Building energy performance tool

Documentation – v2.2

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List of Abbreviations

Abbreviation	Name	Unit
P_{inst}	Installed power	W
t	Time a system is running	h
T_{amb}	Ambient temperature outside the building	°C
$T_{av,amb}$	Average ambient temperature over the calculation period	°C
$T_{amb,design}$	Ambient design temperature	°C
$T_{amb,min}$	Minimum ambient temperature over the year	°C
u	U-value	W/(m²K)
A_{use}	Conditioned area in the building	m²
A_{env}	Area of the envelope elements (e.g. wall)	m²
AC	Air change rate	1/h
c_p	Specific heat coefficient	J/(kg*K)
ρ	Density	kg/m³
$k_{1,2}$	Heat transmission coefficient	W/(m²K) or W/(m²K²)
$_k$ *(subscript)*	Variable at the current state (usually 1 hour)	-
QF	Quality factor for systems	-
CF	Cost factor	-
η_{k,P_n}	Efficiency at design capacity	-
$\eta_{k,P_{int}}$	Efficiency at part load	-
η_k	Effective efficiency at the current state	-
Factor A, B, C, D	Factors to describe boiler efficiencies from the Norm DIN 18599-5	-
$q_{P0,70}$	Specific standby heat demand loss	Wh/m²
T_{supply}	Temperature of the system's supply fluid	°C
T_{design}	Temperature of the system's supply fluid at design capacity	°C
T_{part}	Temperature of the system's supply fluid at part load	°C
T_{min}	Lower limit temperature (for supply temperature)	°C
G_{rad}	Global radiation on a surface	Wh/m²
I_{rad}	Total solar irradiance on a surface	Wh/m²
A_C	Country adjustment	%
COP	Coefficient of performance	-
SCOP	Seasonal coefficient of performance	-
$q_{u,DHW}$	Specific useful energy demand (domestic hot water)	Wh/m²
$q_{f,DHW}$	Specific final energy demand (domestic hot	Wh/m²

Abbreviation	Name	Unit
	water)	
$q_{loss,DHW}$	Specific losses for domestic hot water demand	Wh/m²
$q_{loss,X}$	Specific losses in systems, e.g. for distribution, storage	Wh/m²
l_{pipe}	Pipe length	m
k_{pipe}	Specific heat loss factor	W/(m*K)
$k_{storage}$	Specific heat loss factor	W/(m³*K)
T_{in}	Temperature within the conditioned zone of the building	°C
$V_{storage}$	Storage volume	m³
ε	(Optical) conversion factor	-
H_T	Envelope quality factor (insulation)	W/(m²*K)
SFP	Specific fan power	W/m³
HR	Heat recovery rate	%
z(t)	Time variable for profile	-
q_{dehum}	Energy demand for dehumidification	kWh
$q_{dehum,air}$	Energy demand for dehumidification due to air flow	kWh
$q_{dehum,int}$	Energy demand for dehumidification due to internal sources	kWh
AH_{amb}	Absolute humidity of air at ambient temperature	kg/kg
AH_{target}	Target absolute humidity	kg/kg
H_{evap}	Evaporation enthalpy of water	kWh/kg
AvH_{hour}	Average humidity per hour	kg/hour
GWP	Global warming potential	-
CO_2-eq	Carbon dioxide equivalent	kg
F	Shading factor	-

List of Acronyms

Acronym	Definition
BEP	Building energy performance
CFL	Compact fluorescent lamp
cm	Centimetre
CO_2	Carbon dioxide
DHW	Domestic hot water
DIN	German Industry norm
EER	Energy efficiency ratio

Acronym	Definition
GHG	Greenhouse gas
h	Hour
HVAC	Heating, ventilation, and air conditioning
ISO	International Organization for Standardization
K	Kelvin
kg	Kilogram
kW	Kilowatt
l	Litre
LED	Light-emitting diode
LFL	Linear fluorescent lamp
LPG	Liquefied petroleum gas
m	metre
MFH	Multifamily house
PV	Photovoltaic
SEER	Seasonal energy efficiency ratio
SFH	Single-family house
VRF	Variable refrigerant flow
W	Watt
Wh	Watt-hour

Introduction to the building energy performance tool

The building energy performance (BEP) tool was created to calculate the useful, final, and primary energy demand of single buildings. In addition, it calculates the global cost of energy-related construction measures to determine the cost efficiency of renovation or new building projects. The tool can be accessed at https://globco.buildings-mena.com/.

This document is broken into three chapters:

- **Chapter 1:** Provides additional information for users on the **parameter inputs** of the web app
- **Chapter 2:** Explains the **calculation methodology** in more detail
- **Chapter 3:** Describes the definition and creation of the used **baseline buildings**

1. Documentation online web app

This chapter contains a detailed explanation, so users understand the available inputs in the online web app, including additional information about the parameters, factors, and HVAC systems.

The BEP Tool landing page provides users with three options: they can test the tool for free without registering, create a new account, or log in to an existing account to access saved projects or start new ones. By selecting the "Test" button, users will be directed to the input section of the BEP Tool. Similarly, after registering or logging in, users will be eventually guided to the same input sections, as described below.

The two main sections (1.1 and 1.2) are related to the two input tabs online (General information and Input). The subsections (1.1.1, etc.) are related to the headers of input parameter groups and the subsequent subsections (1.1.1.1, etc.) are the actual parameters that need to be defined online.

1.1 General information

This is the introduction tab. It includes all the general information to set the baseline building.

1.1.1 Project

1.1.1.1 Project name

User must enter a name for the current project. This name will be used in the output graph and table and to save the project.

1.1.2 Location

1.1.2.1 Country

User selects the country where the project is located.

1.1.2.2 Reference city

The reference city is used to select the representative climate according to the region in which the project is located. For each country, various reference cities are available to choose from to ensure the building project is calculated with the correct regional climate input. It is important that the reference city is close to the actual project location and that it has similar climate conditions.

1.1.2.3 Specify baseline

The region—in terms of urban, suburban, village, certain part of country, etc.—also has an impact on the baseline standard. Depending on the country, current average buildings in urban areas have different refurbishment levels, geometries, or HVAC systems than in rural areas. A detailed overview of the effects on the baseline buildings is published on the BUILD_ME website.

Define own baseline - This feature allows the user to customize the baseline by selecting the “Define my own on the next tab” option. Upon selection, an additional tab named "Input Own Baseline" will appear after the "General information" tab, where users can input baseline details.

EPC Baseline - This functionality is only available to people involved in the EPC workflow of the selected country (EPC Expert, EPC Auditor and EPC Scheme Operator). The EPC Baselines are recognizable by the suffix "EPC" and should be selected to start an EPC workflow. Detailed information on the EPC process and additional functionality is included in the EPC Expert Curriculum.

1.1.3 Building type

1.1.3.1 Select building type

The building type must be selected by clicking on the icons. Six types of buildings are available:

- Single-family house (SFH)
- Small multifamily house (SMFH)
- Large multifamily house (LMFH)
- Office
- Schools
- Hotels

Further explanations regarding the building types, their specifications, and photos of representative buildings are available on the BUILD_ME website.

This selection (and the location in the next step) defines the baseline building used to compare the energy performance of the project building. The parameters of the baseline building are also set as default values in the next tab (Input, discussed in Section 1.2). An overview of the baseline buildings is published on the BUILD_ME website.

1.1.3.2 Age group

The **age group** selection is relevant for multiple reasons:

- **Different price assumption.** The renovation case includes 5% additional cost because it generally is related to higher installation cost compared to a new build.
- **Envelope insulation cost consideration.** The insulation cost for the envelope is considered if the insulation is better (u-value is lower) than in the baseline case. However, for the renovation case, the theoretical additional cost for the envelope can be not considered (selection in the Input tab)—e.g. to reflect that the envelope was refurbished in a former project. If new building is selected, the theoretical additional cost is always considered because it is part of the current construction project.

1.1.4 System selection

The systems installed in the project building should be selected here (green button = installed). The default selection depends on the baseline building and represents the typical local standard; however, this can be changed.

The selection can be still adapted in the Input tab.

1.1.5 Mode

This selection allows users to differentiate the Input tab between unexperienced and expert users. If Advanced mode is enabled, the following **additional selections** can be made:

- Wall area according to orientation
- Window area according to orientation
- Thermal heat bridges
- Envelope elements
    - Specific heat capacity and mass distribution
    - Wall and roof colour
- Operational parameters
    - Internal heat gains
    - Additional electricity consumption
    - Cooling and heating setpoint temperature
    - Night setback

The mode can be changed later (after clicking Next) by going back to the General information tab.

1.2 Input

The following sections provide an overview of the input parameters for the calculation, including a more detailed description of each parameter and a list of the calculation aspects these parameters have a relevant impact on.

1.2.1 Geometry-related parameters

Parameter	Description	Relevant for
Building levels (floors)	Number of floors in the building.	Hot water and heat distribution pipes and the related losses
Number of units	Number of separated apartments in residential buildings (SFH = 1).	Hot water demand, which is related to the living area
Net floor height (m)	Room height within the living areas.	Air volume in the building (conversion of air exchange rate into actual volume)

Parameter	Description	Relevant for
Net floor area (m²)	Entire conditioned area of the building (MFH: use the building area, not the apartment area).	• Output of specific energy demand and cost • Air volume in the building • Hot water demand • Building's other electricity demand *High impact on the calculation*
Roof area opaque (m²)	Area of the upper conditioned zone to the outside.	• Cooling/heating losses through transmission • Insulation cost of the roof • Design cooling capacity
Orientation of the building (0 - 89°, where 0° indicates a façade oriented due south)	The alignment of the building relative to cardinal directions. A 0° orientation means that one of the building's façades directly faces south.	More detailed calculation of the heat gains (depending on sun radiation on the façade)
Façade area opaque (excluding windows) (m²)	Vertical (not transparent) area of the conditioned zones to the outside.	• Cooling/heating losses through transmission • Insulation cost of the wall • Design cooling capacity
Share of façade to orientation (m²) *(only in Advanced mode)*	Divide the total façade area into the part facing north, east, south, and west, respectively.	More detailed calculation of the heat gains (depending on sun radiation on the façade)
Window area (m²)	Transparent vertical and horizontal area of the conditioned zones to the outside, including the frame area of the windows.	• Cooling/heating losses through transmission • Cost of the windows • Design cooling capacity
Share of windows to orientation (m²) *(only in Advanced mode)*	Divide the total window area into the part facing north, east, south, and west, respectively.	More detailed calculation of the heat gains (depending on sun radiation on the façade)
Area floor slab (m²)	Area of the lowest conditioned zone against an unconditioned zone (cellar) or the soil.	• Cooling/heating losses through transmission • Insulation cost of the wall • Design cooling capacity

1.2.2 Wall

Parameter	Description	Relevant for
Wall renovation	Only relevant for renovation cases; indicate if the element renovation was part of the project. If No is selected, no costs are considered for this element.	Cost of the element
Absorption	Select the colour type of the building in three different categories (dark, intermediate, light). Dark elements absorb more heat from the sunlight than light colours.	• Heat gains through solar radiation on the element *Low effect on results*
Specific heat capacity (J/(m²K))	Depends on the construction material—materials with higher heat capacity store heat longer. See for more external information: greenspec.co.uk.	• Thermal dynamic behaviour of the building (e.g. adaption to temperature changes) *Low effect on results*
Mass distribution	Spatial distribution of mass within the solid building element. If one homogenous material is used, the mass is equally distributed. A displacement is caused if high proportions of insulation material are used. In this case, the mass core of the element shifts away from the insulated side (e.g. outside is insulated → Class M: Mass concentrated inside). More information is available here.	• Thermal dynamic behaviour of the building (e.g. adaption to temperature changes) *Low effect on results*
U-value (W/(m²K))	Heat transfer coefficient of the building material; describes the amount of heat transferred to the element depending on the temperature difference between outside and inside. A higher u-value causes more heat transfer and has higher cooling/heating demands as a consequence. For additional external information on this topic see: NBS UK or greenspec.co.uk.	• Heating/cooling gains/losses transmitting through the element • Sizing of cooling capacity • Necessary insulation thickness and cost of element *High impact on the energy calculation*
Thermal heat bridge (W/(m²K))	Like the u-value, except it considers the additional heat transfer caused by no insulation in element corners, borders, etc. Added on top of the u-value in this tool.	Heating/cooling gains/losses transmitting through corners and borders of the element

1.2.3 Roof

Parameter	Description	Relevant for
Roof renovation	Only relevant for renovation cases; indicate if the element renovation was part of the project. If No is selected, no costs are considered for the element.	Cost of the element
Absorption	Select the colour type of the building in three different categories (dark, intermediate, light). Dark elements absorb more heat from the sunlight than light colours.	Heat gains through solar radiation on the element *Low effect on results*
Specific heat capacity (J/(m²K))	Depends on the construction material—materials with higher heat capacity store heat longer. Click here for more information.	• Thermal dynamic behaviour of the building (e.g. adaption to temperature changes) *Low effect on results*
Mass distribution	Spatial distribution of mass within the solid building element. If one homogenous material is used, the mass is equally distributed. A displacement is caused if high proportions of insulation material are used. In this case, the mass core of the element shifts away from the insulated side (e.g. outside is insulated: Class M: Mass concentrated inside). More information is available here.	• Thermal dynamic behaviour of the building (e.g. adaption to temperature changes) *Low effect on results*
U-value (W/(m²K))	Heat transfer coefficient of the building material; describes the amount of heat transferred to the element depending on the temperature difference between outside and inside. A higher u-value causes more heat transfer and has higher cooling/heating demands as a consequence. For additional external information on this topic see: NBS UK or greenspec.co.uk.	• Heating/cooling gains/losses transmitting through the element • Sizing of cooling capacity • Necessary insulation thickness and cost of element *High impact on the energy calculation*
Thermal heat bridge (W/(m²K))	Like the u-value, except it considers the additional heat transfer caused by no insulation in element corners, borders, etc. Added on top of the u-value in this tool.	Heating/cooling gains/losses transmitting through corners and borders of the element

