



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

Repository of reference building models and related solution-sets

Deliverable D4.3

Dissemination level: Public
Lead partner: Eurac Research
Due date: 30/09/2022
Type of deliverable: Other
Status: Final version

Published in the framework of:

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



This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 870072

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Revision and history chart:

Version	Date	Editors	Comment
0.1	28/09/2022	Riccardo Gazzin	First draft
0.2	05/10/2022	Roberto Fedrizzi Roberto Lollini	Review of the draft
1	07/10/2022	Riccardo Gazzin	Creation of the final version

Disclaimer:

The project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 870072.

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Table of contents

Executive summary 5

1 Introduction..... 6

 1.1 Cultural-E geo-clusters and solution sets..... 6

2 Support spreadsheet file..... 8

3 General information of the simulations..... 10

 3.1 Building archetypes 10

 3.2 Simulations input..... 11

 3.2.1 Weather data..... 11

 3.3 Building and envelope characteristics 12

 3.3.1 BSDF window 13

 3.4 Internal gains 14

 3.5 Ventilation 15

 3.5.1 Mechanical ventilation 15

 3.5.2 Natural ventilation 16

 3.6 Shading..... 17

 3.7 HVAC system 18

 3.8 PV system 21

 3.9 Outputs 22

4 Conclusions 24

References 25

List of figures

FIGURE 1: "MODELS" SHEET OF THE SUPPORT SPREADSHEET FILE 8

FIGURE 2: "INPUT" SHEET OF THE SUPPORT SPREADSHEET FILE 9

FIGURE 3: LOW-RISE BUILDING GEOMETRY 10

FIGURE 4: HIGH-RISE BUILDING GEOMETRY..... 11

FIGURE 5: TRNSYS MODEL - WEATHER FILE SECTION..... 12

FIGURE 6: TRNSYS MODEL - BUILDING MACRO 13

FIGURE 7: TRNSYS MODEL - BUILDING FILE 13

FIGURE 8: TRNSYS MODEL - BSDF FILE SELECTION 14

FIGURE 9: TRNSYS MODEL - INTERNAL GAINS PROFILES 15

FIGURE 10: TRNSYS MODEL - VENTILATION LOGICS 17

FIGURE 11: TRNSYS MODEL - SHADING SYSTEM LOGICS..... 18

FIGURE 12: P&I DIAGRAM OF THE HVAC SYSTEM 19

FIGURE 13: TRNSYS MODEL - HEAT PUMP 20

FIGURE 14: TRNSYS MODEL - THERMAL STORAGE AND BUFFER..... 21

FIGURE 15: TRNSYS MODEL - PV+BATTERY 22

Executive summary

Building models of low rise and multifamily residential plus energy buildings have been developed to perform dynamic simulation activities and calculate a set of key performance indicators. These models, implemented with TRNSYS v.18.02, have been converted into executable files that can be used by anyone, even without a TRNSYS license, to run their own simulations. With the executable version of the models, users can run dynamic simulations using as a starting point the building archetypes that have been modelled for this task and implementing the solution sets developed for the Cultural-E project.

The building archetypes include a Low-rise and a High-rise building, characterized by different envelopes according to the four geo-clusters (Sub-arctic, Continental, Oceanic and Mediterranean). A centralized and a decentralized solution sets were designed for each geo-cluster. Considering the two building archetypes in four geo-clusters and two solution sets, this results in 16 different combinations. After choosing one of the model combination, some inputs can be customized, as the weather boundary conditions, some parameters of the building energy system and the PV setup. With these simulations, some Key Performance Indicators can be obtained and evaluated. The executable files are uploaded and they are accessible on the Cultural-E website and on Zenodo.

To support the users to tailor the model and to change input parameters, this report comes together with a support spreadsheet file, which contains the list of model parameters that can be changed by the users, as well as other technical and specific information about the building models.

The TRNSYS models, which have been implemented for the simulation activities and that have been converted into executable files, are structured in different parts and blocks. The windows are coupled with an advanced shading system to better control the solar heat gains. The internal gains profiles have been calculated stochastically, while the weather boundary conditions have been implemented by means of EPW files. The HVAC system has been modelled with an Heat Pump connected to a storage. Moreover, the building is equipped with a PV system and a Battery Energy Storage System.

The executable models can be used to observe the variation of the performance of the archetype building with the modelled HVAC system by changing some input parameters which are related to the envelope, the boundary conditions, the HVAC system or the PV system.

1 Introduction

The models for the simulation activities that are described in this document have been developed with TRNSYS software (version 18.02), and have been exported into a executable files that can be downloaded and used by anyone, without the limitations of needing a TRNSYS license or having to be expert users of this simulation software. The executable files will allow every user to simulate a pre-defined building archetype, while tailoring the model by changing some input variables, such as envelope characteristics, technological solution sets for the HVAC system and weather data.

1.1 Cultural-E geo-clusters and solution sets

In the Cultural-E project, technological solution sets for residential Plus Energy Buildings (Cultural-E - PEB definition, 2022) have been developed taking into account the climatic, cultural and social conditions of the different parts of Europe. Countries and areas have been subdivided into the so-called “geo-clusters”. The aim of this work has been to develop parametric building energy simulation models to evaluate solution sets performance in the defined “geo-clusters”.

The geo-clusters definition has been carried out taking mainly into account the climatic conditions of the different European countries, subdividing them in four groups (Sub-arctic, Continental, Oceanic and Mediterranean).

For each geo-cluster, two technological solution sets have been identified. The rationale was to implement innovative solutions that allow to reach the “Plus Energy Building” (PEB) target; and to account for the cultural preferences for the end users, designers and real estates. The Local Demo Working Group (LDWG) teams and partners from WP2 have been involved in a co-design process. LDWG teams provided feedback on acceptability of the solutions by the local market as well as construction paradigms. Partners from WP2 represented user needs and attitudes, in particular towards technology.

For each geo-cultural cluster, two solution sets have been implemented in two different building archetypes (“Low-rise” and “High-rise” multifamily residential building). A first solution set is based on centralized HVAC system, a second solution set based on an HVAC service performed at building unit level by a compact heat pump unit for heating, cooling, dehumidification and Domestic Hot Water (DHW). Each solution set presents adaptations for each geo-cultural cluster, to account for local best practices.

House Management System (including related cloud services and field devices) can be easily tailored to the defined cultural clusters (early adopters, laggards), i.e. by adopting

proper User Interfaces or communication methods to the users, aggressive optimization vs manual controls.

For the energy performance evaluation, building energy models have been implemented based on the two solution sets. Each model implements technical systems and envelope properties, which can be tailored to the specific cluster by changing parameters (i.e. setpoint temperatures, presence of mechanical ventilation, number and position of PV panels, etc).

