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LVS^3

Large Valorisation on Sustainability of Steel Structures

Design Guide

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CONTENTS

1 Introduction and aim

The aim of this document is to provide information on the different steps used for the environmental assessment of steel and composite buildings in Ameco software.

The document was created in the scope of the dissemination project **LVS³: Large Valorisation on Sustainability of Steel Structures** (RFS2-CT-2013-00016).
The Design Guide focuses on:

- A description of the calculation process: the technical specifications detail the successive steps used for the environmental assessment of buildings used in AMECO software,
- A guidance on the use of AMECO tool,
- Application of AMECO on case studies.

The approaches used in the software were developed and validated within the scope of the European RFCS project SB-Steel: *Sustainability of Steel Buildings (SB_Steel, 2014)*.
These complementary methodologies are:

- the macro-components approach, addressing the life cycle assessment of buildings and/or building components but excluding the quantification of energy in the use stage of a building;
- an approach focussing on the use stage of a building and enabling the quantification of the operational energy of buildings.

The document **"Background document"**, also deliverable of the RFCS LVS³ project, provides the detailed description of the adopted approaches: for the assessment of life cycle environmental impacts and for the evaluation of the energy needs of a building during its operational life.

2 Computer code and environment

AMECO is a tool which assesses the environmental impacts of the bearing structures made of steel and concrete. Ameco 3 is an extension of Ameco (version 2), which proposes to take into account the use phase of the building.

Ameco 3 uses the VB2008 computer language. This language is based upon the Microsoft .NET technology. It is then assumed that the Microsoft .NET Framework is set up on the User computer. The .NET Framework is automatically included in the new operating systems (OS) Microsoft Vista and Seven but not in older ones, for which the final User will have to install it before any use of Ameco 3.

The development is based upon the .NET Framework version 2.0, which can be installed on the following OS: Windows 2000 Service Pack 3; Windows 98; Windows 98 Second Edition; Windows ME; Windows Server 2003, Windows XP Service Pack 2. It is then to be noted that Ameco 3 could not be compatible with any configuration not mentioned before.

3 General features of the program AMECO3

3.1 Foreword

Ameco 3 deals with either buildings or bridges made of steel and concrete. It takes into account 24 kinds of quantities into the following groups:

- Quantities describing environmental impacts (GWP, ODP, AP, EP, POPCP, ADP-elements, ADP-fossil fuels).
- Quantities describing resources use, secondary materials and fuels, and use of water (Use of renewable primary energy excluding renewable primary energy resources used as raw materials, Use of renewable energy resources used as raw materials, Total use of renewable primary energy (primary energy and primary energy resources used as raw materials), Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials, Use of non renewable energy resources used as raw materials, Total use of non renewable primary energy (primary energy and primary energy resources used as raw materials), Use of secondary material, Use of renewable secondary fuels, Use of non renewable secondary fuels, Use of net fresh water).
- Other environmental information describing waste categories (Hazardous waste disposed, Non hazardous waste disposed, Radioactive waste disposed).
- Other environmental information describing output flows (Components for reuse, Materials for recycling, Materials for energy recovery, Exported energy).

Furthermore, each quantity is decomposed into 4 modules (Product and Construction process stage, Use stage, End of life, Benefits and loads beyond the system boundaries).

Index	Data available	Abbreviation	Designation	Unit
Environmental impacts				
1	Yes	GWP	Global Warming Potential	tCO_2eq
2	Yes	ODP	Ozone Depletion Potential	t_{CFCeq}
3	Yes	AP	Acidification Potential	t_{SO2eq}
4	Yes	EP	Eutrophication Potential	t_{PO4eq}
5	Yes	POCP	Photochemical Ozone Creation Potential	$t_{Etheneeq}$
6	Yes	ADP-e	Abiotic Depletion Potential – elements	t_{Sbeq}
7	Yes	ADP-ff	Abiotic Depletion Potential – fossil fuels	GJ NCV

Resource use, secondary material and fuels				
8	No	RPE	Use of renewable primary energy excluding renewable primary energy resources used as raw materials	GJ NCV
9	No	RER	Use of renewable energy resources used as raw materials	GJ NCV
10	Yes	RPE-total	Total use of renewable primary energy (primary energy and primary energy resources used as raw materials)	GJ NCV
11	No	Non-RPE	Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials	GJ NCV
12	No	Non-RER	Use of non renewable energy resources used as raw materials	GJ NCV
13	Yes	Non-RPE-total	Total use of non renewable primary energy (primary energy and primary energy resources used as raw materials)	GJ NCV
14	No	SM	Use of secondary material	t
15	No	RSF	Use of renewable secondary fuels	GJ NCV
16	No	Non-RSF	Use of non renewable secondary fuels	GJ NCV
17	Yes	NFW	Use of net fresh water	$10^3 m^3$
Other environmental information describing waste categories				
18	Yes	HWD	Hazardous waste disposed	t
19	Yes	Non-HWD	Non hazardous waste disposed	t
20	Yes	RWD	Radioactive waste disposed	t
Other environmental information describing output flows				
21	No	CR	Components for reuse	t
22	No	MR	Materials for recycling	t
23	No	MER	Materials for energy recovery	t
24	No	EE	Exported energy	t

Table 1 : Environmental impacts

The main additional feature of Ameco 3 is the introduction of the use phase on the calculation of the environmental impact. It allows the estimation of energy needs for a variety of the building systems (heating, cooling…). Their calculation is based on several international norms such as ISO-13370, ISO-13789 and ISO-13790 as well as on European norm (EN 15316).

Ameco has the possibility to consider either a building or a bridge. Nevertheless, the extension of the use phase is only available for buildings.

3.2 Setup

Ameco will be delivered with a setup package, generated by the free application "Install Creator", including:

- the .exe file
- any necessary dynamic or component library (.dll files)
- the databases
- the help files
- the language files
- the icons and any necessary picture

3.3 Languages

Ameco is a multilingual application. All the texts displayed in the GUI are read in separate language files, each one associated to a language. The text in the language files are grouped in blocks and identified by keywords.

3.4 Unit management

Considering the parameters to be defined, the following imposed unit will be considered for the GUI:

Weight:	tons
Dimensions:	m
Slab depths:	mm
Distances:	km
Densities:	kg/m^3
Area of floors	m^2
Energy need	kWh

The units used for the environmental impacts are given in Table 10 (see § 5.2 Global output data of the use phase).

4 Technical description

4.1 Definition of a Project

The calculation of impacts needs several quantities describing the structure, the way elements are transported to the site, and finally some information on how the elements involved will be used after the demolition of the structure.

The calculation of the use phase needs several quantities defining the building that are described hereafter before detailing the equations. In the following, the letter***m*** means month, number *m* ranging from 1 to 12 and the abbreviation***dir*** means direction among N, W, E and S.

4.1.1 Definition of a building structure and general data

4.1.1.1 General parameters

The general definition of the building is given by parameters defined by the User:

Length	ℓ_b
Width	w_b
Number of floors	$n_{b,fl}$
Custom area of the floors	$a_{b,fl,custom}$

The default area of the floors is calculated by the relation:

$$a_{b,fl,default} = n_{b,fl} \ell_b w_b \qquad \text{(Eq 1)}$$

According to the calculation options chosen by the User, the area of floors used in the calculations is the following:

$$a_{b,fl} = a_{b,fl,custom} \quad \text{if the area is defined by the User} \qquad \text{(Eq 2)}$$

$$a_{b,fl} = a_{b,fl,default} \quad \text{else}$$

The location of the building is to be chosen among one of the cities contained in the cities database.

For each city, the following parameters are defined in the database:

Country	
$\theta_{ext}(m)$	outside temperature at month *m* [°C]
$I_{sol,k}(m, dir)$	solar incident radiation in direction *dir* at month *m* [W/m²]
$I_{sol,k,roof}(m)$	solar incident radiation on roof at month *m* [W/m²]
$f_{H,shut}(m)$	fraction of the day in which is night at month *m* for the heating mode (to considerextra insulation provided by shading devices) [-]
$f_{sh,with}(m, dir)$	weighted fraction of the time during which the solar shading is in use [-]
Latitude	latitude of the city
Climate	can be sub-polar, intermediate or tropics
Geiger Climate	can be Csa, Csb, Cfb, Dfb, Dfc

The parameter Climate being known, the following parameter is obtained

$\Delta\theta_{er}$	average difference between external air temp and sky temp depending on *climate* (see **Table 14**~~**Table 14**~~) [°C]

The Annex 3~~Annex 3~~ gives tables of these values for Coimbra, Tampere and Timisoara.

Several uses are available for the building (Residential Building (RB), Office Building (OB), Commercial Building (CB) and Industrial Building (IB)). This choice impacts several default values listed in the following paragraphs.

The shape of the building is rectangular. The associated data are:

ℓ_b	length of north – south facades [m]
w_b	length of east – west facades [m]
$n_{b,fl}$	number of intermediate floors [-]
h_{floor}	height of the floor (identical for all floors) [m]
$h_{floor,ceiling}$	height of the floor under ceiling (identical for all floors) [m]
With the constraint	$h_{floor,ceiling} < h_{floor}$
$a_{b,fl,custom}$	custom area of the floors [m²]

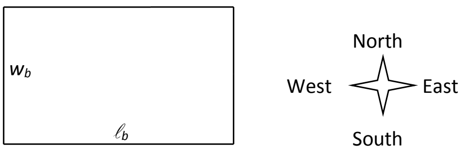


Figure 1 : building shape

The total area of building is calculated by the relation:

$a_{b,fl,default} = (n_{b,fl} + 1).\ell_b .w_b$

The area of floors used in the calculations for module A, C and D is the area of intermediate floors. This area is automatically computed according to:

$a_{b,fl,interm,,default} = n_{b,fl} .\ell_b .w_b$

Three other areas are used:

$A_{conditionedarea}$	totalarea of conditioned zones [m²]
A_{area1}	area of primary conditioned areas (higher internal heat gains) [m²]
A_{area2}	area of other conditioned areas (lower internal heat gains) [m²]

They fulfill:

$$A_{conditionedarea} = A_{area1} + A_{area2}$$

$A_{conditionedarea}$is equal to the total area of building$a_{b,fl,default}$while$A_{area1}$and$A_{area2}$are calculated as a percentage of$A_{conditionedarea}$using the Table 12~~Table 12~~ in **Annex 2** (Area 1 for primary conditioned areas, and Area 2 conditioned areas). These 3 areas are not displayed.

4.1.1.2 Floor slabs

Steel elements:

The steel elements used for the floor slabs of the building are defined by the following parameters.

Type of slab, to be chosen among the following list:

- Plain slab (no steel sheeting)
- Composite slab
- Lost formwork
- Pre-fabricated
- Dry floor

The steel sheetings are chosen in the same database as in Ameco [1][1].

The total mass of steel deck in the building is obtained by:

$$m_{tss} = m_{ssu} a_{b,fl} \quad \text{(Eq 3)}$$

Formatiert: Englisch (USA)

with m_{ssu} the steel deck mass (per unit of area) as obtained from the database;
$a_{b,fl}$ the area of floors (cf. 4.1.1.14.1.1.1)

Concrete elements:

The following parameters of the concrete elements will be used:

Concrete type, to be chosen among the following list:

- In-situ/poured
- Prefabricated

Concrete grade, to be chosen among the following list:

- C20/25
- C30/37

Total thickness of the floor t_{tfl}
Reinforcing steel m_{conrs}

The total concrete weight m_{consl} is calculated using:

$$m_{consl} = a_{b,fl} \rho_{consl} (t_{tfl} - t_{minss} + V_{tmin}) / 10^6 \quad \text{(Eq 4)}$$

where $a_{b,fl}$ the area of floors (cf. 4.1.1.14.1.1.1)
ρ_{consl} = 2360 kg/m³
t_{mniss} the minimum slab thickness of the steel sheeting, obtained from the database
V_{tmniss} the volume of concrete for the minimum slab thickness, obtained from the database

Notes:

- For dry floors, m_{consl} = 0
- For slabs without steel sheetings, $t_{minss} = 0$ and $V_{tmin} = 0$ are considered in the previous formula.

4.1.1.3 Bearing structure

Steel elements:

The parameters defining the steel elements of the structure are defined by the User:

Total mass of beams	m_{tsb}
Total mass of columns	m_{tsc}
Total mass of studs	m_{tst}
Total mass of bolts	m_{tbo}
Total mass of plate connections	m_{tpl}
Loss rate for steel profiles	s_{plos}

The latter means that to have the final mass m for a profile in the structure requires to produce m $(1 + s_{plos})$ of this profile.

Concrete elements:

The parameters describing the concrete structure will be, as for floor slabs:

Total mass of concrete beams	m_{tcb}
Total mass of concrete columns	m_{tcc}
Total mass of reinforcing steel	m_{trs}

Concrete type, to be chosen among the following list:

- In-situ/poured
- Prefabricated

Concrete grade, to be chosen among the following list:

- C20/25
- C30/37

Wood elements:

Beginning with Ameco, wood elements are taken into account through several quantities. The new parameters describing the wood elements are the following:

Total mass of beams	m_{twb}
Total mass of columns	m_{twc}

4.1.1.4 Transport assumptions

Concrete transport from production to construction site:

The parameters defining the concrete transport are the following:

Distance for concrete produced on site	d_{conmix}
Distance for concrete prefabricated	d_{conreg}

Ameco will calculate the parts of concrete produced on site or prefabricated as follows:

Part of concrete produced on site:	$m_{conmix} = m_1 + m_2$	(Eq 5)
Part of concrete prefabricated:	$m_{conreg} = m_3 + m_4$	(Eq 6)

where $m_1 = m_{consl}$ if concrete type for concrete slab elements (cf. 4.1.1.2~~4.1.1.2~~) is in-situ/poured; 0

$m_2 = m_{tcb} + m_{tcc} + m_{trs}$ if concrete type for concrete elements of bearing structure (cf. is in-situ/poured; else $m_2 = 0$

$m_3 = m_{consl}$ if concrete type for concrete slab elements (cf. 4.1.1.2~~4.1.1.2~~) is prefabricated; 0

$m_4 = m_{tcb} + m_{tcc} + m_{trs}$ if concrete type for concrete elements of bearing structure (cf. is prefabricated; else $m_4 = 0$

Steel transport from production to construction site:

The user has the possibility to consider average values from European database for steel transport or not.

Ameco will calculate the total mass of steel transported as follows:

$$m_{tstrtot} = m_{tss} + m_{conrs} + m_{tsb} + m_{tsc} + m_{tsst} + m_{tbo} + m_{tpl} + m_{trs} \quad \text{(Eq 7)}$$

If average values are not used then the following additional parameters are needed:

- Mass of steel transported by train m_{str}
- Distance for steel transported by train d_{str}
- Mass of steel transported by regular truck m_{sreg}
- Distance for steel transported by regular truck d_{sreg}

Furthermore, the following relation has to be fulfilled:

$$m_{tstrtot} = m_{str} + m_{sreg} \quad \text{(Eq 8)}$$

Wood transport from production to construction site:

The parameters defining the wood transport are the following:

- Mass of wood transported by train m_{wtr}
- Distance for wood transported by train d_{wtr}
- Mass of wood transported by regular truck m_{wreg}
- Distance for wood transported by regular truck d_{wreg}

Ameco will calculate the total mass of wood transported:

$$m_{twtrtot} = m_{twb} + m_{twc} \quad \text{(Eq 9)}$$

With Eq 9, the following relation must be fulfilled:

$$m_{twtrtot} = m_{wtr} + m_{wreg} \quad \text{(Eq 10)}$$

4.1.1.5 End of life

The user has the possibility to change all parameters relative to the end of life of elements.

Steel:

For steel elements, a fraction is recycled after the demolition of the building. The ratio of elementrecycled is noted $eol_{element}$. Moreover, some beams and columns can be reused and a specific ratio re_{sbc} is introduced. The fraction of material that is not recycled or reused is lost.

Thus, the ratios defining the end of life of steel are the following, to be defined by the User:

- Recycling of reinforcing steel eol_{srs}
- Recycling of decking eol_{sd}

Recycling of beams and columns eol_{sbc}
Reuse of beams and columns re_{sbc}
Recycling of studs and bolts eol_{sstbo}
Recycling of plates connections eol_{spl}

Concrete:

Concrete elements are not recycled but instead they can be valorised when they are used as gravel. The ratio of concrete element that is valorised is denoted $val_{element}$.

The parameters defining the valorisation of concrete are the following, to be defined by the User:
Valorisation for floors val_{confl}
Valorisation for structure val_{const}

Wood:

After the demolition of a building, a fraction of wood elements is incinerated. During this process, a fraction of the energy released by combustion is converted into electrical power in the thermal unit.

The parameter defining the end of life of wood is this ratio, to be defined by the User:
Incineration with energy recovery
of structural wood elements inc_w

4.1.2 Definition of a bridge

4.1.2.1 Bearing structure

Steel elements:

The parameters defining the steel elements of the bridge are the following, to be defined by the User:

Total mass of profiles m_{tspbr}
Total mass of studs m_{tstbr}
Total mass of end plates m_{tepbr}
Total mass of other sections m_{totbr}
Total mass of other rebars m_{torbr}

Loss rate for steel profiles s_{plos}

This latter means that to have the final mass m for a profile in the structure requires to produce $m (1 + s_{plos})$ of this profile.

Concrete:

The parameters describing the concrete elements of the bridge will be modified as follows:
Total mass of concrete m_{tcbr}
Total mass of reinforcing steel m_{trsbr}

Concrete type, to be chosen among the following list:

- In-situ/poured
- Prefabricated

Concrete grade, to be chosen among the following list:

- C20/25
- C30/37

4.1.2.2 Transport assumptions

Concrete transport from production to construction site:

The parameters defining the concrete transport are the following:
Distance for concrete produced on site $d_{conmixbr}$
Distance for concrete prefabricated $d_{conregbr}$

Ameco will calculate the parts of concrete produced on site or prefabricated as follows:
Part of concrete produced on site: $m_{conmixbr}$
Part of concrete prefabricated: $m_{conregbr}$

where $m_{conmixbr} = m_{tcbr}$ if concrete type for concrete elements is in-situ/poured; else 0
$m_{conregbr} = m_{tcbr}$ if concrete type for concrete elements is prefabricated; else 0

Steel transport from production to construction site:

The user has the possibility to consider average values from European database for steel transport or not.

Ameco will calculate the total mass of steel transported with the following relation:

$$m_{tstrtotbr} = m_{tspbr} + m_{tstbr} + m_{tepbr} + m_{totbr} + m_{torbr} + m_{trsbr} \quad \text{(Eq 11)}$$

If average values are not used then the following additional parameters are needed:
Mass of steel transported by train m_{strbr}
Distance for steel transported by train d_{strbr}
Mass of steel transported by regular truck m_{sregbr}
Distance for steel transported by regular truck d_{sregbr}

Furthermore, the following relation has to be fulfilled:

$$m_{tstrtotbr} = m_{strbr} + m_{sregbr} \quad \text{(Eq 12)}$$

4.1.2.3 End of life

In the same way than for a building, the user has the possibility to change all parameters relative to the end of life for the elements of a bridge.

Steel:

As for buildings, the ratios defining the end of life of steel are the following, to be defined by the User:
Recycling of profiles eol_{spbr}

Reuse of profiles	re_{spbr}
Recycling of studs	eol_{stbr}
Recycling of end plates	eol_{sepbr}
Recycling of other sections	eol_{sotbr}
Recycling of other rebars	eol_{sorbr}
Recycling of reinforcing steel	eol_{srsbr}

Concrete:

With the same definition as for buildings, the ratio defining the valorisation of concrete is the following, to be defined by the User:

Valorisation of concrete val_{conbr}

4.1.3 Building envelope

4.1.3.1 Facade geometry

The description of the walls includes the following parameters:

$A_{lat,tot}(dir)$: area of the wall oriented on direction *dir* calculated automatically as the product of length by height [m²]

$A_{lat,opening}(dir)$ the area of the openings in the *dir* wall defined through a percentage of the total area of the façade area [m²]

$A_{lat}(dir)$: net area of the wall oriented on direction *dir* calculated automatically as the difference between $A_{lat,tot}(dir)$ and $A_{lat,opening}(dir)$ [m²]

$F_{glazing,sh}(dir)$ shading obstruction factor of openings in the *dir* wall, hidden default value 1.

$F_{walls,sh}(dir)$ shading obstruction factor of the *dir* wall, hidden default value 1.

4.1.3.2 Facade properties

The user selects the type of wall and openings (*WallType* and *OpeningType*) among the items of the corresponding lists of macro-components (see **Table 16**~~Table 16~~ and **Table 15**~~Table 15~~ in Annex 2) and variables are updated:

U_{walls} U-value for walls [W/(m².K)], not modifiable

$k_{m,walls}$ inertia per square meters [J/(m².K)],hidden and not modifiable

$U_{mean,opening}$ U-value for openings [W/(m².K)], not modifiable

g_n solar energy transmittance for radiation perpendicular to the glazing, hidden parameter (see **Table 15**~~Table 15~~ in Annex 2) [-]

The selection of the shading device (*ShadingType* and *ShadingColor*, see **Table 21**~~Table 21~~ in Annex 2 the variable:

f_f solar energy transmittance of window with shading device [-]

The default values for *ShadingType* and *ShadingColor* are “No shading device” and “Intermediate”. The ShadingColor is not displayed.

The selection of shutter (ShutterType, see **Table 13**~~Table 13~~ in Annex 2) impacts the value of 4

R_{sh} additional thermal resistance at specific air permeability of shutters [m².K/W]

ΔR_{high} high or very high permeability [m².K/W]

ΔR_{avg} average permeability [m².K/W]

ΔR_{low} low permeability [m².K/W]

These 4 variables are hidden.

The following variables are also hidden:

$NightHeatingActivation$	for shutters control, are they closed during the night in order to reduce the heat losses in winter season through the window, default value according to **Table 23~~Table 23~~** in Annex 2.
$DayCoolingActivation$	for shading devices control, are they activated during the day in order to reduce the solar heat gains in summer season through the windows?, default value according To **Table 23~~Table 23~~** in Annex 2.
$FrameAreaFraction$	default value 0.3 [-]

4.1.3.3 Base floor

Following parameters are used to define the ground floor:

U_f	U-value for the base floor [W/(m².K)]
GroundFloorType	type of ground floor which are to be chosen by the user as “Slab on ground floor” or “Suspended”,
$D_{concretebasefloor}$	Thickness of concrete base floor, default value 0 [m]
$M_{steelbasefloor}$	mass of reinforcing steel, default value 0 [t]

The SoilType (hidden default value) governs two variables:

(ρc)	ground heat capacity (see **Table 22~~Table 22~~** in Annex 2), hidden [J/(m^3.K)]
λ	ground conductivity (see **Table 22~~Table 22~~**), hidden [W/(m.K)]

One other hidden variableisused:

w_{ground}	basement walls thickness, default value 0.2, [m]

The perimeter and the area of the ground floor are not displayed and are automatically calculated using:

$$P_{eri} = 2(w_b + l_b)$$
$$A_{ground} = w_b.l_b$$

Depending on the ground floor (*GroundFloorType*), following parameters are set. They are not displayed.

- Slab on ground floor
  Several options are available for the insulation (*Edgeinsulation*): “*none*”, *horizontal*”, “*vertical*” or “*both*”.
  The other parameters are:

$d_{n,hor}$	thickness of horizontal edge insulation [mm]
λ_{hor}	thermal conductivity of horizontal edge insulation [W/(m.K)]
w_{hor}	width of horizontal edge insulation [m]
$d_{n,vert}$	thickness of vertical edge insulation [mm]
λ_{vert}	thermal conductivity of vertical edge insulation [W/(m.K)]
w_{vert}	depth of vertical edge insulation [m]

- Suspended
  The parameters defining a suspended ground floor are:

h	height of wall above ground as for a basement type ground floor [m]
h_z	height of wall below ground [m]
A_{irflow}	airflow, default value 0.1 [ac/h]
A_{wind}	area of ventilation openings per perimeter length, set to 1, hidden [m²/m]
$w_{avgspeed}$	average wind speed at 10 m height, hidden [m/s]

The last 3 parameters are linked by:

$$w_{avgspeed} = \frac{A_{irflow}.A_{ground}.(h + h_z)}{3600.P_{eri}.A_{wind}}$$

4.1.3.4 Additional parameters

A few additional parameters are related to the building envelope. These parameters are hidden.

R_{se}	external surface resistance, default value 0.04 [m².K/W]
$\alpha_{s,c}$	absorption coefficient for solar radiation, default value 0.5 [-]
h_r	external radiative heat transfer coefficient, default value 4.5 [W/(m².K)]
C_m	internal heat capacity [J/K], computed through:

$$C_m = k_{m,walls}.\sum_{dir} A_{lat}(dir) + k_{m,roof}.A_{roof} + k_{m,ext,floor}.A_{ext,floor} + k_{m,ground}.A_{ground} + k_{m,interm,floor}.a_{b,fl,interm} + k_{m,intern,walls}.\left(Ratio_{intern,walls}.\sum_{dir} A_{lat,tot}(dir)\right)$$

Where:

$k_{m,walls}$	internal heat capacity of walls [J/K/m²], value according to the wall macro-component selected
$k_{m,roof}$	internal heat capacity of roof [J/K/m²], value according to the roof macro-component selected
$k_{m,ext,floor}$	internal heat capacity of external floors [J/K/m²], default value 50000 J/K/m²
$k_{m,ground}$	internal heat capacity of ground floors [J/K/m²], default value 50000 J/K/m²
$k_{m,interm,floor}$	internal heat capacity of intermediate floors [J/K/m²], default value 50000 J/K/m²
$k_{m,intern,walls}$	internal heat capacity of internal walls [J/K/m²], default value twice the value of $k_{m,walls}$ J/K/m²
$Ratio_{intern,walls}$	ratio of the area of internal walls divided by the façade areas, default value 40%

4.1.3.5 Roof

The user selects the macro-component for the roof according to **Table 25** ~~**Table 25**~~

Roof macro-component	U-value	Km
Waterproof membrane	0.31	22456.0
Macro Roof 2	0.373	13435.0

Table 25

~~Roof macro-component~~	~~U-value~~	~~Km~~
~~Waterproof membrane~~	~~0.31~~	~~22456.0~~
~~Macro Roof 2~~	~~0.373~~	~~13435.0~~

~~**Table 25**~~in Annex 2.

The following parameters define the roof:

U_{roof}	U-value for flat roof, default value depending on the macro-component, not modifiable [W/(m².K)]
$A_{ext,floor}$	area of external floor, default value 0, hidden [m²]

A_{roof}	area of the flat part of the roof, default value calculated according to the building dimensions, hidden [m²]
$A_{slopedroof}$	area of the sloped part of the roof, default value 0, hidden [m²]
$A_{roof,opening}$	area of the openings in the roof, default value 0, hidden [m²]
$F_{glazing,sh,roof}$	shading obstruction factor of openings in the roof, default value 1, hidden
$U_{slopedroof}$	U-value for sloped roof, default value 0, hidden [W/(m².K)]
$U_{ext,floor}$	U-value for external floor, default value 0, hidden [W/(m².K)]
$U_{floorunconditionedspace}$	U-value for the floor of unconditioned space, default value 0, hidden [W/(m².K)]

4.1.4 Building occupancy

The building occupancy is divided into three periods per day; moreover a distinction is made between business and weekend days. Finally, two items are considered for the occupancy: on the one hand the presence of occupants, on the other hand, the need of light. These choices may be different between the primary conditioned areas (area 1) and other conditioned areas (area 2).

Each of the 24 choices are described by three quantities:

$h_{function,beg,place,Date,i}$	beginning time [h]
$h_{function,end,place,Date,i}$	ending time [h]
$Gain_{function,place,Date,i}$	internalheat gain [h]

Where *function* ∈ {occupancy; light}, *place* ∈ {area 1; area 2}, *Date* ∈ {Monday to Friday; Saturday to Sunday}, i ∈ {1; 2; 3}.

The default values are shown in **Table 27**~~**Table 27**~~ to **Table 30**~~**Table 30**~~ (in Annex 2) depending on the These 24 quantities are hidden.

The indoor conditions are related to the comfort for the occupants and are defined by 4 parameters. The defaults values are set according to **Table 31**~~**Table 31**~~in Annex 1 and they are not modifiable:

$\theta_{int,set,H}$	heating temperature [°C]
$\theta_{int,set,C}$	cooling temperature [°C]
n_H	air-flow rate for the heating mode (per m²) [ac/h]
n_C	air-flow rate for the cooling mode (per m²) [ac/h]

4.1.5 Building systems

4 building systems are considered.

4.1.5.1 Heating system

The user must set the type of heating system($\eta_{HeatingType\_System}$,see **Table 17**~~**Table 17**~~ in Annex 2).

This choice impacts the efficiency of the heating system considered in calculations:

$\eta_{HeatingEfficiencySystem}$ heating system efficiency, hidden in normal mode [-]

The energy used ($EnergyType_{heating}$), with default values set according to **Table 33**~~**Table 33**~~ in Annex 2, a conversion factor from final energy to primary energy:

$k_{energytype,heating}$ type of energy (see **Table 20**~~**Table 20**~~ in Annex 2) [kgoe/kWh]

These two fields are hidden.

The following quantities are used but are not displayed. The values are set according to **Table 32**~~**Table**~~ Annex 2.

$h_{begd,heating}$ beginning time for working schedule [h]
$h_{end,heating}$ ending time for working schedule [h]
$NbDay_{working,heating}$ number of working days per week [-]

4.1.5.2 Cooling system

The user must set the type of cooling system ($\eta_{CoolingType\_System}$,see **Table 18**~~**Table 18**~~ in Annex 2).

This choice impacts the efficiency of the cooling system:

$\eta_{CoolingEfficiencySystem}$ cooling system efficiency, hidden [-]

The energy used ($EnergyType_{cooling}$), with default values set according to **Table 33**~~**Table 33**~~ in Annex 2, a conversion factor from final energy to primary energy:

$k_{energytype,cooling}$ type of energy (see **Table 20**~~**Table 20**~~) [kgoe/kWh]

These two fields are hidden.

Finally, as for the heating system, a similar variable is defined which is hidden and with a default value set according to **Table 34**~~**Table 34**~~:

$NbDay_{working,cooling}$ number of working days per week [-]

4.1.5.3 Ventilation system

The definition of the ventilation system relies on the use of a heat recovery system ($HeatRecovery$). In that case, the characteristics of the system are:

$HeatRecovery\%$ fraction of the air flow volume that goes through the heat recovery unit, default value 0.8, hidden [-]
η_{hru} efficiency of heat recovery unity, default value 0.6, hidden [-]

4.1.5.4 Domestic Hot Water (DHW) system

The type of DHW system ($\eta_{TypeDHW}$, see **Table 19**~~**Table 19**~~ in Annex 2) is related to the efficiency of the system:

η_{DHW} DHW efficiency system, hidden in normal mode [-]

The energy used ($EnergyType_{DHW}$), with default values set according to **Table 35**~~**Table 35**~~, governs a factor from final energy to primary energy:

$k_{energytype,DHW}$ type of energy (see **Table 20**~~**Table 20**~~) [kgoe/kWh]

The DHW system depends on several parameters:

$\theta_{w,t}$ desired water temperature at tapping point, default value 60, hidden [°C]

$\theta_{w,outside}$	inlet water temperature, default value 15, hidden [°C]
$DHW_{energyreduction}$	fraction of the DHW energy provided by renewable energy sources, default value 0, hidden [-]

4.2 Constants and specific parameters

General constants:

$MonthLength(m)$	number of seconds in the month *m* in mega seconds
$MonthDay(m)$	number of days in the month *m* [-]
$NbDayWorking(m)$	number of working days in the month *m* [-]

The specific following quantities are treated in a specific way. Initially, they are input data but as their meaning could not be clear for the user, they are treated as constants in AMECO 3.

F_w	correction factor for non-scattering glazing [-]
f_w	windshield factor [-]
$b_{tr,U}$	adjustment factor for unconditioned space [-]
$\mathrm{F_{r,v}}$	radiation factor for vertical roof [-]
$\mathrm{F_{r,h}}$	radiation factor for horizontal walls [-]

Specific parameters for the **heating mode**:

$k_{D,cor,H}$	correction factor for heat transfer by transmission [-]
$k_{cor,ve,H}$	correction factor for heat transfer by ventilation [-]
$k_{cor,int,H}$	correction factor for internal gains [-]
$k_{cor,H}$	correction factor for solar heat gains [-]
a_{H0}	dimensionless reference numerical parameter [-]
τ_{H0}	Reference time constant [h]
$b_{H,red}$	Empirical correlation factor (set to 3) [-]

Some of these parameters depend on the GeigerClimate and the presence of a shading device (see Table 26~~Table 26~~).

Specific parameters for the **cooling mode**:

$k_{D,cor,C}$	correction factor for heat transfer by transmission [-]
$k_{cor,ve,C}$	correction factor for heat transfer by ventilation [-]
$k_{cor,int,C}$	correction factor for internal gains [-]
$k_{cor,C}$	correction factor for solar heat gains [-]
a_{C0}	dimensionless reference numerical parameter [-]
τ_{C0}	Reference time constant [h]
$b_{C,red}$	Empirical correlation factor (set to 3) [-]

Some of these parameters depend on the GeigerClimate and the presence of a shading device (see Table 26~~Table 26~~).

Constants for the DHW production:

In accordance with EN15316-3-1, the following three constants are defined (residential buildings).

$X = 62$ [l/(day.m²)]

$Y = 160$ [l/(day.m²)]

$Z = 2$ [l/(day.m²)]

4.3 Calculation of the environmental impact of a structure

4.3.1 Principles

The method used by Ameco includes 24 environmental impacts indicators, each one divided into four modules:

- Module A: Product and Construction process stage
- Module B: Use stage
- Module C: End of life
- Module D: Benefits and loads beyond the system boundaries

The 24 indicators follow the same equations. The only differences between them are the values of coefficients. All these coefficients are given in tables 2 and 3.

The denomination of each coefficient is given in Table 2~~Table 2~~ and values are given in the following paragraphs. The value of all parameters defined in this chapter can be displayed by Ameco. All parameters of this chapter have the same values for buildings and for bridges. They are not modifiable.

In Ameco, impact coefficients will be defined for 10 indicators. For the remaining 14 indicators, they will be set to zero.

Impact coefficient considered	**Denomination**
RER: Steel plate worldsteel	$k_{RERStPl}$
RER: Steel sections worldsteel	$k_{RERStSec}$
GLO: Steel rebar worldsteel	k_{GLOSt}
RER: Steel hot dip galvanized worldsteel	$K_{RERStHDG}$
DE: Concrete C20/25 PE	$k_{DEConC20}$
DE: Concrete C30/37 PE	$k_{DEConC30}$
DE: Glued laminated timber PE [for 1kg]	k_{DEW}
GLO: Value of scrap worldsteel	k_{GLO}
Steel building demolition - impact for 1kg treated	$k_{StBldgDem}$
CH: disposal, building, concrete, not reinforced, to final disposal	k_{CHCon}
CH: disposal, building, reinforcement steel, to final disposal	k_{CHSt}
CH: disposal, building, concrete, not reinforced, to sorting plant [incl. 40% to sanitary landfill]	$k_{CHConPlt}$
CH: disposal, building, reinforcement steel, to sorting plant	$k_{CHStPlt}$
CH: disposal, concrete, 5% water, to inert material landfill	$k_{CHConLdf}$
CH: gravel, unspecified, at mine	k_{CHGr}
RER: Landfill for inert matter (Steel) PE	$k_{RERStLdf}$
EU-27: Waste incineration of wood products (OSB, particle board) ELCD/CEWEP <p-agg> [1kg wood]	k_{EUWWa}
Credit for waste incineration (agg minus p-agg)	k_{Wa}
EU-27: Landfill of wood products (OSB, particle board) PE <p-agg>	k_{EUWLdf}
CH: disposal, inert material, 0% water, to sanitary landfill	k_{CHLdf}
RER: Articulated lorry transport PE [for 1tkm]	k_{RERALT}
Transport by train [for 1tkm]	k_{Tr}
Transport by concrete truck [for 100kgkm]	k_{Cont}
Average european transportation for steel [for 1t on average european distance]	k_{StAvg}
EU-27: Electricity grid mix PE [1kWh]	k_{EUElec}

Electricity Output Recovery	k_{EOR}
RER: Steel plate worldsteel (scrap input)	$k_{RERStPl0}$
RER: Steel sections worldsteel (scrap input)	$k_{RERStSec0}$
RER: Steel hot dip galvanized worldsteel (scrap input)	$k_{RERStHDG0}$
GLO: Steel rebar worldsteel (scrap input)	k_{GLOSt0}

Table 2 : Denomination of coefficient

The acronyms used in **Table 2**~~**Table 2**~~stands for:

Formatiert: Rechtschreibung und Grammatik prüfen

- GLO : Global (average)
- DE : German (average)
- CH : Swiss (average)

The 5 last impact coefficients (no unit) have the same value for all impact indicators:

k_{EOR}	8.865E-01
$k_{RERStPl0}$	1.125E-01
$k_{RERStSec0}$	8.492E-01
$k_{RERStHDG0}$	9.162E-02
k_{GLOSt0}	6.983E-01

Table 3 : Values for scrap input coefficients

4.3.1.1 Parameters describing environmental impacts

The Table 4 contains values of coefficients for the indicators GWP, ODP, AP, EP, POCP, ADP-elements, ADP-fossil fuels.

	GWP	ODP	AP	EP	POCP	APD-e	ADP-ff
	t CO2 eq / t	t CFC eq / t	t SO2 eq / t	t Ethene eq / t	t PO4 eq / t	t Sb eq / t	GJ NCV / t
$k_{RERStPl}$	2.458E+00	9.112E-09	6.229E-03	4.424E-04	1.170E-03	5.396E-07	2.538E+01
$k_{RERStSec}$	1.143E+00	4.948E-08	3.158E-03	2.706E-04	5.051E-04	-7.001E-06	1.239E+01
k_{GLOSt}	1.244E+00	1.110E-08	3.533E-03	2.802E-04	5.494E-04	-2.103E-06	1.349E+01
$K_{RERStHDG}$	2.556E+00	3.726E-08	6.980E-03	4.486E-04	1.243E-03	2.318E-05	2.621E+01
$k_{DEConC20}$	9.883E-02	5.635E-11	1.485E-04	2.610E-05	1.740E-05	1.553E-07	4.626E-01
$k_{DEConC30}$	1.114E-01	6.562E-11	1.524E-04	2.553E-05	1.778E-05	1.867E-07	4.545E-01
k_{DEW}	-1.185E+00	1.347E-09	1.179E-03	1.418E-04	1.243E-04	1.317E-07	7.670E+00
k_{GLO}	1.512E+00	-4.834E-08	3.610E-03	9.974E-05	8.072E-04	7.272E-06	1.598E+01
$k_{StBldgDem}$	8.810E-04	3.251E-12	9.345E-06	1.193E-06	8.336E-07	3.461E-10	1.212E-01
k_{CHCon}	1.401E-02	3.098E-09	8.901E-05	2.551E-05	1.590E-05	1.448E-08	2.771E-01
k_{CHSt}	6.732E-02	9.741E-09	4.988E-04	1.387E-04	7.727E-05	2.544E-08	1.017E+00
$k_{CHConPlt}$	1.398E-02	2.527E-09	3.581E-04	2.831E-05	1.456E-05	1.956E-08	2.398E-01
$k_{CHStPlt}$	6.139E-02	7.782E-09	4.629E-04	1.295E-04	6.945E-05	2.279E-08	8.537E-01
$k_{CHConLdf}$	7.102E-03	2.128E-09	4.226E-05	1.223E-05	8.602E-06	7.345E-09	1.785E-01
k_{CHGr}	2.824E-03	3.257E-10	1.760E-05	6.317E-06	2.284E-06	9.374E-09	3.626E-02
$k_{RERStLdf}$	1.396E-02	1.368E-11	8.491E-05	1.163E-05	8.972E-06	4.949E-09	1.865E-01
k_{EUWWa}	1.671E+00	2.920E-09	6.252E-04	1.428E-04	4.099E-05	-4.267E-08	5.289E-01
k_{Wa}	-7.514E-01	-7.786E-08	-4.946E-03	-2.013E-04	-2.622E-04	-3.164E-08	-8.651E+00
k_{EUWLdf}	1.455E+00	2.606E-10	4.386E-04	1.878E-03	3.408E-04	1.370E-08	1.082E+00
k_{CHLdf}	1.228E-02	3.091E-09	7.480E-04	2.565E-05	1.382E-05	1.490E-08	2.781E-01
k_{RERALT}	4.714E-02	1.749E-11	3.085E-04	7.432E-05	-1.260E-04	1.861E-09	6.515E-01
k_{Tr}	1.711E-02	8.846E-10	8.593E-05	9.950E-06	7.298E-06	1.250E-09	2.036E-01
k_{Cont}	1.201E-02	4.452E-12	7.527E-05	1.806E-05	-3.035E-05	4.739E-10	1.659E-01
k_{StAvg}	2.422E+01	1.328E-07	1.548E-01	3.578E-02	-5.727E-02	1.037E-06	3.301E+02
k_{EUElec}	4.887E-01	3.192E-08	2.083E-03	1.118E-04	1.267E-04	4.007E-08	5.569E+00

Table 4 : Values for environmental coefficients

4.3.1.2 Parameters describing resources use, secondary materials and fuels, and use of water

The **Table 5**~~**Table 5**~~ contains values of coefficients for the three indicators:

- Total use of renewable primary energy (primary energy and primary energy resources used as raw materials) [RPE-Total].
- Total use of non renewable primary energy (primary energy and primary energy resources used as raw materials) [Non RPE-Total].
- Use of net fresh water [NFW].