1.2.4 Slab

Parameter	Description	Relevant for
Slab renovation	Only relevant for renovation cases; indicate if the element renovation was part of the project. If No is selected, no costs are considered for the element.	Cost of the element
Specific heat capacity (J/(m²K))	Depends on the construction material—materials with higher heat capacity store heat longer. Click here for more information.	• Thermal dynamic behaviour of the building (e.g. adaption to temperature changes) *Low effect on results*
U-value (W/(m²K))	Heat transfer coefficient of the building material; describes the amount of heat transferred to the element depending on the temperature difference between outside and inside. A higher u-value causes more heat transfer and has higher cooling/heating demands as a consequence. For additional external information on this topic see: NBS UK or greenspec.co.uk.	• Heating/cooling gains/losses transmitting through the element • Sizing of cooling capacity • Necessary insulation thickness and cost of element *High impact on the energy calculation*
Thermal heat bridge (W/(m²K))	Like the u-value, except it considers the additional heat transfer caused by no insulation in element corners, borders, etc. Added on top of the u-value in this tool.	Heating/cooling gains/losses transmitting through corners and borders of the element

1.2.5 Window

Parameter	Description	Relevant for
Window renovation	Only relevant for renovation cases; indicate if the element renovation was part of the project. If No is selected, no costs are considered for the element.	Cost of the element
Type (material)	Window type indicates the relevant window parameters: u-value and g-value (see next two rows).	• u-value and g-value of window • Cost of window
G-value	The g value of the glass defines how well the glass transmits heat from the sun. A g-value of 1.0 represents full transmittance of all solar radiation,	• Solar transmittance through window (heat gains) • Cost of window

Parameter	Description	Relevant for
	while 0.0 represents a window with no solar energy transmittance. In practice though, most g-values will range between 0.2 and 0.7, with solar control glazing having a g-value of less than 0.5. For additional information on window parameters visit greenbuildingstore.co.uk.	
U-value (W/(m²K))	Heat transfer coefficient of the building material; describes the amount of heat transferred to the element depending on the temperature difference between outside and inside. A higher u-value causes more heat transfer and has higher cooling/heating demands as a consequence. For additional external information on this topic see: NBS UK or greenspec.co.uk.	• Heating/cooling gains/losses transmitting through the element • Sizing of cooling capacity • Cost of element *High impact on the energy calculation*
Thermal heat bridge (W/(m²K))	Like the u-value, except it considers the additional heat transfer caused by no insulation in element corners, borders, etc. Added on top of the u-value in this tool.	Heating/cooling gains/losses transmitting through frames and borders of the element
Shading variant	Select different shading elements that can be installed to the building's transparent elements. Fixed shading: A fix horizontal element of about 30cm above the window is modelled that results in shading during high sun altitudes (summer). - Manual shading: Manually closed blends that shade 80% if the solar radiation on the window is >400 W/m² - Automatic shading: Automatic closed blends that shade 80% if the solar radiation on the window is >150 W/m² Click here for more information on the impact and assumptions of the different external shading variants.	• Solar radiation (heat gains) • Cost for shading elements
Shading factor	Many simplified models work with general shading factors (the proportion of sunlight on the window not blocked by the shading	Informational

Parameter	Description	Relevant for
	element). Informs the factor related to the selected shading element.	

1.2.6 Air change rate

Parameter	Description	Relevant for
Free ventilation (1/h)	Reflects the air change in the building caused by opening windows. The factor in 1/h is the proportion of total air volume of the building that is exchanged per hour. This should be set to 0 if mechanical ventilation is installed. Factor is not affected by setbacks (e.g. night setback), so user should provide the average value.	• Heating gains/losses through convection *High impact on the energy calculation*
Infiltration (1/h)	Reflects the (unwanted) air change in the building caused by cracks, door slots, etc. The factor in 1/h is the proportion of total air volume of the building that is exchanged per hour. For additional information see: Wikipedia.org.	• Heating gains/losses through convection • Cost (additional to the envelope because less infiltration implies better construction quality)

1.2.7 Space heating

Parameter	Description	Relevant for
Space heating system	Nine space heating systems are available (see the following list). If a system is not selectable, it is no longer relevant or accessible in the selected country. For more information on the calculation methodology, click here. For system-specific efficiencies, click on the system. • Gas non-condensing • Gas condensing • Oil non-condensing • Oil condensing • Portable LPG (gas) heater • Portable kerosene heater • Heat pump (air-water) • Heat pump (ground source)	• Final energy demand for heating • Investment cost of heating system *High impact on the final energy and global cost calculation*

Parameter	Description	Relevant for
	• Air conditioning system (reversible for heating; air-air heat pump)	
Efficiency class heating system	Select one of five efficiency classes, which reflect the spectrum of the systems available on the market. To indicate the resulting efficiency for the selected class, the standard efficiency at design capacity is displayed online (Resulting efficiency). The detailed parameters of all efficiency classes are available at the following links: • Gas non-condensing • Gas condensing • Oil non-condensing • Oil condensing • Portable LPG (gas) heater • Portable kerosene heater • Heat pump (air-water) • Heat pump (ground source) • Air conditioning system (reversible for heating; air-air heat pump)	Final energy demand • Cost (better efficiency class, results in higher investment cost but less energy cost)

1.2.8 Hot water generator

Parameter	Description	Relevant for
Primary technology	Hot water can be provided with dedicated hot water systems such as dedicated gas or electric heaters or as part of the space heating system (combi system). If the latter is selected, the energy carrier and system type is chosen by the Space heating selection. Only if the heating system is natural gas- and oil-fired boiler or air-water/ground source heat pumps combi system can be selected. For more information on the calculation methodology, click here	• Final energy demand for hot water • Investment cost of hot water system *High impact on the final energy and global cost calculation*
Efficiency class heating system	Select one of five efficiency classes, which reflect the spectrum of the systems available on the market. To indicate the resulting efficiency for the selected class, the standard efficiency at design capacity is	• Final energy demand • Cost (better efficiency class, results in higher investment cost but less energy cost)

Parameter	Description	Relevant for
	displayed online (Resulting efficiency). The detailed parameters of all efficiency classes are available at the following links; if it is a combined system, the efficiency will depend on the space heating system. • Dedicated gas heater • Dedicated electric heater	
Specific useful energy demand	Only visible in advanced mode and when the option “Select if user specific DHW demand to be used” is set to "Yes". The specific hot water demand can be entered manually here, and the calculation engine will consider the entered value as the specific useful energy demand for hot water production.	Final DHW energy demand
Solar system for DHW	If a solar system is installed for Domestic hot water (DHW) supply, select Yes.	Final DHW energy demand
Type of solar system	Flat collectors or tube collectors can be selected. Flat collectors are the cheaper technology. However, due to national programs and availability in the market, tube collectors with thermosyphon boiler can be a cheaper total investment cost. In general, tube collectors are more efficient. Thermosyphon systems have the hot water storage on top of the panel, whereas the complex systems have storage within the building (which is more complex, but also more efficient).	• Final DHW energy demand • Investment and energy cost
Installed area of solar collector	Installed area of solar collectors. Rough rule of thumb is 1 m^2-1.5 m^2 of solar collector area is enough to supply the hot water demand of one person (assumed 35 litres/day with 60°C).	• Coverage rate of solar at the entire DHW demand • Investment cost
Azimuth angle (0=South, 90=West, 180 = North, 270=East)	The azimuth angle of a solar collector refers to the horizontal angle between the collector's orientation and a reference direction, here true south. It determines the direction the collector faces on the horizontal plane, measured in degrees. For	Final DHW energy demand

Parameter	Description	Relevant for
	example, an azimuth angle of 0° indicates the collector is facing true south, while 180° means it is oriented due north.	
Inclination (0=horizontal, 90=vertical)	The inclination angle of a solar collector is the angle formed between the surface of the collector and the horizontal plane. It defines the tilt or slope of the collector, indicating how steeply it is positioned relative to the ground.	Final DHW energy demand
Country adjustment	An optional input where user can adjust the efficiency according to the country specific or system specific parameters.	Final DHW energy demand

1.2.9 Space cooling

Parameter	Description	Relevant for
Space cooling system	Seven space cooling systems are available (see the following list). If a system is not selectable, it is no longer relevant or accessible in the selected country. For more information on the calculation methodology, click here. For system-specific efficiencies, click on the system. • Centralised multi-split system: Consists of one outdoor unit (e.g. located on the rooftop) that supplies several indoor units • VRF: Centralised multi-split with variable refrigerant flow (VRF) • Mounted single split or window air conditioner: Usually a visible smaller system mounted outside the wall or above the window that supplies one room • Movable system: No fixed air conditioning system that can be moved around in the building units • Central system: Air vent distribution • Central system: Fan coil distribution	• Final energy demand for cooling • Investment cost of cooling system *High impact on the final energy and global cost calculation.*

Parameter	Description	Relevant for
	• Central system: Surface distribution	
Efficiency class cooling system	Select one of five efficiency classes, which reflect the spectrum of the systems available on the market or enter your own efficiency value. To indicate the resulting efficiency for the selected class, the standard efficiency at design capacity (Energy efficiency ratio (EER) at 35°C outside, 26°C inside) is displayed online (Resulting efficiency) or can be entered here. The efficiency classes for the split and single units are designed to reflect the spectrum of the energy efficiency classes of air conditioning systems by the European Commission, from A++ to G (see here: Regulations of the EU Commission). The calculation methodology is explained here. Central systems are designed to reflect the different available system types, from scroll to turbo compressors, demand controlled, air-vent or surface distribution, etc. For detailed information on central systems click here. The following links provide detailed parameters for all efficiency classes available in the tool: • Centralised multi-split system: Consists of one outdoor unit (e.g. located on the rooftop) that supplies several indoor units • VRF: Centralised multi-split with variable refrigerant flow • Mounted single split or window air conditioner: Usually a visible smaller system mounted outside the wall or above the window that supplies one room • Movable system: No fixed air conditioning system that can be moved around in the building units • Central system: Air vent distribution • Central system: Fan coil distribution	• Final energy demand • Cost (better efficiency class, results in higher investment cost but less energy cost)

Parameter	Description	Relevant for
	• Central system: Surface distribution	

1.2.10 Mechanical ventilation

Parameter	Description	Relevant for
Type of ventilation system	A mechanical ventilation system replaces the free ventilation and ensures a constant air exchange; it can also reduce heat losses through heat recovery. Three systems are available: one conventional mechanical ventilation and two systems with heat recovery. The heat recovery systems result in significantly higher investment costs but save energy cost (especially for heating). The difference between the two systems with heat recovery is the type of heat exchanger. Cross-flow heat exchangers are cheaper but achieve only about 70% heat recovery; rotary heat exchangers are more expensive and achieve up to 90% heat recovery (in the model the exact values of 70% and 90% are assumed). Free ventilation should be set to 0 if mechanical ventilation is installed.	• Heating gains/losses through convection • Investment cost *High impact on the energy calculation and investment cost*
Air change rate (1/h)	Reflects the volume of air exchanged by the mechanical ventilation system. The factor in 1/h is the proportion of total air volume of the building that is exchanged per hour. Factor is affected by setbacks; if night setback is selected, provide the maximum, not average, value.	• Heating gains/losses through convection • Energy cost (higher airflow can result in higher energy cost)
Heat recovery rate (%)	Heat recovery avoids losses caused by heated air flowing outside. Heat exchangers achieve, depending on the quality, 70%-90% of heat recovery, meaning the convective heat losses are reduced by 10%-30%.	• Heat losses by ventilation

Parameter	Description	Relevant for
	The detailed calculation methodology for heat recovery is described here.	

1.2.11 Photovoltaic

Parameter	Description	Relevant for
Capacity	Capacity of the photovoltaic (PV) system describes the power output of the entire system at standard conditions, i.e. its size. In the informational field, the approximate size to achieve the given capacity is displayed. The detailed calculation methodology for the electricity generated by PV is described here.	• Remaining electricity demand • Investment cost
Total module area	Approximate area needed to achieve the set capacity. If the PV is installed on a flat roof, additional roof space might be needed if the panels are not horizontal to avoid self-shading. The exact area depends on the angle in which the panels are lifted from the horizontal ground (e.g. flat roof).	N/A
Azimuth angle (0=South, 90=West, 180 = North, 270=East)	The azimuth angle of a PV panel refers to the horizontal angle between the PV panel's orientation and a reference direction, here true south. It determines the direction the panel faces on the horizontal plane, measured in degrees. For example, an azimuth angle of 0° indicates the panel is facing true south, while 180° means it is oriented due north.	Remaining electricity demand
Inclination (0=horizontal, 90=vertical)	The inclination angle of a PV panel is the angle formed between the surface of the panel and the horizontal plane. It defines the tilt or slope of the panel, indicating how steeply it is positioned relative to the ground.	Remaining electricity demand
Country adjustment	An optional input where user can adjust the efficiency according to	Remaining electricity demand

	the country specific or system specific parameters, like DC to AC ratio.	

