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Technical Manual

SBEMmt

**SBEMmt: Simplified Building
Energy Model for Malta**

*Part of the Malta National Calculation Methodology:
SBEMmt for assessing the Energy Performance of Buildings*

A Technical Manual for SBEMmt

15 May 2012



This manual and the adaptation of the software tool (SBEMmt) described in it for the Malta Building Regulations were developed by the BRE for the Ministry for Resources and Rural Affairs (MRRA) from the original SBEM Technical Manual which, together with the software tool described in it, were developed by the BRE for the UK's 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 SBEMmt, 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 SBEMmt development team, as a reference document
- Interested users of the tool, assumed to be building professionals such as:
 - Architects
 - Service and M&E engineers
 - Energy surveyors
 - Building energy modellers
 - Suppliers of energy-related building components

It is not intended to be required reading for users of the tool. An overview of the original UK tool (SBEM), in the form of a BRE Information Paper¹, is available², but all users are expected to read and refer to the *iSBEMmt User Guide*³ if using the Malta tool. That Guide contains all the information on the functioning of iSBEMmt needed to operate the tool effectively.

¹ IP 2/07: *SBEM for non-domestic buildings*

² From the BRE Bookshop at www.brebookshop.com.

³ Available from epc.gov.mt.

2. Background

This section of the manual looks at the requirement for a calculation methodology for Malta that complies with Article 3 of the EPBD, which has developed into the Malta National Calculation Methodology (MNCM). It describes which draft prEN and CEN standards have been used to develop a calculation procedure, and how one particular implementation (SBEMmt) 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 Malta National Calculation Methodology (MNCM) and thence to SBEMmt 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. SBEMmt is the implementation of this methodology for non-residential buildings in Malta.

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 CO₂ emissions as a means of comparison, rather than energy consumption, in the standard methodology.

2.2. The Malta National Calculation Methodology (MNCM)

The EPBD calls for a calculation methodology on the energy performance of buildings to be established. The MNCM has been adapted by BRE to provide this calculation from the UK’s National Calculation Methodology (NCM). This manual deals with the calculation methodologies and compliance checking procedures that form the MNCM.

The EPBD permits the inclusion of a CO₂ emission factor in the standard methodology. For Building Regulations certification in Malta, it has been decided to base the building rating on CO₂ 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 Malta is carbon management in order to meet international treaty obligations.

Following on from the Article 3 requirement of the EPBD, the MNCM for non-domestic buildings in Malta calls for a new or existing building to be assessed by comparing its expected annual carbon dioxide emissions with those of a reference building, on a consistent, calculated basis.

2.2.1. Comparison rather than absolute calculation

At the core of the MNCM, for producing Energy Performance Certificates (EPCs), the calculation process compares the carbon emissions of the actual building with those of a “reference building”, which are subjected to a specified “improvement factor”. This constitutes setting the standards in order to satisfy the requirements of Article 4 of the EPBD.

The MNCM 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

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 SBEMmt to deal with the areas not covered by the standards are explained elsewhere in this document.

2.2.3. Parameters required to define a building

In the MNCM, 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. Reference Building

For Malta, the reference building has:

- The same geometry, orientation, and usage as the building being assessed.
- The same standard operating patterns.
- The same weather data.
- Building fabric, glazing types, air tightness, and HVAC and lighting plant substituted by specified standard items:
 - Fixed construction data, which are generally in line with Technical Guide F⁴ requirements, and fixed air tightness.
 - Fixed glazing areas and transmittance values for different orientations.
 - Fixed fuel types for water heating and space cooling and heating.
 - Fixed HVAC system efficiencies, ventilation strategies, and lighting specifications.

2.2.5. Asset Rating

The MNMCM is used to calculate the energy consumption and hence carbon dioxide emissions (in kgCO₂/m².annum) of both the building being evaluated, i.e., the “Building Emission Rate” (BER) and those of the reference building, the “Reference Emission Rate” (RER).

The “Standard Emission Rate” (SER) is the CO₂ emissions (in kgCO₂/m².annum) of the reference building, RER, adjusted by an improvement factor of 20%, i.e., $SER = RER \cdot 0.8$.

The “Asset Rating” (AR) in Malta is then calculated as the ratio of the BER to the SER, multiplied by 100, and rounded to the nearest whole number, i.e., $AR = (BER/SER) \cdot 100$.

2.3. Brief from MRRA

Having reviewed some available software options for implementation of the EPBD requirements for Malta, the Ministry for Resources and Rural Affairs (MRRA) commissioned BRE to adapt the UK tool, the Simplified Building Energy Model (SBEM), for use for Maltese buildings since this software was deemed to be capable of handling the majority of non-domestic buildings and could be made available free to users so that building energy ratings could be carried out on a consistent basis.

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

- SBEMmt, the core calculation engine
- iSBEMmt, an interface based on Microsoft Access®.
- EPCgenMT, the Energy Performance Certificate (EPC) generator
- Standardised databases
- Standardised XML report format

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

⁴ Technical Guidance F: *Conservation of Fuel, Energy, and Natural Resources (Minimum Requirements on the Energy Performance of Building Regulations, 2006)*, Services Division, Building Regulations Office, Malta.

2.4. European standards (CEN) used by SBEMmt

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

SBEMmt follows the above standards as far as is practicable.

2.4.1. Summary of CEN standards used by SBEMmt

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

⁵ Published standards can be obtained online from the British Standards Institution at <http://www.bsonline.bsi-global.com/server/index.jsp>.

3. The calculation process

3.1. Calculation overview

SBEMmt takes inputs from the software user (via the interface) 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 energy rating purposes in new and existing buildings.

SBEMmt 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. SBEMmt 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 iSBEMmt, the SBEMmt 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 gains from occupants and equipment 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 the thermal conditions
5. aggregates the delivered energy by source, and converts it into equivalent CO₂ emissions. This comprises the Building Emission Rate (BER).
6. determines, on the same basis, the CO₂ emissions of a reference building, which has the same geometry, usage, heat gains, temperature set points, lighting requirements and weather data as the actual building but with fixed HVAC system efficiencies, ventilation strategies, and fuel types (see Section 2.2.4).
7. applies a fixed improvement factor to each zone within the reference building. The resulting CO₂ emissions comprise the Standard Emission Rate (SER).

The BER and SER calculations are then handed over to the Energy Performance Certificate module, EPCgenMT, to provide energy rating certification. EPCgenMT:

1. calculates the asset rating of the actual building (see Section 2.2.5), and converts it into an energy band on an “A to G” scale.
2. produces a standardised XML file containing all the necessary data that would allow the preparation of the following standardised reports:
 - a. a certificate showing the asset rating and energy band of the actual building.
 - b. a report setting out recommendations for cost-effective improvements to the energy performance of the actual building.

Intermediate results produced by SBEMmt 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 iSBEMmt acts as the interface between the user and the SBEMmt calculation engine. As far as possible, the user is guided towards appropriate databases, and then the input is formatted so that data is presented correctly to the calculation engine.

The steps involved in the input are as follows:

- User defines the activities taking place and inputs the areas they occupy in the 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.
- Weather data for Malta is available in a built-in standard database and is applicable to all building locations in Malta.
- 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 view the key results on energy consumption and CO₂ emissions calculated by SBEMmt and the asset rating and energy band determined by the EPCgenMT module.

Hence, the user interacts with the interface module, iSBEMmt, 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.

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 effective thermal capacity for the building elements, the HVAC systems efficiencies, and lighting data and controls by either selecting from the internal databases or inputting parameters directly (see Sections 3.3.2 and 3.3.3).

3.2.3. Locked databases

SBEMmt 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 (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 MNMCM 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, which 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 64 activity types to choose from.

The MNMCM 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 (illuminance requirements)

- Ventilation standards (fresh air requirements)
- 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
- 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 actual and reference buildings. The need is to ensure that comparisons with 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 SBEMmt are described below.

As part of improving consistency of application and certification, the activities in the MNMCM Activity Database have been chosen to follow those of the UK's NCM Activity Database. .

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

Centre	
Non-residential Institutions - Crown and County Courts	Law courts
Non-residential Institutions - Education	Non-residential education and training centres.
Non-residential Institutions - Libraries Museums and Galleries	Art galleries, museums and libraries.
Non-residential Institutions - Primary Health Care Building	Non-residential clinics and health centres.
General Assembly and Leisure plus Night Clubs and Theatres	Cinemas, music and concert halls, bingo and dance halls, swimming baths, skating rinks, gymnasiums or sports arenas (except for motor sports or where firearms are used). This type also includes night clubs and theatres.
Others - Car Parks 24 hrs	Enclosed or underground car park reserved for parking cars with 24 hrs operation.
Others - Emergency services	Includes fire stations.
Others - Miscellaneous 24hr activities	Miscellaneous 24hr activities.
Others - Passenger terminals	Airport, Bus, Train and Sea Port passenger terminals.
Others - Stand alone utility block	Modular building that just provides shower/toilet facilities.
Others -Telephone exchanges	Telephone exchanges.
Residential spaces	Residential spaces within non-domestic buildings and not designed or altered for use as a separate dwelling.

Table 1: List of building types

Activity Type	Description
24 hrs Consulting/treatment areas	For all A&E consulting/treatment/work areas, occupied and conditioned 24 hours a day.
24x7 Generic Office Area	Areas to perform 24 x7 hrs office work including offices and meeting rooms. It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space, areas for photocopiers and fax machines and staff lounges.
24x7 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.
Display area	An area where display lighting is used to illuminate items.
Display window	An area where display lighting is used to illuminate items with glazing onto the outside such as a shop window, but which is boxed/enclosed, separated from the main retail space.
Domestic Bathroom	An area specifically used for bathing/washing. Contains a bath and/or shower and usually a basin and toilet.
Domestic Bedroom	An area primarily used for sleep.
Domestic Circulation	For all circulation areas within the dwelling.
Domestic Dining room	An area which is primarily used for eating meals.
Domestic Kitchen	The area within the dwelling where food is prepared
Domestic Lounge	The main reception room of the home.
Domestic Toilet	An area containing a toilet and basin which is separate from the main bathroom
Dry sports hall	An area where indoor sports can be played.
Eating/drinking area	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 contain conveyer belts; security check areas, which may include equipment such as x ray machines; and baggage reclaim areas.
Generic Office Area	Areas to perform office work including offices and meeting rooms. It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space, areas for photocopiers and fax machines and staff lounges.
Generic Ward	For all areas containing beds which accommodate either single or multiple patients. It includes toilets, ward storage, staff accommodation, day patient accommodation and intensive care units.
Hall/lecture theatre/assembly area	An area which can accommodate a large number of seated people.
Heavy Plant Room	For heavy plant rooms with 24hr low-medium internal gains from equipment and transient occupancy.
Hydrotherapy pool hall	The area in which the hydrotherapy pool is contained.
Ice rink	An area which contains an ice rink.
Industrial process area	An area for industrial process work, usually involving large machinery or equipment.
Laboratory	A facility that provides controlled conditions in which scientific research, experiments, and measurement may be performed.