	RPE-Total	Non RPE total	NFW
	GJ NCV / t	GJ NCV / t	$10^3 m^3$ / t
$k_{RERStPl}$	2.987E-01	2.577E+01	1.352E-02
$k_{RERStSec}$	6.107E-01	1.419E+01	1.332E-03
k_{GLOSt}	2.362E+00	1.406E+01	1.387E-02
$K_{RERStHDG}$	5.477E-01	2.768E+01	1.586E-02
$k_{DEConC20}$	3.458E-02	5.084E-01	3.208E-04
$k_{DEConC30}$	3.692E-02	5.077E-01	3.225E-04
k_{DEW}	1.855E+01	8.766E+00	6.636E-01
k_{GLO}	-8.226E-01	1.423E+01	1.307E-02
$k_{StBldgDem}$	4.747E-03	1.216E-01	1.228E-04
k_{CHCon}	2.259E-03	2.879E-01	1.264E-02
k_{CHSt}	5.325E-03	1.043E+00	3.083E-02
$k_{CHConPlt}$	8.531E-03	2.821E-01	4.905E-02
$k_{CHStPlt}$	9.525E-03	9.019E-01	5.568E-02
$k_{CHConLdf}$	1.464E-03	1.855E-01	7.997E-03
k_{CHGr}	6.248E-03	6.613E-02	3.753E-02
$k_{RERStLdf}$	1.450E-02	1.960E-01	2.788E-04
k_{EUWWa}	1.618E-02	6.576E-01	4.269E-03
k_{Wa}	-1.063E+00	-1.172E+01	-1.042E-03
k_{EUWLdf}	4.911E-02	1.134E+00	3.901E-02
k_{CHLdf}	4.758E-03	3.005E-01	3.552E-04
k_{RERALT}	2.553E-02	6.539E-01	6.604E-04
k_{Tr}	3.643E-02	2.858E-01	1.561E-04
k_{Cont}	6.499E-03	1.665E-01	1.681E-04
k_{StAvg}	1.694E+01	3.428E+02	3.275E-01
k_{EUElec}	1.246E+00	8.534E+00	3.829E-03

Table 5 : Values for resources use, secondary materials and fuels, and use of water coefficients

Due to the lack of data, the coefficients for the following indicators are set to zero (it leads to an impact value of zero):

- Use of renewable primary energy excluding renewable primary energy resources used as raw materials [RPE].
- Use of renewable energy resources used as raw materials [RER].
- Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials [Non-RPE].
- Use of non renewable energy resources used as raw materials [Non-RER].
- Use of secondary material [SM].
- Use of renewable secondary fuels [RSF].
- Use of non renewable secondary fuels [Non-RSF].

4.3.1.3 Other environmental information describing waste categories

The **Table 6~~Table 6~~** contains values of coefficients for the following indicators:

- Hazardous waste disposed.
- Non hazardous waste disposed.
- Radioactive waste disposed.

	Hazardous waste disposed	Non hazardous waste disposed	Radioactive waste disposed
	t /t	t / t	t / t
$k_{RERStPl}$	-6.239E-04	-1.306E-03	-1.663E-04
$k_{RERStSec}$	-5.212E-04	-8.676E-04	-3.832E-04
k_{GLOSt}	-2.460E-04	-1.186E-04	-1.428E-04
$k_{RERStHDG}$	-4.771E-04	-6.745E-04	-4.717E-04
$k_{DEConC20}$	0.000E+00	0.000E+00	-1.859E-05
$k_{DEConC30}$	0.000E+00	0.000E+00	-2.164E-05
k_{DEW}	0.000E+00	1.483E+00	4.461E-04
k_{GLO}	-1.536E-05	-3.524E-06	5.177E-04
$k_{StBldgDem}$	0.000E+00	0.000E+00	0.000E+00
k_{CHCon}	0.000E+00	0.000E+00	0.000E+00
k_{CHSt}	0.000E+00	0.000E+00	0.000E+00
$k_{CHConPlt}$	0.000E+00	0.000E+00	0.000E+00
$k_{CHStPlt}$	0.000E+00	0.000E+00	0.000E+00
$k_{CHConLdf}$	0.000E+00	0.000E+00	0.000E+00
k_{CHGr}	0.000E+00	0.000E+00	0.000E+00
$k_{RERStLdf}$	0.000E+00	1.000E+00	-3.459E-06
k_{EUWWa}	0.000E+00	-6.430E-02	-3.659E-05
k_{Wa}	0.000E+00	1.940E+00	9.767E-04
k_{EUWLdf}	0.000E+00	4.813E-01	-1.972E-05
k_{CHLdf}	0.000E+00	0.000E+00	0.000E+00
k_{RERALT}	0.000E+00	0.000E+00	-9.099E-07
k_{Tr}	0.000E+00	0.000E+00	-3.383E-05
k_{Cont}	0.000E+00	0.000E+00	0.000E+00
k_{StAvg}	0.000E+00	0.000E+00	-5.190E-03
k_{EUElec}	0.000E+00	-1.827E+00	-1.220E-03

Table 6 : Values for other environmental information describing waste categories

4.3.1.4 Other environmental information describing output flows

The coefficients are unknown and set to zero for the following four indicators in Ameco 3:

- Components for reuse.
- Materials for recycling.
- Materials for energy recovery.
- Exported energy.

4.3.2 Environmental impact of a building

4.3.2.1 Module **A**

The equations for the assessment of the environmental impacts for the module A are:

Module A				
Product stage	A1 Raw material supply	Concrete of floors	$m_{consl}\ k_{DECon}$
		Steel sheets	$m_{tss}\ k_{RERStHDG}$
		Concrete of structure	$(m_{tcb} + m_{tcc})\ k_{DECon}$
		Steel reinforcement	$(m_{conrs} + m_{trs})\ k_{GLOSt}$
		Steel beams	$m_{tsb}(1 + S_{plos})\ k_{RERStSec}$
		Steel columns	$m_{tsc}(1 + S_{plos})\ k_{RERStSec}$
		Wood beams	$m_{twb}\ k_{DEW}$
		Wood columns	$m_{twc}\ k_{DEW}$
	A3 Manufacturing	Production losses	$(m_{tsb} + m_{tsc})\ S_{plos}\ k_{RERALT}/\ 10$
		Steel studs and bolts	$(m_{tst} + m_{tbo})\ k_{GLOSt}$
		Plate connections	$m_{tpl}\ k_{RERStPl}$
	A1-A3	Macro-component	
Construction process stage	A4 Transport	Concrete - mixer truck	$m_{conmix}\ d_{conmix}\ k_{Cont}/\ 100$
		Concrete - regular truck	$m_{conreg}\ d_{conreg}\ k_{RERALT}/\ 1000$
		Steel - regular truck	$m_{sreg}\ d_{sreg}\ k_{RERALT}/\ 1000$
		Steel - train	$m_{str}\ d_{str}\ k_{Tr}/\ 1000$
		Steel - average transport	$m_{tstrtot}\ k_{StAvg}$
		Wood - train	$m_{wtr}\ d_{wtr}\ k_{Tr}/\ 1000$
		Wood - regular truck	$m_{wreg}\ d_{wreg}\ k_{RERALT}/\ 1000$
		Macro-component	
Total Module A			Sum of all quantities in module A

Table 7 : environmental impacts for module A

In this Table, the highlighted equations show the relations modified or added in the frame of the LVS3 project.

Considering the parameters added for the ground floor, following equations are modified:

Total concrete weight $m_{consl,LVS3}$:

$m_{consl,LVS3} = m_{consl} + D_{concretebasefloor}\ A_{ground}\ .\ \rho_{consl}$

Mass of steel reinforcement:

$(m_{conrs} + m_{trs} + M_{steelbasefloor})\ k_{GLOSt}$

An additional part is taken into account for the product stage:

$$Macro - component_{A1-A3} = \sum_{dir} A_{lat}(dir)\,.\,k_{A1-A3,wall} + \sum_{dir} A_{lat,opening}(dir)\,.\,k_{A1-A3,opening} + A_{roof}\,.\,k_{A1-A3,roof}$$

Total mass of steel transported $m_{tstrtot,LVS3}$ is now:

$m_{tstrtot,LVS3} = m_{tstrtot} + M_{steelbasefloor}$

An additional part is taken into account for the construction process stage:

$$Macro - component_{A4} = \sum_{dir} A_{lat}(dir) \,.\, k_{A4,wall} + \sum_{dir} A_{lat,opening}(dir) \,.\, k_{A4,opening} + A_{roof} . k_{A4,roof}$$

The values of $k_{A1\text{-}A3,wall}$, $k_{A4,wall}$, $k_{A1\text{-}A3,opening}$ and $k_{A4,opening}$ are indicated in Annex 4~~Annex 4~~.

4.3.2.2 Module B: Use phase

The use phase calculation involves several steps. The first step is dedicated to the computation of characteristics of the ground floor.

Then the energy need for the space heating and the associated solar heat gains are evaluated.

A similar procedure is used for the space cooling and the associated solar heat gains.

The next step is dedicated to the domestic hot water system.

The final part summarizes all these calculations.

4.3.2.2.1 Evaluation of the characteristics of the ground floor (ISO 13370)

The aim of this part is to compute H_g, H_{pi}, H_{pe}, α and β.

Independently of the *GroundFloorType*, the following intermediate variables are estimated:

$$B' = \frac{A_{ground}}{0.5P_{eri}}$$

$$d_{ground} = w_{ground} + \frac{\lambda}{U_f}$$

$$\delta = \sqrt{\frac{3.15\ 10^7 \lambda}{\pi(\rho c)}}$$

$$U_g = \frac{2.\lambda}{\pi B' + d_{ground}} . ln\left(1 + \frac{\pi B'}{d_{ground}}\right)$$

- As the internal temperature is assumed to be constant, we have:

$$H_{pi} = 0$$

- Furthermore, for the ground floor type considered the value of α is unique:

$$\alpha = 0$$

The rest of quantities depend on the **type of ground floor**.

- **Slab on ground floor**

- β is set to one for slab on ground floor:

$$\beta = 1$$

H

H_g computation:

$$U = \begin{cases} U_g & if\ d_{ground} < B' \\ \dfrac{\lambda}{0.457B' + d_{ground}} & \text{else} \end{cases}$$

It leads to:

$$H_g = U.A_{ground}$$

H_{pe} computation

$$d'_{n,hor} = \left(\frac{\lambda}{\lambda_{hor}} - 1\right).d_{n,hor}.10^{-3}$$

$$d'_{n,vert} = \left(\frac{\lambda}{\lambda_{vert}} - 1\right).d_{n,vert}.10^{-3}$$

$$H_{pe,hor} = 0.37P_{eri}.\lambda.\left[\left(1 - exp\left(-\frac{w_{hor}}{\delta}\right)\right).ln\left(1 + \frac{\delta}{d_{ground} + d'_{n,hor}}\right) + exp\left(-\frac{w_{hor}}{\delta}\right).ln\left(1 + \frac{\delta}{d_{ground}}\right)\right]$$

$$H_{pe,vert} = 0.37P_{eri}.\lambda.\left[\left(1 - exp\left(-\frac{2.w_{vert}}{\delta}\right)\right).ln\left(1 + \frac{\delta}{d_{ground} + d'_{n,vert}}\right) + exp\left(-\frac{2.w_{vert}}{\delta}\right).ln\left(1 + \frac{\delta}{d_{ground}}\right)\right]$$

$$H_{pe} = \begin{cases} 0.37P_{eri}.\lambda.ln\left(1 + \frac{\delta}{d_{ground}}\right) & if\ edgeinsulation = none \\ H_{pe,hor} & if\ edgeinsulation = horizontal \\ H_{pe,vert} & if\ edgeinsulation = vertical \\ min(H_{pe,hor}; H_{pe,vert}) & else \end{cases}$$

H_{pe} computation

$$H_{pe} = \begin{cases} 0.37P_{eri}.\lambda.\left[exp\left(\frac{-h_z}{\delta}\right).ln\left(1 + \frac{\delta}{d_{ground}}\right) + 2.\left(1 - exp\left(\frac{-h_z}{\delta}\right)\right).ln\left(1 + \frac{\delta}{d_w}\right)\right] & if\ BasementType = heated \\ A_{ground}.U_f.\dfrac{0.37P_{eri}.\lambda.\left(2 - exp\left(\frac{-h_z}{\delta}\right)\right).ln\left(1 + \frac{\delta}{d_{ground}}\right) + h.P_{eri}.U_{walls} + 0.33n_H.V}{\frac{(A_{ground} + h_z.P_{eri}).\lambda}{\delta} + h.P_{eri}.U_{walls} + 0.33n_H.V + A_{ground}.U_f} & if\ BasementType = unheated\ and\ for\ the\ heating\ calculation \\ A_{ground}.U_f.\dfrac{0.37P_{eri}.\lambda.\left(2 - exp\left(\frac{-h_z}{\delta}\right)\right).ln\left(1 + \frac{\delta}{d_{ground}}\right) + h.P_{eri}.U_{walls} + 0.33n_C.V}{\frac{(A_{ground} + h_z.P_{eri}).\lambda}{\delta} + h.P_{eri}.U_{walls} + 0.33n_C.V + A_{ground}.U_f} & if\ BasementType = unheated\ and\ for\ the\ cooling\ calculation \end{cases}$$

- **Suspended floor**

- $\beta$is set to zero for suspended floor:

$$\beta = 0$$

H_g computation

$$U_x = \frac{2.h.U_{walls}}{B'} + \frac{1450.A_{wind}.w_{avgspeed}.f_w}{B'}$$

$$U_{eq} = \frac{1}{\frac{1}{U_f} + \frac{1}{U_g}}$$

$$H_g = U_{eq}.A_{ground}$$

H_{pe} computation

$$H_{pe} = U_f.\frac{0.37P_{eri}.\lambda.ln\left(1 + \frac{\delta}{d_{ground}}\right) + U_x.A_{ground}}{\frac{\lambda}{\delta} + U_x + U_f}$$

4.3.2.2.2 Energy need for space heating and solar heat gains

The calculation of energy need and solar heat gains is quite similar for heating and for cooling. Only a few equations differ and some variables have specific values depending on the mode considered. Thus, the calculation will be based on the same module in Ameco 3 and specificities of each mode will be taken into account.

- **Preassignment**

Before beginning the computation of energy need for space heating, quantities related to the heating mode are assigned. They are:

$$H_g = H_{g,H}$$
$$H_{pi} = H_{pi,H}$$
$$H_{pe} = H_{pe,H}$$
$$\overline{\theta_i} = \theta_{int,set,H}$$
$$k_{D,cor} = k_{D,cor,H}$$
$$k_{cor,ve} = k_{cor,ve,H}$$
$$k_{cor,int} = k_{cor,int,H}$$
$$k_{cor} = k_{cor,H}$$
$$f_{shut}(m) = f_{H,shut}(m)$$

$$AFR_{floor} = n_H$$

$$a_0 = a_{H0}$$

$$\tau_0 = \tau_{H0}$$

$$b_{red} = b_{H,red}$$

$$\eta_{EfficiencySystem} = \eta_{HeatingEfficiencySystem}$$

$$k_{energytype} = k_{energytype,heating}$$

- **Heat transfer by transmission**

The following formulas focus on the heat transfer to the ground.

The average annual external temperature is:

$$\overline{\theta_e} = \sum_m \frac{\theta_{ext}(m)}{12}$$

The amplitudes of variations in monthly mean temperature are:

$$\widehat{\theta_\iota} = 0$$

$$\widehat{\theta_e} = \frac{max(\theta_{ext}(m)) - min(\theta_{ext}(m))}{2}$$

And the monthly mean temperatures for the month *m* follow:

$$\theta_i(m) = \overline{\theta_\iota} - \widehat{\theta_\iota}.cos\left(2\pi\frac{m-\tau_m}{12}\right)$$

$$\theta_e(m) = \overline{\theta_e} - \widehat{\theta_e}.cos\left(2\pi\frac{m-\tau_m}{12}\right)$$

Where$\tau_m$is the month index when the outside temperature is minimum.

The monthly heat flow rate is:

$$\emptyset(m) = H_g.(\overline{\theta_\iota} - \overline{\theta_e}) - H_{pi}\widehat{\theta_\iota}.cos\left(2\pi\frac{m-\tau_m+\alpha}{12}\right) + H_{pe}\widehat{\theta_e}.cos\left(2\pi\frac{m-\tau_m-\beta}{12}\right)$$

It leads to the monthly ground heat coefficient:

$$H_g(m) = \frac{\emptyset(m)}{\theta_i(m) - \theta_e(m)}$$

Finally, the total heat transfer to the ground is:

$$Q_{tr,g}(m) = \frac{24}{1000}.\emptyset(m).MonthDay(m)\ [\text{kWh}]$$

The heat transfer by transmission is evaluated for several part of the building envelope namely the walls, the glazing, the roof, the external floor and the ground floor.

<u>Walls</u>

$$A_{lat} = \sum_{dir} A_{lat}(dir)$$

Using the total lateral area of walls, the walls heat transfer coefficient by transmission to the external environment is calculated:

$$H_{D,walls} = U_{walls}.A_{lat}.k_{D,cor}$$

And then the walls total heat transfer by transmission:

$$Q_{tr,walls}(m) = \frac{H_{D,walls}}{3.6}\left(\overline{\theta_i} - \theta_{ext}(m)\right).MonthLength(m) \text{ [kWh]}$$

<u>Glazing</u>

$$A_{lat,opening} = \sum_{dir} A_{lat,opening}(dir)$$

$$U_{W+shut,0} = \frac{1}{\frac{1}{U_{mean,opening}} + R_{sh} + \Delta R_{avg}}$$

$$U_{W+shut}(m) = U_{W+shut,0}.f_{shut}(m) + U_{mean,opening}.\left(1 - f_{shut}(m)\right)$$

So, the glazing heat transfer coefficient by transmission to the external environment is:

$$H_{D,glazing}(m) = \begin{cases} U_{W+shut}(m).A_{lat,opening}.k_{D,cor} & if\ NightHeatdingActivation = YES \\ U_{mean,opening}.A_{lat,opening}.k_{D,cor} & \text{else} \end{cases}$$

And the associated glazing total heat transfer by transmission:

$$Q_{tr,glazing}(m) = \frac{H_{D,glazing}(m)}{3.6}\left(\overline{\theta_i} - \theta_{ext}(m)\right).MonthLength(m) \text{ [kWh]}$$

<u>External floor and ground floor</u>

For the external floor heat transfer coefficient by transmission, the formula is:

$$H_{D,ext,floor} = U_{ext,floor}.A_{ext,floor}.k_{D,cor}$$

Thus, the external floor total heat transfer by transmission follows:

$$Q_{tr,ext,floor}(m) = \frac{H_{D,ext,floor}}{3.6}\left(\overline{\theta_i} - \theta_{ext}(m)\right).MonthLength(m) \text{ [kWh]}$$

The total heat transfer by transmission to the ground is given by:

$$Q_{tr,ground}(m) = Q_{tr,g}(m).k_{D,cor} \text{ [kWh]}$$

<u>Roof</u>

The roof heat transfer coefficients by transmission are defined in the same way with other coefficients:

$$H_{D,roof} = U_{roof}.A_{roof}.k_{D,cor}$$

$$H_{D,pitchedroof} = U_{slopedroof}.A_{slopedroof}.b_{tr,U}.k_{D,cor}$$

For the roof total heat transfer by transmission, equations are:

$$Q_{tr,roof}(m) = \frac{H_{D,roof}}{3.6}\left(\overline{\theta_i} - \theta_{ext}(m)\right).MonthLength(m) \text{ [kWh]}$$

$$Q_{tr,pitchedroof}(m) = \frac{H_{D,pitchedroof}}{3.6}\left(\overline{\theta_i} - \theta_{ext}(m)\right).MonthLength(m) \text{ [kWh]}$$

The overall transmission total heat transfer by transmission is then calculated:

$$Q_{tr}(m) = Q_{tr,walls}(m) + Q_{tr,glazing}(m) + Q_{tr,ext,floor}(m) + Q_{tr,roof}(m) + Q_{tr,ground}(m) + Q_{tr,pitchedroof}(m) \quad \text{[kWh]}$$

The heat transfer coefficients by transmission to the ground and to unconditioned spaces are estimated by:

$$H_{g,cor}(m) = H_g(m).k_{D,cor}$$

$$H_u = A_{slopedroof}.U_{unconditionedarea}.b_{tr,U}.k_{D,cor}$$

The overall heat transfer coefficient by transmission is computed with:

$$H_D(m) = H_{D,walls} + H_{D,glazing}(m) + H_{D,ext,floor} + H_{D,roof}$$

$$H_{tr,adj}(m) = H_D(m) + H_{g,cor}(m) + H_u$$

- **Heat transfer by ventilation**

The heat transfer by ventilation involves these formulas:

Airflow rate (m^3/s):

$$q_{ve,k} = \frac{AFR_{floor}.h_{floor,ceiling}.A_{conditionedarea}}{3600}$$

Temperature adjustment factor:

$$b_{ve,k} = \begin{cases} 1 & if\ HeatRecovery = NO \\ 1 - \dfrac{HeatRecovery\%}{100}.\eta_{hru} & else \end{cases}$$

Time average airflow rate (m^3/s):

$$q_{ve,k,mn} = q_{ve,k}.f_{ve,t,k}$$

Where the time fraction of operation of the air flow for a day is:

$$f_{ve,t,k} = 1$$

So that, the heat transfer coefficient by ventilation is:

$$H_{ve,adj} = 1200.b_{ve,k}.q_{ve,k,mn}$$

And the associated total heat transfer by ventilation follows:

$$Q_{ve}(m) = \frac{H_{ve,adj}}{3.6}\left(\bar{\theta_i} - \theta_{ext}(m)\right).MonthLength(m).k_{cor,ve} \text{ [kWh]}$$

- **Internal heat gains**

Internal heat gains are calculated using the same method for gains related to the presence of occupants and appliances into the building and for the lightning of the building.

Some intermediate variables are introduced:

$$\begin{aligned} PartA = A_{area1}.\big[&\left|h_{occ,beg,kitch,MtoF,1} - h_{occ,end,kitch,MtoF,1}\right|.Gain_{occ,kitch,MtoF,1} \\ &+ \left|h_{occ,beg,kitch,MtoF,2} - h_{occ,end,kitch,MtoF,2}\right|.Gain_{occ,kitch,MtoF,2} \\ &+ \left|24 - h_{occ,beg,kitch,MtoF,3} + h_{occ,end,kitch,MtoF,3}\right|.Gain_{occ,kitch,MtoF,3}\big] \end{aligned}$$

$$\begin{aligned} PartB = A_{area2}.\big[&\left|h_{occ,beg,other,MtoF,1} - h_{occ,end,other,MtoF,1}\right|.Gain_{occ,other,MtoF,1} \\ &+ \left|h_{occ,beg,other,MtoF,2} - h_{occ,end,other,MtoF,2}\right|.Gain_{occ,other,MtoF,2} \\ &+ \left|24 - h_{occ,beg,other,MtoF,3} + h_{occ,end,other,MtoF,3}\right|.Gain_{occ,kitch,MtoF,3}\big] \end{aligned}$$

$$\begin{aligned} PartC = A_{area1}.\big[&\left|h_{occ,beg,kitch,StoS,1} - h_{occ,end,kitch,StoS,1}\right|.Gain_{occ,kitch,StoS,1} \\ &+ \left|h_{occ,beg,kitch,StoS,2} - h_{occ,end,kitch,StoS,2}\right|.Gain_{occ,kitch,StoS,2} \\ &+ \left|24 - h_{occ,beg,kitch,StoS,3} + h_{occ,end,kitch,StoS,3}\right|.Gain_{occ,kitch,StoS,3}\big] \end{aligned}$$

$$\begin{aligned} PartD = A_{area2}.\big[&\left|h_{occ,beg,other,StoS,1} - h_{occ,end,other,StoS,1}\right|.Gain_{occ,other,StoS,1} \\ &+ \left|h_{occ,beg,other,StoS,2} - h_{occ,end,other,StoS,2}\right|.Gain_{occ,other,StoS,2} \\ &+ \left|24 - h_{occ,beg,other,StoS,3} + h_{occ,end,other,StoS,3}\right|.Gain_{occ,kitch,StoS,3}\big] \end{aligned}$$

Then, the heat gains from occupants and appliances are deduced:

$$\begin{aligned} \phi_{int,mn}(m) = &\frac{NbDayWorking(m).\{PartA + PartB\}}{1000} \\ &+ \frac{\left(MonthDay(m) - NbDayWorking(m)\right).\{PartC + PartD\}}{1000} \end{aligned}$$

*PartA2, PartB2, PartC2, PartD2*are computed in the same way as for *PartA, PartB, PartC, PartD*but using “light” values instead of “occupancy” values.

And the heat gains from lightning are:

$$\begin{aligned} \phi_{int,l,mn}(m) = &\frac{NbDayWorking(m).\{PartA2 + PartB2\}}{1000} \\ &+ \frac{\left(MonthDay(m) - NbDayWorking(m)\right).\{PartC2 + PartD2\}}{1000} \end{aligned}$$

The total heat gains from internal sources are finally estimated by:

$$Q_{int}(m) = \left(\emptyset_{int,mn}(m) + \emptyset_{int,l,mn}(m)\right).k_{cor,int} \text{ [kWh]}$$

- **Solar heat gains**

The calculation of solar heat gain can be divided in two parts. The first deals with glazing while the second focuses on walls.

Glazing

The solar radiation through glazing is estimated by:

$$F_{glazing,sh,ok,k}A_k I_{sol,k}(m,dir) = k_{cor}.A_{lat,opening}(dir).F_{glazing,sh}(dir).I_{sol,k}(m,dir).g_n.F_w.(1-FrameAreaFraction)$$

$$F_{glazing,sh,ok,k}A_k I_{sol,k,hor}(m) = A_{roof,opening}.F_{glazing,sh,roof}.I_{sol,k,roof}(m).g_n.F_w.(1-FrameAreaFraction)$$

And, the radiation to the sky by:

$$\phi_{r,glazing}(dir) = U_{mean,opening}.R_{se}.A_{lat,opening}(dir).h_r.\Delta\theta_{\mathrm{er}}.\mathrm{F_{r,v}}$$

$$\phi_{r,glazing,hor} = U_{mean,opening}.R_{se}.A_{roof,opening}.h_r.\Delta\theta_{\mathrm{er}}.\mathrm{F_{r,h}}$$

Then, the heat flow by solar gains through glazing is deduced:

$$\phi_{glazing,sol,mn,k}(m,dir) = F_{glazing,sh,ok,k}A_k I_{sol,k}(m,dir) - \phi_{r,glazing}(dir)$$

$$\phi_{glazing,sol,mn,k,hor}(m) = F_{glazing,sh,ok,k}A_k I_{sol,k,hor}(m) - \phi_{r,glazing,hor}$$

At last, the overall solar heat gains through glazing are computed:

$$Q_{sol,glazing}(m) = \frac{MonthLength(m)}{3.6}.\left[\sum_{dir}\phi_{glazing,sol,mn,k}(m,dir) + \phi_{glazing,sol,mn,k,hor}(m)\right]\ [\mathrm{kWh}]$$

Walls

The solar radiation for walls is estimated by:

$$F_{walls,sh,ok,k}A_k I_{sol,k}(m,dir) = \alpha_{s,c}.R_{se}.U_{walls}.A_{lat}(dir).F_{walls,sh}(dir).I_{sol,k}(m,dir).k_{cor}$$

$$F_{walls,sh,ok,k}A_k I_{sol,k,hor}(m) = \alpha_{s,c}.R_{se}.U_{roof}.A_{roof}.I_{sol,k,roof}(m)$$

And, the radiation to the sky by:

$$\phi_{r,walls}(dir) = U_{walls}.R_{se}.A_{lat}(dir).h_r.\Delta\theta_{\mathrm{er}}.\mathrm{F_{r,v}}$$

$$\phi_{r,walls,hor} = U_{roof}.R_{se}.A_{roof}.h_r.\Delta\theta_{\mathrm{er}}.\mathrm{F_{r,h}}$$

As for glazing, the heat flow by solar gains through walls (wall shading reduction factor not included in the calculation) is:

$$\phi_{walls,sol,mn,k}(m,dir) = F_{walls,sh,ok,k}A_k I_{sol,k}(m,dir) - \phi_{r,walls}(dir)$$

$$\phi_{walls,sol,mn,k,hor}(m) = F_{walls,sh,ok,k}A_k I_{sol,k,hor}(m) - \phi_{r,walls,hor}$$

Finally, the overall solar heat gain through walls is computed:

$$Q_{sol,walls}(m) = \frac{MonthLength(m)}{3.6}.\left[\sum_{dir}\phi_{walls,sol,mn,k}(m,dir) + \phi_{walls,sol,mn,k,hor}(m)\right]\ [\mathrm{kWh}]$$

- **Total heat transfer and heat gains**

The total heat transfer Q_{ht} and the heat gains Q_{gn} are calculated according to:

$$Q_{ht}(m) = Q_{tr}(m) + Q_{ve}(m)$$

$$Q_{gn}(m) = Q_{sol,glazing}(m) + Q_{sol,walls}(m) + Q_{int}(m)$$

- **Energy need for heating**

The last part is devoted to the calculation of the energy need for heating. It relies on two sub steps: the estimation of dynamic parameters and the heating month length.

Dynamic parameters

A first gain utilization factor is introduced:

$$\gamma_H(m) = \frac{Q_{gn}(m)}{Q_{ht}(m)}$$

The time constant of the building is defined by:

$$\tau = \frac{C_m}{3600} \frac{1}{H_{tr,adj}(1) + H_{ve,adj}}$$

$$a = a_0 + \frac{\tau}{\tau_0}$$

A second gain utilization factor is also used:

$$\eta_{gn}(m) = \begin{cases} \dfrac{a}{a+1} & if\ \gamma_H(m) = 1 \\ \dfrac{1}{\gamma_H(m)} & if\ \gamma_H(m) < 0 \\ \dfrac{1-\gamma_H(m)^a}{1-\gamma_H(m)^{1+a}} & else \end{cases}$$

Heating month length

$$\gamma_{lim} = \frac{1+a}{a}$$

$$\gamma_H(m+0.5) = \frac{\gamma_H(m) + \gamma_H(m+1)}{2}$$

$$\gamma_H(m-0.5) = \frac{\gamma_H(m-1) + \gamma_H(m)}{2}$$

$$\gamma_1(m) = \min\big(\gamma_H(m-0.5); \gamma_H(m+0.5)\big)$$

$$\gamma_2(m) = \max\big(\gamma_H(m-0.5); \gamma_H(m+0.5)\big)$$

$$\gamma_{1bool}(m) = \begin{cases} 0 & if\ \gamma_1(m) > \gamma_{lim}\ or\ \gamma_1(m) < 0 \\ \text{“LESS”} & else \end{cases}$$

$$\gamma_{2bool}(m) = \begin{cases} \text{”MORE”} & if\ \gamma_2(m) > \gamma_{lim} \\ 0 & if\ \gamma_2(m) < 0 \\ 1 & else \end{cases}$$

Two intermediate quantities are defined:

$$val(m) = \frac{1}{2} \frac{\gamma_{lim} - \gamma_1(m)}{\gamma_H(m) - \gamma_1(m)}$$

$$interm(m) = \frac{1}{2} + \frac{1}{2} \frac{\gamma_{lim} - \gamma_H(m)}{\gamma_2(m) - \gamma_H(m)}$$

And also one condition that depends on the value of heating month quantities:

$$cond(m) = \begin{cases} 0 & if\ \gamma_{1bool}(m) \neq "LESS" \\ 1 & if\ \gamma_{2bool}(m) \neq "MORE" \\ val(m) & if\ \gamma_H(m) > \gamma_{lim} \\ interm(m)\ else & \end{cases}$$

So that the final variable $\gamma_{cor}(m)$ can be estimated:

$$\gamma_{cor}(m) = \begin{cases} cond(m) & if\ \gamma_1(m) > 0\ or\ \gamma_2(m) > 0 \\ 0 & else \end{cases}$$

<u>Energy need for heating</u>

$$f_{hr} = \frac{h_{end,heating} - h_{beg,heating}}{24} . \frac{NbDay_{working,heating}}{7}$$

$$a_{red}(m) = \begin{cases} f_{hr} & if\ 1 - \frac{b_{red}.\tau_0.\gamma_H(m).(1-f_{hr})}{\tau} < f_{hr} \\ 1 & if\ 1 - \frac{b_{red}.\tau_0.\gamma_H(m).(1-f_{hr})}{\tau} > 1 \\ 1 - \frac{b_{red}.\tau_0.\gamma_H(m).(1-f_{hr})}{\tau} & else \end{cases}$$

The monthly energy need (sensible energy) follows:

$$Q_{H,month}(m) = a_{red}(m).max\left(0; Q_{ht}(m) - max\left(0; \eta_{gn}(m)\right).Q_{gn}(m)\right).\gamma_{cor}(m)\ [\text{kWh}]$$

The yearly energy need (sensible energy) is then:

$$Q_{nd} = \sum_m Q_{month}(m)\ \ [\text{kWh/year}]$$

So, the yearly delivered (final or secondary) energy is defined by:

$$Q_{delivered} = \begin{cases} 0 & if\ the\ user\ has\ selected\ no\ heating\ system \\ & \frac{Q_{nd}}{\eta_{EfficiencySystem}}\left[\frac{\text{kWh}}{\text{year}}\right] else \end{cases}$$

And the associated yearly primary energy need for heating is:

$$Q_{prim} = Q_{delivered}.k_{energytype}\ [\text{kgoe/year}]$$

4.3.2.2.3 Energy need for space cooling and solar heat gains

As stated in 4.3.2.2.24.3.2.2.2, most of formulas used for the heating remain valid for the cooling mode. formulas that are changed are described here.

- **Preassignment**

The first step is the assignment of variables related to the cooling mode:

$$H_g = H_{g,C}$$

$$H_{pi} = H_{pi,C}$$

$$H_{pe} = H_{pe,C}$$

$$\overline{\theta_i} = \theta_{int,set,C}$$

$$k_{D,cor} = k_{D,cor,C}$$

$$k_{cor,ve} = k_{cor,ve,C}$$

$$k_{cor,int} = k_{cor,int,C}$$

$$k_{cor} = k_{cor,C}$$

$$f_{shut}(m) = 0$$

$$AFR_{floor} = n_C$$

$$a_0 = a_{C0}$$

$$\tau_0 = \tau_{C0}$$

$$b_{red} = b_{C,red}$$

$$\eta_{EfficiencySystem} = \eta_{CoolingEfficiencySystem}$$

$$k_{energytype} = k_{energytype,cooling}$$

- **Heat transfer to the ground**

In that part, equations are unchanged.

- **Heat transfer by transmission**

The glazing heat transfer by transmission to the external environment becomes:

$$H_{D,glazing}(m) = U_{mean,opening}.A_{lat,opening}.k_{D,cor}$$

- **Heat transfer by ventilation**

The following formulas are simplified for the cooling mode:

$$f_{ve,t,k} = 1$$

$$b_{ve,k} = 1$$

- **Internal gains**

Equations remain the same as for the heating mode.

- **Solar heat gains**

For glazing, the formulas for solar radiation evolve:

$$F_{C,sh,gl}(m,dir) = 1 - f_{sh,with}(m,dir) + f_{sh,with}(m,dir).\frac{f_f}{g_n.F_w}$$

$$A_{sol,c}(m,dir) = \begin{cases} F_{C,sh,gl}(m,dir).g_n.F_w.(1 - FrameAreaFraction) & if\ DayCoolingActivation = YES \\ g_n.F_w.(1 - FrameAreaFraction) & else \end{cases}$$

$$F_{glazing,sh,ok,k}A_kI_{sol,k}(m,dir) = A_{lat,opening}(dir).F_{glazing,sh}(dir).I_{sol,k}(m,dir).A_{sol,c}(m,dir).k_{cor}$$

- **Total heat transfer and heat gains**

The formulas are identical.

- **Dynamic parameters**

The second gain utilization factor is now:

$$\eta_{gn}(m) = \begin{cases} \frac{a}{a+1} & if\ \gamma_H(m) = 1 \\ 1 & if\ \gamma_H(m) < 0 \\ \frac{1 - \gamma_H(m)^{-a}}{1 - \gamma_H(m)^{-(1+a)}} & else \end{cases}$$

- **Cooling month length**

The heating month length step is now called cooling month length step. Even if the approach is globally the same, the new associated formulas are:

$$inv\gamma_{lim} = \frac{1+a}{a}$$

$$inv\gamma_H(m) = \frac{1}{\gamma_H(m)}$$

$$inv\gamma_H(m+0.5) = \frac{inv\gamma_H(m) + inv\gamma_H(m+1)}{2}$$

$$inv\gamma_H(m-0.5) = \frac{inv\gamma_H(m-1) + inv\gamma_H(m)}{2}$$

$$inv\gamma_1(m) = \min\big(inv\gamma_H(m-0.5); inv\gamma_H(m+0.5)\big)$$

$$inv\gamma_2(m) = \max\big(inv\gamma_H(m-0.5); inv\gamma_H(m+0.5)\big)$$

$$inv\gamma_{1bool}(m) = \begin{cases} 0 & if\ inv\gamma_1(m) > inv\gamma_{lim} \\ \text{“LESS”} & else \end{cases}$$

$$inv\gamma_{2bool}(m) = \begin{cases} \text{”MORE”} & if\ inv\gamma_2(m) > inv\gamma_{lim} \\ 1 & else \end{cases}$$

$$invval(m) = \frac{1}{2}\frac{inv\gamma_{lim} - inv\gamma_1(m)}{inv\gamma_H(m) - inv\gamma_1(m)}$$

$$invinterm(m) = \frac{1}{2} + \frac{1}{2}\frac{inv\gamma_{lim} - inv\gamma_H(m)}{inv\gamma_2(m) - inv\gamma_H(m)}$$

$$invcond(m) = \begin{cases} 0 & if\ inv\gamma_{1bool}(m) \neq LESS \\ 1 & if\ inv\gamma_{2bool}(m) \neq \text{MORE} \\ invval(m) & if\ inv\gamma_H(m) > inv\gamma_{lim} \\ invinterm(m) & else \end{cases}$$

$$\gamma_{cor}(m) = \begin{cases} invcond(m) & if\ inv\gamma_1(m) > 0\ or\ inv\gamma_2(m) > 0 \\ 1 & else \end{cases}$$

- **Energy need for cooling**

As for the cooling month length step, the energy need for cooling step is derived from the energy need for heating step.

Only two formulas are changed:

$$f_{hr} = \frac{NbDay_{working,cooling}}{7}$$

End the monthly energy need (sensible energy) for cooling:

$$Q_{C,month}(m) = a_{red}(m).max\left(0; Q_{gn}(m) - max(0;\eta_{gn}).Q_{ht}(m)\right).\gamma_{cor}(m)$$

The yearly primary energy need for cooling is:

$$Q_{delivered} = \begin{cases} 0 & if\ the\ user\ has\ selected\ no\ cooling\ system \\ & \frac{Q_{nd}}{\eta_{EfficiencySystem}}\left[\frac{\text{kWh}}{\text{year}}\right] else \end{cases}$$

4.3.2.2.4 Energy need for DHW production

The first step is to compute a few intermediate quantities:

$$a = \begin{cases} \frac{X.ln(A_{conditionedarea}) - Y}{A_{conditionedarea}} & if\ A_{conditionedarea} > 30 \\ Z & else \end{cases}$$

$$V_w = a.A_{conditionedarea}$$

$$\Delta T_{\text{req}} = \theta_{w,t} - \theta_{w,outside}$$

$$Q_w(m) = \frac{4.182}{3.6}\frac{V_w}{1000}\Delta T_{\text{req}}.MonthDay(m)\ [\text{kWh}]$$

The yearly energy need for DHW (sensible energy) is:

$$Q_{DHW,nd} = \sum_m Q_w(m)\ [\text{kWh/year}]$$

The yearly delivered (final or secondary) energy for DHW is:

$$Q_{DHW,delivered} = \begin{cases} 0 & \textit{if the user has selected no DHW system} \\ Q_{DHW,nd} \cdot \dfrac{1 - DHW_{energyreduction}}{\eta_{DHW}} \text{ [kWh/year]} & \textit{else} \end{cases}$$

Thus, the yearly primary energy need for DHW is:

$$Q_{DHW,prim} = Q_{DHW,delivered} \cdot k_{energytype,DHW} \text{ [kgoe/year]}$$

4.3.2.3 Module **C**

The equations for the assessment of the environmental impacts for the module C are:

Module C			
End of life	C1 Deconstruction	Steel sheets	$m_{tss}\ k_{StBldgDem}$
		Steel beams	$m_{tsb}\ k_{StBldgDem}$
		Steel columns	$m_{tsc}\ k_{StBldgDem}$
		Steel studs and bolts	$(m_{tst}+ m_{tbo})\ k_{StBldgDem}$
		Plate connections	$m_{tpl}\ k_{StBldgDem}$
	C2 Transport	Steel sheets	$m_{tss}\ k_{RERALT}/ 10$
		Steel beams	$m_{tsb}\ k_{RERALT}/ 10$
		Steel columns	$m_{tsc}\ k_{RERALT}/ 10$
		Steel studs and bolts	$(m_{tst} + m_{tbo})\ k_{RERALT}/ 10$
		Plate connections	$m_{tpl}\ k_{RERALT}/ 10$
		Wood beams	$m_{twb}\ k_{RERALT}/ 10$
		Wood columns	$m_{twc}\ k_{RERALT}/ 10$
		Macro-component	
	C3 Waste processing	Concrete of floors to sorting plant	$m_{consl}\ eol_{srs}\ k_{Corr}$
		Concrete of structure to sorting plant	$(m_{tcb} + m_{tcc})\ eol_{srs}\ k_{Corr}$
		Rebars to sorting plant	$(m_{conrs} + m_{trs})\ eol_{srs}\ k_{CHStPlt}$
	C4 Disposal	Steel sheets	$m_{tss}(1 - eol_{sd})\ k_{RERStLdf}$
		Steel beams	$m_{tsb}(1 - eol_{sbc})\ k_{RERStLdf}$
		Steel columns	$m_{tsc}(1 - eol_{sbc})\ k_{RERStLdf}$
		Steel studs and bolts	$(m_{tst} + m_{tbo})\ (1 - eol_{stbo})\ k_{RERStLdf}$
		Plate connections	$m_{tpl}(1 - eol_{spl})\ k_{RERStLdf}$
		Concrete of floors landfilled	$m_{consl}\ [\ (1 - eol_{srs})\ k_{CHCon}+ (eol_{srs}- val_{confl})\ k_{CHConLdf}]$
		Concrete of structure landfilled	$(m_{tcb}+ m_{tcc})\ [\ (1 - eol_{srs})\ k_{CHCon}+ (eol_{srs}- val_{const})\ k_{CHConLdf}\ ]$
		Rebars landfilled	$(m_{conrs}+ m_{trs})\ (1 - eol_{srs})\ k_{CHSt}$
		Wood beams	$m_{twb}(inc_w\ k_{EUWWa} + (1 - inc_w)\ k_{EUWLdf})$
		Wood columns	$m_{twc}(inc_w\ k_{EUWWa}+ (1 - inc_w)\ k_{EUWLdf})$
		Macro-component	
Total Module C			Sum of all quantities in module C

Table 8 : environmental impacts for module C

The equations modified or added in the frame of LVS3 project are highlighted.

