EPA-ED Formulas
Calculation scheme

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Energy Performance Assessment Method for Existing Dwellings

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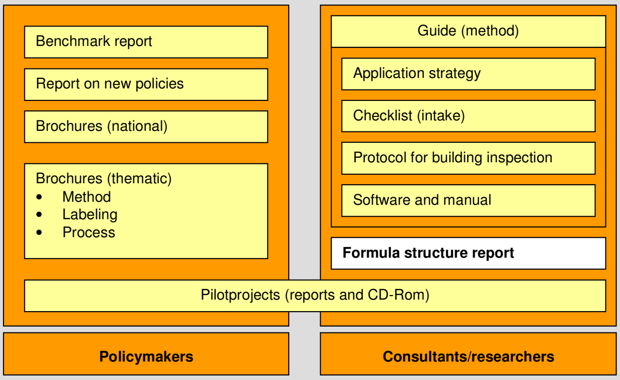
Contents

1 Introduction

OVERVIEW OF EPA-ED PRODUCTS

The EPA-ED project produced a number of products directed to policy makers, consultants and researchers. The EPA-ED method is a consultancy approach in line with the Energy Performance Directive for Buildings established by the European Commission. Reports, brochures and a CD-ROM accompany this method in order to facilitate policy makers in implementing the method on national or regional level.



Positioning of products of the EPA-ED project

For policy makers there is a ***benchmark report*** describing the status and context of the existing dwelling stock in Denmark, the Netherlands, Austria and Greece. The ***report on new policies*** shows the framework of policies, actors and stakeholders that EPBD is to be implemented in. ***National brochures*** describe how EPA-ED can affect Energy Performance Assessment in the countries involved in EPA-ED. ***Thematic brochures*** cover some specific issues like a short description of the method, issues regarding energy labelling and the process of energy performance assessment.

For consultants and researchers there is a ***guide*** describing the EPA-ED method. More detailed information on how to apply the method in the market is described in the ***report on application strategies***. To facilitate the consultant during the process a ***checklist for the intake*** of the client is available, together with information about adequate data acquisition by means of an ***inspection protocol***. The ***EPA-ED software*** is available for calculating the energy performance of the building(s) and quantifying the effect of energy saving measures. Background information about the software is provided in a working document describing the ***formula structure***.

The report you are about to read is highlighted in above scheme.

The EPA-ED method and tools serve two goals:

1. to produce an Energy Performance Certificate for an existing dwelling, as requested by the EC Energy Performance of Buildings Directive

The Energy Performance Certificate consists of the energy performance of the dwelling (in the form of one or more numeric indicators, determined with a standardised use of the dwelling), reference values and recommendations for the cost-effective improvement of the energy performance. The Energy Performance Certificate is mandatory and should be made available when an existing dwelling is sold or rented out.

2. to produce tailored advice on the energy performance of an existing dwelling

The tailored energy performance advice is a voluntary instrument and can be used by dwelling owners to improve the energy performance of their dwelling taking into account the actual use of the dwelling. Therefore the actual energy consumption is taken into account. Energy savings as a result of energy saving measures are thus fully tailored to (the behaviour of) the actual occupant.

The calculations needed to make these products can be performed by the EPA-ED software tool. The tool consists of a generic calculation core and a country specific user interface. The core contains formulas which are mostly based on European standards and which are generically applicable (for all countries). However the boundary conditions for these formulas and the values of the various constants are country specific. These constants are defined in the user interface. The user interface is not generic, but it can be adapted for each country according to the wishes and needs of the different countries. This may even include extra calculations.

In this document the formulas of the calculation core are given. These formulas are based on existing European standards, if possible.

About this report

In chapter 2 the sources of the formulas are given. Chapter 3 contains the formulas of the calculation. Chapter 4 gives an overview of all the input and output of the calculation core. In chapter 5 some definitions are given that clarify the formulas.

2 Basic assumptions

In this chapter the basic assumptions are discussed. Here some general aspects of the calculation are mentioned, as well as the various sources of the formulas. The first paragraph is about the general aspects of the calculation. These are taken from the EPA-ED brief [9]. In the second paragraph the formulas that come from the prEN 13790 are mentioned. After that, for each of the aspects of the energy calculation the source is given.

2.1 General aspects of the calculation

The accuracy of the EPA-ED calculation should be such that an investment decision can be made upon it. For this a static calculation is sufficient, if certain dynamic aspects are taken into account properly. An example is the utilisation of heat gains. The dynamic aspect can be modelled by introducing a mass dependant correction coefficient.
The time step in the calculation should be as long as possible, without loosing accuracy. This has led to a time step of one month.
The method contains a one zone calculation because in most cases this is sufficient. However sometimes a multi zone approximation can be reached with only small adaptations, for instance an unheated attic can be treated as a part of the roof structure instead of a part of the living space of the dwelling. Differences in comfort levels within a dwelling (windows in bedrooms and unheated spaces) can be taken care of by means of corrections that can be applied on the heat transfer coefficient or the U value.

The energy saving measures can concern a number of things. It can be a change of building part, a change of construction layer, the adding of a building part, the adding of a construction layer, a change of installation component, the adding of an installation component. It is very difficult to put all these options into the energy calculation. Therefore only the resulting (variant) dwelling will be defined, and not the *change* of the dwelling. This leads to the following calculation scheme:

- First the current situation (existing situation) is described, and the energy consumption is calculated.
- Then the building is adapted by applying a number of measures. This leads to a variant building description and a new calculated energy consumption.
- The savings are calculated as the difference in energy consumption between current situation and variant situation.
- The costs of the measures are calculated in a seperate calculation.
- The results of the calculations are integrated to calculate the pay back time.

The calculation method is applicable to both a single dwelling and an apartment building containing a number of dwellings.

2.2 Considerations for defining the formulas

The possible sources for the formulas of the energy calculations have been investigated. The prEN 13790, Thermal performance of buildings – Calculation of energy use for space heating [1] is the most important source for the formulas. The following possibilities occured:

1. In some cases the prEN 13790 provides formulas.
2. Sometimes the formulas from the prEN are not really suitable for the existing stock but they can be simplified or modified.
3. However in some other cases the formulas are not suitable at all for the existing stock of dwellings, or they simply don't exist. In those cases other formulas have to be defined, based on existing (and validated) models. The sources of these formulas are given in paragraph 2.3.

In the table below for all the aspects the source is given (indicated with an "x"). A grey cell indicates that the prEN doesn't provide any formulas for that aspect. The table is only about the energy calculation. The financial calculations are not mentioned here.

Table 1: Aspects of the calculation and possible sources

Aspect	prEN 13790	modified or simplified prEN	other	Remark
Internal and external temperatures		x		θ_i and θ_e standardised for labelling, free input for other calculation
Transmission	x			
Weighting factor b for unheated zones		x		Method in prEN 13790 can be used, but user input is possible as well
Sunspaces		x		Formula from prEN 13790, with geometrical assumptions
Ventilation			x	Formulas not applicable for existing stock
Solar gains	x			Solar heat gain factor into calculation; F_w*g in interface (input) I_{sol} (radiation) given for 8 orientations and 3 tilt angles in library
Internal gains		x		Unheated zones not in calculation
Heat gain utilisation factor	x			Heat capacity c given in interface; no detailed calculation for each structure
Installation efficiency			x	Distinction between efficiency of generation and distribution
Solar contribution (other than sunspaces)	x	x	x	Collector systems: simplified method
Cooling			x	Method from Dutch Standard
DHW			x	DHW demand volume is an input variable
Auxiliary energy			x	Key number in calculation core
Lighting (common provisions)			x	Key number in calculation core
PV cells			x	Key number for system efficiency in calculation core
CHP unit			x	Distinction between efficiency of heat and electricity production
Energy consumption			x	If more fuels: division in percentage of demand
Energy Indicator			x	EI will be calculated as a simple performance figure, e.g. energy per m^2 . More complicated calculations can be implemented in the user interface
Indoor climate			x	Method from Dutch non-residential calculation scheme is used.

The tool has been developed based on the existing European standards. In case new European Standards will be available, and these conflict with the formulas in the EPA-ED tool, the formulas from the standards will be implemented in the EPA-ED calculation.

2.3 Literature sources for each formula

In the following list for each aspect of the calculation the source of the formulas is given.

2.3.1 Heating energy consumption

Transmission heat losses
The formulas are from [1]. The (optional) calculation of the b-factor is in accordance with [3].

Ventilation heat losses
The basic formula is from [1]. However the calculation of the resulting ventilation rate in [1] is not applicable to existing buildings, because it deals with demands instead of real rates. Therefore the total ventilation rate is subdivided into 4 different parts. The determination of these flow rates is part of the user interface.
The calculation of the heat recovery system is in accordance with [1].

Internal gains
The formulas are from [1]. The effect of gains in unheated spaces has been neglected.

Solar gains
The formulas are from [1]. The effect of gains in unheated spaces has been neglected. The calculation of the transmittance of glazing in [1] includes the factors F_w and $g_{\perp}$. This formula has not been implemented in the calculation core. It is assumed that the user will give the resulting transmittance as an input variable.
The effect of movable shading devices is modelled with an extra F_M factor. The value may differ between heating and cooling calculation.

The unheated sunspace formulas are in accordance with [1]. However there are some extra simplifications. The assumptions are a rectangular shape of the sunspace and an envelope completely made of glass.

Utilisation factor of heat gains
The formulas are from [1]. The detailed calculation of the total heat capacity of the building is not implemented in the calculation core. The heat capacity is calculated using a key number and the gross floor area.

Installation efficiency
In [1] there are no formulas related to installation efficiencies. Also in other European standards this part of the calculation is not yet treated. The implementation in EPA-ED is a general approach with the total efficiency divided into generation efficiency and distribution efficiency. In the user interface each country can define its own installation efficiencies.

Contribution of solar collector
In the European standards there are no formulas about the implementation of the contribution of solar collectors into the energy consumption calculation.
In the EPA-ED calculation it is assumed that the energy produced by the solar collector should be corrected for the distribution efficiency, but not for the generation efficiency.

2.3.2 Cooling energy consumption

The cooling calculation is not described in European standards.

The formulas given here are from [7]. This source is about non-residential buildings, but there is information that the same formulas are applicable for residential buildings.

2.3.3 Domestic hot water energy consumption

The DHW calculation is not described in European standards.

The determination of the hot water *demand* is part of the user interface. Here each country can use its own formulas to calculate the demand, based on number of persons, or gross floor area. The possibilities are numerous and therefore it is not part of the calculation core.

The calculation of the energy consumption is straight forward including a temperature difference, the heat capacity of water and two efficiencies (generation and distribution).

The contribution of the solar collector is assumed to be a reduction on the energy *demand* for DHW and heating (and not on the *total energy consumption*). This means that the installation efficiency effects the actual contribution.

2.3.4 Contribution of solar collector systems
The contribution of the solar collector system is calculated based on an average efficiency.

2.3.5 Auxiliary energy
The auxiliary energy is not described in European standards.
The general approach of the calculation is to sum the auxiliary energy consumption of the various installations. The auxiliary energy consumption of each installation is part of the user interface. Each country can define its own values.

2.3.6 Lighting energy
The lighting energy is not described in European standards.
The EPA-ED method includes a key number to calculate the energy consumption. This key number is part of the user interface.

2.3.7 PV cells
The contribution of PV cells is not described in European standards.
The EPA-ED method contains a system efficiency to calculate the energy contribution. This method is described in [6].

2.3.8 CHP unit
CHP units are not described in European standards.
The EPA-ED method makes a distinction between heat production and electricity production. The heat production efficiency is used in the heating calculation. The produced electricity is assumed to be an extra reduction of the total primary energy consumption. This method is described in [4].

2.3.9 Energy consumption in other units
The conversion to other units is straightforward using material properties. For electricity a plant efficiency can be taken into account.

2.3.10 Actual energy consumption
The correction of the actual energy consumption is from the Dutch EPA method [6]. This correction has been extended to make correction for cooling energy consumption possible as well.

2.3.11 CO2 emission
The conversion from energy consumption to CO2 emission is straightforward. It is based on material properties.

2.3.12 Renewable energy
The definitions of renewable energy are from the Altener project Build on RES [5]. The second definition of renewable energy (black window approach) was expressed in net energy (heat demand). In EPA-ED it is converted to primary energy using the efficiencies of the installation and conversion factor of the fuels.

2.3.13 Energy Indicator
The energy indicator is not described in European Standards. The formula in EPA-ED is a simple indicator, expressing the amount of primary energy per m^2 gross floor area. Other indicators, which may be country specific, can be defined in the user interface.