Output from simulations of the executable model is arranged in order to be handled by the Data Visualization Library (Avella, Mauro, & Belleri, Data Visualization Library, 2021) to assess the KPIs for the desired configuration.

Executable models are publicly available in an online repository. Users can download the models for the desired building archetype (Low-rise, High-rise), choose among the two solution sets and change the editable parameters, and finally run simulations for custom locations and weather conditions.

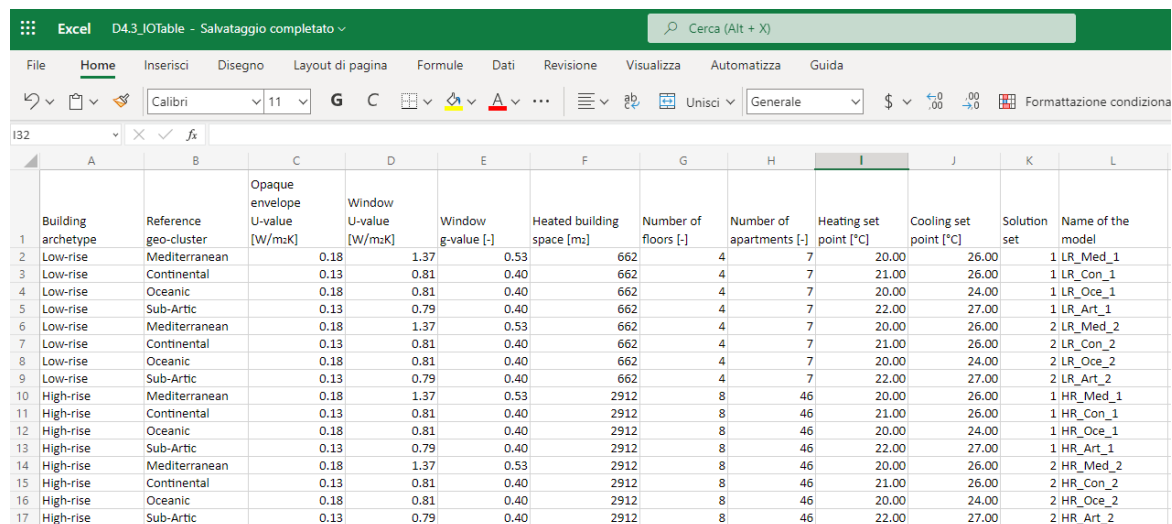
The following pages describe the structure of building models and their characteristics. Together with the description, instructions on how to customize and tailor the models are reported.

2 Support spreadsheet file

Together with this report and the simulation models, in this deliverable users can find a spreadsheet file that can be used as a guide to a proper utilization of these models.

The file comprises the following sheets:

- MODELS:** here the user can find the list of the implemented models, which represent the starting point for their energy simulation. These base models are made for the two building archetypes (Low-rise and High-rise), the two solution sets (centralized and de-centralized) and the four geo-clusters (Sub-arctic, Continental, Oceanic and Mediterranean), which influence the thermal characteristics of the envelope components, the heating/cooling setpoint and the solution sets components. This results in a total of 16 configurations that users can select as a starting point for their simulations.



	A	B	C	D	E	F	G	H	I	J	K	L
	Building archetype	Reference geo-cluster	Opaque envelope U-value [W/m ² K]	Window U-value [W/m ² K]	Window g-value [-]	Heated building space [m ²]	Number of floors [-]	Number of apartments [-]	Heating set point [°C]	Cooling set point [°C]	Solution set	Name of the model
1	Low-rise	Mediterranean	0.18	1.37	0.53	662	4	7	20.00	26.00	1 LR_Med_1	
2	Low-rise	Continental	0.13	0.81	0.40	662	4	7	21.00	26.00	1 LR_Con_1	
3	Low-rise	Oceanic	0.18	0.81	0.40	662	4	7	20.00	24.00	1 LR_Oce_1	
4	Low-rise	Sub-Artic	0.13	0.79	0.40	662	4	7	22.00	27.00	1 LR_Art_1	
5	Low-rise	Mediterranean	0.18	1.37	0.53	662	4	7	20.00	26.00	2 LR_Med_2	
6	Low-rise	Continental	0.13	0.81	0.40	662	4	7	21.00	26.00	2 LR_Con_2	
7	Low-rise	Oceanic	0.18	0.81	0.40	662	4	7	20.00	24.00	2 LR_Oce_2	
8	Low-rise	Sub-Artic	0.13	0.79	0.40	662	4	7	22.00	27.00	2 LR_Art_2	
9	High-rise	Mediterranean	0.18	1.37	0.53	2912	8	46	20.00	26.00	1 HR_Med_1	
10	High-rise	Continental	0.13	0.81	0.40	2912	8	46	21.00	26.00	1 HR_Con_1	
11	High-rise	Oceanic	0.18	0.81	0.40	2912	8	46	20.00	24.00	1 HR_Oce_1	
12	High-rise	Sub-Artic	0.13	0.79	0.40	2912	8	46	22.00	27.00	1 HR_Art_1	
13	High-rise	Mediterranean	0.18	1.37	0.53	2912	8	46	20.00	26.00	2 HR_Med_2	
14	High-rise	Continental	0.13	0.81	0.40	2912	8	46	21.00	26.00	2 HR_Con_2	
15	High-rise	Oceanic	0.18	0.81	0.40	2912	8	46	20.00	24.00	2 HR_Oce_2	
16	High-rise	Sub-Artic	0.13	0.79	0.40	2912	8	46	22.00	27.00	2 HR_Art_2	

Figure 1: "MODELS" sheet of the support spreadsheet file

- INPUT:** here the user finds the customizable variables (e.g. temperature setpoints, number and position of PV panels, etc). In this sheet, you can also find the standard values that have been set for the base models (Low-rise and High-rise)

	Note:	LOW-RISE				HIGH-RISE							
		Medit	Cont	Oce	SArt	Medit	Cont	Oce	SArt				
GENERAL													
Timestep [minutes]	5	5	5	5	5	5	5	5	5				
Simulation start [h]	0	0	0	0	0	0	0	0	0				
Simulation stop [h]	9504	9504	9504	9504	9504	9504	9504	9504	9504				
Building rotation from azimuth [°]	0	45	45	45	45	45	45	45	45				
BUILDING SYSTEM													
Winter season start [h]	6888	15th October	6888	6552	6888	6168	6888	6552	6888	6168			
Winter season end [h]	2496	15th April	2496	2880	2496	3216	2496	2880	2496	3216			
		Possible range: 0.75-5 for Low-rise building; 2.25-15 for High-rise building.											
Volume DHW thermal energy storage [m3]	0.977	Please, select a value in those ranges				0.977	0.977	0.977	0.977	3.283	3.283	3.283	3.283
Night setback	0	1 if there is a setback, 0 if there is not a setback								0	0	0	0
Start heating plant - morning [h]	6	6	6	6	6	6	6	6	6	6	6	6	
Stop heating plant - morning [h]	12	22	22	22	22	22	22	22	22	22	22	22	
Start heating plant - afternoon [h]	14	These three must be the same if only night setback is used								22	22	22	22
Stop heating plant - afternoon [h]	22	22	22	22	22	22	22	22	22	22	22	22	
Buffer max temperature heating [°C]	45	45	45	45	45	45	45	45	45	45	45	45	
Buffer min temperature cooling [°C]	7	7	7	7	7	7	7	7	7	7	7	7	
Minimum ambient temperature [°C]	-5	-5	-12	-8	-17	-5	-12	-8	-17	-5	-12	-8	-17