Considering the parameters added for the ground floor, following equations are modified:

An additional part is taken into account for the transport:

$$Macro-component_{C2} = \sum_{dir} A_{lat}(dir).k_{C2,wall} + \sum_{dir} A_{lat,opening}(dir).k_{C2,opening} + A_{roof}.k_{C2,roof}$$

Total concrete weight $m_{consl,LVS3}$:

$m_{consl,LVS3} = m_{consl} + D_{concretebasefloor}\, A_{ground} \cdot \rho_{consl}$

Rebars to sorting plant

$(m_{conrs} + m_{trs} + M_{steelbasefloor})\, eol_{srs}\, k_{CHStPlt}$

Rebars landfilled:

$(m_{conrs} + m_{trs} + M_{steelbasefloor})\, (1 - eol_{srs})\, k_{CHSt}$

An additional part is taken into account for the transport:

$$Macro-component_{C4} = \sum_{dir} A_{lat}(dir).k_{C4,wall} + \sum_{dir} A_{lat,opening}(dir).k_{C4,opening} + A_{roof}.k_{C4,roof}$$

The values of $k_{C2,wall}$, $k_{C4,wall}$, $k_{C2,opening}$ and $k_{C4,opening}$ are indicated in Annex 4~~Annex 4~~.

4.3.2.4 Module **D**

The equations for the assessment of the environmental impacts for the module D are:

Module D			
Benefits and loads beyond the system boundaries	D Benefits	Concrete of floors	$- m_{consl}\, val_{confl}\, k_{CHGr}$
		Steel sheets	$- m_{tss}(eol_{sd} - k_{RERStHDG0})\, k_{GLO}$
		Concrete of structure	$- (m_{tcb} + m_{tcc})\, val_{const}\, k_{CHGr}$
		Steel reinforcement	$- (m_{conrs} + m_{trs})\, (eol_{srs} - k_{GLOSt0})$
		Steel beams	$- m_{tsb}[\, (eol_{sbc} - k_{RERStSec0})\, k_{GLO} + re_{sbc}\, (k_{RERStSec} - k_{StAvg}/\, 1000)\,]$
		Steel columns	$- m_{tsc}[\, (eol_{sbc} - k_{RERStHDG0})\, k_{GLO} + re_{sbc}\, (k_{RERStSec} - k_{StAvg}/\, 1000)\,]$
		Steel studs and bolts	$- (m_{tst} + m_{tbo})\, (eol_{stbo} - k_{GLOSt0})\, k_{GLO}$
		Plate connections	$- m_{tpl}(eol_{spl} - k_{RERStPl0})\, k_{GLO}$
		Wood beams	$- m_{twb}(inc_w\, k_{Wa} + (1 - inc_w)\, k_{EOR}\, k_{EUElec}/\, 3.6)$
		Wood columns	$- m_{twc}(inc_w\, k_{Wa} + (1 - inc_w)\, k_{EOR}\, k_{EUElec}/\, 3.6)$
		Macro-component	
Total Module D			Sum of all quantities in module D

Table 9 : environmental impacts for module D

The equations modified or added in the frame of LVS3 project are highlighted.

Considering the parameters added for the ground floor, following equations are modified:

Total concrete weight $m_{consl,LVS3}$:

$m_{consl,LVS3} = m_{consl} + D_{concretebasefloor}\ A_{ground}\ .\ \rho_{consl}$

Impact of the steel reinforcement:

$-\ (m_{conrs} + m_{trs} + M_{steelbasefloor})\ (eol_{srs} - k_{GLOSt0})$

An additional part is taken into account for the transport:

$$Macro - component_D = \sum_{dir} A_{lat}(dir)\,.\,k_{D,wall} + \sum_{dir} A_{lat,opening}(dir)\,.\,k_{D,opening} + A_{roof}.\,k_{D,roof}$$

The values of $k_{D,wall}$, $k_{D,wall}$, $k_{D,opening}$ and $k_{D,opening}$ are indicated in **Annex 4**~~**Annex 4**~~.

5 Software output

The results of Ameco will be displayed as follows in the Results tab, depending on the option chosen by the user:

- as a calculation sheet,
- as an histogram or a table for the impact selected. The histogram will distinguish the modules A, C, D and also the total A to C and A to D.
- as a radial graph summarizing the total A to C and A to D for all impacts.

The detailed results for the use phase will be displayed in dedicated tables in the calculation sheet following the description made in 5.15.1. The results for the impacts will be displayed both in the sheet and in the graphical interface.

5.1 Detailed output data of the use phase

Results tables for the use phase will be displayed in the calculation sheet, one for the energy need for space heating, one for the energy need for space cooling, one for the energy need for DHW production, one summarizing the energy totals and finally one dedicated to the solar heat gains. The graphical disposition will be based on the excel file provided by University of Coimbra as presented in the followings paragraphs.

5.1.1 Energy need for space heating

For the heat transfer by transmission, the sum of positive elements over month is displayed. It includes:

$$Q_{tr,walls} = \sum_m max\left(Q_{tr,walls}(m), 0\right)$$

$$Q_{tr,glazing} = \sum_m max\left(Q_{tr,glazing}(m), 0\right)$$

$$Q_{tr,extfloor} = \sum_m max\left(Q_{tr,ext,floor}(m), 0\right)$$

$$Q_{tr,roof} = \sum_m max\left(Q_{tr,roof}(m), 0\right) + max\left(Q_{tr,pitchedroof}(m), 0\right)$$

$$Q_{tr,ground} = \sum_m max\left(Q_{tr,ground}(m), 0\right)$$

$$Q_{tr,total} = \sum_m max(Q_{tr}(m), 0)$$

For the heat transfer by ventilation and the heat gains, sums are calculated in the following way:

$$Q_{ve} = \sum_m max(Q_{ve}(m), 0)$$

$$Q_{sol,glaz} = \sum_m max\left(Q_{sol,glazing}(m), 0\right)$$

$$Q_{sol,opaq} = \sum_m Q_{sol,walls}(m)$$

$$Q_{int} = \sum_m Q_{int}(m)$$

Moreover, heat transfer breakdown (heat transfer by transmission and heat transfer by ventilation) are displayed in a bar chart.

In addition to these quantities, the monthly energy need for space heating and the associated global quantities are shown. Values per square meter of unconditioned area are also calculated.

ENERGY FOR SPACE HEATING		Heating season length:	4.5

HEAT TRANSFER BY TRANSMISSION							HEAT TRANSFER BY VENTILATION			HEAT GAINS		
										GLAZED	OPAQUE	INTERNAL
$Q_{tr,WALLS}$	$Q_{tr,GLAZING}$	$Q_{tr,EXT\,FLOOR}$	$Q_{tr,ROOF}$	$Q_{tr,GROUND}$	$Q_{tr,TOTAL}$		Q_{ve}			$Q_{sol,GLAZ}$	$Q_{sol,OPAQ}$	Q_{int}
2395.1	4373.4	321.2	0.0	782.0	9038.0	kWh/year	2849.2	kWh/year	kWh/year	17162.7	470.0	6679.3

ENERGY NEED FOR HEATING

$Q_{H,nd}$	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh	211.5	140.5	52.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.7	178.3
kWh/m²	1.7	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.4

ENERGY BREAKDOWNS

BUILDING TOTALS FOR HEATING		
ENERGY NEED	681.8	kWh/year
	5.5	kWh/m²/year

DELIVERED ENERGY		170.4	kWh/yea	PRIMARY		49.4	kgoe/yea
COP:	4	1.4	kWh/m²/	f_{conv}:	0.29	0.4	kgoe/m²/

Figure 2 : excel sheet providing results for the energy need for space heating

5.1.2 Energy need for space cooling

As the same quantities are computed in both the heating mode and the cooling mode, results are shown in the same manner (see Figure 3Figure 3).

ENERGY FOR SPACE COOLING		Cooling season length:	5.2

HEAT TRANSFER BY TRANSMISSION							HEAT TRANSFER BY VENTILATION			HEAT GAINS		
										GLAZED	OPAQUE	INTERNAL
$Q_{tr,WALLS}$	$Q_{tr,GLAZING}$	$Q_{tr,EXT\,FLOOR}$	$Q_{tr,ROOF}$	$Q_{tr,GROUND}$	$Q_{tr,TOTAL}$		Q_{ve}			Q_{sol}	Q_{sol}	Q_{int}
4278.0	9914.4	573.8	0.0	1458.3	18460.5	kWh/year	10517.4	kWh/year	kWh/year	8836.4	565.1	7547.6

ENERGY NEED FOR COOLING

$Q_{C,nd}$	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh	0.0	0.0	0.0	0.0	334.1	676.9	853.7	717.0	578.4	78.9	0.0	0.0
kWh/m²	0.0	0.0	0.0	0.0	2.7	5.5	6.9	5.8	4.7	0.6	0.0	0.0

BUILDING TOTALS FOR COOLING		
ENERGY NEED	3239.1	kWh/year
	26.2	kWh/m²/year

DELIVERED ENERGY		1079.7	kWh/yea	PRIMARY		313.1	kgoe/yea
COP:	3	8.7	kWh/m²/	f_{conv}:	0.29	2.5	kgoe/m²/

Figure 3 : excel sheet providing results for the energy need for space cooling

5.1.3 Energy need for DHW production

For the Domestic Hot Water production, only the monthly energy need and the yearly associated value are present as shown in Figure 4~~Figure 4~~.

ENERGY NEED FOR DWH PRODUCTION

$Q_{C,nd}$	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh	217.8	203.3	225.1	217.8	225.1	217.8	225.1	225.1	217.8	225.1	217.8	225.1
kWh/m²	1.8	1.6	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8

BUILDING TOTALS FOR DHW PRODUCTION

ENERGY NEED	2642.6	kWh/year
	21.3	kWh/m²/year
DELIVERED ENERGY	2936.3	kWh/yea
η: 0.90	23.7	kWh/m²/
PRIMARY ENERGY	851.5	kgoe/year
f_{conv}: 0.29	6.9	kgoe/m²/year

Figure 4 : excel sheet providing results for the energy need for DHW production

5.1.4 Energy totals

One part of the result tab is dedicated to total values, they are computed as follows:

$$Q_{H+C,nd}(m) = Q_{H,month}(m) + Q_{C,month}(m)$$

$$Q_{T,nd}(m) = Q_{H,month}(m) + Q_{C,month}(m) + Q_{DHW,month}(m)$$

The yearly total energy need is the addition of the yearly energy need for space heating, the yearly energy need for space cooling and the yearly energy need for DHW. The total delivered energy and primary energy are computed in the same way.

ENERGY TOTALS (DHW + HEATING + COOLING)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
$Q_{H+C,nd}$ (kWh)	211.5	140.5	52.7	0.0	334.1	676.9	853.7	717.0	578.4	78.9	98.7	178.3
$Q_{T,nd}$ (kWh)	429.3	343.8	277.7	217.8	559.2	894.7	1078.8	942.0	796.2	304.0	316.5	403.4
$Q_{DHW,nd}$ (kWh)	217.8	203.3	225.1	217.8	225.1	217.8	225.1	225.1	217.8	225.1	217.8	225.1

BUILDING TOTALS PER YEAR

TOTAL ENERGY NEED	6563.5	kWh/year
	53.0	kWh/m²/year
TOTAL DELIVERED ENERGY	4186.4	kWh/yea
	33.8	kWh/m²/
TOTAL PRIMARY ENERGY	1214.1	kgoe/year
	9.8	kgoe/m²/year

Figure 5 : excel sheet providing results summarizing the energy totals

5.1.5 Solar heat gains

The monthly heat gains for glazing and walls are recalled in two tables (see Figure 6Figure 6).

SOLAR HEAT GAINS

HEATING MODE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
$Q_{sol,GLAZED}$ (kWh)	1121.8	1069.1	1554.4	1673.5	1671.9	1712.5	1770.3	1803.8	1589.4	1393.5	918.3	884.1
$Q_{sol,\ OPAQUE}$ (kWh)	-10.1	0.9	39.1	64.5	73.7	89.7	94.7	86.5	51.9	21.1	-16.6	-25.3

COOLING MODE

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
$Q_{sol,GLAZED}$ (kWh)	435.2	559.9	736.4	846.6	1066.5	1037.3	991.2	803.3	738.7	614.1	524.0	483.0
$Q_{sol,\ OPAQUE}$ (kWh)	-4.4	6.5	47.4	73.8	83.3	99.9	105.2	96.9	60.6	28.5	-11.9	-20.8

Figure 6 : excel sheet providing results for solar heat gains

5.2 Global output data of the use phase

The aim of Ameco is to assess environmental impacts, thus the detailed information calculated in the use phase must be evaluated in terms of impacts. In order to do this, the following procedure is used for each of the 24 impacts:

$$ModuleB_{impact} = Q_{heating,delivered} \cdot k_{heating} + Q_{cooling,delivered} \cdot k_{cooling} + Q_{DHW,delivered} \cdot k_{DHW}$$

Where $k_{heating}, k_{cooling}, k_{DHW}$ depends on the energy type and the impact according to the

Abbreviation	Designation	Electricity	Gas	Liquid	Solid	Biomass	Unit
Environmental impacts							
GWP	Global Warming Potential	4.82E-01	4.84E-01	4.33E-01	2.92E-01	0	tCO2eq
ODP	Ozone Depletion Potential	4.32E-10	7.97E-11	3.11E-11	3.02E-11	0	t_{CFCeq}
AP	Acidification Potential	2.28E-03	1.61E-03	2.95E-03	1.34E-03	0	t_{SO2eq}
EP	Eutrophication Potential	1.20E-04	7.85E-05	1.46E-04	1.70E-04	0	t_{PO4eq}
POCP	Photochemical Ozone Creation Potential	1.34E-04	3.49E-04	4.41E-04	1.43E-04	0	$t_{Etheneeq}$
ADP-e	Abiotic Depletion Potential – elements	6.63E-08	1.18E-07	1.04E-07	5.01E-09	0	t_{Sbeq}
ADP-ff	Abiotic Depletion Potential – fossil fuels	8.48E+00	5.02E+01	5.07E+01	2.79E+01	0	GJ NCV

Resource use, secondary material and fuels							
RPE	Use of renewable primary energy excluding renewable primary energy resources used as raw materials	1.41E+00	2.41E-01	8.53E-02	5.72E-02	0	GJ NCV
RER	Use of renewable energy resources used as raw materials	0	0	0	0	0	GJ NCV
RPE-total	Total use of renewable primary energy (primary energy and primary energy resources used as raw materials)	1.41E+00	2.41E-01	8.53E-02	5.72E-02	0	GJ NCV
Non-RPE	Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials	4.90E+00	5.05E+00	8.06E+00	1.28E+00	0	GJ NCV
Non-RER	Use of non renewable energy resources used as raw materials	3.60E+00	4.52E+01	4.26E+01	2.66E+01	0	GJ NCV
Non-RPE-total	Total use of non renewable primary energy (primary energy and primary energy resources used as raw materials)	8.50E+00	5.03E+01	5.07E+01	2.79E+01	0	GJ NCV
SM	Use of secondary material	0	0	0	0	0	t
RSF	Use of renewable secondary fuels	1.73E-04	3.37E-04	2.97E-04	1.53E-05	0	GJ NCV
Non-RSF	Use of non renewable secondary fuels	1.82E-03	3.54E-03	3.13E-03	1.60E-04	0	GJ NCV
NFW	Use of net fresh water	1.84E+00	3.12E-01	1.36E-01	6.88E-02	0	$10^3 m^3$

Other environmental information describing waste categories							
HWD	Hazardous waste disposed	0	0	0	0	0	t
Non-HWD	Non hazardous waste disposed	1.92E+00	3.32E-01	1.10E-01	4.94E+00	0	t
RWD	Radioactive waste disposed	1.25E-03	2.07E-04	6.31E-05	2.47E-05	0	t

Other environmental information describing output flows							
CR	Components for reuse	0	0	0	0	0	t
MR	Materials for recycling	0	0	0	0	0	t
MER	Materials for energy recovery	0	0	0	0	0	t
EE	Exported energy	0	0	0	0	0	t

Tables10 : impact coefficient for the use phase

6 Guidance on the Use of AMECO3 software

AMECO3 allows the calculations of the environmental impacts of any type of buildings and bridges. For building applications, AMECO 3 allows also the calculation of the operational energy use, including the heating, cooling and hot water energy consumptions.

This guidance aims to adapt the help menu of previous versions of AMECO according the new improvements that are done in the scope of the LVS³ project, for the building project.

Various modules are available for input and treatment of the parameters. The modules are selected with the Study toolbar and are displayed in the working zone. For the complete study of a building, including the use phase, the modules are the following ones:

- Project
- Building
- Envelope
- Base floor
- Roof
- Occupancy
- Systems
- Floors
- Structure
- Transport
- Results

If the field corresponding to the option “Structure only” is selected as “Yes”, only the following modules are available:

- Project
- Building
- Floors
- Structure
- Transport

The user can choose the purpose of the calculation through the Building module.

6.1 Project

In this module, optional parameters are to be defined to identify the project. These parameters are used for the edition of the calculation sheet, but the fields can remain empty without affecting the calculations. The five following parameters can be entered:

- the name of the project
- the name of the building
- the company in charge of the study
- the name of the user
- a comment.

Those fields are optional and can then remain empty without affecting the calculations.

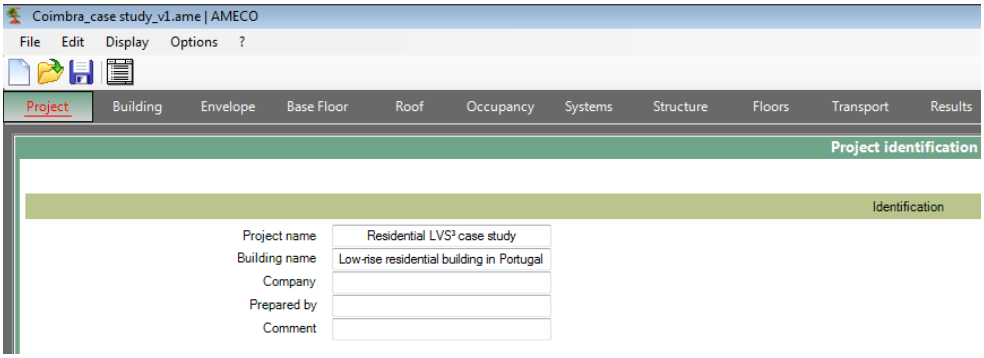


Figure 7 : Project definition

6.2 Building

6.2.1 General parameters

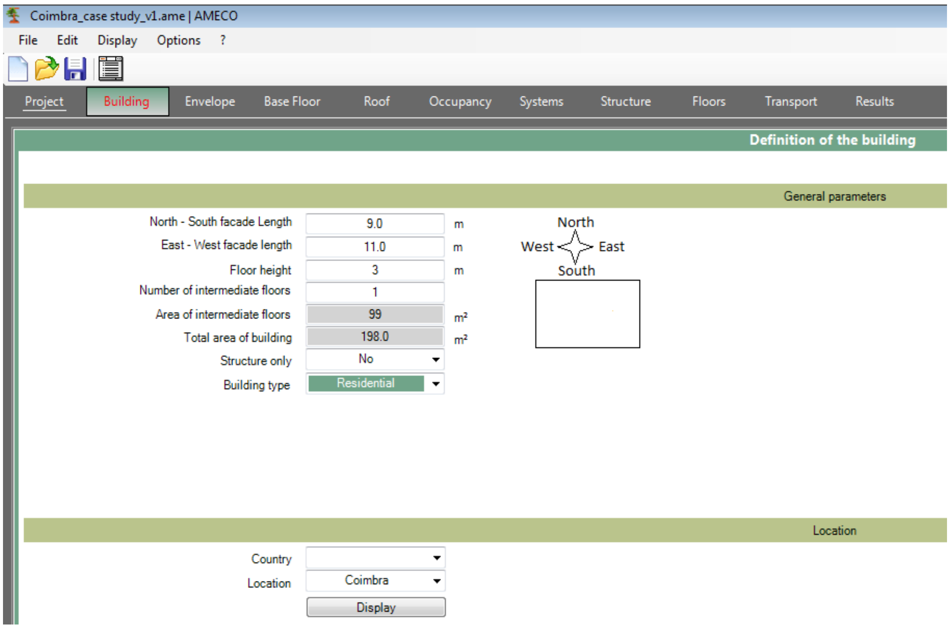


Figure 8 : building main features, calculation of the use phase included

In this module, the user defines the general parameters of the building:

- The North - South length ℓ_b;
- the East – West length w_b;

The definition of those dimensions allows orientating the building. Only rectangular building can be introduced in AMECO3.

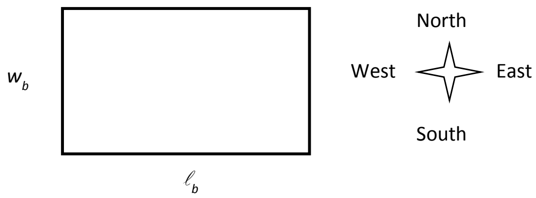


Figure 9 : building shape

- the floor height;
- the number of floors n;
- the total areas of the intermediate floors, calculated from the above parameters. The calculation is based on $a_{def,floors} = n\ \ell_b\ w_b$, assuming that each floor has the same area. That value excludes the ground floor area;
- the total area of the building, calculated by taking into account N+1 floors;
- The purpose of the calculation through the field “Structure only”.
  That option gives the possibility to the user, by choosing “Yes”, to skip the energy consumptions calculations. In that case, only the environmental impacts due to the materials used to erect the building structure, such as primary beams and columns as well as intermediate floors, and their corresponding transport impacts, will be taken into account in the calculation.

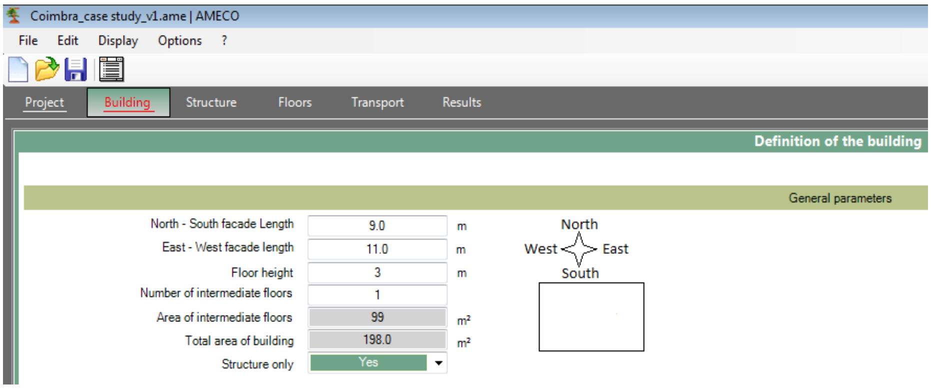


Figure 10 : building main features, calculation of the use phase excluded

If the user selects “No”, complementary modules are displayed, related to definition of the parameters required to calculate the operational energy of the building. The first field displayed, if the use phase is included in the calculations, is the building type;

- The building type can be selected from the pull-down menu, between the following choices:
    - Residential
    - Office
    - Commercial
    - Industrial;

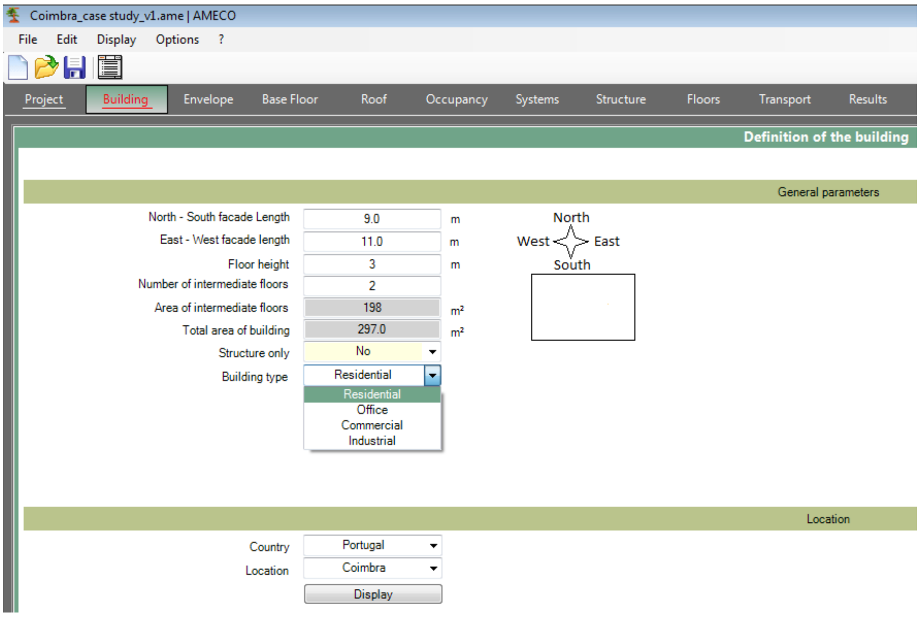


Figure 11 : Building type selection

The type of the building has an impact on the use phase calculation only. Indeed, building's users have an impact on the building consumptions. By example, lighting systems produces extra heat energy in offices, which can potentially increase of the cooling demand.

For each building type, a specific use scenario is defined, such as occupancy, light and allocation between zones having different function within a same building, expressed as a percentage of the total floor area. The details of the use scenario corresponding to each building type are shown in the next chapters of the Design guide.

6.2.2 Location

In the lower part of the module, the user defines the location of the building, by selecting:

In the lower part of the module, the user defines the location of the building, by selecting:

- the country ;
- a corresponding city ;

23 countries and 48 cities are available in AMECO3:

Country	City
Austria	Vienna, Graz
Belarus	Minsk
Belgium	Brussells
CzechRepublic	Prague
England	London
Finland	Helsinki, Tampere
France	Nantes, Paris, Montpellier, Marseille, Nice
Germany	Berlin, Munich, Hamburg
Greece	Thessaloniki, Athens
Italy	Milan, Rome, Sanremo, Genova
Netherlands	Amsterdam
Norway	Oslo
Poland	Warsaw
Portugal	Lisbon, Porto, Coimbra
Romania	Bucharest, Timisoara
Russia	Moscow, Arhanglesk
Slovakia	Bratislava
Slovenia	Ljubljana
Spain	Madrid, Barcelona, Sevilla, La Coruna, Salamanca, Vigo, Bilbao
Sweden	Stockholm, Kiruna, Ostersund
Switzerland	Zurich
Turkey	Istambul, Ankara
Ukraine	Kiev

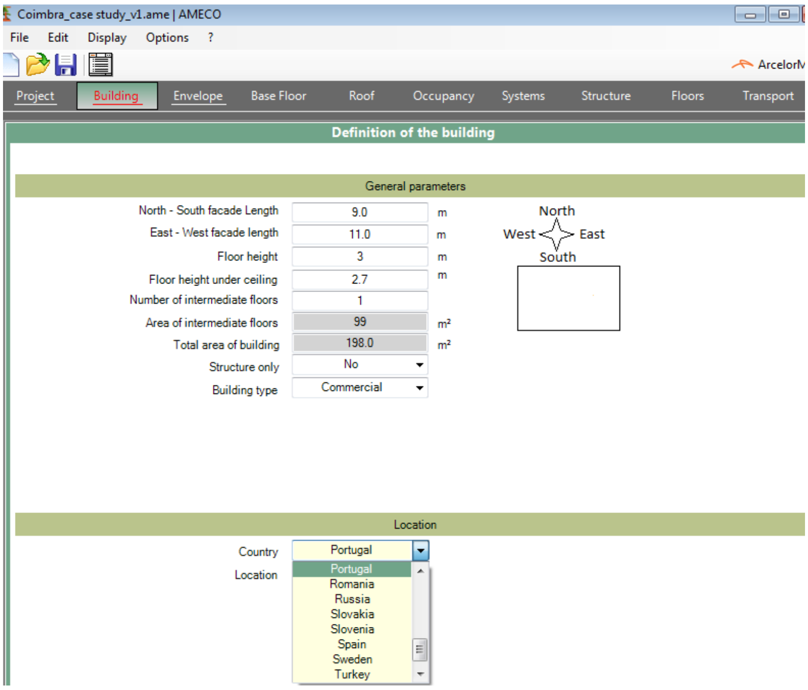


Figure 12 : Selection of the country

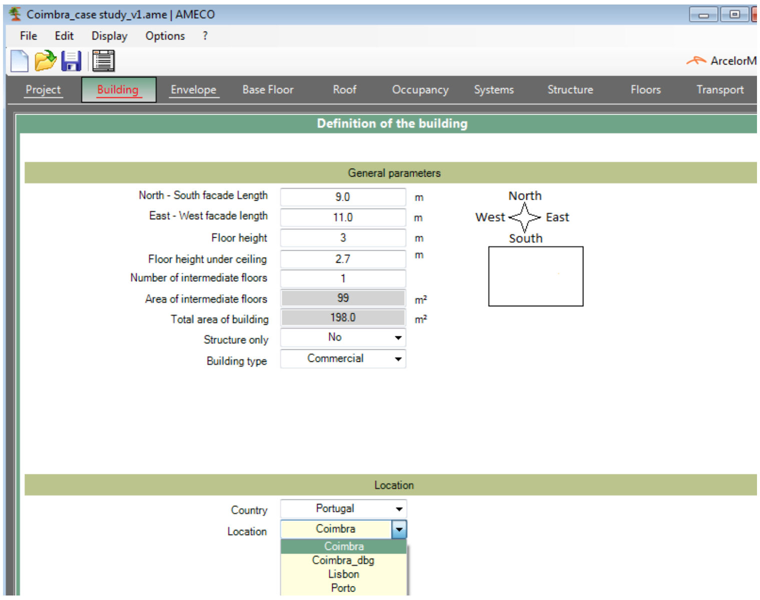


Figure 13 : Selection of the corresponding city

By clicking on the button “Display”, the user can see the climate data related to the selected location, as displayed on the next figure:

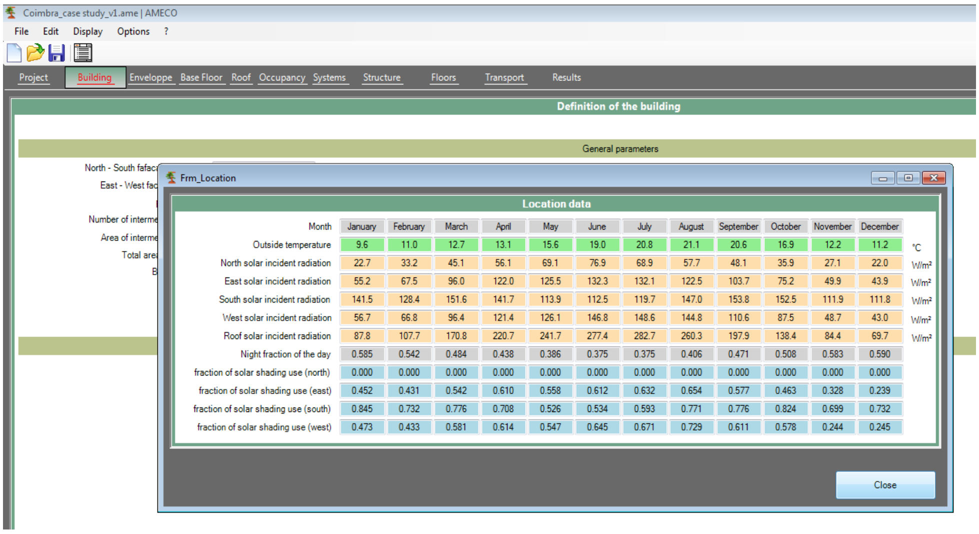


Figure 14 : Location data

6.2.3 Envelope

On the upper part of the envelope section, the user has access to the facade features:

- The areas of walls that are calculated automatically for each orientation. Those areas are obtained by multiplying the corresponding length by the building height by the number of floors + 1;
- The opening areas for each orientation, by defining a percentage of the total area of the facade.

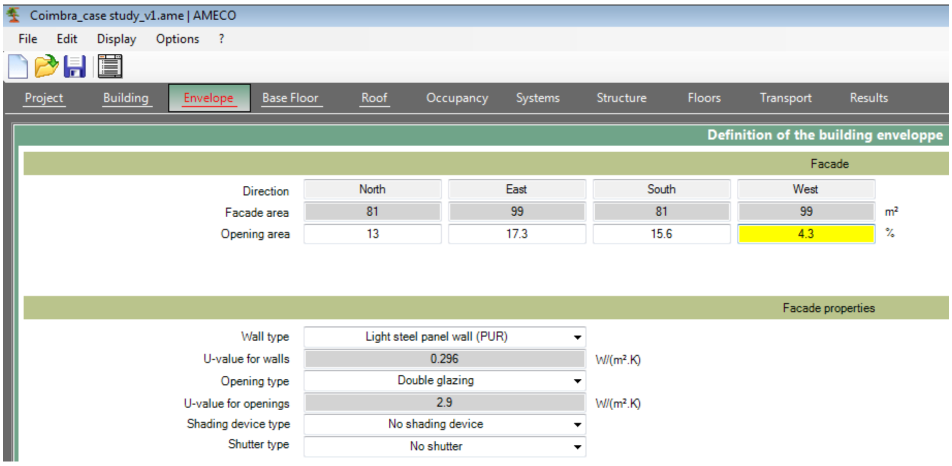


Figure 15 : envelope description

In the lower part of the envelope section, the facade properties are defined:

- The wall type, which is the composition of the façade.
  There are 3 main types of walls defined in AMECO 3:
    - Light steel panel wall;
    - Double clay brick wall;
    - Sandwich panel.

Light steel panel wall and double clay brick wall type are available with different type of insulation product material:
- Rockwool;
- EPS (expanded polystyrene);
- XPS (extruded polystyrene);
- PUR (polyurethane).

Sandwich panel are based on polyurethane, with different thicknesses: 80mm and 200 mm.

The wall types are illustrated in the following figures:

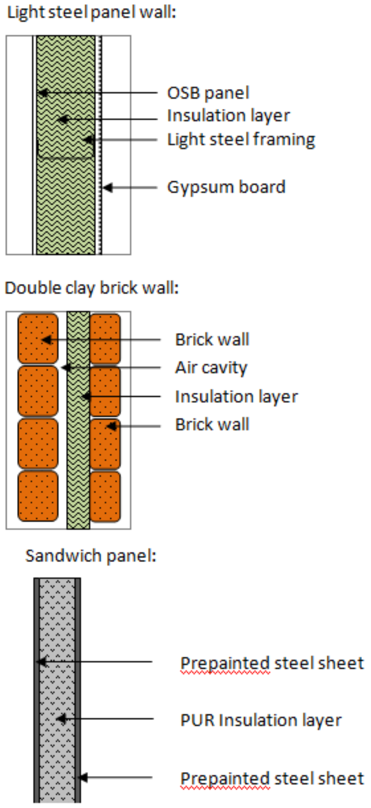


Figure 16 : wall components schemas and description, available in AMECO3

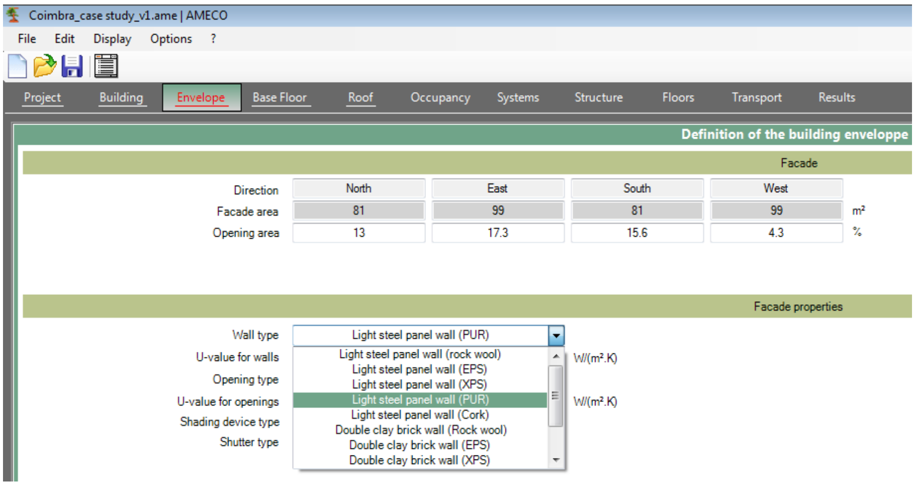


Figure 17 : Wall type selection

The corresponding environmental impacts for all wall configurations are described in the background document.

- The U-value, also known as the thermal transmittance, is displayed according the user selection. The U-values of the wall types have been calculated taking into account the integrated thermal bridges.

