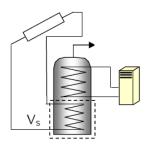
If the hot water storage vessel is shared between the solar energy system and the back-up hot water system, then the storage losses are already accounted for in Section 4.3.1: Hot Water storage. If the solar system has a dedicated hot water storage vessel, then the storage losses are calculated using the same procedure as in 4.3.1: Hot Water storage.



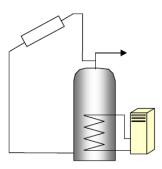
a) With separate solar cylinder



c) Combi boiler



b) With a twin-coil cylinder



d) Direct system

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.
 - 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}: specifies the overall heat loss coefficient of all pipes in the solar loop, 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 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 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.solusemi}, in kWh

The (monthly) useful contribution of the solar thermal system to the hot water requirements of the building is calculated as:

 $\boldsymbol{Q}_{W,\text{soluse,mi}} = \boldsymbol{Q}_{W,\text{solout,mi}} - \boldsymbol{Q}_{\text{solls,mi}}$, where

- Q_{W.solout.mi} is the heat output of the solar thermal system in month i, in kWh
- o Q_{solls,mi} are the thermal losses of the solar system in month i, in kWh

Solar thermal output system: QW.solout.mi

The output of the solar thermal system is calculated as:

$$Q_{W,solout,mi} = f \cdot Q_{W,solus,mi} = (aY_{w,mi} + bX_{w,mi} + cY_{w,mi}^{2} + dX_{w,mi}^{2} + eY_{w,mi}^{3} + fX_{W,mi}^{3}) \cdot Q_{W,solus,mi}$$

where

- o Q_{W,sol,us,mi} are the hot water requirements in month i, in kWh
- X_{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.

$$X_{mi} = \frac{A \cdot U_{loop} \cdot \eta_{loop} \cdot \Delta T_{mi} \cdot f_{st} \cdot t_{mi}}{Q_{W,solus,m_i} \cdot 1000}, \text{ where }$$

- A is the collector area, in m².
- 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/m²K:

$$U_{loop} = a_1 + a_2 \cdot 40 + \frac{U_{loop,p}}{A}, \text{ where }$$

- 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 $U_{100DD} = 5 + 0.5 \cdot A$
- \circ 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,
 - $\Delta \eta = \frac{(\eta_o \cdot A \cdot a_1)}{(U_{st})_{hx}}$ and $(U_{st})_{hx}$ is the heat transfer rate of the heat exchanger(s) in the solar loop, in W/K
 - For direct systems, $\Delta \eta = 0$
 - $\circ~$ if the heat exchanger characteristics in the collector loop are not known, then $\eta_{\text{loop}} \text{=} 0.85$
- $\circ \quad \Delta T_{mi} \,$ is the reference temperature difference in month i

$$\Delta T_{mi} = T_{ref,mi} - T_{e,avg,mi}$$
, where

- T_{ref,mi} is the reference temperature ion month i, in °C T_{ref,mi}=11.6+1.18T_w+3.86T_{cw}-1.32T_{e,avg,mi}
 - T_w is the desired hot water temperature taken as equal to 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, $f_{st} = (\frac{V_{ref}}{V_{sol}})^{0.25}$
 - \circ V_{ref} is the reference volume equal to 75 litres per m² of collector
 - V_{sol} is the solar storage tank volume, in litres
- \circ t_{mi} is the length of month i, in h
- \circ Q_{W(H),sol,us,mi} are the hot water requirements in month i, in kWh
- Y_{mi} is a value that depends on the collector data (zero-loss collector efficiency) and the solar irradiance on the collector plane

$$Y_{mi} = \frac{A \cdot IAM \cdot \eta_o \cdot \eta_{loop} \cdot I_{mi} \cdot t_{mi}}{Q_{solus,mi} \cdot 1000} \text{, where}$$

- $\circ~I_{mi}$ is the average solar irradiance on the collector plane during the month i, in W/m^2
- a,b,c,d,e are the correlation factors depending on the storage tank type as shown in Table 29. 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 | | |
|---|--------|--|
| а | 1.029 | |
| b | -0.065 | |
| с | -0.245 | |
| d | 0.0018 | |
| е | 0.0215 | |
| f | 0 | |

Table 29: Correlation factors - Adapted from EN 15316-4-4:2007

Calculation of auxiliary energy consumption: W_{sol,aux,m}

The auxiliary energy consumption (electricity required by the circulation pumps) of the solar thermal system, in kWh, is calculated according to:

- $\circ~$ For thermosiphon systems or forced circulation systems assisted with photovoltaics, $W_{\text{sol,aux,mi}}{=}0$
- For forced circulation systems using grid electricity,

$$W_{sol,aux,mi} = \frac{P_{aux,nom} \cdot t_{aux,mi}}{1000}$$
, where

• Paux,nom is the nominal input power of the circulation pumps, in W.

If $P_{aux,nom}$ is not known, $P_{aux,nom} = 25 + 2 \cdot A$

taux,mi is the operation time of the pump in month i, in h

The annual operation time of the circulation pump is 2000h. 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 5% of the annual operation time of the pump).

Thermal losses of the solar system: Q_{sollsmi}

The thermal losses of the solar system are given by the addition of the storage tank heat losses $Q_{W,solst,ls,mi}$ plus the heat distribution losses between the thermal solar system and the back-up heater $Q_{bu,disls,mi}$

 $Q_{solls,mi} = Q_{W,solst,ls,mi} + Q_{bu,dis,ls,mi}$, where

- Solar storage tank losses Q_{W,sol,st,ls,mi}
 - For combined cylinders, the solar storage tank losses are calculated as part of the hot water module calculations
 - 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.
- Distribution losses Q_{bu,dis,Is,mi}

If there are pipes between the SES and the back-up system, this specifies whether the distribution pipes between the solar energy system and back-up heating source are insulated as follows:

- If the pipes are insulated $Q_{bu,dis,ls,mi} = 0.02 \cdot (Q_{sol,out,mi} / Q_{sol,us,mi})$
- If the pipes are not insulated $Q_{bu,dis,ls,mi} = 0.05 \cdot (Q_{sol,out,mi} / Q_{sol,us,mi})$

4.9.3. Outputs produced

SBEM deducts the useful hot water produced by the solar thermal energy system from the requirements to be met by the HWS to which the solar energy system is linked.