Figure 2: "INPUT" sheet of the support spreadsheet file

- DAY-HOUR CORRELATION:** this can be used as support when a date input needs to be filled in a hourly format. For example, the winter season starting and ending date can be modified by the user, but cannot be provided as a day/month format, but only in hours (counting from January 1st). Hence, with this table is possible to easily link a certain day of the year to the corresponding time unit.

3 General information of the simulations

The building simulation models are built to assess the building energy performance throughout one whole year, with a default time-step of 5 minutes. A pre-conditioning time of one extra month is included to allow the building envelope temperature to reach the operation conditions. As previously mentioned, these models have been implemented with TRNSYS v.18.02.

In the following sections of this document some screenshots of the TRNSYS model are shown. These are reported not as instructions but as a description of the model. The executable file are structured in a different but simpler way, easier to manage for users who are not familiar with TRNSYS.

3.1 Building archetypes

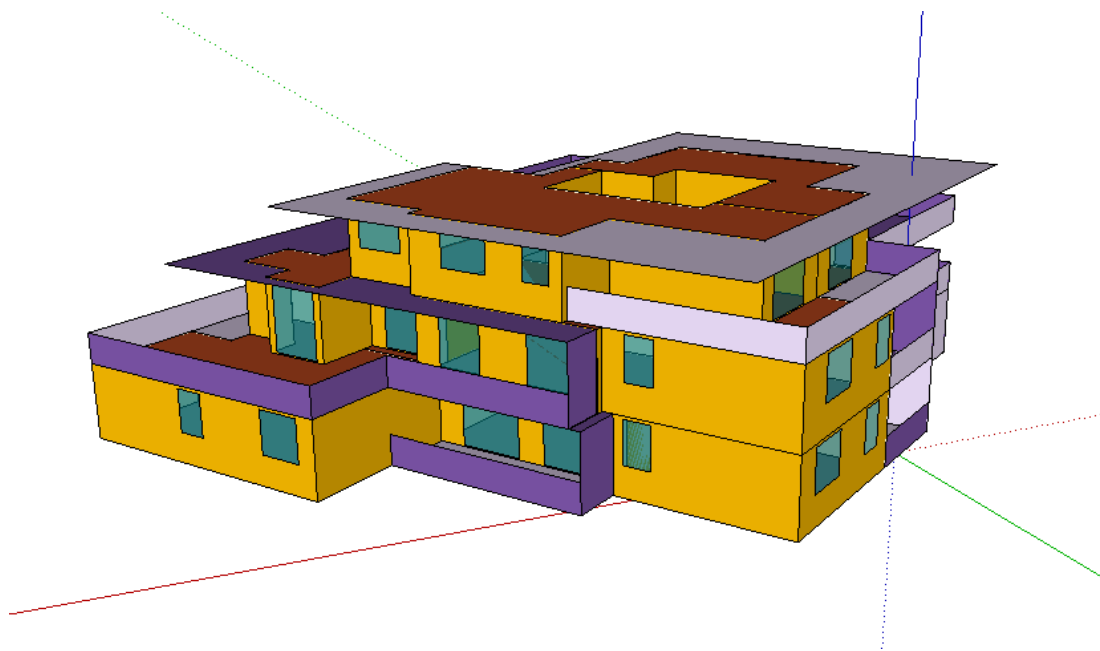


Figure 3: Low-Rise building geometry

The first building archetype is the “Low-rise” building (Figure 3), which represents the Italian demo-case (Cultural-E - Italian demo case, 2022). It is a multifamily residential building composed by 7 apartments. Considering the limited number of apartments, each of them has been subdivided in two thermal zones for the simulations (living-space and night-space). These apartments are distributed in 4 floors, and they have different volumes and orientations.

The other archetype is the “High-rise” building, represented in Figure 4. The geometry of the building was inspired by the one implemented for the H2020 BuildHeat project

(Horizon 2020 - BuildHEAT), and later on adapted for the H2020 BIPVBOOST project (Horizon 2020 - BIPVBOOST). Starting from this geometry, the TRNSYS model for Cultural-E has been developed. This extends vertically, having 8 floors and a total of 46 apartments. Among these 8 floors, 3 of them have been modelled (ground, intermediate and upper floor), to get a complete picture of the building behavior while avoiding an unnecessarily heavy simulation model to manage. It was in fact assumed that the intermediate floors behavior would be similar to the modelled ones. For each apartment, only one thermal zone has been modelled. To avoid an excessive and unrealistic contemporaneity of the internal gains, different stochastic gains profiles have been implemented and distributed among the building floors.

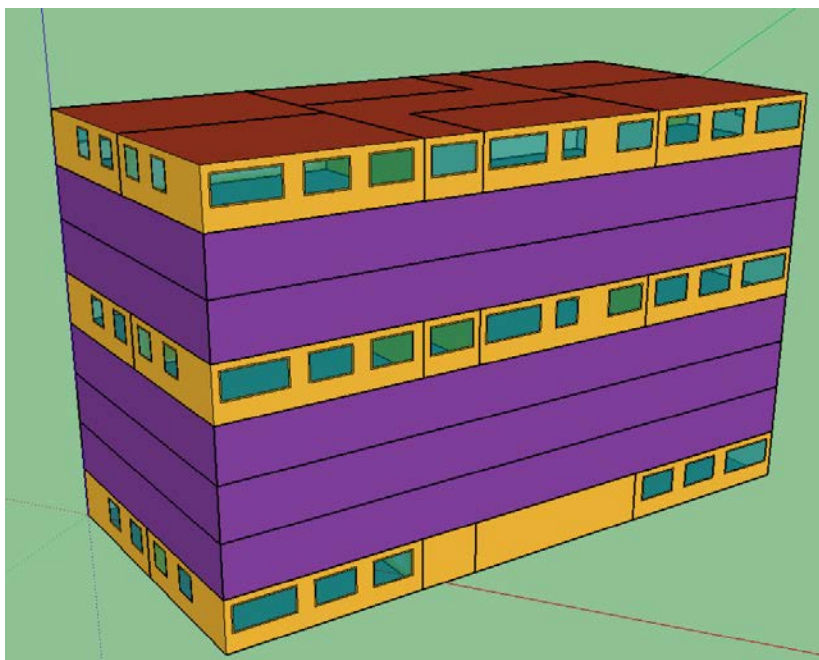


Figure 4: High-rise building geometry

3.2 Simulations input

3.2.1 Weather data

The user can set the location of the building they want to investigate. Weather files (in “.epw” format) adopted in the simulation include hourly values of a series of physical quantities, such as: dry bulb and dew point temperature, relative humidity, direct and diffuse solar irradiation, ground temperature, wind direction and speed and some others. Weather files of many locations around the world are freely downloadable from the web (Ladybug) (Climate.OneBuilding, 2022). The simulation software uses these weather files to determine the boundary conditions of the simulation at each time-step.