2.3.14 Indoor climate calculation
The calculation of the indoor climate is based on a Dutch calculation method for non-residential buildings [10]. The formulas and the values of the constants are assumed to be valid for dwellings as well.

2.3.15 Financial calculations
The definition of the simple pay-back time and the nett present value pay-back time is from standard economics work.

3 Calculation

This chapter describes the formulas used in the calculation. A distinction is made between the energy calculation (paragraph 1 to 13), the indoor climate calculation (paragraph 14) and the financial calculation (paragraph 15).

The basic calculation is in primary energy. The various parts of the energy calculation are expressed in primary energy and summed up to get the total energy consumption. The conversion to other units (m^3 of gas, kWh electricity, etc.) will be performed afterwards (described in paragraph 13). All variables referring to these units have an extra index (e.g. “el” or “gas”). The variables expressed in primary energy have no extra index.

The total annual primary energy consumption equals:

$$Q_{Tot;year} = Q_{Heating;year} + Q_{Cooling;year} + Q_{DHW;year} + Q_{Auxiliary;year} + Q_{Lighting;year} - Q_{PV;year} - Q_{CHP;year} \quad [1]$$

where

$Q_{Tot;year}$	=	total annual primary energy consumption	[MJ/year]
$Q_{Heating;year}$	=	space heating annual energy consumption	[MJ/year]
$Q_{Cooling;year}$	=	annual cooling energy consumption	[MJ/year]
$Q_{DHW;year}$	=	annual domestic hot water energy consumption	[MJ/year]
$Q_{Auxiliary;year}$	=	annual auxiliary energy consumption	[MJ/year]
$Q_{Lighting;year}$	=	annual lighting energy consumption	[MJ/year]
$Q_{PV;year}$	=	annual decrease of primary energy consumption due to PV	[MJ/year]
$Q_{CHP;year}$	=	annual decrease of primary energy consumption due to CHP	[MJ/year]

3.1 Heating energy consumption

The annual energy consumption for space heating equals the sum of the monthly values.

$$Q_{Heating;year} = \sum_n Q_{Heating;n} \quad [2]$$

where

$Q_{Heating;year}$	=	annual space heating energy consumption	[MJ/year]
$Q_{Heating;n}$	=	space heating energy consumption for month *n*	[MJ/month]

Only months that are part of the heating season are included in the summation. The heating season is defined in the climate data.

The monthly energy consumption for space heating equals the sum of the energy consumption of all the installations involved:

$$Q_{Heating;n} = \sum_i Q_{H;n;i} \quad [3]$$

where

$Q_{Heating;n}$	=	space heating energy consumption for month *n*	[MJ/month]
$Q_{H;n;i}$	=	space heating energy consumption of heating system *i* for month *n*	[MJ/month]

For each installation the monthly energy consumption equals the fraction of the heat demand delivered by the installation divided by the total installation efficiency. The contribution of the solar collector leads to a reduction of the heat demand corrected by the distribution efficiency.

$$Q_{H;n;i} = \frac{F_{H;i} \times \left(\frac{Q_{HD;n}}{\eta_{H;dist;i}} - Q_{Sol;col;heat;n} \right)}{\eta_{H;gen;i}} \qquad [4]$$

The effective contribution of the solar collector cannot be higher than the heat demand divided by the distribution efficiency so the monthly energy consumption cannot be negative.

if $Q_{H;n;i} < 0$ then $Q_{H;n;i} = 0$ [5]

where

$Q_{H;n;i}$	=	space heating energy consumption of heating system *i* for month *n*	[MJ/month]
$F_{H;i}$	=	fraction of heat demand delivered by system *i*	[-]
$Q_{HD;n}$	=	heat demand in month *n*	[MJ/month]
$Q_{Sol;col;heat;n}$	=	contribution of solar system to space heating in month *n*	[MJ/month]
$\eta_{H;dist,i}$	=	distribution efficiency of system *i*	[-]
$\eta_{H;gen,i}$	=	generation efficiency of system *i*	[-]

The monthly heat demand can be written as:

$$Q_{HD} = Q_{Trans} + Q_{Vent} - \eta_{hg} \times (Q_{Int} + Q_{Sol;tot}) \qquad [6]$$

The heat demand can not be negative:

if $Q_{HD} < 0$ then $Q_{HD} = 0$ [7]]

where

Q_{Trans}	=	monthly transmission heat loss	[MJ/month]
Q_{Vent}	=	monthly ventilation heat loss	[MJ/month]
η_{hg}	=	utilisation factor for heat gains	[-]
Q_{Int}	=	monthly internal heat gain	[MJ/month]
$Q_{Sol;tot}$	=	monthly solar gains	[MJ/month]

3.1.1 Transmission heat loss

The transmission heat losses are calculated by means of an overall heat loss coefficient.

$$Q_{Trans} = H_{Trans} \times (\theta_{i;H} - \theta_e) \times t \qquad [8]$$

$$H_{Trans} = \sum_i A_i \times U_i \times b_i \qquad [9]$$

where

Q_{trans}	=	monthly transmission heat loss	[MJ/month]
H_{trans}	=	transmission heat loss coefficient	[W/K]
$\theta_{i;H}$	=	internal (design) temperature during heating period	[˚C]
θ_e	=	monthly average external temperature	[˚C]
t	=	duration of the month (see Table 2)	[Ms]
A_i	=	area of construction part *i* (thermal envelope)	[m^2]
U_i	=	thermal transmittance of construction part *i* (thermal envelope)	[W/m^2K]
b_i	=	temperature correction factor of construction part *i*	[-]

NB the internal temperature is the resulting average temperature including night setback. A more detailed calculation of the resulting temperature as a function of the temperature during day time and night time may be part of the user interface.

Table 2: Duration of the calculation periods

Month	**Number of days**	**Duration [Ms]**
January	31	2.678
February	28	2.419
March	31	2.678
April	30	2.592
May	31	2.678
June	30	2.592
July	31	2.678
August	31	2.678
September	30	2.592
October	31	2.678
November	30	2.592
December	31	2.678

The temperature correction factor b allows for the fact that the temperature outside the construction can differ from the atmosferic air temperature. Therefore the temperature correction factor b is equal to one for constructions facing the outside air. For parts of the building facing earth or unheated spaces such as ground, floors and cellar of crawl spaces the factor is lower (down to zero).

The factor b can be calculated with the following optional equations, or it is an input variable.

$$b = \frac{H_{ue}}{H_{iu} + H_{ue}} \quad [10]$$

$$H_{ue} = H_{T;ue} + H_{V;ue} \quad [11]$$

$$H_{T;ue} = \sum_j A_{j;ue} \times U_{j;ue} \quad [12]$$

$$H_{V;ue} = \rho_{air} \times c_{air} \times q_{v;ue} \quad [13]$$

$$H_{iu} = H_{T;iu} + H_{V;iu} \quad [14]$$

$$H_{T;iu} = \sum_i A_{i;iu} \times U_{i;iu} \quad [15]$$

$$H_{V;iu} = \rho_{air} \times c_{air} \times q_{v;iu} \quad [16]$$

where

b	=	temperature correction factor	[-]
H	=	thermal heat loss coefficient	[W/K]
H_T	=	transmission heat loss coefficient	[W/K]
H_V	=	ventilation heat loss coefficient	[W/K]
A_j	=	area of construction *j*	[m^2]
U_j	=	thermal transmittance of construction *j*	[W/m^2K]

q_v	=	air flow	[m^3/s]

Indices

i	=	constructions in thermal envelope
j	=	constructions in unheated space adjacent to the external environment
ue	=	index for unheated space to external environment
iu	=	index for internal to unheated space

3.1.2 Ventilation heat loss

The monthly ventilation heat losses are calculated as the sum of heat losses through infiltration, natural ventilation, mechanical ventilation and ventilation through the unheated sunspace.

$$Q_{Vent} = H_{Vent} \times (\theta_{i;H} - \theta_e) \times t \qquad [17]$$

$$H_{Vent} = \rho_{air} \times c_{air} \times \left(q_{v;i} + q_{v;n} + (1-\eta_{hr}) \times q_{v;m} + \sum_s b_s \times q_{v;ss;s} \right) \qquad [18]$$

where

Q_{vent}	=	monthly ventilation heat loss	[MJ/month]
H_{vent}	=	(monthly) ventilation heat loss coefficient	[W/K]
θ_i	=	internal (design) temperature during heating period	[˚C]
θ_e	=	(monthly) average external temperature	[˚C]
t	=	duration of the calculation period	[Ms]
ρ_{air}	=	density of air	[kg/m^3]
c_{air}	=	specific heat of air	[J/kgK]
$q_{v;i}$	=	monthly infiltration air flow	[m^3/s]
$q_{v;n}$	=	monthly effective natural ventilation air flow	[m^3/s]
$q_{v;m}$	=	monthly mechanical ventilation air flow (from external)	[m^3/s]
η_{hr}	=	heat recovery efficiency	[-]
$q_{v;ss;s}$	=	airflow entering the heated space via sunspace *s* with temperature correction factor b_s	[m^3/s]
b_s	=	temperature correction factor of sunspace *s*	[-]

Since the ventilation rates are monthly values H_{vent} also differs from month to month.

The airflow through the sunspace is a separate variable; it is not included in the other airflows.

3.1.3 Internal heat gains

The internal gains are calculated based on a monthly average value.

$$Q_{Int} = \Phi_{ih} \times t \qquad [19]$$

where

Q_{Int}	=	monthly internal heat gains	[MJ/month]
Φ_{ih}	=	average monthly internal heat gain in heated space	[W]
t	=	duration of the calculation period (one month)	[Ms]

3.1.4 Solar gains

The total monthly solar heat gains are the sum of the direct and indirect solar gains:

$$Q_{sol;tot} = Q_{sol;t} + Q_{sol;ss} \qquad [20]$$

where

$Q_{sol;tot}$	=	total monthly solar heat gains	[MJ/month]
$Q_{sol;t}$	=	direct solar heat gain through transparent construction parts of the thermal envelope	[MJ/month]
$Q_{sol;ss}$	=	indirect solar heat gains, via a sunspace	[MJ/month]

The direct solar heat gains are the gains through transparent construction parts:

$$Q_{Sol;t} = \sum_j A_j \times F_{F;j} \times F_{S;j} \times F_{M;H;j} \times g_j \times I_{sol;j} \qquad [21]$$

$Q_{sol;t}$	=	direct solar heat gain through transparent construction parts of the thermal envelope	[MJ/month]
A_j	=	area of transparent construction *j*	[m²]
$F_{F;j}$	=	frame factor of transparent construction *j*	[-]
$F_{s;j}$	=	shading correction factor of transparent construction *j* (annual value)	[-]
$F_{M;H;j}$	=	correction factor for movable shading devices of transparent construction *j* in heating calculation (annual value)	[-]
g_j	=	effective total solar energy transmittance of transparent construction *j*	[-]
$I_{sol;j}$	=	monthly solar radiation on transparent construction *j*, having a certain orientation and tilt angle	[MJ/m²/month]

The solar heat gain due to unheated sunspace(s) is the sum of the contributions of the various sunspaces. The gains can be subdivided into *direct* solar gains ($Q_{sol;direct}$) and *indirect* solar gain ($Q_{ss;indirect}$). The latter is the reduction of ventilation and transmission heat loss of the attached dwelling due to temperature rise of the sunspace when solar radiation is absorbed within the sunspace.