Laundry	An area used specifically for washing and/or drying clothes using washing machines and/or tumble dryers.
Light plant room	Areas containing the main HVAC equipment for the building e.g., boilers/air conditioning plant.
Lounges	All areas where passengers are walking/sitting which are not covered by the other space types. This includes departure lounge, corridors, stairways and gate lounges.
Office and consulting areas	Areas to perform management, office and administration work separated from standard customer/public areas. It can include internal corridors providing access to the office spaces, tea making facilities or kitchenettes within the office space and staff lounges.
Operating theatre	For the operating theatre suite, including anaesthetic, scrub & preparation rooms.
Performance area (stage)	For stages with dedicated lighting and equipment in addition to that within the remainder of the space. For stages within other activity areas which do not have specific lighting or additional electrical equipment, do not define these as separate spaces.
Physiotherapy Studio	For all physiotherapy areas, e.g., Fitness Suite/Gym, activity area, Cardiac stress test area.
Post Mortem Facility	Post-Mortem Facility (including Observation room and body preparation area)
Public circulation areas	All public circulation areas such as a foyer. For non public spaces use "Circulation areas (corridors and stairways) - non public"
Reception	The area in a building which is used for entry from the outside, from other building storeys or in general waiting areas containing a reception desk.
Residents common rooms	TV lounges and other common spaces for use of residents. It may contain some hot drink facilities.
Residents kitchen	Common area kitchens used by residents, e.g. in residents' halls.
Retail Warehouse Sales area - chilled	A sales area in Retail Warehouses designed to accommodate a considerable quantity of fridges/freezers such as a supermarket or food hall.
Retail Warehouse Sales area - electrical	Sales areas in Retail Warehouses designed to accommodate considerable electrical equipment loads such as lighting sales areas and IT/TV/Hi-Fi sales areas.
Retail Warehouse Sales area - general	All Sales areas in Retail Warehouses which do not have a large concentration of fridges/freezers or electrical appliances.
Sales area - general	All Sales areas which do not have a large concentration of fridges/freezers or electrical appliances.
Server Room	For areas such as computer server spaces with 24hr low-medium internal gains from equipment and transient occupancy. For an area with 24hrs high gains from equipment, use the 'Data Centre' activity.
Small Shop Unit Sales area - chilled	A sales area in Small Shop Units designed to accommodate a considerable quantity of fridges/freezers such as a supermarket or food hall.
Small Shop Unit Sales area - electrical	Sales areas in Small Shop Units designed to accommodate considerable electrical equipment loads such as lighting sales areas and IT/TV/Hi-fi sales areas.
Small Shop Unit Sales area - general	All Sales areas in Small Shop Units which do not have a large concentration of fridges/freezers or electrical appliances.
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).
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 setpoints define the conditions which the selected HVAC system will be assumed to maintain for the period defined by the heating and cooling schedules.

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 and not currently used by SBEMmt.

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 SBEMmt user can specify the U-value and thermal mass information for a particular wall, window, roof, or floor for which the construction is accurately known. Where the construction is less precisely known, the SBEMmt user can make use of SBEMmt's construction and glazing databases. These databases contain a library of 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 effective thermal capacity and, in the case of glazing, solar and light transmission factors, and these values are then fed directly into the SBEMmt 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). 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). It takes account of, for example, the efficiency of the cold generator, thermal gains to pipework and ductwork, and duct leakage. It does not include energy used by fans and pumps. Since many cooling demand calculations only estimate sensible cooling, the definition may be extended to include allowances for deliberate or inadvertent latent loads.

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

3.3.3.2. Scope

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

EN 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 SBEMmt. 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).

3.3.3.3. Determination of system performance parameters from the mechanisms

The basic energy flow diagram of the HVAC calculation in SBEMmt is shown 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. SBEMmt 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 SBEMmt and inserted into look-up tables in iSBEMmt. 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.

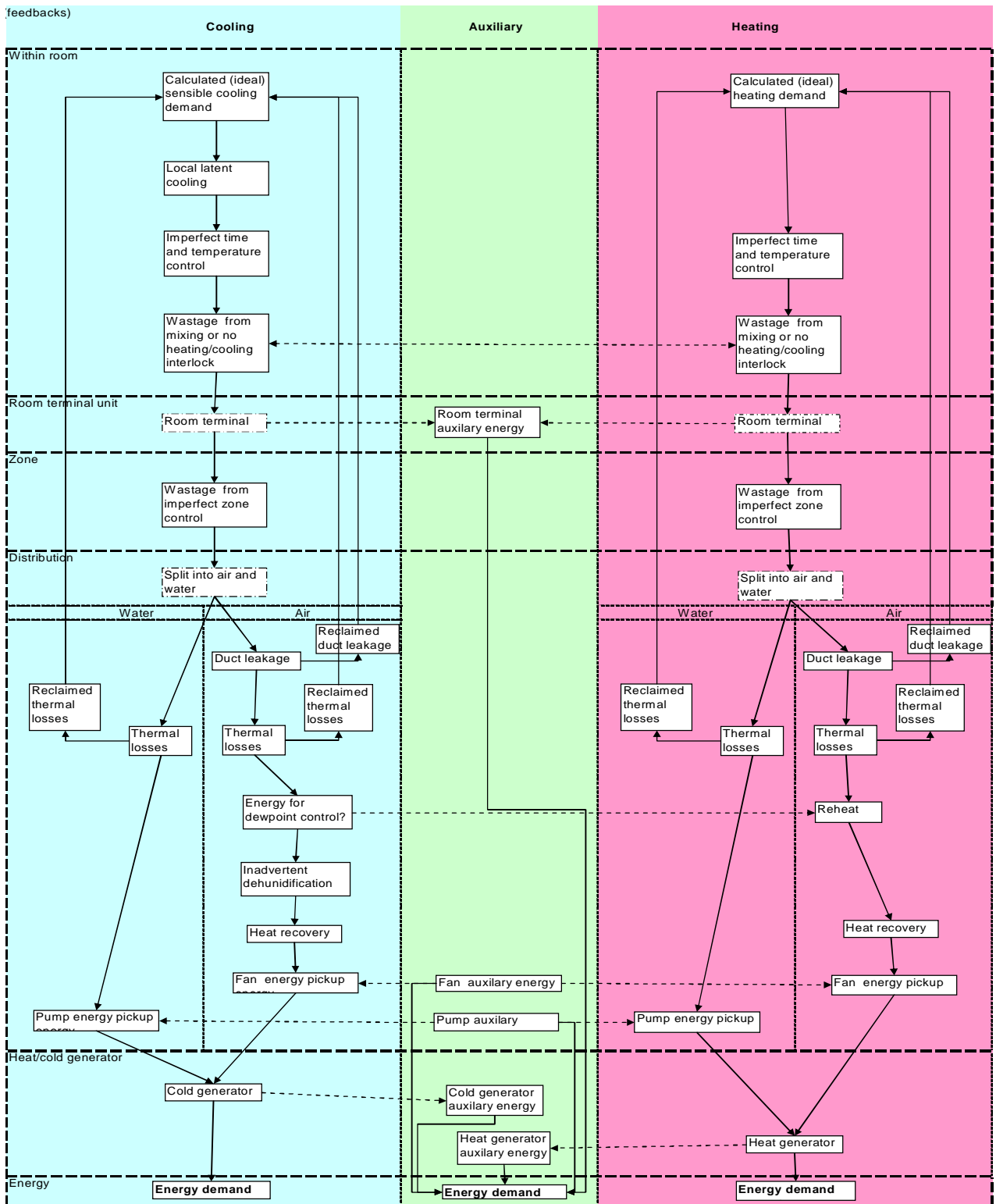


Figure 1: Basic energy flow diagram of the HVAC calculation in SBEMmt

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

Table 3: Mechanisms and key points

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

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

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

Table 5: Parameter list

3.3.3.5. Calibration process

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

The process is illustrated in Figure 2.

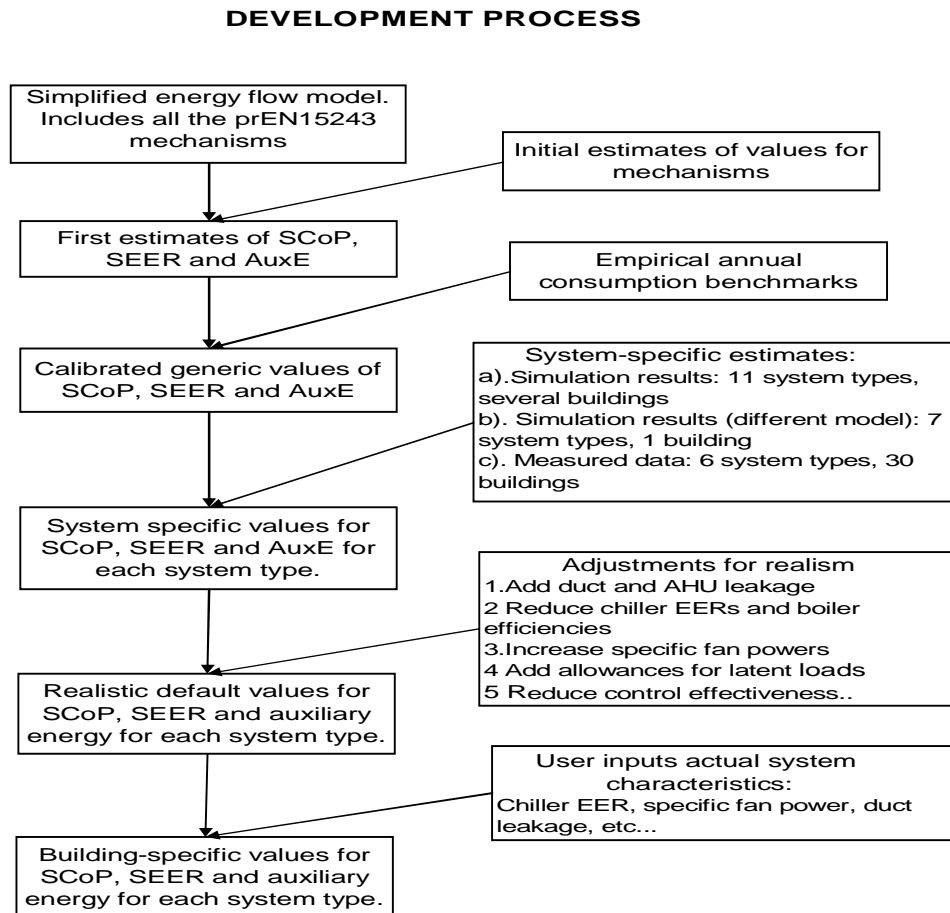


Figure 2: HVAC Model Development Process

We first produced initial estimates of typical values of the flow sheet parameters and calculated initial figures of the three performance parameters (auxiliary energy, SSEFF, and SSEER). With some relatively small adjustments to the initial assumptions, the consumption figures that these implied were brought into general alignment with empirical benchmarks, notably ECG 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 EN 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 $U*((t_r + t_{1.5})/2 - t_o)$
- 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
Convactor heaters	2.3 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.

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

Radiant heating	1.1°C
Radiators	5.3°C
Convactor heaters	8.1°C

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

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 SBEMmt, 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 $2*I*a*r = dt$

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

$$Q_t * h_r / h_t$$

where Q_t is the total heat output, h_r is the radiant efficiency, and h_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

$$I = d * Q_t * h_r / (h_t * A).$$

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),

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

$$\text{So } k = 2 * a * r * d * 0.33 * N * \text{room volume} * h_r / (h_t * A)$$

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

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

RADIANT HEATING SYSTEMS:

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

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

$$k = 0.00438 * N * h * h_r / h_t$$

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

h_r/h_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 h_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 h_r/h_t term simply represents the proportion of the output that is radiant.

The following values are suggested:

Emitter	h_r/h_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 SBEMmt

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 MNCM 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.

Year-round hourly data on the following parameters are pre-processed into monthly figures before being used by SBEMmt:

- 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

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, and link each to one of the previously-defined constructions.
- Within each envelope element, there may be windows/rooftlights or doors. The areas, types, shading systems, and constructions of windows and doors within each envelope element need to be entered.