1.2.12 Lighting

Parameter	Description	Relevant for
Type of lighting technology	Lighting technology can be selected. Electricity demand is calculated with a standard profile for residential or non-residential buildings (see here for more information).	• Electricity demand • Investment cost
Lighting sensors	Lighting sensors can be selected from the list, if available. The inclusion of lighting sensors will reduce electricity demand by automatically shutting off lights when they are not needed.	• Electricity demand • Investment cost

1.2.13 Other operating parameters

Parameter	Description	Relevant for
Internal heat gains	Enter the specific power (W/m²) of the daily average internal heat gains in the building. **Example:** If the total daily internal heat gains are 240 kWh/m², the entered value is 240 Wh/m²/24 h = 10 W/m². If only the maximum internal heat gains in W/m² is known (not the average), consider the profile (see here) to calculate the resulting average, which can be entered. Internal heat gains result from appliances (e.g. cooking stove), people, or lighting. In general, they vary significantly by building and use type. The specific heat gains in multifamily buildings are higher than in single-family houses because the population density is higher. Non-residential buildings, such as retailers, can have even higher internal heat gains if they are crowded. Orientation values for common use cases are as follows: • SFH: 1.9 W/m²	• Heating (and less cooling) energy demand

Parameter	Description	Relevant for
	• MFH: 3.8 W/m² • Office (general): 3.0 W/m² • Retailer (crowded): 4.5 W/m² More values are listed here. Factor is affected by setbacks; if night setback is selected, provide higher, not average, value.	
Additional electricity consumption	Includes all the electricity consumption not related to the HVAC systems or lighting. This is especially important when PV is considered because it has a high impact on the self-consumption rate. Therefore, a general user profile (see Section 2.1.5) is defined to distribute the selected electricity demand over the calculation period. No additional internal heat gains are derived from the electricity consumption level.	• PV feed in (with more electricity demand, less electricity is fed to the grid but self-used)
Setpoint temperature heating	Defines the lowest acceptable temperature within the conditioned area. The useful heating demand is determined to maintain this temperature level. During single hours this temperature may be undercut due to power restrictions of the heating system. If this border temperature should vary (e.g. during the night), it can be considered by enabling Night setback (see Night setback row).	• Useful heating demand *High influence on energy demand*
Setpoint temperature cooling	Defines the highest acceptable temperature within the conditioned area over the entire calculation period. The useful cooing demand is determined to maintain this temperature level. During single hours this temperature may be exceeded due to power restrictions of the cooling system. If this border temperature should vary (e.g. during the night), it can be considered by enabling Night setback (see Night setback row).	• Useful cooling demand *High influence on energy demand*
Conditioned area (heating)	Reduces the part of the conditioned area in comparison to the entire living area as defined in the geometry inputs. The calculated final heating demand is adapted by the factor the user provides for this input.	-

Parameter	Description	Relevant for
Conditioned area (cooling)	Reduces the part of the conditioned area in comparison to the entire living area as defined in the geometry inputs. The calculated final cooling demand is adapted by the factor the user provides for this input.	-
Night setback	Select if an adaption of the setpoint temperatures during a regular period should be considered. Most buildings are not conditioned to the same temperatures during the night as during the day—e.g. offices and schools (outside the operational hours) but also for residential buildings.	• Useful cooling / heating demand
Heating	Enter the setpoint temperature for heating (the lowest acceptable temperature within the conditioned area) during the night setback (e.g. outside operating time, during the night).	-
Cooling	Enter the setpoint temperature for cooling (the highest acceptable temperature within the conditioned area) during the night setback (e.g. outside operating time, during the night).	-
Start	Enter the time (24 h mode) when the night setback starts (e.g. end of operating time, beginning of night).	-
End	Enter the time (24 h mode) when the night setback ends (e.g. start of operating time, end of night). Example of Night setback: start = 22.0, end = 6.0 → night setback temperatures are applied from 10 p.m. to 6:00 a.m.	-

1.2.14 Manual cost input

This section is only visible if the toggle “Enter my own cost” is enabled on the first tab General Information.

It allows the user to enter total own investment cost for all elements and systems, respectively. The total investment value, incl. installation and necessary periphery must be considered and entered here. Only the filled input fields are considered. If no value is entered, the tool calculates the cost in the regular manner. However, if a value is entered, this will overwrite all internal cost calculation for this specific component and take the entered value. Note, no further reality check or comparison between the entered cost and the cost calculated internally for the chosen system is conducted, so if this is used, the numbers should be carefully chosen and adapted to the selected system and building size. The investment costs are treated as internally calculated initial investment cost and therefore also replacement, maintenance, inflation, etc. is considered over the calculation period.

2. Methodology calculation

Figure 1 shows an overview of the calculation methodology behind the online BEP tool.

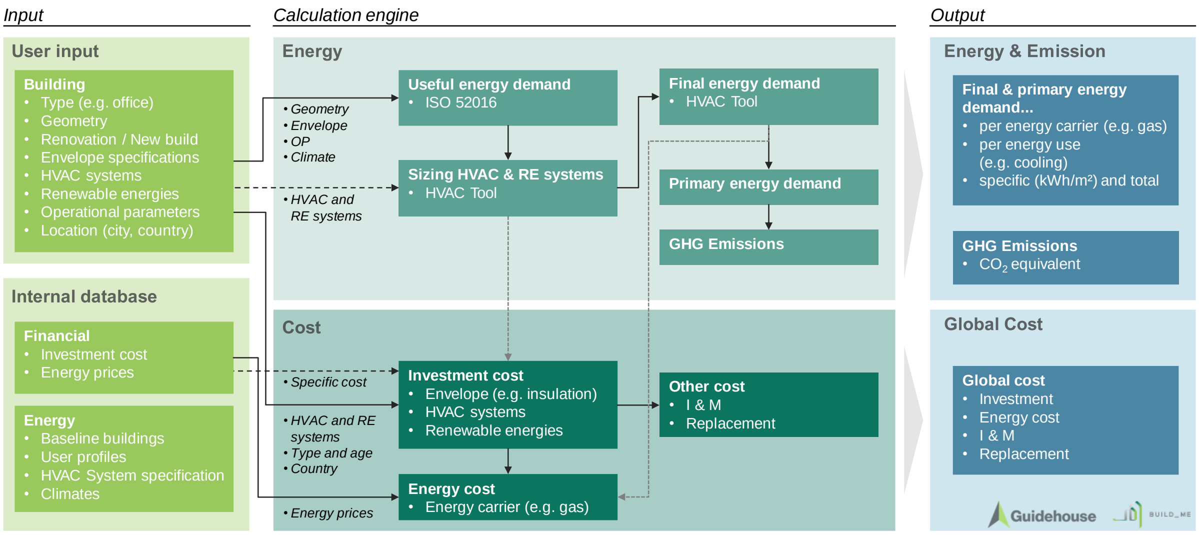


Figure 1. BEP tool calculation methodology

2.1 Useful energy demand calculation

The useful energy demand calculation is based on the international standard for buildings' thermal energy calculation, the EN ISO 52016. This section provides relevant information for the data input and an overview of the factors that are considered by the norm. The detailed calculation procedure is only described for the final energy demand in the next chapter because it is not covered by an international standard methodology.

2.1.1 Envelope elements

2.1.1.1 Wall, roof, slab

The envelope elements have a major impact on the useful energy demand. They cause the conductive heat gains and losses according to their u-value, which is calculated as:

$$q_{envelope} = u * t * (T_{amb} - T_{in})$$

With the u-value in W/m²K, the calculation time (t), and the temperature difference between the outside and inside.

2.1.1.2 Windows

Windows affect the thermal behaviour of the building, mainly by solar gains through the glass. The amount of solar irradiation let into the building is defined by the window's g-value (0, 1). A g-value of 0 allows no radiation to enter through the window, so it is completely closed; a g-value of 0.85 (single-glass) would allow 85% of the radiation to enter the building. The entering solar radiation share is further decreased by the window's frame. The window area is considered to have a frame share of 15% by default. This cannot be changed.

2.1.1.3 Shading

Shading is realized by the selection of three different types, which are further described below:

- Fixed shading elements
- Manual shading elements
- Automatic shading elements

The shading is realized in the model by a shading factor, F. This factor is between 0 and 1, where 0 = no sunlight through window and 1 = no shading. Besides the external shading elements discussed in the following subsections, other factors should be considered for all shading cases (even no shading), namely the window frame and the g-value of the glass (more information on the g-value in Section 2.1.1.2). The general window shading factor, before external shading elements, is set as:

$$F_{window} = (1 - F_{fr}) * G$$

With the frame fraction (F_{fr}) set to 15% and the g-value (G) as set by the window selection.

The impact of all shading elements is considered by reducing the window area (A_{window}) when multiplying it by the resulting shading factors (F_{window} and F_{sh}).

$$A_{transparent} = A_{window} * F_{window} * F_{sh}$$

The external shading factor (F_{sh}) is explained in the following subsections for each case, respectively.

The sun altitude is also considered; if it is below a certain height (angle of 15°), there is no direct radiation (only diffuse) on the windows due to surrounding buildings or other constructions.

Fixed shading

Fixed shading elements are horizontal elements located right over the window (as Figure 2 shows). They cause shading over the entire year; however, the effect is increased in summer due to the higher sun altitude.

Fixed shading has the highest impact on south-orientated windows and is, therefore, only assumed to be installed there. This means that if fixed shading is selected, the windows orientated north, east, and west have no external shading elements.

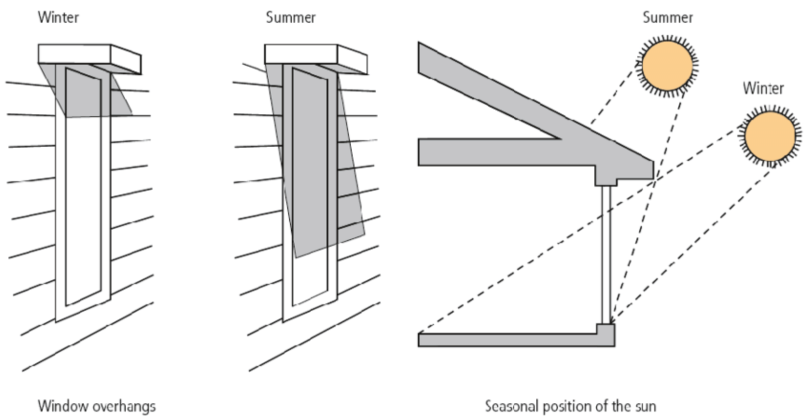


Figure 2. Principal of fixed shading and differences between winter and summer (Akande, Fabiyi, & Mark, 2015; Akande, Fabiyi, & Mark, 2015)

The resulting shading factor for the window is calculated as follows:

$$F_{sh} = \frac{h_{window} - \frac{\tan(\alpha) * l_{fixshading}}{h_{window}}}{h_{window}}$$

With the window height (h_{window}), the horizontal length of the fixed shading element ($l_{fixshading}$), and the angle of the sun (α).

Manual shading

Manual shading implies a general intelligence behind the shading process. If the ambient temperature is below 18°C, no external shading is considered. The manual shading factor of 0.6 is only applied if the radiation on the specific window is higher than 400 W/m². This counts for windows oriented north, east, and west; if the window is oriented south, the shading factor is reduced to 0.2. This reduction is because it is assumed that if the radiation is high on a southern façade, the inhabitants will close their windows entirely.

- If: T_{amb} > 18°C and global radiation > 400 W/m²
- Then: F_{sh}= 0.6 for north, east, and west and F_{sh} = 0.2 for south-orientated windows

Automated shading

Automatic shading implies a high intelligence behind the shading process. If the ambient temperature is below 18°C, no external shading is considered. The manual shading factor of 0.2 is only applied if the radiation on the specific window is higher than 150 W/m² (for all window orientations equally).

- If: T_{amb} > 18°C and global radiation > 150 W/m²
- Then: F_{sh}= 0.2

2.1.1.4 U-value

In general, the u-value is calculated as follows:

$$u = \frac{\lambda}{material\ thickness}$$

λ = thermal conductivity of the material. Table 1 lists the thermal conductivity of common building materials.

Table 1. Thermal Conductivity of Common Building Materials

Material	λ (W/(mK))
Blockwork (light)	0.38
Blockwork (medium)	0.51
Blockwork (dense)	1.63
Brick (exposed)	0.84
Brick (protected)	0.62
Chipboard	0.15
Concrete (aerated)	0.16
Concrete (dense)	1.4
Fibreglass quilt	0.033
Glass	1.05
Glass foam aggregate (dry)	0.08
Hemp slabs	0.40
Hempcrete	0.25
Mineral wool	0.038
Mortar	0.80
Phenolic foam	0.020
Plaster (gypsum)	0.46
Plasterboard (gypsum)	0.16
Polystyrene foam	0.032
Polyurethane foam	0.025
Render (sand/cement)	0.50
Screed (cement/sand)	0.41
Steel	16 - 80
Stone (limestone)	1.30
Stone (sandstone)	1.50
Stone (granite)	1.7 - 4.0
Stone chippings	0.96
Straw bale	0.09
Timber (softwood)	0.14
Timber (hardwood – commonly used)	0.14 - 0.17
Woodfibre board	0.11

If the building element consists of different material layers, the reciprocal values of the single u-values are summed, which is calculated as follows:

$$\frac{1}{u_{total}} = \frac{1}{u_1} + \frac{1}{u_2} + .. . + \frac{1}{u_n}$$

2.1.1.5 Mass distribution

Mass distribution is the spatial distribution of mass within the solid building element. If one homogenous material is used, the mass is equally distributed. A displacement is caused if high proportions of insulation material are used. In this case, the mass core of the element shifts away from the insulated side (e.g. outside is insulated → Class M: Mass concentrated inside). Four different classes are considered in the tool (see Table 2).