$$Q_{sol;ss} = \sum_s Q_{sol;ss;s} \qquad [22]$$

$$Q_{sol;ss;s} = Q_{sol;ss;direct} + Q_{sol;ss;indirect} \qquad [23]$$

$$Q_{sol;ss;direct} = I_{sol;p;s} \times F_{S;s} \times F_{F;s} \times g_{e;s} \times \left(\sum_w F_{F;w;s} \times g_{w;s} \times A_{w;s} + \sum_p \alpha_{p;s} \times A_{p;s} \times \frac{U_{p;s}}{U_{pe;s}} \right) \qquad [24]$$

$$Q_{sol;ss;indirect} = (1 - b_s) \times F_{S;s} \times F_{F;s} \times g_{e;s} \times \left(\sum_a I_{sol;a;s} \times \alpha_{a;s} \times A_{a;s} - \sum_p I_{sol;p;s} \times \alpha_{p;s} \times A_{p;s} \times \frac{U_{p;s}}{U_{pe;s}} \right) \qquad [25]$$

where

$Q_{sol;ss}$	=	total solar heat gain of all sunspaces	[MJ/month]
$Q_{sol;ss;s}$	=	solar heat gain of sunspace *s*	[MJ/month]
$Q_{sol;ss;direct}$	=	direct solar heat gain of sunspace	[MJ/month]
$Q_{sol;ss;indirect}$	=	indirect solar heat gain of sunspace	[MJ/month]
$I_{sol;p;s}$	=	solar radiation on partition wall of sunspace *s* having a certain orientation and tilt angle	[MJ/m^2]
$F_{s;s}$	=	(total) shading correction factor of sunspace *s*	[-]
$F_{F;s}$	=	frame factor of external sunspace envelope of sunspace *s*	[-]
$g_{e;s}$	=	effective total solar energy transmittance of glazing of sunspace *s*	[-]
$F_{F;w;s}$	=	frame factor of transparent part *w* in partition wall of sunspace *s*	[-]
$g_{w;s}$	=	effective total solar energy transmittance of transparent part *w* in partition wall of sunspace *s*	[-]
$A_{w;s}$	=	area of of transparent part *w* in partition wall of sunspace *s*	[m^2]
$\alpha_{p,s}$	=	average solar absorption factor of opaque part *p* of partition wall of sunspace *s*	[-]
$A_{p;s}$	=	area of opaque part *p* of partition wall of sunspace *s*	[m^2]
$U_{p;s}$	=	thermal transmittance of opaque part *j* of partition wall of sunspace *s*	[W/m^{2}K]
$U_{pe;s}$	=	thermal transmittance between the absorbing surface of opaque part *p* of the partition wall and the sunspace *s*	[W/m^{2}K]
b_s	=	temperature correction factor of sunspace *s*	[W/m^{2}K]
$I_{sol;a;s}$	=	solar radiation on absorbing surface *a* in sunspace *s* having a certain orientation and tilt angle	[MJ/m^2]
$\alpha_{a;s}$	=	average solar absorption factor of opaque construction *a* in sunspace *s*	[-]
$A_{a;s}$	=	area of absorbing surface *a* in sunspace *s*	[m^2]

Indices

w = index for transparent contructions in partition wall
p = index for opaque contructions in partition wall
a = index for absorbing surfaces in sunspace

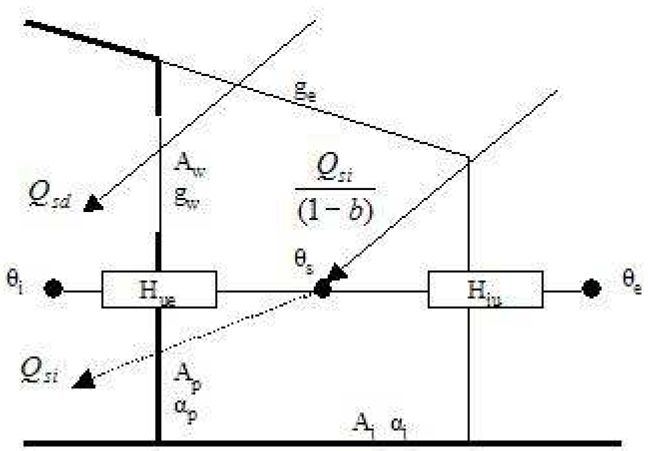


Figure 1: attached sunspace with gains and heat loss coefficients and electrical equivalent network

Sun space geometry calculations

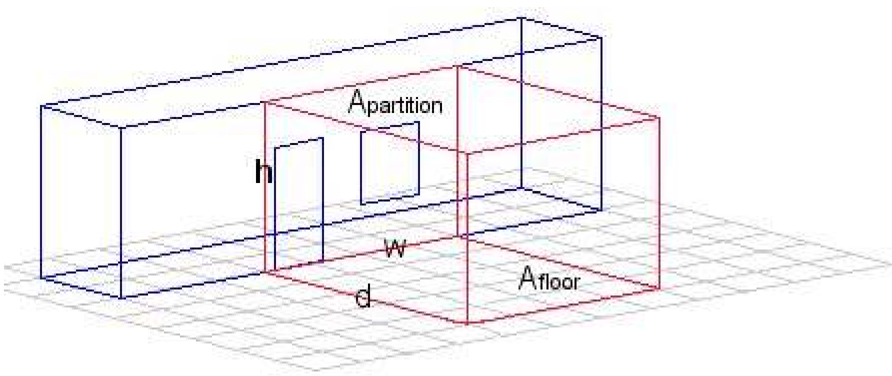


Figure 2: Attached sun space with geometrical parameters.

$$w = \frac{A_{partition}}{h} \quad [26]$$

$$d = \frac{A_{floor}}{w} \quad [27]$$

$$A_{partition} = \sum_w A_w + \sum_p A_p \quad [28]$$

where

h	=	average height of sunspace (input)	[m]
d	=	depth of sunspace, perpendicular to partition wall (calculated)	[m]
w	=	width of partition wall (calculated)	[m]
$A_{partition}$	=	total area of partition wall	[m^2]
A_{floor}	=	floor area of sunspace (input)	[m^2]
A_w	=	area of transparent partition wall construction	[m^2]
A_p	=	area of opaque partition wall construction	[m^2]

The factor b (for unheated spaces) can be calculated by the following equations, or it is an input variable:

$$b = \frac{H_{ue}}{H_{iu} + H_{ue}} \quad [29]$$

$$H_{ue} = H_{T;ue} + H_{V;ue} \quad [30]$$

$$H_{T;ue} = \left(A_{floor} + (2 \times d + w) \times h\right) \times U_{g;ue} + \sum_j A_{j;ue} \times U_{j;ue} \quad [31]$$

$$H_{V;ue} = \rho_{air} \times c_{air} \times n_{v;ue} \times A_{floor} \times h / 3600 \quad [32]$$

$$H_{iu} = H_{T;iu} + H_{V;iu} \quad [33]$$

$$H_{T;iu} = \sum_i A_{i;iu} \times U_{i;iu} \qquad [34]$$

$$H_{V;iu} = \rho_{air} \times c_{air} \times n_{v;ss} \times A_{floor} \times h / 3600 \qquad [35]$$

where

b	=	temperature correction factor	[-]
H	=	thermal heat loss coefficient	[W/K]
H_T	=	transmission heat loss coefficient	[W/K]
H_V	=	ventilation heat loss coefficient	[W/K]
A_j	=	area of construction *j*	[m^2]
U_g	=	thermal transmittance of external glass of sunspace	[W/m^2K]
U_j	=	thermal transmittance of construction *j*	[W/m^2K]
n_v	=	air flow	[1/h]
ρ_{air}	=	density of air	[kg/m^3]
c_{air}	=	specific heat of air	[J/kgK]

Indices

i	=	constructions in thermal envelope
j	=	constructions in unheated space (sunspace) adjacent to the external environment
ue	=	index for unheated space (sunspace) to external environment
iu	=	index for internal to unheated space (sunspace)
ss	=	index for internal to sunspace

3.1.5 Heat gain utilisation factor

The monthly value of the utilisation factor for heat gains is calculated according to:

if γ<>1: $$\eta_{hg} = \frac{(1-\gamma^{a_H})}{(1-\gamma^{a_H+1})} \qquad [36]$$

if γ=1: $$\eta_{hg} = \frac{1}{(1+a_H)} \qquad [37]$$

if $Q_{trans}+Q_{vent}>0$: $$\gamma = \frac{Q_{Int}+Q_{Sol;tot}}{Q_{Trans}+Q_{Vent}} \qquad [38]$$

if $Q_{trans}+Q_{vent}\leq 0$: $$\gamma = 0 \qquad [39]$$

When the external temperature is equal to (or higher than) the indoor temperature the transmission losses and ventilation losses become zero (or negative). In those cases the gain/loss ratio is set to zero to make the calculation possible. The heat demand cannot be negative.

where

η_{hg}	=	heat gain utilisation factor	[-]
γ	=	gain/loss ratio	[-]
a_H	=	numerical parameter depending on the time constant	[-]
Q_{Trans}	=	monthly transmission heat losses	[MJ/month]
Q_{Vent}	=	monthly ventilation heat losses	[MJ/month]
Q_{Int}	=	monthly internal heat gains	[MJ/month]
$Q_{Int;sol;tot}$	=	monthly total solar heat losses	[MJ/month]

The numerical constant is calculated according to:

$$a_H = a_{H;0} + \frac{\tau}{\tau_{H;0}} \quad [40]$$

$$\tau = \frac{C_{dwelling}}{3{,}6 \times (H_{Trans} + H_{Vent})} \quad [41]$$

$$C_{dwelling} = C' \times A_{gross} \quad [42]$$

where

a	=	numerical parameter depending on the time constant	[-]
$a_{H;0}$	=	method constant (= 1 for residential buildings)	[-]
τ	=	time constant	[h]
$\tau_{H;0}$	=	method constant (= 16 for residential buildings)	[h]
$C_{dwelling}$	=	internal heat capacity of the dwelling	[kJ/K]
H_{Trans}	=	transmission heat loss coefficient	[W/K]
H_{Vent}	=	ventilation heat loss coefficient	[W/K]
C'	=	internal heat capacity per m^2 usable floor area	[kJ/Km^2]
A_{gross}	=	gross floor area	[m^2]

3,6 is a conversion factor from W to kJ/h.

Since H_{vent} may differ between the months, so does the time constant of the building τ.

3.1.6 Annual nett gains

The annual total nett gains are equal to the utilisation factor times the internal and solar gains. The nett gains are needed for the comparison to the actual energy consumption.

$$Q_{gains;year} = \sum_n \eta_{hg;n} \times \left(Q_{Int;n} + Q_{Sol;tot;n}\right) \quad [43]$$

where

$Q_{gains;year}$	=	annual total nett gains	[MJ/year]
$\eta_{hg;n}$	=	heat gain utilisation factor in month *n*	[-]
$Q_{Int;n}$	=	internal heat gains in month *n*	[MJ/month]
$Q_{Sol;tot;n}$	=	solar heat gains in month *n*	[MJ/month]

3.2 Cooling energy consumption

The annual energy consumption for cooling equals the sum of the monthly values:

$$Q_{Cooling;year} = \sum_n Q_{Cooling;n} \quad [44]$$

where

$Q_{Cooling;year}$	=	annual energy consumption for cooling	[MJ/year]
$Q_{Cooling;n}$	=	energy consumption for cooling in month *n*	[MJ/month]

Only months are included in the summation that are part of the cooling season. The cooling season is defined in the climate data.

The monthly energy consumption is the sum of all the installations according to:

$$Q_{Cooling;n} = \sum_i Q_{C;n;i} \qquad [45]$$

where

$Q_{Cooling;n}$	=	cooling energy consumption for month *n*	[MJ/month]
$Q_{C;n;i}$	=	monthly cooling energy consumption for system *i*	[MJ/month]

For each installation:

$$Q_{C;n;i} = \frac{F_{C;i} \times Q_{CD}}{\eta_{C;gen;i} \times \eta_{C;distr;i}} \qquad [46]$$

where

$Q_{C;n;i}$	=	cooling energy consumption for system *i*	[MJ]
$F_{C;i}$	=	fraction of cooling demand delivered by installation *i*	[-]
Q_{CD}	=	monthly cooling demand	[MJ/month]
$\eta_{C,gen;i}$	=	generation efficiency of system *i*	[-]
$\eta_{C,distr;i}$	=	distribution efficiency of system *i*	[-]

If there is no cooling installation, the cooling energy consumption is zero.