It is possible to use weather files which are representative for the current climates, or also run simulations with future weather files to test the resilience of the building and its HVAC system.

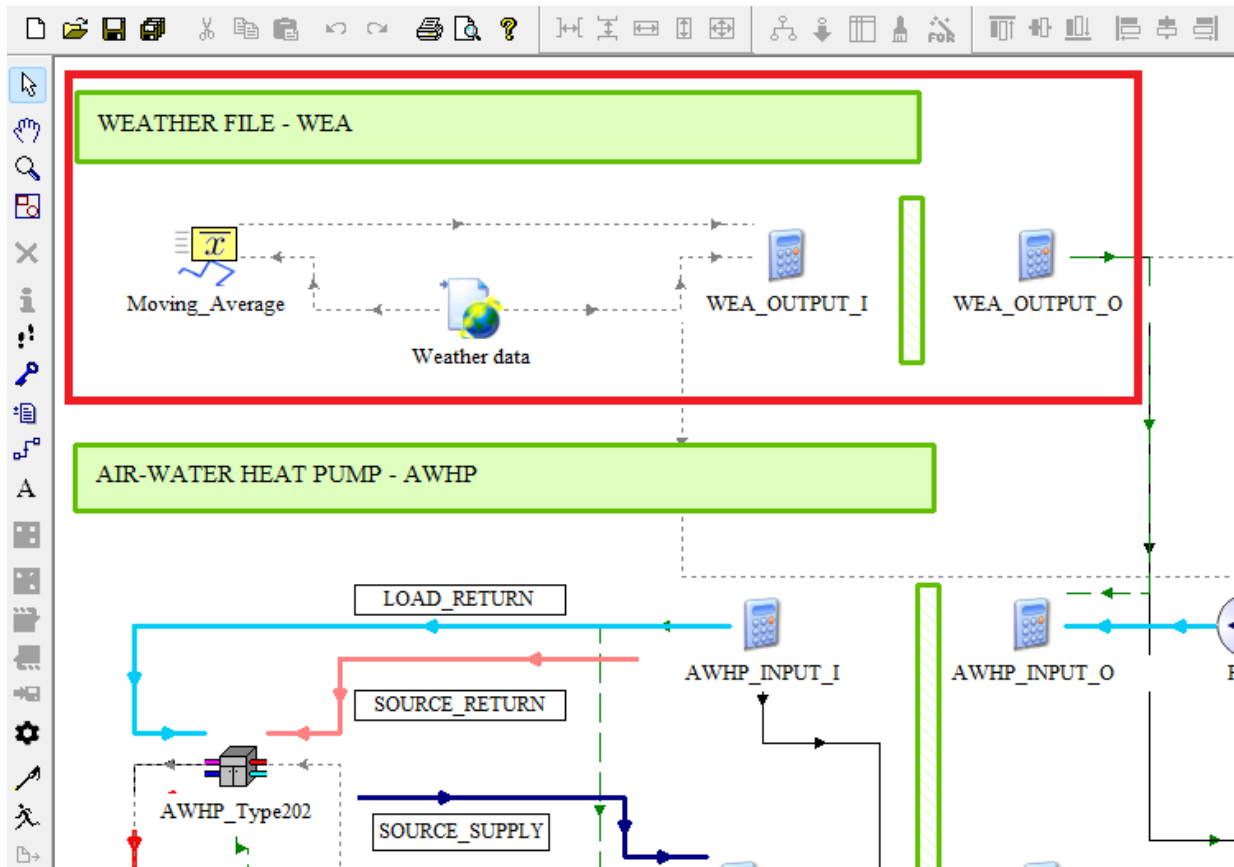


Figure 5: TRNSYS model - weather file section

Figure 5 shows where the TRNSYS types related to the climatic information are located in the TRNSYS model. Please, when running the executable file, consider utilizing a weather file which is coherent with the building that you have chosen as a starting point. For example, a Mediterranean building examined in a sub-arctic climate could lead to unrealistic results.

3.3 Building and envelope characteristics

The envelope's thermal properties were defined to have buildings coherent with the relative geo-cluster. Hence, the thermal transmittance values of all the types of structure (including windows) can be selected depending on the building location, according to the relative geo-cluster (Figure 6 and Figure 7).