Table 2. Mass concentration classes (according to EN ISO 52016-1)

Class	Specification of class
Class I (mass concentrated on the inside)	Construction with insulation material on the outside or similar
Class E (mass concentrated on the outside)	Construction with insulation material on the inside or similar
Class M (mass concentrated on the inside)	Construction material with insulation on inside and outside
Class IE (mass distributed over inside and outside)	Construction with insulation material between two mass components on the inside and outside or similar
Class D (mass distributed equally)	Not insulated construction (e.g. only bricks, concrete) or similar

2.1.1.6 Solar absorption

The solar absorption factor reflects the colour of the outer building element and, therefore, the absorption factor of solar radiation on the surface. Three categories are available:

- Light colour: 0.3
- Medium colour: 0.6
- Dark colour: 0.9

2.1.1.7 Specific heat capacity

Specific heat capacity refers to a material's capacity to store heat for every kilogram (kg) of mass. A material of high thermal mass has a high specific heat capacity. Table 3 lists the heat capacity classes distinguished by the EN ISO 52016-1.

Table 3. Specific heat capacity classes (according to EN ISO 52016-1)

Class	J/(m²*K)	Specification of class
Very light	50,000	Wood as construction material with <10 cm thickness or similar

Class	J/(m²*K)	Specification of class
Light	75,000	Light bricks or concrete with 5-10 cm thickness or similar
Medium	110,000	Light bricks or concrete with 5-10 cm thickness, bricks <7 cm thickness or dense concrete, or similar
Heavy	175,000	Bricks or dense concrete with 7-12 cm thickness or similar
Very heavy	250,000	Bricks or dense concrete >12 cm thickness or similar

2.1.2 Heating and cooling

The useful energy demand for heating and cooling is mainly calculated based on the geometry, envelope parameters, local weather data, and air exchange rate. The detailed calculation methodology is described in the EN ISO 52016-1 international standard.

2.1.3 Hot water

The hot water demand is calculated as described in Section 2.2.2.1.

2.1.4 Internal heat gains

Internal heat gains reflect the heat generated by appliances or people within the building. In the tool, they are entered as the average specific value over the day (24 h). The total daily internal heat gains are calculated as follows:

$$q_{gain} = p_{av,gain} * 24h$$

Table 4 provides average heat gain values depending on the building type and usage. The total daily heat gains are then distributed according to the profiles shown in Figure 3.

The following example demonstrates the calculation: If the average internal heat gain is entered as $p_{av,gain}$ = 10 W/m², then the total daily heat gain is q_{gain} = 10 W/m² * 24 h = 240 Wh/m². The building is a residential building and according to Figure 3, 6% of the daily heat gain is happening from 6:00 a.m. to 7:00 a.m., which means the internal heat gain in this hour is 240 Wh/m² * 6% = 14.4 Wh/m².

Table 4. Overview of internal heat gains (according to DIN 18599-10)

Building Type	Medium heat transmission (Wh/m²/d)	Average heat gain (W/m²)	Per Person (W)	Considered aspects
Residential building (SFH)	45.0	1.9	70.0	People + appliances
Residential building (MFH)	90.0	3.8	70.0	People + appliances
Single office	73.0	3.0	70.0	People + working appliances
Big area office	73.0	3.0	70.0	People + working appliances

Building Type	Medium heat transmission (Wh/m²/d)	Average heat gain (W/m²)	Per Person (W)	Considered aspects
Conference room	101.0	4.2	70.0	People + working appliances
Retailer	108.0	4.5	70.0	People + working appliances
Retailer (food section, including cooling)	-86.0	-3.6	70.0	People + working appliances
School (classroom)	120.0	5.0	60.0	People + working appliances
Auditorium	444.0	18.5	70.0	People + working appliances
Hotel room	114.0	4.8	70.0	People + working appliances
Restaurant	247.0	10.3	70.0	People + working appliances
Fair	152.0	6.3	70.0	People + working appliances
Gym (no spectators)	63.0	2.6	125.0	People
Treatment room (hospital)	117.0	4.9	70.0	People + working appliances
Special treatment room, e.g. emergency room (hospital)	340.0	14.2	70.0	People + working appliances
Storage hall	-	-	-	No internal heat gains

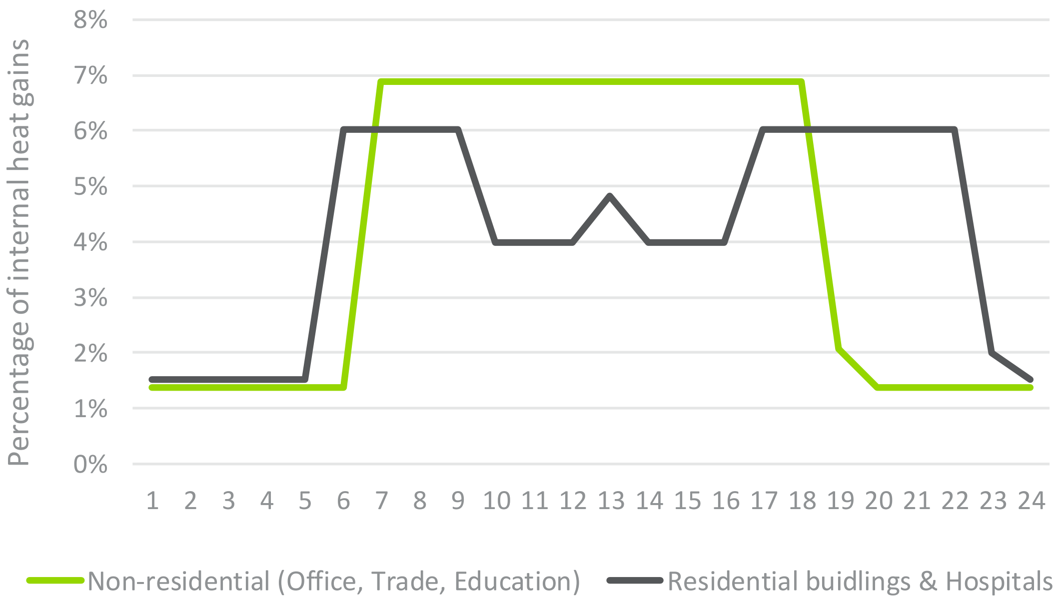


Figure 3. User profiles according to building type

2.1.5 Other electricity

Other electricity is the demand of all electric appliances in the building, except of the ones explicitly calculated in the energy calculation (HVAC and lighting). This includes in general, e.g. cooking, fridge for residential buildings and working appliances for non-residential buildings. Standard demand profiles are used to distribute the demand of the day (see Figure 4).

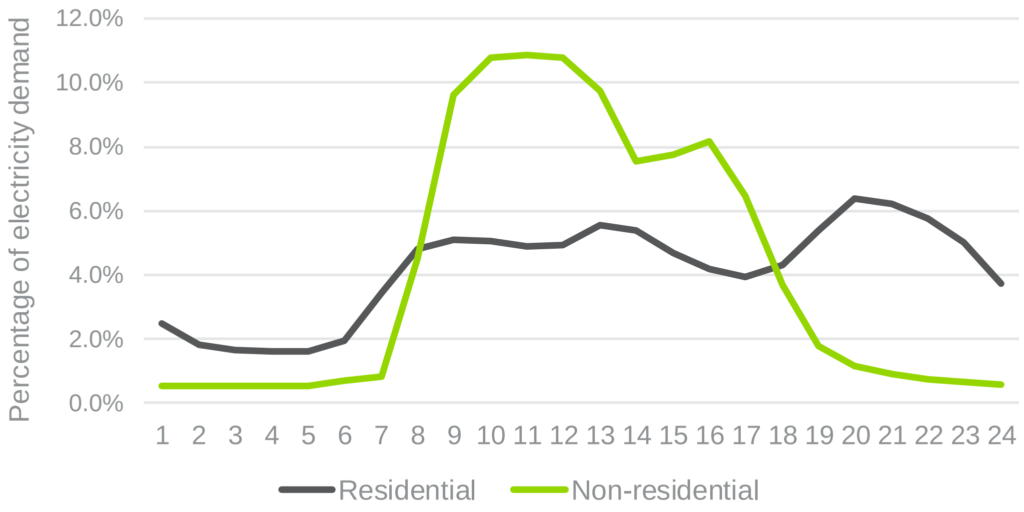


Figure 4. User profiles for other electricity demand according to building type

2.2 Final energy demand calculation

2.2.1 Space heating

Nine space heating systems are available (see following subsections). If a system is not selectable, it is no longer relevant or accessible in the selected country.

After selecting the system, users choose an efficiency class. Each efficiency class contains a set of parameters (depending on the type of heating system) to calculate the efficiency of the heating system according to operating status (e.g. running on partial load or ambient conditions). The following selections discuss all selectable systems, including a table with the parameters of the efficiency classes and the formulae used to calculate the final energy demand.

2.2.1.1 Installed heating load

The installed power is determined to enable heating up to 20°C at the coldest hour of the year by considering the actual transmission and ventilation losses of the building at that temperature.

$$P_{inst} = (20 - T_{amb,design}) * (u \bullet A_{env} + AC_{total} * \rho_{air} * c_{p,air})$$

With the sum product of u-values and envelope areas (u *x* A_{env}), the total air change rate, the density (ρ) and heat coefficient (c_p) of air, and the ambient temperature for the design capacity ($T_{amb,design} = T_{amb, min}$).

2.2.1.2 Heat boiler systems

The calculation is based on the German industry norm for energy calculations of buildings (DIN 18599) and is consistent for all available boiler systems. The system-specific efficiency parameters that depend on the type of boiler system are listed in Table 5 through Table 10. Because the detailed input parameters for HVAC systems are not available, the following standard formulae are used for the efficiency at full load and part load.

$$\eta_{k,P_n} = (A + B \cdot log10\,(P_n))/100$$
$$\eta_{k,P_{int}} = (C + D \cdot log10\,(P_n))/100$$

With η_{k,P_n} as full load efficiency, $\eta_{k,P_{int}}$ as part load efficiency, and the factors A, B, C, D as listed in Table 5 through Table 10. Standby heat demand losses are calculated with:

$$q_{P0,70} = \frac{(E \cdot (P_n)^F)}{100} * t$$

To determine the exact efficiency in the calculated hour depending on the heating need, the actual load demand is calculated by determining the necessary heat supply temperature.

$$T_{supply} = T_{design} - (T_{design} - T_{min}) * \left(1 - \frac{T_{min} - T_{amb}}{T_{min} - T_{amb,design}}\right)$$

With the supply temperature at the design capacity (T_{design} = 70°C), the minimum supply temperature (T_{min} = 25°C), the ambient temperature (T_{amb}), the ambient temperature for the design capacity ($T_{amb,design}$ = $T_{amb,\ min}$ – 3 K), and T_{supply} = 25°C, 70°C.

The actual supply temperature is used to calculate the effective boiler efficiency, η_k.

$$\eta_k = \eta_{k,P_{int}} - (\eta_{k,P_{int}} - \eta_{k,P_n}) * \frac{(T_{supply} - T_{part})}{(T_{design} - T_{part})}$$

With the part load temperature (T_{part}) as defined in Table 5 through Table 10.

The resulting final energy demand is calculated as follows:

$$q_f = \frac{q_u}{\eta_k}$$

Table 5. Gas (non-condensing) efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard efficiency at design capacity	%	91%	89%	86%	86%	84%
Factor B	-	1.50	1.50	1.50	1.50	1.50
Standard efficiency at part load	%	91%	89%	85%	82%	82%
Factor D	-	1.30	1.30	1.50	1.50	1.50
Factor E	-	5.00	5.00	7.00	7.00	7.00
Factor F	-	-0.37	-0.37	-0.37	-0.37	-0.37
Temperature at part load	°C	30.0	30.0	30.0	40.0	50.0
Demand controlled	-	Yes	Yes	Yes	No	No

Table 6. Gas (condensing) efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard efficiency at design capacity	%	97%	94%	94%	92%	89%
Factor B	-	1.00	1.00	1.00	1.00	1.50
Standard efficiency at part load	%	105%	103%	98%	92%	89%
Factor D	-	1.00	1.00	1.00	1.00	1.50
Factor E	-	4.00	4.00	4.00	4.00	7.00
Factor F	-	-0.40	-0.40	-0.40	-0.40	-0.37
Temperature at part load	°C	30.0	30.0	30.0	40.0	50.0
Demand controlled	-	Yes	Yes	Yes	No	No

Table 7. Oil (non-condensing) efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard efficiency at design capacity	%	91%	89%	86%	86%	84%
Factor B	-	1.50	1.50	1.50	1.50	1.50
Standard efficiency at part load	%	91%	89%	85%	82%	82%
Factor D	-	1.30	1.30	1.50	1.50	1.50
Factor E	-	5.00	5.00	7.00	7.00	7.00
Factor F	-	-0.37	-0.37	-0.37	-0.37	-0.37
Temperature at part load	°C	30.0	30.0	30.0	40.0	50.0
Demand controlled	-	Yes	Yes	Yes	No	No

Table 8. Oil (condensing) efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard efficiency at design capacity	%	97%	94%	94%	92%	89%
Factor B	-	1.00	1.00	1.00	1.00	1.50
Standard efficiency at part load	%	105%	103%	98%	92%	89%
Factor D	-	1.00	1.00	1.00	1.00	1.50
Factor E	-	4.00	4.00	4.00	4.00	7.00
Factor F	-	-0.40	-0.40	-0.40	-0.40	-0.37
Temperature at part load	°C	30.0	30.0	30.0	40.0	50.0
Demand controlled	-	Yes	Yes	Yes	No	No

Table 9. Portable LPG (gas) heaters efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard efficiency at design capacity	%	80%	78%	75%	72%	69%

Parameter	Unit	1	2	3	4	5
Factor B	-	1.50	1.50	1.50	1.50	1.50
Standard efficiency at part load	%	82%	80%	77%	75%	72%
Factor D	-	1.30	1.30	1.50	1.50	1.50
Factor E	-	5.00	5.00	7.00	7.00	7.00
Factor F	-	-0.37	-0.37	-0.37	-0.37	-0.37
Temperature at part load	°C	80%	78%	75%	72%	69%
Demand controlled	-	1.50	1.50	1.50	1.50	1.50

Power restrictions

- Maximum output power: 4.5 kW/system
- Minimum output power: 1.5 kW/system

Table 10. Portable kerosene heaters

Parameter	Unit	1	2	3	4	5
Standard efficiency at design capacity	%	63%	60%	58%	55%	50%
Factor B	-	1.50	1.50	1.50	1.50	1.50
Standard efficiency at part load	%	65%	62%	60%	57%	52%
Factor D	-	1.30	1.30	1.50	1.50	1.50
Factor E	-	5.00	5.00	7.00	7.00	7.00
Factor F	-	-0.37	-0.37	-0.37	-0.37	-0.37
Temperature at part load	°C	63%	60%	58%	55%	50%
Demand controlled	-	1.50	1.50	1.50	1.50	1.50

Power restrictions

- Maximum output power: 6.8 kW/system
- Minimum output power: 1.5 kW/system

2.2.1.3 Heat pumps (air-water/ground source)

Two heat pump systems are available for selection (if applicable in the selected country): air source (air-water) and ground source heat pumps. The system-specific efficiency parameters that depend on the type of heat pump are listed separately in Table 11 and Table 12. The calculation methodology is similar for all heat pump types and is explained in this section.