The monthly cooling demand can be written as:

$$Q_{CD} = Q_{Sol;C;tot} + Q_{Int} - \eta_{hl} \times \left(Q_{Trans;C} + Q_{Vent;C}\right) \qquad [47]$$

where

Q_{CD}	=	monthly cooling demand	[MJ/month]
$Q_{Trans;C}$	=	monthly transmission heat losses for cooling	[MJ/month]
$Q_{Vent;C}$	=	monthly ventilation heat loss for cooling	[MJ/month]
η_{hl}	=	utilisation factor on heat losses	[-]
$Q_{Sol;C;tot}$	=	total monthly solar gain for cooling	[MJ/month]
Q_{Int}	=	monthly internal heat gain	[MJ/month]

3.2.1 Internal heat gains

see 3.1.3

3.2.2 Solar gains

The solar gains consist of solar gains through transparent construction parts and solar gains of sunspaces. Solar gains of opaque construction parts are also taken into account in the cooling calculation.

$$Q_{sol;C;tot} = Q_{sol;t} + Q_{sol;ss} + Q_{sol;p} \qquad [48]$$

$Q_{sol;C;tot}$	=	total monthly solar gains for cooling calculation	[MJ/month]
$Q_{sol;t}$	=	monthly solar heat gain through transparent construction parts	[MJ/month]
$Q_{sol;ss}$	=	monthly solar heat gain of sunspace	[MJ/month]
$Q_{sol;p}$	=	monthly solar heat gain trough opaque construction parts	[MJ/month]

The solar heat gains through transparent construction parts are slightly different from the heating calculation because a different shading correction factor for movable shading devices is taken into account:

$$Q_{Sol;t} = \sum_j A_j \times F_{F;j} \times F_{S;j} \times F_{M;C;j} \times g_j \times I_{sol;j} \quad [49]$$

$Q_{sol;t}$	=	direct solar heat gain through transparent construction parts of the thermal envelope	[MJ/month]
A_j	=	area of transparent construction *j*	[m^2]
$F_{F;j}$	=	frame factor of transparent construction *j*	[-]
$F_{s;j}$	=	shading correction factor of transparent construction *j* (annual value)	[-]
$F_{M;C;j}$	=	correction factor for movable shading devices of transparent construction *j* (annual value) for cooling calculation	[-]
g_j	=	effective total solar energy transmittance of transparent construction *j*	[-]
$I_{sol;j}$	=	monthly solar radiation on transparent construction *j*, having a certain orientation and tilt angle	[MJ/m^2/month]

The solar heat gains of sunspaces are equal to the gains in the heating calculation (See 3.1.4)

The solar gains through opaque construction parts is calculated according to:

$$Q_{sol;p} = \sum_i \alpha_{p;i} \times I_{sol;p;i} \times A_{p;i} \times \frac{U_{p;i}}{U_{pe;i}} \quad [50]$$

where

$Q_{sol;p}$	=	monthly solar heat gain trough opaque construction parts	[MJ/month]
$\alpha_{p;i}$	=	average solar absorption factor of opaque part *i*	[-]
$I_{p;i}$	=	total monthly solar radiation on opaque part *i*	[MJ/month m^2]
$A_{p;i}$	=	area of opaque part *i*	[m^2]
$U_{p;i}$	=	thermal transmittance of opaque part *i*	[W/m^{2}K]
$U_{pe;i}$	=	thermal transmittance between the absorbing surface of opaque part *i* and the external environment	[W/m^{2}K]

3.2.3 Transmission heat loss

$$Q_{Trans;C} = H_{Trans} \times \left(\theta_{i;C} + CF \times \Delta\theta_{CF} - \theta_e\right) \times t \quad [51]$$

where

$Q_{Trans;C}$	=	transmission heat loss for cooling	[MJ/month]
H_{Trans}	=	transmission heat loss coefficient (see 2.1.1)	[W/K]
$\theta_{i;C}$	=	internal (design) temperature during cooling period	[˚C]
CF	=	factor indicating the presence of ceiling fans: = 1 if ceiling fans are present = 0 if ceiling fans are not present	[-]
$\Delta\theta_{CF}$	=	increase of comfort temperature because of ceiling fans	[˚C]
θ_e	=	monthly external temperature	[˚C]
t	=	duration of calculation period	[Ms]

The increase of comfort temperature is defined in the national constant library. It cannot be adapted by the user.

3.2.4 Ventilation heat loss

$$Q_{Vent;C} = H_{Vent} \times \left(\theta_{i;C} + CF \times \Delta\theta_{CF} - \theta_e\right) \times t \qquad [52]$$

where

$Q_{vent;C}$	=	monthly ventilation heat loss for cooling calculation	[MJ/month]
H_{vent}	=	ventilation heat loss coefficient (monthly value, see 3.1.2)	[W/K]
$\theta_{i;C}$	=	internal (design) temperature during cooling period	[˚C]
CF	=	factor indicating the presence of ceiling fans: = 1 if ceiling fans are present = 0 if ceiling fans are not present	[-]
$\Delta\theta_{CF}$	=	increase of comfort temperature because of ceiling fans	[˚C]
θ_e	=	(monthly) average external temperature	[˚C]
t	=	duration of the calculation period	[Ms]

3.2.5 Heat loss utilisation factor

The utilisation factor for heat losses depends on the (monthly value of the) loss/gain ratio. When the external temperature is equal to (or higher than) the indoor temperature the transmission losses and ventilation losses become zero (or negative). In those cases the utilisation factor is set to one. This means the transmission and ventilation "losses" are added to the gains. This increases the cooling demand.

if λ<>1, λ>0: $$\eta_{hl} = \frac{\left(1-\lambda^{a_C}\right)}{\left(1-\lambda^{a_C+1}\right)} \qquad [53]$$

if λ=1: $$\eta_{hl} = \frac{1}{\left(1+a_C\right)} \qquad [54]$$

if λ≤0: $$\eta_{hl} = 1 \qquad [55]$$

The loss/gain ratio equals:

$$\lambda = \frac{Q_{Trans;C} + Q_{Vent;C}}{Q_{Sol;C;tot} + Q_{Int}} \qquad [56]$$

where

η_{hl}	=	monthly heat loss utilisation factor	[-]
λ	=	loss/gain ratio	[-]
a_C	=	numerical constant	[-]
$Q_{Trans;C}$	=	monthly transmission heat losses for cooling	[MJ/month]
$Q_{Vent;C}$	=	monthly ventilation heat losses for cooling	[MJ/month]
$Q_{Sol;C;tot}$	=	monthly total solar gains for cooling	[MJ/month]
Q_{Int}	=	monthly internal gains	[MJ/month]

$$a_C = a_{C;0} + \frac{\tau}{\tau_{C;0}} \qquad [57]$$

$$\tau = \frac{C_{dwelling}}{3{,}6 \times (H_{Trans} + H_{Vent})} \quad [58]$$

$$C_{dwelling} = C' \times A_{gross} \quad [59]$$

where

a_C	=	numerical parameter for cooling calculation depending on the time constant of the building	[-]
$a_{C;0}$	=	method constant	[-]
τ	=	time constant of the building	[h]
$\tau_{C;0}$	=	method constant (reference time constant)	[h]
$C_{dwelling}$	=	internal heat capacity of the dwelling	[kJ/K]
H_{Trans}	=	transmission heat loss coefficient	[W/K]
H_{Vent}	=	ventilation heat loss coefficient	[W/K]
C'	=	internal heat capacity per m^2 usable floor area	[kJ/Km^2]
A_{gross}	=	gross floor area	[m^2]

3,6 is a conversion factor from MJ to kWh.

The time constant of the building used in the cooling calculation is the same as the one in the heating calculation. It may differ from month to month because of the variation in ventilation rates.

3.3 Domestic hot water energy consumption (DHW)

The annual energy consumption for domestic hot water equals the sum of the monthly energy consumptions:

$$Q_{DHW;year} = \sum_n Q_{DHW;n} \quad [60]$$

The monthly energy consumption equals the sum of the energy consumptions of all the installations involved.

$$Q_{DHW;n} = \sum_i Q_{DHW;n;i} \quad [61]$$

The monthly energy consumption for each installation equals the gross demand minus the contribution of solar systems divided by the generation efficiency. This result is multiplied by the fraction of the total energy consumption that is delivered by the installation. The gross demand equals the nett demand including the distribution efficiency.

$$Q_{DHW;n;i} = F_{DHW;i} \times \frac{Q_{DHW;gross;n} - Q_{Sol;col;DHW;n}}{\eta_{DHW;gen;i}} \quad [62]$$

The energy consumption cannot be negative. So if the contribution of the solar collector is larger than the gross demand, the consumption is set to zero.

$$Q_{DHW;gross;n} = \frac{Q_{DHW;demand;n}}{\eta_{DHW;distr}} \quad [63]$$

$$Q_{DHW;demand;n} = \frac{V_{DHW} \times \rho_{water} \times c_{water} \times (\theta_{DHW;H} - \theta_{DHW;C})}{12} \quad [64]$$

where

$Q_{DHW;year}$	=	annual energy consumption for domestic hot water	[MJ/year]
$Q_{DHW;n}$	=	domestic hot water energy consumption for month *n*	[MJ/month]
$Q_{DHW;n;i}$	=	domestic hot water energy consumption for month *n* delivered by installation *i*	[MJ/month]
$F_{DHW;i}$	=	fraction of total domestic hot water energy consumption delivered by installation *i*	[-]
$Q_{DHW;gross;n}$	=	gross energy demand for domestic hot water for month *n* (including distribution efficiency)	[MJ/month]
$Q_{sol;col;DHW;n}$	=	contribution of solar system to domestic hot water for month *n* (see 3.4)	[MJ/month]
$\eta_{DHW;gen;i}$	=	generation efficiency of domestic hot water appliance *i*	[-]
$Q_{DHW;demand;n}$	=	energy demand for domestic hot water for month *n*	[MJ/month]
$\eta_{DHW;distr}$	=	distribution efficiency of domestic hot water system	[-]
V_{DHW}	=	annual domestic hot water consumption volume (at boiler temperature)	[m³/year]
ρ_{water}	=	density of water	[kg/m³]
c_{water}	=	specific heat of water	[J/kgK]
$\theta_{DHW;H}$	=	domestic hot water (boiler) temperature	[˚C]
$\theta_{DHW;C}$	=	domestic cold water temperature	[˚C]

12 is the number of months in one year.

The hot water temperature is defined in the national constant library.

The cold water temperature is assumed to be equal to the average annual external temperature:

$$\theta_{DHW;C} = \frac{1}{12} \times \sum_{i=1}^{12} \theta_{e;i} \qquad [65]$$

where

$\theta_{DHW;C}$	=	domestic cold water temperature	[°C]
$\theta_{e;i}$	=	external temperature in month *i*	[°C]

3.4 Contribution of solar collector systems to heating and DHW

3.4.1 Contribution of the solar system

The total annual contribution of the solar collector system is the sum of the monthly values:

$$Q_{Sol;col;year} = \sum_{n} Q_{Sol;col;n} \qquad [66]$$

where

$Q_{sol;col;year}$	=	annual contribution of solar collector	[MJ/year]
$Q_{sol;col;n}$	=	monthly contribution of solar collector	[MJ/month]

The monthly contribution is calculated based on an average efficiency. The average efficiency is an *annual* efficiency.

$$Q_{Sol;col;n} = A_{Col} \times \eta_{Col} \times I_{Sol} \times F_s \qquad [67]$$

$Q_{sol;col;n}$	=	monthly contribution of solar collector	[MJ/month]
A_{col}	=	collector area	[m^2]
η_{col}	=	(annual) average efficiency of solar collector	[-]
I_{sol}	=	monthly average solar radiation with orienation and tilt angle	[MJ/month]
F_s	=	shading correction factor	[-]

3.4.2 Assignment to heating and DHW

The total contribution of the solar collector can be assigned to domestic hot water, or to space heating *and* domestic hot water.