- The opening types, with different U-values, such as:
    - Double glazing
    - Double glazing low emissivity (type 1)
    - Double glazing low emissivity (type 2)
    - Double glazing low emissivity (type 3)

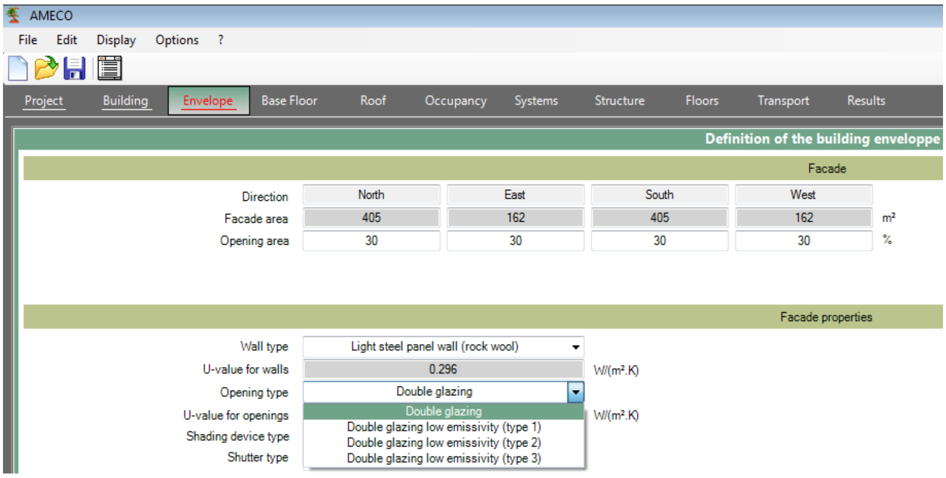


Figure 18 : Opening type selection

- The U-value of the selected window type;

- The shading device type, such as:

    - No shading device
    - Exterior opaque wood device (no insulation)
    - Exterior wood roller shutter (no insulation)
    - Exterior aluminium roller shutter (no insulation)
    - Exterior plastic roller shutter (no insulation)
    - Exterior wood venetian blinds
    - Exterior metal venetian blinds
    - Exterior opaque roller blinds

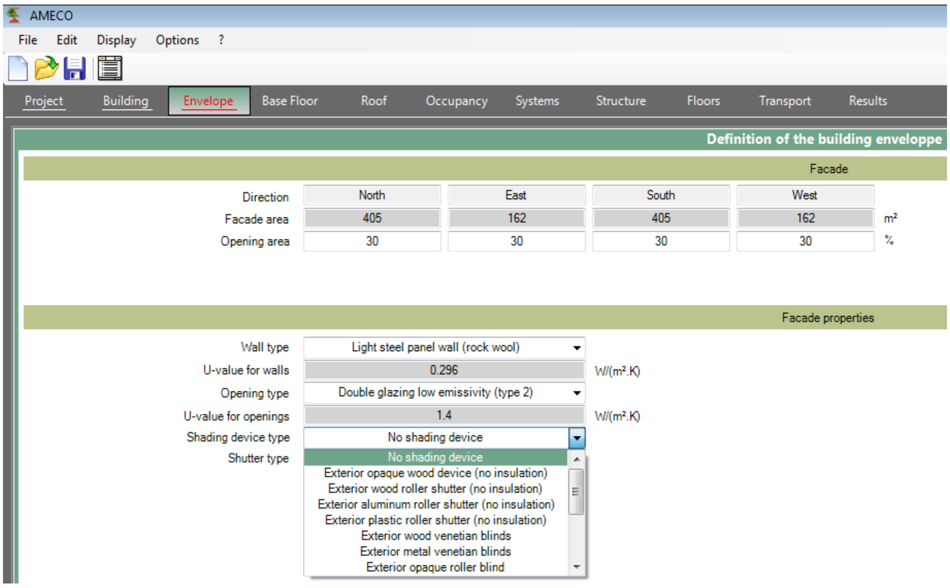


Figure 19 : Shading device type selection

- The shutter type, which can be selected among the following list:
    - No shading device
    - Exterior opaque wood device (no insulation)
    - Exterior wood roller shutter (no insulation)
    - Exterior aluminium roller shutter (no insulation)
    - Exterior plastic roller shutter (no insulation)
    - Exterior wood venetian blinds
    - Exterior metal venetian blinds
    - Exterior opaque roller blinds

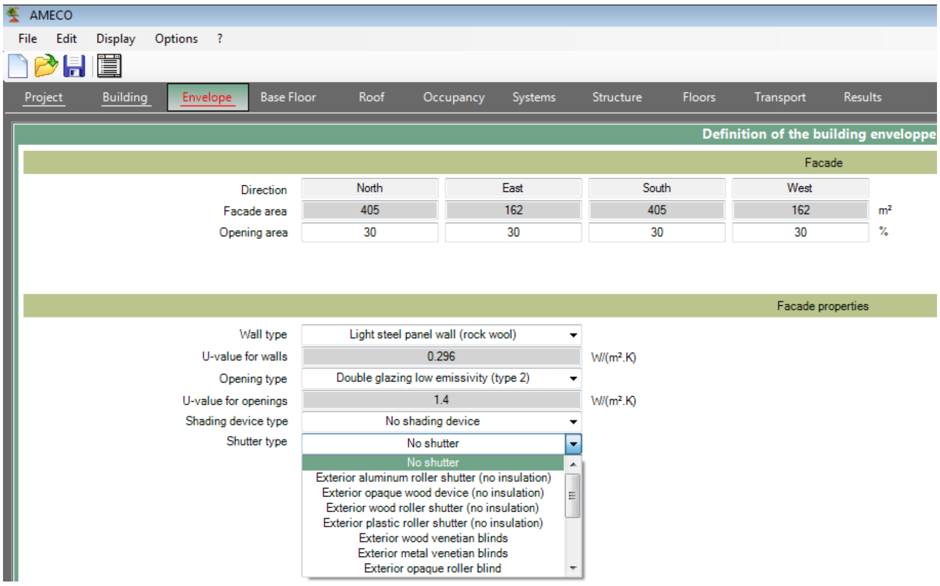


Figure 20 : shutter type selection

6.2.4 Base floor

This module aims defining the features of the base floor:

- the U-value of the base floor, depending on the quantity of insulation;
- the base floor type, selected among the following choices:
  - slab on ground
  - basement floor

The type of the base floor has an influence on the thermal behavior of the building and is characterized by parameters set as default values in order to simplify the interface. Those parameters set as default values are fully described in the background document.

- the thickness of the floor slab, in meter, and
- the total mass of rebars, in tons, used to reinforce the slab.

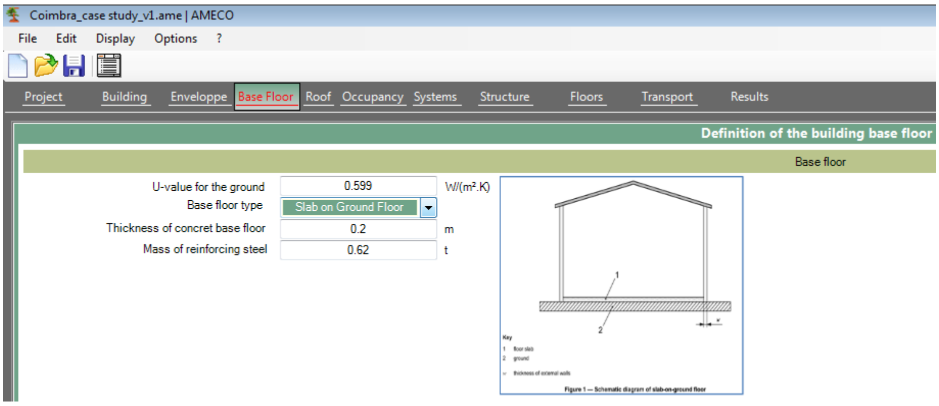


Figure 21 : base floor description

6.2.5 Roof

In this module, the roof component is defined:

- The roof type;
- The corresponding U-value is displayed.

There are two types of roof available:

- Waterproof membrane steel roof
- Roof type 2

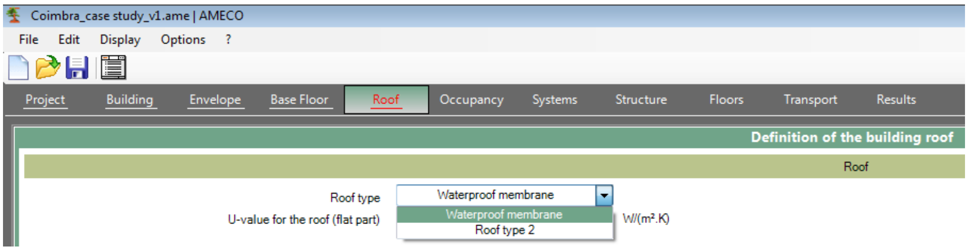


Figure 22 : roof component selection

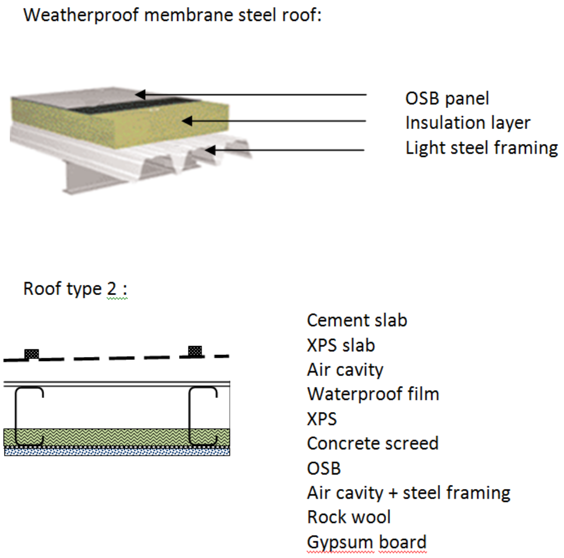


Figure 23 : roof type figure available in AMECO3

6.2.6 Occupancy

This module aims to define the indoor conditions used in the calculation:

- The heating set-point temperature, in degrees, which activate the heating system if the indoor temperature is below this temperature;
- The cooling set-point temperature, in degrees, which activate the cooling system if the indoor temperature is above this temperature;
- The air-flow rate, in number of air-change per hour, corresponding to the heating mode;
- The air-flow rate corresponding to the cooling mode;

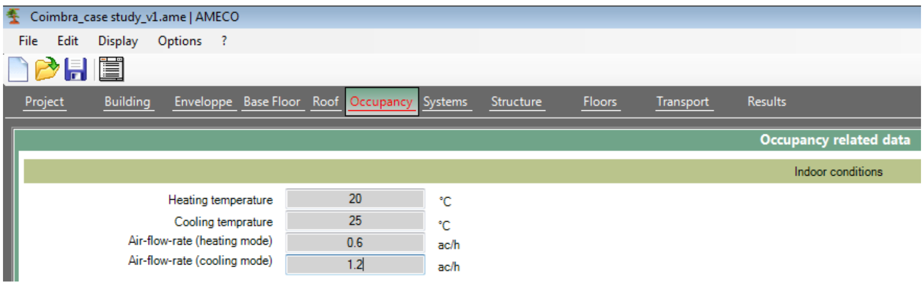


Figure 24 : parameters related to the occupancy scenario of the residential building

Those parameters are set as fixed values and depend directly on the building type selected by the user in the Building module.

6.2.7 Systems

This module is dedicated to define the active energy systems:

- The heating system type, which can be chosen among the following type:
    - Electrical resistance
    - Gas fuel heater
    - Liquid fuel heater
    - Solid fuel heater
    - Split heating
    - No heating

- The cooling system type, which can be:
    - Split cooling
    - Refrigeration machine (compression cycle)
    - Refrigeration machine (absorption cycle)
    - No cooling

- The heat recovery system. This parameter, expressed in percentage, has to be specified if the building is equipped with a double flux ventilation system. In case of natural ventilation, no heat recovery system is implemented in the building.

- The DHW (domestic hot water) system type, which can be chosen from the following list:
    - Electric boiler
    - Gas boiler
    - Stand-alone water heater (condensation)
    - Stand-alone water heater
    - No DHW

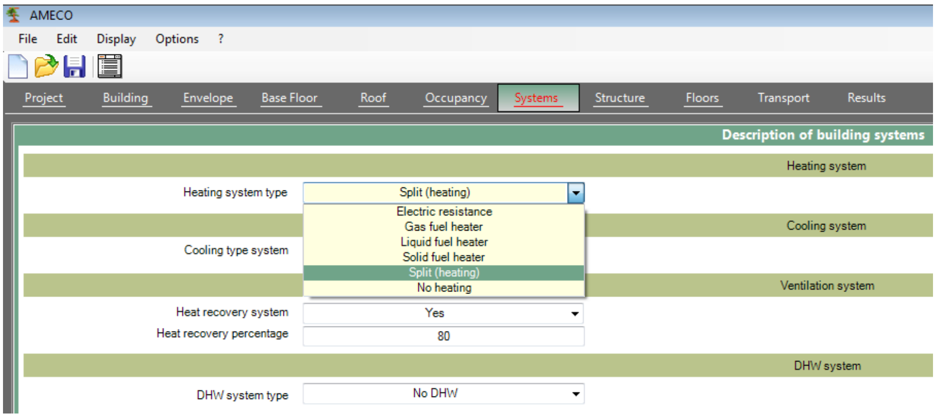


Figure 25 : selection of the heating system type

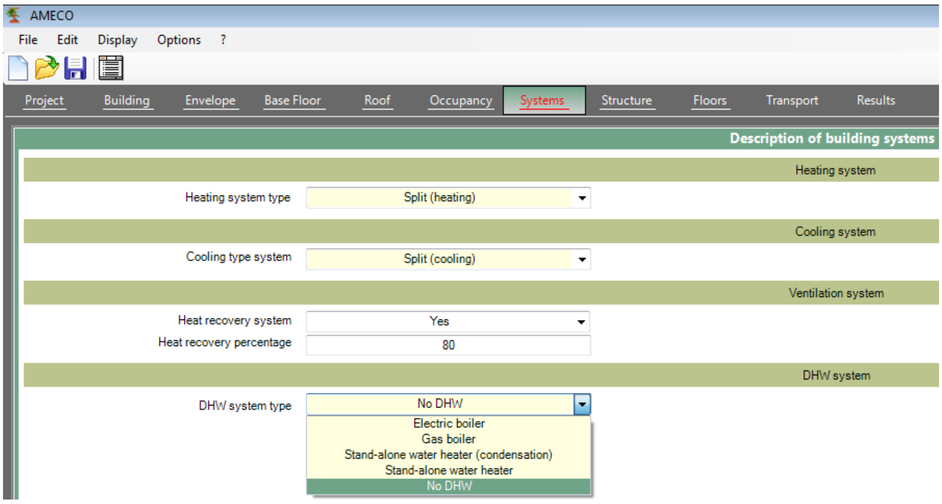


Figure 26 : selection of the Domestic Hot Water system type

6.2.8 Structure

In this module, the steel elements of the building structure have to be specified, expressed in tons.

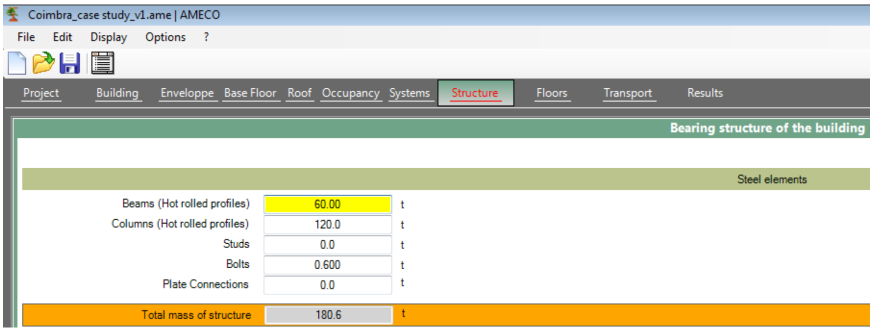


Figure 27 : Definition of the different steel structural element weights

Steel elements

- the total mass of steel beams;
- the total mass of steel columns;
- the total mass of studs;
- the total mass of bolts;
- the total mass of steel parts (plates, angles ...);

6.2.9 Floors

In this module, the parameters for the design of intermediate floors are required.

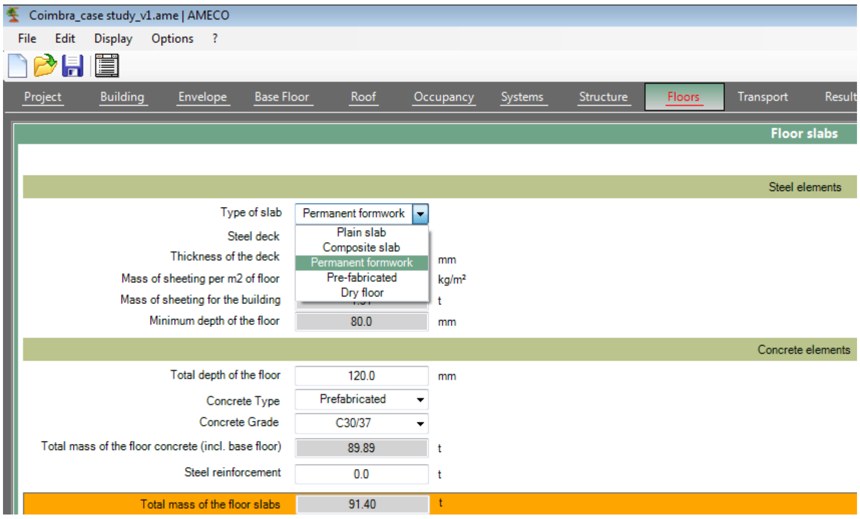


Figure 28 : Selection and definition of the elements of the intermediate floor slabs, if any.

Depending on the choice of floor technology, the user should specify the characteristics of the steel and/or concrete floor elements.

Steel elements
- the type of slab, to be chosen among the following list:
  - plain slab,
  - composite slabs,
  - permanent formwork,
  - prefabricated and
  - dry floors.

All these types except the first ones are based upon the use of specific steel sheetings.
- the steel sheeting used for the slab (if not plain slab), to be chosen among a list obtained according to the selected type of floors in the steel sheeting database.
- the thickness of the steel sheetings (if not plain slabs), to be chosen among a list obtained according to the selected sheet in the steel sheeting database.
- If not plain slabs, the density of the selected steel sheetings is displayed as the total mass of sheetings for the buildings.

Concrete elements
- the content of cement in the concrete used for the floors
- the default concrete density is automatically calculated from the content of cement
- the density of floors concrete is to be defined either as being equal as the default value or directly entered by the User.
- the total depth of the floors (including the steel sheetings if any)
- from this value, the concrete density and the area of floors, the total mass of concrete used for floors is calculated and displayed.
- the total mass of steel reinforcement used for floors is also to be entered.

If the building has no intermediate floor, the user should skip directly to the next module.

6.2.10 Transport

In this module, the parameters for the transport of the elements of the building are entered.

Transport of steel elements

The user has the possibility to select between average data for European transport or User data. In the first case, the default values, detailed in the background document, are taken into account in the calculation. In the latter case, the User data to be defined are the following ones:

- the mass of steel transported by electric train;
- the distance run by these electric trains (one way from the factory to the construction site);
- the mass of steel transported by regular trucks
- the distance run by these trucks (one way from the factory to the construction site);
- the sum of the masses of steel transported by trains and transported by regular trucks is equal to the total mass of steel in the building, including beams, columns, bolts, other steel parts, steel sheetings and reinforcements.

Concrete elements

For the transport of the concrete, two ways are possible: either the concrete is produced on site, meaning a transport of liquid concrete by mixer trucks, or the concrete is prefabricated in factories, meaning a transport of prefabricated elements by regular trucks. The following parameters are thus to be precised for the transport of concrete:

- the mass of concrete produced on site and then transported by mixer trucks;
- the distance run by these mixer trucks (one way from concrete factory to the construction site);
- the mass of prefabricated concrete, transported by regular trucks;
- the distance run by these regular trucks (one way from the factory to the construction site);
- Of course, the sum of the mass of concrete produced on site and of the prefabricated concrete is equal to the total mass of concrete in the building (floors and structure).

The average values that are used are described in the background document.

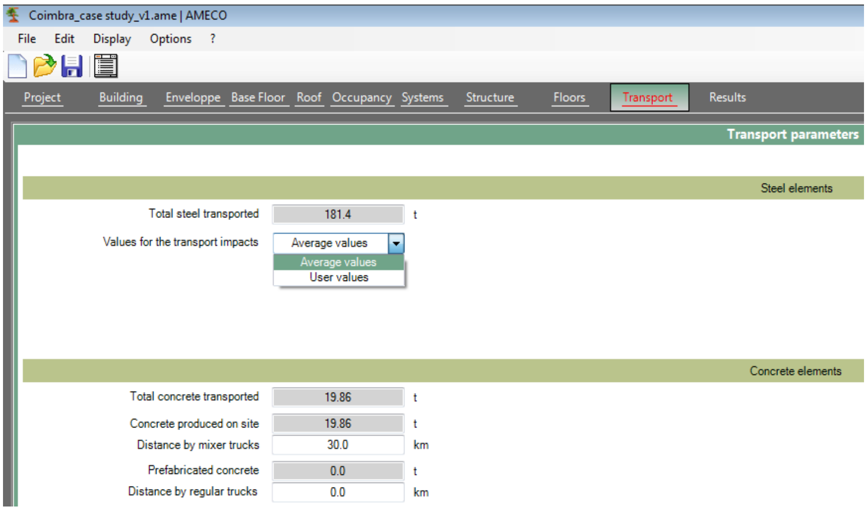


Figure 29 : definition of the parameters related to the transport of the materials, in default mode

If “user values” is selected, the following parameters have to be specified:

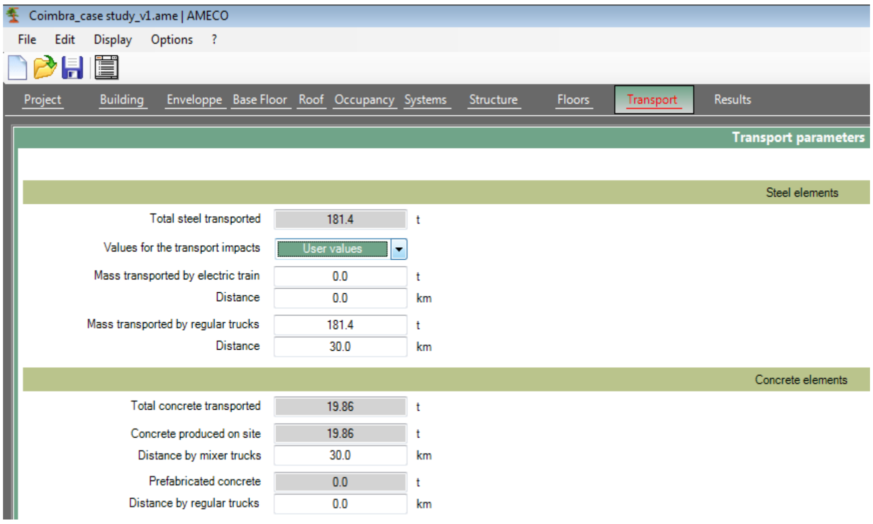


Figure 30 : definition of the parameters related to the transport of the materials, in user values mode

6.2.11 Results

The calculation is launched when the user click on the button “Results”.

The results of the calculations can be either written in the calculation sheet or directly displayed in the User Interface through the Results module. In this latter, described hereafter, Bar charts, Radar charts and tables are available.

6.2.11.1 Bar charts

One specific Bar chart can be drawn in the interface for each indicator:

- Indicators describing environmental impacts (EN15978)
    - Global warming potential, GWP (kg CO_2 equiv)
    - Depletion potential of the stratospheric ozone layer, ODP (kg CFC 11 equiv)
    - Acidification potential of land and water; AP (kg SO_2- equiv)
    - Eutrophication potential, EP (kg $(PO_4)_3$- equiv)
    - Formation potential of tropospheric ozone photochemical oxidants, POCP (kg Ethene equiv)
    - Abiotic Resource Depletion Potential for elements, ADP_elements (kg Sb equiv)
    - Abiotic Resource Depletion Potential of fossil fuels, ADP_fossil fuels (MJ)

- Indicators describing resource use (EN15978)
    - Use of renewable primary energy excluding energy resources used as raw material, (MJ, net calorific value)
    - Use of renewable primary energy resources used as raw material (MJ, net calorific value)
    - Use of non-renewable primary energy excluding primary energy resources used as raw material (MJ, net calorific value)
    - Use of non-renewable primary energy resources used as raw material (MJ, net calorific value)
    - Use of secondary material (kg)

    - Use of renewable secondary fuels (MJ)
    - Use of non-renewable secondary fuels (MJ)
    - Use of net fresh water (m³)

- Indicators describing waste categories (EN15978)
    - Hazardous waste disposed (kg)
    - Non-hazardous waste disposed (kg)
    - Radioactive waste disposed (kg)

- Indicators describing the output flows leaving the system (EN15978)
    - Components for re-use (kg)
    - Materials for recycling (kg)
    - Materials for energy recovery (not being waste incineration) (kg)
    - Exported energy (MJ for each energy carrier)

The choice of the indicators can be done from the Display menu on the left of the screen:

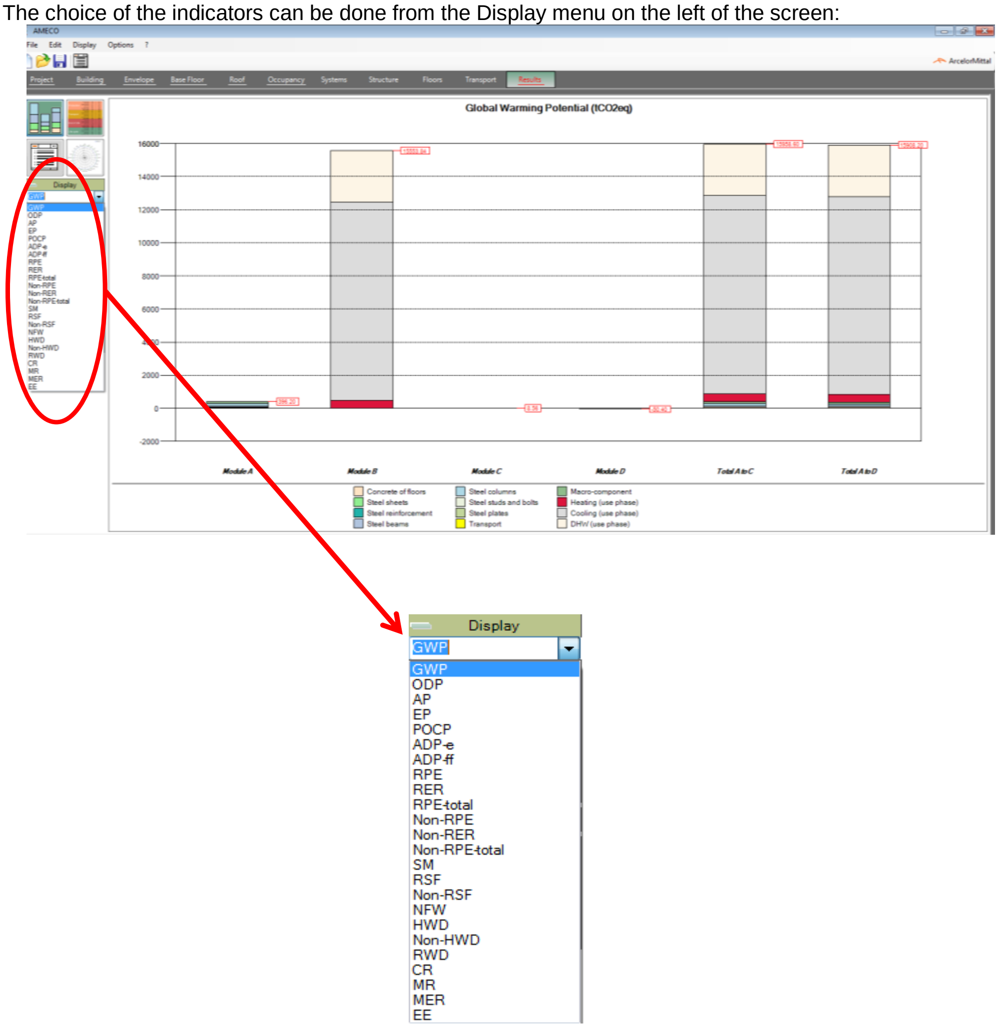


Figure 31 : bar graph and the selection of the displayed indicator: GWP

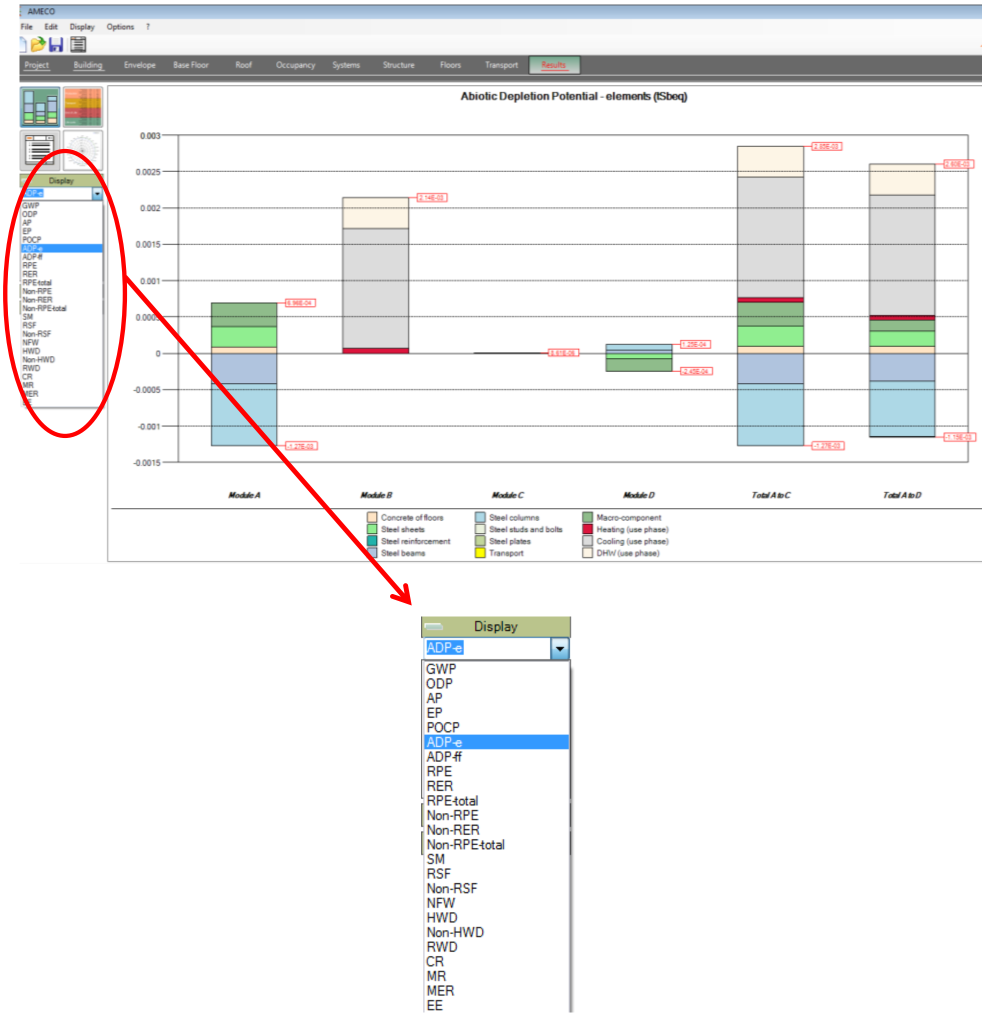


Figure 32 : bar graph and the selection of the displayed indicator: Abiotic Depletion Potential

The results are displayed for the life cycle of the building, for all the modules:

- Module A : Product stage and construction process stage
- Module B : Use stage
- Module C : End of life stage
- Module D : Benefits and loads beyond the product system boundary
- Module A to C (i.e. the sum of the 3modules A, B and C)
- Module A to D : Global life cycle of the building (i.e. the sum of the 4 previous modules)

For each module, the impacts are represented for the following sets of elements (if present in the structure):

Structural components:
- Concrete of floors
- Concrete of the structure
- Steel sheets
- Steel reinforcement
- Steel beams
- Steel columns
- Steel studs and bolts
- Steel plates

Envelope components:
- Macro-component

Transport of all components:
- Transport

Use phase
- Heating
- Cooling
- DHW

6.2.11.2 Table

The impacts results can be displayed in a table, for each phase and set of elements used for bar charts.

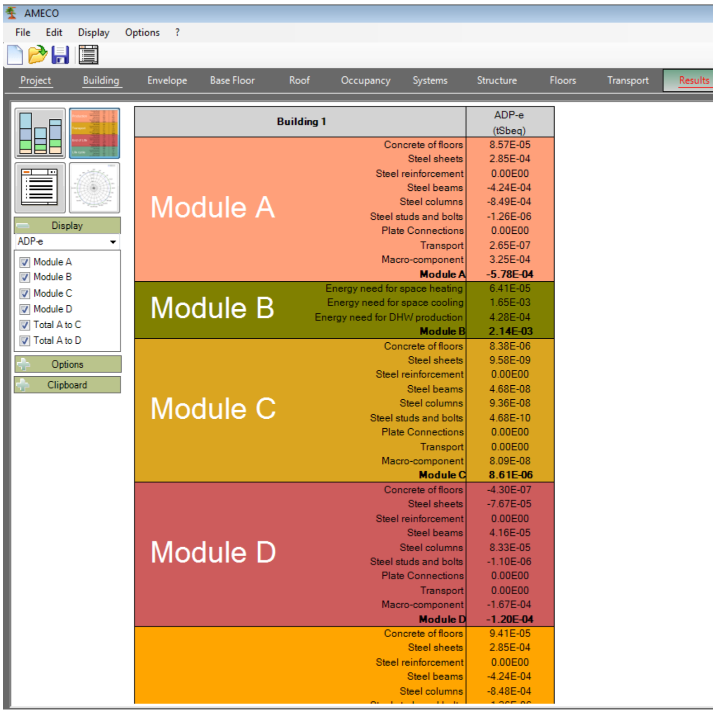


Figure 33 : table displaying the results for the selected indicator

6.2.11.3 Radial graph

The user has also the possibility to display the results in a radial graph summarizing the total of modules A to C and A to D for all indicators.

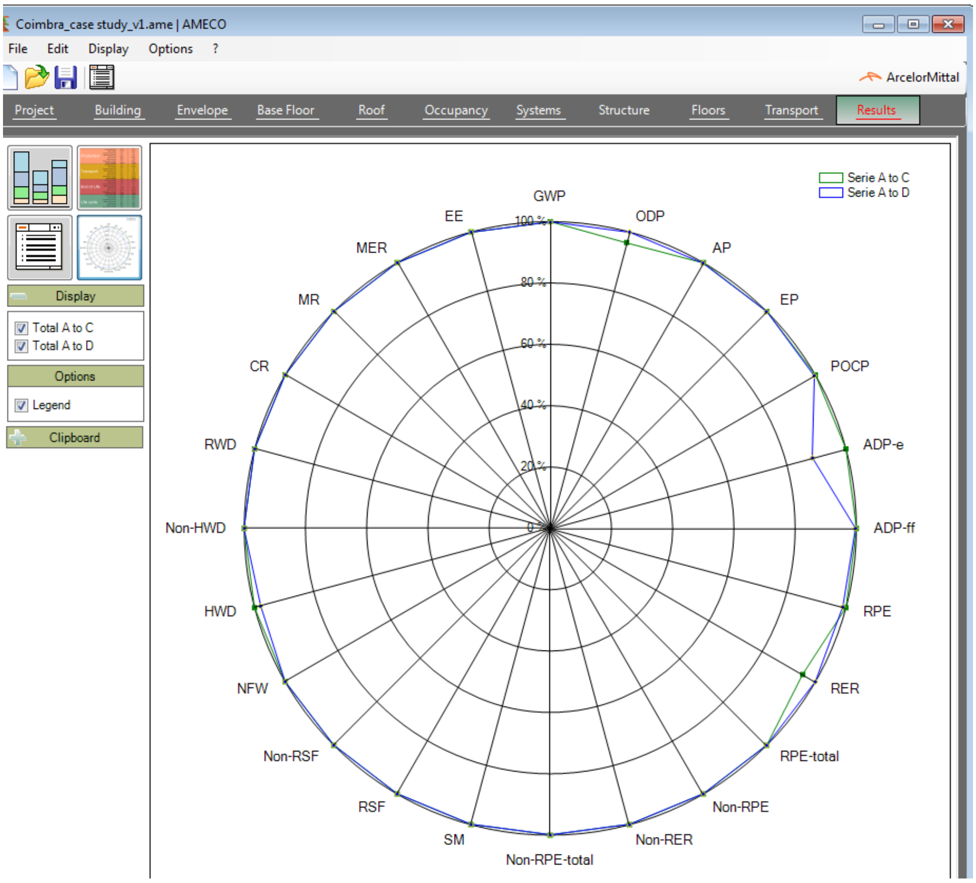


Figure 34 : Radial graph

6.2.11.4 Calculation sheet

A calculation sheet, also called "preliminary design note", can be generated by selecting the icone:

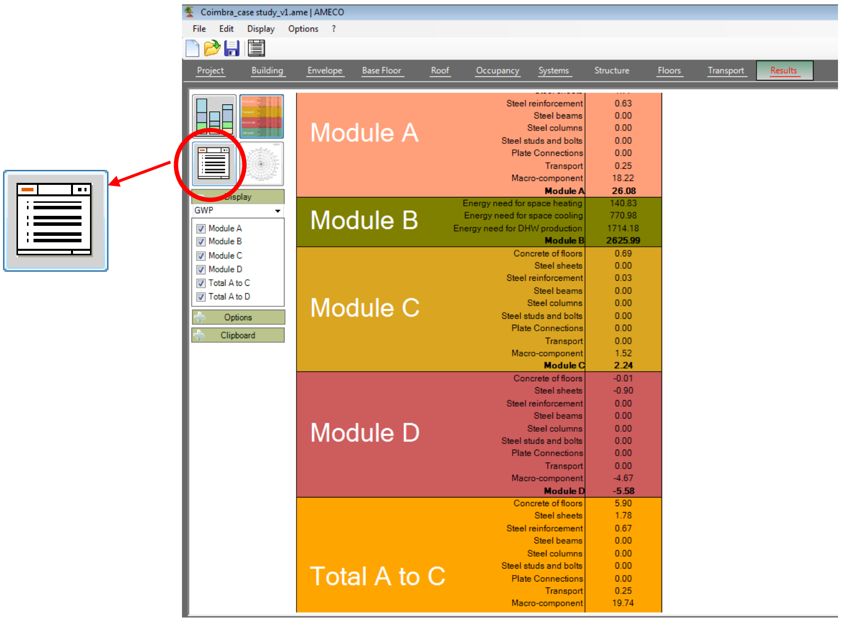


Figure 35 : calculation sheet button

This report, which can be printed, displayed all the inputs and outputs of the building.

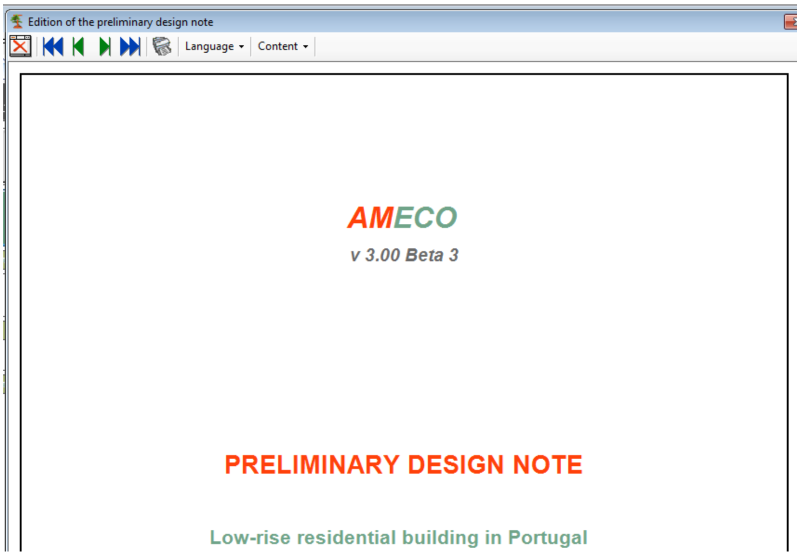


Figure 36 : Preliminary design note

Synthesis

Synthesis of results for Low-rise residential building in Portugal

	Module A	Module B	Module C	Module D	Total A to C	Total A to D
GWP (tCO2eq)	26.08	2625.99	2.24	-5.58	2654.32	2648.73
ODP (tCFCeq)	1.70E-07	2.36E-06	1.50E-07	9.90E-08	2.68E-06	2.78E-06
AP (tSO2eq)	6.81E-02	1.24E01	5.44E-03	-1.74E-02	1.25E01	1.25E01
EP (tPO4eq)	8.29E-03	6.55E-01	1.55E-03	-6.36E-04	6.65E-01	6.64E-01
POCP (tEtheneeq)	8.70E-03	7.32E-01	8.46E-04	-3.16E-03	7.42E-01	7.39E-01
ADP-e (tSbeq)	6.79E-05	3.61E-04	8.87E-07	-4.85E-05	4.30E-04	3.82E-04
ADP-ff (GJ NCV)	292.54	46225.20	14.61	-87.50	46532.35	46444.85
RPE (GJ NCV)	200.15	7710.97	1.09	-79.03	7912.21	7833.18
RER (GJ NCV)	40.38	0.00	0.05	2.01	40.43	42.44
RPE-total (GJ NCV)	5.44	7710.97	0.31	0.46	7716.73	7717.19
Non-RPE (GJ NCV)	104.35	26714.85	15.29	-8.79	26834.50	26825.71
Non-RER (GJ NCV)	0.45	19627.40	0.00	0.00	19627.86	19627.86
Non-RPE-total (GJ NCV)	104.80	46342.26	15.29	-8.79	46462.36	46453.57
SM (t)	47.15	0.00	0.00	0.00	47.15	47.15
RSF (GJ NCV)	1.61	0.95	0.00	0.00	2.55	2.55
Non-RSF (GJ NCV)	16.92	9.90	0.00	0.00	26.83	26.83
NFW (1000 m3)	28.44	10030.69	5.85	0.42	10064.99	10065.41
HWD (t)	4.56E-04	0.00E00	0.00E00	-9.15E-06	4.56E-04	4.47E-04
Non-HWD (t)	31.36	10476.45	0.87	-2.41	10508.68	10506.27
RWD (t)	2.42E-03	6.81E00	2.70E-06	-3.08E-04	6.81E00	6.81E00
CR (t)	0.00	0.00	0.00	0.00	0.00	0.00
MR (t)	0.00	0.00	0.00	0.60	0.00	0.60
MER (t)	0.00	0.00	0.00	0.00	0.00	0.00
EE (t)	0.00	0.00	0.00	0.00	0.00	0.00

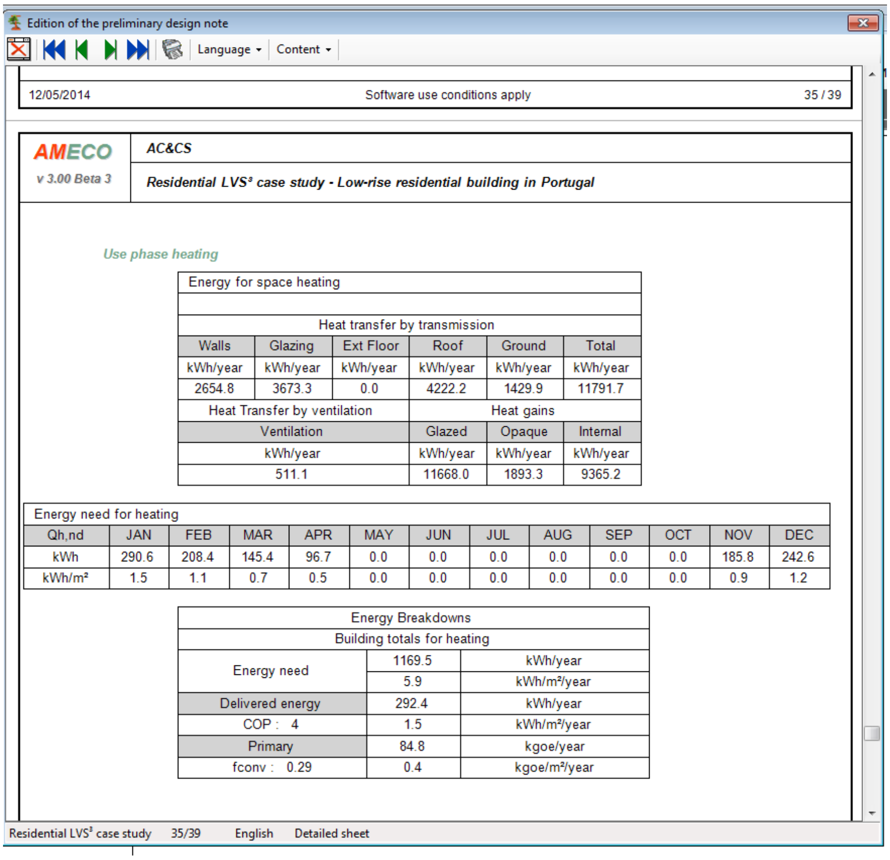
Detailed results

Global Warming Potential

	Module A tCO2eq	Module B tCO2eq	Module C tCO2eq	Module D tCO2eq	Total A to C tCO2eq	Total A to D tCO2eq
Steel total	2.41	0.00	0.04	-0.90	2.44	1.54
Floor sheets	1.77	0.00	0.00	-0.90	1.78	0.88
Concrete total	5.20	0.00	0.69	-0.01	5.90	5.88
Concrete slabs	5.20	0.00	0.69	-0.01	5.90	5.88
Use phase total	0.00	2536.56	0.00	0.00	2536.56	2536.56
Heating	0.00	57.22	0.00	0.00	57.22	57.22
Cooling	0.00	765.16	0.00	0.00	765.16	765.16
DHW	0.00	1714.18	0.00	0.00	1714.18	1714.18
Transport	0.25	0.00	0.00	0.00	0.25	0.25
Total impact of module	26.08	2536.56	2.24	-5.58	2564.89	2559.31

Figure 37 : tables available in the preliminary design note, showing the results for all indicators

The detailed results for the use phase are given in the preliminary design note.