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 has been processed to yield values of global solar radiation for the orientations and inclinations shown in Table 26 and Table 27, respectively. The algorithms used in SEBM follow the standards BS EN 15316-4-6:2007.

4.10.1. Definition of algorithms

Photovoltaic electricity generation

The electricity generated, by a photovoltaic system is calculated as:

$$E_{el,PV,out} = \frac{P_{pk} \bullet E_{sol} \bullet f_{shading} \bullet f_{per}}{I_{ref}}, \text{ where }$$

- *E*_{el,PV,out} is the monthly electricity produced by the photovoltaic modules, in kWh
- *P*_{pk} is the PV array installed peak power, in kW_p, obtained under standard test conditions¹⁶. If it is not included in the input, it is calculated according to *P*_{pk} = *K*_{pk} *A*, where
 - K_{pk} is the default peak power coefficient depending on the type of building integration of the photovoltaic modules as given in Table 30.
 - \circ *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 31 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 system performance value taken from Table 32 according to the ventilation strategy of the PV array (definitions in Table 33).
- *I_{ref}* is the reference solar irradiance equal to 1 kW/m²

| Module type | Peak power coefficient in kWp/m ² |
|--|--|
| Mono crystalline silicon | 0.088 |
| Multi crystalline silicon | 0.080 |
| Multi layer thin film amorphous silicon | 0.035 |
| Other thin film layers | 0.018 |
| Thin film copper-indium-gallium-diselenide | 0.056 |
| Thin film cadmium-telluride | 0.049 |

Table 30: Default peak power coefficient, K_{pk} , (values obtained from the lower performance
values for each technology as published by the Database of Photovoltaic Modules
Performance Parameters produced by Sandia National Laboratories)

¹⁶ Reference testing values of cell temperature θ =25°C, in plane irradiance I_{ref}=1 kW/m², air mass solar reference spectrum AM=1.5 for a PV module or a PV cell testing – EN 6182.9

| Level of over-shading | Mono crystalline silicon | Multi crystalline silicon | Multi layer thin film amorphou s 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 31: Shading factor, f_{shading}, (adapted from SAP 2005 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 amorphou s silicon | Other thin film layers | Thin film copper- indium- gallium- diselenide | Thin film cadmium- telluride |
|--|--------------------------------|---------------------------------|---|---------------------------|---|------------------------------------|
| Strongly ventilated or forced ventilated modules | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Moderately ventilated modules | 0.75 | 0.75 | 0.78 | 0.78 | 0.78 | 0.78 |
| Unventilated modules | 0.70 | 0.70 | 0.73 | 0.73 | 0.73 | 0.73 |

Table 32: System performance factor, f_{per} , (adapted from SAP 2005 but modified 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 module and the surface where it is 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 module 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 it is mounted |

Table 33: PV array ventilation strategy definitions

Carbon dioxide displaced by photovoltaic electricity

$$C_{\scriptscriptstyle PV} = E_{\scriptscriptstyle el, PV, out} \bullet c_{\scriptscriptstyle D}$$

where

 C_{PV} are the monthly carbon dioxide emissions displaced by the electricity generated by the photovoltaic modules, in kgCO₂

 c_D is the amount of carbon dioxide displaced by each unit of electricity produced by the PV modules, in kg per kWh.

4.10.2. Outputs produced

- Monthly electricity produced by the photovoltaic system.
- Carbon dioxide 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 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 CIBSE 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), farm land with boundary hedges and suburban or industrial area to urban with average building height bigger than 15 m
- 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 35.

| Terrain type | K _R | z _o (m) |
|--|----------------|--------------------|
| | terrain factor | roughness |
| 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 34: Terrain categories and related parameters (CIBSE, 2002)

| Product of mean monthly wind speed (m/s) and <i>C_R(z)</i> 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 35: Wind turbine efficiencies

4.11.2. Definition of algorithms

Wind turbine electricity generation

$$Q_{WT} = 0.5 \bullet \rho \bullet (C_R(z) \bullet V_\rho)^3 \bullet A \bullet EPF \bullet K_{WT} \bullet 24 \bullet N/1000$$
 [kWh]

where

 Q_{WT} is the monthly electricity produced by the wind turbine, in kWh

 ρ is the air density ~1.225 kg/m³

 $C_R(z)$ is the roughness coefficient at height z calculated as:

 $C_R(z) = K_R \bullet \ln(z/z_0)$

where

 K_R is the terrain factor (Table 34)

 z_o is the roughness length (Table 34)

z is the wind turbine hub height, in m.

 V_o is the mean monthly wind speed as derived from the CIBSE Test Reference Year for each location, in m/s

A is the turbine swept area, in m^2 , calculated as:

 $A = \pi \bullet D^2 / 4$

where

D is the wind turbine diameter, in m

EPF is the energy pattern factor calculated using the hourly wind speed data as provided by the CIBSE test reference years as:

$$EPF = \frac{APD}{0.5 \bullet \rho \bullet V^3_o}$$

where

APD: is the average power density, in W/m², calculated as

$$APD = \frac{\sum_{i=1}^{8760} 0.5 \bullet \rho \bullet V^{3}_{i}}{8760}$$

where

 V_i is the hourly wind speed as given by the CIBSE TRYs, in m/s

8760 are the number of hours in a year

 $K_{\rm WT}$: is the wind turbine efficiency of conversion, in %, as given in Table 35.

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:

$$A_{VAWT} = \frac{\pi \bullet D_e^2}{4}$$

where

 A_{VAWT} is the swept area of the vertical axis wind turbine, in m²

De vertical axis wind turbine equivalent diameter used for the calculations

Carbon dioxide displaced by wind turbines

$$C_{\scriptscriptstyle WT} = Q_{\scriptscriptstyle WT} \bullet c_{\scriptscriptstyle D}$$

 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 as taken from the NCM Modelling Guide for the displaced electricity.

