Joint Project - Task 40/Annex 52
Net Zero Energy Buildings

Net ZEB evaluation tool – User guide

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Contents

Acronyms

CHP	Cogeneration (combined heat and power)
DHW	Domestic Hot Water
EPBD	Energy Performance of Buildings Directive
IEA	International Energy Agency
Net ZEB(s)	Net Zero Energy Building(s)
STA	Subtask A

Nomenclature

c	specific costs
d, D	delivered energy, weighted delivered energy
e, E	exported energy, weighted exported energy
g, G	generation, weighted generation
l, L	load, weighted load
f_{load}	load match index (generation/load data)
$f_{delivered}$	load match index (delivered/exported energy data)
i	energy carrier
$kgCO_{2eq}$	kg of equivalent carbon emissions
kWh_{pe}	primary energy
w	weighting factor

Terms and definitions

Figure 1 shows the connections between building and energy grids and the relevant terminology [1].

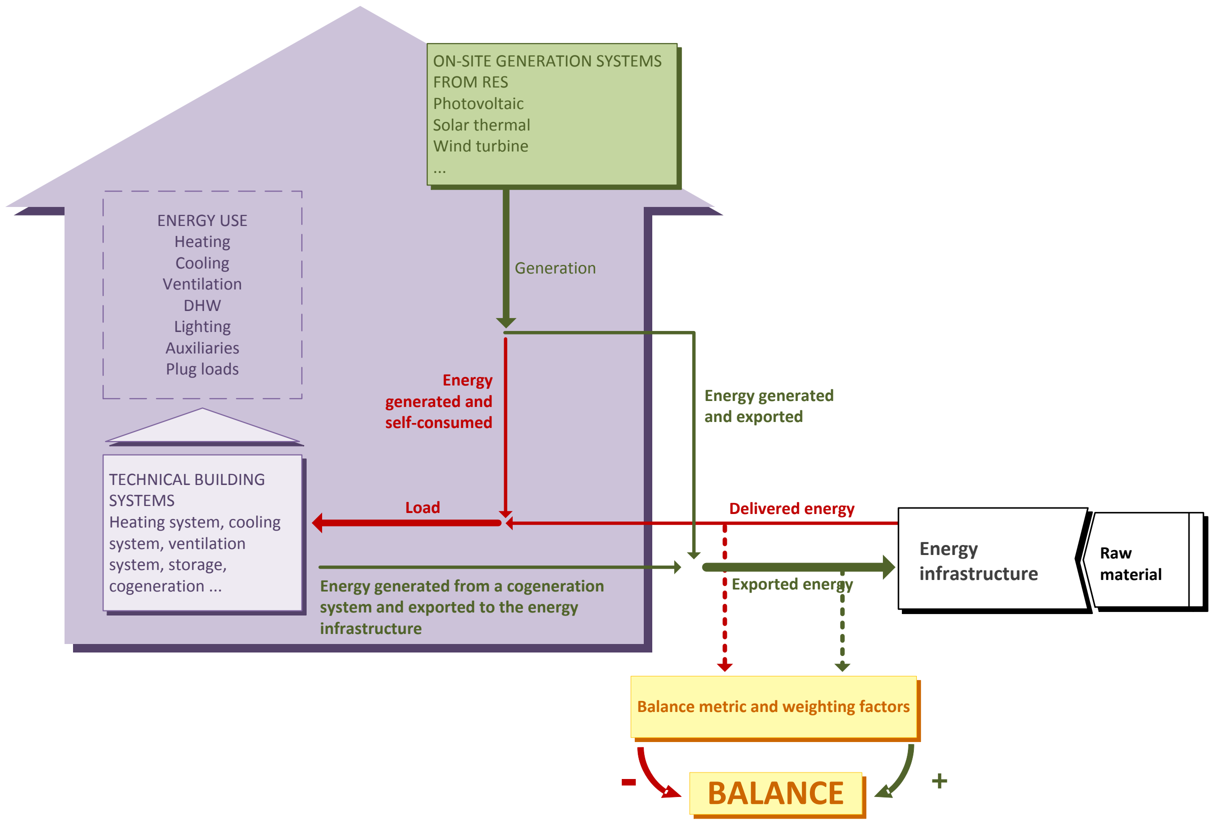

Figure 1. Sketch of connection between building and energy grids showing relevant terminology.

The **delivered energy** is the energy flowing from the grids to buildings, specified per each energy carrier in [kWh/m^{2}y]. This is the energy imported by the building and supplied to the technical building systems through the system boundary, to satisfy the uses taken into account (heating, cooling, ventilation, domestic hot water, lighting, appliances etc.) or to produce electricity.[1] Delivered energy can be calculated for defined energy uses or it can be measured.

The **load** is the building's energy demand, specified per each energy carrier in [kWh/m^{2}y].

The **exported energy** is the energy flowing from buildings to the grids, specified per each energy carrier in [kWh/m^{2}y]. It is the energy delivered by the technical building systems through the system boundary and used outside the system boundary. It can be specified by generation types (e.g. CHP, photovoltaic, etc.) in order to apply different weighting factors. Exported energy can be calculated or it can be measured.

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[1] For active solar and wind energy systems the incident solar radiation on solar panels or on solar collectors or the kinetic energy of wind is not part of the energy balance of the building. It is decided at national level whether or not renewable energy produced on site is part of the delivered energy.

The **generation** is the building's energy generation, specified per each energy carrier in [kWh/m^{2}y].

> NOTE 1 The load/generation may not coincide with delivered energy/exported energy due to self-consumption of energy generated on-site.
>
> NOTE 2 Design calculations to convert building energy needs, such as for heating, cooling, ventilation, hot water, lighting, appliances, into the demand for certain energy carriers (here 'loads'), accounting for system efficiencies and interactions are not performed by this tool; nor are calculations to determine on-site generation or possible self-consumption patterns. Users are encouraged to refer to their relevant national methodologies and regulations for guidance.
>
> NOTE 3 Delivered and exported energy quantities can be used to calculate the balance when monitoring a building. Alternatively, estimates of delivered and exported energy may be available in design phase, depending on the ability to estimate self-consumption of energy carriers generated on-site.

Technical building systems are meant to be the technical equipment for heating, cooling, ventilation, domestic hot water, lighting and electricity production. A technical building system can refer to one or to several building services (e.g. heating system, heating and DHW system) and it is composed of different subsystems.

The **building system boundary** identifies the energy flows flowing in and out the system. It includes:

- Physical boundary: can encompass a single building or a group of buildings; determines whether renewable resources are 'on-site' or 'off-site'.
  The physical boundaries are not specified in the selected definitions as they can depend on building use and national regulations. Users are recommended to fix them to fill out the tool in a consistent way.

- Balance boundary: determines which energy uses (e.g. heating, cooling, ventilation, hot water, lighting, appliances) are included in the balance.
  Except for the Net ZEB limited definition, all operational energy services are included in the balance boundary. A Net ZEB definition that does not include all operational energy services poses a challenge on building performance verification because it requires a more sophisticated measurement system. In particular, for the Net ZEB limited definition it is necessary a sub-metering system to measure the plug loads consumption.

Weighting factors convert the physical units into other metrics, for example accounting for the energy used (or emissions released) to extract, generate, and deliver the energy. Weighting factors may also reflect political preferences rather than purely scientific or engineering considerations. They can be:

> **Symmetric or asymmetric**: a symmetric weighting system uses the same weighting factors for both energy demand and energy supply; an asymmetric weighting system uses different weighting factors for energy demand and energy supply.

Static or quasi-static (or dynamic): a static weighting system does not vary over time (the same weighting factors are used over the whole year); a quasi-static weighting factors uses weighting factors evaluated on monthly bases. Dynamic weighting factors may vary over shorter time steps, but they are not included in this tool.

The **load match index** [6] indicates the fraction of load that is covered by on-site generation systems. All generated part exceeding the load is considered as part of the grid electricity so that the maximum load match index becomes 100%. Please refer to Appendix A.4 for equations.

1. Introduction

Within the STA of the IEA task 40/annex 52, a consistent framework that considers all the relevant aspects characterizing Net ZEBs has been developed. An outcome of the task is to describe the relevant characteristics of Net ZEBs in a series of criteria and relative sub-criteria [1]. For each criterion, different options are available on how to deal with that specific characteristic. Evaluation of criteria and selection of the related options results in different Net ZEB definitions and implications on design solutions.

The awareness that alternative options for a Net ZEB definition are available has led STA work team not to select a unique definition but to show the available options and translate them into balance calculation methodologies and later supported design solutions. So far, a theoretical understanding has been established on this topic and is being disseminated. Within the dissemination means, a worksheet implementing balance calculations for selected definitions has been developed.

The tool:

- includes a reduced number of Net ZEB definitions resulting from the combination of selected criteria and options;
- implements calculations relevant to the different selected definitions;
- includes several criteria and options which are crucial for the development of Net ZEB definitions.

The tool aims at:

- showing how different definitions respond to the same entered building data;
- evaluating solutions adopted in new building design with respect to the selected Net ZEB definitions (for building designers);
- assessing the balance in monitored buildings with respect to the selected Net ZEB definitions (for energy managers);
- assisting the upcoming implementation process of Net ZEBs within the national normative framework (for policy makers).

2. Selection of a reduced number of Net ZEB definitions

A reduced number of Net ZEB definitions have been selected with the following assumptions as starting point:

1. The term Net ZEBs refers to **single buildings**. Net zero energy communities/districts/towns, which are not meant as a set of Net ZEB, but as a synergy of energy supplies and demands of several buildings towards the zero balance, are beyond the scope of task.
2. Net ZEB are **buildings connected to any energy infrastructure** with which they exchange energy. Autonomous buildings are not addressed in the task, as they are considered suitable and profitable only under special boundary conditions (e.g. remote locations, missing energy infrastructure…) [2].
3. The building can feed the grid with electricity from PV, cogeneration units, wind turbines, fuel cells, as well as district heating/cooling networks with heat/cold flows. Fuels like gas, oil, biomass and others are usually imported by the building, but it is not excluded that the building feeds the grid with them as well. For instance, in future, buildings will perhaps export hydrogen obtained by using electricity from a PV system. Hence, **no technology is excluded at this state**, but given the current market development, some technologies will be more recurring than others.
4. The connection to an energy infrastructure introduces the issue of the **building/grid interaction** [3]. The profitability of exported or delivered energy, hence the profitability of the instantaneous load match or the exporting is strictly related to the local grid features and regulations. So far, no indicator has been introduced in the definitions, as investigations are still ongoing within STA on the topic.
5. Given the interaction with external energy infrastructures, the core of the Net ZEB issue is the balance between delivered and exported energy. Whereas in the real operation of the building, the net metering gives as output the actual values of delivered and exported energy, **in the design phase assessments of delivered and exported energy may be available depending on tools or set assumptions in order to estimate self-consumption** of energy carriers generated on-site. However, most building codes do not require design calculations to estimate self-consumption, consequently only generation and load are available and a load/generation balance can be calculated. In this case, it is assumed that the load is entirely satisfied by delivered energy, while the generation is entirely fed into the grid.

The criteria and options considered to form definitions have been derived from [1]. The combination of each option, described in [1] for every criterion and category, generates several definitions. Only few definitions have been selected on the basis of the following criteria:

- definitions should enable their application to both design and monitored building data;
- calculation factors and methodologies should be already available or close to their identification and finalization;
- shared ideas within the project participants have been reflected.