Edition of the preliminary design note

Language ▾ Content ▾

12/05/2014 Software use conditions apply 35 / 39

AMECO v 3.00 Beta 3

AC&CS

Residential LVS³ case study - Low-rise residential building in Portugal

Use phase heating

Energy for space heating					
Heat transfer by transmission					
Walls	Glazing	Ext Floor	Roof	Ground	Total
kWh/year	kWh/year	kWh/year	kWh/year	kWh/year	kWh/year
2654.8	3673.3	0.0	4222.2	1429.9	11791.7
Heat Transfer by ventilation			Heat gains		
Ventilation			Glazed	Opaque	Internal
kWh/year			kWh/year	kWh/year	kWh/year
511.1			11668.0	1893.3	9365.2

Energy need for heating												
Qh,nd	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh	290.6	208.4	145.4	96.7	0.0	0.0	0.0	0.0	0.0	0.0	185.8	242.6
kWh/m²	1.5	1.1	0.7	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.2

Energy Breakdowns		
Building totals for heating		
Energy need	1169.5	kWh/year
	5.9	kWh/m²/year
Delivered energy	292.4	kWh/year
COP : 4	1.5	kWh/m²/year
Primary	84.8	kgoe/year
fconv : 0.29	0.4	kgoe/m²/year

Residential LVS³ case study 35/39 English Detailed sheet

Figure 38 : table related to the use phase consumptions

7 Case studies

7.1 OfficeBuilding

7.1.1 Introduction

The objective is to present the calculation of the environmental impact of an office building and compare different types of structures, using AMECO3 software.

Three types of structural systems are analyzed:

- steel-concrete composite structure
- concrete structure
- optimized steel-concrete composite structure (this optimization has been done on the basis of an ECO-Design)

The structural design was done by an external Engineering office in the scope of a study requested by ArcelorMittal. Furthermore, this structural design was also reviewed by a group of independent experts [4].

The 3 systems are the more common in Europe for office buildings.

7.1.2 Description of the buildings

Dimensions of the building	42.4 m x 24.4 m
Nbr of Superstructure storey	R + 8
Nbr of Infrastructure storey	2
Height of the building	31.2 m
Storey height (floor level to floor level)	3.4 m (except ground floor 4.0 m)

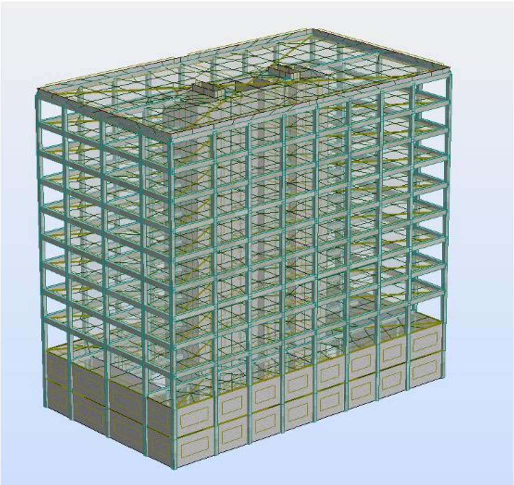


Figure 39 :3D view of the building, including the underground levels

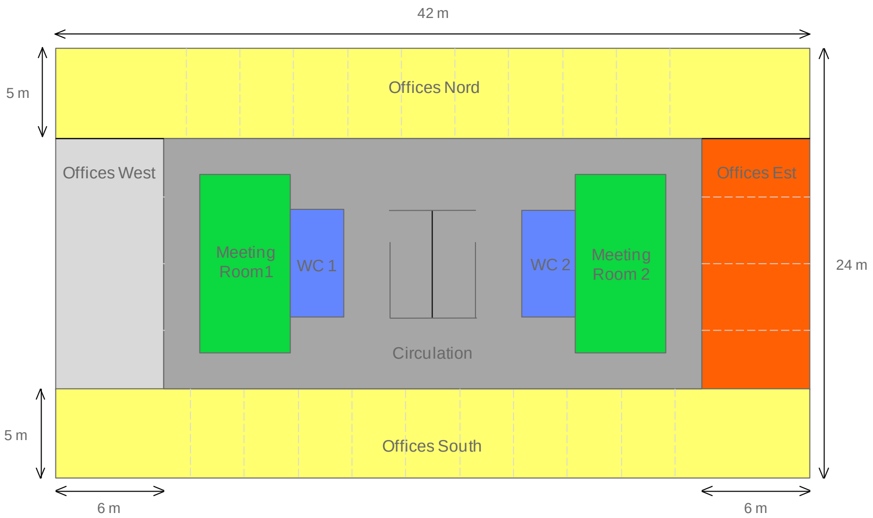


Figure 40 : Typical floor arrangement

Various solutions:

The elements differentiating the 3 buildings cover only the superstructure (columns, beams and slabs), and central stabilization core. The other elements of the structure (foundation and infrastructure), the envelope and the internal finishing are identical.

The envelope is composed of light steel panels, insulated with 50mm of extruded polystyrene (XPS). The windows are equipped with a double glazing, with solar protection for the ones facing south.
The roof is insulated with 18cm of expanded polystyrene (EPS).

The heating and cooling are based on a split system, and there is a mechanical system of ventilation with a heat recovery system. An electrical boiler supplies the demand of hot water.

The services provided by the buildings are considered equivalent as useful building surfaces are equal. Indeed, although the volume of the building is slightly higher in the case of composite structures than in the case of the concrete structure.

The buildings are designed in climatic region of Paris.

Life Time Scheduled (LTS) for buildings is 100 years. Indeed, for office buildings, it is in the vast majority of cases that the structural elements determine the life of the building; the other elements can be renovated or replaced. However, in this study, the materials of the structures are quite compatible with a life of 100 years. Finally, it is interesting to note that the LTS is not a differentiating element between the different building structures examined in this study.

1. Steel and concrete composite solution

The composite steel and concrete building has a composite steel-concrete superstructure and concrete core.

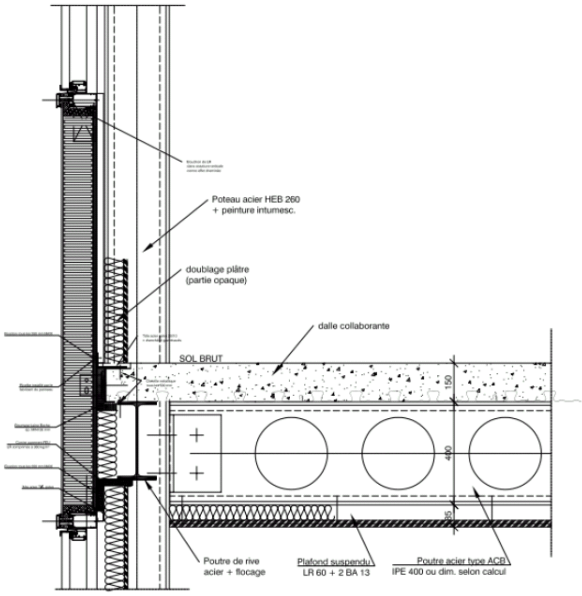


Figure 41 : Detailed view of the structural system

As shown on the Figure 41~~Figure 41~~, the structural system is made of composite cellular beams in steel connected with steel stud at the composite slab.
The composite slab is composed of COFRA+60 steel sheet and concrete C30/37.
The core of the building is in concrete.
This structure corresponds to the actual state of the art of office building on the French Market.

2. Concrete solution

The concrete building has a pre fabricated hollow core slab supported by reinforced concrete structure and concrete core.
The prefabricated hollow core and the reinforced concrete are concrete C30/37.
The core of the building is in concrete.
This structure also corresponds to the actual state of the art of office building on the French Market.

3. Eco-optimized steel-concrete composite structure

The Eco-optimized composite steel and concrete building has a composite steel-concrete superstructure and steel core.
The structural system is made of composite cellular beams in steel S460 connected with steel stud at the composite slab.
The composite slab is composed of COFRA+60 steel sheet and concrete C30/37.
The core of the building is in steel.
This structure is based on the actual state of the art of office building on the French Market, but has been optimized in term of material usage in order to minimize the environmental footprint.

Central core of the buildings:

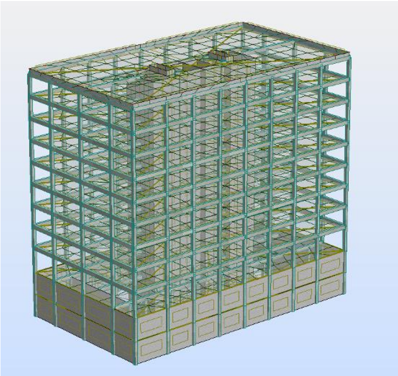


Figure 42 : Concrete core (Solutions 1 & 2)

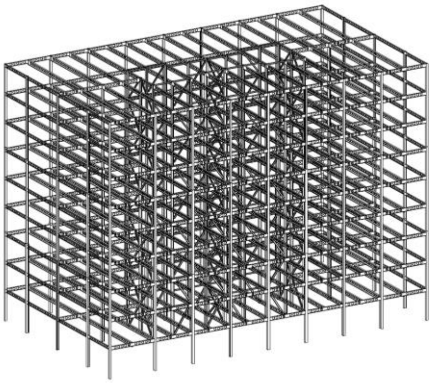


Figure 43 : Steel core (Solution 3)

Structural data for the 3 solutions:

Superstructure	**Structure**				**Floor slab**			
Values in tons (t)	Steel sections	Steel plate connections	Concrete C30/37	Steel reinf.	Steel elements	Total depth	Concret e floor	Steel reinf.
Steel S355	239,9 t	14,994 t	-	-	70.6 t (Cofraplus 60)	150 mm	2246 t	16.56 t
Concrete	-	-	1199 t	59.1 t	-	240 mm + 70 mm of screed	4688 t	16.56 t
Steel S460	197,1 t	11,827 t	-	-	70.6 t (Cofraplus 60)	150 mm	2246 t	16.56 t
Steel core	75,46 t	6,037 t	-	-	-	-	-	-
Concrete core	-	-	1941 t	44,16 t				

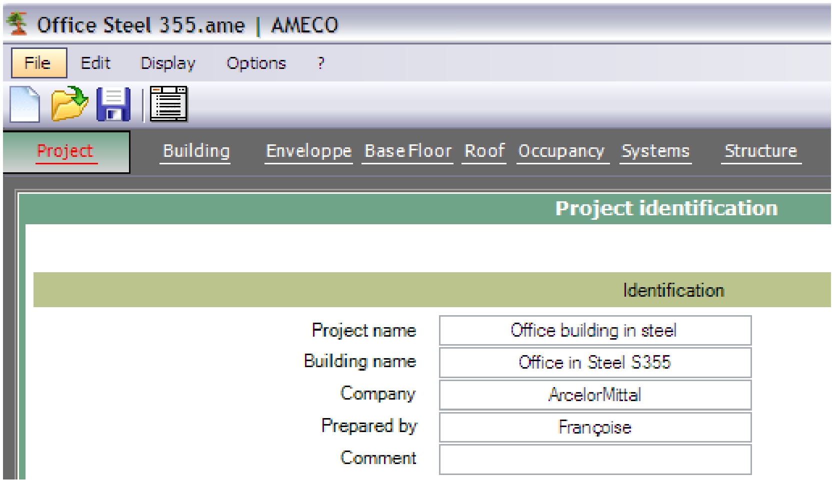
with: Building 1 = Structure in steel S355, and concrete core
Building 2 = Structure in concrete, with concrete core
Building 3 = Structure in steel S460, and steel core

NB : concrete density= 2500 kg/m^3

7.1.3 Environmental analysis with AMECO3 software

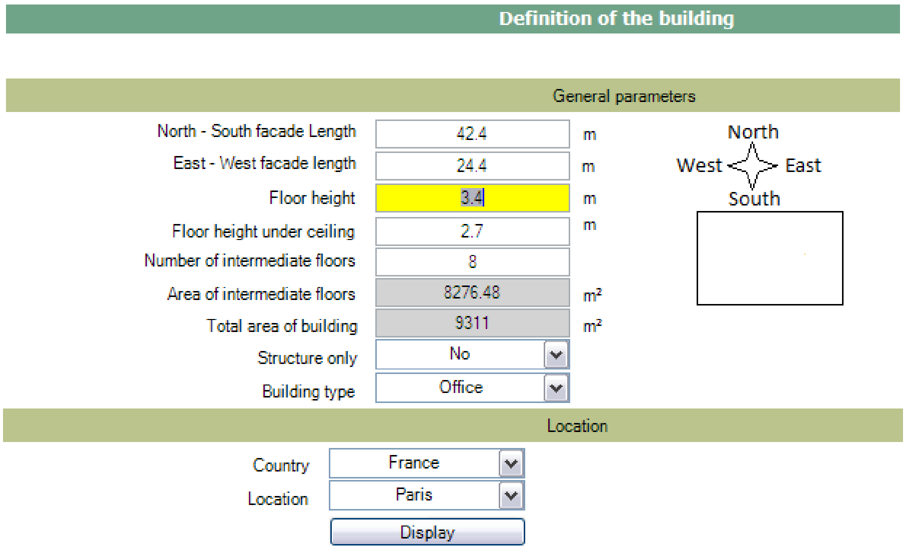
7.1.3.1 Input data in AMECO3 software

⇨ *General data input of the building 1 in AMECO3*

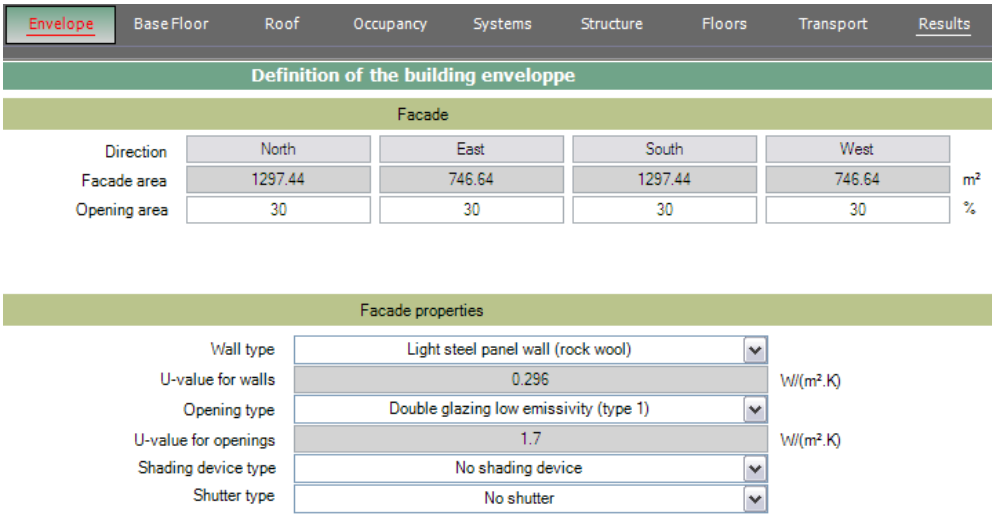


⇨ *Data input for the envelope (Modules A-C-D)*

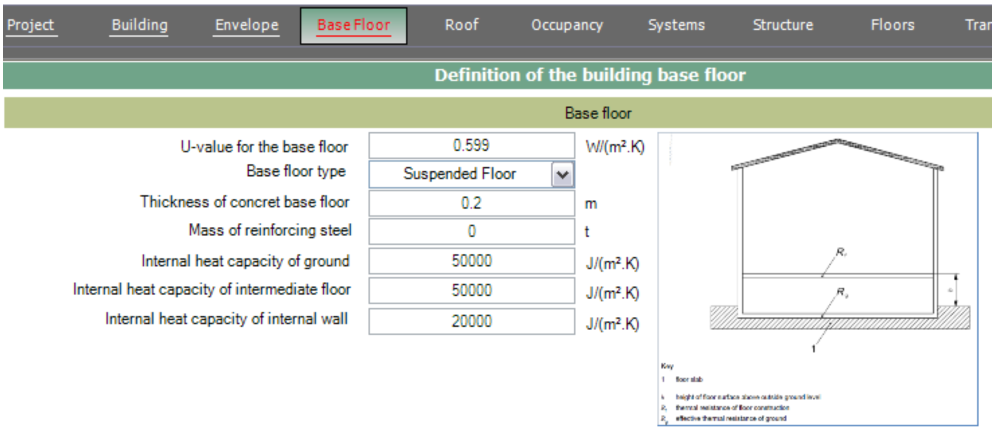
- Definition of the building general data:



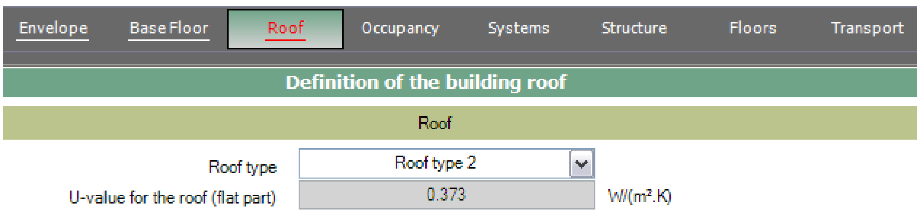
- Definition of the building envelope: thermal characteristics (U-values) used for the envelope (walls, openings, ground and roof) are taken for the components implemented in AMECO3.



- Definition of the building base floor:

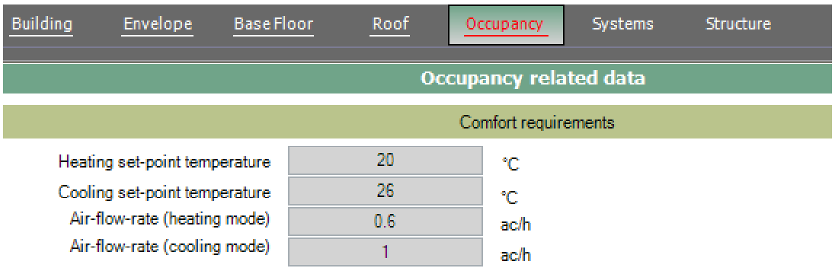


- Definition of the roof:

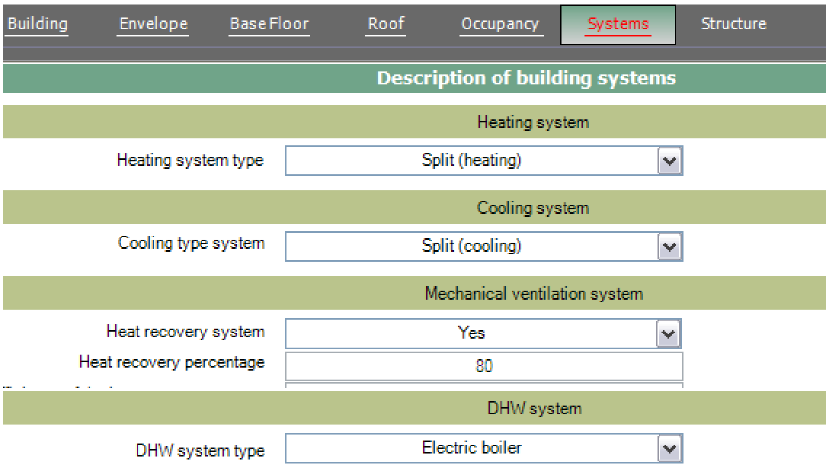


⇨ *Input data for the Use phase of the building (Module B)*

- Definition of the occupancy:



- Description of the building systems:



⇨ *General data for the structure of the building (Module A-C-D)*

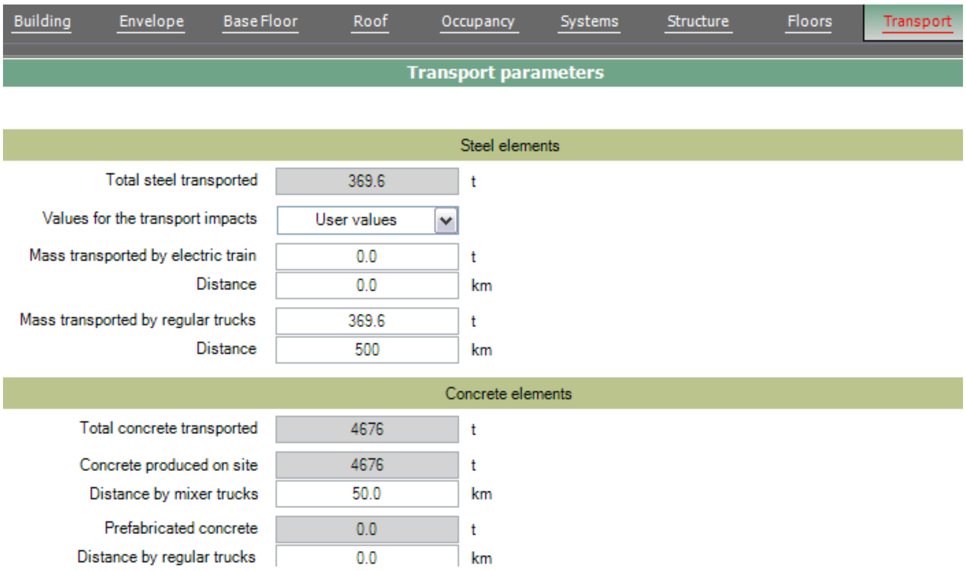
- Description of the bearing structure:

Bearing structure of the building		
Steel elements		
Beams (Hot rolled profiles)	239.9	t
Columns (Hot rolled profiles)	0.0	t
Studs	0.0	t
Bolts	0.0	t
Plate Connections	14.99	t
Concrete elements		
Concrete Type	In-situ/Poured	
Concrete Grade	C30/37	
Beams	0.0	t
Columns	1941	t
Steel reinforcement	44.16	t
Wood elements		
Beams	0.0	t
Columns	0.0	t
Total mass of structure	2240	t

- Description of the floors systems :

Floor slabs		
Steel elements		
Type of slab	Composite slab	
Steel deck	Cofraplus 60	
Thickness of the deck	0.750	mm
Mass of sheeting per m2 of floor	8.53	kg/m²
Mass of sheeting for the building	70.6	t
Minimum depth of the floor	100	mm
Concrete elements		
Total depth of the floor	150.0	mm
Concrete Type	In-situ/Poured	
Concrete Grade	C30/37	
Total mass of the floor concrete (incl. base floor)	2735	t
Steel reinforcement	0.0	t
Total mass of the floor slabs	2805	t

⇨ *Data for the transportation of elements (Module A)*



7.1.3.2 Results of calculation with AMECO3

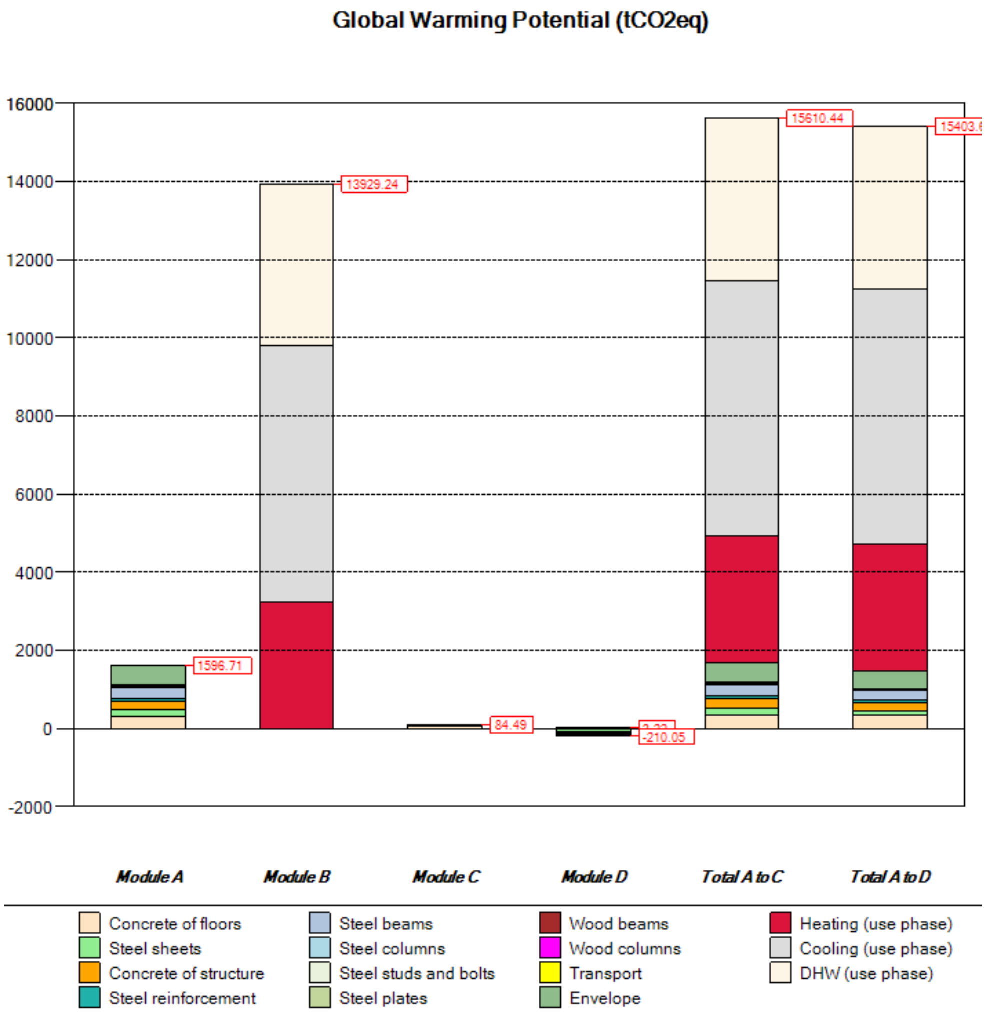
Building 1: steel S355 – concrete core

Detailed results for Global Warming Potential (t CO_2eq):

Office building in steel S355	Module A tCO_2eq	Module B tCO2eq	Module C tCO2eq	Module D tCO2eq	Total A to C tCO2eq	Total A to D tCO2eq
Steel total	549.17	0	4.71	-148.78	553.88	405.1
Beams	276.92	0	1.38	-40.71	278.3	237.59
Columns	0	0	0	0	0	0
Plate connections	36.84	0	0.09	-19.66	36.93	17.27
Reinforcement	54.93	0	2.8	3.22	57.73	60.95
Floor sheets	180.48	0	0.44	-91.63	180.92	89.29
Concrete total	520.77	0	63.22	-3.51	583.99	580.48
Concrete of structure	216.19	0	23.02	-2.74	239.21	236.47
Concrete slabs	304.58	0	40.2	-0.77	344.78	344.01
Envelope	489.99	0	16.55	-54.54	506.54	452
Use phase total	0	13929.24	0	0	13929.24	13929.24
Heating	0	3233.37	0		3233.37	3233.37
Cooling	0	6543.84	0		6543.84	6543.84
DWH	0	4152.03	0		4152.03	4152.03
Transport	36.78	0	0		36.78	36.78
Total impact of module	**1596.71**	**13929.24**	**84.48**	**-206.83**	**15610.43**	**15403.6**

We can notice from these results that the Module B, which is the Use phase of the building, is predominant in comparison with the other modules.

Graphical results for the Global Warming Potential (t CO_2eq):



Building 2: concrete structure and core

Detailed results for Global Warming Potential (t CO2eq):

Office building in concrete	Module A tCO_2eq	Module B tCO2eq	Module C tCO2eq	Module D tCO2eq	Total A to C tCO2eq	Total A to D tCO2eq
Steel total	128.45	0	6.55	7.54	135	142.54
Beams	0	0	0	0	0	0
Columns	0	0	0	0	0	0
Plate connections	0	0	0	0	0	0
Reinforcement	128.45	0	6.55	7.54	135	142.54
Floor sheets	0	0	0	0	0	0
Concrete total	1078.55	0	133.44	-6.28	1211.99	1205.71
Concrete of structure	349.74	0	37.24	-4.43	386.98	382.55
Concrete slabs	728.81	0	96.2	-1.85	825.01	823.16
Envelope	489.99	0	16.55	-54.54	506.54	452
Use phase total	0	13929.24	0	0	13929.24	13929.24
Heating		3233.37			3233.37	3233.37
Cooling		6543.84			6543.84	6543.84
DWH		4152.03			4152.03	4152.03
Transport	60.56	0	0	0	60.56	60.56
Total impact of module	**1757.55**	**13929.24**	**156.54**	**-53.28**	**15843.33**	**15790.05**

Building 3: steel S460 structure and core

Detailed results for Global Warming Potential (t CO2eq):

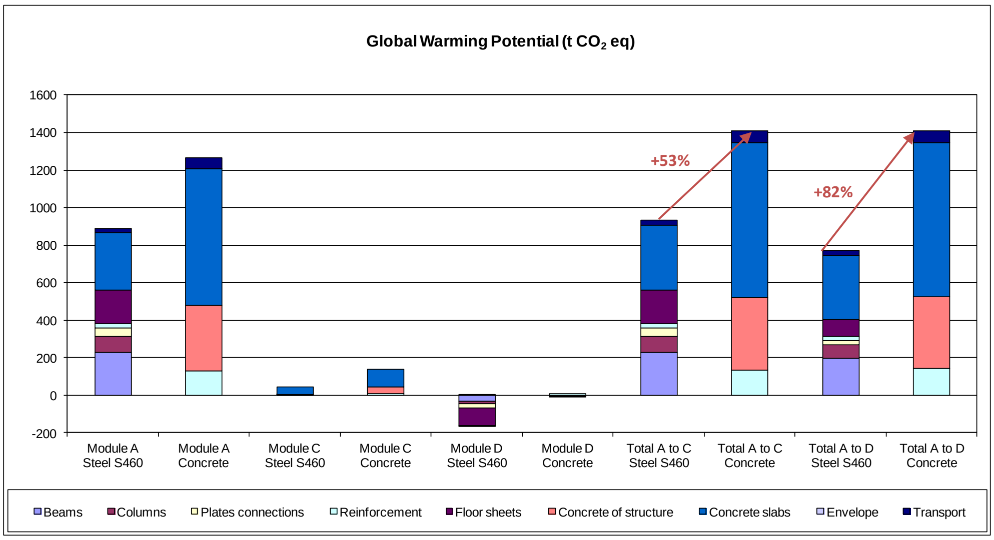
Office building in steel S460	Module A tCO_2eq	Module B tCO2eq	Module C tCO2eq	Module D tCO2eq	Total A to C tCO2eq	Total A to D tCO2eq
Steel total	559.6	0	3.15	-160.09	562.75	402.66
Beams	227.51	0	1.13	-33.44	228.64	195.2
Columns	87.1	0	0.43	-12.8	87.53	74.73
Plate connections	43.91	0	0.1	-23.43	44.01	20.58
Reinforcement	20.6	0	1.05	1.21	21.65	22.86
Floor sheets	180.48	0	0.44	-91.63	180.92	89.29
Concrete total	304.58	0	40.2	-0.77	344.78	344.01
Concrete of structure	0	0	0	0	0	0
Concrete slabs	304.58	0	40.2	-0.77	344.78	344.01
Envelope	489.99	0	16.55	-54.54	506.54	452
Use phase total	0	13929.24	0	0	13929.24	13929.24
Heating		3233.37			3233.37	3233.37
Cooling		6543.84			6543.84	6543.84
DWH		4152.03			4152.03	4152.03
Transport	25.31	0	0	0	25.31	25.31
Total impact of module	**1379.48**	**13929.24**	**59.9**	**-215.4**	**15368.62**	**15153.22**

Again, for the three buildings, we can notice that Module B, which is the Use phase of the building, is predominant in comparison with the other modules. Furthermore, the use phase does not depend on the type (concrete or steel) of the structure of the building.

Those results show that the structure has a very weak influence on the global environmental impacts of the building, in comparison with exploitation and activity of buildings.

The next comparisons will be done in removing the use phase of the building in order to highlight how the type of building influences really the environmental impacts.

The comparison between the building in concrete and the one optimized in steel is illustrated in the following figure.



In term of CO_2 impact, the results provided by the software point out that there is a large discrepancy between the concrete building and the Eco-Optimized building, which can reach 53% for module A to C without taken into account the recycling phase, and up to 82% if recycling of steel and valorization of crushed concrete are taken into account.

This study has highlighted the fact that using composite Steel and Concrete structure ensures a lot of advantages in the field of environmental footprint. This advantage is mainly due to the lightness of composite structures. It was highlighted that the design minimizing the amount of material use will allow reducing the environmental footprint of the structure of buildings.

The recycling of material at the end of life (infinite recycling of steel and valorization of crushed concrete) makes structures most sustainable. The use of the Module D of EN 15804 allows optimizing then environmental footprint of building.

This study has shown that the best choice for office building structure is clearly the composite steel-concrete solution. This solution allows using both materials in their “best configuration”, it means, concrete in compression and steel in tension. It allows reducing the impact of the deflection on the design and by the way, decreasing the total environmental footprint of the building.

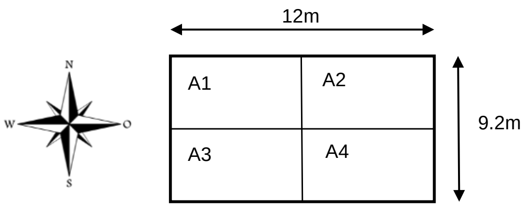
The same conclusion can be adopted for the use of High strength steel. It decreases the total environmental impact of composite structures by minimizing the use of material.

7.2 Residential Building - CasaBuna dwelling in Romania

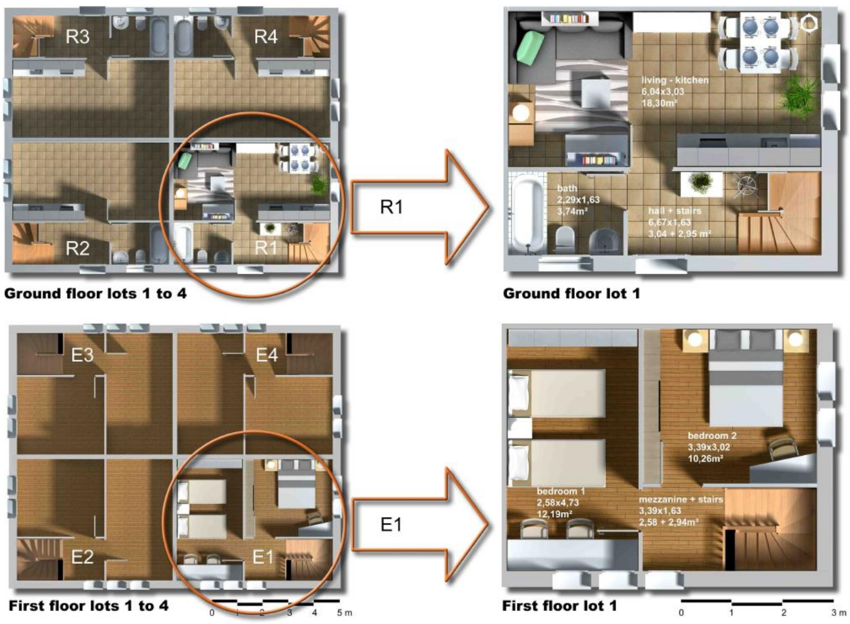
7.2.1 Description of the building

Casa Buna concept is a 4-family house located in Romania.

Casa Bunã building is divided into 4 apartments of 55m² net floor area, equally arranged over 2 floors.



The total height of the building is 6.85 m, up to the top of the inclined roof. As only flat roof can be modeled in AMECO3, the average height of each floor is 2.9m. A vertical cross section and the horizontal plans of the building are provided in Figures below:

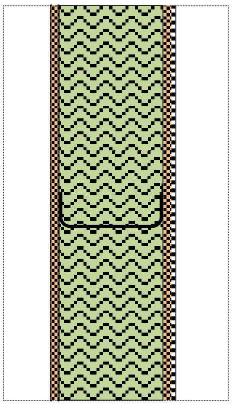


The nex Table summarizes the areas of the building envelope.

Table Walls and glazing areas

	North/South [m²]	West/East [m²]	Sum [m²]
Walls	47	41	87
Glazing	22	12	34
Total areas	69	53	122

The facade is based on a light steel framing structure, enclosed in a Wood panel (OSB), 120mm of rock wool, and plasterboards on the inner side. The facade component is shown at the figure below:



No additional bearing structure is implemented in the building.

The slab on ground is made of reinforced concrete and is 0.2 m thick, insulated with 4cm of extruded polystyrene. The mass of rebars is 0.7t. The intermediate floor is based on dry floor principle.

The windows are made of low-e double glazing and PVC frame.

The following table gives the U-value of the building elements.

WALLS	0.30	W/m^2.K
FLAT ROOF	0.37	W/m^2.K
WINDOWS	1.70	W/m^2.K
BASE FLOOR	0.60	W/m^2.K

It is also required as inputs to specify the internal heat capacities of the floors and the internal wall. The details of the calculation are shown below:

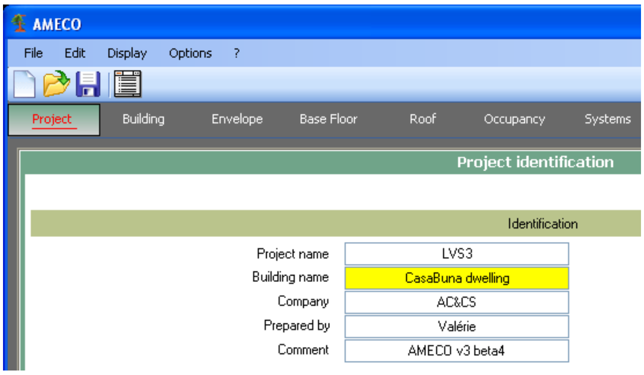
Base floor 0.2 m of concrete + tiles	74324	J/m²K
Intermediate floor Linoleum + OSB + Steel sheet + air layer + plasterboards	32447	J/m²K
Interior walls plasterboards + rockwool + LSF + plasterboards	13081	J/m²K

The heating and cooling needs are provided through split systems, based on set-points temperature of 20 and 25°C respectively. The building is ventilated naturally. The domestic hot water system is based on an electrical boiler with 90% efficiency.

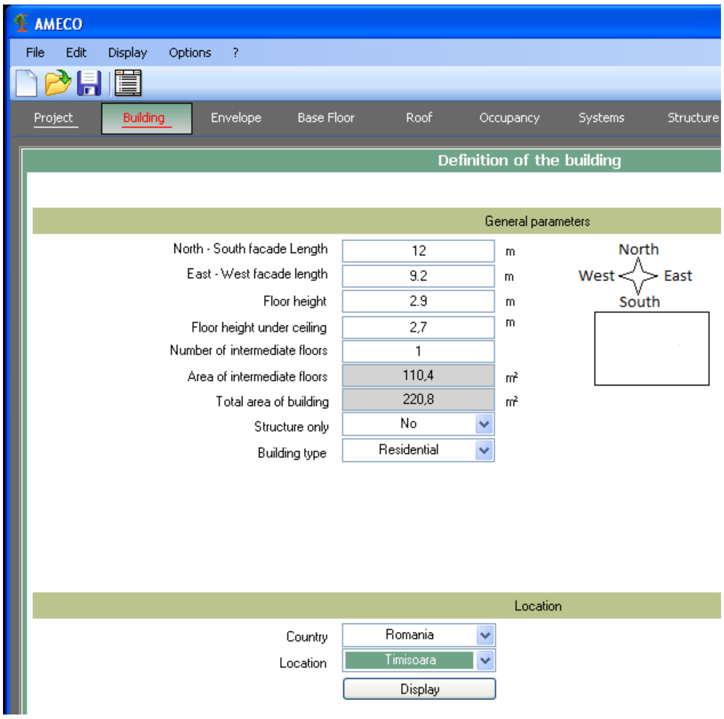
The foundations are excluded from the present study, as well as partitions and doors. The light work, such as internal finishing, and the furniture are also excluded from the analysis. Only extra losses due to integrated thermal bridges are included in the energy consumption of the building.