If the contribution of the solar collector is to domestic hot water only, then:

$$Q_{Sol;col;DHW;n} = Q_{sol;col;n} \quad [68]$$

$$Q_{Sol;col;Heat;n} = 0 \quad [69]$$

If the collector is for both space heating and domestic hot water there is a preference for hot water, according to:

$$Q_{Sol;col;DHW;n} = MIN\{Q_{sol;col;n}, Q_{DHW;gross;n}\} \quad [70]$$

$$Q_{Sol;col;Heat;n} = Q_{sol;col;n} - Q_{Sol;col;DHW;n} \quad [71]$$

where

$Q_{sol;col;DHW;n}$	=	contribution of solar collector system to DHW for month *n*	[MJ/month]
$Q_{sol;col;n}$	=	contribution of solar collector system in month *n*	[MJ/month]
$Q_{DHW;gross;n}$	=	gross energy demand for domestic hot water in month *n*	[MJ/month]
$Q_{sol;col;Heat;n}$	=	contribution of solar collector system to heating for month *n*	[MJ/month]
MIN{ }	:	operator giving the minimum of the arguments	

The annual contribution of the solar collector system to heating and DHW (needed for the comparison to the actual energy consumption) equals:

$$Q_{Sol;col;DHW;year} = \sum_n Q_{Sol;col;DHW;n} \quad [72]$$

$$Q_{Sol;col;Heat;year} = \sum_n Q_{Sol;col;Heat;n} \quad [73]$$

where

$Q_{sol;col;DHW;year}$	=	annual contribution of solar collector system to DHW	[MJ/year]
$Q_{sol;col;DHW;n}$	=	contribution of solar collector system to DHW for month *n*	[MJ/month]
$Q_{sol;col;Heat;year}$	=	annual contribution of solar collector system to heating	[MJ/year]
$Q_{sol;col;Heat;n}$	=	contribution of solar collector system to heating for month *n*	[MJ/month]

3.5 Auxiliary energy consumption

The auxiliary energy consumption equals the energy consumption of the installations for heating, cooling, DHW, plus the energy consumption of fans and miscellaneous equipment. The latter contains all the building related equipment, e.g. elevators.

$$Q_{el;Auxiliary;year} = Q_{el;Aux;H;year} + Q_{el;Aux;C;year} + Q_{el;Aux;DHW;year} + Q_{el;Aux;Fans;year} + Q_{el;Aux;Misc;year}$$ [74]

$$Q_{Auxiliary;year} = Q_{el;Auxiliary;year} \times F_{conv,el}$$ [75]

where

$Q_{el;Auxiliary;year}$	=	total annual auxiliary electricity consumption	[kWh/year]
$Q_{el;Aux;H;year}$	=	annual heating auxiliary energy	[kWh/year]
$Q_{el;Aux;C;year}$	=	annual cooling auxiliary energy	[kWh/year]
$Q_{el;Aux;DHW;year}$	=	annual DHW auxiliary energy	[kWh/year]
$Q_{el;Aux;Fans;year}$	=	annual fan auxiliary energy	[kWh/year]
$Q_{el;Aux;Misc;year}$	=	annual miscellaneous electrical consumption	[kWh/year]
$Q_{Auxiliary;year}$	=	total auxiliary energy consumption (primary energy)	[MJ/year]
$F_{conv;el}$	=	conversion factor of electricity to primary energy	[MJ/kWh]

3.6 Lighting energy consumption

Annual energy consumption for lighting. Only the common provisions, such as lighting in elevators and stairwells, are taken into account.

$$Q_{Lighting} = Q_{el;Lighting} \times F_{conv;el}$$ [76]

where

$Q_{el;Lighting}$	=	lighting electric energy consumption	[kWh]
$Q_{Lighting}$	=	lighting energy consumption (primary energy)	[MJ]
$F_{conv;el}$	=	conversion factor of electricity to primary energy	[MJ/kWh]

3.7 Photovoltaic cells energy contribution

The annual primary contribution of photovoltaic cells (PV cells) is the sum of the monthly values. These are calculated based on a key number per system. The key numbers are user input. More PV systems are possible.

$$Q_{PV;year} = \sum_{n} Q_{PV;n}$$ [77]

$$Q_{PV;n} = Q_{el;PV;n} \times F_{conv;el}$$ [78]

$$Q_{el;PV;year} = \sum_{n} Q_{el;PV;n}$$ [79]

$$Q_{el;PV;n} = \sum_{i} A_{PV;i} \times F_{PV;i} \times I_{sol;n;i} \times F_{s;i}$$ [80]

where

$Q_{PV;year}$	=	annual PV energy production	[MJ/year]
$Q_{PV;n}$	=	total PV primary energy production in month *n*	[MJ/month]
$Q_{el;PV;n}$	=	total PV electric energy production of all systems in month *n*	[kWh/month]
$F_{conv;el}$	=	conversion factor of electricity to primary energy	[MJ/kWh]
$Q_{el;PV;year}$	=	annual PV electric energy production	[kWh/year]

$A_{PV;i}$	=	PV collector area of collector *i*	[m²]
$F_{PV;i}$	=	gains factor (system efficiency) of collector *i*	[kWh/MJ]
$I_{sol;n;i}$	=	solar radiation on PV collector *i* having a certain orientation and tilt angle for month *n*	[MJ/month m²]
$F_{s;i}$	=	shading reduction factor of collector *i*	[-]

3.8 CHP unit energy contribution

A CHP unit (co-generation of heat and power) is an appliance that delivers heat and produces electricity. A CHP unit can be defined with two efficiencies: thermal and electric. The thermal efficiency describes the amount of heat produced given a certain amount of primary energy as an input. The electric efficiency describes the amount of electricity produced given a certain amount of primary energy as an input (figure 2). In the heating and DHW calculation only the thermal efficiency is used. The electricity efficiency is taken into account in the contribution of the CHP, which is an additional term in the overall calculation.

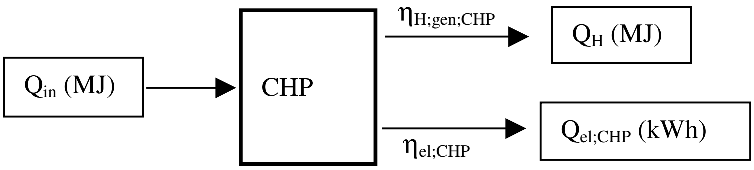


Figure 2: Scheme of CHP efficiencies

It is assumed that the power of the CHP unit is in accordance with the heating demand, and that the produced electricity is always useful. The extra produced electricity (not needed immediately) can be returned to the grid.

$$Q_{CHP;year} = \sum_{n} Q_{CHP;n} \quad [81]$$

$$Q_{CHP;n} = Q_{CHP;in;n} \times \eta_{el;CHP} \times F_{conv;el} \quad [82]$$

$$Q_{CHP;in;n} = Q_{H;n;CHP} + Q_{DHW;n;CHP} \quad [83]$$

$$Q_{el;CHP;year} = \sum_{n} Q_{el;CHP;n} \quad [84]$$

$$Q_{el;CHP;n} = Q_{CHP;in;n} \times \eta_{el;CHP} \quad [85]$$

where

$Q_{CHP;year}$	=	annual contribution of CHP, expressed in primary energy	[MJ/year]
$Q_{CHP;n}$	=	contribution of CHP, expressed in primary energy, in month *n*	[MJ/month]
$Q_{CHP;in;n}$	=	CHP energy consumption in month *n*	[MJ/month]
$\eta_{el;CHP}$	=	electric efficiency of CHP	[kWh/MJ]
$F_{conv;el}$	=	conversion factor of electricity to primary energy	[MJ/kWh]
$Q_{H;n;CHP}$	=	space heating energy consumption delivered by CHP in month *n*	[MJ/month]
$Q_{DHW;n;CHP}$	=	domestic hot water energy consumption delivered by CHP in month *n*	[MJ/month]
$Q_{el;CHP;year}$	=	annual electric energy production of CHP	[kWh/year]
$Q_{el;CHP;n}$	=	electric energy production of CHP in month *n*	[kWh/month]

NB In the general formulas where the installation efficiency is used the index "CHP" is replaced by "i", indicating the number of the installation.

The electric efficiency of the CHP, $\eta_{el;CHP}$, is defined as the amount of electric energy (kWh) produced by the CHP, if the primary energy input is 1 MJ.

3.9 Energy consumption in other units

For each fuel the total consumption equals the sum of the fuel consumption of each installation *i*. The installations refer to heating, cooling and DHW systems. The other parts of this summation (auxiliary, lighting, PV and CHP) are always electric. They are expressed in kWh.

The total electricity consumption:

$$Q_{el;year} = \sum_i Q_{el;year;i} + Q_{el;Auxiliary;year} + Q_{el;Lighting;year} - Q_{el;PV;year} - Q_{el;CHP;year} \quad [86]$$

The total consumption of other fuels:

$$Q_{f;u;year} = \sum_i Q_{f;u;year;i} \quad [87]$$

For each installation:

$$Q_{f;u;i;year} = \frac{k_{f;u;i} \times Q_{i;year}}{F_{conv;f}} \quad [88]$$

where

$Q_{el;year}$	=	total annual electricity consumption	[kWh/year]
$Q_{el;year;i}$	=	total annual electricity consumption of installation *i*	[kWh/year]
$Q_{el;Auxiliary;year}$	=	annual electricity consumption of auxiliary energy	[kWh/year]
$Q_{el;Lighting;year}$	=	annual electricity consumption of lighting energy	[kWh/year]
$Q_{el;PV;year}$	=	annual electricity contribution of PV cells	[kWh/year]
$Q_{el;CHP;year}$	=	annual electricity contribution of CHP unit	[kWh/year]
$Q_{f;u;year}$	=	total annual consumption of fuel *f* with unit *u*	[*unit;fuel*]
$Q_{f;u;i;year}$	=	annual consumption of fuel *f* with unit *u* for installation *i*	[*unit;fuel*]
$k_{f;u;i}$	=	1 for installations *i* using fuel *f* with unit *u* 0 for installations *i* not using fuel *f* with unit *u*	[-]
$Q_{i;year}$	=	annual primary energy consumption of installation *i*	[MJ/year]
$F_{conv;f}$	=	conversion factor of fuel *f* (with fixed unit) to primary energy	[MJ/*unit;fuel*]

3.10Actual energy consumption

To compare the actual energy consumption with the calculated energy consumption the actual consumption first has to be corrected for climate and measuring period. There are two options for this procedure:
- the fuel for heating is not the same as the fuel for cooling
- the fuel for heating is (partly) the same as the fuel for cooling

The method is valid in case electricity is the fuel although in that case there is a lot of non-EPA related energy consumption which should be estimated. This can be troublesome.

The correction for both heating and cooling is based on degree days. The heating degree days influence only the losses, whereas it is assumed that for cooling the degree days influence the total consumption.

3.10.1 Correction method in case of different fuels for heating and cooling

Cooling

The correction for cooling is as follows: First from the total measured energy consumption the consumption for DHW and other (if other consumptions exist) are subtracted, corrected for the duration of the measuring period. After that the total consumption is corrected by the ratio of the number of cooling degree days in the reference year and the measuring period.

$$Q_{measure,C,period;f} = Q_{measure,tot,period;f} - (Q_{DHW;year;f} + Q_{other;year;f}) \times \frac{D_{period}}{D_{year}} \quad [89]$$

$$Q_{measure;C;year;f;corr} = Q_{measure;C;period;f} \times \frac{CDD_{ref;year}}{CDD_{actual;period}} \quad [90]$$

$Q_{measure;C;period;f}$	=	actual consumption of fuel *f* for space cooling in a period	[unit of fuel]
$Q_{measure;tot;period;f}$	=	total measured consumption of fuel *f* in a period	[unit of fuel]
$Q_{DHW;year;f}$	=	annual consumption of fuel *f* for DHW	[unit of fuel]
$Q_{other;year;f}$	=	annual consumption of fuel *f* for all other use	[unit of fuel]
D_{period}	=	number of days in measuring period	[days]
D_{year}	=	number of days per year	[days]
$Q_{measure;C;year;f;corr}$	=	corrected annual actual consumption of fuel *f* for space cooling	[unit of fuel]
$CDD_{ref;year}$	=	number of cooling degree days in a reference year	[°C days]
$CDD_{actual;period}$	=	actual number of cooling degree days in measuring period	[°C days]

The corrected measured energy consumption for cooling should be equal to the calculated energy consumption for cooling if user behaviour is equal.

