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Climate and cultural based design and market valuable technology solutions for Plus Energy Houses

Data visualization library

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Authors:
Francesca Avella, Eurac
Manuel Mauro, Eurac

Contributors:
Annamaria Belleri, Eurac

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0.6	05.05.2021	Francesca Avella	Delivery of the data visualisation library.

Disclaimer:
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1 Executive summary

One of the objectives of the Cultural-E project is the development of data post-processing and visualization methodologies for simulation aided design.

Supporting designers in the early stages of designing Plus Energy Buildings, in fact, is strategic to ensure load reduction while still considering the household practices and enhancing the indoor environmental quality. To achieve this target, it is necessary to make use of effective building energy modelling with a clear view of the simulation results, thus allowing effective communication between the design team and the involved disciplines/stakeholders.

As a first step, a survey was disseminated among European designers[1]. It aimed to identify the performance indicators that are meaningful to designers and stakeholders, also trying to identify which aspects of building performance evaluation need to be investigated the most.
The main findings of the investigation in terms of performance indicators highlight that the annual final energy consumption is the most preferred energy indicator, possibly because it portrays an overall picture of the total consumption by the end users. Among the indicators of indoor environmental quality, indoor temperature related aspects (the number of overheating hours and the number of comfort hours without any energy input) are considered the most important. With regards to the field of renewable energy, designers care more about the percentage share of renewable energy sources over total energy use, rather than the ability of the building to match its own load by on-site generation while contributing to the needs of the local grids. Finally, the received feedback indicates that more attention is paid to the energy aspects of the building, giving less importance to the indoor air quality and comfort in terms of daylighting level. Based on the feedback received from targeted questions, informative data visualization charts and ready-made scripting, have been defined.

Data visualizations are automated by a script that generates interactive charts and produces an output report with clear interpretation keys starting from basic hourly output data series (air temperature, operative temperature, heating/cooling demand etc.); The tool makes use of a standard structure for data science projects, that aims at correctness and reproducibility. The results are multiple and comprise: an installable Python library, Jupyter notebooks and HTML reports, data clean-up scripts for the standard input data, and an effective development environment.
A Jupyter Notebook is an industry standard for data analysis and visualization, and as described on the home page of the project:

[1] For more information on the main findings of the data visualization library survey, please refers to the article "How to support the design of Plus Energy Buildings: survey results" in the 2nd newsletter of the Cultural-E project. https://www.cultural-e.eu/design-pebs-survey-results/

"The Jupyter Notebook is an open-source web application that allows you to create and share documents that contain live code, equations, visualizations and narrative text. Uses include: data cleaning and transformation, numerical simulation, statistical modelling, data visualization, machine learning, and much more."

The report is mainly composed by two core sections:
The first one, called Input, is related to the introduction of the inputs needed for setting up and understanding the model. This part is also organized to offer a complete overview of the model with detailed specifications of building components and systems. Standard input data sets include meaningful summary visualization on climate data, building geometry (Area, S/V, WWR etc.), internal gains, solar gains, building construction (U-value, thermal mass etc.) and glazing system properties (U-value, g-value etc.), infiltration and ventilation losses etc.
The second section, called Output, has been organized in two parts presenting the main results deriving from the building performance simulations in terms of energy and comfort.
With the aim to standardize as much as possible the way to present the output, the sections have been organized in "cards" which summarize their most important aspects. In Table 1 you can find an example of a "card".

Table 1 Example of output card.

Information required	Data	
Output	Presentation of the output shown by the graph in the final unit of measurement	
Output format	Graphic format in which the results are presented (for example hourly, monthly, annual, etc.)	
Input needed	Input lists necessary for the creation of the graph:	
	Complete input name	Input ID
Input source	Output file, deriving from the simulation, that contains all the inputs or outputs necessary for the presentation of the result	
File format	The file format required for the output file (it can be required: .epw, .out, .BAL). In case of other format, it is necessary to change this information directly in the script code.	
Script	Script that generates the chart	
Chart		
Description of the graph	Standard description of the chart	
Interpretation of results	Interpretations deriving from the results analysis	

At the end of the compilation of the report, the designer can have clear indications of the performance of his building. Thanks to the standardized and automated aspect of the library, it will be possible not only to simplify the building analysis process but also to carry out comparative assessments between multiple buildings, making this process more streamlined.

2 Introduction

The aim of the data visualization library is to collect custom and ready-made scripting for simulation input report and output post-processing. The data visualization should also be easy to understand and provide the right level of information needed to design PEB.

2.1 Main settings of the data visualisation library

In this perspective, to represent the simulation results as standardized as possible, the first step is to set each thermal zone (during the design of the 3d model) using a fixed code, as shown in Table 2 (it will be used also in association with the name of the input/output).

Table 2: Information required to fill in the ID zone.

Information required for ID zone	Possible ID	Example
Floor number	F0 (ground floor) F1 (first floor) F2 (second floor) ….	F0dayAx (as an example, you will find this code always in the report)
Use of the zones	Day (living area) Night (sleeping area) Strs (stairwell) Bas (basement) Undf (unique area or undefined use) ….	
Unique number of the apartment	A B C …	
Subdivision of the zones in case they are too large	x (could be a number 1, 2, 3…)	

Once the model has been set on the simulation software, it is time to set the output files that will be used in the data visualization library to generate input and output results.
To avoid the possibility of running into errors resulting from the use of an excessive number of output files, it is required to reduce their amount. It is advisable to set only two output files deriving from the simulation[2]:

- The first output file will include all the inputs required for the first section of the report, called Input. To set the inputs in an automated way, it is suggested to print them as "output" of the model. How to rename the input, is indicated in Table 3, **Error! Reference source not found.**, **Error! Reference source not found.**, Table 6, **Error! Reference source not found.**, **Error! Reference source not found.**, Table 9. Please note that each input will be preceded by [IN] and not all of them have their own ID as it is only needed for the results that will be generated automatically.
- The second output file will contain all the output in hourly timestep, necessary to create the related graphs in the section Output. In addition to this single output file, those produced automatically by the simulator are also considered[3].
  If TRNSYS[4] is used as the simulation tool, it is necessary to set the printer in hourly format, with a month of preconditioning and by setting the maximum number of outputs that the printer can generate by default. In this way, by connecting the calculator outputs to the printer, the names will be automatically generated in the right way.

During the compilation of the data visualization library, you will be asked to manually enter some parts, and some will be automatically generated by the script.
To standardize the library as much as possible, the person responsible for the simulation is asked to set the simulation with a timestep of one hour, so in a second moment the script can use it to generate the graphs in the necessary output format (hourly, monthly, annual). Also, the data visualization library will perform most of the calculations outside the simulation software using the script (for example, calculations related to the conversion of units of measurement).
Thanks to the data visualization library, it is possible to generate all the graphs for the total number of thermal zones that may sometimes be useless for your purpose. For this reason, it is advisable to focus only on the thermal zones that are worth investigating. Of course, feel free to focus on all your model.

[2] Please note that the generated output files must have the first row corresponding to the ID and subsequent rows containing the values.
The first column always corresponds to the timestep.
[3] Please note that you cannot control the name of the outputs generated automatically by the simulation tool so, they will not contain the thermal zone code.
[4] http://www.trnsys.com/

2.2 How to use the tool

As previously mentioned, the tool makes use of a standard structure for data science projects, that aims at correctness and reproducibility. The results are multiple and comprise: an installable Python library, data clean-up scripts for the standard input data, and an effective development environment.
For more information, please refer to the homepage of the project on which this work is based: Cookiecutter Data Science.

The tool is available at this link: https://github.com/EURAC-EEBgroup/CULTURAL-E-Data-Visualization-Library

The tool requires **Python** version 3.5 or above, thus you need to install it on your machine together with its package manager **pip**, then you can proceed to the installation of the requirements in **requirements.txt** with:

pip install -r requirements.txt

Consider using a **virtualenv** before doing this (strongly recommended).

The **/data/raw** folder contains some example data from a simulation respecting the naming conventions. This is where you will have to move your simulation's output files. Once you added your files to the folder head to the **/src/data/make_dataset.py** script and adapt it to the names of the new files if different. You can clean-up the data, and have it ready for the analysis, by running the following command in a terminal:

make data

Finally, head to the **/notebooks** folder and open the file **1.0-report.ipynb** in your Jupyter Notebook editor. Running this notebook will output a standardized set of graphs describing the main results of the simulation in the data folder.

Feel free to modify the notebook at your convenience to tailor the analysis to your needs.

```
├── LICENSE
├── Makefile           <- Makefile with commands like `make data` or `make train`
├── README.md          <- The top-level README for developers using this project.
├── data
│   ├── external       <- Data from third party sources.
│   ├── interim        <- Intermediate data that has been transformed.
│   ├── processed      <- The final, canonical data sets for modeling.
│   └── raw            <- The original, immutable data dump.
│
├── docs               <- A default Sphinx project; see sphinx-doc.org for details
│
├── notebooks          <- Jupyter notebooks. Naming convention is a number (for ordering),
│                         the creator's initials, and a short `-` delimited description, e.g.
│                         `1.0-jqp-initial-data-exploration`.
│
├── reports            <- Generated analysis as HTML, PDF, LaTeX, etc.
│   └── figures        <- Generated graphics and figures to be used in reporting
│
├── requirements.txt   <- The requirements file for reproducing the analysis environment, e.g.
│                         generated with `pip freeze > requirements.txt`
│
├── setup.py           <- makes project pip installable (pip install -e .) so src can be imported
├── src                <- Source code for use in this project.
│   ├── __init__.py    <- Makes src a Python module
│   │
│   ├── data           <- Scripts to download or generate data
│   │   └── make_dataset.py
│   │
│   └── visualization  <- Scripts to create exploratory and results oriented visualizations
│       └── visualize.py
│
└── tox.ini            <- tox file with settings for running tox; see tox.readthedocs.io
```

2.3 Summary of the process

Figure 1 and Figure 2 show a summary of the process related to using the data visualization library.
Please note that more detailed information is contained in the previous paragraphs.