7.2.2 Input data in AMECO3 software

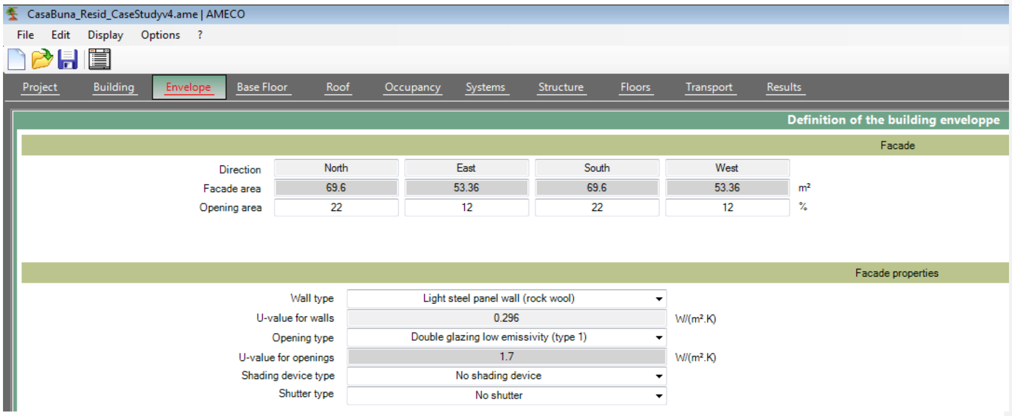
7.2.2.1 General data input of the residential building in AMECO3

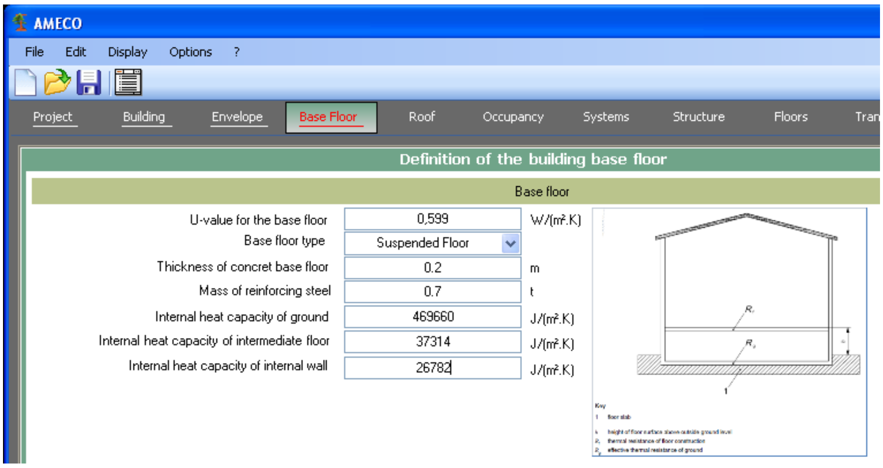


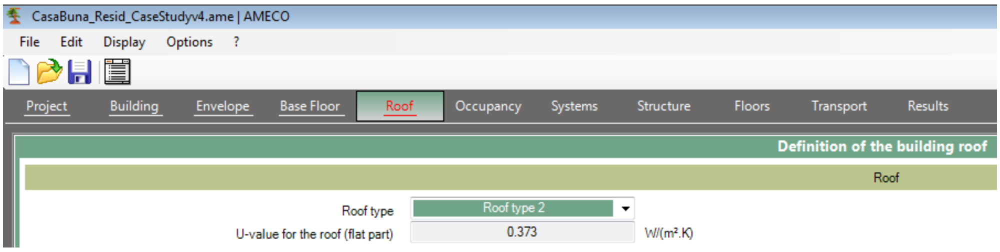
7.2.2.2 Data input for the geometry (Modules A-C-D)



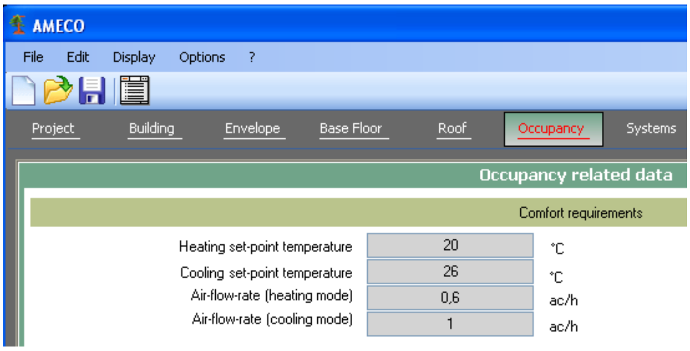
7.2.2.3 Input data for the components of the building (Module A-B-C-D)

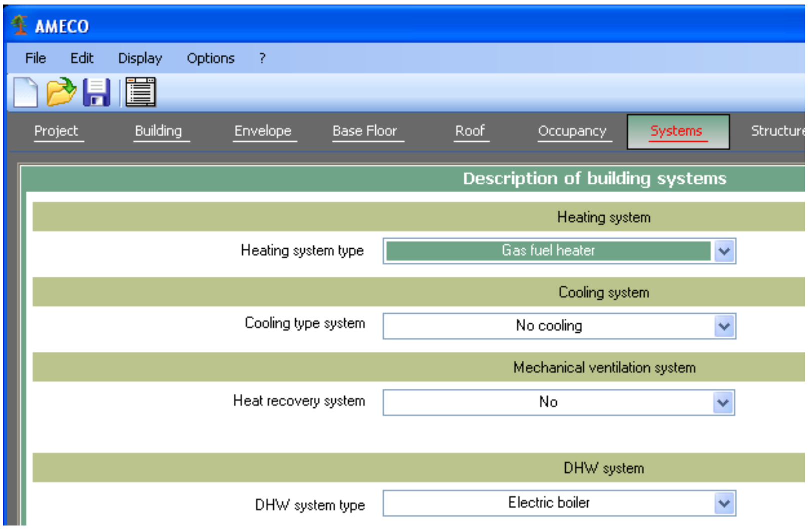




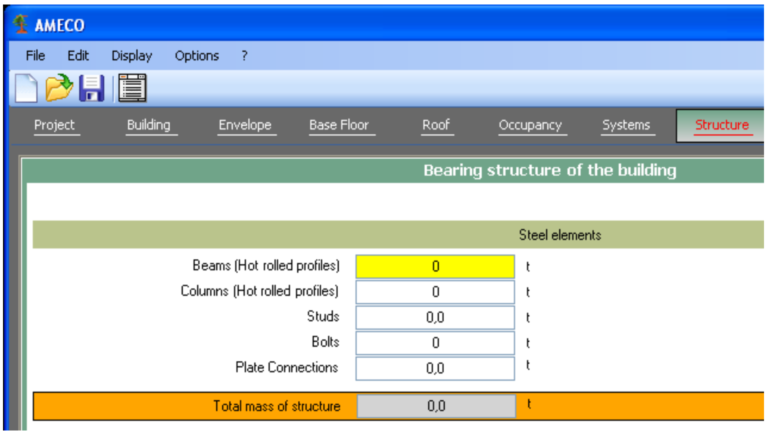


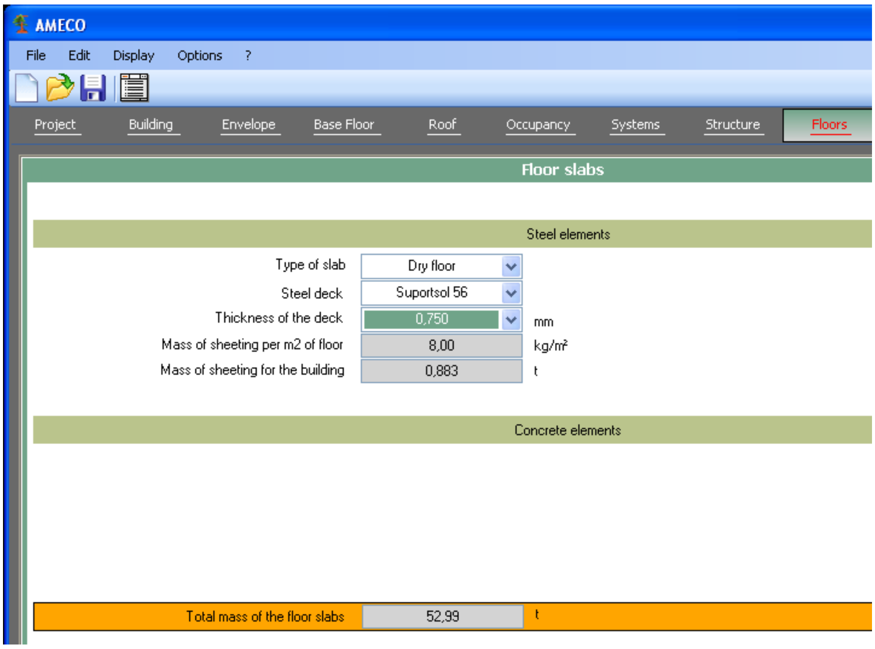
7.2.2.4 Input data for the use phase of the building (Module B)



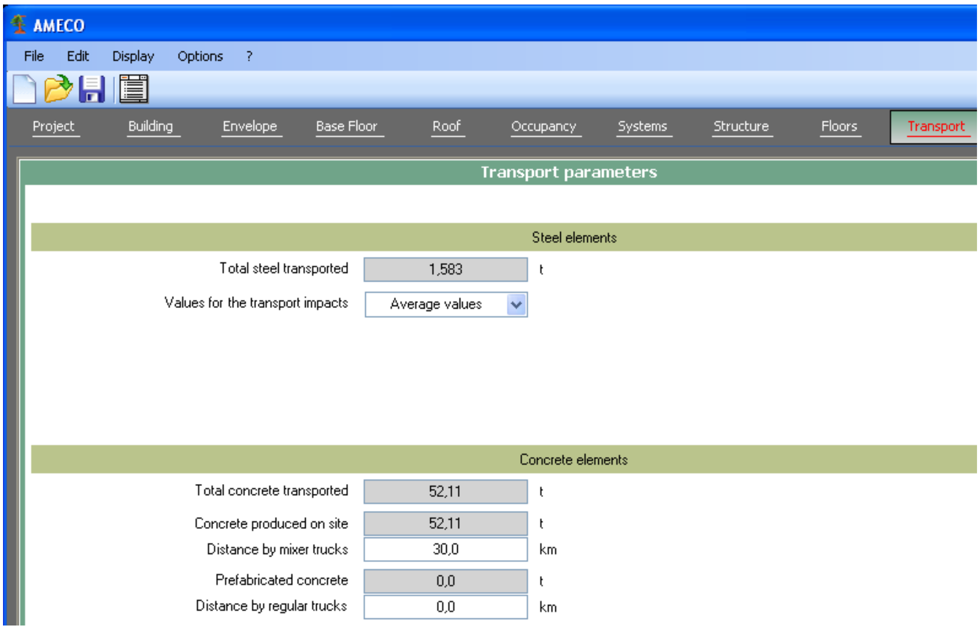


7.2.2.5 General data for the structure of the building (Module A-C-D)





7.2.2.6 Data for the transportation of elements (Module A)



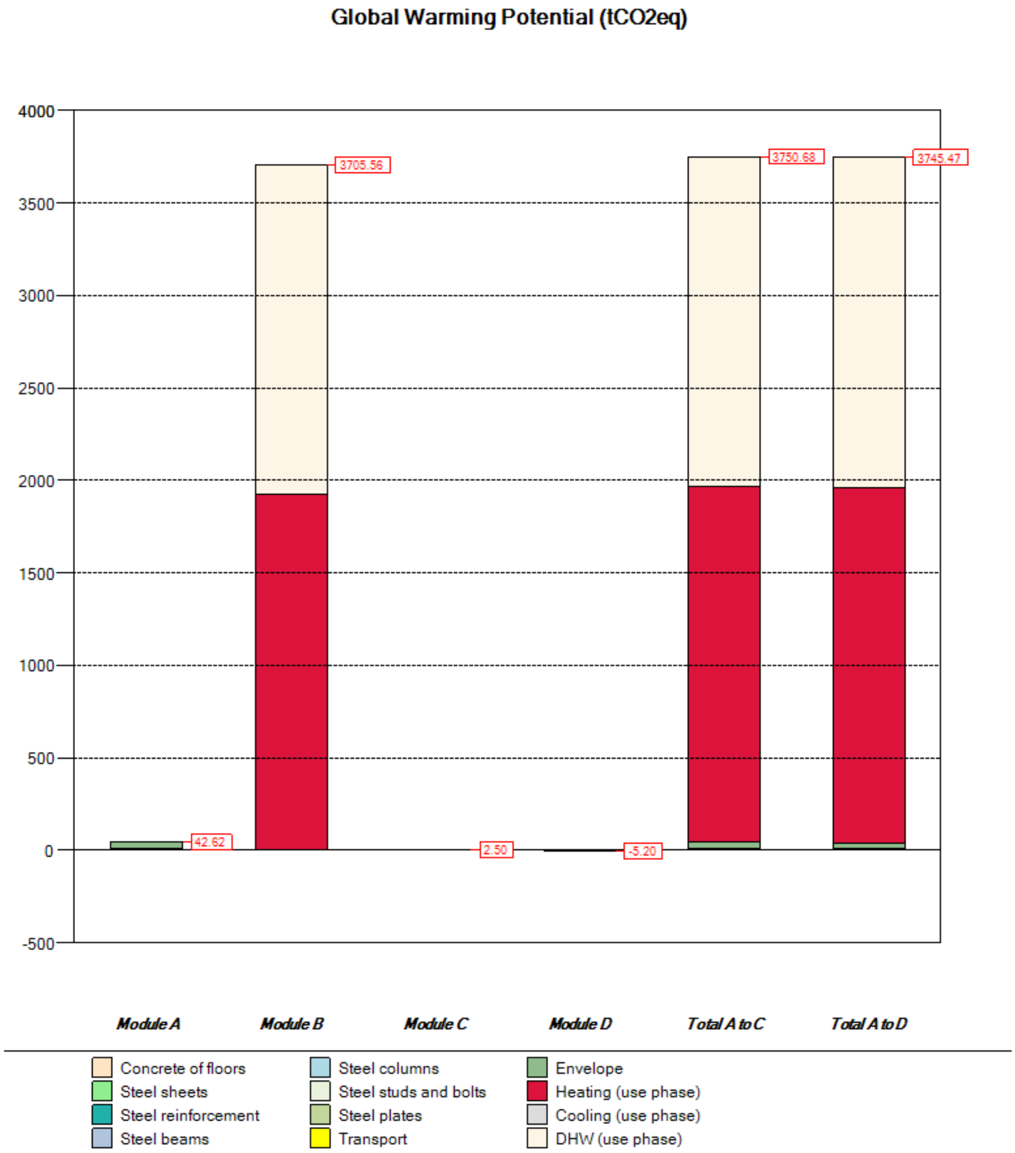
7.2.3 Results of calculation with AMECO3

The table summing up all the results for all impacts through the whole life cycle of CasaBuna dwelling is shown here under:

Synthesis of results for CasaBuna dwelling

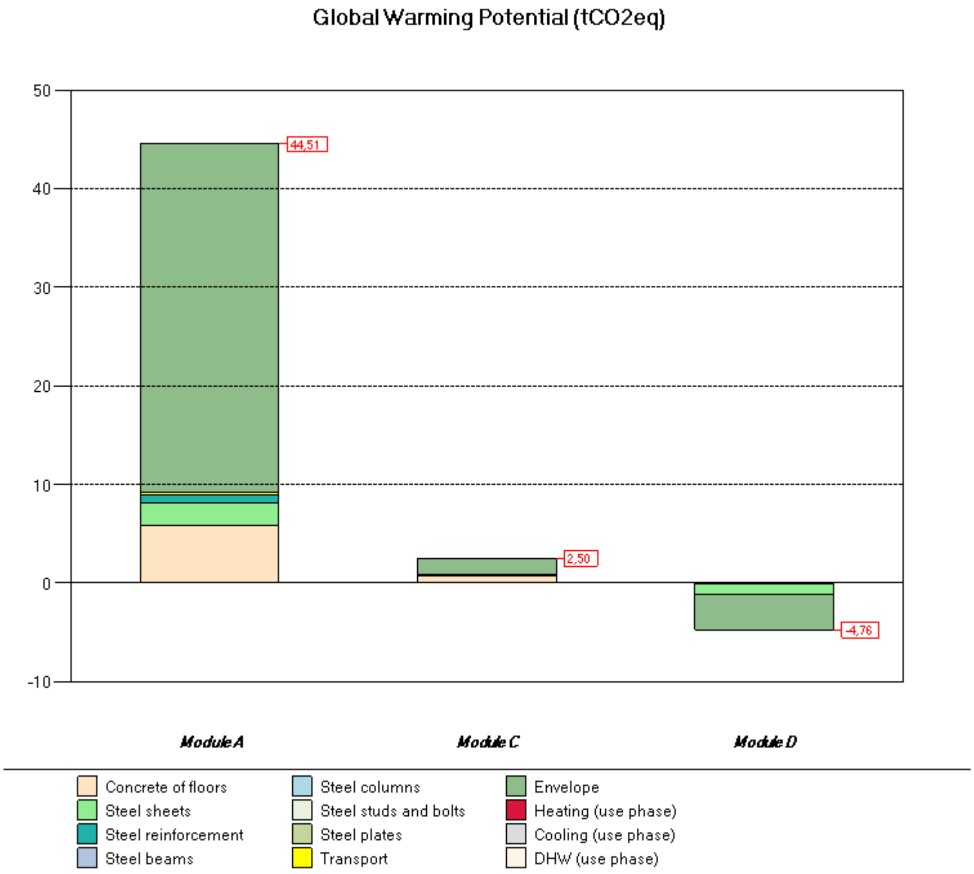
	Module A	Module B	Module C	Module D	Total A to C	Total A to D
GWP (tCO2eq)	42.62	3705.56	2.50	-5.20	3750.68	3745.47
ODP (tCFCeq)	5.40E-07	1.92E-06	1.68E-07	1.04E-07	2.63E-06	2.73E-06
AP (tSO2eq)	1.68E-01	1.48E01	6.82E-03	-1.54E-02	1.50E01	1.50E01
EP (tPO4eq)	1.60E-02	7.56E-01	1.80E-03	-5.05E-04	7.74E-01	7.74E-01
POCP (tEtheneeq)	1.66E-02	1.88E00	1.19E-03	-3.06E-03	1.90E00	1.90E00
ADP-e (tSbeq)	8.55E-05	7.15E-04	1.06E-06	-4.81E-05	8.02E-04	7.54E-04
ADP-ff (GJ NCV)	425.87	230888.89	19.13	-81.51	231333.89	231252.38
RPE (GJ NCV)	304.22	6191.49	3.87	-70.42	6499.58	6429.16
RER (GJ NCV)	81.29	0.00	0.25	1.96	81.53	83.49
RPE-total (GJ NCV)	7.11	6191.49	0.35	0.59	6198.95	6199.54
Non-RPE (GJ NCV)	138.18	38193.48	17.25	-11.15	38348.92	38337.77
Non-RER (GJ NCV)	0.66	192789.01	0.00	0.00	192789.67	192789.67
Non-RPE-total (GJ NCV)	138.85	230982.49	17.25	-11.15	231138.59	231127.44
SM (t)	52.68	0.00	0.00	0.00	52.68	52.68
RSF (GJ NCV)	1.79	1.98	0.00	0.00	3.77	3.77
Non-RSF (GJ NCV)	18.87	20.80	0.00	0.00	39.67	39.67
NFW (1000 m3)	1281.53	8049.61	139.52	-29.94	9470.66	9440.73
HWD (t)	5.94E-04	0.00E00	0.00E00	-1.17E-05	5.94E-04	5.82E-04
Non-HWD (t)	38.17	8431.51	1.25	-3.07	8470.93	8467.86
RWD (t)	3.11E-03	5.45E00	3.91E-06	-3.93E-04	5.45E00	5.45E00
CR (t)	0.00	0.00	0.00	0.00	0.00	0.00
MR (t)	0.00	0.00	0.00	0.76	0.00	0.76
MER (t)	0.00	0.00	0.00	0.00	0.00	0.00
EE (t)	0.00	0.00	0.00	0.00	0.00	0.00

The results show that the use phase is predominant for all impacts. Focusing on the Global Warming Potential impact, shown in the following graph, the use phase accounts for more than 99% of the total GWP impacts (module A to D) of the building.The structural system impacts are nearly neglectable.


Global Warming Potential (tCO2eq)
4000
3500
3000
2500
2000
1500
1000
500
0
-500
42.62
3705.56
2.50
-5.20
3750.68
3745.47
Module A
Module B
Module C
Module D
Total A to C
Total A to D
Concrete of floors
Steel sheets
Steel reinforcement
Steel beams
Steel columns
Steel studs and bolts
Steel plates
Transport
Envelope
Heating (use phase)
Cooling (use phase)
DHW (use phase)

CasaBuna dwelling		GWP (tCO2eq)
Module A	Concrete of floors	5.80
	Steel sheets	2.26
	Steel reinforcement	0.87
	Steel beams	0.00
	Steel columns	0.00
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	0.23
	Envelope	33.46
	Module A	**42.62**
Module B	Energy need for space heating	1922.38
	Energy need for space cooling	0.00
	Energy need for DHW production	1783.18
	Module B	**3705.56**
Module C	Concrete of floors	0.77
	Steel sheets	0.01
	Steel reinforcement	0.04
	Steel beams	0.00
	Steel columns	0.00
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	0.00
	Envelope	1.68
	Module C	**2.50**
Module D	Concrete of floors	-0.01
	Steel sheets	-1.15
	Steel reinforcement	0.00
	Steel beams	0.00
	Steel columns	0.00
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	0.00
	Envelope	-4.04
	Module D	**-5.20**
Total A to C	**Total A to C**	**3750.68**
Total A to D	**Total A to D**	**3745.47**

Focusing on the GWP impacts of the production of the materials only (module A), we can see that 79% of the total impact is due to the envelope components, including facade, roof and windows.



The energy consumption of the building is 15.6 kWh/m²y.

Use phase heating

Energy for space heating					
Heat transfer by transmission					
Walls	Glazing	Ext Floor	Roof	Ground	Total
kWh/year	kWh/year	kWh/year	kWh/year	kWh/year	kWh/year
4845.1	5968.3	0.0	3328.8	3008.7	16882.1
Heat Transfer by ventilation			Heat gains		
Ventilation			Glazed	Opaque	Internal
kWh/year			kWh/year	kWh/year	kWh/year
8963.6			14064.4	783.0	10757.0

Energy need for heating												
Qh,nd	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh	911.2	606.4	435.1	129.2	0.0	0.0	0.0	0.0	0.0	100.9	454.8	816.6
kWh/m²	4.1	2.7	2.0	0.6	0.0	0.0	0.0	0.0	0.0	0.5	2.1	3.7

Energy Breakdowns		
Building totals for heating		
Energy need	3454.2	kWh/year
	15.6	kWh/m²/year
Delivered energy	3970.4	kWh/year
COP : 0.87	18.0	kWh/m²/year
Primary	341.5	kgoe/year
fconv : 0.086	1.5	kgoe/m²/year

Given that the use phase accounts for more than 99%, this case study highlights the benefit of high thermal performance of envelope components, in order to decrease the impacts of the use phase. This will allow to reduce the overall environmental impacts over the whole life cycle of the building.

7.3 Industrial hall

7.3.1 Scope of the study

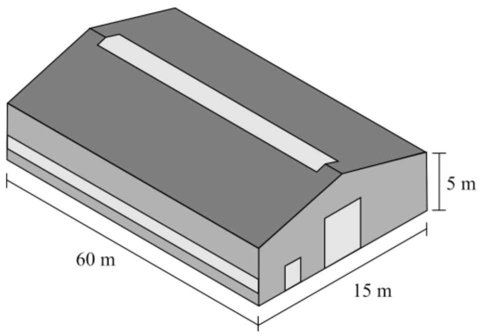
The objective of the study is to assess and compare the environmental impacts of an industrial building, based on 2 different structural systems:

- Pinned-base portal frame, composed of hot rolled profiles
- Rigid-base columns, pinned girder, composed of reinforced concrete columns & girder

Two different grades will be taken into account in the calculation of the steel structural system.

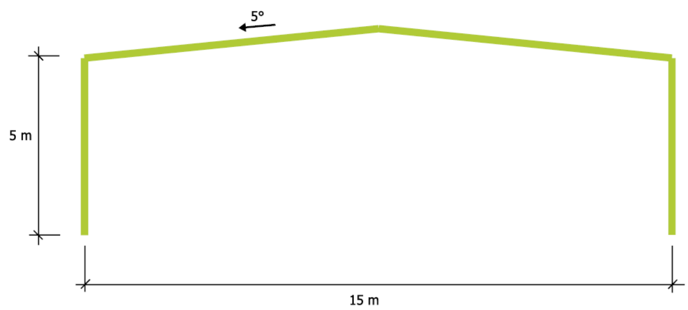
7.3.2 Description of the building

The single storey building is a 900m² industrial hall and can be seen at the following figure:



7.3.3 Structural system

The structural frames span on 15 m and the bay distance between each portal is 6m. The height is 5 m and the roof pitch is 5°, as shown in the following figure:



The structural components for the 3 variants of systems are described in the following table:

Structural component	Variant 1 Steel frame S235	Variant 2 Steel frame S460	Variant 3 Concrete frame
Girder	IPE 450	IPE 330	Precast concrete unit T80
			Reinforcement BSt500 202.5 kg/m³
Columns	Primary : IPE400 Secondary : HEA480	Primary : IPE400 Secondary : HEA480	Concrete section 0.4x0.4m C30/37
			Reinforcement BSt500 108.1 kg/m³

A picture of the steel structural system is shown below.

The buildings are designed in climatic region of Paris.

The base floor is a reinforced concrete slab on ground floor, with perimeter insulation.

The bill of the structural materials is detailed in the table below.

Structural component	Variant 1 Steel frame S235	Variant 2 Steel frame S460	Variant 3 Concrete frame
Girder	6.88 t	4.33 t	Concrete : 34.19 t
			Reinforcement : 2.93 t
Columns	4.17 t	4.17 t	Concrete : 30.12 t
			Reinforcement : 1.38 t
Studs	/	/	/
Bolts	43 kg	43 kg	/
Plate connections	336 kg	336 kg	/
Base floor	Concrete : 425.7 kg	Concrete : 425.7 kg	Concrete : 425.7 kg
	14.4 t	14.4 t	14.4 t

7.3.4 Envelope components

The facade is composed of 80 mm Polyurethane sandwich panel, but the thickness of the facade component will be increase up to 200mm thick in order to see the influence on the environmental results.

The pitched roof (5°) is made of supporting steel sheets of 1mm thick, and 140mm of mineral wool.

The windows are made of double glazing and Aluminium frame.

The following table gives the U-value of the building elements.

WALLS : PU sandwich panels **Thickness : 80mm** **Thickness : 200mm**	 0.33 0.12	W/m².K
ROOF	0.31	W/m².K
WINDOWS	2.6	W/m².K
BASE FLOOR	0.44	W/m².K

The internal heat capacity of the envelope elements are described below.

Base floor 0.2 m of concrete	460000	J/m²K
Intermediate floor	0	J/m²K
Interior walls	0	J/m²K

7.3.5 HVAC systems

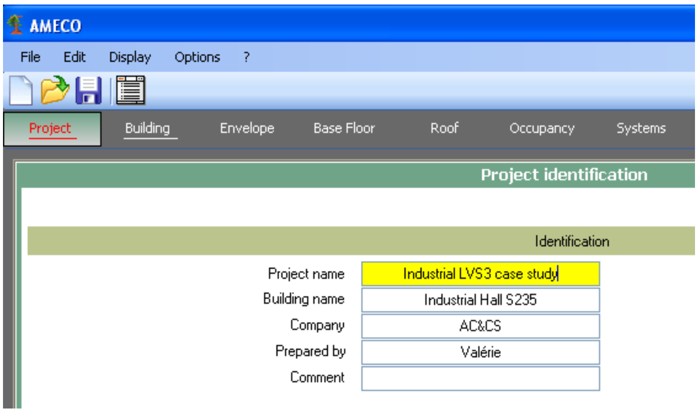
The heating system is a gas fuel heater, based on set-points temperature of 20°C. Neither cooling system nor mechanical ventilation nor domestic hot water system is implemented in the building.

7.3.6 Main hypothesis

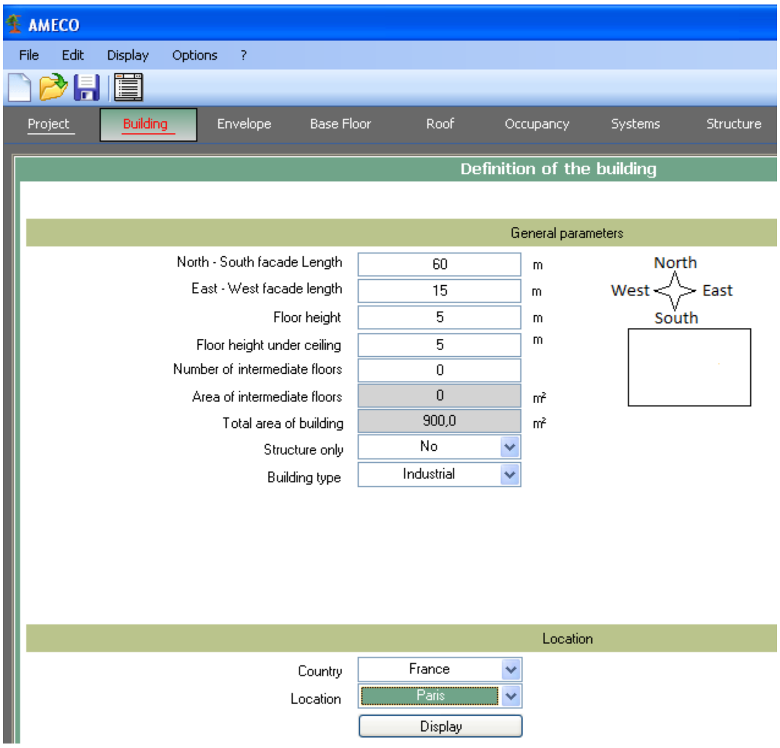
The foundations are excluded from the present study, as well as partitions and doors. The light work, such as internal finishing, and the furniture are also excluded from the analysis. Only extra losses due to integrated thermal bridges are included in the energy consumption of the building.

7.3.7 Input data in AMECO3 software

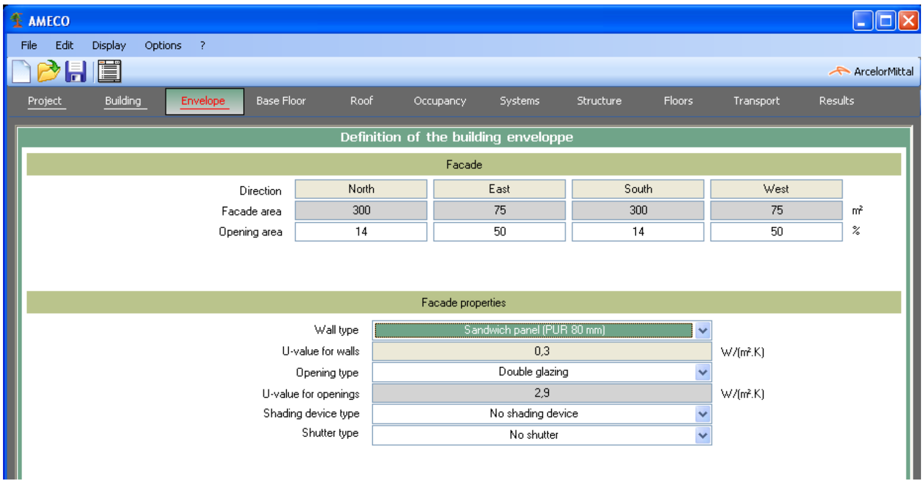
7.3.7.1 General data input of the industrial building in AMECO3

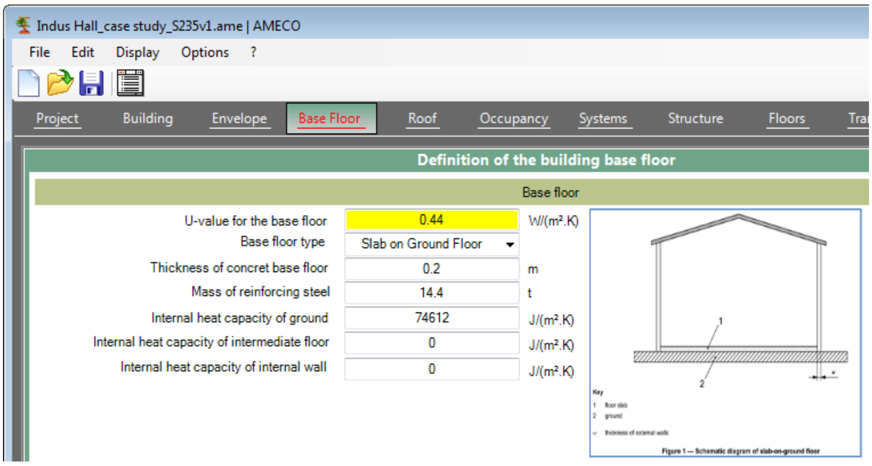


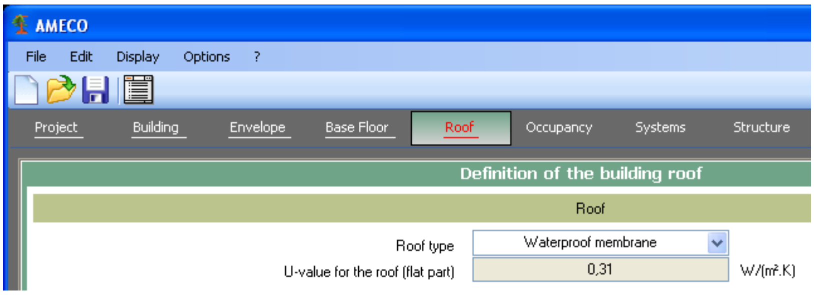
7.3.7.2 Data input for the geometry (Modules A-C-D)



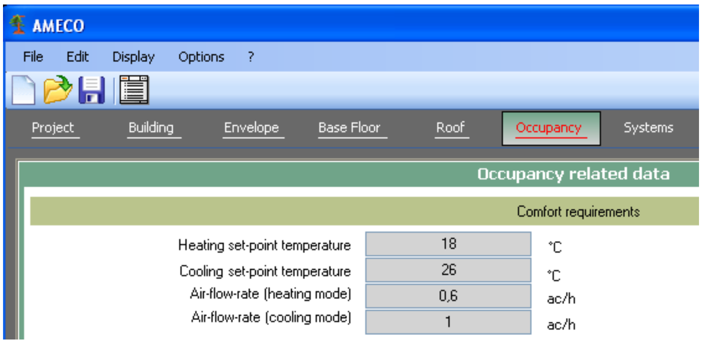
7.3.7.3 Input data for the components of the building (Module A-B-C-D)

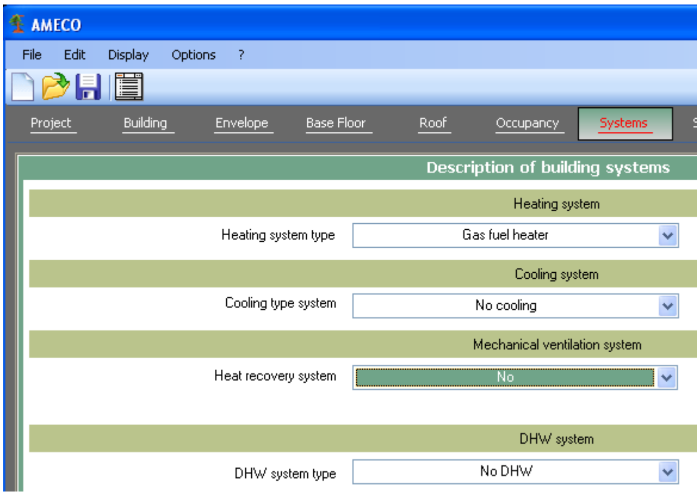






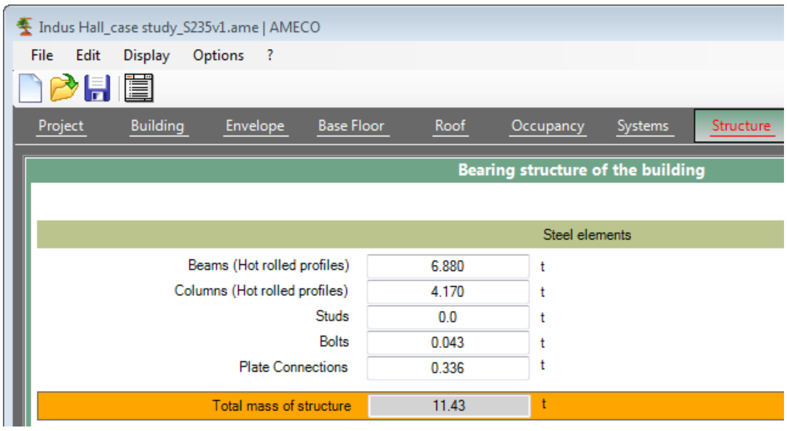
7.3.7.4 Input data for the use phase of the building (Module B)



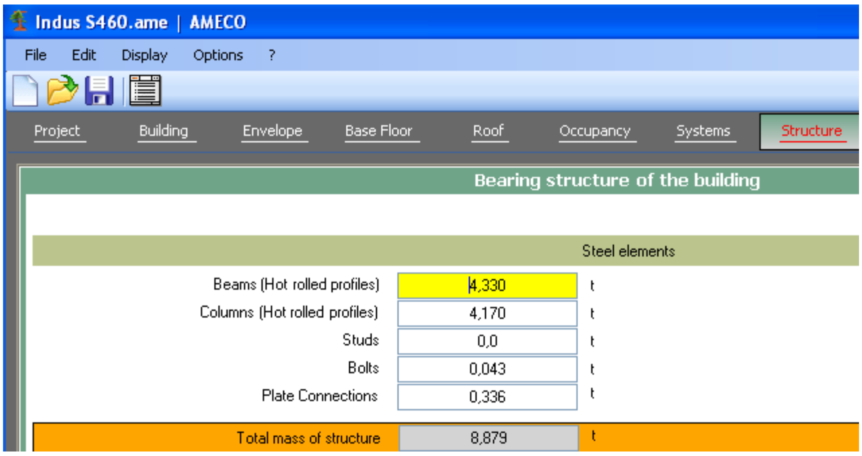


7.3.7.5 General data for the structure of the building (Module A-C-D)

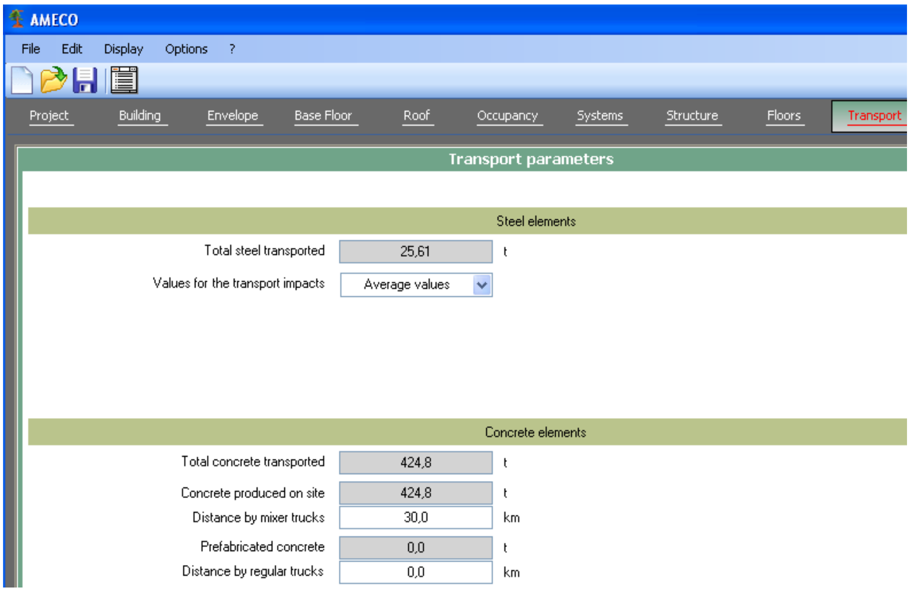
For the industrial hall S235:



For the industrial hall S460:



7.3.7.6 Data for the transportation of elements (Module A)



7.3.8 Results of calculation with AMECO3

7.3.8.1 S235 steel structural system

The table below shows the results for each environmental impact of the building based on the structural system with a grade of S235.