4.11.3. Outputs produced

- Monthly electricity produced by the wind turbine.
- Carbon dioxide emissions 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).
- Power seasonal efficiency: is the total 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 space heating demand supplied by the CHP generator
- Building hot water supplied: specifies the percentage of the hot water demand supplied by the CHP generator.
- Building space cooling supplied: specifies the percentage of the building space cooling demand supplied by the trigeneration plant
- 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 iSBEM for information purposes only. This value is not used in the calculations

4.12.2. Definition of algorithms

Amount of fuel used by the CHP plant

$$F = \frac{H_{SH} \bullet p_{SH} + H_{HW} \bullet p_{HW} + \frac{H_{SC} \bullet p_{SC}}{SEER}}{\eta_{TH}}$$

where

F is the fuel requirements by the CHP plant, in kWh

 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

SEER is the heat-fired chiller seasonal energy efficiency ratio.

 η_{TH} is the seasonal heat efficiency of the CHP plant defined as the total useful heat supplied divided by the total fuel energy input (using the gross calorific value).

Carbon dioxide generated by the CHP plant fuel requirements

 $F_c = F \bullet c$

where

 F_{C} is the monthly carbon dioxide emission due to the fuel used by the CHP plant, in kgCO₂

F is the CHP plant fuel requirements, in kWh

 $c_{\rm c}$ is the carbon emission rate of the fuel used by the CHP plant, in kgCO_2/kWh, as taken from Approved Document L2A

Electricity generated by the CHP plant

 $E = F \bullet \eta_E$

where

E is the power (electricity) generated by the CHP plant, in kWh

 η_E is the seasonal power efficiency of the CHP plant

Carbon dioxide displaced by the CHP plant

 $C_E = E \bullet c_D$

 C_E 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 as taken from the NCM Modelling Guide for the displaced electricity

4.12.3. Outputs produced

- Carbon dioxide emissions generated by the CHP plant fuel requirements
- Electricity produced by the CHP plant
- Carbon dioxide displaced due to the electricity generated by the CHP plant

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 DCLG to fulfil the role of 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. 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 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 it 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 information. This structure is dealt with in full detail in the *iSBEM User Guide*¹⁷, 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
 - o Walls
 - o Roofs
 - o Floors
 - o Doors
 - o Glazing
- Geometry definition for each building element surrounding every zone:
 - o Size
 - o orientation
 - o **construction**
 - o thermal bridges
 - links between elements
- Building services setting up the systems used in the building
 - HVAC systems

¹⁷ Available from the <u>www.ncm.bre.co.uk</u> web site

- 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 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 CO_2 emissions for the heating, cooling, ventilation, lighting, and hot water systems which serve a particular building. This can be used in a number of applications. In particular, the way it has been designed by BRE answers the needs of the EPBD, as described under the following headings.

6.1. Building Regulations compliance

The call by the EPBD 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 to Part L (ADL2A), 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 carbon emissions of a "Building Emission Rate" (BER) no worse than a "Target Emission Rate" (TER).

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 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).

DCLG have commissioned SBEM and 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 BRUKL module, which draws on data recorded for SBEM to establish whether various elemental values meet the minimum standards in the Approved Documents and the Non-domestic Building Services Compliance Guide.

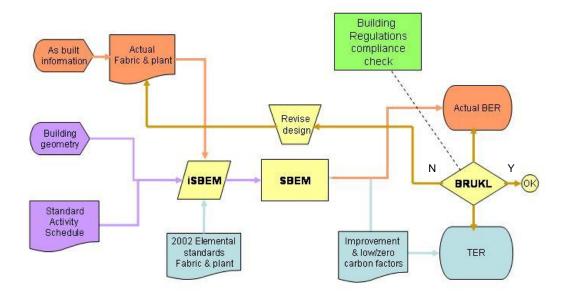


Figure 11: Inputs, calculations and comparisons involved in Building Regulations compliance checking procedures in SBEM

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 has collaborated with other software providers to enable them to develop alternative interfaces to SBEM, including links with other design software.

6.2. Asset rating

The EPBD calls 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 for their potential to be operated efficiently. The asset rating will be 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 will be 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 will be maintained so that government can report to the EU on the carbon 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 will be 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 description of the reference building and the EPC rating scale are defined in the NCM Modelling Guide for the respective building regulations. The EPC will also display the numerical value on which the rating is based, to aid differentiation within rating bands.

SBEM is capable of working out the intrinsic energy and carbon performance of buildings against the standardised operating patterns required for the asset rating; this process is the same as that required for checking Building Regulations compliance.

For a new building, producing the EPC would be undertaken using the data collected for the compliance check, by pressing another tab.

For an existing building which has not gone through the compliance check, the actual construction and system parameters are input instead of those which might be needed to achieve Building Regulation compliance. It is appreciated that some of this information may be difficult to acquire for existing buildings – for instance drawings and schedules of the current construction may no longer be available. Default values for constructions, HVAC, HWS, and lighting system parameters based on age, generic appearance, etc., are provided.

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 DCLG 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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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:

 $HWS_i = (HWS \times HPm) / HPF$

where:

HWS_i is the monthly *i* HW demand (I/m² per month);

HWS is the nominal HW demand value for the specific activity (I/m² per day); Field 'HWS' in the 'activity' table of NCM_Activity database.

HPm 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 week day; Field HWS_HP_FACTOR' in the 'activity' table of the NCM_Activity database.

Therefore, for hourly calculations, the monthly HWS demand could be calculated as:

 $HWS_h = (HWS \times HPh) / HPF$

where:

HWS_h is the hourly *h* HW demand (I/m^2 per hour);

HWS is the nominal HW demand value for the specific activity (I/m²/day); Field 'HWS' in the 'activity' table of the NCM_Activity database.

HPh 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 week day; 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