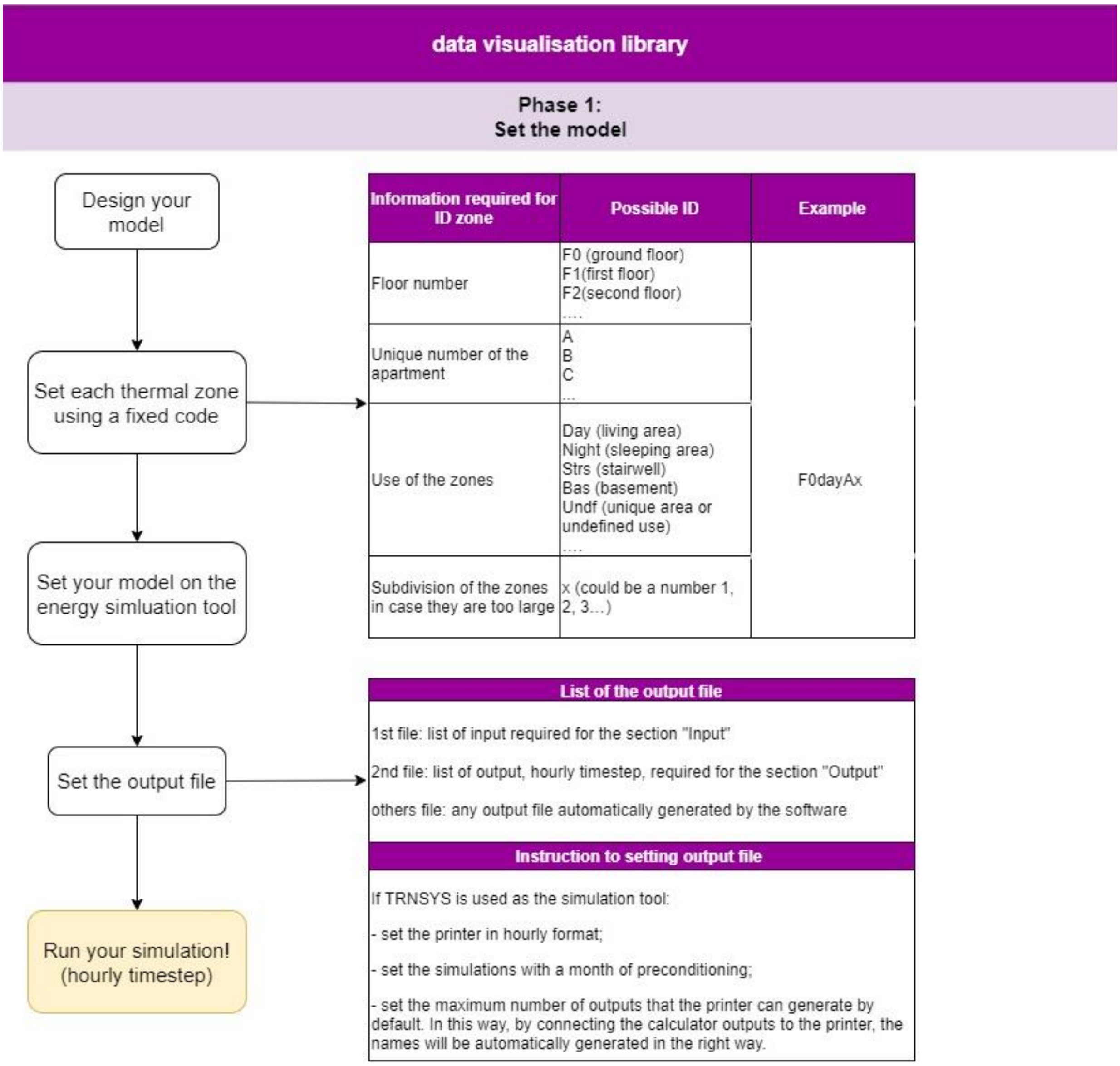


FIGURE 1 EXPLANATION OF THE FIRST PHASE OF THE WHOLE PROCESS OF THE DATA VISUALIZATION PROCESS

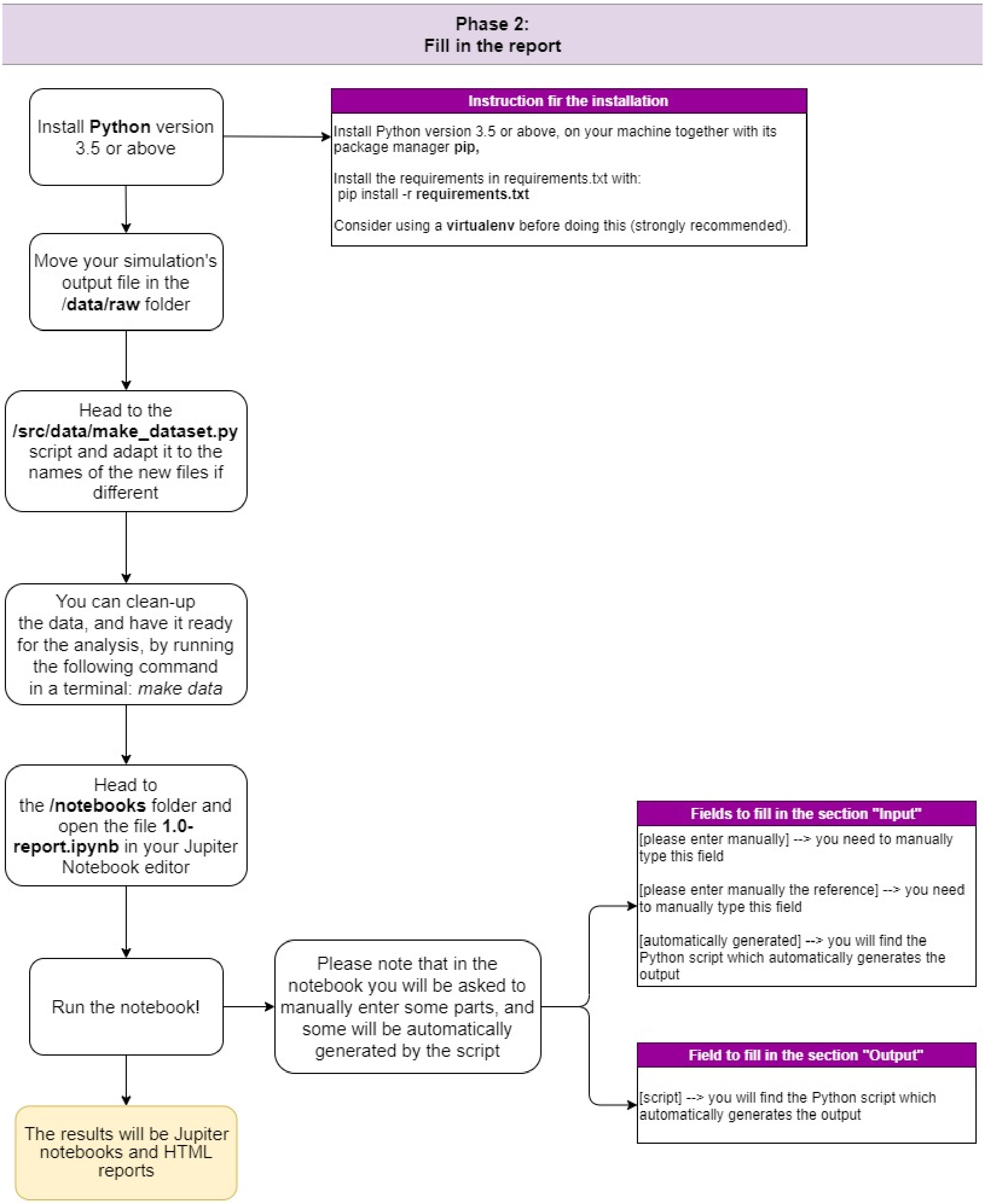


FIGURE 2 EXPLANATION OF THE SECOND PHASE OF THE WHOLE PROCESS OF THE DATA VISUALISATION PROCESS

3 Input

[Please enter with a picture of the 3d model].

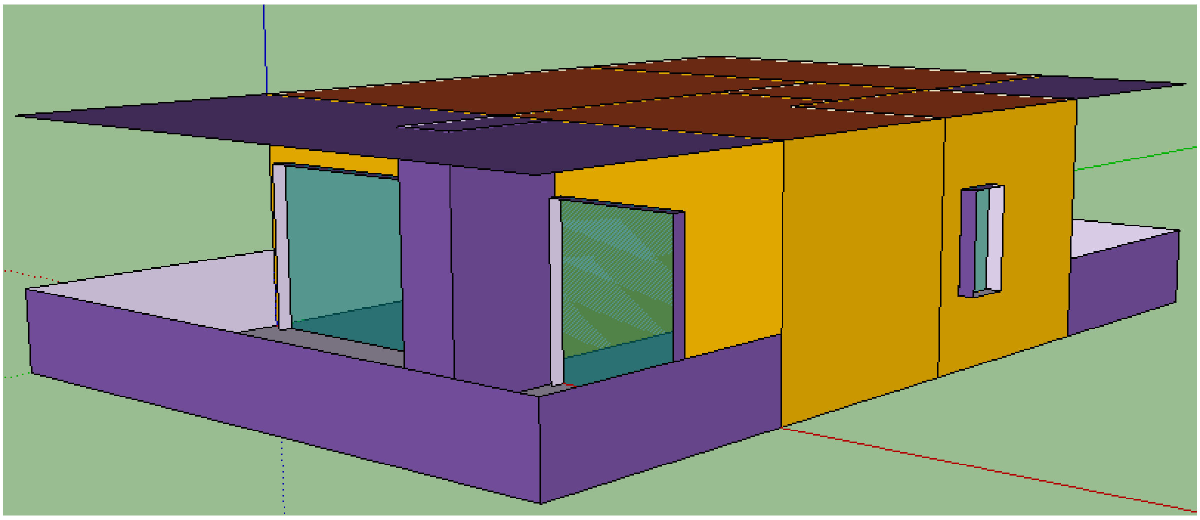


FIGURE 3 3D MODEL OF THE BUILDING

[please enter manually a brief description of the model, considering that more detailed information will be entered in the following sections]

3.1 General data of the building

Please enter the following general information related to the building.

Table 3 General building inputs

Information required	ID	Data
Type of building	-	[please enter manually]
Location	-	[please enter manually]
Gross floor area [m^2]	IN_GFA	[automatically generated]
Net floor area [m^2]	IN_NIA	[automatically generated]
S/V ratio	IN_SV	[automatically generated]
No. of floor	-	[please enter manually]
Number of thermal zones	-	[please enter manually]
Photovoltaic system	-	[please enter manually Yes/No]
PV capacity [kWp]	IN_PV_kWp	[automatically generated]

PV area [m^2]	IN_A_PV	[automatically generated]
Battery capacity [kWh]	IN_PV_bat	[automatically generated]
Technology installed	-	[please enter manually]
Position [façade or roof]	-	[please enter manually]
Tilt angle [°]	IN_PV_Tilt	[automatically generated]
Azimuth [°]	-	[please enter manually with the value and the reference. E.g., Azimuth=90° where: Nord=0°, East=90°, South=180°, West=270°]
Space for additional information/system	-	[please enter manually]

3.2 Thermal zones

Please fill in this table for the information related to the thermal zones. This information must be provided for each thermal zone.