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 MNCM defines

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.

zoning rules that should be applied when assessing a building for 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 virtual, e.g., between a daylit perimeter and a core *Zone*, no envelope element should be defined. SBEMmt will then assume no transfer of heat, coolth, or light across the boundary, in either direction. In the context of iSBEMmt, 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 iSBEMmt 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.

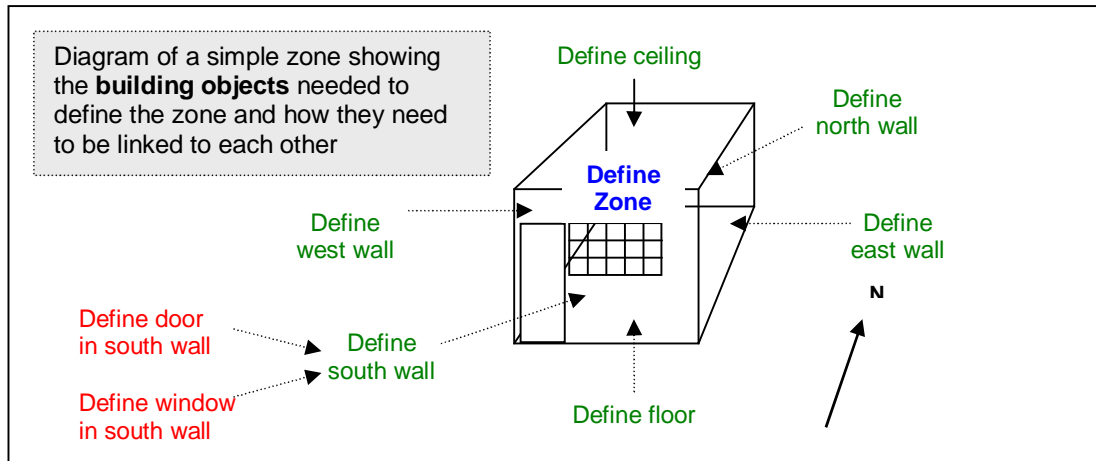


Figure 3: Diagram of building objects needed to define a simple zone

3.4.3. Thermal bridges

Heat losses through thermal bridges in SBEMmt are represented by a fixed alpha value of 10% of the U-values of all the construction elements in the project.

4. The calculation algorithms

The calculation methodology can, in theory, be based on any process which evaluates the energy consumption, and hence CO₂ emissions of a building, as long as it complies with the following MNCM 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 reference building, defined in a standard way

The calculation method in SBEMmt 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 MNCM, and that only one implementation of the monthly average calculation method will be accepted in Malta, namely SBEMmt. 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, the following energy calculations needed to be determined:

- Fixed lighting with different control systems
- Hot water for washing
- Contributions from renewable energy systems such as solar thermal water heating and photovoltaic electricity

4.1. Space heating and cooling energy demand

In EN 13790, the building energy demands for heating and cooling are based on the heat balance of the building zones (Note: EN 13790 only deals with sensible cooling and heating demand in a single room). This energy demand for the building is then the input for the energy balance of the heating and cooling systems, and hence, the CO₂ emissions for the building as a whole. The main structure of the calculation procedure is summarised in Table 6. The options chosen for SBEMmt from those available in the EN ISO 13790, and the resulting equations to be used are described and/or referenced in Table 7.

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)

Table 6: 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	6.2, 6.3.2

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

	recovery	2916:1998 methodology, where according to efficiency of heat recovery system, the air flow to be heated is effectively reduced.	
26	Night-time ventilation for free cooling	Optional in SBEMmt	9.4.3
27	Special elements	Optional; if applied, comply with 9.4.4	9.4.4
28	Internal heat sources, including cold sources (i.e., sinks, etc)	Calculate contribution using equations 16, 17 & 18	10.2, 10.3.1
29	Heat dissipated by system within the building	Impact on building heating/cooling needs ignored in SBEMmt, but heat dissipated is included in system efficiency adjustment factors	10.3.1
30	Heat gain from people and appliances	Determined from activity area database	10.3.2.1
31	Heat gain from lighting	Determined using method described in this manual	10.3.2.2
32	Heat to/from washing water and sewerage	Ignored in SBEMmt	10.3.2.3
33	Heat dissipated from or absorbed by heating, cooling and ventilation systems	Determined from efficiency factors	10.3.2.4
34	Heat from processes or goods	Determined from activity area database	10.3.2.5
35	Total solar heat sources	Equations 22 & 23 based on monthly average solar irradiance from weather data, including the effect of gains in adjacent unconditioned spaces	11.2
36	Effective solar collecting area of glazed elements	Equations 24, 27 & 29. Movable shading is included. Shading factors determined from user input	11.3.2, 11.4.1, 11.4.2, 11.4.3
37	Frame fraction	Included in SBEMmt	11.4.4
38	Effective collecting area of opaque elements	Equations 25, 26 & equations in 11.4.5 including 30 to deal with radiation from the element to the sky. Sky temperature taken from weather data	11.3.3, 11.4.5
39	Gain utilisation factor for heating	Equations 31, 32, 33 & 34 using reference numerical parameter for monthly calculation based on calculated building time constant (see below)	12.2.1.1
40	Loss utilisation factor for cooling	Equations 35, 36, 37, 38 & 39 using reference numerical parameter for monthly calculation based on calculated building time constant (see below)	12.2.1.2
41	Building time constant	Equations 40 (heating) and 41 (cooling) using internal heat capacity of building	12.2.1.3
42	Internal heat capacity of building	Sum of internal capacities of all building elements, using κ_m values calculated according to EN ISO 13786:2005	12.3.1
43	Internal temperatures used in energy calculations	Where heating or cooling is continuous during the whole heating period, use the set-point temperature indicated by the	13.1

		activity area database. If not continuous, see below.	
43	Correction for holiday periods	SBEMmt 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 calculated building time constant and difference in set-point temperature for normal heating and intermittent periods.	13.2.1
45	Correction for intermittent cooling	Equations 44 & 45, which need input of calculated building time constant 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	SBEMmt 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	SBEMmt'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 SBEMmt	Annex B
55	Alternative formulation for monthly cooling	Not implemented in SBEMmt	Annex D

	method		
56	Heat loss of special envelope elements (e.g., ventilated walls)	Not implemented in SBEMmt	Annex E
57	Solar gains of special elements (e.g., unconditioned sunspaces, opaque elements with transparent insulation, ventilated walls)	Basic implementation of sunspaces in SBEMmt.	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 SBEMmt	Annex H
60	Accuracy of the method	Not required for MNMCM	Annex I
61	Conventional input data (to be used in the absence of national data)	Not required for MNMCM – use activity area database	Annex J

Table 7: Options chosen in the CEN standard EN ISO 13790:2004

4.1.1. Calculation method

SBEMmt 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.

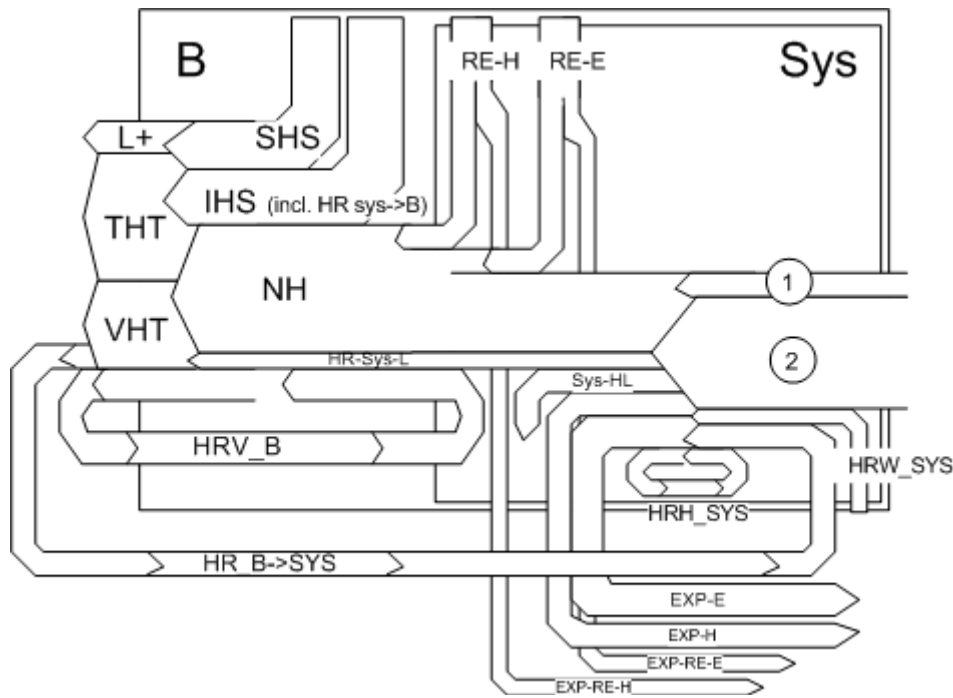
4.1.2. Overall energy balances for building and systems

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.

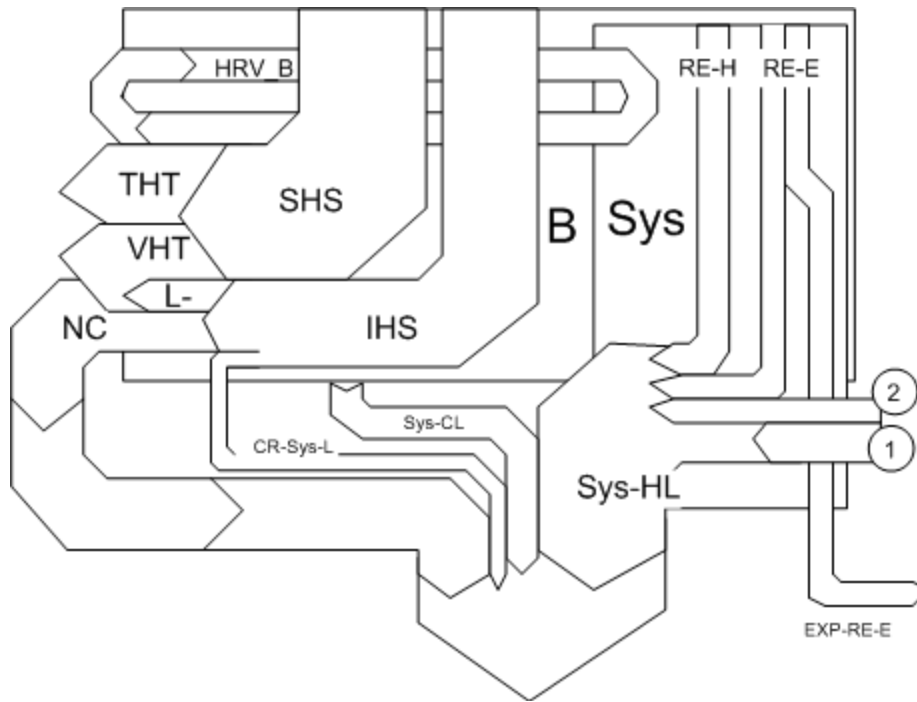


Key

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

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

Figure 4: Energy balance of a building for space heating



Key

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

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

Figure 5: Energy balance of a building for space cooling

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 SBEMmt.

The floor area within the boundary of the building is the useful floor area A_{fl} of the building. The dimension system used to calculate A_{fl} uses the internal dimensions of each zone's structural elements (i.e., the internal horizontal dimensions between the internal surfaces of the external zone walls and half-way through the thickness of the internal zone walls) so

that the area presented to the heat flux from inside the building coincides with the overall internal dimensions.