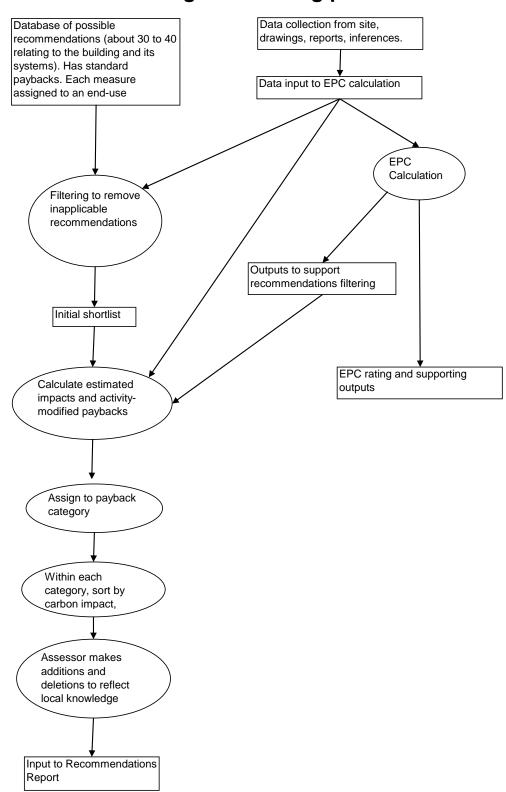


Figure 12: Schematic logic of recommendations filtering process

The initial list of potential recommendations is a subset of those collected by AECOM (formerly Faber Maunsell) 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
 - Heating kWh/m², Cooling kWh/m², Lighting kWh/m², Hot water kWh/m², Auxiliary kWh/m²
 - $\circ~$ Heating kgCO_2/m², Cooling kgCO_2/m², Lighting kgCO_2/m², Hot water kgCO_2/m², Auxiliary kgCO_2/m²
 - o Identify which of these services are actually present in the building
 - Calculate % of carbon emissions attributable to each end-use
- From calculations already carried out for EPC rating, record Actual Building
 - Heating kWh/m², Cooling kWh/m², Lighting kWh/m², Hot water kWh/m², Auxiliary kWh/m²
 - $\circ~$ Heating kgCO_2/m², Cooling kgCO_2/m², Lighting kgCO_2/m², Hot water kgCO_2/m², Auxiliary kgCO_2/m²
 - Calculate % of "energy" (price-weighted?) attributable to each end-use
 - Calculate % of carbon emissions attributable to each end-use
- From calculations already carried out for EPC rating, record Typical Building
 - 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 Notional and Typical
 - If Actual < Notional, classify heating energy efficiency as "good"
 - If Notional <= Actual < Typical, classify heating energy efficiency as "fair"

o Otherwise, classify heating energy efficiency as "poor"

- For heating, compare Actual kgCO₂/m² with Notional and Typical
 - If Actual < Notional, classify heating carbon efficiency as "good"
 - If Notional <= Actual < Typical, classify heating carbon efficiency as "fair"
 - Otherwise, classify heating carbon efficiency as "poor"

B2.2.2 Cooling

- For cooling, compare Actual **kWh/m**² with Notional Note – We can't use reference building as it is mixed-mode. Criteria are based on system efficiencies relative to that of the notional building, bearing in mind that the notional building system is 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 kgCO₂/m² with Notional
 - But ignore virtual cooling (overheating is captured later)
 - If Actual < 0.85 x Notional, classify cooling carbon efficiency as "good"
 - If 0.85 x Notional <= Actual < 1.5 x Notional, classify cooling carbon efficiency as "fair"
 - Otherwise, classify cooling carbon efficiency as "poor"

B2.2.3 Lighting

- For lighting, compare Actual kWh/m² with 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 kgCO₂/m² with Notional and Typical
 - If Actual < Notional, classify lighting carbon efficiency as "good"
 - If Notional <= Actual < Typical, classify lighting carbon efficiency as "fair"
 - Otherwise, classify lighting carbon efficiency as "poor"

B2.2.4 Domestic Hot Water

- For hot water, compare Actual kWh/m² with 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 kgCO₂/m² with Notional and Typical
 - If Actual < Notional, classify hot water carbon efficiency as "good"
 - If Notional <= Actual < Typical, classify hot water carbon efficiency as "fair"
 - Otherwise, classify hot water carbon efficiency as "poor"

B2.2.5 Auxiliary (Mechanical Ventilation)

- For Auxiliary, compare Actual kWh/m² with Notional and Typical
 - If Actual < Notional, classify Auxiliary energy efficiency as "good"
 - If Notional <= Actual < Typical, classify Auxiliary energy efficiency as "fair"

o Otherwise, classify Auxiliary energy efficiency as "poor"

- For Auxiliary, compare Actual kgCO₂/m² with 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"

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 CO₂) is then compared to the original building energy (and CO₂).

B2.3.1 Heating

B2.3.1.1 Heating efficiency

• Check if using default heating efficiency – if yes trigger EPC-H4

<u>Note:</u> 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 >= 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 carbon 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 36: Fuel Price factors

- Assess likely scale of energy impact from proportion of total "energy" (assumed to be price-weighted using factor from Table 36 above). 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
- Assess likely scale of carbon impact from proportion of total carbon. Calculate new heating (and, if appropriate HWS) carbon emissions as ratio between actual efficiency and **0.89**. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, 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 36 above). 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon. Calculate new heating (and, if appropriate HWS) carbon emissions as ratio between actual efficiency and 0.81. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, potential impact is "low"
- If heating fuel is electricity, check heat generator efficiency, if less than 2, trigger recommendation EPC-R1 (consider GSHP) and EPC-R5 (consider ASHP)
 Note: CoP of 2 is the worst allowable in the HVAC guide. But the air-source 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 36 above). 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
- Assess likely scale of carbon impact from proportion of total carbon. Calculate new heating (and, if appropriate HWS) carbon emissions as ratio between actual efficiency and 2.2. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, 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 36 above). 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 carbon impact from proportion of total carbon. Calculate new heating (and, if appropriate HWS) carbon emissions as ratio between actual efficiency and 3.1. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, potential impact is "low"

B2.3.1.2 Heating controls

- Does the heating system have centralised time control?
- If not 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 36 above),
 - If total energy cost for building changes by more than 4%, impact is "high"
 - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above),
 - If total energy cost for building changes by more than 4%, impact is "high"
 - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above),

- If total energy cost for building changes by more than 4%, impact is "high"
- If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above),
 - If total energy cost for building changes by more than 4%, impact is "high"
 - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above),
 - If total energy cost for building changes by more than 4%, impact is "high"
 - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"
- Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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

<u>Note:</u> Assessing impact of recommendation **EPC-C1** is done similarly to that for recommendation **EPC-C2** shown below.