Table 4 Thermal zone inputs

Information required	ID	Data
Thermal zone	-	[please enter manually]
Main exposure	-	[please enter manually]
Floor area [m^2]	IN_A_F0dayAx	[automatically generated]
Volume [m^3]	IN_V_F0dayAx	[automatically generated]
Glazed area [m^2]	IN_WinA_F0dayAx	[automatically generated]
WWR [%]	IN_WWR_F0dayAx	[automatically generated]
Presence of ceiling fan (yes/no)	-	[please enter manually]
People density [pers/m^2]	-	[please enter manually the reference]
Lighting density [W/m^2]	-	[please enter manually the reference]
Electric equipment [W/m^2]	-	[please enter manually the reference]
Heating setpoint temperature [°C]	-	[please enter manually the reference]
Heating system limited or unlimited	-	[please enter manually if limited or unlimited]

Heating system power (in case of limited) [kW]	IN_QHEAT_F0dayAx	[automatically generated]
Cooling setpoint temperature [°C]	-	[please enter manually the reference]
Cooling system (limited or unlimited)	-	[automatically generated]
Cooling system power (in case of limited) [kW]	IN_QCOOL_F0dayAx	[automatically generated]
Natural ventilation rates [ACH]	-	[please refer to **Error! Reference source not found.**]
Infiltration rates [ACH]	-	[please enter manually the reference]
Mechanical ventilation typology (centralized/decentralized)	-	[please enter manually]
Mechanical ventilation [ACH]	-	[please enter manually the reference]
Heat recovery efficiency [%]	-	[please enter manually the reference]
HVAC system	-	[please enter manually]
Space for additional information/system	-	[please enter manually]

Please fill in this table with the general information required on the internal gains.

Table 5 Internal gains

Information required	ID	Data
Convective fraction of sensible heat gains from persons.	IN_IG_CONVPER	[automatically generated]
Convective fraction of sensible heat gains from electric equipment.	IN_IG_CONVAPL	[automatically generated]
Convective fraction of sensible heat gains from lighting.	IN_IG_CONVLGT	[automatically generated]
Sensible heat gain per person (active) [W/pers]	IN_IG_PER_S1	[automatically generated]
Sensible heat gain per person (sleeping) [W/pers]	IN_IG_PER_S0	[automatically generated]

Latent heat gain per person (active) [kg/s/pers]	IN_IG_LATPER_S1	[automatically generated]
Latent heat gain per person (sleeping) [kg/s/pers]	IN_IG_LATPER_S0	[automatically generated]
Appliances consumption (in use) [W/m²]	IN_IG_APL_S1	[automatically generated]
Appliances consumption (standby) [W/m²]	IN_IG_APL_S0	[automatically generated]
Lighting consumption [W/m²]	IN_IG_LGT	[automatically generated]
Space for additional information/system	-	[please enter manually]

[Please enter manually the heating setpoint schedule chart if you think it might be interesting].

FIGURE 4 HEATING SETPOINT SCHEDULE APPLIED IN THE SIMULATIONS.

[Please enter manually the cooling setpoint schedule chart if you think it might be interesting].

FIGURE 5 COOLING SETPOINT SCHEDULE APPLIED IN THE SIMULATIONS.

[Please enter manually the occupancy schedule chart if you think it might be interesting].

FIGURE 6 OCCUPANCY SCHEDULE APPLIED IN THE SIMULATIONS.

[Please enter manually the lighting schedule chart if you think it might be interesting].

FIGURE 7 LIGHTING SCHEDULE APPLIED IN THE SIMULATIONS.

[Please enter manually the appliances schedule chart if you think it might be interesting].

FIGURE 8 APPLIANCES SCHEDULE APPLIED IN THE SIMULATIONS.

3.3 Building envelope

3.3.1 Opaque envelope components

Please fill in the following table with the information related to the opaque envelope components. Please enter manually the entire table except for the section "U-value [W/m²K]" which will be generated automatically.

Table 6 Opaque envelope inputs

Building element	Layer (I – O)	Thickness [m]	Thermal Conductivity [W/mK]	Density [kg/m3]	Thermal Capacity [J/kgK]	U-value [W/m²K]
External wall	1.					[automatically generated] IN_U_EXT_WALL
	2.					
	3.					
	…					
Adjacent wall	1.					[automatically generated] IN_U_ADJ_WALL
	2.					
	3.					
	…					
Boundary wall	1.					[automatically generated] IN_U_BND_WALL
	2.					
	3.					
	…					
Roof	1.					[automatically generated] IN_U_ROOF
	2.					
	3.					
	…					
Ceiling/ Interior floor	1.					[automatically generated] IN_U_FLOOR
	2.					
	3.					
	…					
Ground floor	1.					[automatically generated] IN_U_GDFLOOR
	2.					
	3.					
	…					
Space for additional information/system						[please enter manually]

3.3.2 Glazed envelope components

For each thermal zone, please fill in the following tables with the information related to the glazed envelope components. In addition, if there are different windows in your thermal zone, please fill in for each window typology.[5]

Table 7 Glazed envelope inputs.

Information required	ID	Data
Reference thermal zone [ID]	-	[please enter manually]
Typology and layer description	-	[please enter manually]
Orientation	-	[please enter manually]
Manual or automated windows	-	[please enter manually]
If automated windows	-	[please enter the strategy]
Window area [m^2]	IN_WinAx_F0dayAx	[automatically generated]
Ug [W/m^2K]	IN_Ugx_F0dayAx	[automatically generated]
G-value	IN_Gx_value_F0dayAx	[automatically generated]
Uf [W/m^2K]	IN_Ux_F0dayAx	[automatically generated]
Frame dimensions [m x m]	-	[please enter manually]
Space for additional information	-	[please enter manually]

Information required	ID	Data
Presence of shading (yes/no)	-	[please enter manually]
Typology of shading	-	[please enter manually]
Application of shading (external or internal)	-	[please enter manually]
Slat angle	-	[please enter manually]
Solar reflectance	IN_SRIx_F0dayAx	[automatically generated]
Manual or automated shading	-	[please enter manually]

[5] Please note that in **Error! Reference source not found.**, **Error! Reference source not found.**, Table 9, the symbol [x] near the first part of the ID (e.g., IN_WinA**x,** IN_WIN_OF**x**, IN_SHD**x** etc.) indicates the number of that specific window (e.g., IN_WinA**01,** IN_WIN_OF**01**, IN_SHD**01** etc.), in case you are considering different windows in your thermal zone.

Additional shading elements (balcony…)	-	[please enter manually]
Space for additional information	-	[please enter manually]

For automated windows, please enter the table with the strategy.

Table 8 Ventilation strategy

No. strategy	Signal/parameter	Logic function	Opening factor (0-close, 1-open)	Natural ventilation rates [ACH]
1	[please enter manually]	[please enter manually]	IN_WIN_OFx_F0dayAx	IN_WIN_OFx_ACH_F0dayAx
	[please enter manually]	[please enter manually]		
	[please enter manually]	[please enter manually]		
No.	[please enter manually]	[please enter manually]	IN_WIN_OFx_F0dayAx	IN_WIN_OFx_ACH_F0dayAx

For automated shadings, please enter the table with the strategy.

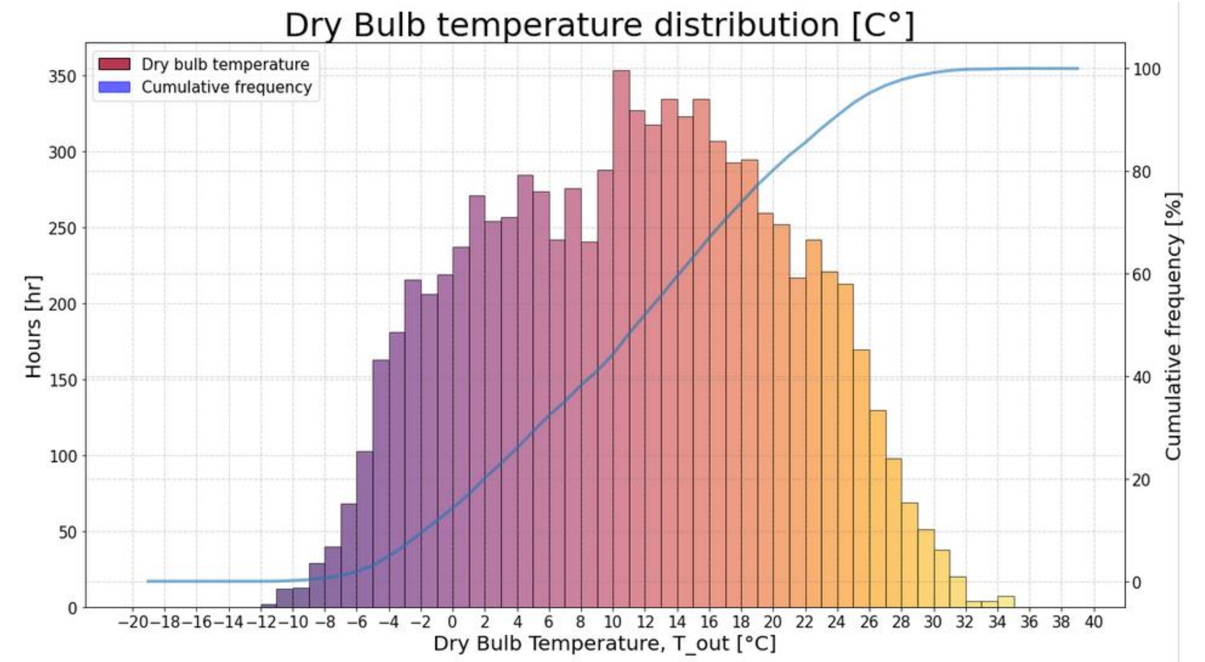
Table 9 Shading strategy.