4.1.4. Thermal zones

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

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

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

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

4.1.5. Climate data

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

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

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

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

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

4.1.7. Energy demand for heating

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

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

subject to $Q_{NH} \geq 0$

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

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

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

$Q_{G,H}$ 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:

$$Q_{NC} = Q_{G,C} - h_{L,C} \cdot Q_{L,C}$$

subject to $Q_{NC} \geq 0$

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

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

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

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

$h_{L,C}$ 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:

$$Q_L = Q_T + Q_V$$

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

Q_L is the total heat transfer, in MJ;

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

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

The total heat sources, Q_G , of the building zone for a given calculation period, are:

$$Q_G = Q_i + Q_s$$

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

Q_G are the total heat sources, in MJ;

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

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

4.1.10. Total heat transfer by transmission

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

$$Q_T = \sum_k \{H_{T,k} \cdot (q_i - q_{e,k})\} \cdot t \cdot f$$

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:

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

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 m^2 , (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 $W/(m^2 \cdot K)$;

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

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

Since the heat loss through thermal bridge junctions is replaced by an alpha value of 10% in SBEMmt, the term $\sum_k l_k \Psi_k$ is replaced with the product of α and $\sum_i A_i U_i$ where $\alpha=0.1$.

4.1.11. Total heat transfer by ventilation

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

4.1.12. Heat gains

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

The heat gains are calculated by

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

where:

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

Q_i is the internal heat production, in MJ;

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

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

4.1.12.1. Internal heat sources

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

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).

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 m²;

3.6 is the conversion factor from kWh to MJ;

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

4.1.12.2. Solar heat gain through transparent constructions

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

$$Q_{sun,t} = \sum_j (q_{sun,j} \times f_{sh,j} \times f_{sun,j} \times g_j \times f_f)$$

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 ;

$A_{r,j}$ is the areas of window j , in m², including the frame;

f_f is the computation value for the frame factor, taken as (1-frame factor for window from user input)

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

The shading correction factor can be calculated from:

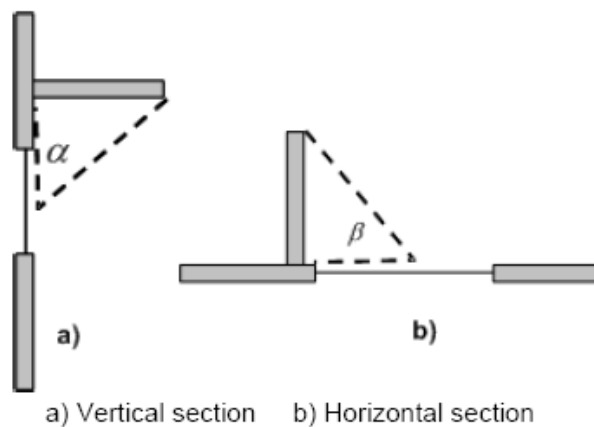
$$f_{sh,j} = F_o F_f$$

where

F_o is the partial shading correction factor for overhangs;

F_f is the partial shading correction factor for fins.

The shading from overhangs and fins depends on overhang or fin angle, latitude, orientation, and local climate. Seasonal shading correction factors for typical climates are given in Table 8 and Table 9.



Key

α overhang angle

β fin angle

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

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

Overhang angle	S	E/W	N
0°	1	1	1
30°	0.73	0.73	0.71
45°	0.58	0.58	0.56
60°	0.40	0.41	0.40

Table 8: Partial shading correction factor for overhang, F_o

Fin angle	S	E/W	N
0°	1	1	1
30°	0.94	0.93	1
45°	0.84	0.85	1
60°	0.72	0.76	1

Table 9: Partial shading correction factor for fins, F_f

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 10 as the value corresponding to the orientation of the glazing and its tilt from the horizontal.

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

Table 10: Correction factor F_w for g-value of non-scattering glazing

4.1.12.2.1. Calculation of the reduction factor for moveable solar protection

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

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

where

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

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

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

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

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

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

intensity of incident solar radiation for all hours in the month, I_{sol} , i.e., $f_{sh,with} = \frac{I_{sol>300}}{I_{sol}}$

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

This method applies to all types of 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 6)

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

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

where

$t_{e,B}$ is the solar transmittance of the solar protection device, which is obtained from Table 11 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);

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

$$a_{e,B} = 1 - t_{e,B} - r_{e,B}$$

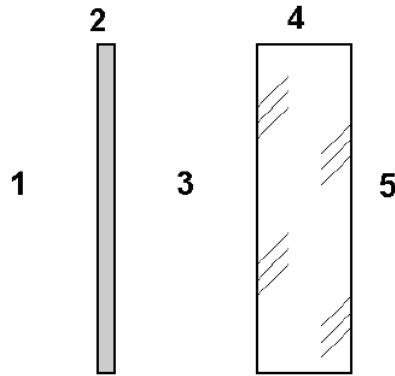
where $r_{e,B}$ is the solar reflectance of the solar protection device, which is obtained from Table 11 for typical solar protection devices;

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

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

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

where U_g is the thermal transmittance of the window, in W/m^2K .



Key

- 1 Exterior
- 2 Solar protection device
- 3 Unventilated air space
- 4 Glazing
- 5 Interior

Figure 7: Characteristic position of external solar protection device

Transmittance $t_{e,B}$		Reflectance $\rho_{e,B}$			
		white	pastel	dark	black
Opaque	0,0	0,7	0,5	0,3	0,1
Medium translucent	0,2	0,6	0,4	0,2	0,1
High translucent	0,4	0,4	0,3	0,2	0,1

Table 11: Data for typical solar protection devices

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:

$$g_{gl+sh} = g_{gl} \times \left(1 - (g_{gl} \times r_{e,B}) - \left(a_{e,B} \times \frac{G}{G_3} \right) \right)$$

where

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

$r_{e,B}$ is the solar reflectance of the solar protection device, which is obtained from Table 11 for typical solar protection devices;

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

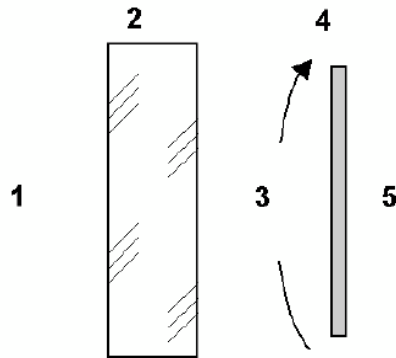
$$a_{e,B} = 1 - t_{e,B} - r_{e,B}$$

where $t_{e,B}$ is the solar transmittance of the solar protection device, which is obtained from Table 11 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 $\text{W/m}^2\text{K}$.



Key

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

Figure 8: Characteristic position of internal solar protection device

4.1.12.3. Solar heat gain through opaque constructions

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

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

where:

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

f_{ab} is a factor 0.045 which consists of an assumed value of 0.9 for the dimensionless absorption coefficient for solar radiation of the opaque construction multiplied by the external surface heat resistance which is taken as $0.05 \text{ m}^2\text{K/W}$.

$q_{sun,j}$ is the quantity of solar radiation per month on the plane in MJ/m^2 , for weather location and orientation of construction part j ;

$U_{c,j}$ is the thermal transmittance of construction part j ; in $\text{W/m}^2\text{K}$;

$A_{c,j}$ is the area of construction part j , in m^2 .

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, h_H is a function of the gain/loss ratio, γ_H , and a numerical parameter, a_H , that depends on the building inertia, according to the following equation:

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

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

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

with

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

where (for each month and for each building zone)

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

γ_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:

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

where

$a_{0,H}$ is a dimensionless reference numerical parameter, determined according to Table 12;

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 12, in hours.

$a_{0,H}$	$t_{0,H}$
1.0	15

Table 12: Values of the numerical parameter $a_{0,H}$ and reference time constant $t_{0,H}$ for heating for a monthly calculation method

NOTE: The gain utilisation factor is defined independently of the heating system characteristics, assuming perfect temperature control and infinite flexibility. A slowly

responding heating system and a less-than-perfect control system can significantly affect the use of gains.

4.1.14. Loss utilisation factor for cooling

The loss utilisation factor for cooling, h_C , is a function of the loss/gain ratio, λ_C , and a numerical parameter, a_C , that depends on the building thermal inertia, according to the following equation:

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

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

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

with

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

where (for each month and each building zone)

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

I_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_C is a dimensionless numerical parameter depending on the time constant, t_C , defined by:

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

where

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

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 13, in hours.

$a_{0,C}$	$t_{0,C}$
1.0	15

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

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

4.1.15. Building time constant for heating and cooling mode

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:

$$\tau_H = \frac{C_m / 3,6}{H_{L,H}}$$

where

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

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

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

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

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

$$\tau_C = \frac{C_m / 3,6}{H_C}$$

where

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

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

H_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:

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

where

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

k_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;

r_{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 14, 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 14: Maximum thickness to be considered for internal heat capacity

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 MNM 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 MNM Activity Database is used as the internal temperature of the building zone.

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

4.1.16.2. Quasi-continuous heating

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

Mode A:

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

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

Mode B:

- If the time constant of the building zone is greater than 3 times the duration of the longest reduced heating period, then the set-point temperature for the heating

calculation is the set-point temperature for the normal heating mode. See illustration in c) of Figure 9.

4.1.17. Corrections for intermittency, monthly method

4.1.17.1. Heating

In the case of intermittent heating which does not fulfil the conditions in Section 4.1.16.2, the energy demand for heating, $Q_{H,interm}$, in MJ, is calculated by using the following equation:

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

where

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

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

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

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

and where

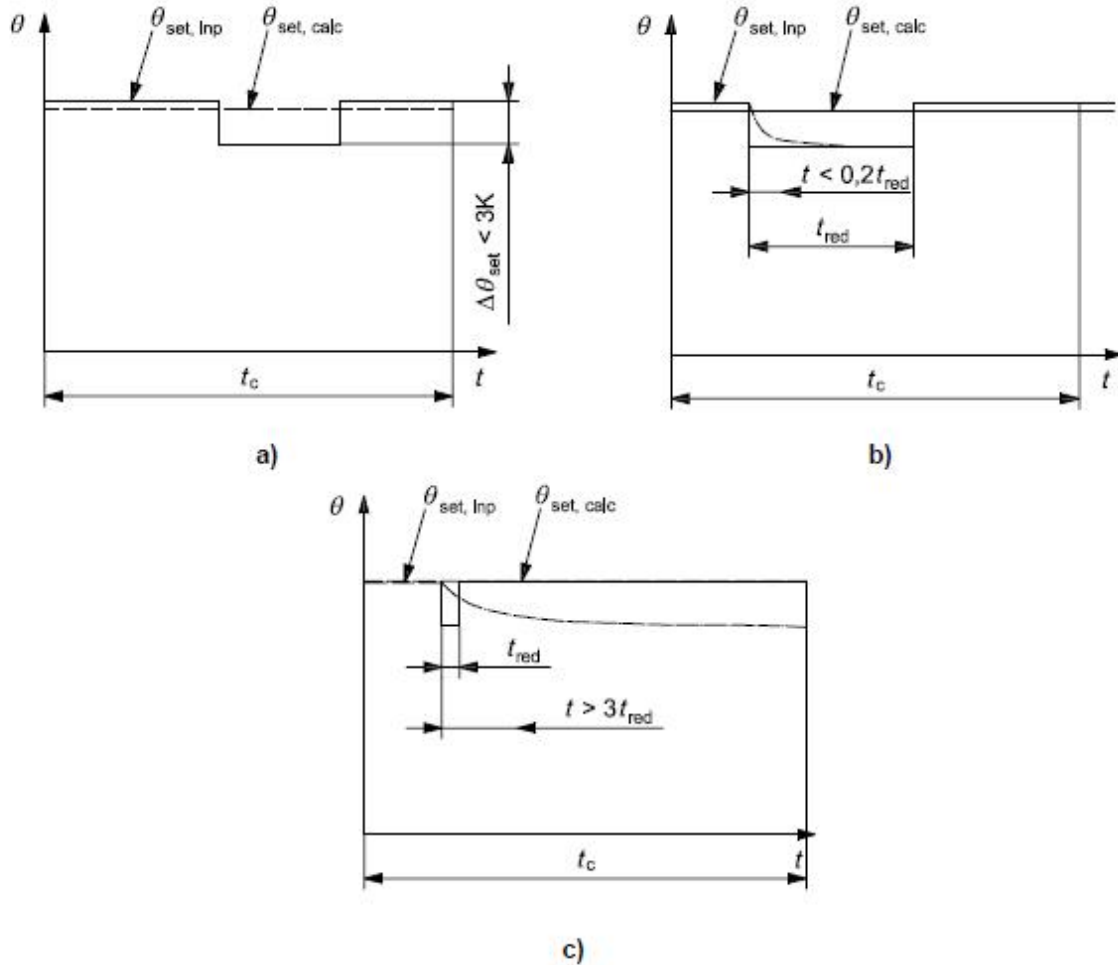
$f_{H,hr}$ is the fraction of the number of hours in the month with a normal heating set-point (no reduced set-point or switch-off);