Heating

The correction is as follows: First from the total measured energy consumption the consumption for DHW and other (if other consumptions exist) are subtracted, corrected for the duration of the measuring period. After that the contribution of solar collectors is added and the efficiency for heating (generation and distribution) is taken into account to calculate the (uncorrected) heat demand. If more than one fuels are involved the heat demands are all summed up. After that the heat gains are added to calculate the heat losses. These losses are then corrected for degree days. After that the calculation is performed backwards. The energy consumptions of DHW and the solar gains are corrected for the total duration of the measuring period.

$$Q_{measure,H,period;f} = Q_{measure,tot,period;f} - (Q_{DHW;year;f} + Q_{other;year;f}) \times \frac{D_{period}}{D_{year}} \quad [91]$$

where

$Q_{measure;H;period;f}$	=	actual consumption of fuel *f* for space heating in a period	[unit of fuel]
$Q_{measure;tot;period;f}$	=	total measured consumption of fuel *f* in a period	[unit of fuel]
$Q_{DHW;year;f}$	=	annual consumption of fuel *f* for DHW	[unit of fuel]

$Q_{other;year;f}$	=	annual consumption of fuel *f* for all other use	[unit of fuel]
D_{period}	=	number of days in measuring period	[days]
D_{year}	=	number of days per year	[days]

$$Q_{hd;period} = \sum_f \left(Q_{measure,H,period;f} \times \frac{F_{conv;f} \times \eta_{H;gen}}{F_{H;f}} + Q_{sol;col;heat;year} \times \frac{D_{period}}{D_{year}} \right) \times \eta_{H;dist} \quad [92]$$

$$Q_{loss;period} = Q_{hd;period} + Q_{gains;year} \times \frac{D_{period}}{D_{year}} \quad [93]$$

$$Q_{loss;year;corr} = Q_{loss;period} \times \frac{HDD_{ref;year}}{HDD_{actual;period}} \quad [94]$$

$$Q_{hd;year;corr} = Q_{loss;year;corr} - Q_{gains;year} \quad [95]$$

For each fuel *f*:

$$Q_{measure;H;year;f;corr} = \frac{F_{H;f} \times \left(\frac{Q_{hd;year;corr}}{\eta_{H;dist}} - Q_{sol;col;heat;year} \right)}{\eta_{H;gen}} \times \frac{1}{F_{conv;f}} \quad [96]$$

where

$Q_{hd;period}$	=	heat demand in period	[MJ/period]
$Q_{measure;H;period;f}$	=	actual consumption of fuel *f* for space heating in a period	[unit of fuel]
$F_{conv;f}$	=	conversion factor to primary energy of fuel *f*	[MJ/unit fuel]
$\eta_{H;gen}$	=	generation efficiency of heating installation using fuel *f*	[-]
$F_{H;f}$	=	fraction of heat demand for space heating covered by fuel *f*	[-]
$Q_{sol;col;heat;year}$	=	annual contribution of solar collector to heating demand	[MJ/year]
D_{period}	=	number of days in period	[days]
D_{year}	=	number of days per year	[days]
$\eta_{H;dist}$	=	distribution efficiency of heating installation using fuel *f*	[-]
$Q_{loss;period}$	=	heat loss in period	[MJ/period]
$Q_{gains;year}$	=	(nett) annual heat gains (internal and solar, including utilisation factor)	[MJ/year]
$Q_{loss;year;corr}$	=	heat losses corrected for the local climate and the length of the period	[MJ/year]
$HDD_{ref;year}$	=	number of heating degree days in a reference year	[°C day]
$HDD_{actual;period}$	=	actual number of heating degree days in a period	[°C day]
$Q_{hd;year;corr}$	=	corrected annual heat demand	[MJ/year]
$Q_{measure;H;year;f;corr}$	=	corrected annual energy consumption for space heating related to fuel *f*	[unit of fuel]

The actual energy consumption after correction should be equal to the calculated energy consumption for heating if the user behaviour is equal (internal temperature, internal gains, ventilation rates). The internal heat gains and ventilation rates should be estimated as well as possible. Then the internal temperature can be calculated by means of “fitting”, because it is the only unknown variable.

3.10.2 Correction method in case of identical fuels

If the fuels for heating and cooling are the same the correction procedure from the previous paragraph can only be applied by means of an iteration because another degree of freedom has been added to the calculation. This procedure is not implemented because of the risk of non converging results. The approach is simpler: the actual cooling consumption is based on the corrected calculated annual consumption and all the other correction is put into the heating consumption, because this calculation is more accurate.

Cooling

The correction for cooling is as follows: the total calculated annual consumption is multiplied by the ratio of the number of degree days to determine the consumption in the measuring period.

$$Q_{measure;C;period;f} = Q_{Cooling;year;f} \times \frac{CDD_{actual;period}}{CDD_{ref;year}} \qquad [97]$$

$Q_{measure;C;period;f}$	=	actual consumption of fuel *f* for space cooling in a period	[unit of fuel]
$Q_{Cooling;year;f}$	=	calculated annual consumption for cooling of fuel *f*	[unit of fuel]
$CDD_{ref;year}$	=	number of cooling degree days in a reference year	[°C days]
$CDD_{actual;period}$	=	actual number of cooling degree days in measuring period	[°C days]

It is not possible to verify the determined cooling energy consumption.

Heating

The correction is the same as in the previous paragraph, but now besides DHW and "other" energy consumption also the energy consumption for cooling is subtracted.

$$Q_{measure,H,period;f} = Q_{measure,tot,period;f} - (Q_{DHW;year;f} + Q_{other;year;f}) \times \frac{D_{period}}{D_{year}} - Q_{measure;C;period;f}$$

[98]

where

$Q_{measure;H;period;f}$	=	actual consumption of fuel *f* for space heating in a period	[unit of fuel]
$Q_{measure;tot;period;f}$	=	total measured consumption of fuel *f* in a period	[unit of fuel]
$Q_{DHW;year;f}$	=	annual consumption of fuel *f* for DHW	[unit of fuel]
$Q_{other;year;f}$	=	annual consumption of fuel *f* for all other use	[unit of fuel]
D_{period}	=	number of days in measuring period	[days]
D_{year}	=	number of days per year	[days]

$$Q_{hd;period} = \sum_f \left(Q_{measure,H,period;f} \times \frac{F_{conv;f} \times \eta_{H;gen}}{F_{H;f}} + Q_{sol;col;heat;year} \times \frac{D_{period}}{D_{year}} \right) \times \eta_{H;dist} \qquad [99]$$

$$Q_{loss;period} = Q_{hd;period} + Q_{gains;year} \times \frac{D_{period}}{D_{year}} \qquad [100]$$

$$Q_{loss;year;corr} = Q_{loss;period} \times \frac{HDD_{ref;year}}{HDD_{actual;period}} \qquad [101]$$

$$Q_{hd;year;corr} = Q_{loss;year;corr} - Q_{gains;year} \qquad [102]$$

For each fuel *f*:

$$Q_{measure;H;year;f;corr} = \frac{F_{H;f} \times \left(\dfrac{Q_{hd;year;corr}}{\eta_{H;dist}} - Q_{sol;col;heat;year} \right)}{\eta_{H;gen}} \times \frac{1}{F_{conv;f}} \qquad [103]$$

where

$Q_{hd;period}$	=	heat demand in period	[MJ/period]
$Q_{measure;H;period;f}$	=	actual consumption of fuel *f* for space heating in a period	[unit of fuel]
$F_{conv;f}$	=	conversion factor to primary energy of fuel *f*	[MJ/unit fuel]
$\eta_{H;gen}$	=	generation efficiency of heating installation using fuel *f*	[-]
$F_{H;f}$	=	fraction of heat demand for space heating covered by fuel *f*	[-]
$Q_{sol;col;heat;year}$	=	annual contribution of solar collector to heating demand	[MJ/year]
D_{period}	=	number of days in period	[days]
D_{year}	=	number of days per year	[days]
$\eta_{H;dist}$	=	distribution efficiency of heating installation using fuel *f*	[-]
$Q_{loss;period}$	=	heat loss in period	[MJ/period]
$Q_{gains;year}$	=	annual heat gains (internal and solar)	[MJ/year]
$Q_{loss;year;corr}$	=	heat losses corrected for the local climate and the length of the period	[MJ/year]
$HDD_{ref;year}$	=	number of heating degree days in a reference year	[°C day]
$HDD_{actual;period}$	=	actual number of heating degree days in a period	[°C day]
$Q_{hd;year;corr}$	=	corrected annual heat demand	[MJ/year]
$Q_{measure;H;year;f;corr}$	=	corrected annual energy consumption for space heating related to fuel *f*	[unit of fuel]

The actual energy consumption after correction should be equal to the calculated energy consumption for heating if the user behaviour is equal (internal temperature, internal gains, ventilation rates). The internal heat gains and ventilation rates should be estimated as well as possible. Then the internal temperature can be calculated by means of “fitting”, because it is the only unknown variable.

3.10.3 Degree days

The heating degree days can be calculated as the sum of all the months in the measuring period (or year) according to:

$$HDD = \sum_{n} HDD_n \qquad [104]$$

$$HDD_n = (\theta_{i;H;base} - \theta_{e;n}) \times D_{month;n} \quad \text{if } \theta_{e;n} \le \theta_{threshold} \qquad [105]$$

$$HDD_n = 0 \quad \text{if } \theta_{e;n} > \theta_{threshold} \qquad [106]$$

HDD	=	total number of heating degree days	[°C day]
HDD_n	=	number of heating degree days in month *n*	[°C day]
$\theta_{i;H;base}$	=	base internal temperature for heating degree days	[°C]
$\theta_{e;n}$	=	external temperature in month *n* (of measuring period or reference year)	[°C]
$D_{month;n}$	=	number of days in month *n* (table 1)	[day]

In the calculation only external temperatures below $\theta_{threshold}$ are taken into account. $\theta_{threshold}$ may be equal to $\theta_{i;H;base}$ or even lower.

The cooling degree days can be calculated as the sum of all the months in the measuring period (or year) according to:

$$CDD = \sum_n CDD_n \qquad [107]$$

$$CDD_n = \left(\theta_{e;n} - \theta_{i;C;base}\right) \times D_{month;n} \qquad \text{if } \theta_{e;n} \geq \theta_{C;threshold} \qquad [108]$$

$$CDD_n = 0 \qquad \text{if } \theta_{e;n} < \theta_{C;threshold} \qquad [109]$$

CDD	=	total number of cooling degree days	[°C day]
CDD_n	=	number of cooling degree days in month *n*	[°C day]
$\theta_{i;C;base}$	=	base internal temperature for cooling degree days	[°C]
$\theta_{e;n}$	=	external temperature in month *n* (of measuring period or reference year)	[°C]
$D_{month;n}$	=	number of days in month *n*	[day]

In the calculation only external temperatures above $\theta_{C;threshold}$ are taken into account. $\theta_{C;threshold}$ may be equal to $\theta_{i;C;base}$ or higher.

The base temperatures and the threshold temperatures are defined in the national constant library.

3.11 CO_2 emission

The total CO_2 emission equals the sum of the CO_2 emission per fuel.

$$E_{CO2;year} = \sum_f Q_{f;u;year} \times F_{CO2;f;u} \qquad [110]$$

where

$E_{CO2;year}$	=	annual CO_2 emission	[kg/year]
$Q_{f;u;year}$	=	annual fuel consumption of fuel *f* with unit *u*	[unit/year]
$F_{CO2;f;u}$	=	CO_2 emission conversion factor of fuel *f* per unit *u*	[kg/unit]

3.12 Renewable energy

In the EU Altener project Build on RES two definitions of renewable energy are given: one that only includes the active solar energy, and one that only includes passive solar energy [5]. These definitions are used here. For both definitions the absolute value of the renewable energy and the fraction of the renewable energy compared to the total energy consumption are calculated.

3.12.1 Fraction of renewable energy (no passive solar energy)

The fraction of renewable energy is calculated using the contribution of PV cells, CHP unit and active solar energy. The energies are expressed in primary energy.

$$F_{renewable} = \frac{Q_{PV;year} + Q_{CHP;year} + Q_{Sol;col;year;R}}{Q_{tot;year} + Q_{PV;year} + Q_{CHP;year} + Q_{Sol;col;year;R}} \quad [111]$$

$$Q_{renewable} = Q_{PV;year} + Q_{CHP;year} + Q_{Sol;col;year;R} \quad [112]$$

where

$F_{renewable}$	=	fraction of renewable energy	[-]
$Q_{PV;year}$	=	annual contribution of photovoltaic cells	[MJ/year]
$Q_{CHP;year}$	=	annual contribution of CHP	[MJ/year]
$Q_{Sol;col;year;R}$	=	annual contribution of solar collector system	[MJ/year]
$Q_{tot;year}$	=	total annual primary energy consumption	MJ/year]
$Q_{renewable;year}$	=	total annual amount of renewable energy	MJ/year]

The contribution of the solar collector system should first be converted to primary energy:

$$Q_{Sol;col;year;R} = Q_{Sol;col;DHW;year} \times \sum_i \frac{F_{DHW;i}}{\eta_{DHW;gen;i}} + Q_{Sol;col;Heat;year} \times \sum_i \frac{F_{H;i}}{\eta_{H;gen;i}} \quad [113]$$

$Q_{Sol;col;year;R}$	=	annual contribution of solar collector system	[MJ/year]
$Q_{Sol;col;DHW;year}$	=	annual contribution of solar collector system to DHW	[MJ/year]
$F_{DHW;i}$	=	fraction of DHW demand delivered by system *i*	[-]
$\eta_{DHW;gen;i}$	=	generation efficiency of DHW system *i*	[-]
$Q_{Sol;col;Heat;year}$	=	annual contribution of solar collector system to heating	[MJ/year]
$F_{H;i}$	=	fraction of heat demand delivered by system *i*	[-]
$\eta_{H;gen;i}$	=	generation efficiency of heating system *i*	[-]

3.12.2 Fraction of renewable energy (passive solar energy)

The fraction of renewable energy of passive solar energy can be calculated using a black window approach. This means that the total energy consumption is calculated in case all the g values of the windows are set to zero. This energy consumption is $Q_{tot;without;year}$. The difference between is $Q_{tot;without;year}$ and $Q_{tot;year}$ is the amount of renewable energy.