The selection of definitions considers different aspects. Not all the options of all the parameters have been considered. Below the four definitions proposed in the spreadsheet:

Net ZEB limited (minimum requirements for a Net ZEB in compliance with the European Directive [4]): A low energy building, fulfilling any national/local energy efficiency requirements, which offsets the yearly balance between its weighted energy demand for heating, DHW, cooling, ventilation, auxiliaries and built-in lighting (for non-residential buildings only), and the weighted energy supplied by on-site generation systems driven by on or off site sources and connected to the energy infrastructure. Static (or quasi-static) and symmetric primary energy factors are used as weights in the balance.

Net ZEB primary: A low energy building, fulfilling any national/local energy efficiency requirements, which offsets the yearly balance between its weighted loads for heating, DHW, cooling, ventilation, auxiliaries and lighting and every kind of plug loads (electrical mobility included), and the weighted energy supplied by only on site generation systems driven by on or off site sources and connected to the energy infrastructure. Static (or quasi-static) and symmetric primary energy factors are used as weights in the balance.

Net ZEB strategic: A building which offsets the yearly balance between its weighted energy demand for heating, DHW, cooling, ventilation, auxiliaries, built-in lighting and every kind of plug loads and the weighted energy supplied by on/off-site generation systems driven by on/off site sources and connected to the energy infrastructure. Weighting factors are static (or quasi-static) and asymmetric, varying on the basis of the energy carrier, the technology used as energy supply system and its location.

Net ZEB carbon: A building which offsets the yearly balance between its weighted energy demand for heating, DHW, cooling, ventilation, auxiliaries, embodied energy, built-in lighting and every kind of plug loads and the weighted energy supplied by on site generation systems driven by on or off site sources and connected to the energy infrastructure. Static (or quasi-static) carbon factors are used as weights in the balance. They can be symmetric or asymmetric, depending on the energy carrier, technologies used as energy supply systems and their location.

3. The tool for the evaluation of Net ZEB definitions

The Net ZEB evaluator is an Excel-based tool that enables balance calculation, operating costs and Load Match Index for the selected Net ZEB definitions and for different input data sources.

Running Net ZEB evaluator

The tool has been developed within Microsoft Excel 2010 and there could be some incompatibilities with older excel versions. While opening the file, it is necessary to enable content and approve to make the file a Trusted Document and enable all macros and contents.

The workbook comprises several worksheets:

- Building data
- Static weighting factors
- Quasi-static weighting factors
- Operating costs
- Net ZEB evaluation
- Quasi-static Net ZEB evaluation

The first four worksheets collect input data and the last ones report results. Balance calculation can be performed both in static and quasi-static mode (if the building exchanges electricity and thermal energy only). Balance calculation in static mode will be performed if yearly data about energy demand and supply are entered in the first sheet and static weighting factors related to the considered energy carriers are entered in the related sheet. Balance calculation in quasi-static mode will be performed if monthly data about energy demand and supply are entered in the first sheet and quasi-static weighting factors related to the considered energy carriers are entered in the related sheet. In this case, only buildings that exchange electricity and/or thermal energy with the energy infrastructure are considered. Quasi-static mode balance results are not consistent for buildings that exchange with the energy infrastructure other kind of energy carriers. Furthermore, quasi-static balance mode will result the same value for Net ZEB limited and net ZEB primary, because the tool does not include monthly plug loads input.
Input data cells are yellow and some of them are locked or contain warnings to prevent the filling of input data where not appropriate. A note field for every table row has been inserted to allow users making comments or citations. Calculation macros are run by clicking the green arrow-buttons at the bottom of the sheets (see Figure 2).
Input data should refer to the same year or to the same design calculation method or calculated by dynamic simulations using the same weather file.

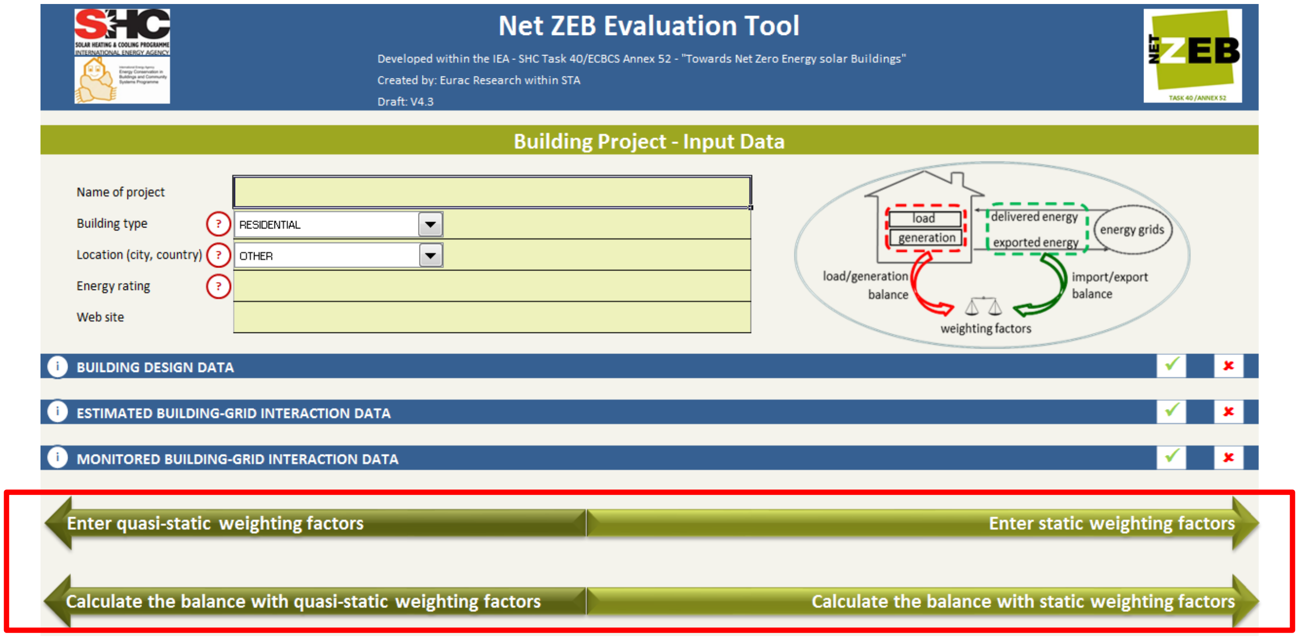


Figure 2. The Net ZEB evaluator tool. Macros are run by clicking the green arrows-button at the bottom of teach sheet.

Information on how to complete the tables is available in the question mark boxes. Definitions and terminology are available in info boxes. Nevertheless, the content of the work sheet is in accordance with [1].

3.1. Building data

In the building data sheet (Figure 3) input data about building energy demand (load or delivered energy) and supply (generation or exported energy) have to be entered.

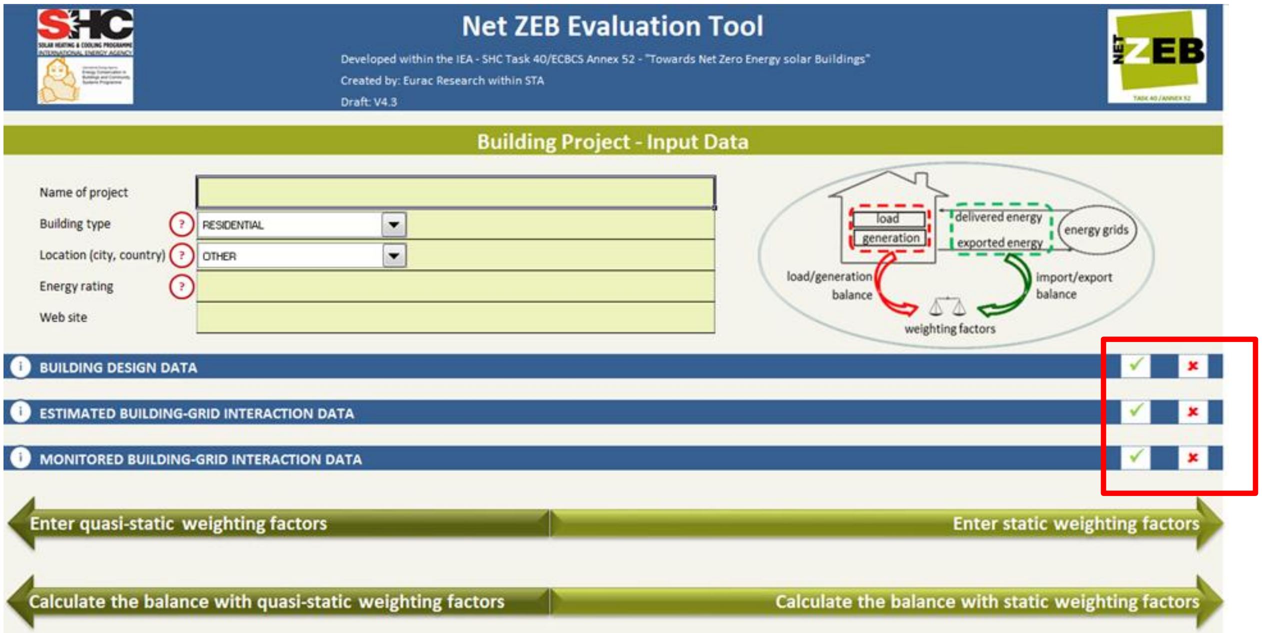


Figure 3. The building data sheet.

In the Building Project – Input Data section, general building data can be entered. The building type has to be selected from the dropdown list. Depending on the selected building type, different calculations will be implemented with respect to the first definition. The first definition, Net ZEB limited, excludes built-in lighting in case of a residential building, but includes it in case of non-residential buildings.[ii] For non-residential buildings users can specify the building type in the cell near the dropdown list.

By selecting the country from the location dropdown list, default values for static weighting factors, if available, will be automatically entered in the related sheet.

In order to allow checking the balance with different kinds of input data, the Building data sheet of the tool is divided into three sections:

1. Building design data
2. Estimated building - grid interaction data
3. Monitored building - grid interaction data

Each section can be easily opened or closed by clicking on the buttons on the right (Figure 3).

The tool enables to enter yearly values of delivered and exported energy or load and generation, but requires monthly values for the load match factor calculation. All values should be specified in [kWh/m²]. Users should refer to their relevant national methodologies and regulations for the area to consider. The area value should be the same for all the data entered in the spreadsheet.

[ii] The Net ZEB limited definition represents the minimum requirements for a nearly net zero energy building in compliance with the European Directive [4].

3.1.1. Building design data

Design data about building load and generation have to be filled to check the generation/load balance. <u>The spreadsheet is not meant to substitute any tool for calculating building loads. For this reason, it does not need any envelope features or any efficiency conversion of energy systems as input.</u>
Users should refer to their relevant national methodologies and regulations for design calculations to convert building energy needs and determine on-site generation or possible self-consumption patterns [5].

This section is divided into three tables:

- g_i energy generation from building systems
- l_i energy load of building systems
- design monthly data about load and generation

The table **g_i Energy generation from building systems** (Figure 4) requires the renewable energy generated from different building systems. The most recurrent technologies have been considered and there are blank cells where other technologies and other generated energy carriers can be added.

g_i Energy generation from building systems

	g_i - energy generation by: \ i - energy carrier	i1 electricity [kWh_{el}/m^2y]	i5 heat to district heating [kWh_h/m^2y]	i6 cold to district cooling [kWh_c/m^2y]	i8 *enter one more energy source produced [kWh/m²y]*	i9 *enter one more energy source produced [kWh/m²y]*	i10 *enter one more energy source produced [kWh/m²y]*	i11 *enter one more energy source produced [kWh/m²y]*	Note
building on-site generation systems connected to the energy infrastructure	PV								
	cogeneration/trigeneration								
	solar thermal								
	enter one more generation system								
	enter one more generation system								
	TOTAL								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine								
	enter one more generation system								
	enter one more generation system								
	TOTAL								

Figure 4. Energy generation from building systems table.