• Find cold generator efficiency

- 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 36 above).
 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon. Calculate new cooling carbon emissions as ratio between actual efficiency and 2.5. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, 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% < = 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
 - VAV, constant volume, multizone, terminal reheat, dual duct P=5%
 - Fan coil, induction P = 2%
 - 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 36 above),
 - If total energy cost for building changes by more than 4%, impact is "high"
 - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"

- If total carbon emissions from the building change by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- If 10% < = 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
 - VAV, constant volume, multizone, terminal reheat, dual duct P=10%
 - Fan coil, induction P = 4%
 - 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 > = 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 36 above).
 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon. Calculate new cooling carbon emissions as ratio between actual efficiency and 0.8. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, potential impact is "low"
- If 0.7 > = 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 36 above). 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon. Calculate reduction in hot water energy as ratio between actual HWS efficiency and 0.75. Determine % change in total building carbon emissions

- If change in total carbon is > 4% potential impact is "high"
- If 4% > = change in total carbon > 0.5%, potential impact is "medium"
- Otherwise change in total carbon, potential impact is "low"

B2.3.3.2 Hot water storage

- Check whether there is hot water storage
- If storage heat loss > default value* 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 36 above). 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon. Calculate reduction in hot water energy as 50% of storage losses. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, 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 36 above). 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% > = change in total energy > 0.5%, potential impact is "medium"
 - Otherwise change in total energy potential impact is "low"
 - Assess likely scale of carbon impact from proportion of total carbon. Calculate reduction in hot water energy as 30% of total hot water energy. Determine % change in total building carbon emissions
 - If change in total carbon is > 4% potential impact is "high"
 - If 4% > = change in total carbon > 0.5%, potential impact is "medium"
 - Otherwise change in total carbon, 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 carbon contents and prices differ.

If coal, trigger recommendations EPC-F2, EPC-F3, EPC-F6

If hot water is provided by the space heating boiler, include hot water in energy and carbon proportions below

 Assess likely scale of energy impact from proportion of total "energy" (assumed to be price-weighted using factor from Table 36 above), 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 by more than 4%, impact is "high"
- If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact for EPC-F2 from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above), 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 by more than 4%, impact is "high"
- If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact for EPC-F3 (from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above), for EPC-F6 (coal to oil)

Note: For simplicity assume no change in boiler efficiency - savings are due to fuel price only

- If total energy cost for building changes by more than 4%, impact is "high"
- If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact from proportion of total carbon
 - If total carbon emissions for **EPC-F6** from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"

• If heating fuel is oil or LPG trigger recommendations **EPC-F1**, **EPC-F4** If hot water is provided by the space heating boiler, include hot water in energy and carbon proportions below

 Assess likely scale of energy impact from proportion of total "energy" (assumed to be price-weighted using factor from Table 36 above), for EPC-F1 (oil 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 by more than 4%, impact is "high"
- If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact for EPC-F1 from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above), for EPC-F4 (oil 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 by more than 4%, impact is "high"
- If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact for EPC-F4 from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 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 36 above), for **EPC-F5** (gas 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 by more than 4%, impact is "high"
 - If total energy cost for building changes by less than or equal to 4% but more than 0.5%, impact is "medium"
- Otherwise impact is "low"
- Assess likely scale of carbon impact for EPC-F5 from proportion of total carbon
 - If total carbon emissions from the building change by more than 4%, impact is "high"
 - If total carbon emissions from the building change by less than or equal to 4% but more than 0.5%, impact is "medium"
 - Otherwise impact is "low"

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
- Assess likely impact on carbon
 - Impact is assessed by changing all T12 lamps to T8 lamps and assessing the % change in CO₂ for the project
- 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
 - Assess likely impact on carbon
 - Impact is assessed by changing all T8 lamps to T5 lamps and assessing the % change in CO₂ for the project
- 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 (EPC-L2) and assessing the % change in energy for the project
 - Assess likely impact on carbon
 - Impact is assessed by changing all GLS lamps to CFL (EPC-L2) and assessing the % change in CO₂ for the project
- 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
 - Assess likely impact on carbon
 - 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
- 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.
 - Assess likely impact on carbon
 - 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 CO impact will be the same.

B2.3.6 Renewables

- Is a wind turbine installed?
 - If not trigger recommendation EPC-R2
 - Energy impact is (always?) low
 - Carbon impact is (always?) low

- Is solar thermal water heating installed?
- If not trigger recommendation EPC-R3
 - Energy impact is (always?) low
 - Carbon impact is (always?) low
- Is a photovoltaic system installed?
 - If not trigger recommendation EPC-R4
 - Energy impact is (always?) low
 - Carbon impact is (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 Overall consumption for end-use | | | | |
| CO ₂ accounted for by 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 37: 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 37 applied to heating energy
 - $\circ \quad \text{Assess likely impact on carbon}$
 - Use Table 37 applied to heating carbon

Identify flat roofs

- If any have U value > 1.0, trigger recommendation EPC-E2
 - Assess likely impact on energy (assumed price weighted)
 Use Table 37 applied to heating energy
 - Assess likely impact on carbon
 - Use Table 37 applied to heating carbon

Walls

Identify solid walls

- If any have U value > 1.0, trigger recommendation EPC-E3
 - Assess likely impact on energy (assumed price weighted)
 Use Table 37 applied to heating energy
 - Assess likely impact on carbon
 - Use Table 37 applied to heating carbon

Identify cavity walls

- If any have U value > 1.0, trigger recommendation EPC-E4
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 37 applied to heating energy
 - o Assess likely impact on carbon

• Use Table 37 applied to heating carbon

Glazing

Identify 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 37 applied to heating energy
 - Assess likely impact on carbon
 - Use Table 37 applied to heating carbon
- And trigger recommendation EPC-E8
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 37 applied to heating energy
 - Assess likely impact on carbon
 - Use Table 37 applied to heating carbon

Floors

- If any have U value > 1.0 trigger recommendation EPC-E1
 - Assess likely impact on energy (assumed price weighted)
 Use Table 37 applied to heating energy
 - Assess likely impact on carbon
 - Use Table 37 applied to heating carbon

Airtightness

- If permeability > 14, trigger recommendation EPC-E7
 - Assess likely impact on energy (assumed price weighted)
 - Use Table 37 applied to heating energy
 - o Assess likely impact on carbon
 - Use Table 37 applied to heating carbon

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 (always?) medium
 - Carbon impact is (always?) medium

B2.4 Next step: "Triggered" recommendations now need prioritising

To calculate **PAYBACK** for each recommendation, adjust standard paybacks (from Table 40) 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*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 FM 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 ECG019 (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 38.

| 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 38: 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 carbon content of different fuels by multiplying the financial payback by the relative carbon 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 39.