The final energy demand is calculated with the useful energy demand (precalculated by the tool) and the efficiency depending on the load status and ambient conditions. To reflect the current load status, the necessary heat supply temperature is calculated first as follows.

$$T_{supply} = T_{design} - (T_{design} - T_{min}) * \left(1 - \frac{T_{min} - T_{amb}}{T_{min} - T_{amb,design}}\right)$$

With the supply temperature at the design capacity (T_{design}) depending on the efficiency class (see Table 11 and Table 12), the minimum supply temperature (T_{min} = 25°C), the ambient temperature (T_{amb}), which is the ground temperature for ground source heat pumps), the ambient temperature for the design capacity ($T_{amb,design} = T_{amb,\ min}$ – 3 K), and T_{supply} = 25°C, T_{design}.

The resulting efficiency of the heat pump is calculated as follows:

$$\eta_k = \frac{T_{supply} + 273.15}{T_{supply} - (T_{amb})} * QF$$

With T_{amb} ≥ 12°C and the quality factor of the heat pump (*QF)* as:

$$QF = \frac{COP * (T_{supply} - T_{design})}{(T_{supply} + 273.15)}$$

With the COP at standard conditions and the standard supply temperature (T_{design}) as listed in Table 11 and Table 12.

The resulting final energy demand is calculated as follows:

$$q_f = \frac{q_u}{\eta_k}$$

Bivalence point of air source heat pump

When the outside temperature is very low, air source heat pumps have technical boundaries to supply the necessary heat power. Also, the heat pump is not designed for the coldest conditions because it is only needed a few days per year. To ensure the heat demand is met, an electrical resistance heater is installed (COP = 1) that provides the additional heat power.

Additional components must be considered to calculate the final energy demand for air source heat pumps. First, the maximum possible heat power the heat pump can deliver at the given ambient temperature (P_k) must be calculated. The maximum is compared with the needed useful power demand (Q_{heat}/t). If the necessary power demand is higher, the difference must be provided by the electrical resistance heater ($P_{resistance}$).

The maximum heat power output of the heat pump ($P_{k,max}$) at a given ambient temperature is calculated as follows:

$$P_k = \frac{\eta_k}{\eta_{design}} * P_{design} = \frac{\frac{T_{supply} + 273.15}{T_{supply} - (T_{amb})} * QF}{\eta_{design}} * P_{design} = \frac{(T_{supply} - T_{design})}{\left(T_{supply} - T_{amb}\right)} * P_{design}$$

The difference between the possible output and the useful heat demand provides the power that will be supplied by the electrical resistance heater. It will only count if the following equation is less than 0, which means the demand (P_{heat}) is higher than the maximum power output ($P_{k,max}$).

$$\Delta P = P_{resistance} = -\min\left[0;\ P_{k,max} - \frac{Q_{heat}}{t}\right] = -\min[0; P_{k,max} - P_{heat}]$$

$P_{resistance}$ is provided with an efficiency (COP) of 1.

Table 11. Air source heat pump efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard design system supply temperature	°C	35.00	35.00	40.00	40.00	40.00
Standard design system return temperature	°C	27.00	27.00	30.00	30.00	30.00
COP at standard conditions	-	3.84	3.20	2.70	2.00	1.90
Bivalence point	°C	-15.00	-7.00	-7.00	-7.00	-7.00
Standard supply temperature	°C	2.00				

Table 12. Ground source heat pump efficiency parameters

Parameter	Unit	1	2	3	4	5
Standard design system supply temperature	°C	35.00	35.00	40.00	40.00	40.00
Standard design system return temperature	°C	27.00	27.00	30.00	30.00	30.00
COP at standard conditions	-	5.16	4.30	3.40	2.60	2.00
Bivalence point	°C	-15.00	-7.00	-7.00	-7.00	-7.00
Standard supply temperature	°C	0.00				

2.2.1.4 Air-air heat pump/reversible split unit

In contrast to the air-water and ground source heat pumps, the air-air heat pump is calculated with the operational parameters at certain ambient temperatures as given in Table 13. The efficiency values (SCOP) are selected to reflect the available spectrum according to the energy efficiency labelling directive of the European Commission for energy efficiency classes for air conditioners, except double ducts and single ducts). The according class is indicated in the last row of the table.

Table 13. Air-air heat pump operational parameters at ambient temperatures

Parameter	Unit	1	2	3	4	5
Efficiency at -7°C	-	4.80	4.00	3.30	2.70	1.50
Efficiency at +2°C	-	5.00	4.20	3.50	2.80	1.70
Efficiency at +7°C	-	5.40	4.60	3.90	3.00	2.10
Efficiency at +10°C	-	5.70	4.90	4.20	3.20	2.40
European energy efficiency class	-	A++/A+++	A+	B/A	D/C	G

The actual efficiency is determined by linear interpolating of the actual ambient temperature outside with the corresponding value of the chosen efficiency class. For example, if efficiency class 1 is taken and the ambient temperature is -2.5°C than the efficiency of the air-air heat pump is as follows:

$$\eta = 4.8 + (5.0 - 4.8) * \frac{-7°C - (-2.5)°C}{-7°C - 2°C} = 4.9$$

The resulting final energy demand is calculated as follows:

$$q_f = \frac{q_u}{\eta}$$

2.2.1.5 Heat losses

Distribution

Not currently considered because all the heating pipes are assumed to be within the conditioned areas.

Storage

Not currently considered because heat storage is assumed to be within the conditioned area.

Auxiliary energy demand

This is no auxiliary energy demand for portable heaters. The auxiliary energy demand of central boilers consists of the electricity needed for the pumps to distribute the heated water, which is calculated as follows.

$$Q_{aux} = P_{pump} * t$$

With the running time of the system either 8,760 h per year (if not demand controlled) or only if an actual heat demand is calculated (demand controlled).

2.2.2 Domestic hot water

Hot water demand is only recommended for residential buildings and hotels, since the main demand results from showers and bathing. Other hot water demand, such as warm water in toilet basins is neglectable. Therefore, the calculation method is tailored to residential application. It is either produced by dedicated DHW systems (gas, electric) or in combination with the central space heating system.

Dedicated water heaters are instantaneous systems, that are assumed to be sized to produce enough hot water for showering. This means, the systems have a power output of at least 10 to 20 kW per Appartement – depending on the average outside temperature in the country. The central systems are considered to have always a hot water storage. That means, no additional power is necessary (besides the power for space heating installed anyway), but a water storage and the necessary pipes and pumps for the distribution within the building.

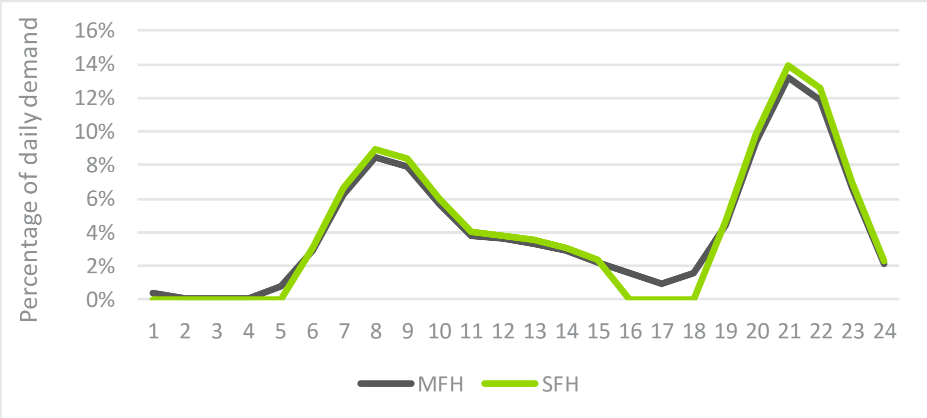
Solar panels can be used to support the DHW supply. However, the conventional system should be selected— solar DHW systems are usually sized to meet around 30%-60% of the total DHW demand. The residual demand is covered by the selected system.

2.2.2.1 DHW demand

The specific useful hot water energy demand of an apartment or SFH is estimated as follows:

$$q_{u,DHW} = (16.5 - 0.05 * A_{use}) * \left(\frac{45 - T_{av,amb}}{35}\right) * t$$

With the living area (A_{use}), the average annual ambient temperature ($T_{av,amb}$) is consider to be a regional factor, and $q_{u,DHW}$ = [8.5, 16.5] in kWh/(m²a). Subsequently, this demand is distributed with the profile shown in Figure 5 over 24 hours.



For non-residential buildings, it is assumed that there is a significantly reduced hot water demand. Therefore, only 20% of the determined hot water demand as for residential buildings is considered. An exception are hospitality buildings and hospitals where the hot water demand is actually increased by an additional 30% to the residential buildings. This is mainly since there are even more people that shower than in apartments or SFH.

Figure 5. DHW demand profiles for residential buildings

2.2.2.2 Dedicated gas and electric heater

The final energy demand of the dedicated heaters is calculated as follows:

$$q_{f,DHW} = \frac{q_{u,DHW} + q_{loss,DHW}}{\eta_k}$$

With the boiler's efficiency (η) as listed in Table 14 and Table 15 and the losses calculated as indicated in the following section.

2.2.2.3 Combined heater systems

If a combined heating system is selected (combi system), the hot water is produced by the space heating system. Therefore, the calculation of the final energy demand for hot water production is analogous to the space heating calculation of the selected space heating system.

2.2.2.4 Hot water supply and storage temperature

The hot water supply temperature is assumed to be never less than $T_{supply} \geq 55°C$. This is a standard temperature to provide all DHW demand types (kitchen water, shower water, etc.). The storage temperature and the supply temperature are assumed to be the same. The previously mentioned $T_{supply} \geq 55°C$ does not apply if a solar system based on thermosyphon storage is used (see details in Section 2.2.2.5). In that case, the minimal supply (and storage) temperature is $T_{supply} \geq 35°C$.

The storage temperature (and therefore the supply temperature) is dynamic depending on the current load status of the hot water storage. This is calculated as follows:

$$T_{supply} = T_{storage} = Load\ status\ storage\ [\%] * \frac{T_{storage,max}}{T_{storage,min}} + T_{storage,min}$$

With the load status of the storage as a percentage value between 0 and 1.

The storage load is simply defined by summing up all inputs (solar DHW contribution) and outputs (DHW useful demand, storage, and distribution losses) as follows:

$$Load\ status\ of\ storage(t) = LSS(t-1) + Q_{solar}(t) - Q_{useful,demand}(t) - Q_{losses}(t)$$

2.2.2.5 Solar DHW

The solar collector's energy production is calculated as follows:

$$Q_{solar} = (\ I_{rad} * A_{panel} * \left(\varepsilon - k_1 * \frac{T_{supply} - T_{amb}}{G_{rad,h}} - k_2 * I_{rad} * \left(\frac{T_{supply} - T_{amb}}{G_{rad,h}}\right)^2\right) - k_2 * \frac{T_{supply} - T_{amb,comp}}{G_{rad}}\ ) * A_c$$

With I_{rad} as the total solar irradiation on a surface, A_{panel} as the area of the collector surface, ε as the conversion factor, k_1 and k_2 as heat transmission coefficients, T_{supply} as the DHW supply temperature, and $T_{amb,comp}$ as the temperature of the system components. I_{rad} is calculated as follows based on the azimuth angle, ϑ_p and inclination angle, θ_i of the solar collector.

$$I_{rad} = I_{diff} * \left(\frac{1 + \cos\theta_i}{2}\right) + I_b * (\sin\theta_s * \cos\theta_i + \cos\theta_s * \cos(\vartheta_p - \vartheta_s) * \sin\theta_i)$$

Where I_{diff} is the diffuse radiation on the surface, I_b is the beam radiation, θ_s is the solar altitude and ϑ_s is the solar azimuth.

The result is further multiplied by a country adjustment factor, A_c to include any country specific parameters in the calculation if needed.

All relevant distribution losses are considered in the formulae above. Only the additional energy for the circulation pump is added as auxiliary energy (see Section 2.2.2.7).The storage losses are calculated as listed in Section 2.2.2.6 in the general DHW storage losses because the same storage for conventional and solar DHW production is assumed.