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

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 heating

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:

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

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

and where

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

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

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;

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

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

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

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

where

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

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

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

$Q_{NC,j}$ is the energy demand for cooling of the considered zone per month, 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, z_s , that are serviced by the same combination of systems:

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

where

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

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

$Q_{NC,yr,zs}$ is the annual energy demand for cooling for all building zones, z_s , 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 use for heating, $Q_{sys,H}$, and the annual energy use for cooling, $Q_{sys,C}$, including system losses are determined as a function of the energy demands for heating and cooling in the following way: as energy loss and auxiliary energy of the system, $Q_{sys_loss,H,i}$ and $Q_{sys_aux,H,i}$ and $Q_{sys_loss,C,i}$ and $Q_{sys_aux,C,i}$ per energy carrier i , expressed in MJ. The losses and auxiliary energy comprise generation, transport, control, distribution, storage, and emission.

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 the whole building, the 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

$$Q_{v-heat} = H_{v-heat} \cdot (q_i - q_e) \cdot n \cdot 0.0864$$

where

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

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

q_i is the internal (indoor) temperature (the heating set-point taken from the MNCM Activity database for the activity zone where the envelope belongs)

q_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

4.2.1.1. Ventilation heat loss coefficient

$$H_{v-heat} = r_a \cdot c_a \cdot u_{v-heat} \cdot A$$

where

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

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

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

A is the zone floor area, in m²

4.2.1.2. Ventilation air flow rate

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

where

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

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

h_{HR} is the efficiency of the heat recovery system. The default values are shown in Table 15, which can be over-ridden by the user.

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

$u_{v,n,heat}$ is the air flow rate through the conditioned space resulting from natural ventilation, in l/sm² floor area. This value has been obtained using the ventilation requirements as established in the MNMCM 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 15: 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

$$Q_{v-cool} = H_{V-cool} \cdot (q_i - q'_e) \cdot n \cdot 0.0864$$

where

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

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

q_i is the internal (indoor) temperature (the cooling set-point taken from the MNMCM Activity database for the activity zone where the envelope belongs)

q'_e is the external air temperature during the day, i.e., work hours (monthly average obtained from the hourly weather data for the location);

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

0.0864 is a conversion factor

4.2.2.1. Ventilation heat loss coefficient

$$H_{V-cool} = r_a \cdot c_a \cdot u_{v-cool} \cdot A$$

where

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

$r_a \cdot c_a$ 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 l/sm² floor area

A is the zone floor area, in m²

4.2.2.2. Ventilation air flow rate

$$u_{v-cool} = u_{v-inf} / 3.6 + u_{v,m}$$

where

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

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

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

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. The details for implementing demand-controlled ventilation are outlined below.

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

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

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

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

For zones whose ventilation is defined as natural, the options available in iSBEMmt 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 MNCM 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 MNCM activity database multiplied by the peak occupancy density during the occupied period (i.e., l/s.m²),

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

where FAR_{min} is the ventilation rate per person from the MNM 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 16.

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

Table 16: 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 ($u_{v-inf-stack}$)

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

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

where:

Q_{4Pa} is the air leakage characteristics for a pressure difference of 4 Pa, in $\text{m}^3\text{/hm}^2$ of outer envelope, i.e., the average volume of air (in $\text{m}^3\text{/h}$) that passes through unit area of the building envelope (in m^2) 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 17, 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).

θ_i is the internal (indoor) temperature (the heating set-point taken from the MNM Activity database for the activity zone where the envelope belongs)

		m3/h per m2 of outer enveloppe (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 ; non residential except industrial	low	0.5	1	2.5
	average	1	2	5
	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)			outer area/vol
leakages level		n4Pa	n10Pa	n50Pa	
single family	low	0.4	0.8	1.9	0.75
	average	0.8	1.5	3.8	0.75
	high	1.5	2.6	7.5	0.75
multi family ; non residential except industrial	low	0.2	0.4	1.0	0.4
	average	0.4	0.8	2.0	0.4
	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 floor area (exp n = 0.667)			outer area / floor area
leakages level		Q4Pa	Q10Pa	Q50Pa	
single family	low	0.9	1.8	4.5	1.8
	average	1.8	3.6	9.0	1.8
	high	3.6	6.3	18.0	1.8
multi family ; non residential except industrial	low	0.6	1.1	2.8	1.1
	average	1.1	2.2	5.5	1.1
	high	2.2	3.9	11.0	1.1
industrial	low	1.5	3.0	7.5	1.5
	average	3.0	5.3	15.0	1.5
	high	6.0	10.5	30.0	1.5

Table 17: Examples of leakages characteristics

Calculate infiltration due to the wind impact ($u_{v-inf-wind}$)

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

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

where:

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

ΔC_p is the wind pressure coefficient defined as:

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

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

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

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

Calculate the resulting air flow, u_{v-sw} , for each zone using the following equation:

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

where:

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

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

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

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

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

where:

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

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

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

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

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

where:

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

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

4.2.5. Outputs produced

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

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

4.3. Hot water demand

Demand for each zone is calculated as:

$$\text{Hot water Demand (MJ/month)} = \text{Database demand} * 4.18 / 1000 * \text{zone AREA} * \Delta T$$

where

Database demand is the hot water demand from the Activity database, in l/m^2 per month.

ΔT is the temperature difference (deg K that water is heated up), taken as $42^\circ K$ (assuming the water enters at $18^\circ C$ and is heated up to $60^\circ C$).

$4.18 / 1000$ 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:

$$\text{Distribution loss} = 0.17 * \text{Hot water demand}$$

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:

$$\text{Storage volume (litres)} = \text{Daily demand (MJ/day)} * 18$$

where

$$\text{Daily demand} = \text{Maximum monthly demand} / \text{Number of days in the month}$$

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

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

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

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 volume*⁵ is the storage volume, in litres, if the annual hot water demand were 5 MJ/m², i.e., it is calculated as = $(5/365) * 18 * \text{Area served}$

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:

$$\text{Loop length} = \text{sqrt}(\text{Area served}) * 4.0$$

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;

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) / 500

where

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:

$$W_{light} = \frac{\sum_{j=1}^{12} \left[N_j \times \left(\sum_{i=1}^{24} [P_j (F_{Dji} \times F_{Oji})] + \sum_{i=1}^{24} (P_{dj} \times F_{Od}) + (24 \times P_p) \right) \right]}{1000} \text{ kWh/m}^2 \text{ year}$$

With:

N_j = [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_{dj} = Display lighting power in W/m² for each hour of month j

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

F_{Oji} = 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 reference buildings, P_j

For the actual building

- **Where lighting parameters are not available:**

The user assigns a lamp type to each zone based on Table 18, where the luminaire efficacy can be pro-rated against the reference lighting curve (which is based on 55 luminaire lumens per circuit-watt) defined by the equation:

$$\text{Power density per 100 Lux} = 2.11 + 0.008 \times R + 0.069 \times R^2$$

to infer a power density per 100 lux for the general lighting.

where R is the ratio of the total wall area¹¹ to the total floor area, and the maximum value for R is 8. The power density per 100 lux is then multiplied by the illuminance level for the activity type, which is determined by the MNCM activity database, and divided by 100.

The resulting power density (W/m^2) will vary as a function of the geometry of each zone modelled.

- **Where a full lighting design has been carried out:**

Use the actual lighting circuit wattage, multiply it by the illuminance level for this zone from the Activity database, divide it by the illuminance level for which the lighting design was carried out, and divide it by the zone area.

- **Where lighting has been chosen but a full illuminance calculation has not been carried out:**

The user defines the lamp efficacy in lumens per circuit-watt and the light output ratio of the luminaire. The efficacy of the lighting system is then determined in terms of luminaire lumens per circuit-watt, which can be pro-rated against a reference lighting curve (which is based on 55 luminaire lumens per circuit-watt) defined by the equation:

$$\text{Power density per 100 Lux} = 2.11 + 0.008 \times R + 0.069 \times R^2$$

to infer a power density per 100 lux for the general lighting.

where R is the ratio of the total wall area to the total floor area, and the maximum value for R is 8. The power density per 100 lux is then multiplied by the illuminance level for the activity type, which is determined by the MNCM activity database, and divided by 100.

For the reference building

Obtain the installed power by dividing the illuminance level for the activity type by 100, then multiply by $3.75 \text{ W/m}^2/100 \text{ lux}$ for office, storage and industrial spaces or $5.2 \text{ W/m}^2/100 \text{ lux}$ for all other spaces and by the floor area of the space.

¹¹ For the purposes of the lighting power density calculation, the total wall area includes exposed facades and internal partitions, but not virtual partitions/walls used to define perimeter zones in open plan areas. The floor area should exclude voids in the floor or virtual ceilings.

Lamp Type	Luminaire lumens per circuit Watt	
	Side-lit and not daylight activities	Top-lit activities
LED	27.5	33.0
Tungsten and Halogen	7.5	9.0
Fluorescent - compact	22.5	27.0
T12 Fluorescent - halophosphate - low frequency ballast	25.0	30.0
T8 Fluorescent - halophosphate - low frequency ballast	27.5	33.0
T8 Fluorescent - halophosphate - high frequency ballast	32.5	39.0
T8 Fluorescent - triphosphor - high frequency ballast	36.3	43.5
Metal Halide	25.0	39.0
High Pressure Mercury	22.5	27.0
High Pressure Sodium	35.0	42.0
T5 Fluorescent - triphosphor-coated - high frequency ballast	37.5	45.0
Fluorescent (no details)	22.5	27.0

Table 18: Luminous efficacies used by SBEMmt in correspondence to the lamp types selected

4.4.2. Calculate display lighting power in the actual and reference buildings, P_{dj}

For the actual building

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 MNMCM display lighting value associated with the activity.

For the reference building

The display lighting in the reference building is based on the display lighting power density from the MNMCM activity database.