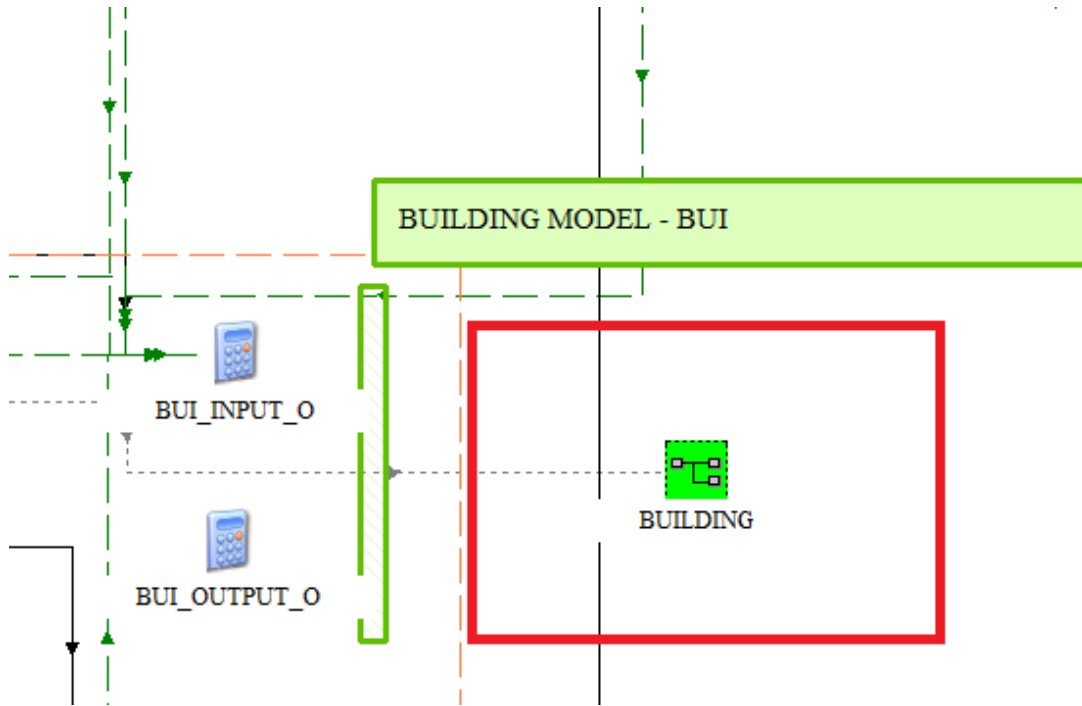


Figure 6: TRNSYS model - BUILDING macro

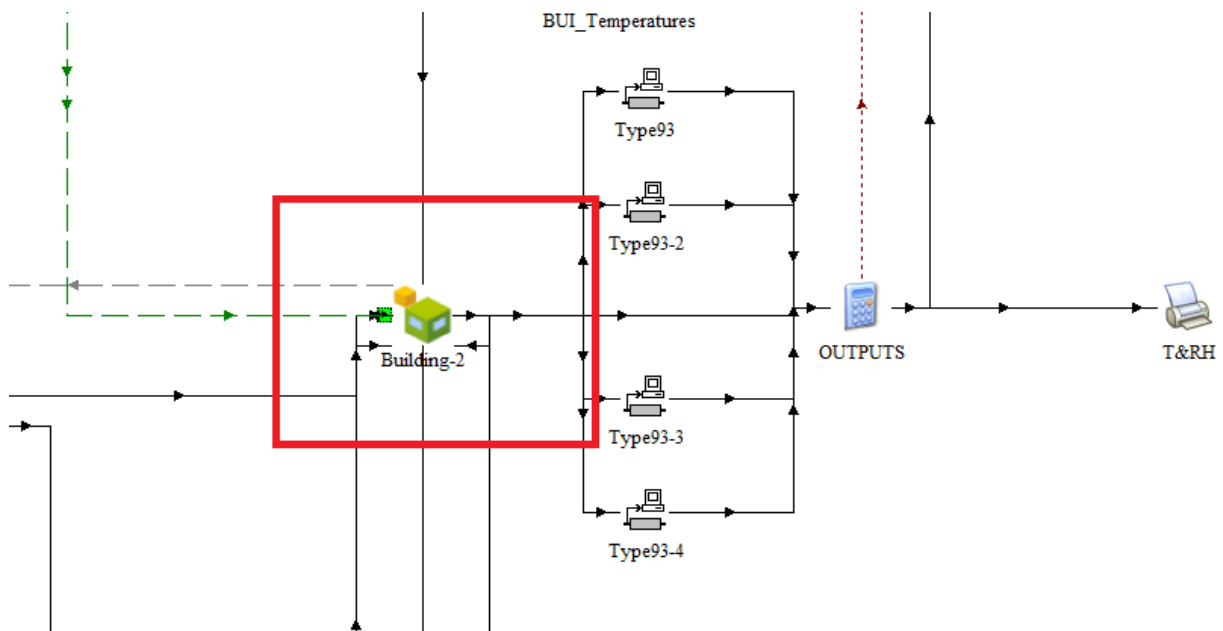


Figure 7: TRNSYS model - Building file

3.3.1 BSDF window

This building model utilizes a set of BSDF windows files to better simulate the behavior of the fenestration system with shading.

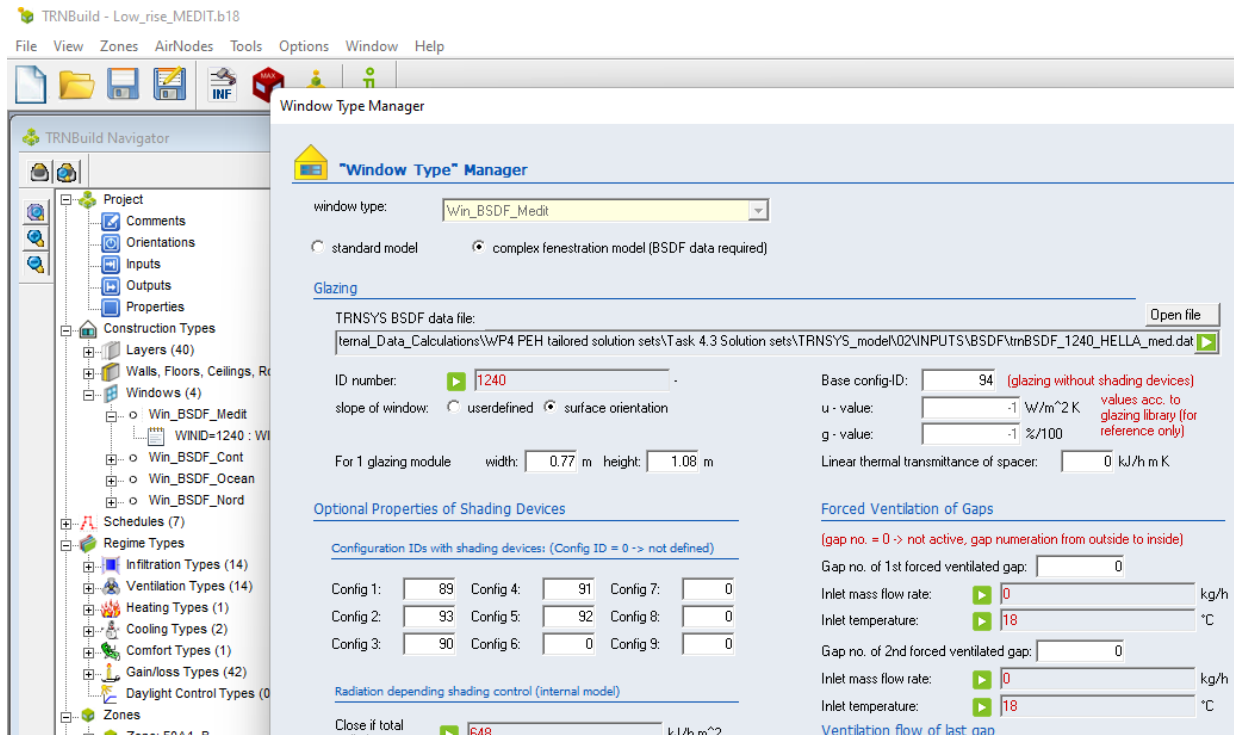


Figure 8: TRNSYS model - BSDF file selection

3.4 Internal gains

The thermal influence of internal gains, caused by appliances, lighting and people presence, is simulated taking into account the occupation profile of the building. The occupancy profile of the building has been determined by a stochastic approach (Zambrano, Oberegger, & Salvalai, 2021). In the executable model, a series of different stochastic profiles, for each geo-cluster, have been implemented. In this way, an excessive overlapping of the internal gains effect can be avoided. In fact, each thermal zone can be connected to a certain occupancy profile. These profiles have been initially implemented for the Oceanic geocluster, starting from national statistics and surveys from the UK, and then adapted to the other geoclusters according to the related electricity consumption data. The section of the model dedicated to the internal gains is represented in Figure 9.