As each energy carrier refers to a univocal i-number, if other sections of the sheets are going to be filled each energy carrier has always to refer to the same i-number.

The overall generation of the i-th energy carrier can be here accounted in two cases:

1. If the energy carrier is produced by a system connected to an energy grid with the possibility to export, it is recommended to write in the table the entire amount of generation and in the following table "l_i Energy load of building systems" to write the load as it would be in absence of any generation and self-consumption.

2. Else if the energy carrier is produced by a system not connected to any energy grid, two options are available:

- consider the generation as totally self-consumed, thereby no value in this table should be entered, but in the table "l_i Energy load of building systems" load should be written as it is, that already accounts the effect of generation and self-consumption;
- consider it as a generation, thereby the overall i-th energy carrier should be entered in the table "l_i energy load of building systems" without accounting for the effect of generation and self-consumption.

If the self-consumption can be estimated, using import/export balance should be considered (if possible also for the other energy carriers).
There is the possibility to enter the total on-site generation and the total off-site generation for each energy carrier. In this case values entered in other cells will not be taken into account and average static weighting factors of the generation systems will be applied.
This option has to be considered only if the generation of every building system is not known.
The table **l_i Energy load of building systems** (Figure 5) requires energy loads for different final uses and different energy carriers: if some loads are aggregated, for instance gas loads for DHW plus heating, users can fill just one cell and add comments on the value entered.
The itemization of final uses on one hand is to have an immediate link to the building codes; on the other hand it is necessary because Net ZEB limited definition does not include all the final uses.

l_i Energy load of building systems

l_i- building systems load \ i - energy carrier	i1 electricity [kWh$_{el}$/m²y]	i2 oil [kWh$_{ol}$/m²y]	i3 gas [kWh$_g$/m²y]	i4 biomass [kWh$_b$/m²y]	i5 heat from district heating [kWh$_h$/m²y]	i6 cold from district cooling [kWh$_c$/m²y]	i7 *embodied energy [kWh/m²y]*	Note
heating					24.60			
DHW					25.00			
cooling								
built-in lighting	12.00							
auxiliaries	0.50							
ventilation	4.50							
plug loads	18.00							
cogeneration/trigeneration								
other							5.00	
TOTAL								

Figure 5. Energy load of building systems table.

Embodied energy can be included in the balance as well by entering the value in the cell (other, i7), as shown in Figure 5, and by setting all the weighting factors for the 7th energy carrier as 1.
If the total energy load is entered, the balance calculation relies on that value and a message warns that the balances relevant to the Net ZEB limited and the Net ZEB primary definitions will output the same result, as the tool does not recognize the inclusion or exclusion of plug loads and built-in lighting.
In the load/generation balance interactions between generation systems and loads are overlooked. It is equivalent to assume that, per each energy carrier, the load is entirely satisfied by delivered energy while the generation is entirely exported to the grid.
So far the worksheet gives the possibility to estimate the Load Match Index [6] for electricity and thermal energy and to calculate the balance with quasi-static (monthly) weighting factors. The input data for these estimations are required in the table **Design monthly data about load and**

generation (Figure 6). Load Match Index will be here calculated as the ratio between monthly values of the i-th carrier generated by the building systems connected to any energy infrastructure, and the monthly values of the overall load of the same energy carrier.

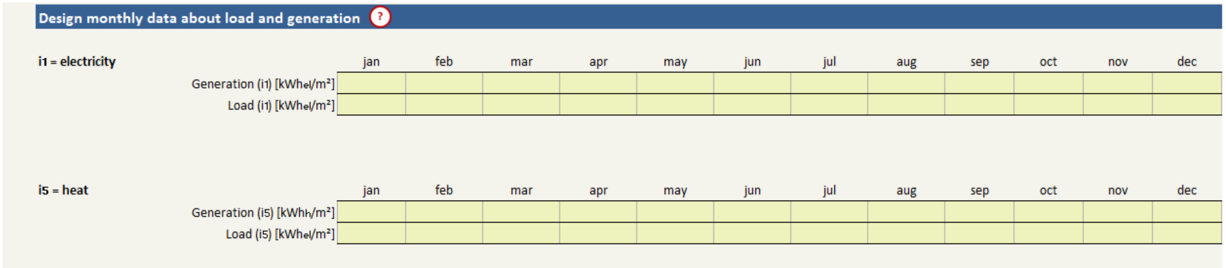


Figure 6. Monthly data of g_i and l_i for load match index calculation table.

3.1.2. Estimated building - grid interaction data

In case dynamic simulations, accounting for the simultaneousness of the energy supply from renewable sources and the loads, are available or specific assumptions are set about this [7], it is possible to estimate the balance between delivered and exported energy as well.
Delivered energy is the energy imported by the building from the grid. It takes into account the interactions between generation systems and loads. If per each energy carrier all the production is exported, the delivered energy is equal to the consumption. If part of the production is self-consumed, the delivered energy is reduced because part of the generation has covered the loads. For the same reason, per each energy carrier exported energy could differ from the generation. This section could be used also to calculate the so called “monthly net balance” [1] by filling the yearly values as the sum of the monthly net values (see Appendix A).
The simulation time step should be entered as information about the accuracy of the data and estimated data about delivered energy for plug loads as well (see Figure 7). The estimated import/export balance relevant to the Net ZEB limited definition cannot be evaluated unless assumed data about plug loads are entered in the proper cell.
Delivered energy for plug loads includes all the delivered energy that is not used for heating, DHW, cooling, built-in lighting (in non-residential case only), ventilation, auxiliaries, cogeneration/trigeneration.

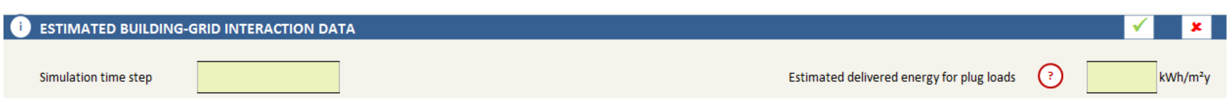


Figure 7. Estimated building – grid interaction section: simulation time step and estimated delivered energy for plug loads should be entered.

Similarly to the previous one, this section is divided into three tables:

- e_i estimated exported energy carriers
- d_i estimated delivered energy carriers
- estimated monthly data about exported and delivered energy

The table **e$_i$ estimated exported energy carriers** (Figure 8) requires yearly exported energy carrier, derived from detailed simulations on the specified time steps or assumptions on self-consumption in the case “monthly net balance” has to be calculated (see Appendix A).

e$_i$ Estimated exported energy carriers

e$_i$ - exported energy by:	i - energy carrier	i1 electricity [kWh_{el}/m^2y]	i5 heat to district heating [kWh_h/m^2y]	i6 cold to district cooling [kWh_c/m^2y]	i8 *enter one more energy source produced [kWh/m^2y]*	i9 *enter one more energy source produced [kWh/m^2y]*	i10 *enter one more energy source produced [kWh/m^2y]*	i11 *enter one more energy source produced [kWh/m^2y]*	Note
building on-site generation systems connected to the energy infrastructure	PV								
	cogeneration/trigeneration								
	solar thermal								
	enter one more generation system								
	enter one more generation system								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine								
	enter one more generation system								
	enter one more generation system								

Figure 8. Estimated exported energy carriers table.

The table **d$_i$ estimated delivered energy carriers** (Figure 9) requires yearly delivered energy carrier, derived from detailed simulations on the specified time step or assumptions on self-consumption in the case “monthly net balance” has to be calculated (see Appendix A).

d$_i$ Estimated delivered energy carriers

i - energy carrier	i1 electricity [kWh_{el}/m^2y]	i2 oil [kWh_{oil}/m^2y]	i3 gas [kWh_g/m^2y]	i4 biomass [kWh_b/m^2y]	i5 heat from district heating [kWh_h/m^2y]	i6 cold from district cooling [kWh_c/m^2y]	i7 *enter one more energy source [kWh/m^2y]*	Note
d$_i$ - delivered energy								

Figure 9. Estimated delivered energy carriers table.

Monthly data of delivered, exported and generated energy (electricity and thermal energy) are required in the table **Estimated monthly data about exported and delivered energy** (Figure 10). Load Match Index will be here calculated as the ratio between the amount of the i-th energy carrier generated by the building systems connected to any energy infrastructure and self-consumed for any final use, and the overall load of the same energy carrier for all the final uses. Generation data on monthly basis are not needed to assess the import/export balance in quasi-static mode.

Estimated monthly data about exported and delivered energy

i1 = electricity	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Exported (i1) [kWh_{el}/m^2]												
Delivered (i1) [kWh_{el}/m^2]												
Generation (i1) [kWh_{el}/m^2]												

i5 = heat	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Exported (i5) [kWh_h/m^2]												
Delivered (i5) [kWh_h/m^2]												
Generation (i5) [kWh_h/m^2]												

Figure 10. Estimated monthly data about exported and delivered energy table.

3.1.3. Monitored building - grid interaction data

The monitored import/export balance can be calculated entering in this section monitoring data about delivered and exported energy, if available, to test Net ZEB definitions in the building operation mode.
For clarifications about delivered and exported energy, please refer to par. 3.1.2.
The time resolution of monitored data should be entered as information of the accuracy of the data. Delivered energy for plug loads should be monitored and entered in the proper cell to calculate the monitored balance relevant to the Net ZEB limited definition.

MONITORED BUILDING-GRID INTERACTION DATA				
Time resolution of monitored data		Monitored delivered energy for plug loads		kWh/m²y

Figure 11. Monitored building – grid interaction section: time resolution of monitored data and monitored delivered energy for plug loads should be entered.

Similarly to the previous ones, this section is divided into three tables:

- e_i monitored exported energy carriers
- d_i monitored delivered energy carriers
- monitored monthly data about exported and delivered energy

The table **e_i monitored exported energy carriers** (Figure 12) requires yearly exported energy carrier, derived from monitoring.

e_i Monitored exported energy carriers

	i - energy carrier / e_i - exported energy by:	i1 electricity [kWh$_{el}$/m²y]	i5 heat to district heating [kWh$_h$/m²y]	i6 cold to district cooling [kWh$_c$/m²y]	i8 *enter one more energy source produced [kWh/m²y]*	i9 *enter one more energy source produced [kWh/m²y]*	i10 *enter one more energy source produced [kWh/m²y]*	i11 *enter one more energy source produced [kWh/m²y]*	Note
building on-site generation systems connected to the energy infrastructure	PV								
	cogeneration/trigeneration								
	solar thermal								
	enter one more generation system								
	enter one more generation system								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine								
	enter one more generation system								
	enter one more generation system								

Figure 12. Monitored exported energy carriers table.

The table **d_i monitored delivered energy carriers** (Figure 13) requires yearly delivered energy carrier, derived from monitoring.

d_i Monitored delivered energy carriers

i - energy carrier	i1 electricity [kWh$_{el}$/m²y]	i2 oil [kWh$_{oil}$/m²y]	i3 gas [kWh$_g$/m²y]	i4 biomass [kWh$_b$/m²y]	i5 heat from district heating [kWh$_h$/m²y]	i6 cold from district cooling [kWh$_c$/m²y]	i7 *enter one more energy source [kWh/m²y]*	Note
d_i - delivered energy								

Figure 13. Monitored delivered energy carriers table.

Monthly data of delivered, exported and generated energy (electricity and thermal energy), derived from monitoring, are required in the table **Monitored monthly data about exported and delivered energy** (Figure 14). Load Match Index will be here calculated as the ratio between the amount of the i-th energy carrier generated by the building systems connected to any energy infrastructure and self-consumed for any final use, and the overall load of the same energy carrier for all the final uses. Generation data on monthly basis are not needed to assess the import/export balance in quasi-static mode.