Thermosyphon system

This system type (with storage above the solar panel) has some additional factors. The supply temperature for hot water is decreased to T_{supply}= 35°C (instead of 55°C). Furthermore, the storage is located outside the heated zones, so the heat losses of the storage are calculated with the ambient temperature outside.

2.2.2.6 Storage and distribution losses

The distribution system losses are only relevant if there is a circulation system. For SFHs, this is off by default, whereas all other buildings have a circulation system for DHW. All installed pipes are considered to be located within the conditioned area.

$$q_{loss,dis} = l_{pipe} * k_{pipe} * (T_{supply} - T_{in}) * t$$

With the specific heat loss factor (k_{pipe}) as listed in Table 14 and Table 15, the hot water temperature (T_{water}), the indoor temperature (T_{in}), and the length of the indoor pipelines as follows:

$$l_{pipe} = 0.005 * A_{use}^{1.38} + 0.11 * \left(\frac{A_{use}}{Number\ apartments}\right)^{1.24}$$

2.2.2.7 Auxiliary energy demand for boilers

If a dedicated hot water system is installed or the central space heating system is selected to provide domestic hot water, it is assumed the hot water is distributed via circulation pumps. Consequently, there is an additional (electric) energy demand depending on the pumps power load (P_{pump}) that depends on the efficiency class of the DHW system and is indicated in Table 14 and Table 15.

$$q_{loss,circ} = P_{pump} * t$$

Every hot water system is considered to have hot water storage to ensure stable DHW supply over the day. The necessary volume is calculated as follows:

$$V_{storage} = \frac{5}{3} * A_{use}$$

The specific heat losses of the storage are defined as follows:

$$k_{storage} = \frac{V_{storage}}{1000} * Storage\ Factor$$

With the Storage Factor depending on the efficiency class as listed in Table 14 and Table 15.

The final storage losses depend on the temperature difference between the conditioned area (storage is located within the conditioned area) and the hot water in the storage.

$$q_{loss,storage} = k_{storage} * (T_{supply} - T_{in}) * t$$

With T_{supply} as the hot water supply temperature and T_{in} as the temperature in the conditioned area.

2.2.2.8 Dedicated DHW systems

Table 14. Dedicated gas water heater efficiency parameters

Parameter	Unit	1	2	3	4	5
Efficiency	-	90%	85%	80%	75%	65%
Power of DHW circulation pump	W	5	18	83	123	136
Storage heat loss factor	W/K	2	3	4	5	6

Table 15. Dedicated electric water heater efficiency parameters

Parameter	Unit	1	2	3	4	5
Efficiency	-	99%	99%	99%	99%	99%
Power of DHW circulation pump	W	5	18	83	123	136
Storage heat loss factor	W/K	2	3	4	5	6

Combined DHW system

The combined generation of space heating and DHW is possible with gas- and oil-fired boiler systems and air-water and ground source heat pumps. One of these systems must be selected under space heating if combi-DHW system is chosen.

Consequently, the final energy demand for the DHW supply is calculated in a similar manner to these systems. For conventional boiler systems, the efficiency from the space heat generation section is taken. For heat pumps, the necessary supply temperature is significantly higher, which is considered when calculating the actual system efficiency as follows:

$$\eta_k = \frac{T_{supply} + 273.15}{T_{supply} - T_{amb}} * QF$$

With the quality factor (*QF)* of the heat pumps as calculated under Section 2.2.1 and the supply temperature (T_{supply} = 55°C) set to the minimum requirement.

The resulting final energy demand is calculated as follows:

$$q_{f,DHW} = \frac{q_{u,DHW}}{\eta}$$

2.2.3 Space cooling

2.2.3.1 Installed cooling load

The design cooling capacity or installed cooling load is determined by the envelope standard of the building and its ground area. The quality of the building envelope is determined as the sum product of the vector of u-values with the areas of the corresponding envelope elements:

$$H_T = u \cdot A$$

Depending on the envelope's quality (H_T), the necessary cooling load is chosen from the following table, which is distinguished between residential and non-residential buildings:

Table 16. Factors to determine the necessary space cooling load

Parameter	1	2	3	4	5
H_T	< 0.15	< 0.3	< 0.5	< 1.0	≥ 1.0
Installed cooling load – residential (W/m²)	20	40	70	100	130
Installed cooling load – non-residential (W/m²)	60	70	90	110	150

For example, if all envelope elements have a u-value of 0.4 W/(m²*K) in a residential building with 120 m² of living area, the building has a H_T = 0.4 that leads to the system sizing as follows:

$$P_{cool} = 70\frac{W}{m^2} * 120\,m^2 = 8.4\,kW$$

2.2.3.2 Split units, window mounted and moveable systems

This section describes the calculation methodology for all single and multi-split units (including VRF) as well as window-mounted or moveable systems. Although their efficiencies vary and the application must be verified (e.g. window-mounted system is unlikely to condition an entire building), the calculation methodology used is similar.

The split unit's efficiency mainly depends on the ambient temperature. Therefore, the selectable systems have predefined efficiencies for four different ambient temperatures as listed in Table 17 through Table 20. The seasonal energy efficiency ratio (SEER) is also indicated; these values are also displayed online and are used for the classification within the European efficiency labelling scheme (as indicated in the last row of each table).

The actual efficiency is calculated with a linear approximation between the given efficiency values depending on the outside temperature. To consider that the efficiency values are standardized at 26°C indoor temperature, the actual outside temperature is increased if the indoor temperature is lower than 26°C and decreased if it is higher than 26°C:

$$T_k = T_{amb} + 26 - T_{in}$$

With the reference temperature (T_k), the linear approximation of the efficiency at every hour is calculated with the values in Table 17 through Table 20 as fixed points. The following is an example for the calculation of the efficiency if T_k ≥ 33°C and T_k < 35°C:

$$\eta_k = \frac{35°C - T_k}{35°C - 33°C} * (\eta_{33°C} - \eta_{35°C}) + \eta_{35°C}$$

The resulting final energy demand is calculated as follows:

$$q_f = \frac{q_u}{\eta_k}$$

Table 17. Movable system efficiency parameters

Parameter	Unit	1	2	3	4	5
Efficiency at 35°C (EER)	-	3.80	3.05	2.24	1.59	1.28
Efficiency at 33°C	-	4.12	3.31	2.43	1.69	1.35
Efficiency at 26°C	-	5.64	4.53	3.33	2.09	1.67
Efficiency at 20°C	-	7.73	6.21	4.56	2.59	2.08
Energy efficiency class*	-	A+++	A++	A+	F	G

*According to European energy labelling of air conditioners (Regulation (EU) No. 626/2011)

Table 18. Mounted single split or window air conditioner efficiency parameters

Parameter	Unit	1	2	3	4	5
Efficiency at 35°C (EER)	-	5.63	4.52	3.32	2.36	1.89
Efficiency at 33°C	-	6.10	4.90	3.60	2.50	2.00
Efficiency at 26°C	-	8.36	6.71	4.93	3.10	2.48
Efficiency at 20°C	-	11.45	9.20	6.76	3.84	3.08
Energy efficiency class*	-	A++	A++	B	F	G

*According to European energy labelling of air conditioners (Regulation (EU) No 626/2011)

Table 19. Centralised multi-split system efficiency parameters

Parameter	Unit	1	2	3	4	5
Efficiency at 35°C (EER)	-	5.43	4.68	3.65	2.95	2.53
Efficiency at 33°C	-	5.80	5.00	3.90	2.80	2.40
Efficiency at 26°C	-	7.48	6.45	5.03	2.35	2.02
Efficiency at 20°C	-	9.65	8.32	6.49	1.98	1.69
Energy efficiency class*	-	A++	A++/A+	B	F/G	G

*According to European energy labelling of air conditioners (Regulation (EU) No 626/2011)

Table 20. VRF – centralised multi-split with variable refrigerant flow efficiency parameters

Parameter	Unit	1	2	3	4	5
Efficiency at 35°C (EER)	-	4.30	4.00	3.70	3.40	
Efficiency at 33°C	-	7.47	6.29	5.12	3.95	
Efficiency at 26°C	-	10.00	8.13	6.26	4.39	-
Efficiency at 20°C	-	14.00	11.22	8.44	5.66	
Energy efficiency class*	-	A+++	A++	A+	B/C	

*According to European energy labelling of air conditioners (Regulation (EU) No 626/2011)

2.2.3.3 Central systems

The system efficiency calculation is similar to the methodology for decentralized split units (see Section 2.2.3.2). Depending on the type of central air- conditioning system, however, additional factors need to be considered. Central systems are distinguished, among other things, by:

- Compressor type: Turbo, screw, or piston/scroll
- Temperature of the cooling fluid (6°C, 10°C, 14°C)

The compressor type restricts the cooling load that can be achieved to:

- Piston/scroll: 10 kW-1,500 kW
- Screw: 200 kW-2,000 kW
- Turbo: 500 kW-8,000 kW

The installation of these type of systems is not relevant for smaller cooling loads (e.g. SFH).

To reduce the level of complexity, these compressor options are not selectable in the tool. However, they are considered in the design of the five efficiency classes. Table 21 provides project developers with advanced knowledge of their system with reference systems for the given efficiencies.

Table 21. Overview which space cooling type is covered by selecting an efficiency class

<table>
<tr><th>System specification</th><th>Factors</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td rowspan="2">Example 1:
Turbo compressor
(500 kW-8,000 kW)</td><td>Quality</td><td>Good</td><td>Medium</td><td rowspan="2">-</td><td rowspan="2">-</td><td rowspan="2">-</td></tr>
<tr><td>Fluid T.</td><td>14°C,
10°C</td><td>10°C,
6°C</td></tr>
<tr><td rowspan="2">Example 2:
Screw compressor
(200 kW-2,000 kW)</td><td>Quality</td><td rowspan="2">-</td><td>Best</td><td>Good</td><td>Medium</td><td rowspan="2">-</td></tr>
<tr><td>Fluid T.</td><td>14°C</td><td>14°C,
10°C,
6°C</td><td>10°C,
6°C</td></tr>
<tr><td rowspan="2">Example 3:
Scroll compressor
(10 kW-1,500 kW)</td><td>Quality</td><td rowspan="2">-</td><td rowspan="2">-</td><td>Good</td><td>Good</td><td>Medium</td></tr>
<tr><td>Fluid T.</td><td>14°C</td><td>10°C,
6°C</td><td>10°C,
6°C</td></tr>
</table>

The core energy efficiency parameters are the same for all the three central system options because the cool-generating units do not change (see Table 22). However, they are distinguished by the way of distributing the cooling load within the building—either distributed by air ventilation (through air ducts), fan coil units located in the rooms (comparable to the indoor units of split systems), or surface cooling elements (the wall's and ceiling's core is cooled). Table 22 describes the differences in the calculation.

Table 22. Efficiencies of central space cooling systems

Parameter	Unit	1	2	3	4	5
Efficiency at 35°C	-	6.78	5.12	3.30	2.92	1.50
Efficiency at 26°C	-	10.18	7.67	4.95	3.50	1.80
Efficiency at 22°C	-	11.68	8.81	5.68	3.76	1.93
European energy efficiency class	-	A+++	A+	B	F	G

Efficiencies exclude distribution losses.

The distribution needs additional energy, either for a fan to allow airflow through the building or to transport the cooling liquid to the rooms. The power is defined as the specific value of the amount of airpower of system, which depends on the buildings size and the efficiency class. The air ventilation distribution energy is calculated as follows:

$$q_{vent} = \frac{P_{cool}}{P_{design}} * (V_{air} - V_{mech}) * SFP$$

With the specific fan power (SFP) as listed in Table 23 through Table 25, the air volume flow reduced by the air volume moved by the mechanical ventilation and, in case demand control is enabled, the reduction through part load operation (P_{cool}/P_{design}).

The internal power for the cooling fluid is calculated as follows:

$$q_{pump} = \frac{P_{cool}}{P_{design}} * P_{design} * p_{pump}$$

With the specific pump power (p_{pump}) depending on the efficiency class (see Table 23 through Table 25) and the actual cooling load (P_{cool}).

In the following sections, the specific power requirements are listed per distribution type and efficiency class (omitted if not applicable); some system-specific information is also provided.

Central cooling – air vent distribution

The central system provides cool air that is distributed through rather big ventilation ducts throughout the building. Additional electricity demand for the fan (SFP) is needed.

Table 23. Central cooling – air vent distribution efficiency parameters

Parameter	Unit	1	2	3	4	5
SFP	W/m³	0.70	0.90	1.20	1.50	2.00
Fan demand controlled	-	TRUE	TRUE	TRUE	TRUE	FALSE
Specific power of system pumps	W/kW	2.5	5.0	10.0	15.0	20.0

Central system – fan coil distribution

This central system provides a cooling liquid to indoor units in each conditioned room of the building. A higher pump power is needed compared to the air ventilation distribution; however, less air needs to be pumped through the building (only from each indoor unit/fan coil into the room).

Table 24. Central system – fan coil distribution efficiency parameters

Parameter	Unit	1	2	3	4	5
SFP	W/m³	0.15	0.19	0.26	0.32	0.43
Fan demand controlled	-	TRUE	TRUE	TRUE	TRUE	TRUE
Specific power of system pumps	W/kW	7.5	15	30.0	45	60

Central system – surface distribution

This central system provides cooling fluid to all conditioned rooms within the building. Therefore, it has the highest pump power of the three central system variations. The cooling fluid flows either within the walls and ceilings (in the concrete core of the building) or large surface elements are installed below the ceiling, along the walls or beneath the floor (comparable to underfloor heating). The surface distribution needs less cold cooling fluids than the other two distribution types, which results in a higher overall efficiency of the system.