| | From | | | | | | | | | |
|------------|---------|------|------|------|------|--------|------------|-------------------|--------------|---------------|
| То | 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 39: 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 of less than (or equal to?) three years
 - o Sort these by decreasing magnitude of carbon saving
 - o If there are more than 15, select the first 15
 - o These are the "recommendations with a short payback"
- Select all recommendations with payback of between three and seven years
 - o Sort these by decreasing magnitude of carbon saving
 - \circ If there are more than 10, select the first 10
 - These are the "recommendations with a medium payback"
- Select all recommendations with payback of more than seven years
 - o Sort these by decreasing magnitude of carbon saving
 - o 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 carbon saving
 - If there are more than 10, select the first 10
 - o 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 his or her 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 carbon 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 carbon 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 carbor | omissions | | | |
| The overall energy efficiency for heating is | | | | |
| The carbon efficiency for heating is <i>fair</i> | ian | | | |
| The heating system efficiency is good | | | | |
| The heat generator efficiency is good | | | | |
| | | | | |
| The worst insulation level of some window | s is <mark>poor</mark> | | | |
| * Recommendation: Replace/improve | Medium | Medium | Medium | Medium |
| glazing i.e. install double glazing | | | | |
| The worst insulation level of walls is fair | | | | |
| The worst insulation level of roofs is poor | | | | |
| * Recommendation: Install/improve roof | Poor | Poor | High | High |
| insulation | | | | |
| The worst insulation level of floors is fair | | | | |
| Cooling accounts for 20% of the corbo | amiaaiana | | | |
| Cooling accounts for 30% of the carbon The overall energy performance for cooling | | | | |
| The carbon efficiency for cooling is <i>poor</i> | | | | |
| The cooling system efficiency is poor | | | | |
| * Recommendation: pressure test and | Good | Good | Medium | Medium |
| seal ductwork | 0000 | 0000 | moulum | modium |
| The cold generator efficiency is fair | | | | |
| * Recommendation: when next replacing | Good | Good | Medium | High |
| the chiller, select a high performance | | | | |
| model | | | | |
| The demand for cooling is poor | | | | |
| * Recommendation: reduce solar gain by | Good | Good | Low | Medium |
| use of shading devices or reflective film | | | | |
| (If no pooling quoter is installed in a space | the everbactiv | ar rick can be al | acted and report | ko di |
| (If no cooling system is installed in a space Some spaces in this building have a signif | | | пескей али тероп | eu. |
| Recommendation: reduce solar gain by | Good | Good | Low | Medium |
| use of shading devices or reflective film | 0000 | 0000 | LOW | Medium |
| | | | | <u> </u> |
| Lighting accounts for 25% of carbon en | nissions | | | |
| The overall energy performance of lighting | | | | |
| The carbon efficiency of lighting is good | 0 | | | |
| The energy efficiency of the worst lighting | systems in this | building is <mark>poor</mark> | | |
| * Recommendation: replace tungsten | Good | Good | Potentially | Potentially |
| GLS lamps with CFLs | | | medium but | medium but |
| | | | requires more | requires more |
| | | | assessment | assessment |
| | f | | | |
| Hot water provision accounts for 10% of | | SIONS | | |
| The energy performance of hot water prov The carbon efficiency of hot water provision | | | | |
| The carbon enciency of not water provisio | | | | |
| Mechanical ventilation accounts for 5% | of carbon omi | ssions | | |
| The energy efficiency of mechanical ventil | | 0010113 | | |
| The carbon efficiency of mechanical ventil | | | | |
| * Recommendation: consider replacing | Medium | Good | Medium | Good |
| extract fans | | | | |