Monitored monthly data about exported and delivered energy

i1 = electricity	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Exported (i1) [kWh_{el}/m^2]												
Delivered (i1) [kWh_{el}/m^2]												
Generation (i1) [kWh_{el}/m^2]												

i5 = heat	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Exported (i5) [kWh_h/m^2]												
Delivered (i5) [kWh_h/m^2]												
Generation (i5) [kWh_h/m^2]												

Figure 14. Monitored monthly data about exported and delivered energy table.

3.2. Weighting factors

Weighting factors have to be introduced to convert the final energy into the metrics considered in the selected definitions (primary energy, CO_2 carbons and a user defined metric) allowing the balance calculation.
Two weighting factor sheets (Figure 15) allow entering static and/or quasi-static weighting factors on monthly basis [8].
Each two-way energy carrier can be weighted symmetrically, using the same weighting factors for both demand and supply quantities, or asymmetrically, using different factors. By symmetrically weighting system the energy exported to the grid will avoid an equivalent generation somewhere else in the grid. Asymmetric weighting may be used to account for the negative effect of on-site generation if that is not accounted for somewhere else in the balance [1].

3.2.1. Static weighting factors

Static weighting factors convert values of demand and supply into the metrics considered in the selected definitions.

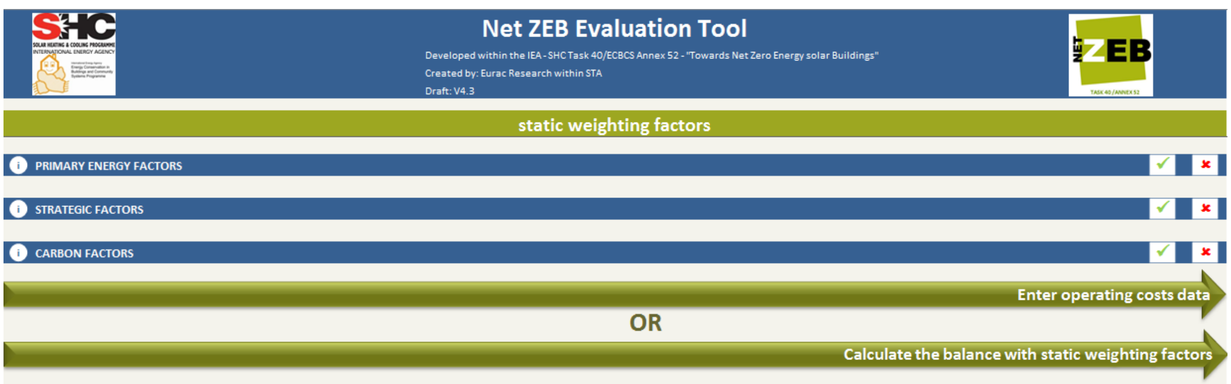


Figure 15. The static weighting factors sheet.

To assess Net ZEB limited and Net ZEB primary definitions symmetric primary energy factors (Figure 16) have to be entered.

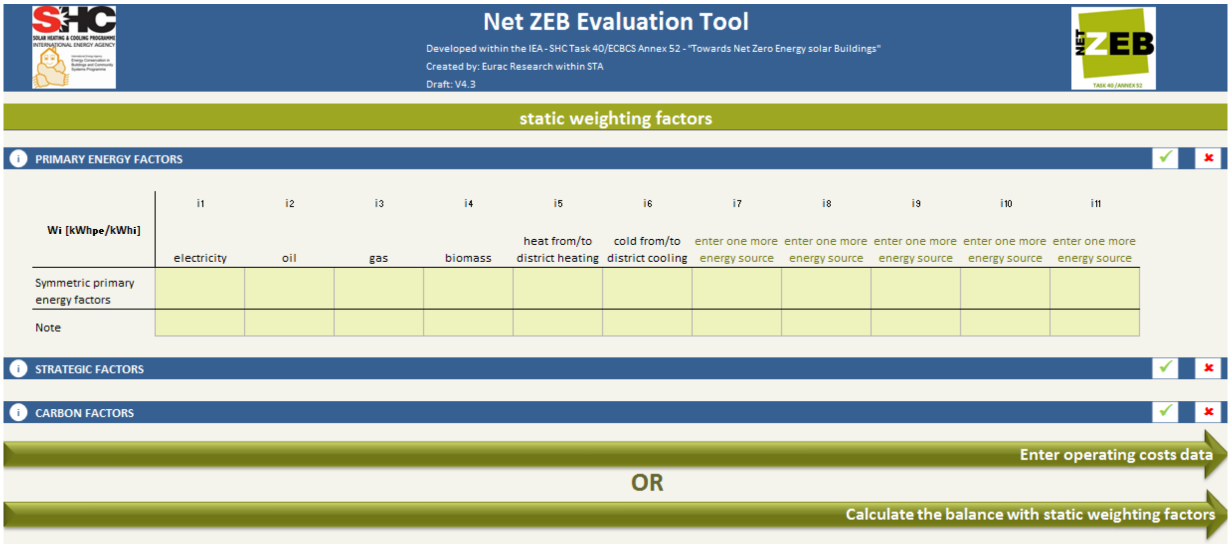


Figure 16. Primary energy factors section of the weighting factor sheet.

To assess the Net ZEB strategic definition asymmetric strategic weighting factors (Figure 17) have to be entered. The Net ZEB strategic definition is meant to be used to test every kind of combination not included in the other three definitions as all supply and demand items are allowed. In this way, strategic factors can be asymmetric primary energy factors or carbon factors.

Furthermore, strategic factors can be used to promote or discourage the adoption of certain technologies and energy carriers as well as include the conversion of primary sources into energy carriers.

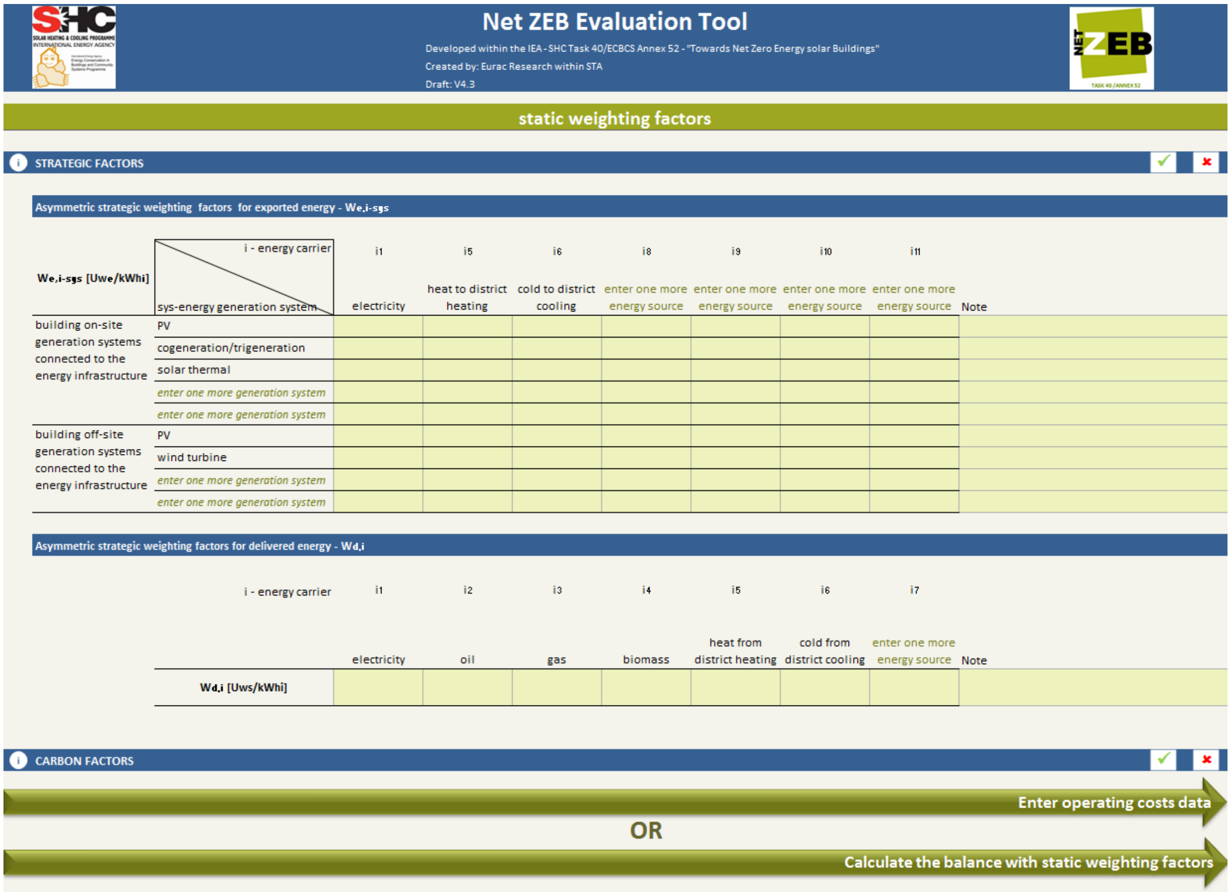


Figure 17. Strategic factors section of the weighting factor sheet.

To assess the Net ZEB carbon definition symmetric or asymmetric carbon weighting factors (Figure 18) have to be entered. Symmetric carbon weighting factors can be obtained by entering the same weighting factor for exported energy and delivered energy of each energy carrier.

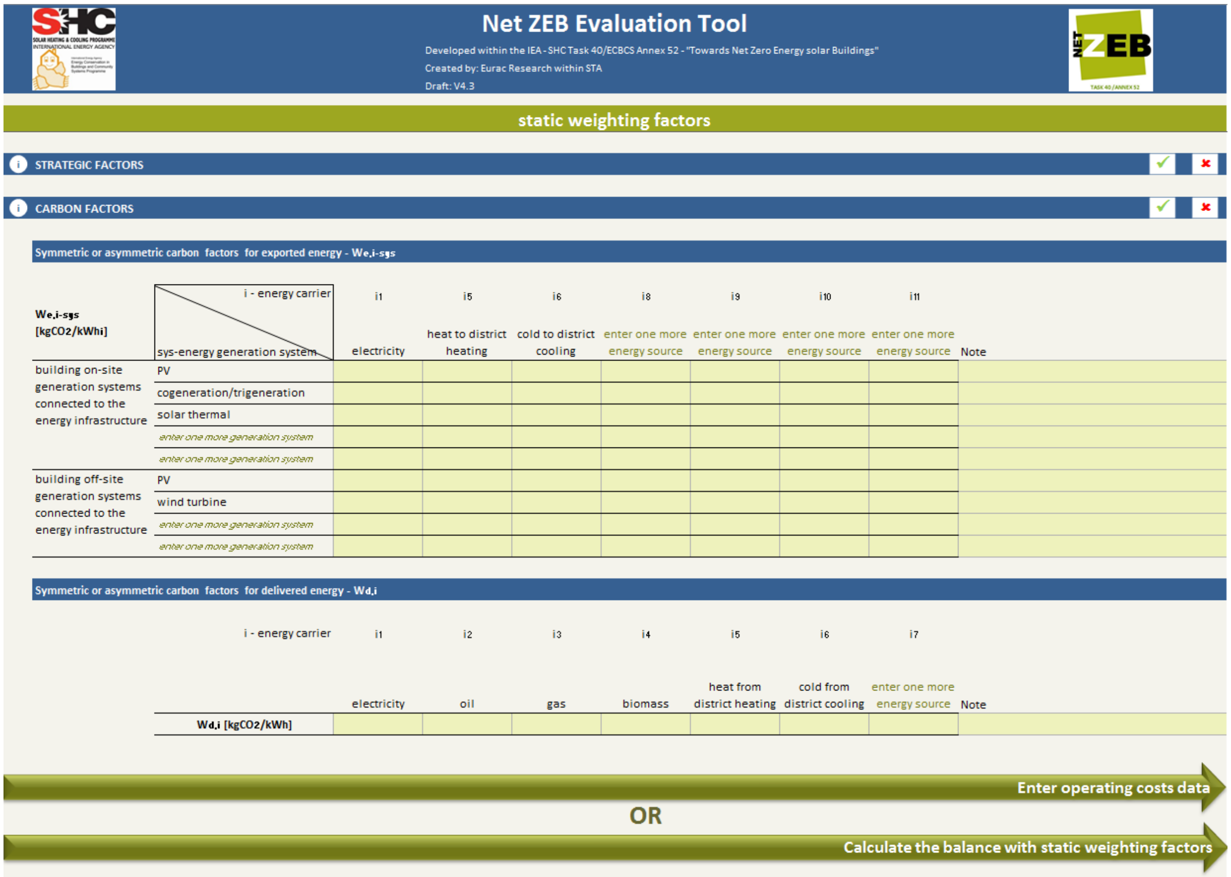


Figure 18. Carbon factors section of the weighting factor sheet.