No. strategy	Signal/parameter	Logic function	Shading factor (0-open, 1-close)
1	[please enter manually]	[please enter manually]	IN_SHDx_F0dayAx
	[please enter manually]	[please enter manually]	
	[please enter manually]	[please enter manually]	
No.	[please enter manually]	[please enter manually]	IN_SHDx_F0dayAx

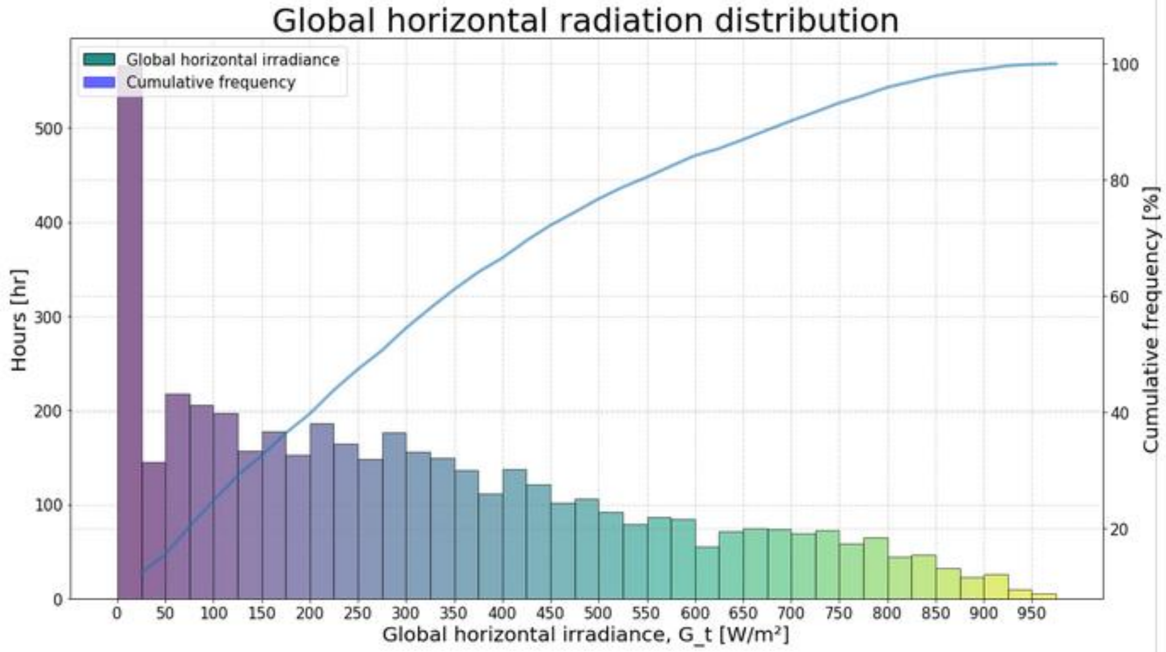
3.4 Climate Data

The weather conditions of a location play an important role in the energy performance of a building. In the next subsections, some results in terms of outdoor air temperature, global horizontal irradiance, and relative humidity, are presented.

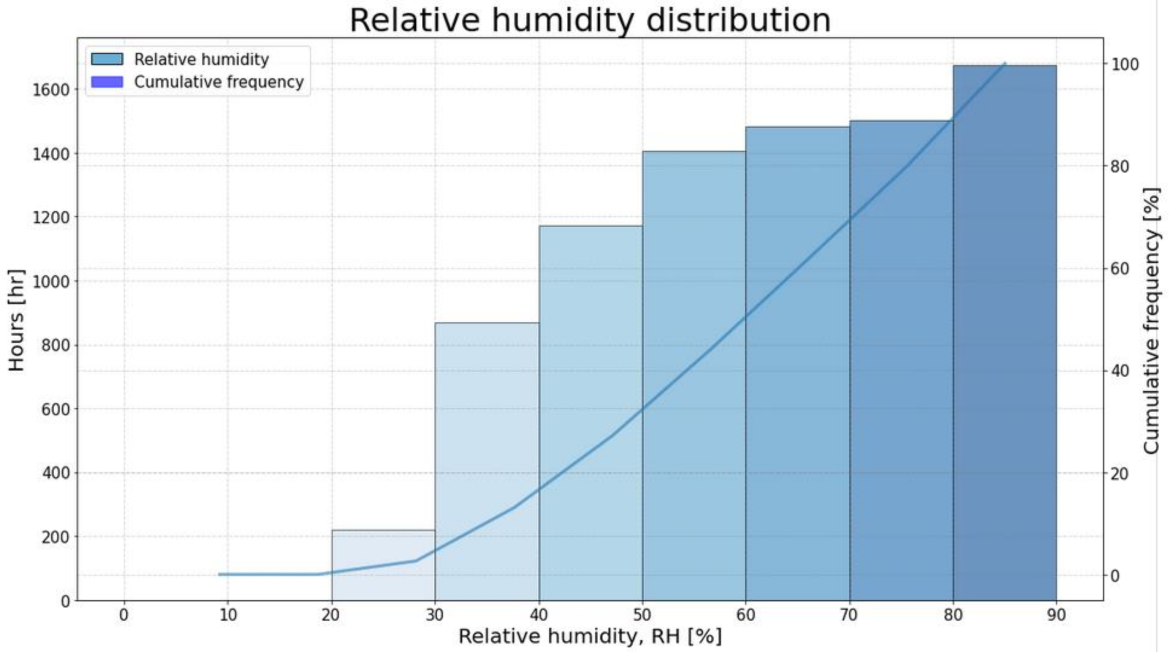
3.4.1 Dry Bulb temperature

Information required	Data	
Output	Dry Bulb temperature distribution [C°]	
Output format	Hourly	
Input needed	Dry Bulb temperature [C°]	Dry Bulb temperature
Input source	Weather file	
File format	.epw	
Script	[automatically generated]	
		
Description of the graph	Hourly dry-bulb temperature distribution and the cumulative frequency of a standard year.	
Interpretation of results	[Please enter manually this field]	

3.4.2 Global Horizontal Irradiance

<table>
<tr><td>Information required</td><td colspan="2">Data</td></tr>
<tr><td>Output</td><td colspan="2">Global horizontal radiation distribution</td></tr>
<tr><td>Output format</td><td colspan="2">Hourly</td></tr>
<tr><td>Input needed</td><td>Global horizontal radiation [W/m²]</td><td>Global horizontal radiation</td></tr>
<tr><td>Input source</td><td colspan="2">Weather file</td></tr>
<tr><td>File format</td><td colspan="2">.epw</td></tr>
<tr><td>Script</td><td colspan="2">[automatically generated]</td></tr>
<tr><td colspan="3">
</td></tr>
<tr><td>Description of the graph</td><td colspan="2">Hourly global horizontal radiation distributions and the cumulative frequency of a standard year.</td></tr>
<tr><td>Interpretation of results</td><td colspan="2">[Please enter manually this field]</td></tr>
</table>

3.4.3 Relative humidity

Information required	Data	
Output	Relative humidity distribution	
Output format	Hourly	
Input needed	Relative humidity [%]	Relative humidity
Input source	Weather file	
File format	.epw	
Script	[automatically generated]	
		
Description of the graph	Hourly relative humidity distribution of a standard year	
Interpretation of results	[Please enter manually this field]	

4 Output

This section presents the main results in terms of energy and comfort necessary to evaluate the performance of the building. As mentioned in the introduction, all the significant graphs have been organized by card.

4.1 Energy Output

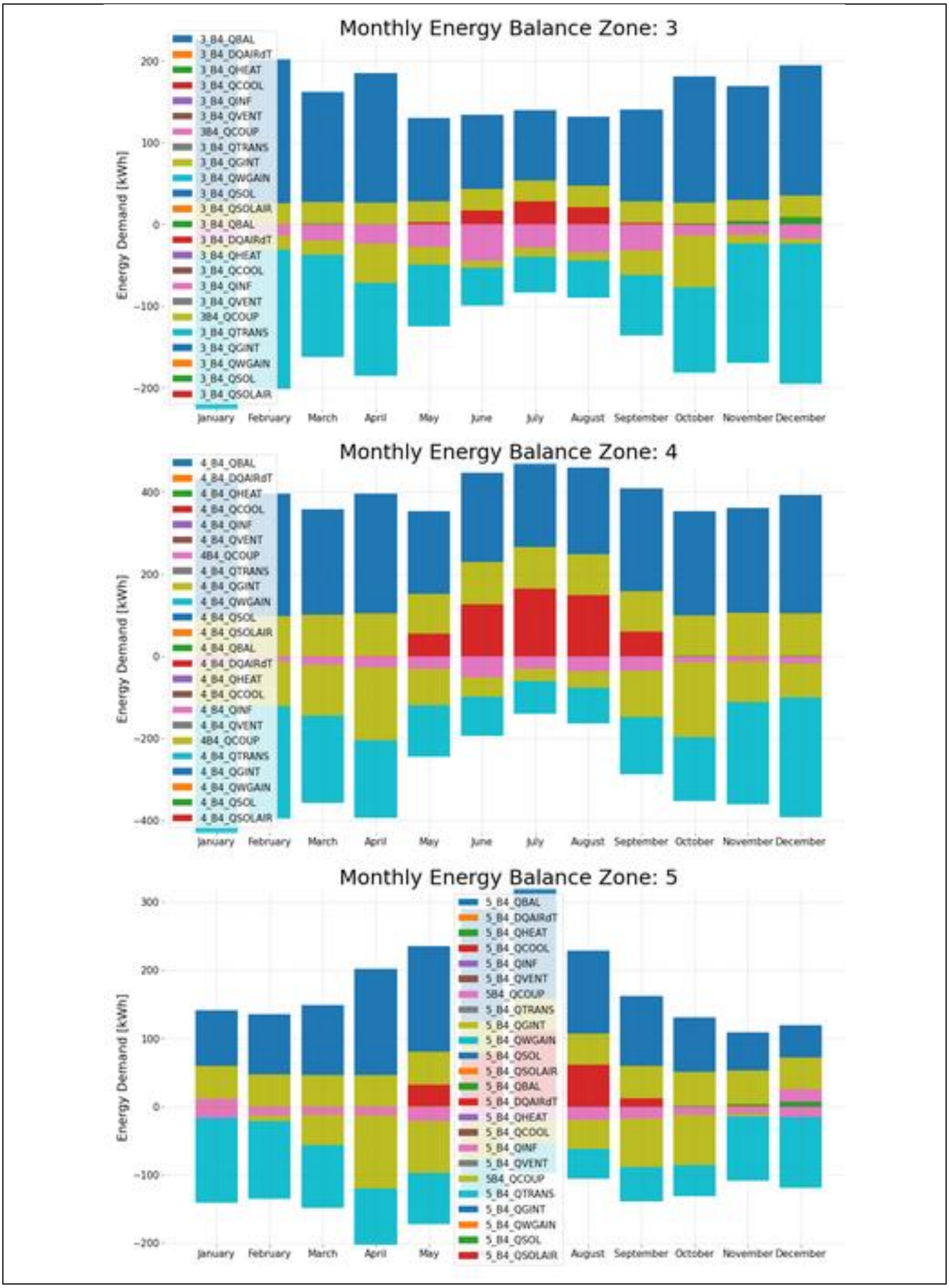
This section shows the main results in terms of energy balance of the building, energy consumption considering the total energy use of the house and overall heating load considering an ideal heating and/or cooling system. It also gives information on the use of renewable energy in case a photovoltaic system has been installed in the building.

4.1.1 Monthly energy balance for a single zone

It generates as many graphs as the number of thermal zones.