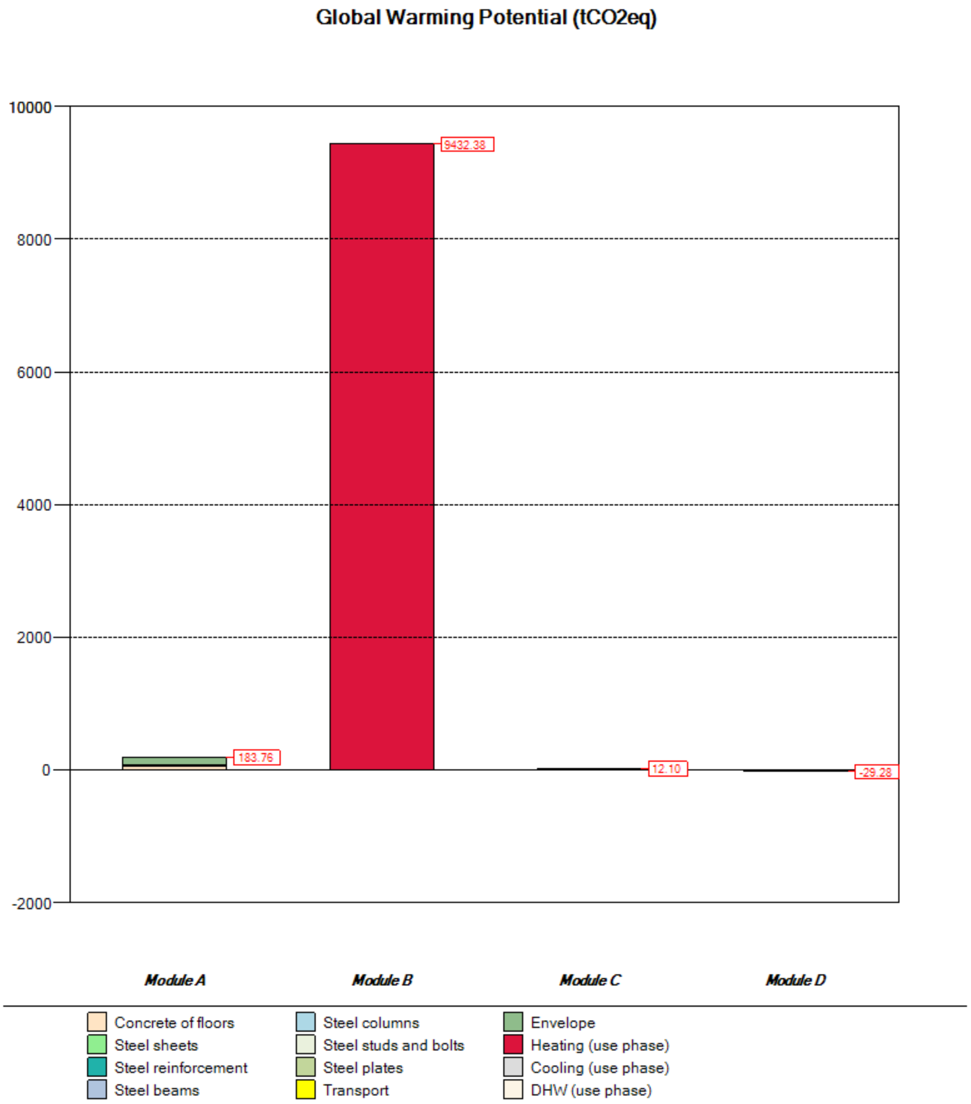
Synthesis of results for Industrial hall

	Module A	Module B	Module C	Module D	Total A to C	Total A to D
GWP (tCO2eq)	183.76	9432.38	12.10	-29.28	9628.25	9598.97
ODP (tCFCeq)	1.09E-06	1.55E-06	1.42E-06	7.58E-07	4.06E-06	4.82E-06
AP (tSO2eq)	5.26E-01	3.14E01	5.03E-02	-7.53E-02	3.19E01	3.19E01
EP (tPO4eq)	6.40E-02	1.53E00	1.69E-02	-2.80E-03	1.61E00	1.61E00
POCP (tEtheneeq)	5.92E-02	6.80E00	8.53E-03	-1.51E-02	6.87E00	6.86E00
ADP-e (tSbeq)	1.75E-03	2.30E-03	8.20E-06	-2.54E-04	4.07E-03	3.81E-03
ADP-ff (GJ NCV)	2041.70	978869.63	138.42	-285.35	981049.75	980764.40
RPE (GJ NCV)	1285.91	4687.50	6.33	-264.44	5979.75	5715.31
RER (GJ NCV)	47.75	0.00	0.00	13.72	47.75	61.47
RPE-total (GJ NCV)	68.65	4687.50	2.91	-0.65	4759.06	4758.41
Non-RPE (GJ NCV)	887.83	98391.18	148.73	-22.75	99427.74	99404.99
Non-RER (GJ NCV)	2.43	880547.69	0.00	0.00	880550.12	880550.12
Non-RPE-total (GJ NCV)	890.26	978938.87	148.73	-22.75	979977.86	979955.11
SM (t)	444.40	0.00	0.00	-0.94	444.40	443.46
RSF (GJ NCV)	14.61	6.56	0.00	0.00	21.18	21.18
Non-RSF (GJ NCV)	153.83	69.05	0.00	0.00	222.88	222.88
NFW (1000 m3)	30396.65	6075.63	157.18	-100.49	36629.47	36528.98
HWD (t)	4.53E-03	0.00E00	0.00E00	-9.19E-05	4.53E-03	4.44E-03
Non-HWD (t)	276.33	6464.29	5.42	-4.14	6746.03	6741.89
RWD (t)	2.37E-02	4.04E00	1.65E-05	-8.53E-04	4.06E00	4.06E00
CR (t)	0.00	0.00	0.00	1.11	0.00	1.11
MR (t)	0.00	0.00	0.00	0.33	0.00	0.33
MER (t)	0.00	0.00	0.00	0.00	0.00	0.00
EE (t)	0.00	0.00	0.00	0.00	0.00	0.00

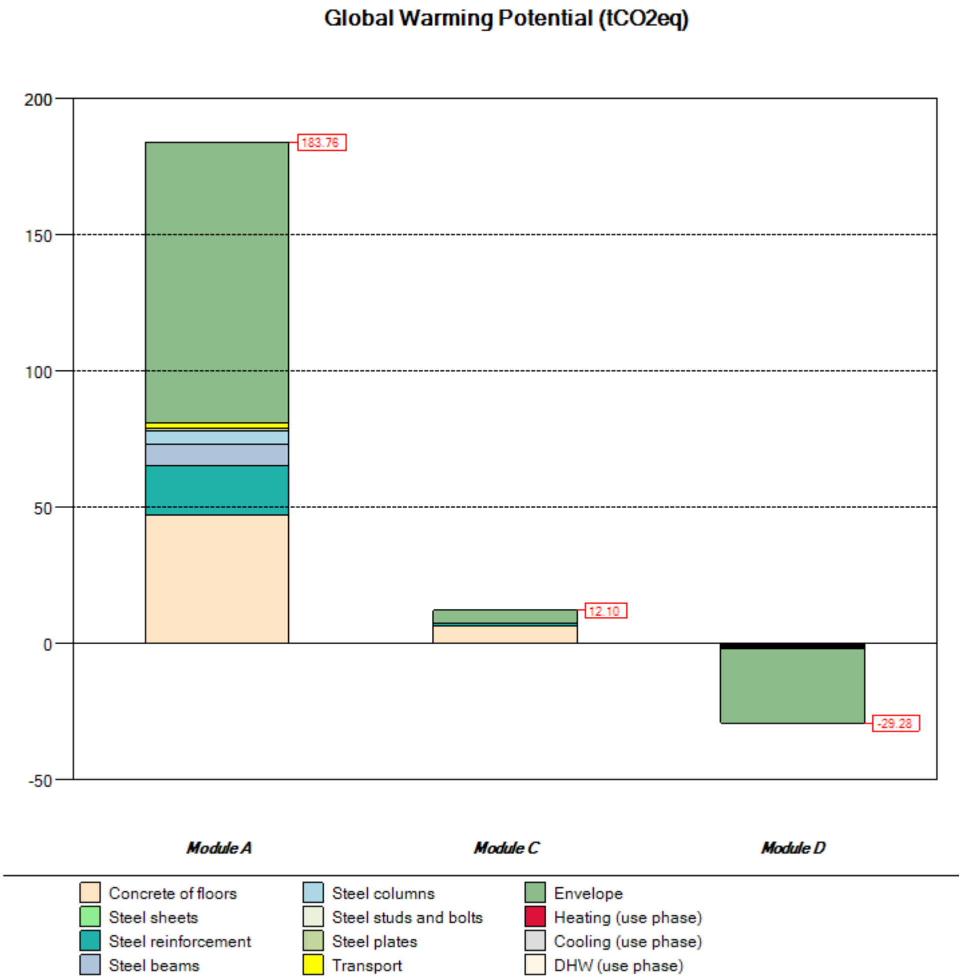
We can see that the impacts of Module B are predominant for each impact.

The details of the GWP impact for each type of building component including transport are detailed below.

The module B accounts for about 99% of the global GWP impact (inc. Module A to D) for this building based on the steel S235 structural system, as highlighted by the following graph:



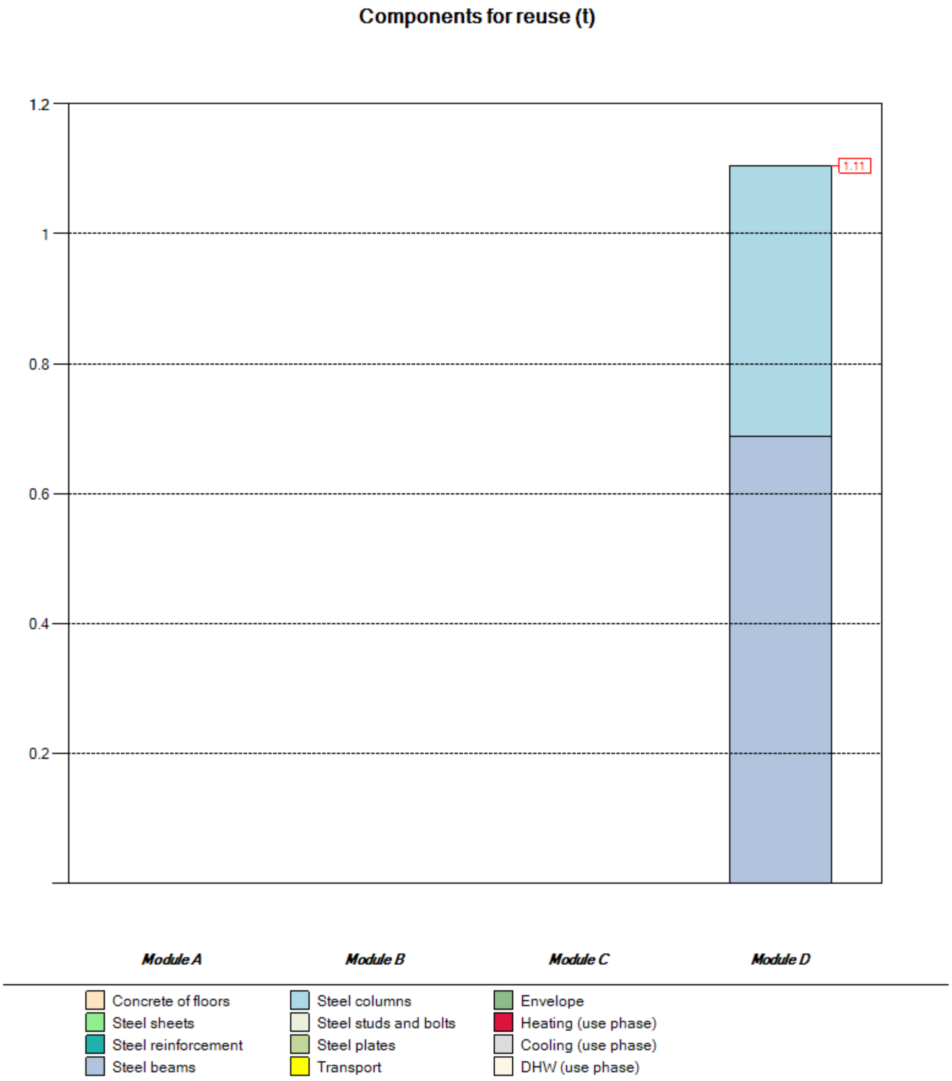
The GWP impacts due to the materials used to erect the building, such as the structural system and the envelope components, are shown on the graph below:



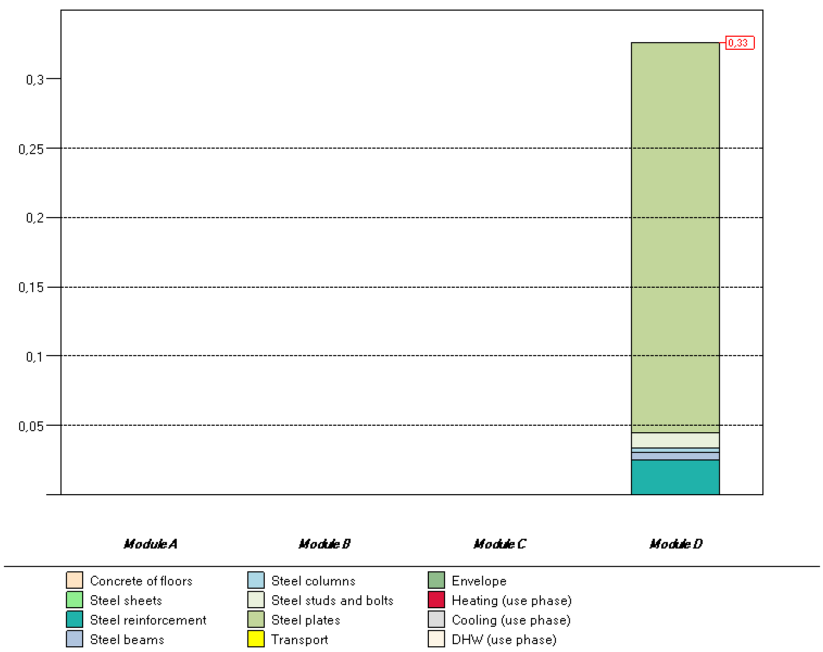
We can see that for module A, the envelope materials accounts for 56% of the total GWP impact.

The GWP impact of the structural system is 78.6 tCO_2-eq and the GWP impacts due to the concrete of floors is equal to 47.31 tCO2-eq, which represents 60% of the GWP impacts of the global structural system.

Module D highlights the benefits of the end-of-life of building components, which can be either through the reuse of components, or material recycling, as shown on the graphs below.



Materials for recycling (t)



The heating energy consumption is equal to 19 kWh/m²y and detailed in the table below.

Use phase heating

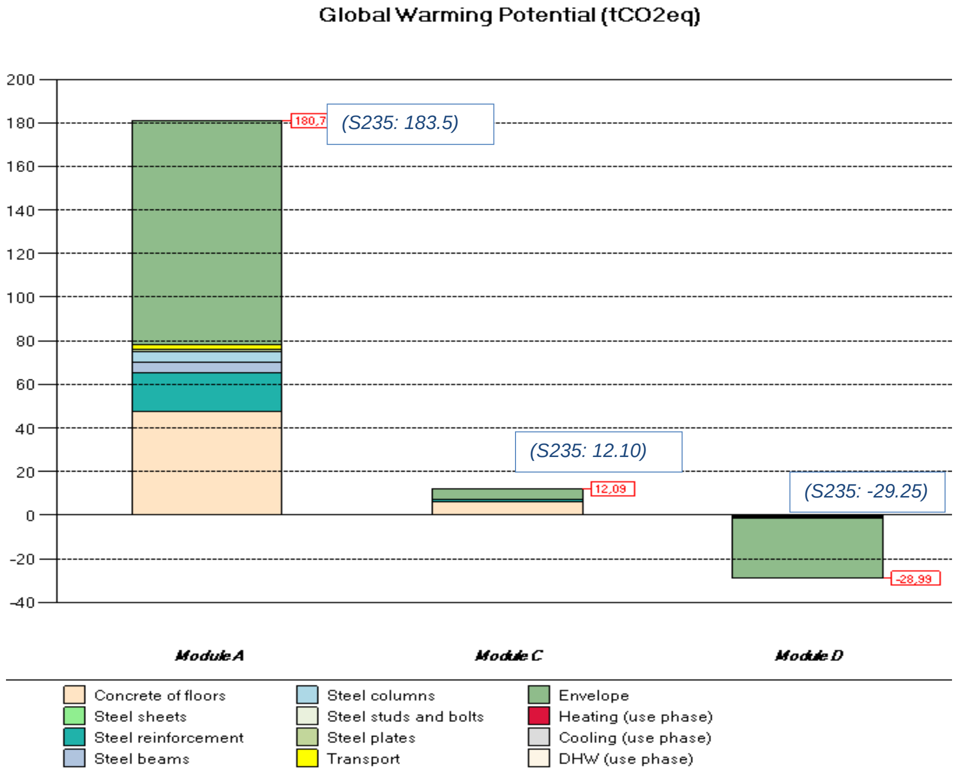
Energy for space heating					
Heat transfer by transmission					
Walls	Glazing	Ext Floor	Roof	Ground	Total
kWh/year	kWh/year	kWh/year	kWh/year	kWh/year	kWh/year
11050.9	28739.9	0.0	17389.8	11212.7	66993.5
Heat Transfer by ventilation			Heat gains		
Ventilation			Glazed	Opaque	Internal
kWh/year			kWh/year	kWh/year	kWh/year
52169.4			42631.5	1661.1	64941.9

Energy need for heating												
Qh,nd	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh	3642.1	3040.8	2279.5	1099.0	8.5	0.0	0.0	0.0	0.0	755.8	2582.3	3540.6
kWh/m²	4.0	3.4	2.5	1.2	0.0	0.0	0.0	0.0	0.0	0.8	2.9	3.9

Energy Breakdowns		
Building totals for heating		
Energy need	16948.6	kWh/year
	18.8	kWh/m²/year
Delivered energy	19481.1	kWh/year
COP : 0.87	21.6	kWh/m²/year
Primary	1675.4	kgoe/year
fconv : 0.086	1.9	kgoe/m²/year

7.3.8.2 S460 steel structural system

Increasing the steel grade allows reducing the total weight of the steel structure : from 6.66t of S235 steel down to 4.33t, which makes a total reduction of 2.33t of steel structural elements. Then, this involves a reduction of the total GWP impacts of the module A, C & D.



The GWP impact of the steel structural system due the increase of the steel grade is 10.69 tCO_2-eq, allowing a net reduction of 2.69 tCO2-eq compared to the GWP impacts of the S235 steel system.

The GWP impacts due to the envelope components accounts for 57% of the total impact of the module A, which is similar to the ratio obtained by the S235 structural system.

The details of the GWP impacts due to the S460 structural system is shown below :

Detailed results

Global Warming Potential

	Module A tCO2eq	Module B tCO2eq	Module C tCO2eq	Module D tCO2eq	Total A to C tCO2eq	Total A to D tCO2eq
Steel total	28.60	0.00	0.97	-1.44	29.57	28.13
Beams	5.00	0.00	0.03	-0.49	5.03	4.54
Columns	4.81	0.00	0.03	-0.47	4.84	4.37
Studs and bolts	0.05	0.00	0.00	-0.02	0.05	0.04
Plates connections	0.83	0.00	0.00	-0.43	0.83	0.40
Concrete total	47.31	0.00	6.29	-0.12	53.61	53.49
Concrete slabs	47.31	0.00	6.29	-0.12	53.61	53.49
Envelope	102.75	0.00	4.83	-27.43	107.58	80.15
Use phase total	0.00	9432.38	0.00	0.00	9432.38	9432.38
Heating	0.00	9432.38	0.00	0.00	9432.38	9432.38
Cooling	0.00	0.00	0.00	0.00	0.00	0.00
DHW	0.00	0.00	0.00	0.00	0.00	0.00
Transport	2.09	0.00	0.00	0.00	2.09	2.09
Total impact of module	180.76	9432.38	12.09	-28.99	9625.23	9596.24

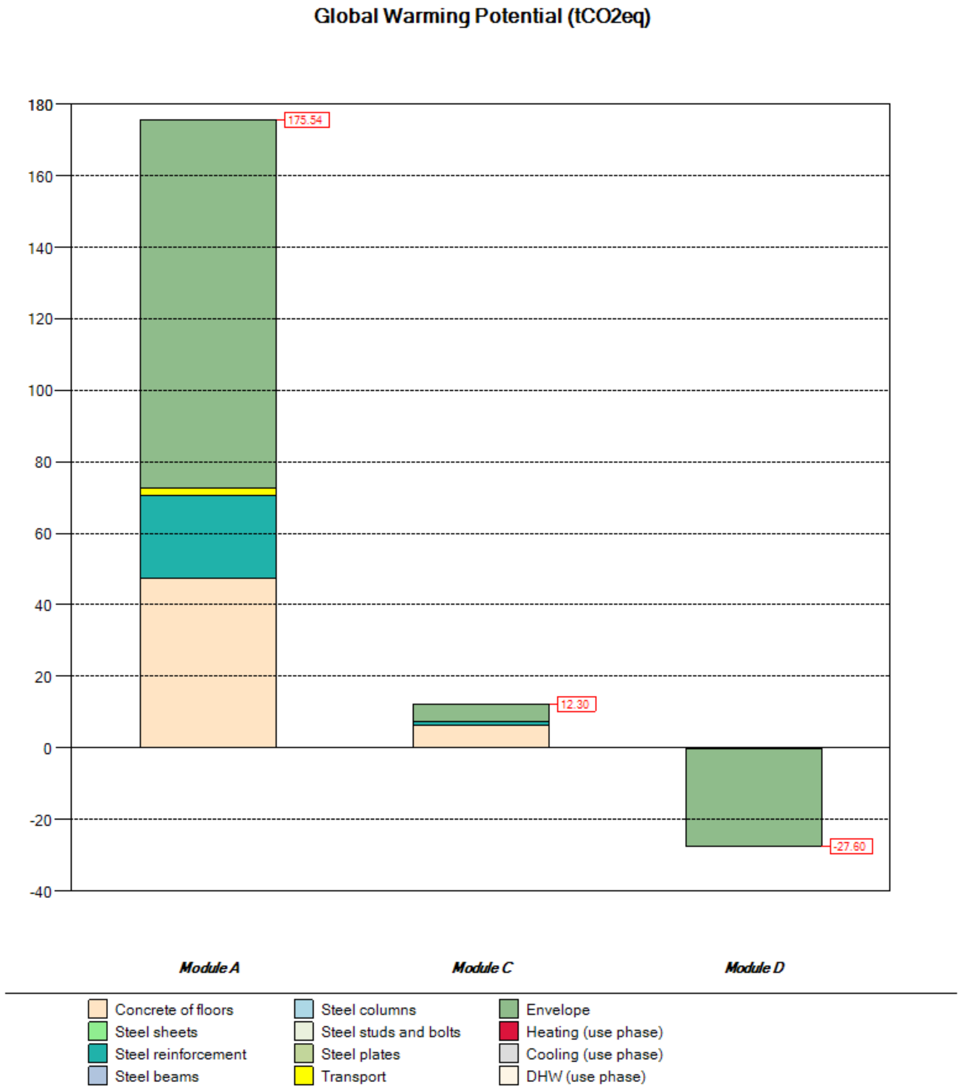
7.3.8.3 Concrete structural system

The table below sums up all the environmental impacts of the building made with a concrete structural system.

Industrial hall		GWP (tCO2eq)
Module A	Concrete of floors	47.31
	Steel sheets	0.00
	Steel reinforcement	23.26
	Steel beams	0.00
	Steel columns	0.00
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	2.21
	Envelope	102.75
	Module A	**182.70**
Module B	Energy need for space heating	9432.38
	Energy need for space cooling	0.00
	Energy need for DHW production	0.00
	Module B	**9432.38**
Module C	Concrete of floors	6.29
	Steel sheets	0.00
	Steel reinforcement	1.18
	Steel beams	0.00
	Steel columns	0.00
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	0.00
	Envelope	4.83
	Module C	**13.07**
Module D	Concrete of floors	-0.12
	Steel sheets	0.00
	Steel reinforcement	-0.05
	Steel beams	0.00
	Steel columns	0.00
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	0.00
	Envelope	-27.43
	Module D	**-27.69**
Total A to C	**Total A to C**	**9628.16**
Total A to D	**Total A to D**	**9600.47**

We can see that the impacts due to the use phase are there again predominant and equal to the ones obtained by the industrial steel buildings.

The GWP impacts per components and per module are detailed below.



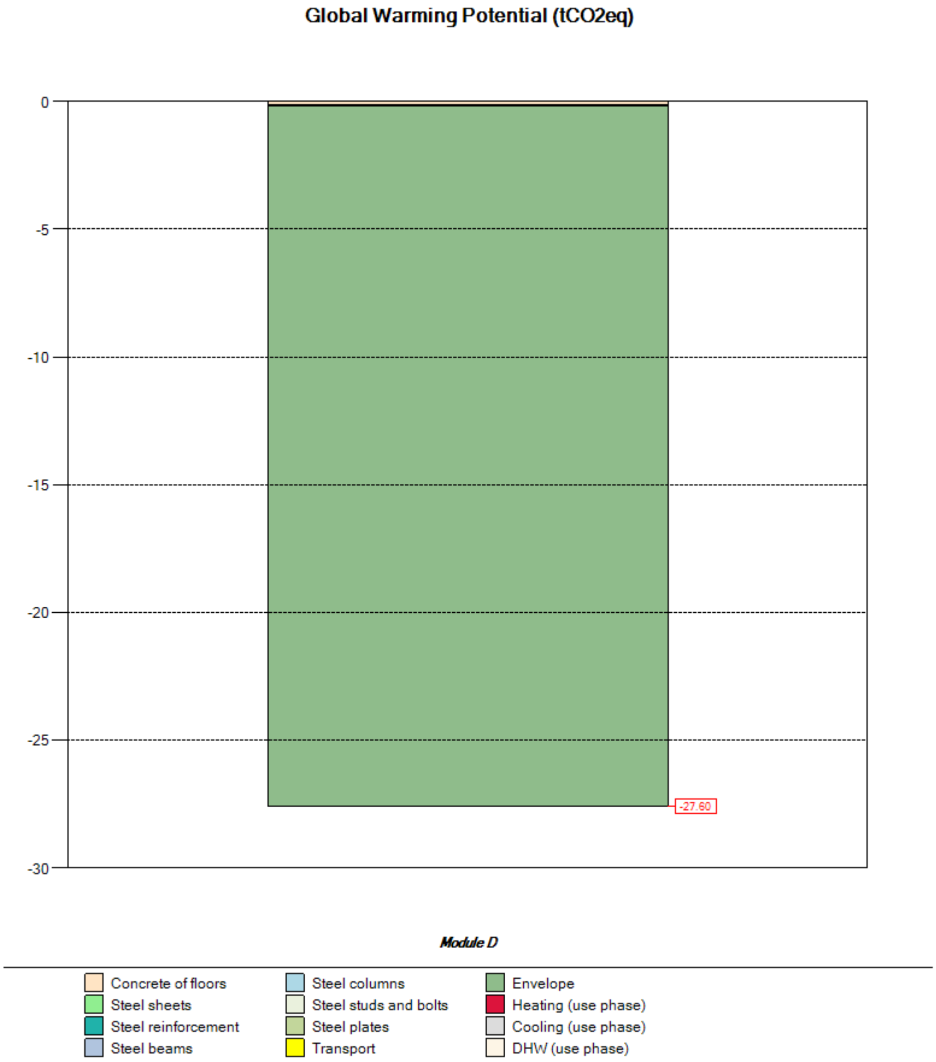
The module A has a total GWP impact of 182.7 tCO_2-eq. The total GWP impacts due to the structural system are equal to 79.95 tCO_2-eq, with 29% due to the rebars, as shown in the table below :

Global Warming Potential

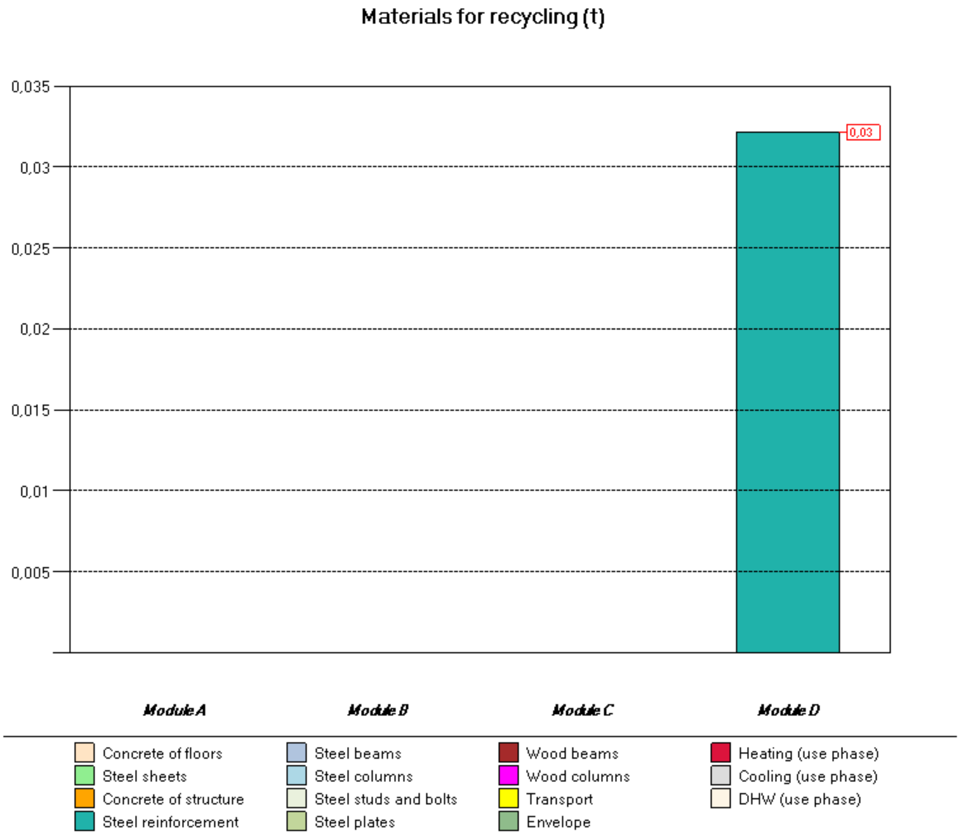
	Module A tCO2eq	Module B tCO2eq	Module C tCO2eq	Module D tCO2eq	Total A to C tCO2eq	Total A to D tCO2eq
Steel total	23.26	0.00	1.18	-0.05	24.44	24.39
Reinforcement	23.26	0.00	1.18	-0.05	24.44	24.39
Concrete total	54.48	0.00	7.06	-0.21	61.54	61.33
Concrete of structure	7.16	0.00	0.77	-0.09	7.93	7.84
Concrete slabs	47.31	0.00	6.29	-0.12	53.61	53.49
Envelope	102.75	0.00	4.83	-27.43	107.58	80.15
Use phase total	0.00	24590.14	0.00	0.00	24590.14	24590.14
Heating	0.00	24590.14	0.00	0.00	24590.14	24590.14
Cooling	0.00	0.00	0.00	0.00	0.00	0.00
DHW	0.00	0.00	0.00	0.00	0.00	0.00
Transport	2.21	0.00	0.00	0.00	2.21	2.21
Total impact of module	182.70	24590.14	13.07	-27.69	24785.91	24758.22

The concrete of floor account for 26% of the total GWP impacts of the module A.

The graph below shows the GWP impacts of the module D, highlighting the benefits of the recycled materials within the envelope elements: mainly light steel framing elements in facade components and steel sheet in the roof.

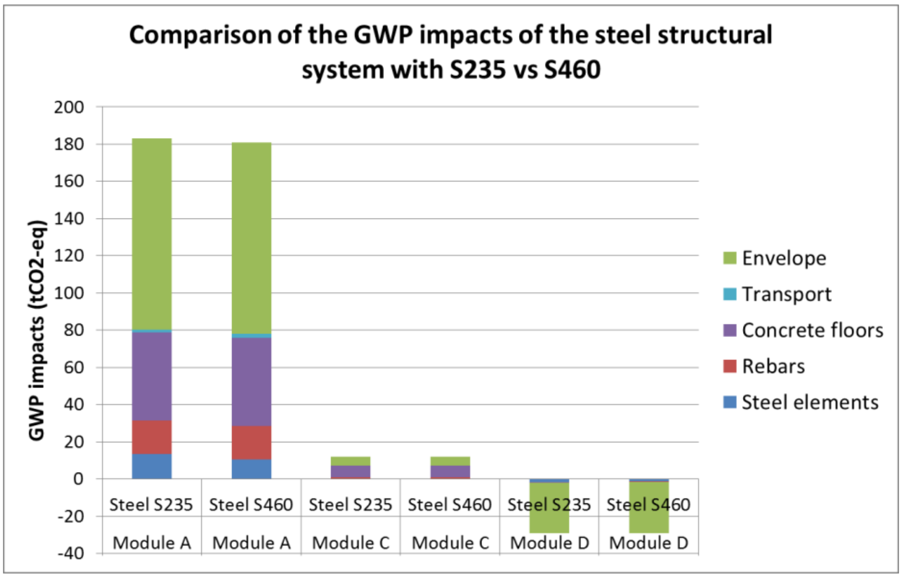


The materials that can be recycled represents 0.03 t, which is lower than the steel S235 building (0.33t).



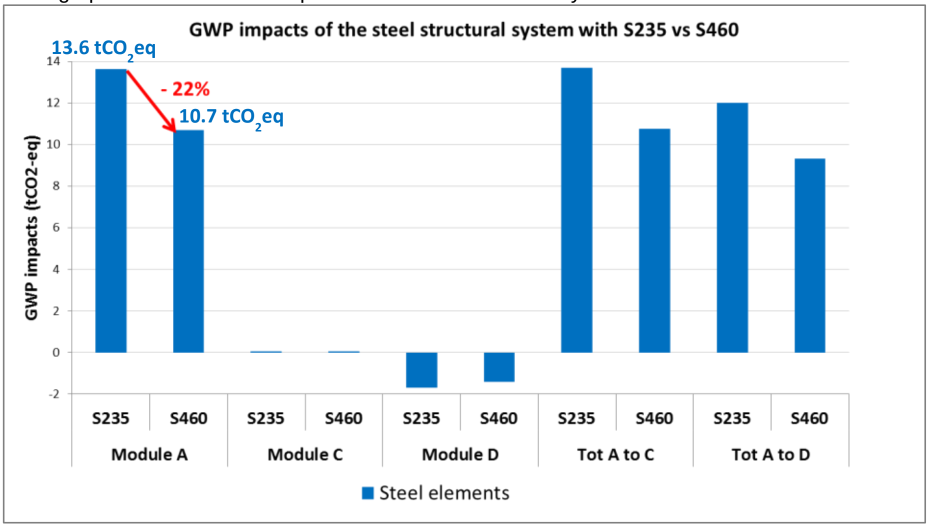
7.3.8.4 Comparison of the GWP impacts of the S235 vs S460 structural solutions

The graph below displays the GWP impacts of the structural system with Steel S235 compared to Steel S460 :



As previously said, the envelope materials accounts for about 56% of the total GWP impact of the product & process stage (module A).

The next graph shows the GWP impacts of the steel structural system :

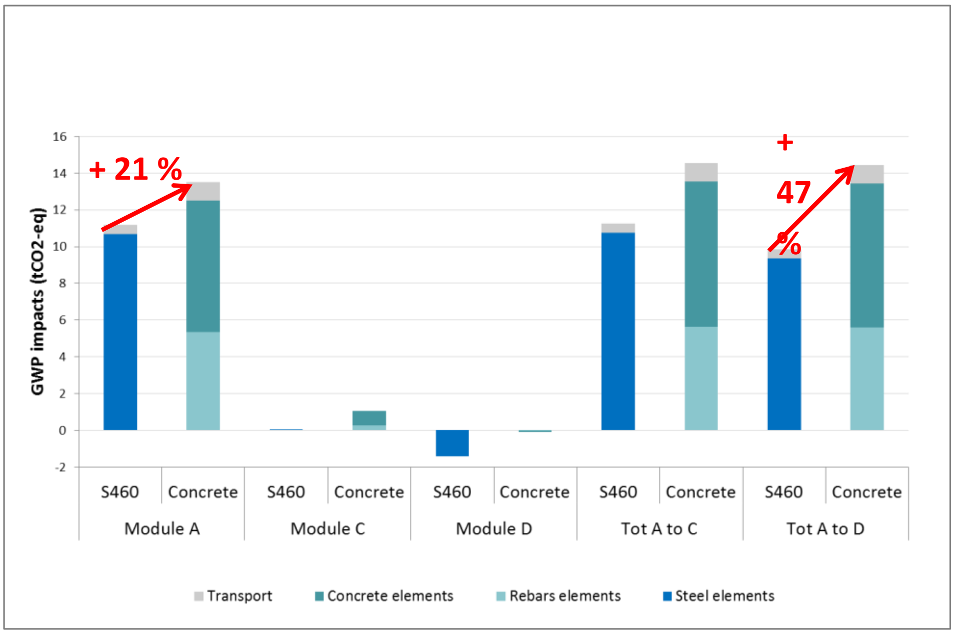


Increasing the steel grade allows a total weight reduction of 2.3 tons of steel structural elements and reducing 22% of tCO2eq for the module A of structural system.

7.3.8.5 Comparison of the GWP impacts of the steel S460 vs concrete structural systems.

The graph below shows the comparison of the total GWP impacts of the structural system made with steel S460 and concrete, in module A, C & D.

The details of the GWP impacts of each structural system are shown below:



We can see that the concrete structure solution involves an increasing of 47% of GWP in tCO2eq from modules A to D, and 21% of impacts due to the fabrication of materials.

This highlights that steel Structures made of hot rolled sections are more sustainable than concrete one, even without taking into account the recycling. Thanks to the recycling of materials at the End of Life (infinite recycling of steel and valorization of crushed concrete), the difference between steel and concrete solution increases.

7.3.9 Analysis of the environmental benefits due to increase of the insulation thickness

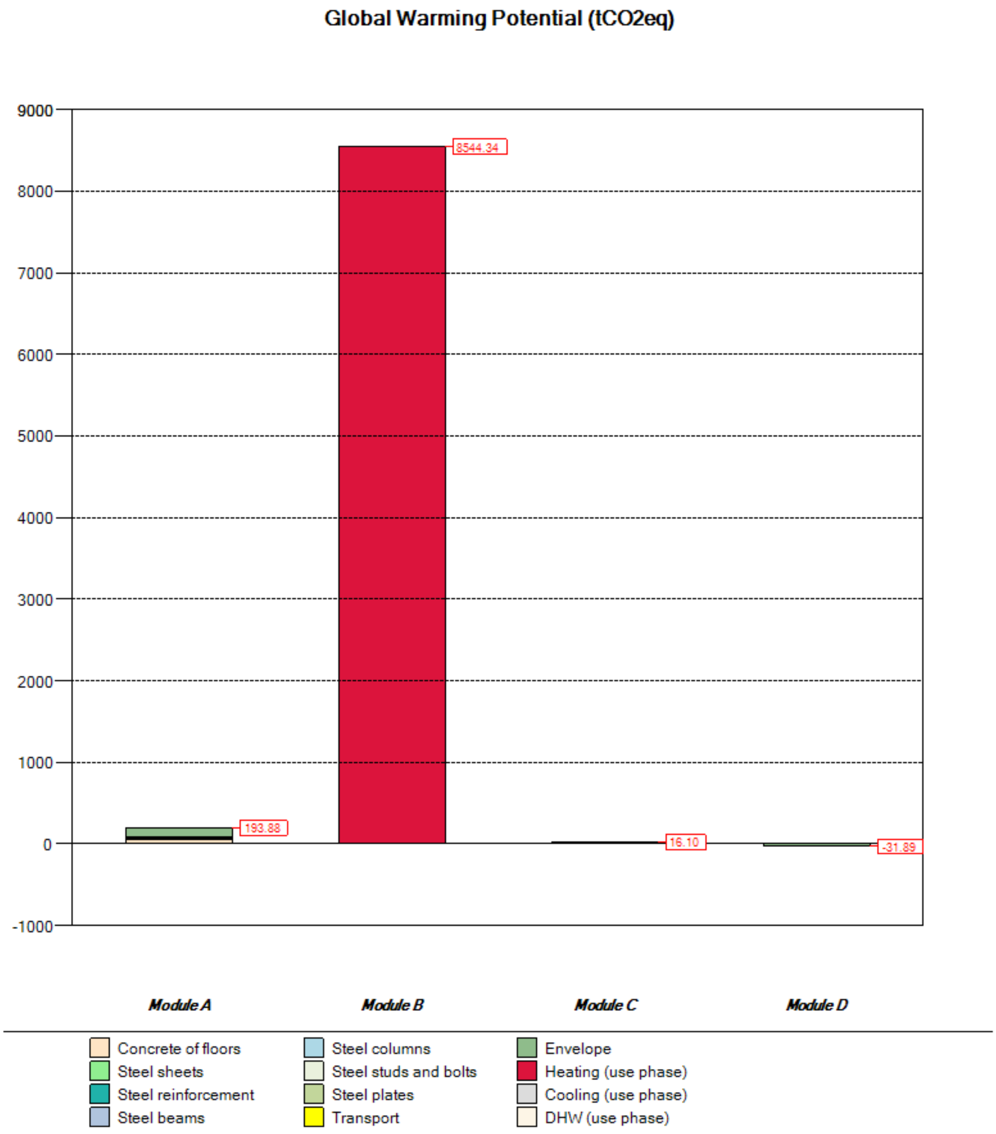
As described in the previous chapter, the use phase accounts for more than 99% of the total GWP impacts of the life cycle of the building.