In the note field, the primary and carbon weighting factor sources should be cited and a reason for the strategic factor choice should be given.

3.2.2. Quasi-static weighting factors

Quasi-static weighting factors convert monthly values of demand and supply into the metrics considered in the selected definitions. In this case weighting factors values should be entered for every month.

The sheet structure is the same as the static weighting factors one. The input data tables are slightly different as they include only two energy carriers (electricity and heat), see Figure 19.

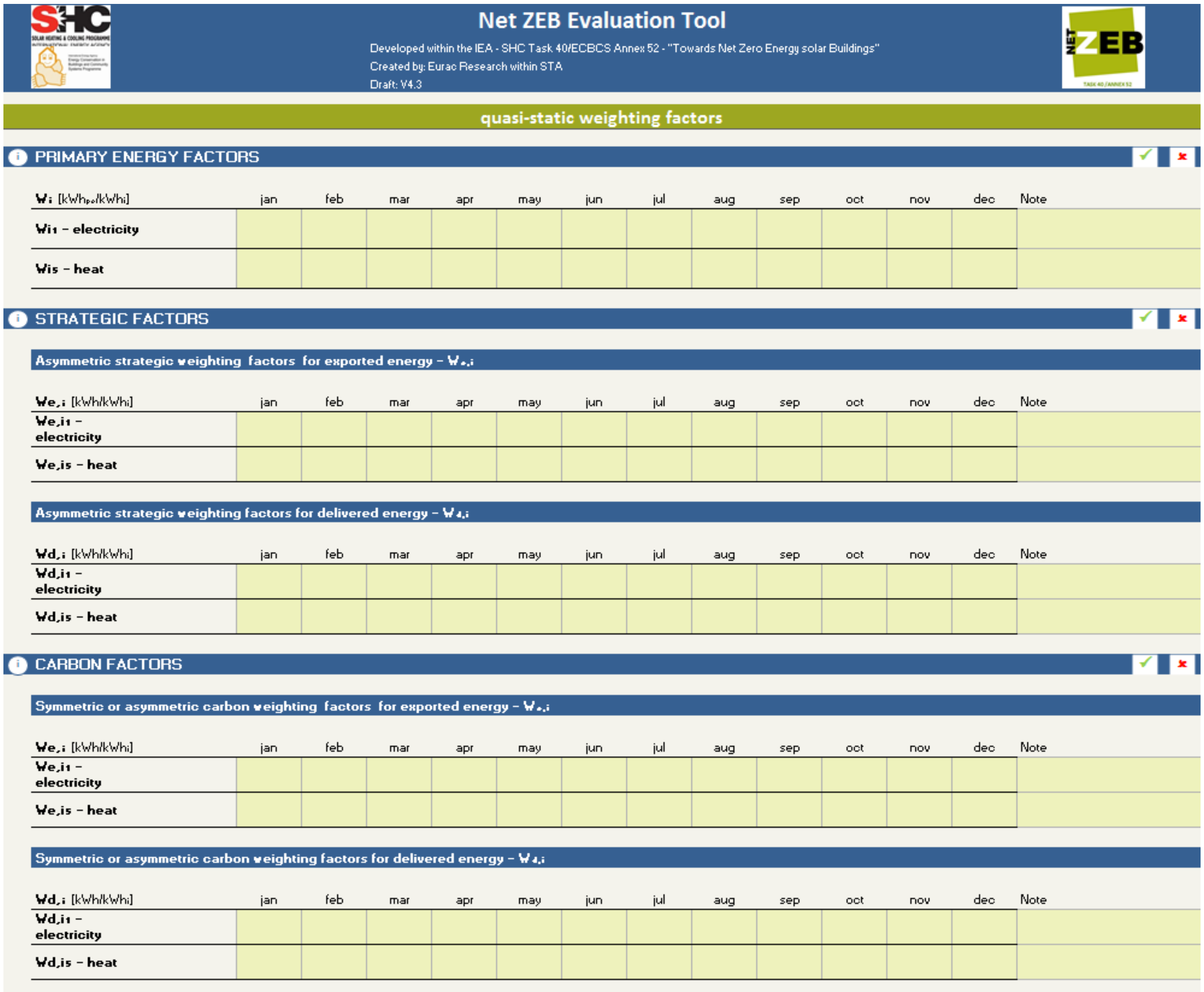


Figure 19. Quasi-static weighting factors sheet.

3.3. Operating energy costs

This sheet (Figure 20) aims at entering specific operating energy costs for exported and delivered energy and incentives for generation from renewable energy sources, if any, for each energy carrier and building system. Incentives are meant as subsidized feed-in tariff for energy generated by renewable sources.

This allows estimating operating cost for every selected definition and for every kind of data entered in the worksheet.

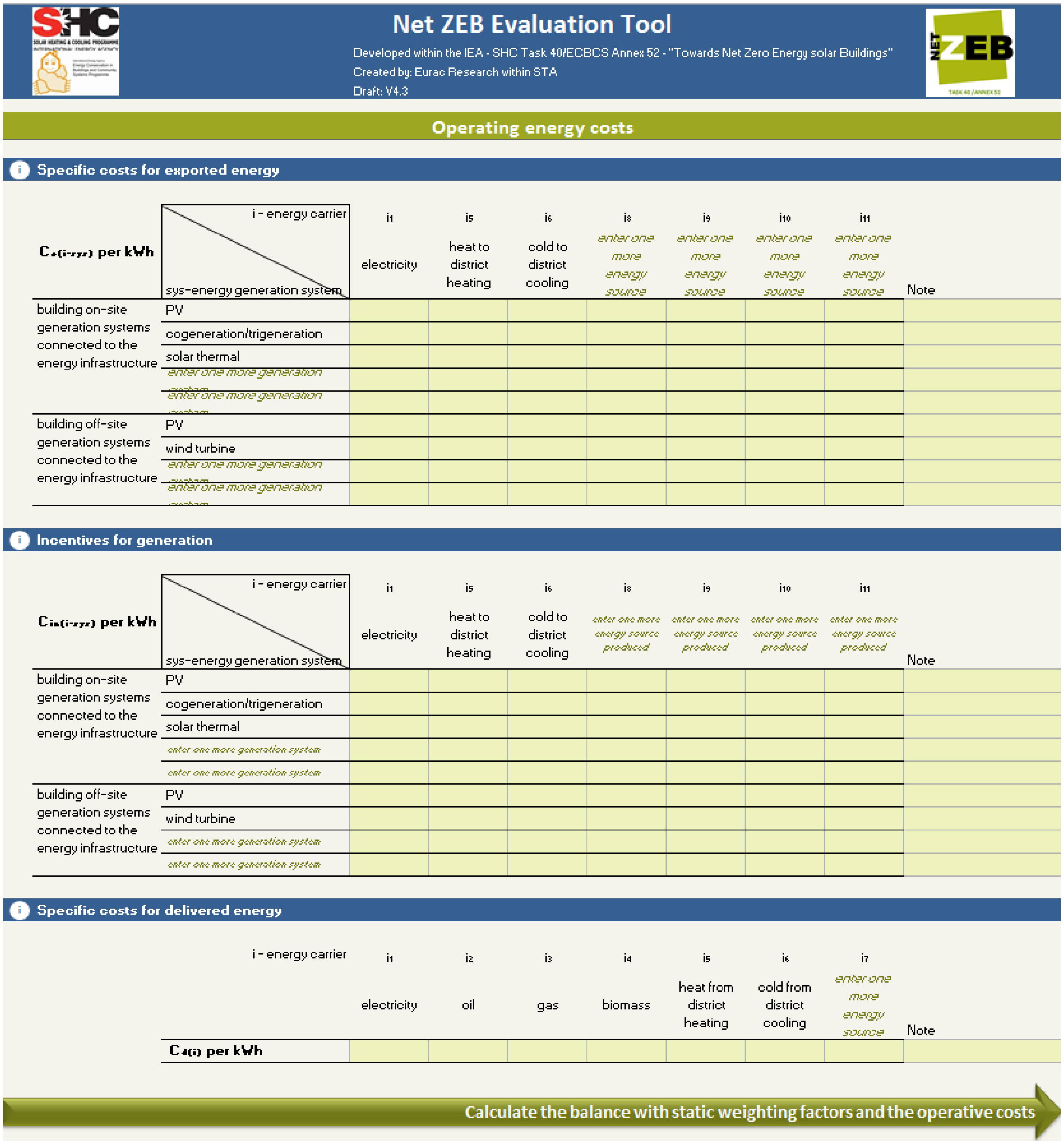


Figure 20. The operating energy costs sheet.

3.4. Net ZEB evaluation

The balance results are shown in the Net ZEB evaluation and/or the quasi-static Net ZEB evaluation sheet (Figure 21) that have almost the same structure. By clicking on each Net ZEB definition name, a description of the criteria selected for that definition compares.

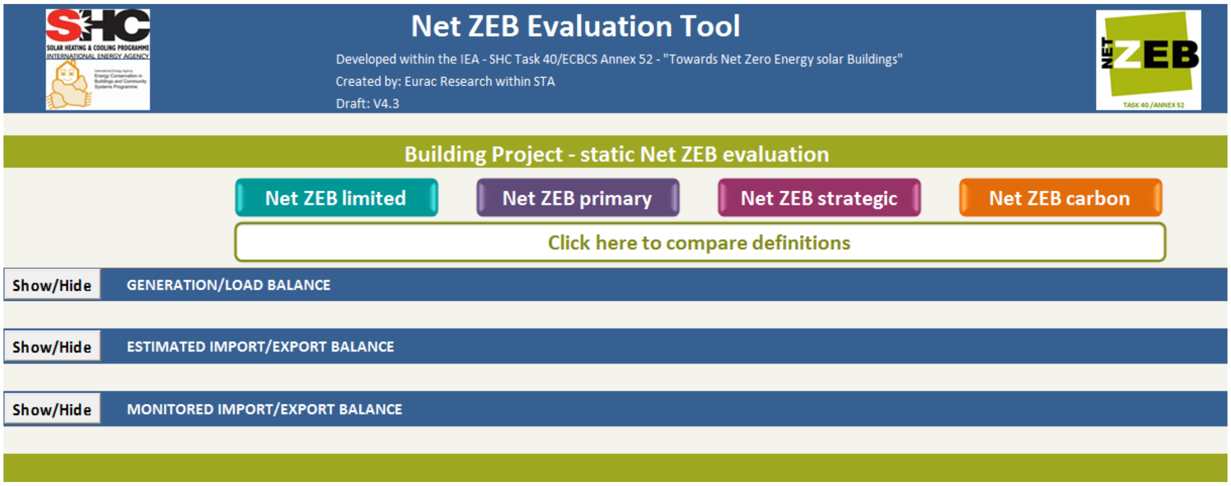


Figure 21. The Net ZEB evaluation sheet.