4.4.3. Calculate parasitic power, P_p

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 standalone sensors = 0.3 W/m², or user can specify value for system used.
- Occupancy sensing: default = 0.3 W/m², 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 SBEMmt 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:

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

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

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

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:

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

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 location from the weather data set.

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 SBEMmt) 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 SBEMmt) a period when the lighting is required follows a period when the lighting is not required
- (not currently included in SBEMmt) following a period when the space has been completely unoccupied for at least an hour; or
- (not currently included in SBEMmt) 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:

$$F_D = (\text{area daylit by side windows}) * 0.5 + (1 - \text{area daylit by side windows}) * 0.5$$

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.

4.4.5. Occupancy correction, F_{Oji}

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

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

In corridors and other circulation areas and sales and display areas, F_o equals 1 even if occupancy sensing or manual control is provided, unless an automatic time switch switches off the lighting.

4.4.5.1. Local occupancy sensing

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

In these expressions F_{OC} is given in Table 19. System types are defined in the CEN standard PrEN 15193: *Energy performance of buildings — Energy requirements for lighting*.

Occupancy Sensing	F_{OC}
<i>Systems without automatic presence or absence detection</i>	
Manual On/Off Switch	1.00
Manual On/Off Switch + additional automatic sweeping extinction signal	0.95
<i>Systems with automatic presence and/or absence detection</i>	
Auto On / Dimmed	0.95
Auto On / Auto Off	0.90
Manual On / Dimmed	0.90
Manual On / Auto Off	0.82

Table 19: F_{OC} values

4.4.6. Time switching – used for display lighting only – calculate F_{Od}

Automatic time switch:

If there is an automatic time-switch for display lighting, then

$$F_{Od} = 1 - f$$

where $f = 0.2$ to represent a reduction of 20% in the power density of display lighting.

If there is no time-switch for display lighting, then $f = 0$.

4.5. 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.

4.6. Cooling energy use

Cooling energy use is determined on a monthly basis for each HVAC system defined in the building. Having calculated the energy demand for cooling in each zone of the building (Q_{NC}) as described in section 4.1.8, 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.

4.7. 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, SBEMmt 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/m²) and then multiplied by the area of the zone in (m²), 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 with the heating is at the set-point in the daily/weekly/annual schedules from the MNM 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 20 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 21 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 ¹² only	Yes
Central heating using water: convectors	LTHW only	Yes
Central heating using water: floor heating	LTHW only	Yes
Other local room heater - fanned	None	No
Other local room heater - unfanned	None	No
Unflued radiant heater	None	No
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 ¹³	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
Terminal reheat (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 20: 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 21: Pump power density for actual building

¹² Low temperature hot water

¹³ Chilled water

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 22:

$$FPS_1 = (FAR_{max} \times SFP_{central}) + (SCR \times SFP_{terminal})$$

$$FPS_2 = \text{Greater of } (FAR_{max}, SCR) \times SFP_{central}$$

$$FPS_3 = \text{Greater of } \left(\frac{SCR}{5}, FAR_{max} \right) \times SFP_{central}$$

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

where FAR_{max} is the peak fresh air supply rate (l/s.m²) that is set by the MNM 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:

$$SCR = \frac{\text{Greater of } (PSH, PSC)}{(r \times C_p \times \Delta T)}$$

where $\rho = 1.2 \text{ kg/m}^3$, $C_p = 1.018 \text{ kJ/kgK}$, $\Delta T = 8\text{K}$, 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	-
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
Indoor packaged cabinet (VAV)	FPS ₁
Fan coil systems	FPS ₁
Induction system	FPS ₃
Constant volume system (fixed fresh air rate)	FPS ₂
Constant volume system (variable fresh air rate)	FPS ₂
Terminal reheat (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 22: 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 MNCM 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)

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

$$\text{Distribution efficiency} = \frac{\text{Hot water demand (MJ/month)}}{\left[\text{Hot water demand (MJ/month)} + \text{Distribution losses (MJ/month)} \right. \\ \left. + \text{Storage losses (MJ/month)} + \text{Secondary circulation losses (MJ/month)} \right]}$$

Calculate hot water energy consumption for the HWS as:

Hot Water energy consumption

$$\text{Hot water energy consumption (MJ/month)} = \frac{\left[\frac{\text{Hot water demand}}{\text{Distribution efficiency}} \right]}{\text{HW generator efficiency}}$$

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

$$\text{Hot water energy consumption (MJ/month)} = \frac{\left[\left(\frac{\text{Hot water demand}}{\text{Distribution efficiency}} \right) - \text{Contribution from CHP} \right] - \text{Contribution from solar water heating system}}{\text{HW generator efficiency}}$$

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 23 and Table 24, respectively.

For the purposes of SBEMmt 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

General

- HWS which the solar energy system is serving: Specifies the name given by the user for the hot water system (HWS) to which the solar energy system (SES) is connected. This parameter is needed for the software to know the primary fuel that is being displaced by the solar energy system.
- Area: specifies the solar collector maximum projected area through which un-concentrated solar radiation enters the collector, in m²
- Orientation: specifies the orientation of the solar 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
N
NE
E
SE
S
SW
W
NW

Table 23: Orientations for which the solar radiation has been calculated

Inclinations
0
15

30
45
60
75
90

Table 24: 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 25 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.
- a_1 : is the linear heat loss coefficient from the collector test standards EN 12975-2 and related to the aperture area, in W/m^2K .
- a_2 : is the temperature dependence of the heat loss coefficient from the collector test standards EN 12975-2 and related to the aperture area, in W/m^2K
- 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 25: 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.

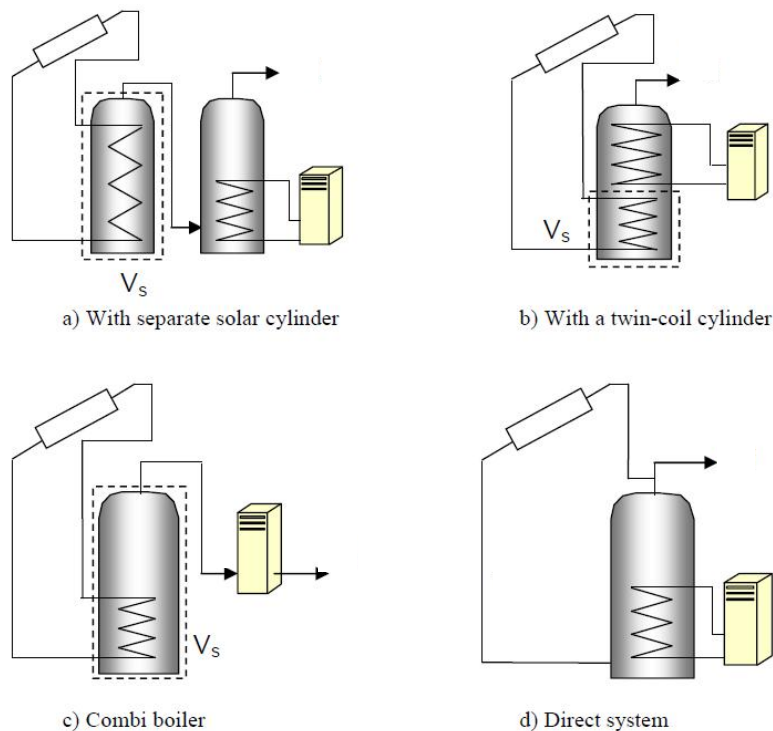


Figure 10: Arrangements for solar pre-heating (these schematics are not intended to show safety measures and devices needed to make the systems safe - Adapted from SAP 2005.

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: $Q_{W,sol,use,mi}$, in KWh

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

$$Q_{W,sol,use,mi} = Q_{W,sol,out,mi} - Q_{sol,ls,mi} , \text{ where}$$

- $Q_{W,sol,out,mi}$ is the heat output of the solar thermal system in month i, in kWh
- $Q_{sol,ls,mi}$ are the thermal losses of the solar system in month i, in KWh

Solar thermal output system: $Q_{W,sol,out,mi}$

The output of the solar thermal system is calculated as:

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

where

- $Q_{W,sol,us,mi}$ 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.

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

- 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 $U_{loop,p} = 5 + 0.5 \cdot A$
- η_{loop} is the efficiency factor of the collector taking into account the influence of the heat exchanger calculated as:
 - if the heat exchanger characteristics in the collector loop are known, then
 - § $\eta_{loop} = 1 - \Delta\eta$, where,
 - $\Delta\eta = \frac{(\eta_o \cdot A \cdot a_1)}{(U_{st})_{hx}}$ and $(U_{st})_{hx}$ is the heat transfer rate of the heat exchanger(s) in the solar loop, in W/K
 - For direct systems, $\Delta\eta = 0$
 - if the heat exchanger characteristics in the collector loop are not known, then $\eta_{loop}=0.85$
- ΔT_{mi} is the reference temperature difference in month i
 - § $\Delta T_{mi} = T_{ref,mi} - T_{e,avg,mi}$, where
 - $T_{ref,mi}$ is the reference temperature in 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 from the weather data set

- f_{st} is the storage tank capacity correction factor, $f_{st} = \left(\frac{V_{ref}}{V_{sol}}\right)^{0.25}$
 - V_{ref} is the reference volume equal to 75 litres per m^2 of collector
 - V_{sol} is the solar storage tank volume, in litres
- t_{mi} is the length of month i, in h
- $Q_{W(H),sol,us,mi}$ 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

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

- 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 26. The values used are those calculated in the f-chart method (*John A. Duffie and William A. Beckman: Solar Engineering of Thermal Process. Wiley-Interscience ed., 1991*).

Correlation factors for collector arrays connected to hot water storage tanks	
a	1.029
b	-0.065
c	-0.245
d	0.0018
e	0.0215
f	0

Table 26: Correlation factors - Adapted from EN 15316-4-4:2007

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

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

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

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

§ $P_{aux,nom}$ is the nominal input power of the circulation pumps, in W.

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

§ $t_{aux,mi}$ 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: $Q_{sol,ls,mi}$

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

$$Q_{sol,ls,mi} = Q_{W,sol,st,ls,mi} + Q_{bu,dis,ls,mi}, \text{ where}$$

○ 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 $Q_{bu,dis,ls,mi}$

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

SBEMmt 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 23 and Table 24, respectively. The algorithms used in SEBM follow the standards EN 15316-46:2007.

4.10.1. Definition of algorithms

Photovoltaic electricity generation

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

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

- $E_{el,PV,out}$ is the annual electricity produced by the photovoltaic modules, in kWh
- P_{pk} is the PV array installed peak power, in kW_p, obtained under standard test conditions¹⁴. It is calculated according to $P_{pk} = K_{pk} \cdot A$, where
 - K_{pk} is the default peak power coefficient depending on the type of building integration of the photovoltaic modules as given in Table 27.
 - A is the area of the photovoltaic panels, excluding the supporting construction (without the frame), in m²
- E_{sol} is the annual solar radiation on the PV system, in kWh/m²
- $f_{shading}$ is the over-shading factor taken from the Table 28 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 29 according to the ventilation strategy of the PV array (definitions in Table 30).
- I_{ref} is the reference solar irradiance equal to 1 kW/m²

Module type	Peak power coefficient in kW _p /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 27: 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)

¹⁴ Reference testing values of cell temperature $\theta=25^{\circ}\text{C}$, in plane irradiance $I_{ref}=1 \text{ kW/m}^2$, air mass solar reference spectrum AM=1.5 for a PV module or a PV cell testing – EN 6182.9

Level of over-shading	Mono crystalline silicon	Multi crystalline silicon	Multi layer thin film amorphous silicon	Other thin film layers	Thin film copper-indium-gallium-diselenide	Thin film cadmium-telluride
None or very little <20%	1	1	1	1	1	1
Modest [20-60%]	0.7	0.7	0.8	0.8	0.8	0.8
Significant [60-80%]	0.5	0.5	0.6	0.6	0.6	0.6
Heavy >80%	0.3	0.3	0.4	0.4	0.4	0.4

Table 28: 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 amorphous 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
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 29: 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.
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 30: PV array ventilation strategy definitions

Carbon dioxide displaced by photovoltaic electricity

$$C_{PV} = E_{el,PV,out} \cdot c_D$$

where

C_{PV} are the annual 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

- Annual 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 weather data set, 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 SBEMmt purposes, this efficiency is considered to change with the monthly wind speed and turbine rated power according to Table 32.