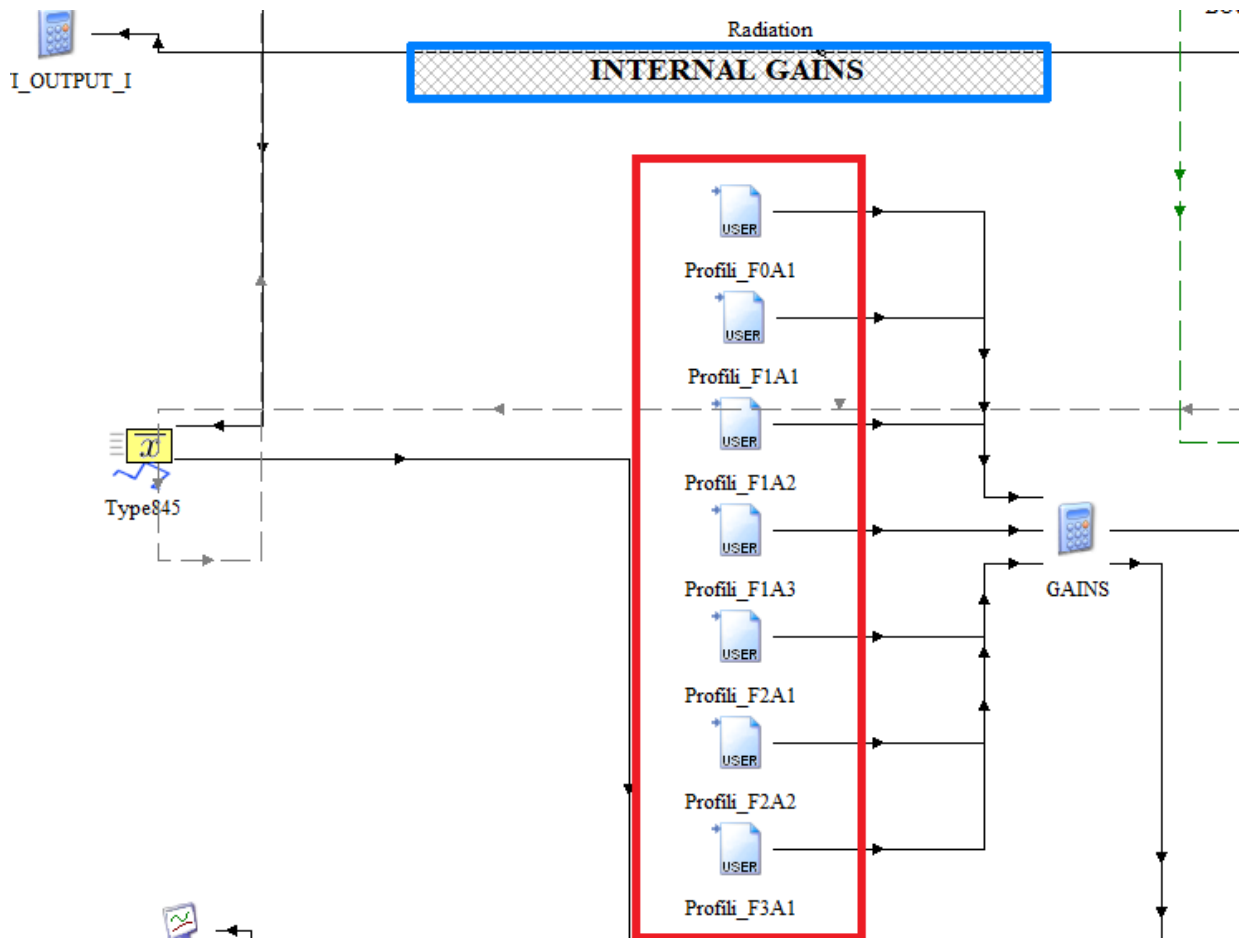


Figure 9: TRNSYS model - Internal gains profiles

3.5 Ventilation

In the modelled buildings, both natural and mechanical ventilation are involved. They follow different operation logics that are described in the following paragraphs.

3.5.1 Mechanical ventilation

For these models, mechanical ventilation system has been implemented through two different technologies belonging to the Cultural-E project. One solution is the decentralized ventilation machine integrated into the Active Window System (D3.3), while in the other type of ventilation, the air change rate is provided by a compact air-to-air heat pump (Passipedia, 2020).

3.5.1.1 Decentralized ventilation units

The ventilation units run only when the natural ventilation is not active (windows are closed), having a constant airflow rate that is a characteristic of the ventilation machine

(typical values used are in the range of 40-50 m³/h). A heat recovery system, with an efficiency of 70%, is present in the machine.

3.5.1.2 Ventilation provided by a heat pump

In this case, the ventilation system runs only in certain conditions. In particular, the ventilation control is determined by the CO₂ concentration level, the indoor air temperature and humidity, to guarantee healthy and comfortable environmental conditions for the occupants. CO₂ threshold is fixed at around 1200 ppm, while the set point temperatures are also dependent on the cultural preferences and on the local regulations.

3.5.2 Natural ventilation

Natural ventilation can be set in the models as complementary to the mechanical ventilation. For the day-time natural ventilation to be activated, certain conditions should be met:

- At least one person is present
- During summer, natural ventilation can be activated during daytime, while the outdoor temperature is included in a certain acceptable range (not too cold, not too hot) and the indoor temperature is above a threshold. Additionally, during summer nighttime, natural ventilation can be activated to help cooling down the building.
- During winter, natural ventilation is activated half an hour in the morning, replicating the behavior of the occupants, who usually want to have new fresh air in the apartments after the night.

The air change rate for natural ventilation is set to 2 vol/h.

The ventilation logics are implemented in the “VENTILATION” calculator type, inside the “BUILDING” macro, as shown in Figure 10.