To get an overview of the criteria selected for each definition, a comparison table is provided, as shown in Figure 22.

A Net Zero Energy Building is the "building system" delimited by set physical boundaries, connected to any energy infrastructure, which balance between its weighted energy loads and supplies is zero.

		Net ZEB limited	Net ZEB primary	Net ZEB strategic	Net ZEB carbon
Building system boundary	Balance boundary	HEATING DHW COOLING VENTILATION AUXILIARIES BUILT-IN LIGHTING (only non residential buildings)	HEATING DHW COOLING VENTILATION AUXILIARIES BUILT-IN LIGHTING PLUG LOADS	HEATING DHW COOLING VENTILATION AUXILIARIES BUILT-IN LIGHTING PLUG LOADS	HEATING DHW COOLING VENTILATION AUXILIARIES BUILT-IN LIGHTING PLUG LOADS
Weighting system	Metric	PRIMARY ENERGY	PRIMARY ENERGY	Whichever metric desired	CARBON EMISSION
	Symmetry	SYMMETRIC	SYMMETRIC	SYMMETRIC or ASYMMETRIC	SYMMETRIC or ASYMMETRIC
	Time dependent accounting	STATIC OR QUASI-STATIC	STATIC OR QUASI-STATIC	STATIC OR QUASI-STATIC	STATIC OR QUASI-STATIC
Net ZEB balance	Energy efficiency	NATIONAL/LOCAL ENERGY EFFICIENCY REQUIREMENTS ARE FULFILLED	NATIONAL/LOCAL ENERGY EFFICIENCY REQUIREMENTS ARE FULFILLED	ANY NATIONAL/LOCAL ENERGY EFFICIENCY REQUIREMENTS HAS TO BE FULFILLED	ANY NATIONAL/LOCAL ENERGY EFFICIENCY REQUIREMENTS HAS TO BE FULFILLED
	Energy supply	ON SITE GENERATION DRIVEN BY ON/OFF SITE SOURCES	ON SITE GENERATION DRIVEN BY ON/OFF SITE SOURCES	ON/OFF SITE GENERATION DRIVEN BY ON/OFF SITE SOURCES	ON SITE GENERATION DRIVEN BY ON/OFF SITE SOURCES

Figure 22. A comparison table between the definitions considered in the spreadsheet.

Some buttons allow showing or hiding balance results from different kind of input data:

- Generation/load balance by building design data
- Estimated building - grid interaction balance by simulation data
- Monitored building – grid interaction balance by monitored data

Results are shown as in Figure 23. Balance results are reported for each definition, identified by the frame cell color, in the upper part of the section.
The **weighted demand** is here meant as the sum of all delivered energy or load, obtained summing all energy carriers each multiplied by its respective weighting factor. The **weighted**

supply is meant as the sum of all the exported energy or generation, obtained summing all energy carriers each multiplied by its respective weighting factor.

The balance is calculated as the difference between the weighted exported energy (or generation) and the weighted delivered energy (or load). A positive number means that the weighted annual energy exported (or generated) is more than the weighted annual energy delivered (or load). On the contrary a negative number indicates that the weighted annual energy delivered is higher than the weighted annual energy exported. Balance equation is showed by clicking on the links button.

Balance results are represented in the graph on links. X-coordinate represents the weighted demand and y-coordinate represents the weighted supply. If the weighted supply equals the weighted demand, the point falls to the bisector (dashed green line) and the balance is zero. If the balance is positive, the point falls upon the bisector and if the balance is negative the point falls under the bisector.

Monthly values of load and generation or of delivered and exported energy are shown in the graphs on the upper/lower right side of the section. Average electricity and thermal load match are reported in the respective cells.

In the lowest part of the section operating costs are reported for each definition, identified by the frame cell color.

<u>Net ZEB strategic balance metric cell is editable so that users can fill the chosen metric.</u>

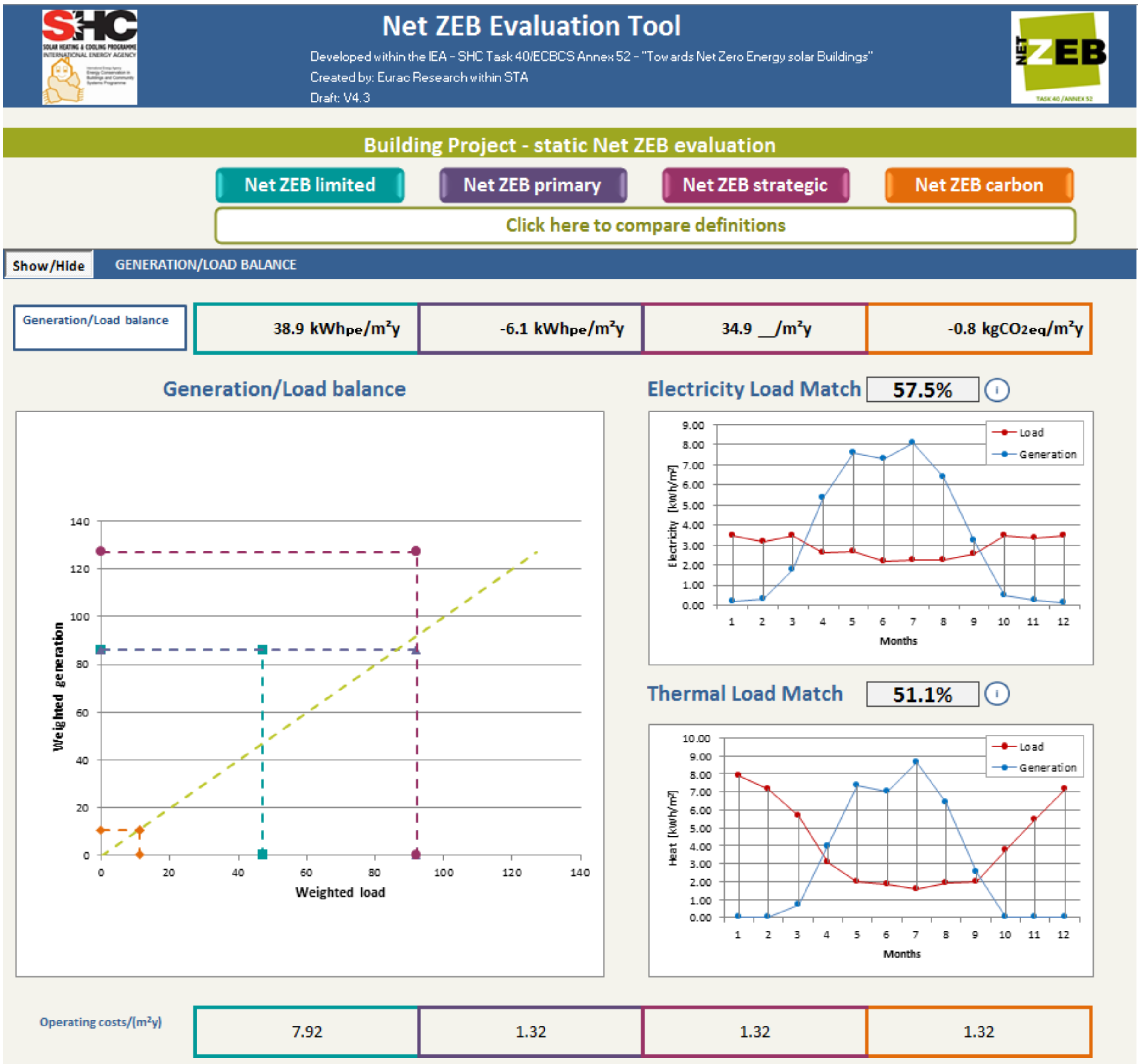


Figure 23. Spreadsheet output example.

4. Example

The use of the Net ZEB definitions evaluator tool is showed using as example the residential building Glasbruket, a five dwelling terraced house situated in the South of Sweden.
The building is designed with a large roof with integrated PV modules. On the top of the roof, which is horizontal, solar thermal collectors are placed. The building is designed to be connected to the electricity grid and district heating network.
No energy storage is installed in the building. Instead, the building relies on the grid and therefore it will always export energy when the building's system generates a surplus and import energy when the building's system does not produce the quantities of energy required.
First step to do is to enter building data. Since the project is still in the design phase, the user can fulfill the cells concerning the building design data and the estimated building-grid interaction. Monthly data about load/generation and delivered/exported energy are available too, as simulations have been performed to evaluate the building-grid interaction [9].
The building exchanges electricity and heat, produced on-site from on-site sources, with the grid and the district heating. Input data about building design are shown in Figure 24 and Figure 25.

g_i Energy generation from building systems

	i - energy carrier / g_i - energy generation by:	i1 electricity [kWh_{el}/m^2y]	i5 heat to district heating [kWh_h/m^2y]	i6 cold to district cooling [kWh_c/m^2y]	i8 *enter one more energy source produced [kWh/m^2y]*	i9 *enter one more energy source produced [kWh/m^2y]*	i10 *enter one more energy source produced [kWh/m^2y]*	i11 *enter one more energy source produced [kWh/m^2y]*	Note
building on-site generation systems connected to the energy infrastructure	PV	41.00							
	cogeneration/trigeneration								
	solar thermal		30.70						
	enter one more generation system								
	enter one more generation system								
	TOTAL								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine								
	enter one more generation system								
	enter one more generation system								
	TOTAL								

l_i Energy load of building systems

i - energy carrier / l_i - building systems load	i1 electricity [kWh_{el}/m^2y]	i2 oil [kWh_o/m^2y]	i3 gas [kWh_g/m^2y]	i4 biomass [kWh_b/m^2y]	i5 heat from district heating [kWh_h/m^2y]	i6 cold from district cooling [kWh_c/m^2y]	i7 *enter one more energy source [kWh/m^2y]*	Note
heating					24.60			
DHW					25.00			
cooling								
built-in lighting	12.00							
auxiliaries	0.50							
ventilation	4.50							
plug loads	18.00							
cogeneration/trigeneration								
other								
TOTAL								

Figure 24. Building design input data of the Glasbruket building.

As it is a residential building, built-in lighting and plug loads have to be added in the "Energy load of building systems" table to evaluate properly the Nearly Net ZEB balance.

Design monthly data about load and generation

i1 = electricity

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Generation (i1) [kWh$_{el}$/m²]	0.18	0.28	1.77	5.34	7.59	7.29	8.06	6.39	3.25	0.47	0.26	0.15
Load (i1) [kWh$_{el}$/m²]	3.48	3.14	3.48	2.61	2.67	2.22	2.25	2.25	2.56	3.48	3.37	3.48

i5 = heat

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Generation (i5) [kWh$_{h}$/m²]	0.00	0.00	0.71	4.00	7.33	7.04	8.64	6.39	2.56	0.02	0.00	0.00
Load (i5) [kWh$_{el}$/m²]	7.91	7.16	5.64	3.11	2.02	1.88	1.61	1.94	2.01	3.73	5.47	7.13

Figure 25. Monthly data about load and generation of heat and electricity for the load match index evaluation.

In order to assess the building-grid interaction, dynamic simulations must be performed to estimate the self-consumption. In this case, delivered energy due to different building systems is not necessary, only total delivered energy is needed. Estimation of delivered energy for plug loads is required to calculate only the Nearly Net ZEB balance.

Input data about estimated building-grid interaction data are shown in Figure 26 and Figure 27.