In this definition the active solar energy (collectors and PV) and the contribution of the CHP is not taken into account.

$$F_{renewable} = \frac{Q_{tot;without;year} - Q_{tot;year}}{Q_{tot;without;year}} \quad [114]$$

$$Q_{renewable} = Q_{tot;without;year} - Q_{tot;year} \quad [115]$$

where

$F_{renewable}$	=	fraction of renewable energy	[-]
$Q_{tot;without;year}$	=	total annual energy consumption with g-values set to zero (black window: no solar contribution)	[MJ/year]
$Q_{tot;year}$	=	total annual energy consumption	[MJ/year]
$Q_{renewable}$	=	total annual amount of renewable energy	[MJ/year]

3.13 Energy Indicator

The energy indicator has been implemented as a simple figure representing the total (primary) energy consumption per m² gross area.

$$EI = \frac{Q_{tot;year}}{A_{gross}} \qquad [116]$$

EI	=	Energy Indicator	[MJ/m²]
$Q_{tot;year}$	=	total annual energy consumption	[MJ]
A_{gross}	=	gross area	[m²]

More energy indicators can be defined in the user interface.

3.14 Indoor climate calculation

The quality of the indoor climate is judged using a simple calculation based on the cooling demand in the hottest month of the year (which is July), and the specific heat losses. The calculated value is a temperature difference, indicating the risc of overheating.

$$\theta_{ic} = \frac{Q_{CD;July}}{\left(H_{Trans;C} + H_{Vent;C}\right) \times t_{July}} \qquad [117]$$

where

θ_{ic}	=	indoor climate temperature annual savings of fuel *f* with unit *u*	[°C]
$Q_{CD;July}$	=	cooling demand in month July	[MJ/month]
$H_{trans;C}$	=	specific transmission heat loss coefficient for cooling	[W/K]
$H_{Vent;C}$	=	specific ventilation heat loss coefficient for cooling	[W/K]
t_{July}	=	duration of month July (see Table 2)	[Ms]

The risc of overheating depends on the value of θ_{ic}. See table 4.

Table 4 Risc of overheating based on θ_{ic}

Value of θ_{ic}	**Risc of overheating**
$\theta_{ic} < \theta_{overheating1}$	Low
$\theta_{overheating1} \leq \theta_{ic} < \theta_{overheating2}$	Moderate
$\theta_{ic} \geq \theta_{overheating2}$	High

The values of $\theta_{overheating1}$ and $\theta_{overheating2}$ are country specific. They are defined in the national constant library.

Dutch values (from non-residential sector, but assumed to be valid for dwellings as well) are 2 and 6 °C respectively.

If a cooling installation is present, then the risk of overheating is "low" per definition.

3.15 Financial calculations

The financial calculation consists of the calculation of the energy cost savings, the investment costs and the pay-back time.

3.15.1 Savings

The savings for each fuel *f* (with a certain unit *u*) are the difference between energy consumption in the reference situation and the energy consumption in the variant situation:

$$S_{f;u} = Q_{f;u;year;ref} - Q_{f;u;year;var} \quad [118]$$

where

$S_{f;u}$	=	annual savings of fuel *f* with unit *u*	[*unit*/year]
$Q_{f;u;year;ref}$	=	annual consumption of fuel *f* in reference situation	[*unit*/year]
$Q_{f;u;year;var}$	=	annual consumption of fuel *f* in variant	[*unit*/year]

The savings per year in local currency are:

$$CS = \sum_f S_{f;u} \times P_{f;u} \quad [119]$$

where

CS	=	annual cost savings	[local currency/year]
$S_{f;u}$	=	annual savings of fuel *f* with unit *u*	[unit/year]
$P_{f;u}$	=	costs of fuel *f* per unit *u*	[local currency /unit]

3.15.2 Investment costs

Costs are always calculated for a package of measures. A package may consist of one measure only.

$$C = \sum_m C_m \quad [120]$$

where

C	=	investment costs of package of measures	[local currency]
C_m	=	investment costs of measure *m*	[local currency]

3.15.3 Pay-back time

Two pay-back times are calculated:

- the simple pay-back time
- the nett present value pay-back time (including interest and inflation rates)

<u>Simple pay-back time:</u>

$$T_{PB;S} = \frac{C}{CS} \qquad [121]$$

<u>Nett Present Value pay-back time:</u>

$$T_{PB;N} = \frac{\ln\left(1 - \frac{C}{CS} \times (1 + r_i) \times (1 - x)\right)}{\ln(x)} \qquad [122]$$

$$x = \frac{(1 + r_{inf\,l})}{(1 + r_i)} \qquad [123]$$

where

$T_{PB;S}$	=	simple pay-back time	[year]
C	=	investment costs of measures	[local currency]
CS	=	annual savings of measures	[local currency/ year]
$T_{PB;N}$	=	nett present value pay-back time	[year]
r_i	=	interest rate	[-]
r_{infl}	=	inflation rate	[-]
x	=	help variable (ratio of inflation and interest rates)	[-]

If x equals 1 then the nett present value pay back time cannot be calculated according to the previous formula. In that case it equals the simple pay- back time.

If x=1 then

$$T_{PB;N} = \frac{C}{CS} \qquad [124]$$

4 Input and output

4.1 Introduction

In this chapter a list of the input and output is given.

The structure of the calculation tool is as follows.

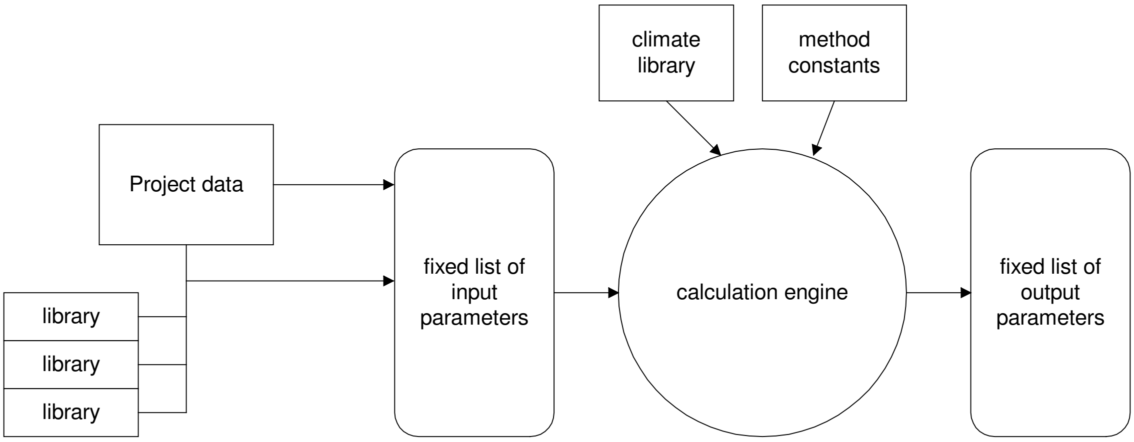


Figure 3 Scheme of the calculation tool

The central part is the calculation engine. The calculation has a fixed number of predescribed input parameters, and a fixed number of output parameters.
The calculation uses a predescribed climate library. Furthermore the calculation contains a number of country dependant constants, such as parameters for the utilisation of heat gains. These cannot be adjusted by the individual user.

To provide the data for the input, each country can specify the input parameters in their own specific way, or, in some cases, the parameters from a library can be used. The libraries can be adapted by each country; they contain data that can be a standard set and can be used in calculations over and over again, such as construction data.

4.2 Input

In the following table all the input variables user for the calculation core that should be specified by the are given. The other input variables (climate data and method constants) are specified in the next paragraph. Most input variables can be filled in by means of a library. This depends on the user interface.

symbol	**unit**	**description**
for the dwelling		
A_{gross}	[m^2]	gross floor area
h	[m]	mean storey height
$\theta_{i;H}$	[˚C]	internal (design) temperature for heating
$\theta_{i;C}$	[˚C]	internal (design) temperature for cooling
$q_{v;i}$	[m^3/s]	infiltration air flow (monthly value)
$q_{v;n}$	[m^3/s]	natural ventilation air flow (monthly value)
$q_{v;m}$	[m^3/s]	mechanical ventilation air flow (monthly value)

$q_{v,ss}$	[m³/s]	air flow from sunspace to heated space (annual value)
η_{hr}	[-]	efficiency of heat recovery of ventilation air
Φ_{ih}	[W]	monthly average internal heat gain
C'	[kJ/Km²]	internal heat capacity per m² gross floor area
CF	[-]	factor indicating the presence of ceiling fans =1 if ceiling fans are present =0 if ceiling fans are not present
for DHW		
V_{DHW}	[m³]	annual domestic hot water consumption volume
N_P	[-]	number of persons (not needed in formulas in core, but in transformation from interface to core input, and input that can be given easily)
for opaque constructions (thermal envelope)		
A	[m²]	area
U	[W/m²K]	thermal transmittance coefficient
b	[-]	temperature correction factor
α	[-]	average solar absorption factor of surface side directed to external environment
U_{pe}	[W/m²K]	thermal transmittance of absorbing surface to external environment or unheated space
-	[°]	orientation angle
-	[°]	tilt angle
for glazing (thermal envelope)		
A	[m²]	area
U	[W/m²K]	thermal transmittance coefficient
F_F	[-]	frame factor
F_S	[-]	shading correction factor
$F_{M;H}$	[-]	movable shading device correction factor
$F_{M;C}$	[-]	movable shading device correction factor for cooling calculation
b	[-]	temperature correction factor
g	[-]	effective total solar energy transmittance
-	[°]	orientation angle
-	[°]	tilt angle
for sunspaces		
g_e	[-]	effective total solar energy transmittance of glazing in external sunspace envelope
F_F	[-]	frame factor of sunspace glass
F_S	[-]	shading correction factor of sunspace
-	[°]	orientation angle of partition wall
-	[°]	tilt angle of partition wall
A_w	[m²]	area of transparent part *w* of partition wall
U_w	[W/m²K]	thermal transmittance of transparent part *w* of partition wall
g_w	[-]	effective total solar energy transmittance of transparent part *w* of partition wall
$F_{F;w}$	[-]	frame factor of transparent part *w* of partition wall
U_p	[W/m²K]	thermal transmittance of opaque part of partition wall
A_p	[m²]	area of opaque part *p* of partition wall
α_p	[-]	solar absorption factor of opaque part *p* of partition wall
A_a	[m²]	area of absorbing area *a* in sunspace

α_a	[-]	solar absorption factor of absorbing area *a* in sunspace
-	[°]	orientation angle of absorbing area *a* in sunspace
-	[°]	tilt angle of absorbing area *a* in sunspace
extra for calculation of b		
$U_{g;ue}$	[W/m²K]	thermal transmittance of glazing in external sunspace envelope
$n_{v;ue}$	[1/h]	ventilation air change rate of sunspace (with external air)
U_j	[W/m²K]	thermal transmittance of absorbing area in sunspace
h_{ss}	[m]	average height of sunspace
$A_{floor;ss}$	[m²]	floor area of sunspace
for each heating installation		
$\eta_{H;gen}$	[-]	generation efficiency
$\eta_{H;distr}$	[-]	distribution efficiency
F_H	[-]	fraction of heating demand delivered by installation
$\eta_{el;CHP}$	[-]	electric efficiency for CHP
$Q_{el;aux;H;year}$	[kWh/year]	annual heating auxiliary energy
for each cooling installation		
$\eta_{C;gen}$	[-]	cooling generation efficiency
$\eta_{C;distr}$	[-]	cooling distribution efficiency
F_C	[-]	fraction of cooling demand delivered by installation
$Q_{el;aux;C;year}$	[kWh/year]	annual cooling auxiliary energy
for each DHW installation		
$\eta_{DHW;gen}$	[-]	DHW generation efficiency
$\eta_{DHW;distr}$	[-]	DHW distribution efficiency
F_{DHW}	[-]	fraction of DHW demand delivered by installation
$Q_{el;aux;DHW;year}$	[kWh/year]	annual DHW auxiliary energy
for (thermal) solar collector system		
A_{col}	[m²]	collector area
η_{col}	[-]	annual average efficiency of solar system
-	[°]	orientation angle of solar collector system
-	[°]	tilt angle of solar collector system
F_s	[-]	shading correction factor of solar collector system
-	[-]	indication whether contribution of solar collector system is to space heating and DHW or to DHW only
for PV cells		
A_{PV}	[m²]	area of photovoltaic cells
F_{pv}	[kWh/MJ]	efficiency of PV cells
-	[°]	orientation angle of PV system
-	[°]	tilt angle of PV system
F_s	[-]	shading correction factor of PV system
for other consumption		
$Q_{el;aux;Fans;year}$	[kWh/year]	annual fan auxiliary energy
$Q_{el;aux;Misc;year}$	[kWh/year]	annual miscellaneous auxiliary energy
$Q_{el;Lighting}$	[kWh/year]	annual electricity consumption for lighting
for measures		
C	[local currency]	investment costs (for each measure)

for actual energy consumption		
$Q_{measure;tot;period;f}$	[unit]	total measured energy consumption of fuel *f* in a period
$\theta_{e;actual;n}$	[˚C]	actual monthly external temperature
D_{period}	[days]	days in measuring period