In order to reduce drastically the energy consumptions and thus the environmental impacts of the building, one common solution is to improve the energy efficiency of the envelope components, by increasing the thickness of the insulation.

It is easy with AMECO to analyze the influence of such modifications.

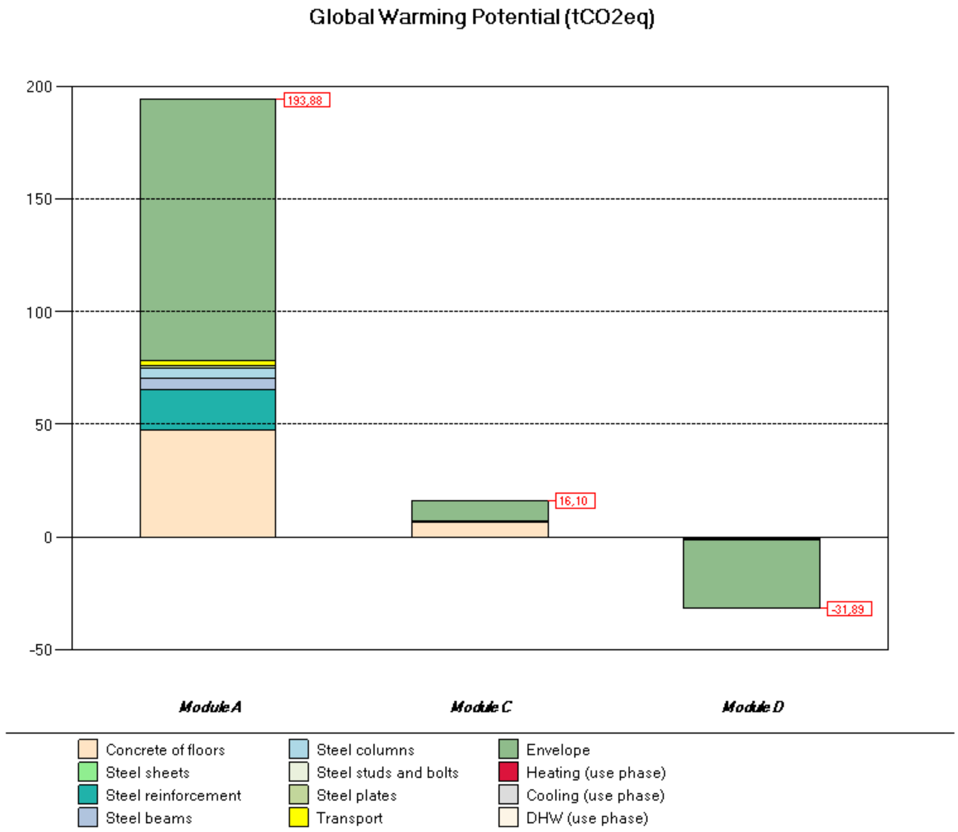
The thickness of the insulation of the façade component (sandwich panels in this case) equal to 80mm has been increased up to 200mm.

The GWP impacts for the use phase has reduced and allows a net saving of 888 tCO2-eq :



Industrial hall		GWP (tCO2eq)
Module A	Concrete of floors	47.31
	Steel sheets	0.00
	Steel reinforcement	17.91
	Steel beams	5.00
	Steel columns	4.81
	Steel studs and bolts	0.05
	Plate Connections	0.83
	Transport	2.09
	Envelope	115.87
	Module A	**193.88**
Module B	Energy need for space heating	8544.34
	Energy need for space cooling	0.00
	Energy need for DHW production	0.00
	Module B	**8544.34**
Module C	Concrete of floors	6.29
	Steel sheets	0.00
	Steel reinforcement	0.91
	Steel beams	0.03
	Steel columns	0.03
	Steel studs and bolts	0.00
	Plate Connections	0.00
	Transport	0.00
	Envelope	8.85
	Module C	**16.10**
Module D	Concrete of floors	-0.12
	Steel sheets	0.00
	Steel reinforcement	-0.04
	Steel beams	-0.49
	Steel columns	-0.47
	Steel studs and bolts	-0.02
	Plate Connections	-0.43
	Transport	0.00
	Envelope	-30.33
	Module D	**-31.89**
Total A to C	**Total A to C**	**8754.33**
Total A to D	**Total A to D**	**8722.44**

The extra amount of insulation increases the total of GWP impacts of module A, to 193.88 tCO_2-eq, which corresponds to an increase of 13.12 tCO_2-eq.

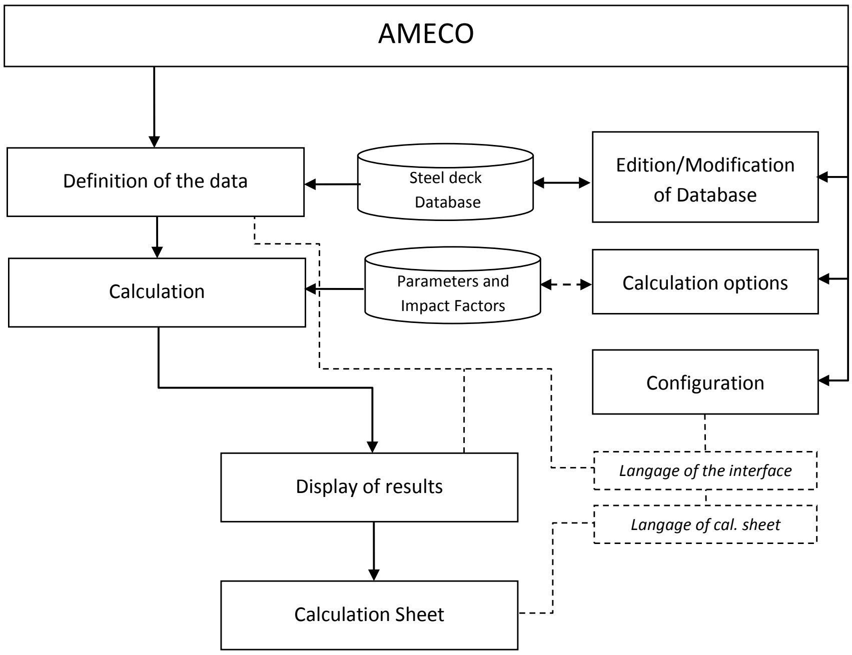


Compared to the energy consumption reduction, this is negligible, highlighting the interest of improving the energy efficiency of a building.

8 References

[1] P-O. MARTIN, AMECO SOFTWARE Technical Manual, report DRV/10-DRC-107/002-A, CTICM, 2010.
[2] C. THAUVOYE, AMECO 2 SOFTWARE Technical and Software Specifications, report DRV/12-DRV-123/001-A, CTICM, 2012.
[3] P. SANTOS, Excel sheet calculation, University of Coimbra, 2013
[4] BIO Intelligence Service, Evaluation de la Qualité Environnementale de Bâtiments Tertiaires – Aspects environnementaux, ArcelorMittal, Juillet 2013

Annex 1.Global Architecture of Ameco



Annex 2.Non climatic tables

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
m	1	2	3	4	5	6	7	8	9	10	11	12
MonthLength	2.6784	2.4192	2.6784	2.5920	2.6784	2.5920	2.6784	2.6784	2.5920	2.6784	2.5920	2.6784
MonthDay	31	28	31	30	31	30	31	31	30	31	30	31
NbDayWorking	23	20	21	22	23	20	23	22	21	23	21	22

Table 11 : MonthLength [10^6 s], MonthDay [days] and NbDayWorking [days] in the month *m*

Building type	Area 1		Area 2	
	Label	Default %	Label	Default %
RB	Living area	40	Other	60
OB	Office area	80	Other	20
CB	Shopping area	60	Other	40
IB	Hall	80	Other	20

Table 12 : Definitions of areas

Shutter type	R_{sh} [m2.K/W]	Permeability to air		
		Δrhigh	Δravg	Δrlow
		[m2.K/W]		
No shutter	0.00	0.00	0.00	0.00
Exterior aluminum roller shutter (no insulation)	0.01	0.00	0.12	0.00
Exterior opaque wood device (no insulation)	0.10	0.00	0.16	0.00
Exterior wood roller shutter (no insulation)	0.10	0.00	0.16	0.00
Exterior plastic roller shutter (no insulation)	0.10	0.00	0.16	0.00
Exterior wood venetian blinds	0.01	0.09	0.00	0.00
Exterior metal venetian blinds	0.01	0.09	0.00	0.00
Exterior opaque roller blind	0.01	0.09	0.00	0.00
Exterior translucid roller blind	0.01	0.09	0.00	0.00
Interior shutter	0.01	0.00	0.00	0.24
Interior opaque curtains	0.00	0.00	0.00	0.00
Interior transparent curtains	0.00	0.00	0.00	0.00
Interior opaque wood device	0.10	0.00	0.00	0.31
Roller shutters of plastic with foam filling	0.15	0.13	0.19	0.26
Shutters of wood, 25mm to 30mm thickness	0.20	0.14	0.22	0.30

Table 13 :$R_{sh}, \Delta R_{high}, \Delta R_{avg}, \Delta R_{low}$ additional thermal resistance at specific air permeability of shutters

	$\Delta\theta_{er}$
SUB-POLAR	9
INTERMEDIATE	11
TROPICS	13

Table 14 : average difference temperature between external air temp and sky temp (ISO 13790)

OpeningType	gn	U-value
Double glazing	0.78	2.9
Double glazing low-emissivity (type 1)	0.72	1.7
Double glazing low-emissivity (type 2)	0.67	1.4
Double glazing low-emissivity (type 3)	0.65	1.2

Table 15 : gn-solar energy transmittance for radiation perpendicular to the glazing, and U-value (source EN 15193)

Wall macro-component	U-Value	km
B2010.20.1a(rock wool)	0,296	13391
B2010.20.1b(EPS)	0,296	13391
B2010.20.1c(XPS)	0,296	13391
B2010.20.1d(PUR)	0,296	13391
B2010.20.1e(Cork)	0,296	13391
B2010.20.2a(Rock wool)	0,305	62047
B2010.20.2b(EPS)	0,305	62047
B2010.20.2c(XPS)	0,305	62047
B2010.20.2d(PUR)	0,305	62047
B2010.20.2e(Cork)	0,305	62047
B2010.20.2f(Glass wool)	0,305	62047

Table 16 :Wall type

Heating system efficiency	
Electric resistance	1
Gas Fuel Heater	0.87
Liquid Fuel Heater	0.8
Solid Fuel Heater	0.6
Split (Heating)	4

Table 17 : heating system efficiency

Cooling system efficiency	
Split (Cooling)	3
Refrigeration machine (compression cycle)	3
Refrigeration machine (absorption cycle)	0.8
No cooling	0.0

Table 18 : cooling system efficiency

DHW system efficiency	
Electric Boiler	0.9
Gas Boiler	0.6
Stand-alone Water Heater (condensation)	0.72
Stand-alone Water Heater	0.4
No DHW	0.0

Table 19 : DHW system efficiency

Energy type	
Electricity	0.29
Gas	0.086
Liquid fuel	0.086
Solid fuel	0.086
Biomass	0

Table 20 : Conversion factor to primary energy depending on the type of final energy

	Shading device color		
Shading device type	Light	Intermidiate	Dark
No shading device	1.00	1.00	1.00
Exterior opaque wood device (no insulation)	0.03	0.05	0.06
Exterior wood roller shutter (no insulation)	0.04	0.05	0.07
Exterior aluminum roller shutter (no insulation)	0.04	0.07	0.09
Exterior plastic roller shutter (no insulation)	0.04	0.07	0.09
Exterior wood venetian blinds	0.08	0.08	0.08
Exterior metal venetian blinds	0.09	0.09	0.09
Exterior opaque roller blind	0.04	0.06	0.08
Exterior translucid roller blind	0.16	0.18	0.2
Interior shutter	0.47	0.59	0.69
Interior opaque curtains	0.37	0.46	0.55
Interior transparent curtains	0.39	0.48	0.58
Interior opaque wood device	0.35	0.46	0.58
Exterior roller shutters of plastic (with insulation)	0.04	0.07	0.09
Shutters of wood, 25mm to 30mm thickness	0.04	0.05	0.07

Table 21 : solar energy thermal transmittance of window with shading device

	λ	ρc
Clay or silt	1.5	3000000.00
Sand or gravel	2	2000000.00
Homogeneous rock	3.5	2000000.00
Default	2	2000000.00

Table 22 : conductivity and heat capacity of ground (ISO 13370)

Shading device type	Day cooling
No device	*No*
All other choices	*Yes*

Table 23 : Default values for "Night heating" and "Day cooling"

Shading device type	Nightheating

No device	*No*
All other choices	*Yes*

Table 24 : Default values for shutter device

Roof macro-component	U-value	Km
Waterproof membrane	0.31	22456.0
Macro Roof 2	0.373	13435.0

Table 25 : Macro-component for roof)

	Heating mode						Cooling mode					
	Shading devices ON											
Region	a_{H0}	τ_{H0}	$k_{D,cor,H}$	$K_{cor,ve}$	$K_{cor,H}$	$K_{cor,int,H}$	a_{C0}	T_{C0}	$k_{D,cor,C}$	$K_{cor,ve,C}$	$K_{cor,C}$	$K_{cor,int,C}$
Csa	1.00	15.67	1.00	1.00	0.90	0.93	1.20	15.00	1.07	1.00	0.83	0.90
Csb	1.33	15.00	1.00	1.07	0.97	0.93	1.10	15.00	1.03	1.10	0.97	1.00
Cfb	1.33	15.00	0.93	0.83	1.10	1.07	1.30	15.00	1.00	1.00	1.00	1.03
Dfb	1.30	14.67	0.83	0.90	1.25	1.25	1.00	15.00	1.07	1.07	0.97	1.00
Dfc	1.25	14.33	0.83	0.83	1.17	1.50	1.00	15.00	1.00	1.00	1.00	1.00
	Shading devices OFF											
Region	a_{H0}	τ_{H0}	$k_{D,cor,H}$	$K_{cor,ve}$	$K_{cor,H}$	$K_{cor,int,H}$	a_{C0}	T_{C0}	$k_{D,cor,C}$	$K_{cor,ve,C}$	$K_{cor,C}$	$K_{cor,int,C}$
Csa	0.93	15.00	1.00	1.00	1.03	1.03	1.25	15.00	1.17	1.33	0.83	0.90
Csb	1.13	15.00	1.00	0.97	1.03	1.00	0.93	15.00	1.08	1.17	0.87	0.87
Cfb	1.17	15.00	1.00	0.93	1.00	1.03	1.08	15.00	1.08	1.33	0.90	0.87
Dfb	1.33	15.00	0.93	0.87	1.17	1.10	1.20	15.00	1.00	1.00	0.83	0.90
Dfc	1.50	14.00	0.80	0.80	1.07	1.20	1.00	15.00	1.17	1.17	0.92	0.90

Table 26 : Correction factors for each climatic region

			RESIDENTIAL BUILDINGS					
			Area 1 (Living room plus kitchen)			Area 2 (Other conditioned areas)		
			From	To	Gain (W/m²)	From	To	Gain (W/m²)
OCCUPANCY	Monday to Friday	Period 1	07.00	17.00	8.0	07.00	17.00	1.0
		Period 2	17.00	23.00	20.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	6.0
	Saturday and Sunday	Period 1	07.00	17.00	8.0	07.00	17.00	2.0
		Period 2	17.00	23.00	20.0	17.00	23.00	4.0
		Period 3	23.00	07.00	2.0	23.00	07.00	6.0
LIGHT	Monday to Friday	Period 1	07.00	17.00	0	07.00	17.00	0
		Period 2	17.00	23.00	10	17.00	23.00	5
		Period 3	23.00	07.00	0	23.00	07.00	0
	Saturday and Sunday	Period 1	07.00	17.00	10	07.00	17.00	5
		Period 2	17.00	23.00	10	17.00	23.00	5
		Period 3	23.00	07.00	0	23.00	07.00	0

Table 27 : Default values Occupancy and Light scenarios for Residential buildings

			OFFICE BUILDINGS					
			Area 1: Office spaces			Area 2: Other rooms, lobbies, corridors		
			From	To	Gain(W/m²)	From	To	Gain(W/m²)
OCCUPANCY	Monday to Friday	Period 1	07.00	17.00	20.0	07.00	17.00	8.0
		Period 2	17.00	23.00	2.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	1.0
	Saturday and Sunday	Period 1	07.00	17.00	2.0	07.00	17.00	1.0
		Period 2	17.00	23.00	2.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	1.0
LIGHT	Monday to Friday	Period 1	07.00	17.00	10	07.00	17.00	5
		Period 2	17.00	23.00	5	17.00	23.00	5
		Period 3	23.00	07.00	0	23.00	07.00	0
	Saturday and Sunday	Period 1	07.00	17.00	0	07.00	17.00	0
		Period 2	17.00	23.00	0	17.00	23.00	0
		Period 3	23.00	07.00	0	23.00	07.00	0

Table 28 : Default values Occupancy and Light scenarios for Office buildings

			COMMERCIAL BUILDINGS					
			Area 1			Area 2		
			From	To	Gain	From	To	Gain
OCCUPANCY	Monday to Friday	Period 1	07.00	17.00	20.0	07.00	17.00	8.0
		Period 2	17.00	23.00	2.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	1.0
	Saturday and Sunday	Period 1	07.00	17.00	2.0	07.00	17.00	1.0
		Period 2	17.00	23.00	2.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	1.0
LIGHT	Monday to Friday	Period 1	07.00	17.00	20.0	07.00	17.00	15
		Period 2	17.00	23.00	0	17.00	23.00	0
		Period 3	23.00	07.00	0	23.00	07.00	0
	Saturday and Sunday	Period 1	07.00	17.00	20	07.00	17.00	15
		Period 2	17.00	23.00	0	17.00	23.00	0
		Period 3	23.00	07.00	0	23.00	07.00	0

Table 29 : Default values Occupancy and Light scenarios for Commercial buildings

			INDUSTRIAL BUILDINGS					
			Area 1			Area 2		
			From	To	Gain	From	To	Gain
OCCUPANCY	Monday to Friday	Period 1	07.00	17.00	20.0	07.00	17.00	8.0
		Period 2	17.00	23.00	2.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	1.0
	Saturday and Sunday	Period 1	07.00	17.00	2.0	07.00	17.00	1.0
		Period 2	17.00	23.00	2.0	17.00	23.00	1.0
		Period 3	23.00	07.00	2.0	23.00	07.00	1.0
LIGHT	Monday to Friday	Period 1	07.00	17.00	13	07.00	17.00	13
		Period 2	17.00	23.00	5	17.00	23.00	5
		Period 3	23.00	07.00	0	23.00	07.00	0
	Saturday and Sunday	Period 1	07.00	17.00	0	07.00	17.00	0
		Period 2	17.00	23.00	0	17.00	23.00	0
		Period 3	23.00	07.00	0	23.00	07.00	0

Table 30 : Default values Occupancy and Light scenarios for Industrial buildings

Fields	unit	RB	OB	CB	IB
Heating temperature	°C	20	20	20	18
Cooling temperature	°C	26	26	26	26
Air flow rate (heating) (minimum value to ensure good indoor air quality)	ac/h	0.60	0.60	0.60	0.60
Air flow rate (cooling)	ac/h	1.00	1.00(	1.00(	1.00

Table 31 : Default values for Indoor conditions

Fields	RB	OB	CB	IB
Beginning time	17h00	07h00	09h00	08h00
Ending time	23h00	17h00	19h00	17h00
Number of days / week	7	5	6	5

Table 32 : Default values for Heating systems

Heating/Cooling system type	Default value for “*Energy used*”
Electric resistance	Electric
Gas fuel heater	Gas
Liquid fuel heater	Liquid fuel
Solid fuel heater	Solid fuel
Split (heating)	Electricity
Split cooling	Electric
Refrigeration machine compression	Electric
Refrigeration machine absorption	Electric

Table 33 : Default values for Energy used for heating / Cooling

Fields	RB	OB	CB	IB
Number of days / week	7	5	6	5

Table 34 : Default values for “Number of working days for cooling”

DHW system type	Default value for “*Energy used*”
Electric boiler	Electric
Gas boiler	Gas
Stand alone heater condensation	Gas
Stand alone heater	Gas

Table 35 : Default values for Energy used for DHW production

Annex 3.Climatic tables

Country :**Portugal**
Latitude: 40
Climate: Intermediate
GeigerClimate: Csb

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Solar Incident Radiation W/m2	North	22.7	33.2	45.1	56.1	69.1	76.9	68.9	57.7	48.1	35.9	27.1	22.0
	East	55.2	67.5	96.0	122.0	125.5	132.3	132.1	122.5	103.7	75.2	49.9	43.9
	South	141.5	128.4	151.6	141.7	113.9	112.5	119.7	147.0	153.8	152.5	111.9	111.8
	West	56.7	66.8	96.4	121.4	126.1	146.8	148.6	144.8	110.6	87.5	48.7	43.0
	Roof	87.8	107.7	170.8	220.7	241.7	277.4	282.7	260.3	197.9	138.4	84.4	69.7
Air Temp. [°C]		9.6	11.0	12.7	13.1	15.6	19.0	20.8	21.1	20.6	16.9	12.2	11.2
$f_{H,shut}$ [-]		0.585	0.542	0.484	0.438	0.386	0.375	0.375	0.406	0.471	0.508	0.583	0.590

Table 36 : climatic data for **Coimbra**

Country :**Finland**
Latitude: 61
Climate: Intermediate
GeigerClimate: Dfc

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Solar Incident Radiation W/m2	North	3	12	27	46	70	82	72	56	36	17	6	2
	East	4	28	48	90	126	140	131	103	59	30	8	4
	South	13	85	100	142	159	159	161	138	105	65	22	16
	West	5	31	54	90	129	139	139	101	59	30	8	4
	Roof	7	34	76	139	211	237	224	166	97	46	12	5
Air Temp. [°C]		-6.3	-6.7	-2.6	3.0	9.3	13.5	16.6	15.2	9.5	4.6	-1.0	-4.2
$f_{H,shut}$ [-]		0.727	0.616	0.500	0.376	0.267	0.183	0.226	0.328	0.450	0.565	0.693	0.750

Table 37 : climatic data for **Tampere**

Country :**Romania**
Latitude: 45
Climate: Intermediate
GeigerClimate: Cfb

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Solar Incident Radiation W/m2	North	19	28	43	57	72	80	74	61	47	34	22	16
	East	31	52	81	105	132	146	144	130	95	73	40	26
	South	80	112	128	129	129	128	141	152	153	155	95	69
	West	32	54	74	102	125	138	141	131	98	76	39	28
	Roof	50	84	136	182	235	266	271	234	168	121	62	43
Air Temp. [°C]		0.0	1.5	5.2	10.7	16.8	19.4	22.1	21.4	16.4	11.6	5.7	1.4
$f_{H,shut}$ [-]		0.622	0.546	0.488	0.428	0.366	0.333	0.363	0.388	0.468	0.527	0.583	0.625

Table 38 : climatic data for **Timisoara**

	$f_{sh\text{-}with}$			
	NORTH	EAST	SOUTH	WEST
MONTH	[-]	[-]	[-]	[-]
JAN	0.00	0.45	0.85	0.47
FEB	0.00	0.43	0.73	0.43
MAR	0.00	0.54	0.78	0.58
APR	0.00	0.61	0.71	0.61
MAY	0.00	0.56	0.53	0.55
JUN	0.00	0.61	0.53	0.65
JUL	0.00	0.63	0.59	0.67
AUG	0.00	0.65	0.77	0.73
SEP	0.00	0.58	0.78	0.61
OCT	0.00	0.46	0.82	0.58
NOV	0.00	0.33	0.70	0.24
DEC	0.00	0.24	0.73	0.25

Table 39 : f_{shwith}, weighted fraction of the time with the solar shading in use for Coimbra

	$f_{sh\text{-}with}$			
	NORTH	EAST	SOUTH	WEST
MONTH	[-]	[-]	[-]	[-]
JAN	0.00	0.19	0.70	0.20
FEB	0.00	0.44	0.74	0.40
MAR	0.00	0.50	0.73	0.41
APR	0.00	0.52	0.65	0.48
MAY	0.00	0.59	0.65	0.54
JUN	0.00	0.63	0.62	0.59
JUL	0.00	0.62	0.70	0.62
AUG	0.00	0.64	0.76	0.63
SEP	0.00	0.53	0.79	0.57
OCT	0.00	0.48	0.84	0.53
NOV	0.00	0.27	0.70	0.28
DEC	0.00	0.12	0.64	0.17

Table 40 : f_{shwith}, weighted fraction of the time with the solar shading in use for Timisoara

	$f_{sh\text{-}with}$			
	NORTH	EAST	SOUTH	WEST
MONTH	[-]	[-]	[-]	[-]
JAN	0.00	0.00	0.05	0.00
FEB	0.00	0.00	0.59	0.00
MAR	0.00	0.00	0.47	0.05
APR	0.00	0.19	0.54	0.21
MAY	0.00	0.25	0.42	0.24
JUN	0.00	0.23	0.29	0.22
JUL	0.00	0.31	0.40	0.35
AUG	0.00	0.22	0.32	0.14
SEP	0.00	0.00	0.32	0.00
OCT	0.00	0.00	0.38	0.00
NOV	0.00	0.00	0.44	0.00

DEC	0.00	0.00	0.00	0.00

Table 41 : f_{shwith}, weighted fraction of the time with the solar shading in use for Tampere

Annex 4.Impacts parameters for macro-component

The 24 environmental impacts are recalled in Table 42Table 42.

Index	Abbreviation	Designation
1	**GWP**	Global Warming Potential
2	**ODP**	Ozone Depletion Potential
3	**AP**	Acidification Potential
4	**EP**	Eutrophication Potential
5	**POCP**	Photochemical Ozone Creation Potential
6	**ADP-e**	Abiotic Depletion Potential – elements
7	**ADP-ff**	Abiotic Depletion Potential – fossil fuels
8	**RPE**	Use of renewable primary energy excluding renewable primary energy resources used as raw materials
9	**RER**	Use of renewable energy resources used as raw materials
10	**RPE-total**	Total use of renewable primary energy (primary energy and primary energy resources used as raw materials)
11	**Non-RPE**	Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials
12	**Non-RER**	Use of non renewable energy resources used as raw materials
13	**Non-RPE-total**	Total use of non renewable primary energy (primary energy and primary energy resources used as raw materials)
14	**SM**	Use of secondary material
15	**RSF**	Use of renewable secondary fuels
16	**Non-RSF**	Use of non renewable secondary fuels
17	**NFW**	Use of net fresh water
18	**HWD**	Hazardous waste disposed
19	**Non-HWD**	Non hazardous waste disposed
20	**RWD**	Radioactive waste disposed
21	**CR**	Components for reuse
22	**MR**	Materials for recycling
23	**MER**	Materials for energy recovery
24	**EE**	Exported energy

Table 42 : Environmental impacts

For the wall macro-component, the following impacts coefficients are set to zero: RPE_total, Non_RPE, Non_RER, NonRPE_total, SM, RSF, Non_RSF, HWD, Non_HWD, RWD, CR, MR, MER, EE.

Non zero impact coefficients for the wall macro-component are listed hereafter.

Macro-component	Impact	GWP	ODP	AP	EP	POCP	ADP_e	ADP_ff	RPE	RER	NFW
Light steel panel wall (rock wool)	k_{A1A3}	6,50E-02	6,43E-10	2,65E-04	2,41E-05	3,27E-05	3,06E-08	7,09E-01	7,13E-01	1,86E-01	4,53E-02
Light steel panel wall (rock wool)	k_{A4}	5,86E-05	1,03E-15	2,63E-07	6,05E-08	-8,58E-08	2,19E-12	8,14E-04	8,14E-04	3,19E-05	8,27E-04
Light steel panel wall (rock wool)	k_{C2}	5,13E-05	8,98E-16	2,28E-07	5,23E-08	-7,40E-08	1,92E-12	7,12E-04	7,12E-04	2,79E-05	7,23E-04
Light steel panel wall (rock wool)	k_{C4}	4,94E-04	9,24E-14	7,35E-07	1,13E-07	1,91E-07	4,32E-11	1,68E-03	1,68E-03	1,25E-04	2,46E-03
Light steel panel wall (rock wool)	k_D	-1,73E-02	3,41E-10	-4,81E-05	-1,17E-06	-1,13E-05	-2,10E-07	-3,05E-01	-3,14E-01	9,76E-03	9,10E-03
Light steel panel wall (EPS)	k_{A1A3}	5,18E-02	8,13E-10	1,44E-04	1,03E-05	6,33E-05	2,82E-08	6,75E-01	6,81E-01	1,73E-01	-2,27E-02
Light steel panel wall (EPS)	k_{A4}	5,17E-05	9,05E-16	2,32E-07	5,34E-08	-7,57E-08	1,93E-12	7,18E-04	7,18E-04	2,81E-05	7,29E-04
Light steel panel wall (EPS)	k_{C2}	4,33E-05	7,57E-16	1,92E-07	4,41E-08	-6,24E-08	1,62E-12	6,00E-04	6,00E-04	2,35E-05	6,10E-04
Light steel panel wall (EPS)	k_{C4}	6,79E-03	8,54E-14	8,87E-07	1,50E-07	1,70E-07	5,61E-11	1,84E-03	1,84E-03	1,38E-04	1,39E-02
Light steel panel wall (EPS)	k_D	-2,22E-02	3,41E-10	-7,24E-05	-2,60E-06	-1,27E-05	-2,10E-07	-3,70E-01	-3,78E-01	9,55E-03	2,86E-03
Light steel panel wall (XPS)	k_{A1A3}	5,52E-02	6,41E-10	1,53E-04	1,09E-05	3,16E-05	2,99E-08	7,89E-01	7,93E-01	1,79E-01	4,28E-02
Light steel panel wall (XPS)	k_{A4}	6,00E-05	1,05E-15	2,69E-07	6,20E-08	-8,79E-08	2,24E-12	8,33E-04	8,33E-04	3,27E-05	8,47E-04
Light steel panel wall (XPS)	k_{C2}	4,94E-05	8,65E-16	2,19E-07	5,04E-08	-7,13E-08	1,84E-12	6,85E-04	6,85E-04	2,69E-05	6,97E-04
Light steel panel wall (XPS)	k_{C4}	1,07E-02	1,04E-13	1,16E-06	2,01E-07	2,06E-07	7,46E-11	2,36E-03	2,36E-03	1,78E-04	2,14E-02
Light steel panel wall (XPS)	k_D	-2,52E-02	3,41E-10	-8,70E-05	-3,46E-06	-1,36E-05	-2,10E-07	-4,08E-01	-4,17E-01	9,42E-03	-8,93E-04
Light steel panel wall (PUR)	k_{A1A3}	6,70E-02	6,44E-10	1,66E-04	1,43E-05	2,81E-05	8,52E-08	9,22E-01	9,25E-01	1,92E-01	1,27E-01
Light steel panel wall (PUR)	k_{A4}	6,00E-05	1,05E-15	2,69E-07	6,20E-08	-8,79E-08	2,24E-12	8,33E-04	8,33E-04	3,27E-05	8,47E-04

Light steel panel wall (PUR)	k_{C2}	4,94E-05	8,65E-16	2,19E-07	5,04E-08	-7,13E-08	1,84E-12	6,85E-04	6,85E-04	2,69E-05	6,97E-04
Light steel panel wall (PUR)	k_{C4}	7,11E-03	1,30E-13	3,30E-06	7,68E-07	3,15E-07	7,64E-11	3,02E-03	3,02E-03	1,89E-04	1,75E-02
Light steel panel wall (PUR)	k_{D}	-2,22E-02	3,41E-10	-7,23E-05	-2,60E-06	-1,27E-05	-2,10E-07	-3,70E-01	-3,78E-01	9,55E-03	2,86E-03
Light steel panel wall (Cork)	k_{A1A3}	5,39E-02	6,40E-10	1,60E-04	1,55E-05	2,50E-05	2,72E-08	5,78E-01	5,82E-01	3,90E-01	6,91E-02
Light steel panel wall (Cork)	k_{A4}	9,34E-05	1,64E-15	4,19E-07	9,64E-08	-1,37E-07	3,49E-12	1,30E-03	1,30E-03	5,08E-05	1,32E-03
Light steel panel wall (Cork)	k_{C2}	4,28E-05	7,49E-16	1,90E-07	4,37E-08	-6,17E-08	1,60E-12	5,94E-04	5,94E-04	2,33E-05	6,03E-04
Light steel panel wall (Cork)	k_{C4}	3,98E-04	7,44E-14	5,92E-07	9,07E-08	1,54E-07	3,48E-11	1,36E-03	1,36E-03	1,01E-04	1,98E-03
Light steel panel wall (Cork)	k_{D}	-1,73E-02	3,41E-10	-4,81E-05	-1,17E-06	-1,13E-05	-2,10E-07	-3,05E-01	-3,14E-01	9,76E-03	9,10E-03

Macro-component	Impact	GWP	ODP	AP	EP	POCP	ADP_e	ADP_ff	RPE	RER	NFW
Double clay brick wall(Rock wool)	k_{A1A3}	8,12E-02	3,62E-12	1,33E-04	1,58E-05	1,21E-05	4,00E-09	6,11E-01	6,11E-01	1,02E-01	1,56E-01
Double clay brick wall(Rock wool)	k_{A4}	3,67E-04	6,43E-15	1,65E-06	3,79E-07	-5,37E-07	1,37E-11	5,10E-03	5,10E-03	2,00E-04	5,18E-03
Double clay brick wall(Rock wool)	k_{C2}	3,21E-04	5,62E-15	1,43E-06	3,28E-07	-4,64E-07	1,20E-11	4,46E-03	4,46E-03	1,75E-04	4,53E-03
Double clay brick wall(Rock wool)	k_{C4}	1,78E-02	3,32E-12	2,64E-05	4,04E-06	6,86E-06	1,55E-09	6,05E-02	6,05E-02	4,50E-03	8,83E-02
Double clay brick wall(Rock wool)	k_{D}	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Double clay brick wall(EPS)	k_{A1A3}	7,46E-02	8,86E-11	7,23E-05	8,96E-06	2,74E-05	2,81E-09	5,94E-01	5,96E-01	9,56E-02	1,22E-01
Double clay brick wall(EPS)	k_{A4}	3,58E-04	6,27E-15	1,61E-06	3,70E-07	-5,24E-07	1,34E-11	4,97E-03	4,97E-03	1,95E-04	5,05E-03
Double clay brick wall(EPS)	k_{C2}	3,13E-04	5,48E-15	1,39E-06	3,20E-07	-4,52E-07	1,17E-11	4,35E-03	4,35E-03	1,70E-04	4,42E-03
Double clay brick wall(EPS)	k_{C4}	2,09E-02	3,31E-12	2,65E-05	4,06E-06	6,85E-06	1,56E-09	6,06E-02	6,06E-02	4,50E-03	9,40E-02
Double clay brick wall(EPS)	k_{D}	-2,46E-03	-4,97E-14	-1,22E-05	-7,17E-07	-7,02E-07	-4,49E-11	-3,21E-02	-3,21E-02	-1,06E-04	-3,12E-03
Double clay brick wall(XPS)	k_{A1A3}	7,63E-02	3,00E-12	7,67E-05	9,23E-06	1,15E-05	3,64E-09	6,51E-01	6,51E-01	9,88E-02	1,55E-01
Double clay brick wall(XPS)	k_{A4}	3,59E-04	6,29E-15	1,61E-06	3,71E-07	-5,25E-07	1,34E-11	4,98E-03	4,98E-03	1,95E-04	5,06E-03
Double clay brick wall(XPS)	k_{C2}	3,14E-04	5,50E-15	1,39E-06	3,20E-07	-4,53E-07	1,17E-11	4,36E-03	4,36E-03	1,71E-04	4,43E-03
Double clay brick wall(XPS)	k_{C4}	2,29E-02	3,32E-12	2,66E-05	4,09E-06	6,87E-06	1,57E-09	6,08E-02	6,08E-02	4,52E-03	9,78E-02
Double clay brick wall(XPS)	k_{D}	-3,94E-03	-7,96E-14	-1,95E-05	-1,15E-06	-1,12E-06	-7,18E-11	-5,14E-02	-5,14E-02	-1,70E-04	-5,00E-03
Double clay brick wall(PUR)	k_{A1A3}	8,22E-02	4,11E-12	8,33E-05	1,09E-05	9,80E-06	3,13E-08	7,17E-01	7,17E-01	1,05E-01	1,97E-01
Double clay brick wall(PUR)	k_{A4}	3,59E-04	6,29E-15	1,61E-06	3,71E-07	-5,25E-07	1,34E-11	4,98E-03	4,98E-03	1,95E-04	5,06E-03

Double clay brick wall(PUR)	k_{C2}	3,14E-04	5,50E-15	1,39E-06	3,20E-07	-4,53E-07	1,17E-11	4,36E-03	4,36E-03	1,71E-04	4,43E-03
Double clay brick wall(PUR)	k_{C4}	2,11E-02	3,34E-12	2,77E-05	4,37E-06	6,92E-06	1,57E-09	6,12E-02	6,12E-02	4,53E-03	9,58E-02
Double clay brick wall(PUR)	k_{D}	-2,46E-03	-4,99E-14	-1,21E-05	-7,15E-07	-7,02E-07	-4,52E-11	-3,22E-02	-3,22E-02	-1,07E-04	-3,12E-03
Double clay brick wall(Cork)	k_{A1A3}	7,57E-02	2,30E-12	8,06E-05	1,16E-05	8,25E-06	2,27E-09	5,46E-01	5,46E-01	2,04E-01	1,68E-01
Double clay brick wall(Cork)	k_{A4}	3,62E-04	6,35E-15	1,63E-06	3,74E-07	-5,30E-07	1,35E-11	5,03E-03	5,03E-03	1,97E-04	5,11E-03
Double clay brick wall(Cork)	k_{C2}	3,17E-04	5,55E-15	1,41E-06	3,23E-07	-4,57E-07	1,18E-11	4,40E-03	4,40E-03	1,72E-04	4,47E-03
Double clay brick wall(Cork)	k_{C4}	1,77E-02	3,31E-12	2,63E-05	4,03E-06	6,84E-06	1,55E-09	6,03E-02	6,03E-02	4,48E-03	8,80E-02
Double clay brick wall(Cork)	k_{D}	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

Macro-component	Impact	GWP	ODP	AP	EP	POCP	ADP_e	ADP_ff	RPE	RER	NFW
Double clay brick wall(Glass wool)	k_{A1A3}	7,81E-02	3,81E-12	9,80E-05	1,33E-05	8,60E-06	6,07E-07	6,13E-01	6,13E-01	1,05E-01	1,68E-01
Double clay brick wall(Glass wool)	k_{A4}	3,61E-04	6,32E-15	1,62E-06	3,73E-07	-5,28E-07	1,35E-11	5,01E-03	5,01E-03	1,96E-04	5,09E-03
Double clay brick wall(Glass wool)	k_{C2}	3,16E-04	5,53E-15	1,40E-06	3,22E-07	-4,56E-07	1,18E-11	4,38E-03	4,38E-03	1,72E-04	4,45E-03
Double clay brick wall(Glass wool)	k_{C4}	1,77E-02	3,31E-12	2,63E-05	4,03E-06	6,83E-06	1,55E-09	6,03E-02	6,03E-02	4,48E-03	8,80E-02
Double clay brick wall(Glass wool)	k_D	5,96E-04	-7,23E-12	3,71E-07	1,04E-06	1,78E-07	1,03E-12	1,80E-04	1,85E-04	-7,20E-05	-1,53E-03

For the opening macro-component, the impact coefficients are identical for all opening type. Furthermore, the impact coefficients are zero for transport in module A (labelled k_{A4}), for Disposal in module C (labelled k_{C4}) and for benefits in module D (labelled k_D).

Non zero impacts for the opening macro-component are listed hereafter.

impact	GWP	ODP	AP	EP	POCP	ADP_e	ADP_ff	RPE	RER	RPE_total	Non_RPE	Non_RER
k_{A1A3}	1,39E-01	2,11E-12	5,98E-04	1,09E-04	5,02E-05	8,85E-07	1,64E+00	6,72E-02	0,00E+00	6,72E-02	1,71E+00	1,53E-02
k_{C2}	3,52E-04	4,82E-15	2,24E-06	3,07E-07	2,10E-07	1,33E-10	4,63E-03	3,99E-04	0,00E+00	3,99E-04	4,84E-03	0,00E+00

impact	NonRPE_total	SM	RSF	Non_RSF	NFW	HWD	Non_HWD	RWD	CR	MR	MER	EE
k_{A1A3}	1,73E+00	0,00E+00	2,14E-05	1,97E-04	6,22E-04	0,00E+00	2,25E-01	3,36E-05	0,00E+00	0,00E+00	0,00E+00	0,00E+00
k_{C2}	4,84E-03	0,00E+00	8,67E-06	1,87E-05	2,64E-06	0,00E+00	2,68E-02	8,47E-08	0,00E+00	0,00E+00	0,00E+00	0,00E+00