ESTIMATED BUILDING-GRID INTERACTION DATA

Simulation time step: 1h

Estimated delivered energy for plug loads: 10.0 kWh/m²y

e$_i$ Estimated exported energy carriers

	e$_i$ - exported energy by: \ i - energy carrier	i1 electricity [kWh$_{el}$/m²y]	i5 heat to district heating [kWh$_{h}$/m²y]	i6 cold to district cooling [kWh$_{c}$/m²y]	i8 *enter one more energy source produced [kWh/m²y]*	i9 *enter one more energy source produced [kWh/m²y]*	i10 *enter one more energy source produced [kWh/m²y]*	i11 *enter one more energy source produced [kWh/m²y]*	Note
building on-site generation systems connected to the energy infrastructure	PV	32.60							
	cogeneration/trigeneration								
	solar thermal		34.50						
	enter one more generation system								
	enter one more generation system								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine								
	enter one more generation system								
	enter one more generation system								

d$_i$ Estimated delivered energy carriers

i - energy carrier	i1 electricity [kWh$_{el}$/m²y]	i2 oil [kWh$_{oil}$/m²y]	i3 gas [kWh$_{g}$/m²y]	i4 biomass [kWh$_{b}$/m²y]	i5 heat from district heating [kWh$_{h}$/m²y]	i6 cold from district cooling [kWh$_{c}$/m²y]	i7 *enter one more energy source [kWh/m²y]*	Note
d$_i$ - delivered energy	28.60				48.70			

Figure 26. Estimated building-grid interaction data from simulations.

Load Match Index evaluation requires monthly data about exported and delivered energy and generation. If not all these data are inserted, the Load Match Index result is not reliable.

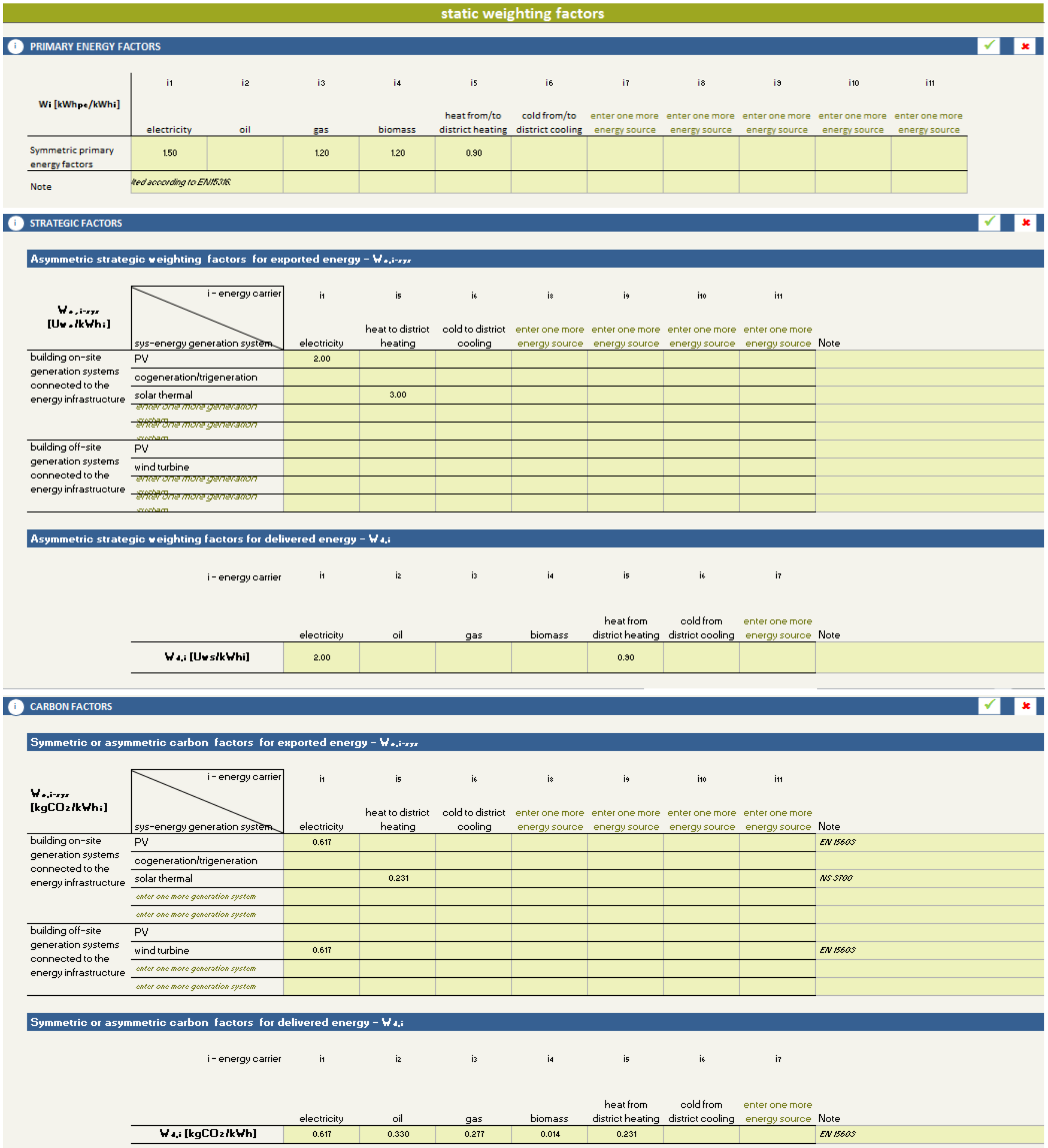
Estimated monthly data about exported and delivered energy

i1 = electricity	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Exported (i1) [kWh_{el}/m^2]	0.00	0.00	1.09	4.37	6.40	6.08	6.83	5.32	2.49	0.03	0.00	0.00
Delivered (i1) [kWh_{el}/m^2]	3.30	2.86	2.80	1.65	1.48	1.01	1.01	1.18	1.80	3.04	3.11	3.33
Generation (i1) [kWh_{el}/m^2]	0.18	0.28	1.77	5.34	7.59	7.29	8.06	6.39	3.25	0.47	0.26	0.15

i5 = heat	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Exported (i5) [kWh_{h}/m^2]	0.00	0.00	0.64	3.73	6.89	6.62	8.19	6.02	2.41	0.02	0.00	0.00
Delivered (i5) [kWh_{h}/m^2]	8.19	7.41	5.74	2.89	1.58	1.46	1.16	1.57	1.87	3.80	5.63	7.37
Generation (i5) [kWh_{h}/m^2]	0.00	0.00	0.71	4.00	7.33	7.04	8.64	6.39	2.56	0.02	0.00	0.00

Figure 27. Monthly data about exported, delivered and generation of heat and electricity for the load match index evaluation.

Second step consists in inserting weighting factors (see Figure 28). Users can use the default values provided by the tool or refer to their national codes and standards or test different weighting factors set to evaluate the balance results.
In this case, static weighting factors about electricity and heat to/from district heating must be added. Primary energy factors and symmetric carbon factors are inserted as well as asymmetric strategic factors for electricity and symmetric strategic factors for heat. In this way, the electricity export could be boosted.
Strategic and carbon factors could be different for every generation system as well as their efficiency in energy conversion.
The weighting factors are used to calculate both load/generation and import/export balance.



static weighting factors

PRIMARY ENERGY FACTORS

Wi [kWhpe/kWhi]	i1 electricity	i2 oil	i3 gas	i4 biomass	i5 heat from/to district heating	i6 cold from/to district cooling	i7 enter one more energy source	i8 enter one more energy source	i9 enter one more energy source	i10 enter one more energy source	i11 enter one more energy source
Symmetric primary energy factors	1.50		1.20	1.20	0.90						
Note	ited according to EN15316										

STRATEGIC FACTORS

Asymmetric strategic weighting factors for exported energy – $W_{e,i\text{-}sys}$

$W_{e,i\text{-}sys}$ [Uwe/kWhi]	i – energy carrier / sys – energy generation system	i1 electricity	i5 heat to district heating	i6 cold to district cooling	i8 enter one more energy source	i9 enter one more energy source	i10 enter one more energy source	i11 enter one more energy source	Note
building on-site generation systems connected to the energy infrastructure	PV	2.00							
	cogeneration/trigeneration								
	solar thermal		3.00						
	enter one more generation system								
	enter one more generation system								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine								
	enter one more generation system								
	enter one more generation system								

Asymmetric strategic weighting factors for delivered energy – $W_{d,i}$

i – energy carrier	i1 electricity	i2 oil	i3 gas	i4 biomass	i5 heat from district heating	i6 cold from district cooling	i7 enter one more energy source	Note
$W_{d,i}$ [Uws/kWhi]	2.00				0.90			

CARBON FACTORS

Symmetric or asymmetric carbon factors for exported energy – $W_{e,i\text{-}sys}$

$W_{e,i\text{-}sys}$ [kgCO2/kWhi]	i – energy carrier / sys – energy generation system	i1 electricity	i5 heat to district heating	i6 cold to district cooling	i8 enter one more energy source	i9 enter one more energy source	i10 enter one more energy source	i11 enter one more energy source	Note
building on-site generation systems connected to the energy infrastructure	PV	0.617							EN 15603
	cogeneration/trigeneration								
	solar thermal		0.231						NS 3700
	enter one more generation system								
	enter one more generation system								
building off-site generation systems connected to the energy infrastructure	PV								
	wind turbine	0.617							EN 15603
	enter one more generation system								
	enter one more generation system								

Symmetric or asymmetric carbon factors for delivered energy – $W_{d,i}$

i – energy carrier	i1 electricity	i2 oil	i3 gas	i4 biomass	i5 heat from district heating	i6 cold from district cooling	i7 enter one more energy source	Note
$W_{d,i}$ [kgCO2/kWh]	0.617	0.330	0.277	0.014	0.231			EN 15603

Figure 28. Primary energy, strategic and carbon factors input data.

If an evaluation on operating costs is desired too, specific cost for exported and delivered energy and any incentives have to be added in the operating costs sheet.

Last step is to verify results by clicking on the “calculate the balance with static weighting factors” button. The results show how the same input data about load/generation or delivered/exported energy can bring to different balance values, depending on the weighting system used and the required balance boundary. Further outputs that can be obtained are the electricity and thermal load match and the operating costs per m^2, calculated taking into account the same balance items and boundary conditions of the respective definitions.

Balance results are shown in Figure 29 and Figure 30. As monitoring data about delivered and exported energy are not available, the third section (monitored import/export balance) gives no result.