Figure 13: Example format for optional additional information

B5.0 Working list of EPC recommendations

Note: Wording of recommendations to be reviewed

| CODEDESCRIPTIONCATEGORYCurrently using an average of FAIR and POOR values of FOOR values of relation to the POT values of relation of FOOR values of relation of FOOR values of relation of POOR values of relation of the POOR values of relation values of relation values of relation values of relation of the POOR values of relation values of relation of the POOR values of relation values of relation of the POOR values of relation values of relation values of relation values of relation | . 1010. 110101 | | | PAYBACK | |
|--|----------------|-------------------------------------|-------------|----------------------------|--|
| EPC-C2install high efficiency chiller EPC-C3COOLING3.5EPC-W1High efficiency water heater EPC-W1HOT-WATER4.15EPC-W1DHW storage insulation DHW secondary circulation time controlHOT-WATER4.5EPC-W2DHW point of use systemHOT-WATER4.5EPC-W2DHW point of use systemHOT-WATER8EPC-E1insulate floorENVELOPE15EPC-E2insulate roofENVELOPE6.5EPC-E3insulate solid wallsENVELOPE3.7EPC-E6insulate solid wallsENVELOPE4.6EPC-E7pressure testENVELOPE7EPC-E8insulate loftENVELOPE7EPC-E7pressure testENVELOPE9.3EPC-F1Oil or LPG to natural gas (heating)FUEL-SWITCHING3.81EPC-F2Coal to biomass (heating)FUEL-SWITCHING3.81EPC-F3gas to biomass (heating)FUEL-SWITCHING6.7EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING8.4EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING8.4EPC-F4Ine controlHEATING5.8EPC-F4Install condensing boilerHEATING5.8EPC-F4local time controlHEATING5.8EPC-F4local time controlHEATING3.8EPC-F4local there optionersHEATING5.8EPC-F4local there optionersHEATING5.8EPC-F4loca | CODE | DESCRIPTION | CATEGORY | Currently using an average | |
| EPC-C3Inspect and seal ductworkCOOLING7.5EPC-W1High efficiency water heaterHOT-WATER4.15EPC-W3DHW storage insulationHOT-WATER3.8DHW secondary circulation timeHOT-WATER4.5EPC-W2DHW point of use systemHOT-WATER8EPC-E1insulate floorENVELOPE15EPC-E2insulate floorENVELOPE25EPC-E3insulate sold wallsENVELOPE3.7EPC-E4cavity wall insulationENVELOPE3.7EPC-E5secondary glazingENVELOPE5.6EPC-E6insulate loftENVELOPE7EPC-E7pressure testENVELOPE7EPC-E8improve glazingENVELOPE9.3EPC-F1Oil or LPG to natural gas (heating)FUEL-SWITCHING3.75EPC-F2Coal to biomass (heating)FUEL-SWITCHING3.81EPC-F3Coal to biomass (heating)FUEL-SWITCHING6.72EPC-F6Coal to oil (heating)FUEL-SWITCHING6.72EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-F6Coal to oil (heating)FUEL-SWITCHING3.81EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-F7ControlHEATING5.8EPC | EPC-C1 | default chiller efficiency | COOLING | 3 | |
| EPC-W1High efficiency water heater DHW storage insulation DHW storage insulation DHW secondary circulation time controlHOT-WATER4.15EPC-W2DHW point of use systemHOT-WATER4.5EPC-W2DHW point of use systemHOT-WATER8EPC-E1insulate roofENVELOPE15EPC-E2insulate roofENVELOPE25EPC-E3insulate solid wallsENVELOPE3.7EPC-E4cavity wall insulationENVELOPE4.6EPC-E5secondary glazingENVELOPE5.6EPC-E6insulate loftENVELOPE7EPC-E7pressure testENVELOPE9.3EPC-F1Oli or LPG to natural gas (heating)FUEL-SWITCHING3.75EPC-F2Coal to biomass (heating)FUEL-SWITCHING3.81EPC-F3Gas to biomass (heating)FUEL-SWITCHING6.72EPC-F4Oli or LPG to biomass (heating)FUEL-SWITCHING8.4EPC-F5Gas to biomass (heating)FUEL-SWITCHING8.4EPC-F4Ioeal time controlHEATING1.8EPC-F4Ioeal time controlHEATING2.5Heating optimum start and stopEPC-H3install condensing boilerHEATINGEPC-H4default heat generator efficiencyHEATING3.6EPC-H3install condensing boilerHEATING3.5EPC-H4default heat generator efficiencyHEATING2.5Heating0VERHEATING3.5EPC-H3Install high efficiency boi | EPC-C2 | install high efficiency chiller | COOLING | 3.5 | |
| EPC-W3 DHW storage insulation DHW secondary circulation timeHOT-WATER3.8EPC-W2DHW point of use systemHOT-WATER4.5EPC-W2DHW point of use systemHOT-WATER8EPC-E1insulate foorENVELOPE25EPC-E3insulate solid wallsENVELOPE6.5EPC-E4cavity wall insulationENVELOPE3.7EPC-E5secondary glazingENVELOPE5.6EPC-E6insulate loftENVELOPE5.6EPC-E7pressure testENVELOPE7EPC-E8improve glazingENVELOPE9.3EPC-F1Oil or LPG to natural gas (heating)FUEL-SWITCHING1.08EPC-F2Coal to natural gas (heating)FUEL-SWITCHING6.7EPC-F3Coal to biomass (heating)FUEL-SWITCHING6.7EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING6.7EPC-F5gas to biomass (heating)FUEL-SWITCHING6.7EPC-F6Coal to id (heating)FUEL-SWITCHING5.8EPC-H5local time controlHEATING1.8EPC-H6controlHEATING5.8EPC-H7controlHEATING2.3EPC-H3install condensing boilerHEATING3EPC-H4default heat generator efficiencyHEATING3EPC-H3install condensing boilerHEATING3EPC-H3Install condensing boilerHEATING3EPC-L4IdeHTING1.8EPC-L2G.5< | EPC-C3 | Inspect and seal ductwork | COOLING | 7.5 | |
| DHW secondary circulation timeEPC-W4controlHOT-WATER4.5EPC-W4controlENVELOPE15EPC-E1insulate floorENVELOPE15EPC-E2insulate solid wallsENVELOPE6.5EPC-E3insulate solid wallsENVELOPE3.7EPC-E4cavity wall insulationENVELOPE3.7EPC-E5secondary glazingENVELOPE5.6EPC-E6insulate loftENVELOPE7EPC-E7pressure testENVELOPE7EPC-F1Oil or LPG to natural gas (heating)FUEL-SWITCHING3.75EPC-F2Coal to biomass (heating)FUEL-SWITCHING3.75EPC-F3Coal to biomass (heating)FUEL-SWITCHING6.72EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING6.72EPC-F5Goal to oil (heating)FUEL-SWITCHING6.72EPC-F6Coal to oil (heating)FUEL-SWITCHING6.72EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-H6local time controlHEATING5.8EPC-H7controlHEATING5.8EPC-H6local time controlHEATING3.81EPC-H7controlHEATING3.81EPC-H6local time controlHEATING2.5heating optimum start and stopE5EPC-H3install condensing boilerHEATING3.81EPC-H4local start expressionE5EPC-H3install condens | EPC-W1 | High efficiency water heater | HOT-WATER | 4.15 | |
| EPC-W2DHW point of use systemHOT-WATER8EPC-E1insulate floorENVELOPE15EPC-E2insulate roofENVELOPE25EPC-E3insulate solid wallsENVELOPE6.5EPC-E4cavity wall insulationENVELOPE3.7EPC-E5secondary glazingENVELOPE4.6EPC-E6insulate loftENVELOPE7EPC-E7pressure testENVELOPE9.3EPC-F1Oil or LPG to natural gas (heating)FUEL-SWITCHING1.08EPC-F2Coal to natural gas (heating)FUEL-SWITCHING3.75EPC-F3Coal to biomass (heating)FUEL-SWITCHING6.7EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING6.7EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING6.7EPC-F5gas to biomass (heating)FUEL-SWITCHING8.4EPC-F6Coal to oil (heating)FUEL-SWITCHING8.4EPC-F6Coal to oil (heating)FUEL-SWITCHING5.8EPC-H6Room temperature controlHEATING1.8EPC-H7controlHEATING2.5heating weather compensationEPC-H4default heat generator efficiencyHEATING3EPC-H3install high efficiency boilerHEATING3EPC-H4default heat generator efficiencyHEATING3EPC-L1T12 to T8LIGHTING0.6EPC-L2GLS to CFLLIGHTING3.5EPC-L3HP mercury to SON re | EPC-W3 | | HOT-WATER | | |
| EPC-E1insulate floorENVELOPE15EPC-E2insulate roofENVELOPE25EPC-E3insulate solid wallsENVELOPE6.5EPC-E4cavity wall insulationENVELOPE3.7EPC-E5secondary glazingENVELOPE4.6EPC-E6insulate loftENVELOPE7EPC-E7pressure testENVELOPE7EPC-E8improve glazingENVELOPE9.3EPC-F1Oli or LPG to natural gas (heating)FUEL-SWITCHING3.75EPC-F2Coal to biomass (heating)FUEL-SWITCHING3.81EPC-F3Coal to biomass (heating)FUEL-SWITCHING6.72EPC-F4Oli or LPG to biomass (heating)FUEL-SWITCHING8.4EPC-F6Coal to oil (heating)FUEL-SWITCHING8.4EPC-F6Coal to ind (heating)FUEL-SWITCHING8.4EPC-F6Iocal time controlHEATING1.8EPC-F6coal time controlHEATING2.5Heating optimum start and stopEPC-H6controlsHEATING3EPC-H8controlsHEATING32.5EPC-H4default heat generator efficiencyHEATING33EPC-L1T12 to T8LIGHTING0.63EPC-L2GLS to CFLLIGHTING3.52.8EPC-L4HP mercury to SON replacementsLIGHTING3.5EPC-L5T8 to T5LIGHTING3.5EPC-L6HP mercury to SONLIGHTING3.5 <t< td=""><td></td><td></td><td></td><td></td></t<> | | | | | |
| EPC-E2insulate roofENVELOPE25EPC-E3insulate solid wallsENVELOPE6.5EPC-E4cavity wall insulationENVELOPE3.7EPC-E5secondary glazingENVELOPE4.6EPC-E6insulate loftENVELOPE7EPC-E7pressure testENVELOPE7EPC-E8improve glazingENVELOPE9.3EPC-F1Oil or LPG to natural gas (heating)FUEL-SWITCHING1.08EPC-F2Coal to natural gas (heating)FUEL-SWITCHING3.61EPC-F3Coal to biomass (heating)FUEL-SWITCHING6.7EPC-F4Oil or LPG to biomass (heating)FUEL-SWITCHING8.4EPC-F5gas to biomass (heating)FUEL-SWITCHING8.4EPC-F6Coal to oil (heating)FUEL-SWITCHING8.4EPC-F1local time controlHEATING5.8EPC-F2coal time controlHEATING5.8EPC-F4local time controlHEATING5.8EPC-F6coal time controlHEATING5.8EPC-F7controlsHEATING5.8EPC-F7controlsHEATING5.8EPC-F7controlsHEATING2.3EPC-F7controlsHEATING2.3EPC-F7controlsHEATING2.3EPC-F7controlsHEATING3EPC-F7controlsHEATING2.3EPC-F7install condensing boilerHEATING3EPC-F7Glas to CFL <td< td=""><td></td><td></td><td></td><td></td></td<> | | | | | |
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| EPC-L6HP mercury to SONLIGHTING3.5EPC-L7Mains to HF ballastLIGHTING5.7EPC-V1overheatingOVERHEATING1.7EPC-R1consider GSHPRENEWABLES11.7EPC-R2install wind turbineRENEWABLES15.9EPC-R3install solar thermal water heatingRENEWABLES20.2EPC-R4install PV systemRENEWABLES44.7 | EPC-L3 | HP mercury to SON replacements | LIGHTING | 1.8 | |
| EPC-L7Mains to HF ballastLIGHTING5.7EPC-V1overheatingOVERHEATING1.7EPC-R1consider GSHPRENEWABLES11.7EPC-R2install wind turbineRENEWABLES15.9EPC-R3install solar thermal water heatingRENEWABLES20.2EPC-R4install PV systemRENEWABLES44.7 | EPC-L5 | T8 to T5 | LIGHTING | 2.8 | |
| EPC-V1overheatingOVERHEATING1.7EPC-R1consider GSHPRENEWABLES11.7EPC-R2install wind turbineRENEWABLES15.9EPC-R3install solar thermal water heatingRENEWABLES20.2EPC-R4install PV systemRENEWABLES44.7 | EPC-L6 | HP mercury to SON | LIGHTING | 3.5 | |
| EPC-R1consider GSHPRENEWABLES11.7EPC-R2install wind turbineRENEWABLES15.9EPC-R3install solar thermal water heatingRENEWABLES20.2EPC-R4install PV systemRENEWABLES44.7 | EPC-L7 | Mains to HF ballast | LIGHTING | 5.7 | |
| EPC-R2install wind turbineRENEWABLES15.9EPC-R3install solar thermal water heatingRENEWABLES20.2EPC-R4install PV systemRENEWABLES44.7 | EPC-V1 | overheating | OVERHEATING | 1.7 | |
| EPC-R3install solar thermal water heatingRENEWABLES20.2EPC-R4install PV systemRENEWABLES44.7 | EPC-R1 | consider GSHP | RENEWABLES | 11.7 | |
| EPC-R4 install PV system RENEWABLES 44.7 | EPC-R2 | install wind turbine | RENEWABLES | 15.9 | |
| , | EPC-R3 | install solar thermal water heating | RENEWABLES | 20.2 | |
| EPC-R5consider ASHPRENEWABLES9.8 | | - | | | |
| | EPC-R5 | consider ASHP | RENEWABLES | 9.8 | |