Information required	Data	
Output	Monthly energy balance of the thermal zone [kWh]	
Output format	Monthly	
Input needed	*in this case the first number of the ID indicates the zone (it is not possible to set the standard index for the thermal zone because it is an automatic output of the software).	
	Power of ideal heating [kJ/h]	1_B4_QHEAT-
	Power of ideal cooling [kJ/h]	1_B4_QCOOL+
	Infiltration gains [kJ/h]	1_B4_QINF+
	Ventilation gains [kJ/h]	1_B4_QVENT+
	Coupling gains [kJ/h]	1B4_QCOUP+
	Transmission into the wall from inner surface node [kJ/h]	1_B4_QTRANS+
	Internal gains (convective+radiative) [kJ/h]	1_B4_QGINT+
	Wall gains [kJ/h]	1_B4_QWGAIN+
	Absorbed solar gains on all inside surface of zone [kJ/h]	1_B4_QSOL+
	Convective energy gain of zone due transmitted solar radiation through external windows which is transformed immediately into a con. heat flow to internal air [kJ/h]	1_B4_QSOLAIR+

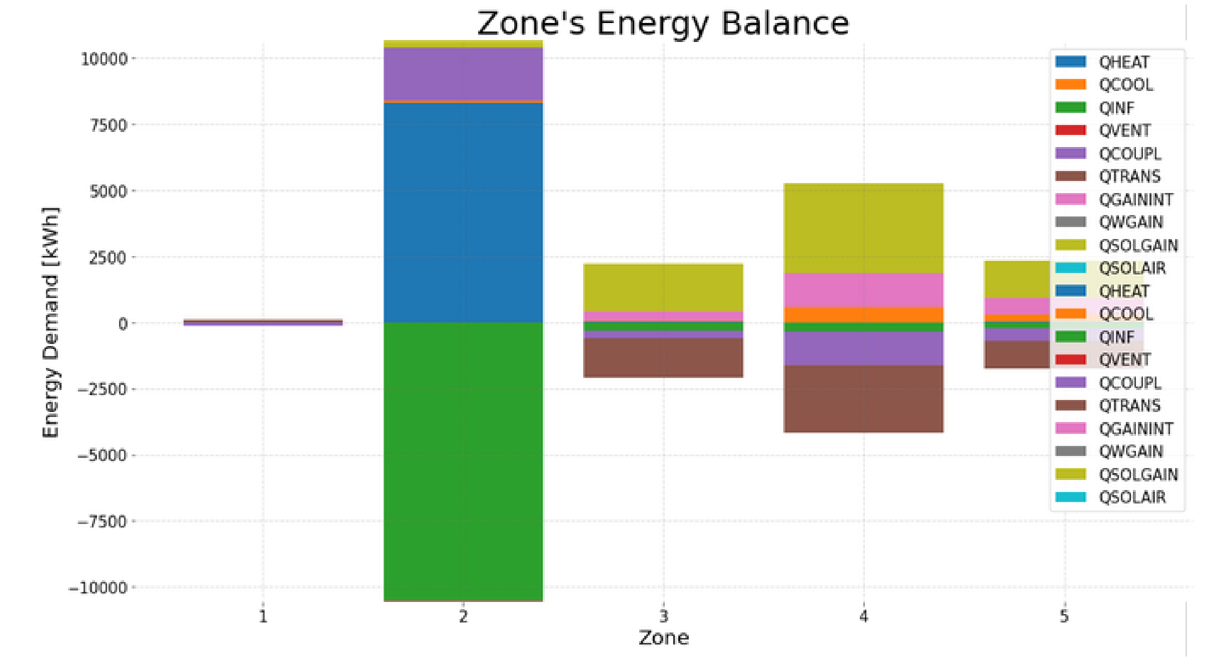
Input source	Energy_zone.BAL
File format	.BAL
Script	[automatically generated]


Monthly Energy Balance Zone: 3
Energy Demand [kWh]
200
100
0
-100
-200
3_B4_QBAL
3_B4_DQAIRdT
3_B4_QHEAT
3_B4_QCOOL
3_B4_QINF
3_B4_QVENT
3B4_QCOUP
3_B4_QTRANS
3_B4_QGINT
3_B4_QWGAIN
3_B4_QSOL
3_B4_QSOLAIR
January
February
March
April
May
June
July
August
September
October
November
December
Monthly Energy Balance Zone: 4
Energy Demand [kWh]
400
200
0
-200
-400
4_B4_QBAL
4_B4_DQAIRdT
4_B4_QHEAT
4_B4_QCOOL
4_B4_QINF
4_B4_QVENT
4B4_QCOUP
4_B4_QTRANS
4_B4_QGINT
4_B4_QWGAIN
4_B4_QSOL
4_B4_QSOLAIR
January
February
March
April
May
June
July
August
September
October
November
December
Monthly Energy Balance Zone: 5
Energy Demand [kWh]
300
200
100
0
-100
-200
5_B4_QBAL
5_B4_DQAIRdT
5_B4_QHEAT
5_B4_QCOOL
5_B4_QINF
5_B4_QVENT
5B4_QCOUP
5_B4_QTRANS
5_B4_QGINT
5_B4_QWGAIN
5_B4_QSOL
5_B4_QSOLAIR
January
February
March
April
May
August
September
October
November
December

Description of the graph	Monthly energy balance of each thermal zone. The heat balance of the building consists of all sources and sinks of energy inside a building and the energy flows through its envelope. It should be always close to 0 since the building is losing as much heat as it gains.
Interpretation of results	[Please enter manually this field]

4.1.2 Annual energy balance for all zones

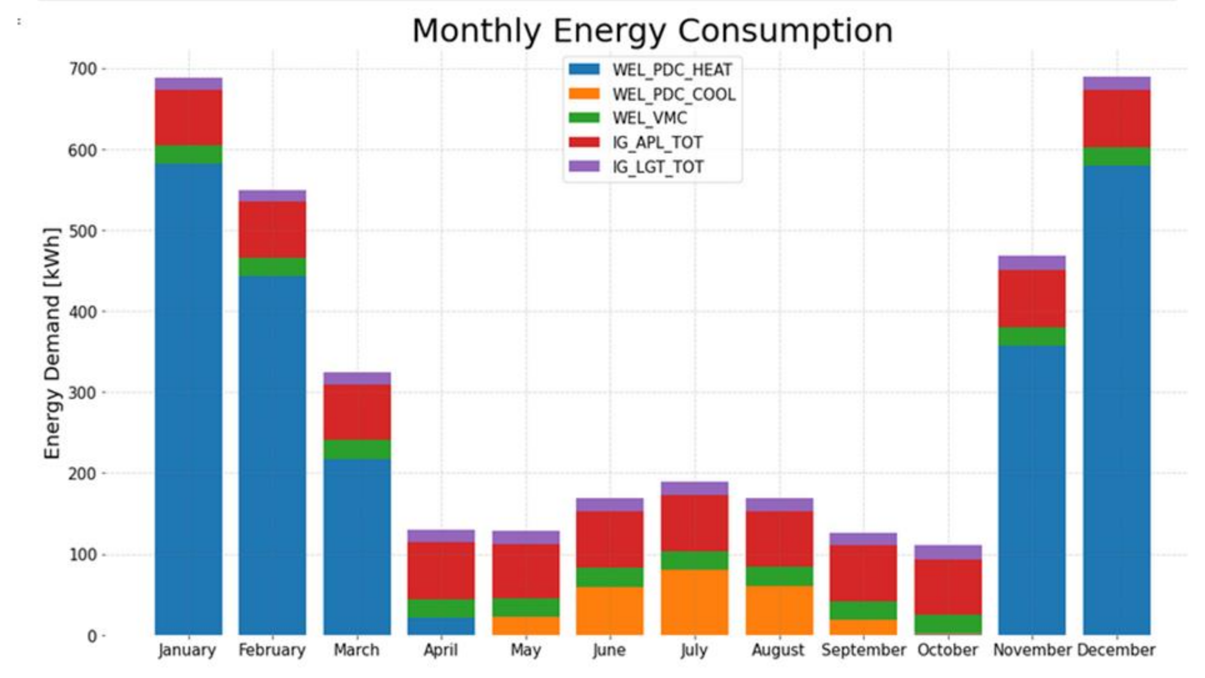
<table>
<tr><th>Information required</th><th colspan="2">Data</th></tr>
<tr><td>Output</td><td colspan="2">Thermal balance split for all zones [kWh]</td></tr>
<tr><td>Output format</td><td colspan="2">Annual</td></tr>
<tr><td rowspan="11">Input needed</td><td colspan="2">*in this case the first number of the ID indicates the zone (it is not possible to set the standard index for the thermal zone because it is an automatic output of the software).</td></tr>
<tr><td>Power of ideal heating [kJ]</td><td>=+QHEAT</td></tr>
<tr><td>Power of ideal cooling [kJ]</td><td>=-QCOOL</td></tr>
<tr><td>Infiltration gains [kJ]</td><td>=+QINF</td></tr>
<tr><td>Ventilation gains [kJ]</td><td>=+QVENT</td></tr>
<tr><td>Coupling gains [kJ]</td><td>=+QCOUPL</td></tr>
<tr><td>Transmission into the wall from inner surface node [kJ]</td><td>=+QTRANS</td></tr>
<tr><td>Internal gains (convective+radiative) [kJ]</td><td>=+QGAININT</td></tr>
<tr><td>Wall gains [kJ]</td><td>=+QWGAIN</td></tr>
<tr><td>Absorbed solar gains on all inside surface of zone [kJ]</td><td>=+QSOLGAIN</td></tr>
<tr><td>Convective energy gain of zone due to transmitted solar radiation through external windows which is transformed immediately into a con. heat flow to internal air [kJ]</td><td>=+QSOLAIR</td></tr>
<tr><td>Input source</td><td colspan="2">SUMMARY.BAL</td></tr>
<tr><td>File format</td><td colspan="2">.BAL</td></tr>
<tr><td>Script</td><td colspan="2">[automatically generated]</td></tr>
</table>



Description of the graph	Annual thermal balance split for all zones. The heat balance of the building consists of all sources and sinks of energy inside a building and the energy flows through its envelope. It should be always close to 0 since the building is losing as much heat as it gains.
Interpretation of results	[Please enter manually this field]