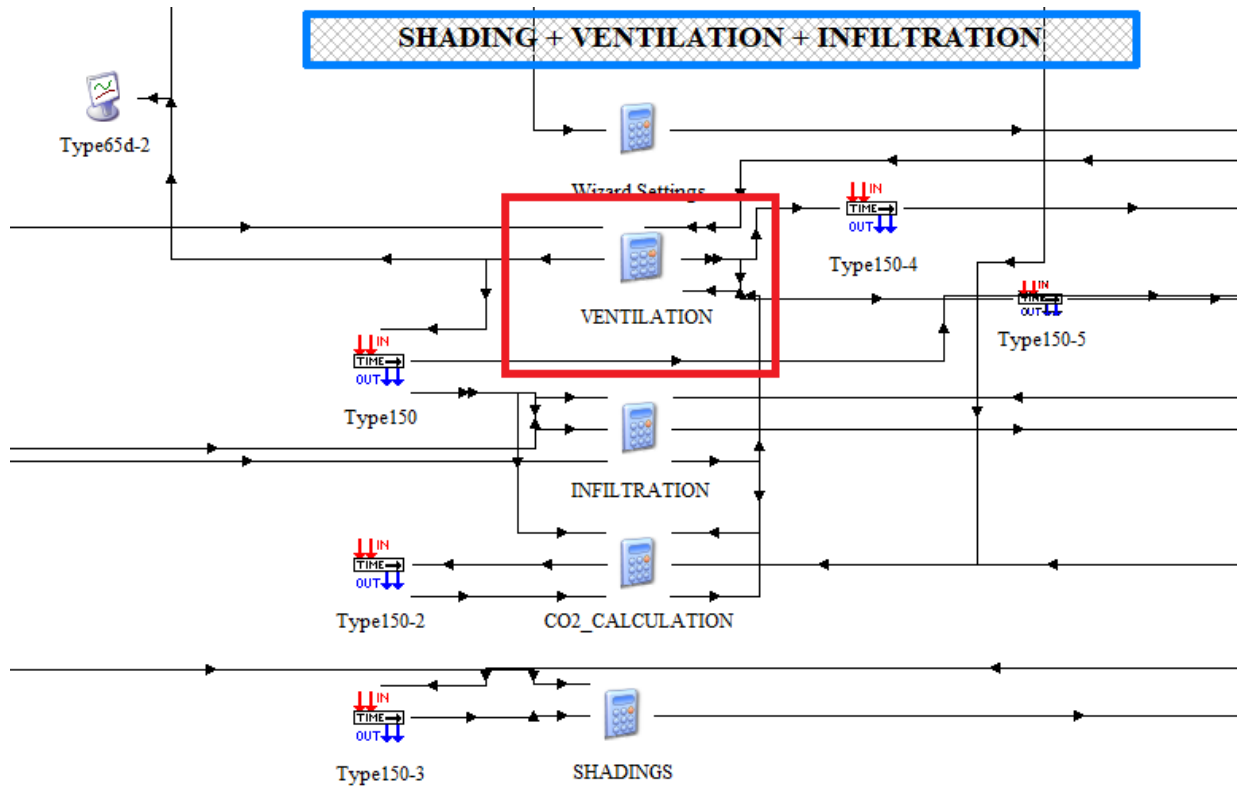


Figure 10: TRNSYS model - Ventilation logics

3.6 Shading

Shading systems have been implemented into the model, regulating the amount of radiation passing through the windows and, therefore, the heat gain through the indoor environment. The type of shadings considered is an external venetian blind system. The shading control logic is dependent on the indoor temperature conditions, the solar radiation and the occupancy state of the room.

The logics of the shading system are set in the “SHADINGS” type, as shown in Figure 11.

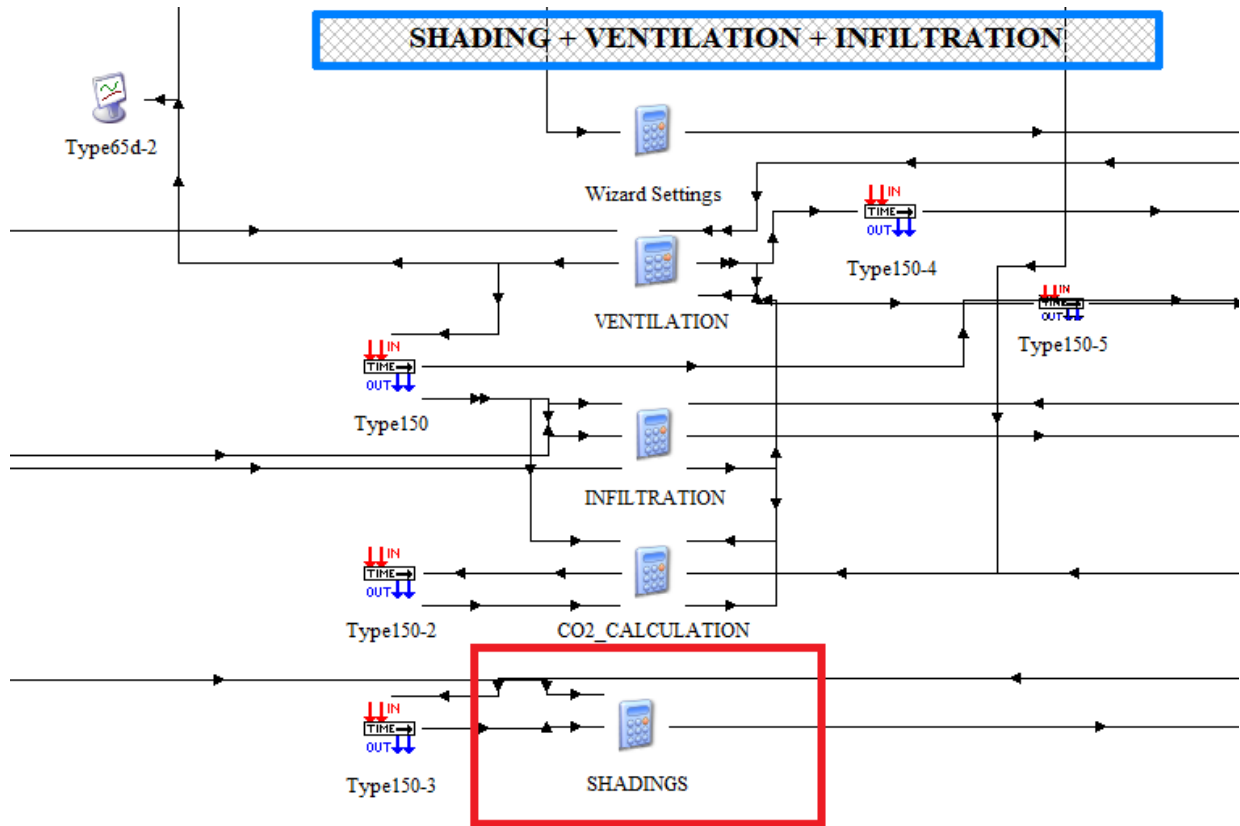


Figure 11: TRNSYS model - shading system logics

3.7 HVAC system

To get accurate estimations of the building energy consumptions, the energy system has to be properly modelled. In this way, the behavior of the HVAC system can be simulated, and the thermal losses that occur during its operation can be calculated. The HVAC system implemented for the simulation is a generic heat pump powered system. The layout of the system is reported in Figure 12.