Table 25. Central system – surface distribution efficiency parameters

Parameter	Unit	1	2	3	4	5
SFP	W/m³	No airflow				
Fan demand controlled	-	No airflow				
Specific power of system pumps	W/kW	22.5	45.0	90.0	135.0	180.0

2.2.4 Dehumidification

The energy demand for dehumidification is the sum of energy required to remove humidity from the air due to air flow and internal sources.

$$q_{dehum} = q_{dehum,air} + q_{dehum,int}$$

The energy demand for dehumidification due to air flow is calculated based on the relative humidity of the air, which is entering the building through ventilation and infiltration. The energy demand for dehumidification due to air flow, $q_{dehum,air}$ is determined as follows:

$$q_{dehum,air} = (AH_{amb} - AH_{target}) * (V_{air} * H_{evap} * 1.18)$$

The target absolute humidity, AH_{target} is determined based on the fixed relative humidity of 60% and the resulting steam pressure at set point temperature. The Absolute humidity of air at ambient temperature, AH_{amb} is calculated using the relative humidity of air, which is available from the weather data. V_{air} is the volume of air entering the building through ventilation and infiltration. H_{evap} is the evaporation enthalpy of water at supply air temperature.

The energy needed for removing the humidity from the air due to internal sources is determined as follows:

$$q_{dehum,int} = AvH_{hour} * H_{evap}$$

Where AvH_{hour} is the average humidity per hour from internal sources and H_{evap} is the evaporation enthalpy of water at supply air temperature.

2.2.5 Mechanical ventilation

The final energy demand for ventilation purposes is determined as follows:

$$q_{vent} = V_{vent} * SFP$$

With the SFP set to 0.6 W/m³ and the volume of the airflow (V_{vent}).

The volume is determined as the total air volume within the building (living area times room height) times the air exchange rate *AC* (1/h]) as given in the following input:

$$V_{vent} = AC_{mech} * A_{living} * h_{room}$$

The heat recovery rate has no influence on the ventilation volume, but the heat losses are caused by air exchange. With the following formula, the general heat losses through ventilation are described. The percentage of heat recovery reduces the ventilation heat losses by reducing the air exchange rate of the mechanical ventilation with the 1-HR_{mech} factor:

$$Q_{vent} = \rho_{air} * c_{air} * V_{vent} * (AER_{mech} * (1 - HR_{mech}) + AER_{infiltration} + AER_{free})$$

With HR_{mech} as the heat recovery rate of the mechanical ventilation (0,1), AC as air change rates, and the density and specific heat capacity of air as ρ_{air} and c_{air}.

A constant air exchange and heat loss (depending on the outside temperature) is modelled.

2.2.6 Photovoltaic

The electricity generation by the installed PV capacity is calculated as follows:

$$q_{PV} = \left(P_{PV} * \left(I_{rad} - \left(I_{rad} * 0.005 * \left(\frac{I_{rad}}{25}\right)\right)\right)\right) * A_c$$

With the installed capacity (P_{pv}), the total solar irradiance on the panel (I_{rad}) and the reference temperature of 25°C (standard conditions PV panel specification). I_{rad} is calculated based on the azimuth and inclination angle of the PV panel, as described in 2.2.2.5 . The result is further multiplied by a country adjustment factor, A_c to include any country specific parameters in the calculation if needed.

2.2.7 Lighting

The different lighting technologies are assumed to have the specifications outlined in Table 26:

Table 26. Lighting specifications by technology

Lighting technology	Lumen/W	Lumen per lamp
Linear fluorescent lamp (LFL)	58	1,000
Compact fluorescent lamp (CFL)	60	1,000

Lighting technology	Lumen/W	Lumen per lamp
Halogen lamp	25	1,000
Classical incandescent lamp	16	800
Light emitting diode (LED) lamp	100	1,000

The necessary lighting is indicated in Table 27 per building type.

Table 27. Necessary lighting by building type

Building Type	Lumen/m²
SFH	300
MFH (MFH/apartment block)	300
Office building	500
Educational building	500
Retail/trade	500
Hospital	500

The necessary lighting electricity demand is calculated as follows:

$$Q_{light} = q_{light} * z(t) * \frac{A_{use}}{p_{light}}$$

With q_{light} as the specific light demand per building type (lumen/m²), A_{use} as the conditioned area, and p_{light} as the specific lighting power (lumen/W). This result is multiplied by a time-dependent factor, z(t), that reflects the standard profile (0, 1) depending on the building type, as displayed in Figure 6.

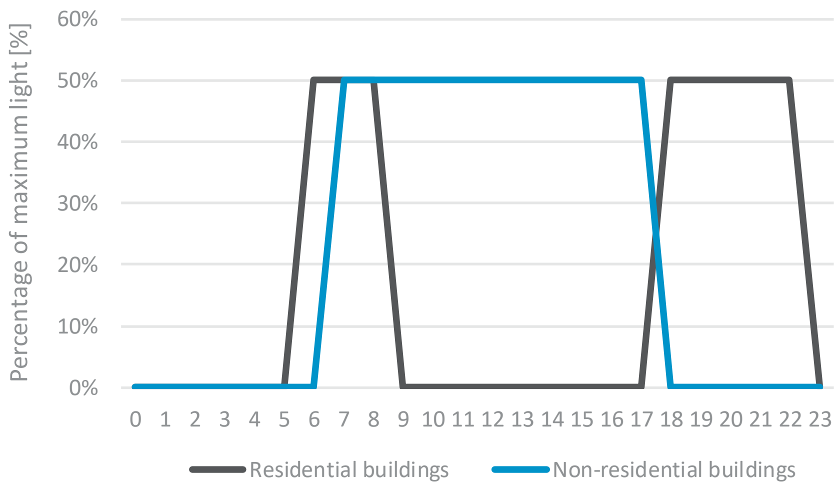


Figure 6. Lighting profile of residential and non-residential buildings

2.3 Additional factors

2.3.1 Primary energy factors

Table 28. Primary energy factors according to energy carrier

Country	Electricity	Gas	LPG	Kerosene	Oil
Egypt	2.6	1.1	1.1	1.1	1.1
Jordan	2.372	1.1	1.1	1.1	1.1
Lebanon	3.0	1.1	1.1	1.1	1.1

2.3.2 Greenhouse gas/CO_2-eq emissions

Typically, greenhouse gas (GHG) emissions are reported in units of carbon dioxide equivalent (CO_2-eq). Gases are converted to CO_2-eq by multiplying their global warming potential (GWP) to the GWP of CO_2. CO_2 has a GWP of 1, while N_2O has a GWP of 298. Table 30 gives an overview of some common GHGs and their GWP. The resulting CO_2-eq emissions for the used energy carrier are listed in Table 29. Emissions not directly related to combustion or the heating/cooling generation process, namely transport, refinery, and mining of the energy carrier, are not considered.

Table 29. CO2-eq emissions according to energy carrier

Country	Electricity (gCO_2-eq/kWh)	Gas (gCO_2-eq/kWh)	LPG (gCO_2-eq/kWh)	Kerosene (gCO_2-eq/kWh)	Oil (gCO_2-eq/kWh)
Egypt	444.0	209.9	236.2	260.4	283.7
Jordan	635.0	209.9	236.2	260.4	283.7
Lebanon	806.0	209.9	236.2	260.4	283.7

Table 30. Global warming potential of selected gases

Molecule	Global warming potential
CO_2	1
CH_4	25
N_2O	298
HFC-23	14,800
HFC-32	675
HFC-41	92
HFC-125	3,500
HFC-134	1,100
HFC-134a	1,430
SF_6	22,800
NF_3	17,200
CF_4	7,390
C_2F_6	12,200

Molecule	Global warming potential
C_3F_8	8,830
C_4F_8	10,300
C_4F_{10}	8,860
C_5F_{12}	9,160
C_6F_{14}	9,300

2.3.3 Reality factor/correction factor

The methodology discussed in Chapter 2 accurately calculates heating and cooling demand if a setpoint temperature range is maintained throughout the entire year and for the entire building (if the conditioned area is not set below 100%). Older or less energy efficient houses have a high theoretical energy demand. In most cases, the theoretical heating and cooling behaviour simulated by the tool, does not reflect the heating or cooling behaviour of the inhabitants. If they have an already high energy demand, it is likely that only parts of the building are heated, cooled, or that higher or lower temperatures are accepted. This behaviour, which is even more relevant for heating than cooling, is reflected by a so-called reality factor. The reality factor reduces the theoretically calculated final energy demand dynamically, following the function shown in Figure 7. This effect is only relevant for energy demand above approx. 100 kWh/m². Until this mark, the function is rather linear, so 70 kWh/m² calculated heat demand is displayed as 70 kWh/m² in the output.

The correction factor that might have been used can always be seen in the Detailed Results tab of the tool. On that tab, the theoretically calculated demand and the corrected demand are displayed in the Energy results section.

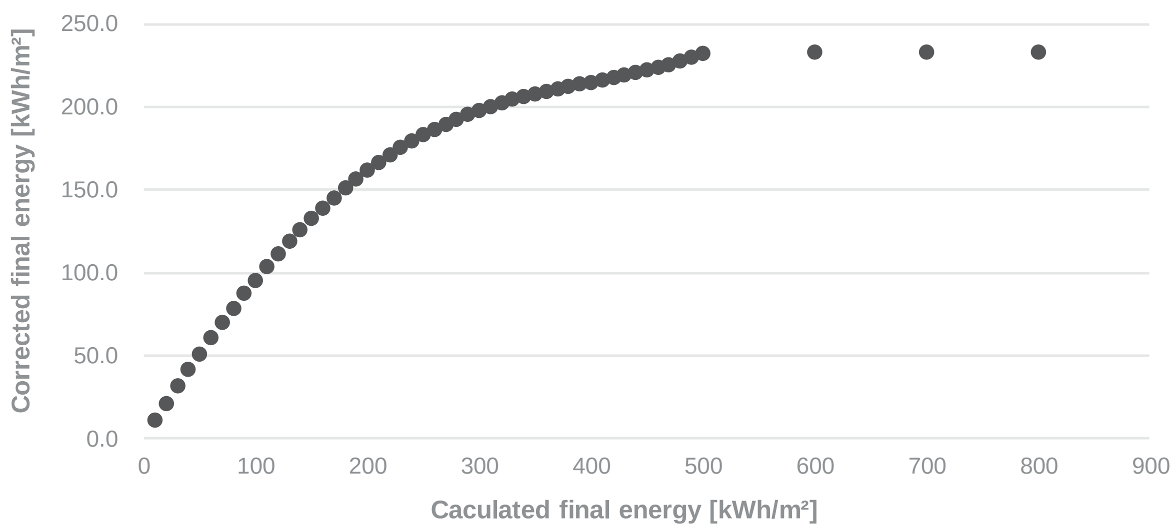


Figure 7. Reality factor – function of resulting final energy demand after correction

An example of high specific energy demands: If the BEP tool calculates a final energy heat demand of 300 kWh/m², the output shows only ca. 200 kWh/m².

2.4 Global cost

This section will describe how the costs are calculated and which assumptions are in the underlying database.

2.4.1 Envelope

The calculation of the envelope cost considers the insulation of the roof, façade and surface, the windows, and the cost to increase the general airtightness of the building's envelope.

To determine the cost for insulation, the tool checks if the given u-value of the envelope element is better than the baseline (which results from the baseline buildings, see Chapter 3). If not, no additional energy efficiency-related cost is applied for this element. If the u-value is better than the baseline case, additional insulation is assumed to have been added to the envelope element. The additional centimetres of insulation are calculated to improve the u-value from the baseline to the given u-value. The additional material results in the envelope cost for the element. The reference values depend on the country, region, and type of building and are listed in Table 37.

2.4.1.1 External walls, roof, and floor

The u-value of the entered project is compared to the baseline's u-value for each element. If the u-value is lower (meaning higher quality), the additional insulation material thickness is calculated as described in the following:

Based on the formula to calculate the resulting u-value of multiple material layers, the necessary u-value of the added insulation layer is calculated as follows:

$$U_{insulation} = \frac{1}{\frac{1}{U_{project}} - \frac{1}{U_{refBuild}}}$$

With the u-value of the insulation layer, the thickness can be calculated with the following equation:

$$d_{insulation} = \frac{\lambda}{U_{insulation}}$$

Lambda (the specific heat coefficient) is assumed to be λ = 0.035 W/m²K, a typical value for insulation material, such as glass wool or polystyrene.

The cost database has specific cost per centimetre insulation material added; the resulting investment cost is as follows:

$$Cost_{element} = d_{insulation} * price_{insulation}$$

To provide an example, Table 31 provides prices for Egypt, Jordan and Lebanon.

Table 31. Envelope cost

Element	Egypt (EUR/m²)	Jordan (EUR/m²)	Lebanon (EUR/m²)
Wall	1.35	4.2	3.15
Roof	1.35	4.2	3.15
Floor	1.35	4.2	3.15

2.4.1.2 Windows

Data collection in the three countries provided an adequate overview of the market prices for windows depending on their u-value (shown in Table 32). The tool offers a wide variety of windows. To derive the specific cost, the values in Table 33were interpolated. Windows with solar glazing are assumed to cost an additional 30 EUR/m² independent from the u-value.

Table 32. Window cost overview, according to u-values

U-Value (W/(m²K)	Egypt (EUR/m²)	Jordan (EUR/m²)	Lebanon (EUR/m²)
5.7	107.6	58	126.5
2.9	181.3	95	151.8
2.4	190.1	114.4	162.1
1.1	212.8	155	182.2
0.9	239.3	NA	202.4

2.4.2 Space heating systems

2.4.2.1 General space heating systems

The investment cost of the heating system includes distribution, storage, and the installation of the system; it is determined based on the heat power output the system needs to deliver. The sizing methodology for the systems is explained in Section 2.2.1.1. Besides the system's size, the energy efficiency class, renovation or new building case, and the location of the market (country) affect the cost.