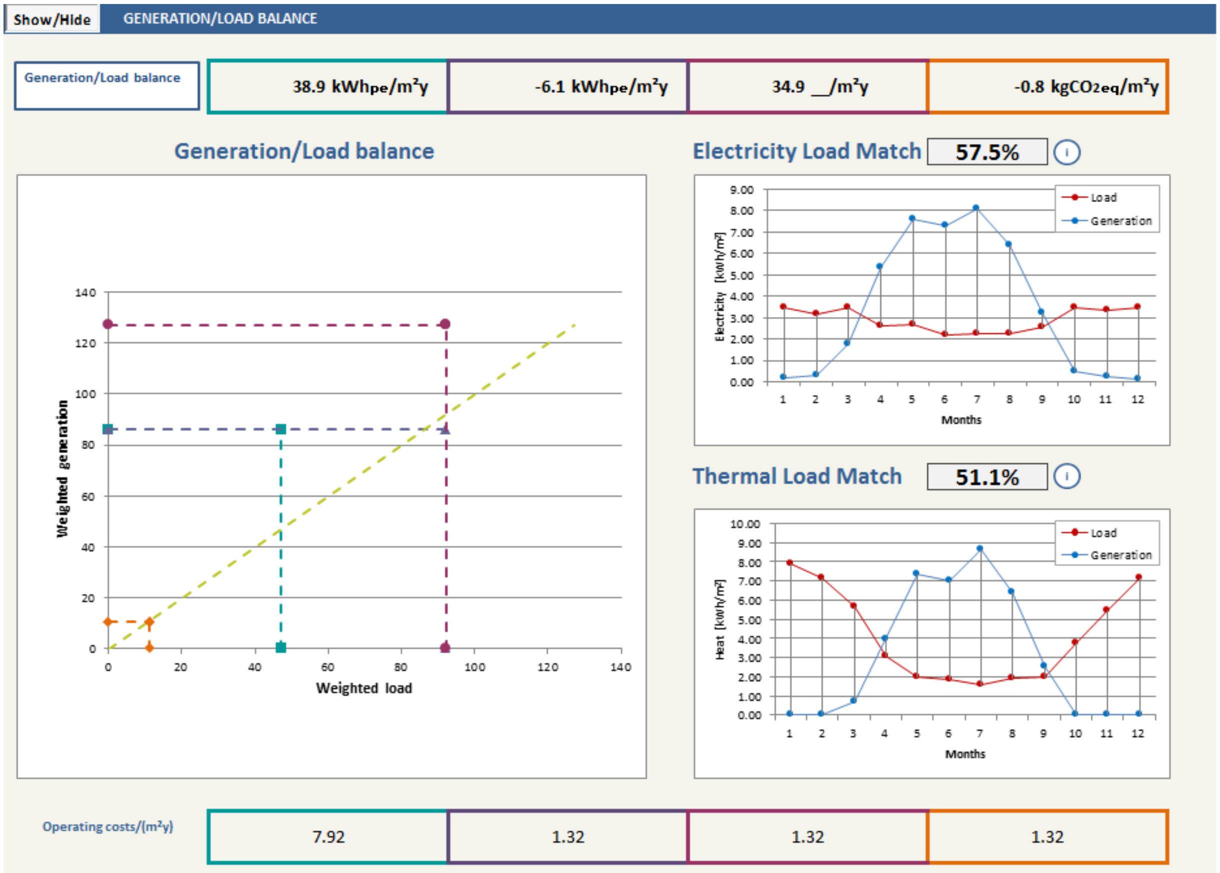


Figure 29. Generation/load balance results.

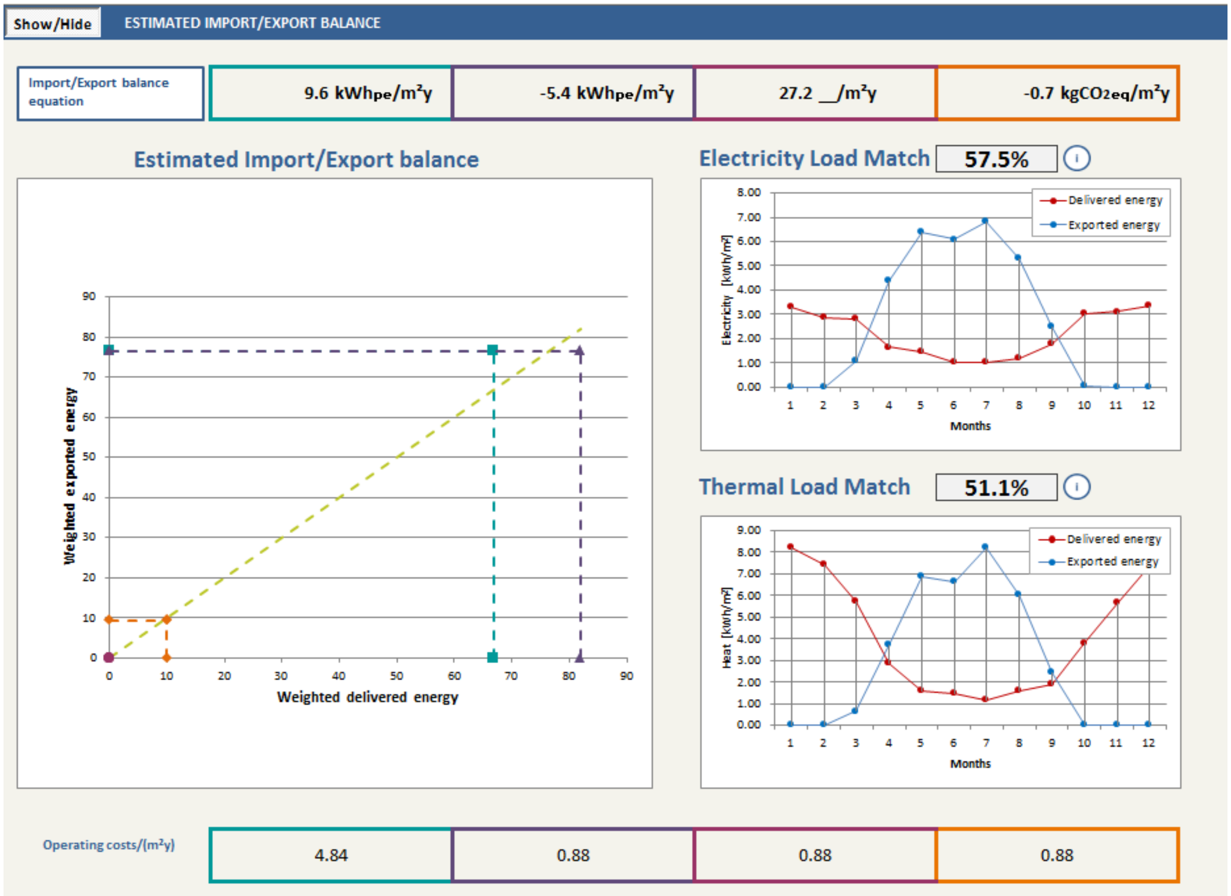


Figure 30. Estimated import/export balance results.

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[5] Marszal A. J., Bourrelle J. S., Musall, E., Gustavsen A., Heiselberg P.,Voss, K., *Net Zero Energy Buildings: Calculation Methodologies – An International View*, Proceedings of EuroSun 2010, Graz, AT.

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Appendix A

A.1 Generation/load balance evaluation

The generation/load balance is in the spreadsheet calculated as in Equation 1.

$$\sum_i g_i \cdot w_{e,i} - \sum_i l_i \cdot w_{d,i} = G - L \geq 0 \qquad \text{Equation 1}$$

where:

i = energy carrier

g_i = generation of the i-th energy carrier

l_i = load of the i-th energy carrier

$w_{e,i}$ = weighting factor for exported i-th energy carrier

$w_{d,i}$ = weighting factor for delivered i-th energy carrier

G = weighted generation

L = weighted load

It is worth noting that overlooking the interactions between generation systems and loads as in the generation balance is equivalent to assume that, per each carrier, the load is entirely satisfied by delivered energy while the generation is entirely fed into the grid.

If quasi-static weighting factors are entered, the generation/load balance is calculated as in Equation 2 for the electricity and heat from district heating energy carriers only.

$$\sum_i^m g_i^m \cdot w_{e,i}^m - \sum_i^m l_i^m \cdot w_{d,i}^m = G - L \geq 0 \qquad \text{Equation 2}$$

where:

i = energy carrier

m= month

g_i^m= generation of the i-th energy carrier in the m-th month

l_i^m= load of the i-th energy carrier in the m-th month

$w_{d,i}^m$ = weighting factor for delivered i-th energy carrier in the m-th month

$w_{e,i}^m$= weighting factor for exported i-th energy carrier in the m-th month

G = weighted generation

L = weighted load

In version 4.3 it is possible to calculate this balance for buildings that exchange with the energy infrastructure electricity and/or thermal energy only.

A.2 Estimated and monitored import/export balance equation

The import/export balance is in the spreadsheet calculated as in Equation 3.

$$\sum_i e_i \cdot w_{e,i} - \sum_i d_i \cdot w_{d,i} = E - D \geq 0 \qquad \text{Equation 3}$$

where:

i = energy carrier

e_i = exported i-th energy carrier

d_i = delivered i-th energy carrier

$w_{e,i}$ = weighting factor for exported i-th energy carrier

$w_{d,i}$ = weighting factor for delivered i-th energy carrier

E = weighted exported energy

D = weighted delivered energy

If quasi-static weighting factors are entered, the import/export balance is calculated as in Equation 4.

$$\sum_i^m e_i^m \cdot w_{e,i}^m - \sum_i^m d_i^m \cdot w_{d,i}^m = E - D \geq 0 \qquad \text{Equation 4}$$

where:

i = energy carrier

m= month

e_i^m= exported i-th energy carrier in the m-th month

d_i^m= delivered energy i-th energy carrier in the m-th month

$w_{d,i}^m$ = weighting factor for delivered i-th energy carrier in the m-th month

$w_{e,i}^m$= weighting factor for exported i-th energy carrier in the m-th month

E = weighted exported energy

D = weighted delivered energy

In version 4.3 it is possible to calculate this balance for buildings that exchange with the energy infrastructure electricity and/or thermal energy only.

A.3 Monthly net balance equation

Even if monthly net balance is not directly calculated by the spreadsheet, it can be get indirectly by filling the yearly values in the “estimated building – grid interaction data” section as the sum of the monthly net values residual as in Equation 5 and Equation 6.

$$g_{m,i} = \sum_{year} max[0; g_i(m) - l_i(m)] \qquad \text{Equation 5}$$

$$l_{m,i} = \sum_{year} max[0; l_i(m) - g_i(m)] \qquad \text{Equation 6}$$

where:

i = energy carrier

$g_i(m)$ = generation of the i-th energy carrier in the m-th month

$g_{m,i}$ = net monthly generation of the i-th energy carrier, annual total

$l_i(m)$ = load of the i-th energy carrier in the m-th month

$l_{m,i}$ = net monthly load of the i-th energy carrier, annual total

According to Equation 3 the monthly net balance is calculated as in Equation 7.

$$\sum_i g_{m,i} \cdot w_{e,i} - \sum_i l_{m,i} \cdot w_{d,i} = G_m - L_m \geq 0 \qquad \text{Equation 7}$$

where:

i = energy carrier

$g_{m,i}$ = net monthly generation of the i-th energy carrier, annual total

$l_{m,i}$ = net monthly load of the i-th energy carrier, annual total

$w_{d,i}$ = weighting factor for delivered i-th energy carrier

$w_{e.i}$ = weighting factor for exported i-th energy carrier

G_m = net monthly generation weighted

L_m = net monthly load weighted

A.4 Load match index

Load Match Index is calculated for electricity and thermal energy carrier from generation/load monthly data as in Equation 8.

$$f_{load,i} = \frac{\sum_{year} min\left[1, \frac{g_i(m)}{l_i(m)}\right]}{12} \qquad \text{Equation 8}$$

where:

$f_{load,i}$ = Load Match Index of the i-th energy carrier

$g_i(m)$ = generation of the i-th energy carrier in the m-th month

$l_i(m)$ = load of the i-th energy carrier in the m-th month

Load Match Index could be calculated for electricity and thermal energy carrier from generation and delivered/exported monthly data as in Equation 9.

$$f_{delivered,i} = \frac{\sum_{year} min\left[1, \frac{g_i(m)}{d_i(m) + g_i(m) - e_i(m)}\right]}{12} \qquad \text{Equation 9}$$

where:

$f_{delivered,i}$ = load match index of the i-th energy carrier

$g_i(m)$ = generation of the i-th energy carrier in the m-th month

$d_i(m)$ = delivered energy of the i-th energy carrier in the m-th month

$e_i(m)$ = exported energy of the i-th energy carrier in the m-th month

$d_i(m)$ + $g_i(m)$- $e_i(m)$ = total consumption in the m-month of the i-th energy carrier