4.1.3 Monthly energy consumption

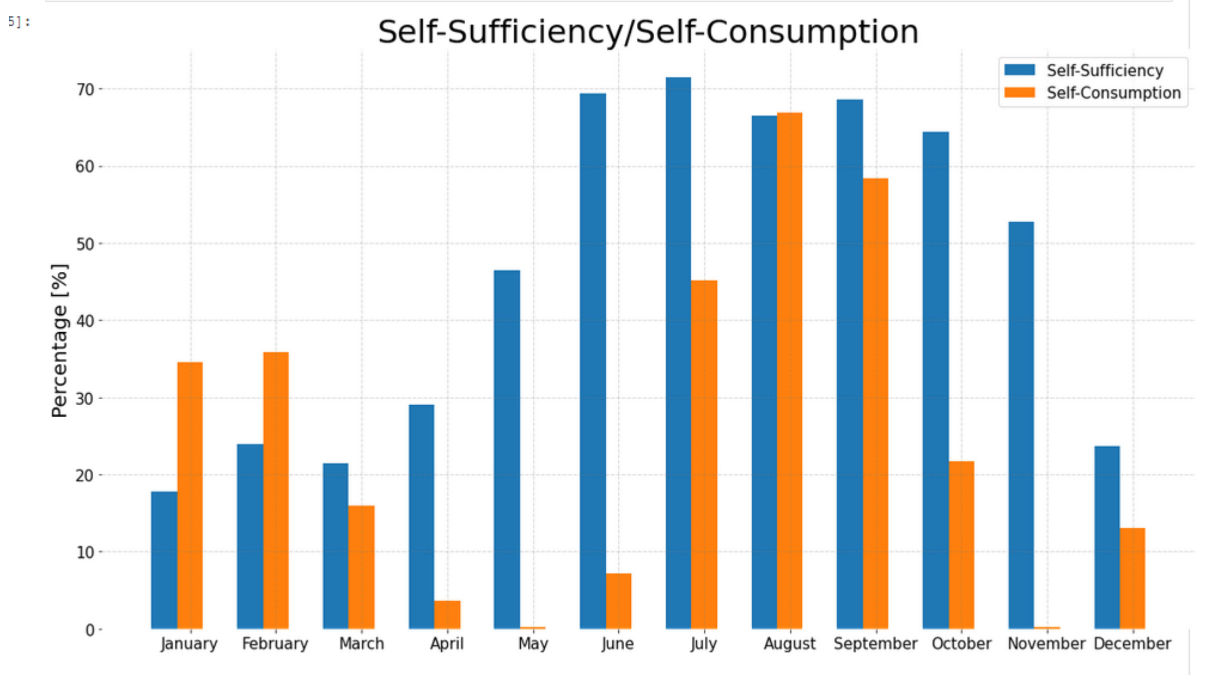
Information required	Data	
Output	Monthly energy consumption estimation considering the total energy use of the house. [kWh]	
Output format	Monthly	
Input needed	Main power products for each type of end-use. Example:	
	Heating power [kJ/h]	QHEAT_TOT
	Cooling power [kJ/h]	QCOOL_TOT
	Ventilation power [kJ/h]	QVMC_TOT
	Lighting power [kJ/h]	QLGT_TOT
	Appliances power [kJ/h]	QAPL_TOT
	[Space for additional information]	[Space for additional information]
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	



Information required	Data
Description of the graph	Monthly building energy consumption
Interpretation of results	[Please enter manually this field]

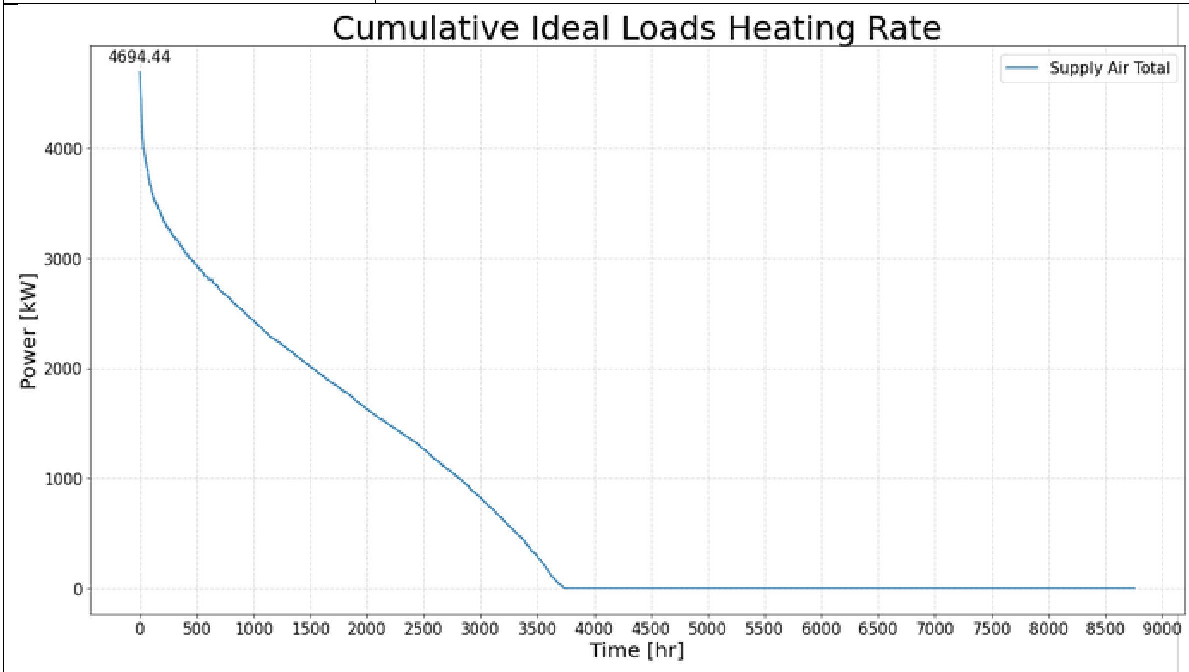
4.1.4 Self-consumption and Self-sufficiency

Information required	Data	
Output	Percentage of renewable energy [%]	
Output format	Monthly	
Input needed	Whole building electricity [W]	QEL_TOT
	PV self-consumption [W]	PV_selfC
	PV production [W]	PV_P
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	



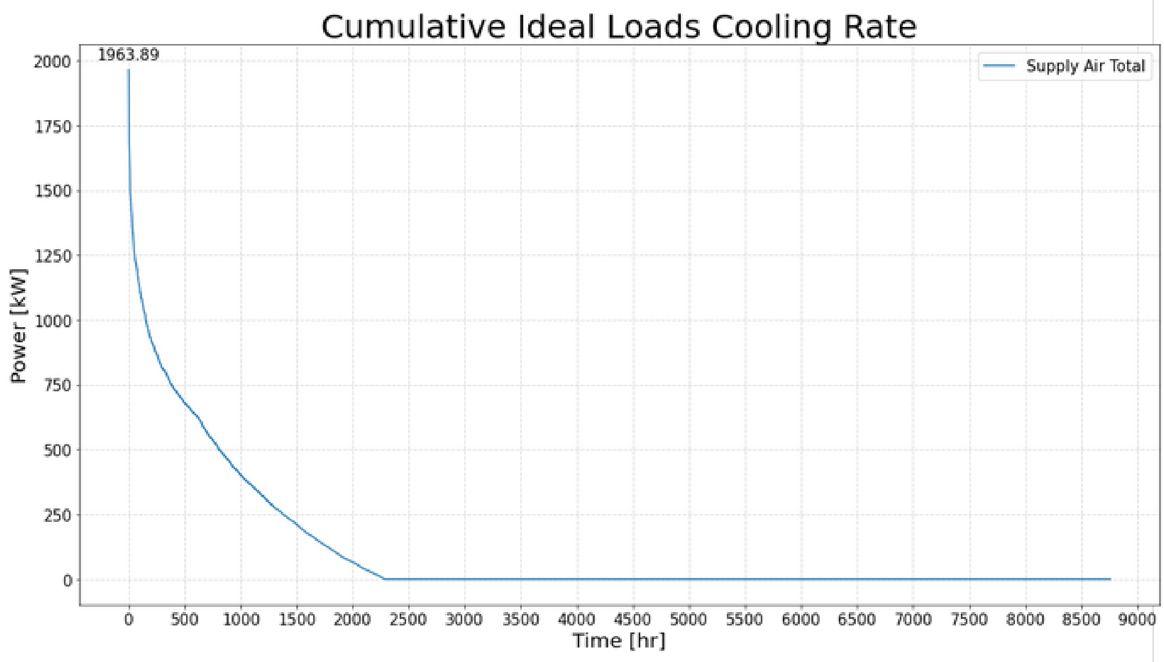
Description of the graph	Self-consumption and self-sufficiency indictors. While the self-consumption is the share of the total produced electricity that is self-consumed by the building owner, self-sufficiency represent the share of the building electric demand, covered by electricity that is produced by PV and self-consumed.
Interpretation of results	[Please enter manually this field]

4.1.5 Cumulative ideal loads Heating Rate

Information required	Data	
Output	Power of total ideal heating (sum of power of ideal heating of all zones) [kW]	
Output format	Hourly	
Input needed	*in this case the number 1 is auotmaically generated by the simuation tool.	
	Heating demand [kJ/h]	SQHEAT_1
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	
		
Description of the graph	Cumulative curve of the heating power of the entire building. The heating system is modelled as an ideal system with infinite heating capacity that supplies conditioned air to the zone meeting all the load requirements and consuming no energy. This allows to calculate overall heating load.	
Interpretation of results	[Please enter manually this field]	

4.1.6 Cumulative ideal loads Cooling Rate

Information required	Data	
Output	Power of total ideal cooling (sum of power of ideal cooling of all zones) [kW]	
Output format	Monthly	
Input needed	*in this case the number 1 is auotmaically generated by the simuation tool.	
	Cooling demand [kJ/h]	SQCOOL_1
Input source	Simulation output file	
Source format	.out	
Script	[automatically generated]	