An individual linear cost function was created for all space heating systems. Table 32 lists the parameters (a, b) for boiler systems, the cost factors in case of a renovation (CF_{renov}), and the cost factor for the efficiency class ($CF_{efficiency}$). P_{heat} represents the heat power output of the system.

$$Cost_{Heating} = (a * P_{heat} + b) * CF_{renov} * CF_{efficiency}$$

All prices are collected for new building cases. The renovation cost factor considers that a system replacement implies higher cost for installation because the existing system must be removed first. Furthermore, the costs are collected for average efficiency systems; the efficiency factor is more than 1 for higher efficiencies and less than 1 for lower efficiencies.

Table 33 shows an extraction of the data used in the tool for selected systems and the Jordan case.

Table 33. Example extraction of the parameters used in the cost calculation for heating systems

Parameters	Gas non-condensing	Gas condensing	Oil non-condensing	Oil condensing
a	179.61	233.49	139.37	181.18
b	85.25	110.83	896.10	1164.93

Parameters	Gas non-condensing	Gas condensing	Oil non-condensing	Oil condensing
(1) Best available	1.10	1.10	1.10	1.10
(2) Good newbuild standard	1.05	1.05	1.05	1.05
(3) Minimum newbuild requirement	1.00	1.00	1.00	1.00
(4) Average low existing building	0.95	0.95	0.95	0.95
(5) Very low efficiency	0.90	0.90	0.90	0.90
Renovation factor	105%	105%	105%	105%

2.4.2.2 Reversible air conditioning

Exceptions to this methodology include reversible air conditioning systems (air-to-air heat pumps) that are primarily used as space cooling systems; these systems can provide space heating as well. Therefore, their costs are always related to the installed cooling system. To consider this, the cost function or cost per kilowatt of installed power is taken from the selected space cooling system. An additional 10% is charged because reversible systems are more expensive than non-reversible systems. The other factors are included as in the methodology for general heating systems, which is explained in the previous subsection.

In this case, only one system purchase is needed for heating and cooling. Therefore, the investment cost for both systems is calculated and the higher system cost is used. This considers that the more demanding power design determines the price (i.e. if higher heating power needed, this should be the driving indicator and vice-versa).

Costs are always displayed in the space cooling system section.

2.4.3 DHW

DHW system costs are calculated according to the formulae of the space heating systems, as described in Section 2.4.2.1.

It deviates for **decentral systems** in the way that one system must be installed per apartment. As an example: In a MFH the peak demand per apartment might be 20 kW, which leads to boiler cost of around 300 EUR/system. Since every apartment has it's own dedicated water heater, the total cost will be the 300 EUR per system times the number of apartments in the building.

The **central systems** are calculated differently. The space heating system supplies the hot water as well, hence no additional kW is installed. However, an additional hot water storage and pipes plus pump to distribute the water in the building is necessary. The cost for the central DHW system is the storage cost multiplied with a factor of 2.5 to reflect the pipes and pumps.

The **costs for thermal solar systems** are calculated using the collector area (entered by the user) times the specific collector area price (includes the system price, either thermosyphon or central system with storage within the building).

$$Cost_{solar} = specific\ cost\ \left[\frac{EUR}{m^2}\right] * collector\ area\ [m^2]$$

2.4.4 Space cooling systems

The space cooling system costs are calculated according to the formulae of the space heating systems, as described in Section 2.4.2.1.

2.4.5 Mechanical ventilation

The mechanical ventilation system costs are calculated like the formulae of the space heating systems, described in Section 2.4.2.1; however, they are not based on the installed capacity. Instead, they are based on the living area ventilated by the system in square metres.

2.4.6 Lighting

The lighting cost is determined by the actual light bulbs needed. The necessary light demand, set in Lux needed, is listed in Table 35. The expected lumen output of each lamp is listed in Table 34. The correction factor of 0.5 is to have a more realistic light distribution (in general, buildings are not perfectly lit in every corner).

$$Number_{Lamp} = Lux_{need} * \frac{A_{use}}{Lumen\ per\ Lamp} * 0.5$$

Table 34. Light output per lamp

Type of lighting	Lumen per W	Lumen per lamp
LFL	58	1,000
CFL	60	1,000
Halogen lamps	25	1,000
Classical incandescent lamps	16	800
LED lamps	100	1,000

Table 35. Light demand per building type

Building type	Lux (lumen/m²)
SFH	300
MFH (MFH/apartment block)	300
Office building	500
Educational building	500
Retail/trade	500
Hospital	300

The resulting cost is calculated with the specific light bulb cost as follows:

$$Cost_{bulps} = Number_{lamp} * Price\ per\ light\ bulp$$

2.4.7 Photovoltaic

The investment costs are calculated based on the specific capacity prices as follows:

$$Cost_{PV} = specific\ cost\ \left[\frac{EUR}{kW}\right] * capacity\ [kW]$$

For PV, the type of feed-in tariff used is very relevant. Section 2.4.7.1 explains more on this topic.

2.4.7.1 Feed-in tariffs/net metering scheme

Besides feed-in tariffs, net metering is a common way to balance the electricity consumption of prosumers and fed into the grid in the region Middle East and North Africa (MENA). Feed-in tariffs define how much the owner of a PV system is paid for their electricity being fed into the grid. However, in the BEP tool, the default setting is that net metering is applied in Egypt, Jordan, and Lebanon. The electricity consumed from the grid and fed into the grid is balanced over a month period. Only the remaining (net) demand is charged by the electricity supplier. If there is an overhang from the previous month (so more electricity was fed in than consumed), this credit can be applied and is taken into account as additional feed into the monthly balance.

For Egypt, an external source described net metering in the following:

The net-metering scheme applies solely to solar energy and allows for excess energy generated by the power plant to be evacuated to relevant Distribution Network or the Transmission Grid (as applicable). The net metering scheme is further subject to the following parameters:

- *The plant must be connected to a network, either the Transmission Grid (for hyper and high voltages) or a Distribution Network (for medium and low voltages); and*
- *The power plant’s capacity must not exceed 20 MW.*

The offsetting mechanics under the net-metering rules apply only to electricity quantities and on a monthly basis so that:

- *net consumption quantity of the off-taker is calculated based on the difference between the total energy consumed by the off-taker from the utility (i.e. Distribution Network or Transmission Grid) and the total energy fed to the utility from the off-taker’s system;*
- *off-taker is invoiced by the utility (i.e. the relevant DisCo or EETC) based on its net consumption based on the applicable progressive utility tariffs;*
- *any excess in metered energy between the off-taker’s generation from the power plant fed to the network and off-taker’s consumption from the utility during a given month shall be are credited in quantities to the off-taker to be offset against its consumption from the following months;*
- *at the end of the financial year for the utility (end of June of every calendar year) any energy amounts outstanding in the off-taker’s credit shall be subject to annual cash reconciliation, whereby the utility will buy such remaining credit at the average cost of*

electricity produced as determined in accordance with the latest service cost report prepared and announced annually by EgyptERA.

The applicable price for the annual cash reconciliation is usually a price that is fairly lower than utility supply price, which has been set at EGP piasters 71.4/kWh for the year 2017/2018 and still applies for the year 2019 as well.[1]

[1] Energy Egypt, "Egypt's Renewable Energy IPP Model – by Shehata & Partners Law Firm," 22 September 2019, https://energyegypt.net/egypts-renewable-energy-ipp-model-by-shehata-partners-law-firm/

3. Baseline buildings

Baseline buildings are only available for Egypt, Jordan, and Lebanon. The data for the baseline buildings was collected in 2020 and reflects only real constructions (not older than 3 years). At least five real cases were used to form one baseline for a building type.

3.1 Comparison of the entered project with the baseline

By default, every project is compared to its according baseline (relevant for Egypt, Jordan, and Lebanon). For other countries, the baseline comparison might not reflect the current situation and is not recommended. A new created project always starts with the applicable baseline building as the default values in the Input tab. If no inputs are changed, the baseline building is calculated.

When the specific project is calculated, the default values must be changed. These changes affect the baseline building in different ways. Some elements need to be adapted to guarantee a valuable reference case, whereas others need to stay fixed so the improvements in the specific projects are considered.

Table 37 shows how the web app methodology for the comparison of baseline buildings and user projects work in detail for each parameter, namely if the parameter is adapted to the entered building (user project) or kept from the baseline (internal data base). Each input parameter is listed. The X in column 2 or 3 indicates if the parameter is changed in the baseline according to the entered project (column 2: Adapted baseline) or if the parameter is kept as defined in the baseline (column 3: Original baseline).

Table 36. Overview of parameters to adapt for the comparison of baseline and user project

Parameter	Adapted baseline	Original baseline
General Information		
Building type	X	
Country	X	
Age group	X	
Reference city (representative climate for the selected climate region)	X	
Specify region (e.g. urban)	X	
Geometry		
Building levels (floors)	X	
Number of dwellings	X	
Net floor height (floor to ceiling)	X	
Net floor area (i.e. living area)	X	
Roof area opaque	X	
Orientation of the building	X	
Façade area opaque (excluding windows)	X	
Share of façade, oriented north	X	
Share of façade, oriented east	X	
Share of façade, oriented south	X	
Share of façade, oriented west	X	
Window area (total = transparent + frame)	X	

Parameter	Adapted baseline	Original baseline
Share of windows, oriented north	X	
Share of windows, oriented east	X	
Share of windows, oriented south	X	
Share of windows, oriented west	X	
Share of windows oriented horizontal	X	
Area floor slab (ground plate)	X	
Wall		
Wall renovation		
Absorption (wall)		X
Specific heat capacity		X
Mass distribution (standard: M)		X
U-value (wall)		X
Thermal heat bridge (wall)		X
Thermal heat bridge (wall)		X
Roof		
Roof renovation		
Absorption (roof)		X
Specific heat capacity		X
Mass distribution (standard: M)		X
U-value (roof)		X
Thermal heat bridge (roof)		X
Thermal heat bridge (roof)		X
Slab		
Slab renovation		
Type (material)		X
Specific heat capacity		X
U-value (slab)		X
Thermal heat bridge (ground plate)		X
Thermal heat bridge (ground plate)		X
Window		
Window renovation		
Window type		X
G-value		X
U-value (window)		X
Thermal heat bridge (window)		X
Thermal heat bridge (window)		X
Shading system renovated?		X
Shading variant		X
Shading factor for movable sun protection elements		X
Air change		
Free ventilation		X
Free ventilation		X
Infiltration		X

Parameter	Adapted baseline	Original baseline
Infiltration		X
Space heating		
Space heating considered	X	
System renovated?		
Space heating system		X
Efficiency class primary heating system		X
Energy carrier		X
Resulting efficiency		X
DHW		
Hot water considered	X	
System renovated?		
System technology		X
Efficiency class primary DHW system		X
Energy carrier		X
Resulting efficiency		X
Specific hot water demand (leave blank if tool should determine it)	X	
Solar system for DHW		X
Type of solar system		X
Installed area of solar collector		X
Azimuth angle		X
Inclination (0=horizontal, 90=vertical)		X
Country adjustment		X
Space cooling		
Space cooling considered	X	
System renovated?		
Space cooling system		X
Efficiency class primary air conditioning system		X
Resulting efficiency (COP)		X
Mechanical ventilation		
Mechanical ventilation system	X	
System renovated?		
Type of ventilation (system)		X
Air change rate: ventilation system	X	
Air change rate: ventilation system	X	
Heat recovery rate		X
PV		
Installed		X
System renovated?		
Capacity		X
Total module area		X
Azimuth angle		X
Inclination (0=horizontal, 90=vertical)		X
Country adjustment		X

Parameter	Adapted baseline	Original baseline
Lighting		
Lighting	X	
System renovated?		
Type of lighting technology		X
Lighting sensors		X
Operational parameters		
Internal heat gains (people, appliances)	X	
Additional electricity consumption (without light, HVAC)	X	
Additional electricity consumption (without light, HVAC)	X	
Conditioned area (heating)		X
Conditioned area (cooling)		X
Setpoint temperature – heating		X
Setpoint temperature – cooling		X
Night setback		X
Heating		X
Cooling		X
Start		X
End		X

3.2 Configuration of baseline buildings

The detailed configuration of the building selected to compare with the currently loaded project is shown by the default values in the Input tab (i.e. they reflect exactly the baseline building) or in the BUILD_ME database (link). Table 37 contains the specification of the envelope for some representative baseline buildings as an example.

Table 37. Baseline u-values

Elements	Wall (W/m^2K)	Roof (W/m^2K)	Floor (W/m^2K)	Window (W/m^2K)
Jordan				
SFH	0.57	0.55	1.2	3
SMFH	0.57	0.55	1.2	5.7
LMFH	0.57	0.55	1.2	5.7
Office building	0.57	0.55	1.2	3
School	0.57	0.55	1.2	5.7
Hotel	0.57	0.55	1.2	3
Egypt				
SFH	2.2	0.56	2.3	5.7
SMFH	2.4	0.76	2.2	5.7
LMFH	2.4	0.76	2.2	5.7
Office building	2.1	0.6	1.9	3

Elements	Wall (W/m²K)	Roof (W/m²K)	Floor (W/m²K)	Window (W/m²K)
School	2.4	0.46	2.6	3
Lebanon				
SFH	0.7	0.7	2.2	1.4
SMFH	0.5	1	2.2	2.8
LMFH	0.6	0.7	2.2	2.8
Office building	0.8	0.7	2.4	2.8
School	0.8	0.598	2.2	2.8

4. References

Akande, O. K., Fabiyi, O., & Mark, I. (2015). Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria. *American Journal of Civil Engineering and Architecture*.

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