4.3 Method constants

Some input is given as method constants. The values of these constants are prescribed by the countries. The values cannot be adjusted by the normal user. In the table the method constants are given.

variable	unit	value (NL)	value (DK)	value (G)	value (A)
U_{pe} (external)	W/m^2K	25			
U_{pe} (unheated)	W/m^2K	7			
$\theta_{i;C}$	˚C	24			
$\theta_{i;H}$	˚C	18			
$\theta_{DHW;H}$	˚C	60			
$a_{H;0}$	-	1			
$\tau_{H;0}$	-	16			
$a_{C;0}$	-	1			
$\tau_{C;0}$	-	16			
$\theta_{i;H;base}$	°C	18			
$\theta_{threshold}$	°C	15			
$\theta_{i;C;base}$	°C	24			
$\theta_{C;threshold}$	°C	24			
$\theta_{overheating1}$	°C	2			
$\theta_{overheating2}$	°C	6			
$\Delta\theta_{CF}$	°C	3			
r_i	-	0.05			
r_{infl}	-	0.02			
Local currency	-	EURO	DK	EURO	EURO

Apart from the method constants that can vary from country to country there is a number of fixed constants valid for all the countries.

constant name	unit	value
$\rho \times c_{water}$	J/kgK	$4.18.10^6$
$\rho \times c_{air}$	J/kgK	1200

4.4 Climate library

The climate library contains the climate data. The structure of this library cannot be adjusted. The following data is required:

Item	Unit
Station name	[-]
Location: longitude (East is positive)	[°]
Location: latitude (North is positive)	[°]
Time zone (time difference with GMT, East is positive)	[h]

Average external temperature (monthly)	[°C]
Total monthly solar radiation: - for 8 orientations: S, SW, W, NW, N, NE, E, SE - for at least 3 tilt angles: vertical, horizontal and one (or more) inbetween e.g. 45 °	[MJ/m^2]
Heating season (start and end month)	[-]
Cooling season (start and end month)	[-]

4.5 Output

The output of the calculation core consists of a fixed list of variables for each calculation variant (existing and variant situation). It contains both the input and the output in a fixed order. In the output, first all the results are in primary energy, and afterwards in fuel units. The output is given in both monthly and annual values.

symbol	unit	description
Input		
[list of input in other table]		
Output		
Primary energy		
$Q_{tot;year}$	[MJ/year]	total annual primary energy consumption
$Q_{Heating}$	[MJ/month]	space heating primary energy consumption of month 1-12
$Q_{Heating;year}$	[MJ/year]	annual space heating primary energy consumption
$Q_{Cooling}$	[MJ/month]	cooling primary energy consumption of month 1-12
$Q_{Cooling;year}$	[MJ/year]	annual cooling primary energy consumption
Q_{DHW}	[MJ/month]	domestic hot water primary energy consumption of month 1-12
$Q_{DHW;year}$	[MJ/year]	annual domestic hot water primary energy consumption
$Q_{Auxiliary}$	[MJ/month]	auxiliary primary energy consumption of month 1-12
$Q_{Auxiliary;year}$	[MJ/year]	annual auxiliary primary energy consumption
$Q_{Lighting}$	[MJ/month]	lighting primary energy consumption of month 1-12
$Q_{Lighting;year}$	[MJ/year]	annual lighting primary energy consumption
Q_{PV}	[MJ/month]	PV primary energy production of month 1-12
$Q_{PV;year}$	[MJ/year]	annual PV primary energy production
Q_{CHP}	[MJ/month]	CHP primary energy production of month 1-12
$Q_{CHP;year}$	[MJ/year]	annual CHP primary energy production
Heating calculation		
Q_{Trans}	[MJ/month]	transmission heat losses in month 1-12
Q_{Vent}	[MJ/month]	ventilation heat losses in month 1-12
Q_{Int}	[MJ/month]	internal gains in month 1-12
$Q_{Sol;}$	[MJ/month]	solar gains in month 1-12
$Q_{Col;heat}$	[MJ/month]	contribution of solar collector to space heating in month 1-12
η_{hg}	[-]	utilisation factor of heat gains in month 1-12
Q_{hd}	[MJ/month]	heating demand in month 1-12
$Q_{Heating}$	[MJ/month]	space heating primary energy consumption of month 1-12
Cooling calculation		
Q_{Trans}	[MJ/month]	transmission heat losses in month 1-12
Q_{Vent}	[MJ/month]	ventilation heat losses in month 1-12

Q_{Int}	[MJ/month]	internal gains in month 1-12
Q_{Sol}	[MJ/month]	solar gains in month 1-12
η_{hl}	[-]	utilisation factor of heat losses in month 1-12
Q_{cd}	[MJ/month]	cooling demand in month 1-12
$Q_{Cooling}$	[MJ/month]	space cooling primary energy consumption of month 1-12
DHW calculation		
Q_{DHW}	[MJ/month]	DHW demand in month 1-12
$Q_{DHW;gross}$	[MJ/month]	gross DHW demand month 1-12
$Q_{Col;DHW}$	[MJ/month]	contribution of solar collector to DHW in month 1-12
Q_{DHW}	[MJ/month]	DHW primary energy consumption of month 1-12
Per fuel f		
$Q_{f;u;year}$	[unit/year]	annual fuel consumption per type of fuel with a certain unit
$Q_{f;Heating;year}$	[../year]	annual space heating energy consumption in fuel unit
$Q_{f;Cooling;year}$	[../year]	annual cooling energy consumption in fuel unit
$Q_{f;Cooling}$	[../month]	cooling energy consumption in fuel unit in month 1-12
$Q_{f;DHW;year}$	[../year]	annual domestic hot water energy consumption in fuel unit
$Q_{f;DHW}$	[../month]	domestic hot water energy consumption in fuel unit in month 1-12
$Q_{el;Auxiliary}$	[kWh/month]	auxiliary electricity consumption in month 1-12
$Q_{el;Auxiliary;year}$	[kWh/year]	annual auxiliary electricity consumption
$Q_{el;Lighting}$	[kWh/month]	lighting electricity consumption in month 1-12
$Q_{el;Lighting;year}$	[kWh/year]	annual lighting electricity consumption
$Q_{el:PV}$	[kWh/month]	PV electricity production in month 1-12
$Q_{el:PV;year}$	[kWh/year]	annual PV electricity production
$Q_{el;CHP}$	[kWh/month]	CHP electricity production in month 1-12
$Q_{el;CHP;year}$	[kWh/year]	annual CHP electricity production
E_{CO2}	[kg/month]	CO_2 emission in month 1-12
$E_{CO2;year}$	[kg/year]	annual CO_2 emission
$Q_{renewable;year}$	[MJ/year]	total annual amount of renewable energy (def 1)
$F_{renewable}$	[-]	fraction of renewable energy (def 1)
$Q_{renewable;year}$	[MJ/year]	total annual amount of renewable energy (def 2)
$F_{renewable}$	[-]	fraction of renewable energy (def 2)
Per fuel f		
$S_{f;u}$	[unit]	annual savings of fuel f
C	[local currency]	total investment costs
CS	[local currency /year]	annual cost savings
$T_{PB,n}$	[year]	nett present value pay-back time
$T_{PB;s}$	[year]	simple pay-back time
EI	[-]	Energy index
..	[-]	List of measures (textual)

5 Definitions

In this chapter a definition is given of all the input and output that require a clear definition.

area
The area of building parts is determined based on the outer dimensions. In case the outer dimensions cannot be determined, the heart-to-heart dimensions are taken.
The usable floor area is based on the inner dimensions of the dwelling.
The area of windows is determined including the frames.

distribution efficiency
The fraction of the generated usable heat and cold which is effectively delivered to a building. See figure 1. The distribution efficiency depends on the system.

external temperature
Temperature of external air

generation efficiency
The fraction of the amount of supplied primary energy that is converted into usable heat or cold. Depending on the fuel of the installation the efficiency should be expressed in the same way as the conversion factor of the fuel is expressed (lower or upper caloric value). The generation efficiency is mostly given by the manufacturer. See figure 4.

usable floor area
The area measured at floor level, between the rising separating constructions that enclose the space.

gross floor area
The area measured at floor level, using the external measures.

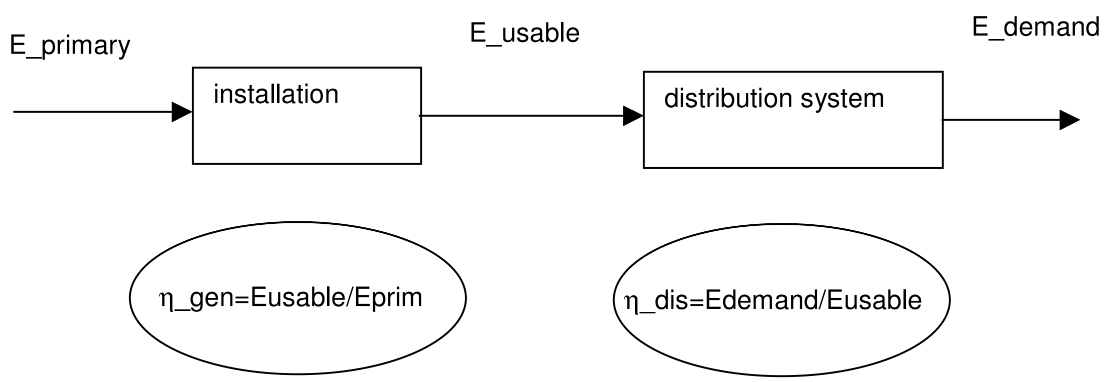


Figure 4: Scheme of efficiencies

6 Literature

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Project Description

The EPA-ED research project seeks to conceptualise and develop the strategic, organisational and technological framework to deliver a model for assessing the energy performance of existing dwellings at European level. This framework intends to stimulate RUE and RES. The efficiency and success of the energy performance assessment-approach (EPA-approach) depends on the way it fits into practice. Thus, a range of relevant issues have been taken into account - from the economic impact of RUE and RES for inhabitants of existing dwellings to integration of measures into maintenance schedules and - from the effects of RUE and RES on the interior climate in dwellings to the strategic impulse of this approach on a national level.

The energy performance assessment method is being developed making use of existing methods available in the European Countries.

The attention for the energy performance of existing dwellings is just starting in most countries. Energy performance can be greatly improved by rational use of energy (RUE) and the use of renewable energy sources (RES). This RTD research project directly addresses both the SAVE and the ALTENER programme, focussing on RUE in (existing) dwellings, while incorporating RES.

The work plan has been structured in 5 research tasks:
Task 1: Benchmark of European conditions related to existing dwellings

- Benchmark of European conditions related to existing dwellings
- Benchmark of existing policies with respect to RUE and RES in existing dwellings
- Benchmark of building regulations with respect to existing dwellings (both legislative and incentive)
- Benchmark of existing housing market and actors
- Benchmark of the energy market
- Benchmark of building and installations technology in existing dwellings
- Benchmark of energy balance of existing dwellings on a national level
- Benchmark of climate data

Task 2: Strategy for stimulating RUE and RES through a uniform Energy Performance Assessment Method

Task 3: Energy Performance Assessment tool

- Description
- Prototype
- Pilot studies in at least one project in each participating country
- Adaptations of the prototype tool
- Supporting tools: check lists, inspection protocols, guidelines etc

Task 4: Translation into new policies

- Set of tools for tuning, accentuating Member State policies, using the EPA-ED method and tool for existing dwellings.
- Recommendations for the development of RUE, RES policies in countries without such policies

Task 5: Dissemination

- Web site, brochures, guide

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