Table 40: Working list of EPC recommendations

| CODE | TEXT |
|------------------|---|
| | The default chiller efficiency is chosen. It is recommended that the chiller system be |
| EPC-C1 | investigated to gain an understanding of its efficiency and possible improvements. |
| EPC-C2 EPC-C3 | Chiller efficiency is low. Consider upgrading chiller plant. Ductwork leakage is high. Inspect and seal ductwork |
| | |
| EPC-W1 | Install more efficient water heater |
| EPC-W3 EPC-W4 | Improve insulation on DHW storage Add time control to DHW secondary circulation |
| EPC-W4 EPC-W2 | Consider replacing DHW system with point of use system |
| | Some floors are poorly insulated – introduce/improve insulation. Add insulation to the exposed |
| EPC-E1 | 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. |
| | Carry out a pressure test, identify and treat identified air leakage. Enter result in EPC |
| EPC-E7 EPC-E8 | calculation Some glazing is poorly insulated. Replace/improve glazing and/or frames. |
| EPC-E0 | 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 EPC-H3 | Consider replacing heating boiler plant with high efficiency type |
| EPC-N3 | 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) |
| | Introduce HF (high frequency) ballasts for fluorescent tubes: Reduced number of fittings |
| EPC-L7 | required 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 |
| EPC-V1 | 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 41: Text for EPC recommendations |