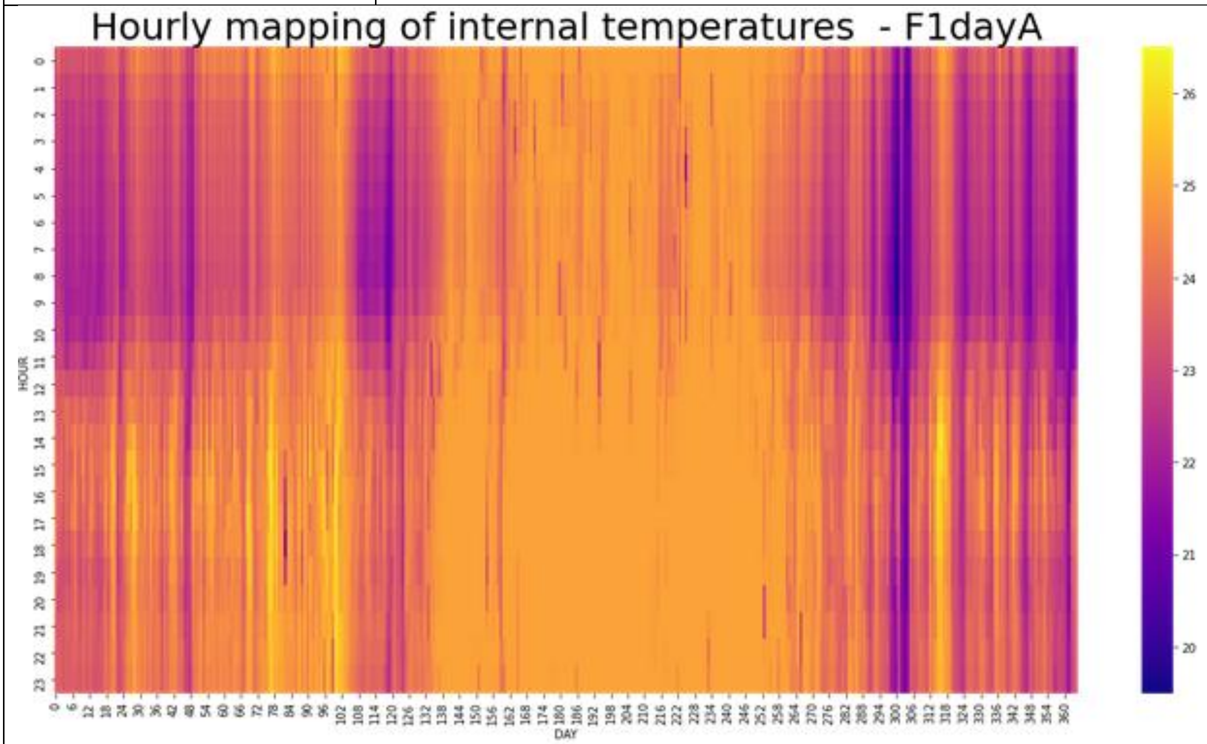
Description of the graph	Cumulative curve of the cooling power of the entire building. The cooling system is modelled as an ideal system with infinite cooling capacity that supplies conditioned air to the zone meeting all the load requirements and consuming no energy. This allows to calculate overall heating load.
Interpretation of results	[Please enter manually this field]

4.2 Comfort Output

This section has been organized to show the main results in terms of thermal comfort, visual comfort and IAQ. For each group of output, you will be asked to enter the results for each thermal zone. If you think it is useful to assess the comfort in only some areas of the building or only in one, enter the results only for those useful for your evaluation.

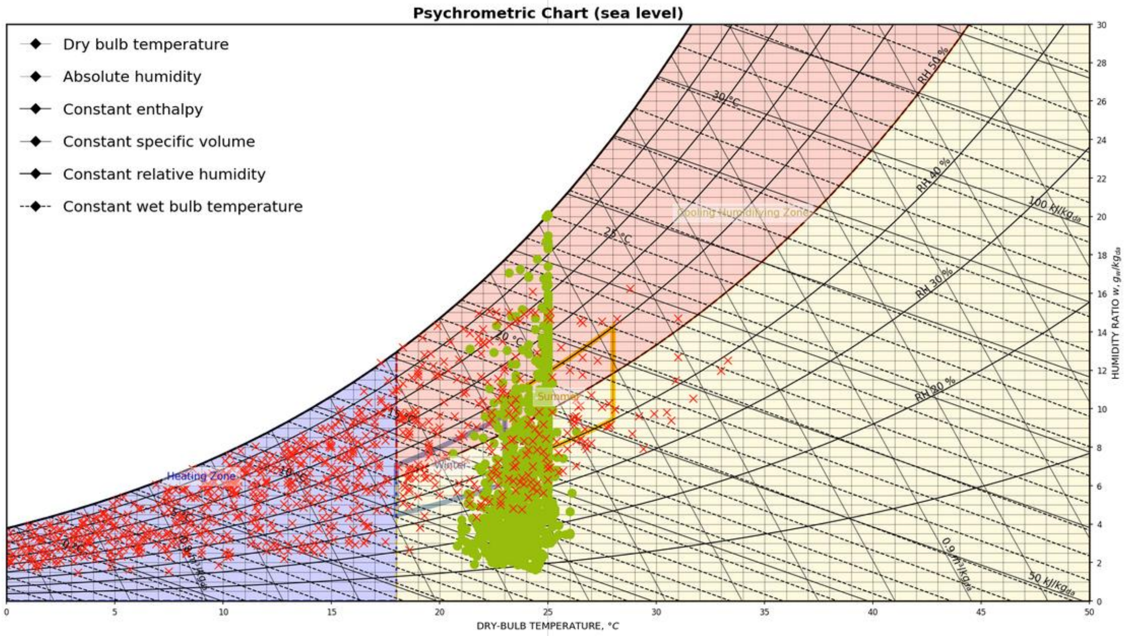
4.2.1 Thermal comfort

4.2.1.1 Mean indoor temperature

Information required	Data	
ID zone	[Please enter manually this field]	
Output	Indoor temperature mapping [C°]	
Output format	Hourly	
Input needed	Indoor air temperature [C°]	TAIR_ F0dayAx
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	
		
Description of the graph	Hourly mapping of internal temperatures. It could be useful to know any areas of thermal discomfort.	
Interpretation of results	[Please enter manually this field]	

4.2.1.2 Psychrometric graph

Information required	Data	
ID zone	[Please enter manually this field]	
Output	Distribution of the simulated/monitored indoor temperature and relative humidity on the psychrometric graph.	
Output format	Hourly	
Input needed	Dry bulb temperature [C°]	Dry bulb temperature
	Relative humidity [%]	Relative humidity
	Indoor air temperature of the zone [C°]	TAIR_F0dayAx
	Relative humidity of the zone [kg/kg]	RELHUM_F0dayAx
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	



Description of the graph	The graph illustrates the distribution of simulated indoor temperature and relative humidity with respect to the two internal thermal condition comfort zones, one for the summer season (in light yellow) and one for the winter season (in light blue). The graph also highlights the outdoor temperature and humidity limits for which the application of some passive control systems can ensure summer comfort conditions without applying air conditioning systems.	
Interpretation of results	[Please enter manually this field]	

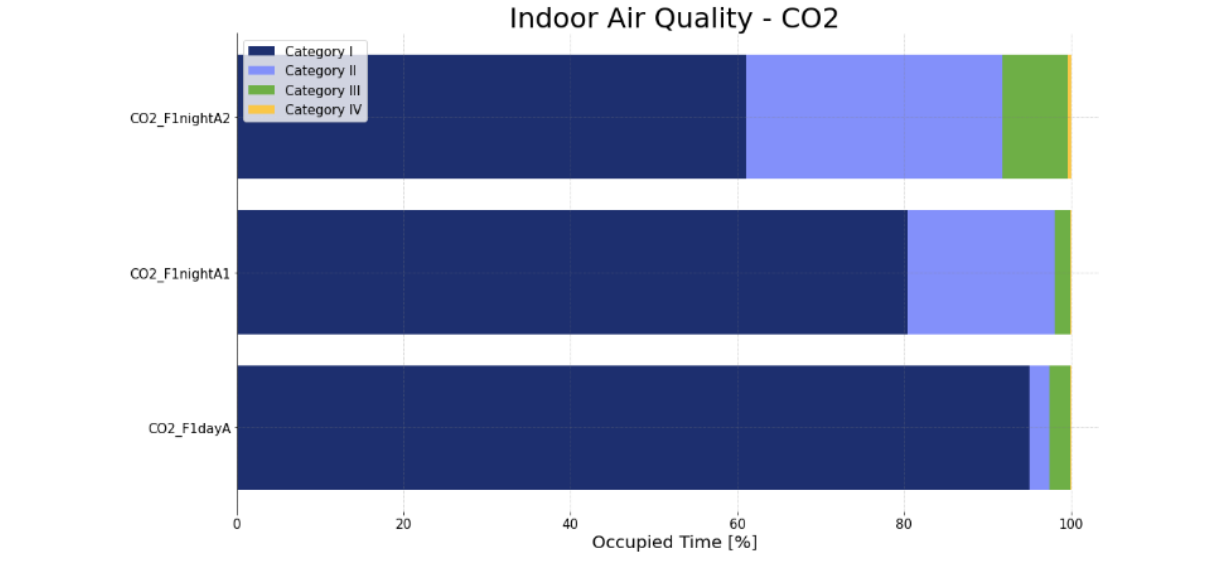
4.2.2 Indoor air quality

In order to assess the air quality of the building during the occupied time, considering the occupants as one of the main pollution sources, the level of the CO_2 concentration generated by the occupants, need to be calculated. The limits for indoor CO_2 concentrations leading to the four IAQ categories have been calculated in accordance with the standard EN 16798-1: 2019[6].

4.2.2.1 IAQ categories for non-adapted persons

<table>
<tr><th>Information required</th><th colspan="2">Data</th></tr>
<tr><td>Output</td><td colspan="2">Percentage of time in which CO_2 ppm concentration within occupied time is in the four categories for each thermal zone [%]</td></tr>
<tr><td>Output format</td><td colspan="2">Annual</td></tr>
<tr><td rowspan="4">Input needed</td><td colspan="2">*fill in the follow rows with the CO_2 concentration for all your thermal zones</td></tr>
<tr><td>CO_2 ppm concentration within occupied time in the living area [ppm]</td><td>CO_2_F0dayAx</td></tr>
<tr><td>CO_2 ppm concentration within occupied time in the sleeping area [ppm]</td><td>CO_2_F0nightAx</td></tr>
<tr><td>[Space for additional information]</td><td>[Space for additional information]</td></tr>
<tr><td>Input source</td><td colspan="2">Simulation output file</td></tr>
<tr><td>File format</td><td colspan="2">.out</td></tr>
<tr><td>Script</td><td colspan="2">[automatically generated]</td></tr>
</table>

[6] EN 16798-1, Energy Performance of Buildings - Ventilation for Buildings - Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustic, 2019.