Terrain type	K_R terrain factor	z_0 (m) roughness length
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 31: Terrain categories and related parameters (CIBSE, 2002)

Product of mean monthly wind speed (m/s) and $C_R(z)$ coefficient	Small turbines (<80 kW)	Medium turbines (>80 kW)
[0,3]	0 %	0 %
[3,4]	20%	36%
[4,5]	20%	35%
[5,6]	19%	33%
[6,7]	16%	29%
[7,8]	15%	26%
[8,9]	14%	23%

>9	14%	23%
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Table 32: Wind turbine efficiencies

4.11.2. Definition of algorithms

Wind turbine electricity generation

$$Q_{WT} = 0.5 \cdot r \cdot (C_R(z) \cdot V_o)^3 \cdot A \cdot EPF \cdot K_{WT} \cdot 24 \cdot N / 1000 \quad [\text{kWh}]$$

where

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

r is the air density $\sim 1.225 \text{ kg/m}^3$

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

$$C_R(z) = K_R \cdot \ln(z / z_o)$$

where

K_R is the terrain factor (Table 31)

z_o is the roughness length (Table 31)

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:

$$A = p \cdot D^2 / 4$$

where

D is the wind turbine diameter, in m

EPF is the energy pattern factor calculated using the hourly wind speed data from the weather data set:

$$EPF = \frac{APD}{0.5 \cdot r \cdot V_o^3}$$

where

APD : is the average power density, in W/m^2 , calculated as

$$APD = \frac{\sum_{i=1}^{8760} 0.5 \cdot r \cdot V_i^3}{8760}$$

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_{WT} : is the wind turbine efficiency of conversion, in %, as given in Table 32.

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:

$$A_{VAWT} = \frac{p \cdot D_e^2}{4}$$

where

A_{VAWT} is the swept area of the vertical axis wind turbine, in m^2

D_e vertical axis wind turbine equivalent diameter used for the calculations

Carbon dioxide displaced by wind turbines

$$C_{WT} = Q_{WT} \cdot c_D$$

C_{WT} is the annual carbon dioxide emissions displaced by the electricity generated by the wind turbine, in $kgCO_2$

c_D is the amount of carbon dioxide displaced by each unit of electricity produced by the wind turbine.

4.11.3. Outputs produced

- Annual 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 weather data set as supplied by the Malta Met Office.
- 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 annual useful heat supplied by the CHP plant divided by the total annual fuel energy input (using the gross calorific value).
- Power seasonal efficiency: is the total annual power generated by the CHP plant divided by the total annual 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 iSBEMmt 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

$$F = \frac{H_{SH} \cdot p_{SH} + H_{HW} \cdot p_{HW} + \frac{H_{SC} \cdot p_{SC}}{SEER}}{h_{TH}}$$

where

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

H_{SH} is the annual space heating demand of the building, in kWh

p_{SH} is the annual proportion (fraction) of the space heating demand supplied by the CHP plant

H_{HW} is the annual hot water demand of the building, in kWh

p_{HW} is the annual proportion (fraction) of the hot water demand supplied by the CHP plant

H_{SC} is the annual space cooling demand of the building, in kWh

p_{SC} is the annual proportion (fraction) of the space cooling demand supplied by the heat fired chillers

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

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

Carbon dioxide generated by the CHP plant fuel requirements

$$F_C = F \cdot c$$

where

F_C is the annual carbon dioxide emission due to the fuel used by the CHP plant, in kgCO₂

F is the CHP plant fuel requirements, in kWh

c is the carbon emission rate of the fuel used by the CHP plant, in kgCO₂/kWh, as taken from Approved Document L2A

Electricity generated by the CHP plant

$$E = F \cdot h_E$$

where

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

h_E is the seasonal power efficiency of the CHP plant

Carbon dioxide displaced by the CHP plant

$$C_E = E \cdot c_D$$

C_E is the annual 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.

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 SBEMmt

SBEMmt requires data to be presented in a standard format through an input interface. iSBEMmt (interface to SBEMmt) was commissioned by MRRA to fulfil the role of default interface.

5.1. iSBEMmt

The iSBEMmt input module acts as the interface between the user and the SBEMmt 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 and the EPC generation module.

5.1.1. Logic behind iSBEMmt structure

iSBEMmt 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 iSBEMmt, 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 iSBEMmt collects the data for SBEMmt

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 *iSBEMmt User Guide*¹⁵, but, in summary, the forms deal with the following:

- General
 - Project and assessor details
 - File handling
- Project database - setting up the constructions used in the building
 - Walls
 - Roofs
 - Floors
 - Doors
 - Glazing
- Geometry - definition for each building element surrounding every zone:
 - Size
 - orientation
 - construction
 - links between elements
- Building services - setting up the systems used in the building
 - HVAC systems
 - Hot water generators including solar hot water

¹⁵ Available from epc.gov.mt.

- 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 SBEMmt

SBEMmt calculates the energy consumption and consequent CO₂ 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 such as building regulations compliance and asset rating calculations. However, MRRA felt that SBEMmt should, for the time being, only be used in Malta for the production of asset rating of local non-residential buildings.

6.1. 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”. 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 SBEMmt. 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 actual building (the BER) and those of a “reference” building subjected to a specified “improvement factor”. The reference building is equivalent to the actual building in geometry, usage, and location, but with fixed construction data, that is generally in line with Guide F requirements, fixed glazing factors for different orientations, fixed fuel sources for water heating and space cooling and heating, and fixed HVAC efficiencies and ventilation strategy.

The description of the reference building and the EPC rating scale are defined in the MNM Modelling Guide. The EPC will also display the numerical value on which the rating is based, to aid differentiation within rating bands.

SBEMmt is capable of working out the intrinsic energy and carbon performance of buildings against the standardised operating patterns required for the asset rating.

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APPENDIX A: 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.

A1.0 Schematic logic of filtering process

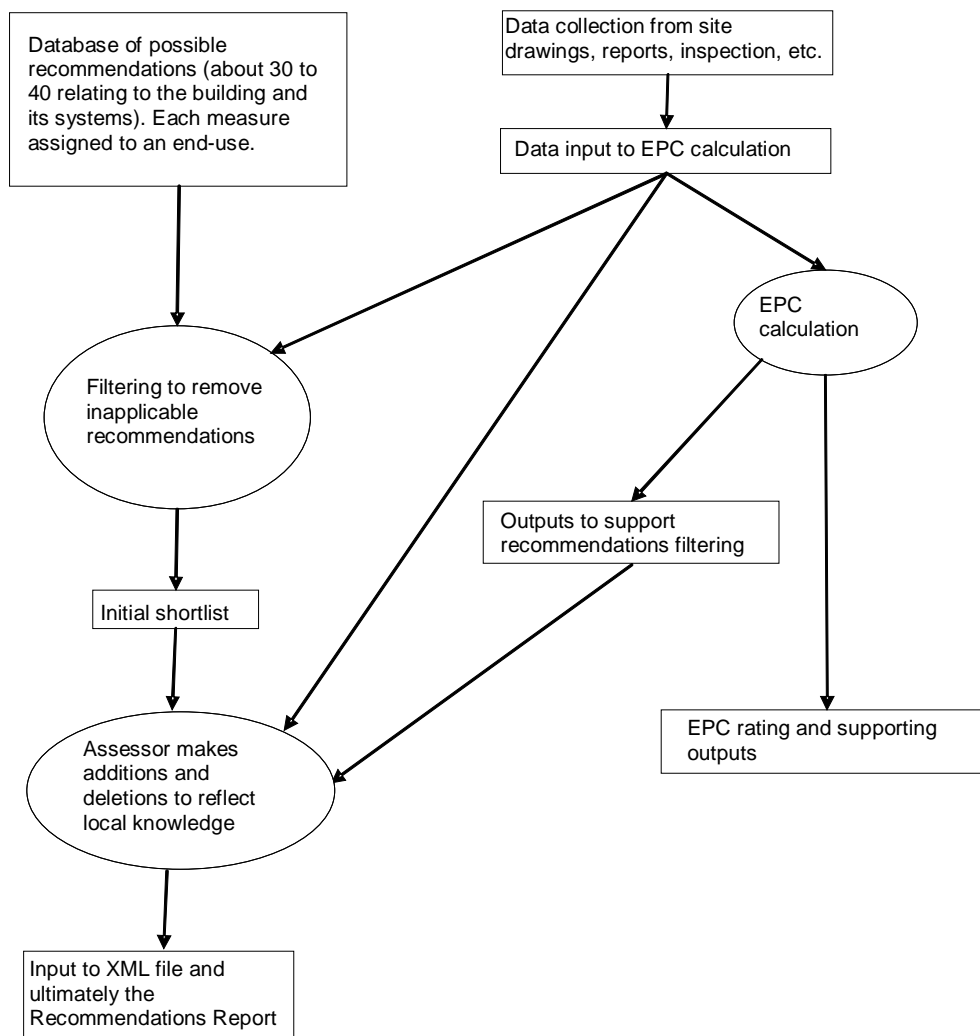


Figure 11: Schematic logic of recommendations filtering process

The filtered recommendations are intended to guide assessors, who have the final responsibility for them. Assessors are able to remove, edit, or add recommendations. They may also comment on recommendations and provide justification for additions and removals.

The format of the Recommendations Report shall be presented in a list form.

A2.0 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).

A2.1 Basic whole-building information

Note: For the purposes of assessing the recommendations, the Typical Building is assumed to have twice the energy consumption and CO₂ emissions of the Reference Building.