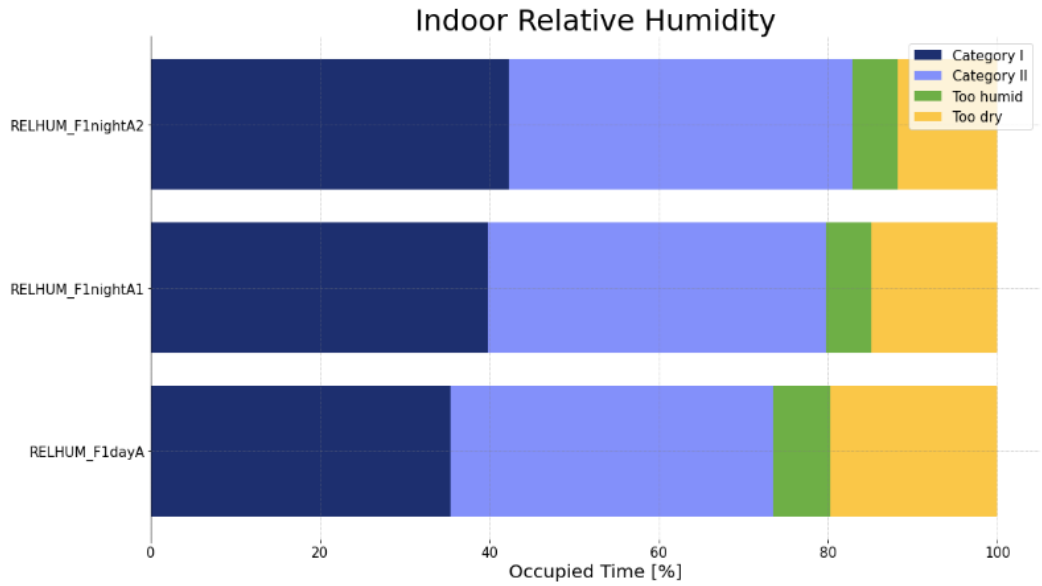


Description of the graph	Comparison of the zones in terms of indoor air quality. The graph indicates the percentage of hours in which the CO_2 concentration is in the four categories in accordance with EN 16798-1: 2019.
Interpretation of results	[Please enter manually this field]

4.2.2.2 Indoor relative humidity categories (EN 16798-1: 2019)

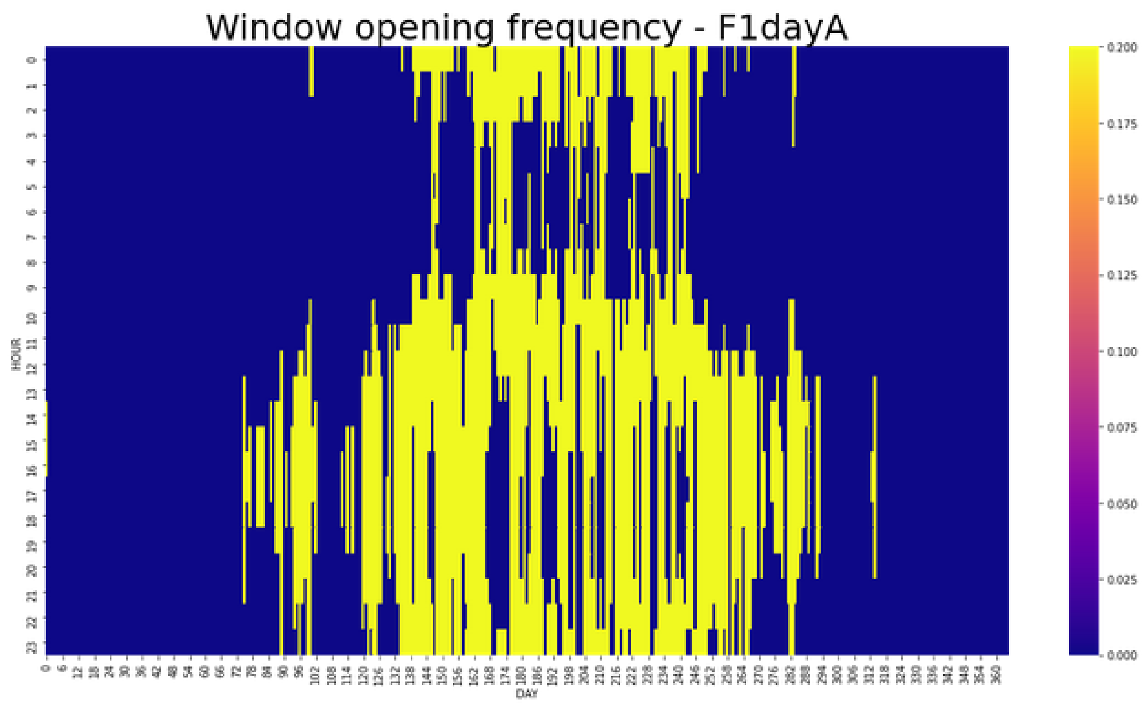
Another necessary parameter to evaluate the internal comfort of a building is the indoor relative humidity. This is important because high or low percentages lead to humid or dry environment, respectively, which has a direct effect on human well-being. An effective way to evaluate this data is to classify the number of hours in which the relative humidity of a thermal zone falls within the categories for humidification and dehumidification, identified in standard EN 16798-1: 2019.

<table>
<tr><td>Information required</td><td colspan="2">Data</td></tr>
<tr><td>Output</td><td colspan="2">Percentage of time in which indoor relative humidity within occupied time is in the four categories for each thermal zone [%].</td></tr>
<tr><td>Output format</td><td colspan="2">Annual</td></tr>
<tr><td rowspan="3">Input needed</td><td colspan="2">*fill in the following rows with the % of relative humidity for all your thermal zones</td></tr>
<tr><td>Relative humidity for the living area [%]</td><td>RELHUM_F0dayAx</td></tr>
<tr><td>Relative humidity for the sleeping area [%]</td><td>RELHUM_F0nightAx</td></tr>
</table>

	schedule occupancy for the living area	
	schedule occupancy for the sleeping area	
	[Space for additional information]	[Space for additional information]
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	
		
Description of the graph	Number of hours within occupied time, when indoor relative humidity of the thermal zones, is within the categories for humidification and dehumidification, identified in standard EN 16798-1: 2019.	
Interpretation of results	[Please enter manually this field]	

4.2.2.3 Natural ventilation

The frequency of opening the windows can be considered an interesting indicator in the evaluation of some aspects related to the performance of a building. Thanks to these parameters it is possible to evaluate, for example, whether the action of natural ventilation alone can guarantee an acceptable level of internal comfort, whether it affects the energy consumption of the building as well as giving indications on how the occupants interact with the building.

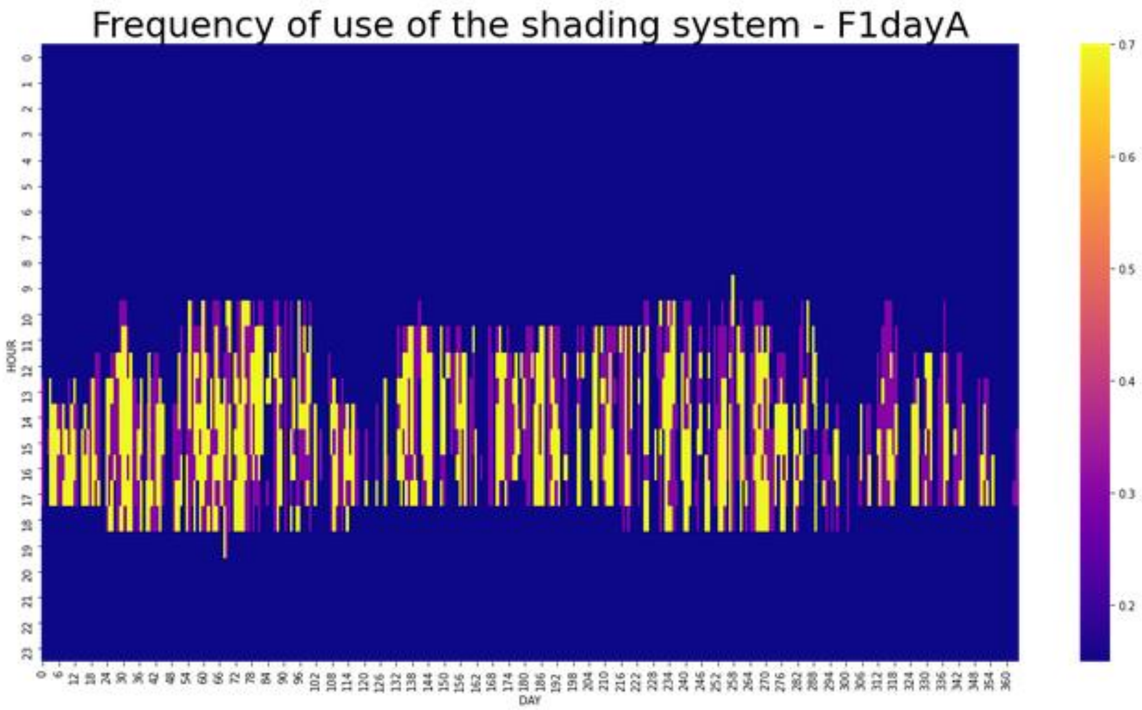
Information required	Data	
ID zone	[Please enter manually this field]	
Output	Number of hours in which the windows are opened	
Output format	Hourly	
Input needed	Window opening factor	WIN_OF_F0dayAx
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	
		
Description of the graph	Numbers of hours in which natural ventilation is used.	
Interpretation of results	[Please enter manually this field]	

4.2.3 Visual comfort

4.2.3.1 Activation of the shadings

Please fill in this table for the significant thermal zone.

Information required	Data	
ID zone	[Please enter manually this field]	
Output	Number of hours in which the shadings are activated	
Output format	Hourly	
Input needed	Window shading factor	SHD_F0dayAx
Input source	Simulation output file	
File format	.out	
Script	[automatically generated]	



Description of the graph	Numbers of hours in which the shadings are used.
Interpretation of results	[Please enter manually this field]

5 Conclusion

In this deliverable a data visualization library has been developed. The aim of this library is to collect custom and ready-made scripting for simulation input report and output post-processing, providing the right level of information needed to address design phase of PEB buildings.

A set of scripts elaborates basic hourly output data series (output from an energy simulation software) to generate interactive charts and a report with clear interpretation keys tailored to PEB. Scripts are grouped into an installable Python library, which is complemented by Jupyter notebooks, HTML template reports, data clean-up scripts for parsing input data.

The report is composed of two main sections: in the first section, the user will enter all the inputs needed to set the model in a proper way and the second part will generate all the meaningful graphs necessary to evaluate the building performance.
By the standardized report, the designer can get a brief overview on PEB building, then review specifications of the components, systems, boundary conditions and in-depth performance assessment.

The library can operate directly on specific input and output file, generated by TRNSYS energy simulation tool, and thus formatted accordingly. TRNSYS energy simulation tool is one of most popular software available for this purpose, but alternative software exists. Designers may decide to use different software tools, and in this case a proper software interface should be developed to adapt file format.
Also, some of the settings presented in the first part of the report are specific to TRNSYS energy simulation tool, but equivalent can be found in alternative software.

Further developments may be:

- To calculate and render PEB KPIs (key performance indicators), currently being defined in D4.1.
- To improve standardization in the report.
- To add automation and ergonomics to the tool.
- To optimize charts.