- From calculations already carried out for EPC rating, record Reference 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
 - 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
 - Heating kgCO₂/m², Cooling kgCO₂/m², Lighting kgCO₂/m², Hot water kgCO₂/m², Auxiliary kgCO₂/m²
 - Calculate % of “energy” (price-weighted?) attributable to each end-use
 - Calculate % of 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

A2.2 Categorise end-uses as good/fair/poor

A2.2.1 Heating

- **For heating**, compare Actual kWh/m² with Reference and Typical
 - If **Actual < Reference**, classify heating energy efficiency as “good”
 - If **Reference <= Actual < Typical**, classify heating energy efficiency as “fair”
 - **Otherwise**, classify heating energy efficiency as “poor”
- **For heating**, compare Actual kgCO₂/m² with Reference and Typical
 - If **Actual < Reference**, classify heating carbon efficiency as “good”
 - If **Reference <= Actual < Typical**, classify heating carbon efficiency as “fair”
 - **Otherwise**, classify heating carbon efficiency as “poor”

A2.2.2 Cooling

- **For cooling**, compare Actual kWh/m² with Reference
 - If **Actual < 0.85 x Reference**, classify cooling energy efficiency as “good”

- If **0.85 x Reference** <= **Actual** < **1.5 x Reference**, classify cooling energy efficiency as “fair”
- **Otherwise**, classify cooling energy efficiency as “poor”
- **For cooling**, compare Actual **kgCO₂/m²** with Reference
 - But ignore virtual cooling (overheating is captured later)
 - If **Actual** < **0.85 x Reference**, classify cooling carbon efficiency as “good”
 - If **0.85 x Reference** <= **Actual** < **1.5 x Reference**, classify cooling carbon efficiency as “fair”
 - **Otherwise**, classify cooling carbon efficiency as “poor”

A2.2.3 Lighting

- **For lighting**, compare Actual **kWh/m²** with Reference and Typical
 - If **Actual** < **Reference**, classify lighting energy efficiency as “good”
 - If **Reference** <= **Actual** < **Typical**, classify lighting energy efficiency as “fair”
 - **Otherwise**, classify lighting energy efficiency as “poor”
- **For lighting**, compare Actual **kgCO₂/m²** with Reference and Typical
 - If **Actual** < **Reference**, classify lighting carbon efficiency as “good”
 - If **Reference** <= **Actual** < **Typical**, classify lighting carbon efficiency as “fair”
 - **Otherwise**, classify lighting carbon efficiency as “poor”

A2.2.4 Domestic Hot Water

- **For hot water**, compare Actual **kWh/m²** with Reference and Typical
 - If **Actual** < **Reference**, classify hot water energy efficiency as “good”
 - If **Reference** <= **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 Reference and Typical
 - If **Actual** < **Reference**, classify hot water carbon efficiency as “good”
 - If **Reference** <= **Actual** < **Typical**, classify hot water carbon efficiency as “fair”
 - **Otherwise**, classify hot water carbon efficiency as “poor”

A2.2.5 Auxiliary

- **For Auxiliary**, compare Actual **kWh/m²** with Reference and Typical
 - If **Actual** < **Reference**, classify Auxiliary energy efficiency as “good”
 - If **Reference** <= **Actual** < **Typical**, classify Auxiliary energy efficiency as “fair”
 - **Otherwise**, classify Auxiliary energy efficiency as “poor”
- **For Auxiliary**, compare Actual **kgCO₂/m²** with Reference and Typical
 - If **Actual** < **Reference**, classify Auxiliary energy efficiency as “good”
 - If **Reference** <= **Actual** < **Typical**, classify Auxiliary energy efficiency as “fair”
 - **Otherwise**, classify Auxiliary energy efficiency as “poor”

A2.3 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*
- *These are generally applied **both** at project and individual component level (there may be exceptions where only one is meaningful)*

A2.3.1 Heating

A2.3.1.1 Heating efficiency

- Check if using default heating efficiency – if yes trigger **EPC-H4**
- 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 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 attributed to the heating system.

- If **0.70** >= heat generator efficiency, classify heat generator efficiency as “poor”
 - Trigger recommendation **EPC-H1** (high efficiency boiler) and if fuel is oil or LPG trigger **EPC-H3** (condensing boiler).
- If heating fuel is electricity, check heat generator efficiency, if less than 2, trigger recommendation **EPC-R1** (consider GSHP) and **EPC-R5** (consider ASHP)

A2.3.1.2 Heating controls

- Does the heating system have centralised time control?
 - If not trigger recommendation **EPC-H2**
- Does the heating system have room by room time control?
 - If not trigger recommendation **EPC-H5**
- Does the heating system have room by room temperature control?
 - If not trigger recommendation **EPC-H6**
- Does the heating system have optimum start and stop control?
 - If not trigger recommendation **EPC-H7**
- Does the heating system have weather compensation controls?
 - If not trigger recommendation **EPC-H8**

A2.3.2 Cooling

A2.3.2.1 Cooling Efficiency

- Check if using default cooling efficiency – if yes trigger **EPC-C1**
- **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**
 - If **2.0** > cold generator efficiency, classify cold generator efficiency as “poor”

§ Trigger recommendation **EPC-C2**

A2.3.2.2 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**

- If **10%** < = duct and AHU leakage, classify duct leakage as “poor”
 - § Trigger recommendation **EPC-C3**

A2.3.1.3 Cooling controls

- Does the cooling system have centralised time control?
 - If not trigger recommendation **EPC-C4**

- Does the cooling system have room by room time control?
 - If not trigger recommendation **EPC-C5**

- Does the cooling system have room by room temperature control?
 - If not trigger recommendation **EPC-C6**

- Does the cooling system have optimum start and stop control?
 - If not trigger recommendation **EPC-C7**

A2.3.3 Hot Water

A2.3.3.1 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**

- If **0.7** > = heat generator efficiency, classify heat generator efficiency as “poor”
 - § And trigger recommendation **EPC-W1** – as above

- If HWS efficiency is “poor”
 - § Trigger recommendation **EPC-W2**

A2.3.3.2 Hot water storage

- Check whether there is hot water storage
- If storage heat loss > default value*0.9, trigger recommendation **EPC-W3**

A2.3.3.3 Secondary HWS circulation

- If there is secondary HWS circulation and there is no time control
 - Trigger recommendation **EPC-W4**

A2.3.4 Fuel Switching

- If heating fuel is oil or LPG trigger recommendation **EPC-F4**

A2.3.5 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**
- Check whether any spaces have T8 lamps
 - § If they do, trigger recommendation **EPC-L5**
- Check whether any spaces have GLS lamps
 - § If they do, trigger recommendations **EPC-L2**
- Check whether any spaces (with fluorescent lamps) have mains frequency ballasts
 - § If they do, trigger recommendation **EPC-L7**
- Check whether any spaces have high-pressure mercury discharge lamps
 - § If they do, trigger recommendations **EPC-L3** and **EPC-L6**

A2.3.6 Renewables

- Is a wind turbine installed?
 - If not trigger recommendation **EPC-R2**
- Is solar thermal water heating installed?
 - If not trigger recommendation **EPC-R3**
- Is a photovoltaic system installed?
 - If not trigger recommendation **EPC-R4**

A2.3.7 Envelope

Roofs

Identify flat roofs

- If any have U value > **1.0**, trigger recommendation **EPC-E2**

Walls

Identify solid walls

- If any have U value > **1.0**, trigger recommendation **EPC-E3**

Identify cavity walls

- If any have U value > **1.0**, trigger recommendation **EPC-E4**

Glazing

Identify all glazing

- If any have U value > **3.5** (assumed single glazed), trigger recommendation **EPC-E5**
- And trigger recommendation **EPC-E8**

Floors

- If any have U value > **1.0** trigger recommendation **EPC-E1**

Airtightness

- If permeability > **14**, trigger recommendation **EPC-E7**

A3.0 Some caveats

These recommendations are 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.

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.

A4.0 Working list of EPC recommendations

CODE	DESCRIPTION	CATEGORY
EPC-C1	Default chiller efficiency	COOLING
EPC-C2	Install high efficiency chiller	COOLING
EPC-C3	Inspect and seal ductwork	COOLING
EPC-C4	Cooling central time control	COOLING
EPC-C5	Cooling local time control	COOLING
EPC-C6	Cooling room temperature control	COOLING
EPC-C7	Cooling optimum start and stop control	COOLING
EPC-W1	High efficiency water heater	HOT-WATER
EPC-W3	DHW storage insulation	HOT-WATER
EPC-W4	DHW secondary circulation time control	HOT-WATER
EPC-W2	DHW point of use system	HOT-WATER
EPC-E1	Insulate floor	ENVELOPE
EPC-E2	Insulate roof	ENVELOPE
EPC-E3	Insulate solid walls	ENVELOPE
EPC-E4	Cavity wall insulation	ENVELOPE
EPC-E5	Secondary glazing	ENVELOPE
EPC-E7	Pressure test	ENVELOPE
EPC-E8	Improve glazing	ENVELOPE
EPC-F4	Oil or LPG to biomass (heating)	FUEL-SWITCHING
EPC-H2	Heating central time control	HEATING
EPC-H5	Heating local time control	HEATING
EPC-H6	Heating room temperature control	HEATING
EPC-H7	Heating optimum start and stop control	HEATING
EPC-H8	Heating weather compensation controls	HEATING
EPC-H1	Install high efficiency boiler	HEATING
EPC-H3	Install condensing boiler	HEATING
EPC-H4	Default heat generator efficiency	HEATING
EPC-L1	T12 to T8	LIGHTING
EPC-L2	GLS to CFL	LIGHTING
EPC-L3	HP mercury to SON replacements	LIGHTING
EPC-L5	T8 to T5	LIGHTING
EPC-L6	HP mercury to SON	LIGHTING
EPC-L7	Mains to HF ballast	LIGHTING
EPC-R1	Consider GSHP	RENEWABLES
EPC-R2	Install wind turbine	RENEWABLES
EPC-R3	Install solar thermal water heating	RENEWABLES
EPC-R4	Install PV system	RENEWABLES
EPC-R5	Consider ASHP	RENEWABLES

Table 33: Working list of EPC recommendations

CODE	TEXT
EPC-C1	The default chiller efficiency is chosen. It is recommended that the chiller system be investigated to gain an understanding of its efficiency and possible improvements.
EPC-C2	Chiller efficiency is low. Consider either upgrading chiller plant or changing system to VRF.
EPC-C3	Ductwork leakage is high. Inspect and seal ductwork
EPC-C4	Add time control to cooling system.
EPC-C5	Add local time control to cooling system.
EPC-C6	Add local temperature control to the cooling system.
EPC-C7	Add optimum start/stop to the cooling system.
EPC-W1	Install more efficient water heater
EPC-W3	Improve insulation on DHW storage
EPC-W4	Add time control to DHW secondary circulation
EPC-W2	Consider replacing DHW system with point of use system
EPC-E1	Some floors are poorly insulated – introduce/improve insulation. Add insulation to the exposed surfaces of floors adjacent to underground, unheated spaces or exterior.
EPC-E2	Roof is poorly insulated. Install/improve insulation of roof.
EPC-E3	Some solid walls are poorly insulated – introduce/improve internal wall insulation.
EPC-E4	Some walls have uninsulated cavities - introduce cavity wall insulation.
EPC-E5	Some windows have high U-values - consider installing secondary glazing
EPC-E7	Carry out a pressure test, identify and treat identified air leakage. Enter result in EPC calculation
EPC-E8	Some glazing is poorly insulated. Replace/improve glazing and/or frames. (reworded)
EPC-F4	Consider switching from oil or LPG to biomass
EPC-H2	Add time control to heating system
EPC-H5	Add local time control to heating system
EPC-H6	Add local temperature control to the heating system
EPC-H7	Add optimum start/stop to the heating system
EPC-H8	Add weather compensation controls to heating system
EPC-H1	Consider replacing heating boiler plant with high efficiency type
EPC-H3	Consider replacing heating boiler plant with a condensing type
EPC-H4	The default heat generator efficiency is chosen. It is recommended that the heat generator system be investigated to gain an understanding of its efficiency and possible improvements.
EPC-L1	Replace 38mm diameter (T12) fluorescent tubes on failure with 26mm (T8) tubes
EPC-L2	Replace tungsten GLS lamps with CFLs: Payback period dependent on hours of use
EPC-L3	Replace high-pressure mercury discharge lamps with plug-in SON replacements
EPC-L5	Consider replacing T8 lamps with retrofit T5 conversion kit. (reworded)
EPC-L6	Replace high-pressure mercury discharge lamps with complete new lamp/gear SON (DL)
EPC-L7	Introduce HF (high frequency) ballasts for fluorescent tubes: Reduced number of fittings required
EPC-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 34: Text for EPC recommendations