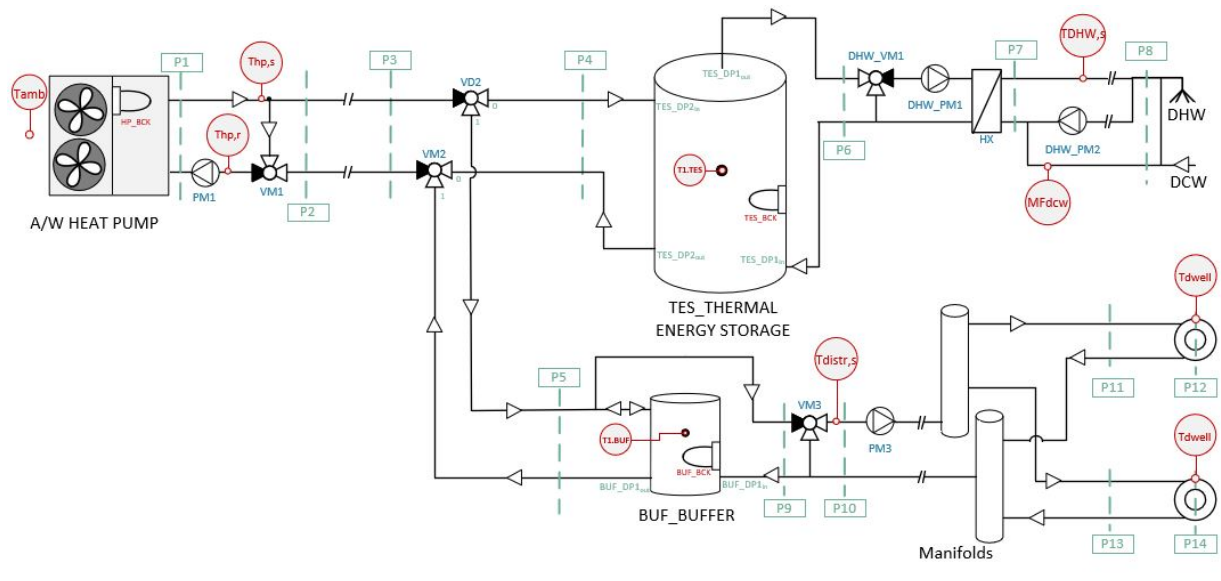


Figure 12: P&I diagram of the HVAC system

The heat pump is modelled with the “AWHP_Type202” type, represented in Figure 13. In this type a series of characteristics of the heat pump are set, as well as its performance map both in heating and cooling mode.

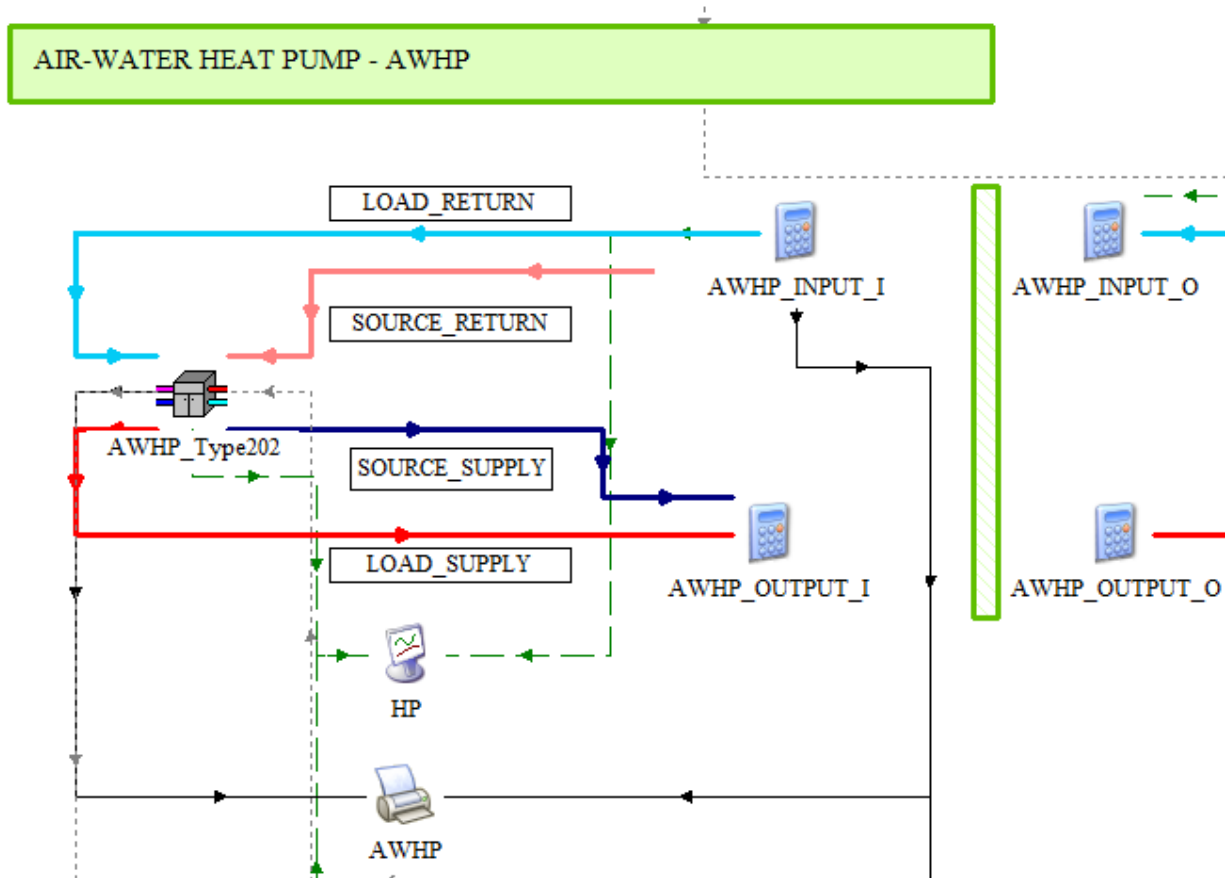


Figure 13: TRNSYS model - heat pump

The Thermal Energy Storage (TES) and the thermal buffer are modelled in the model sections shown in Figure 14.

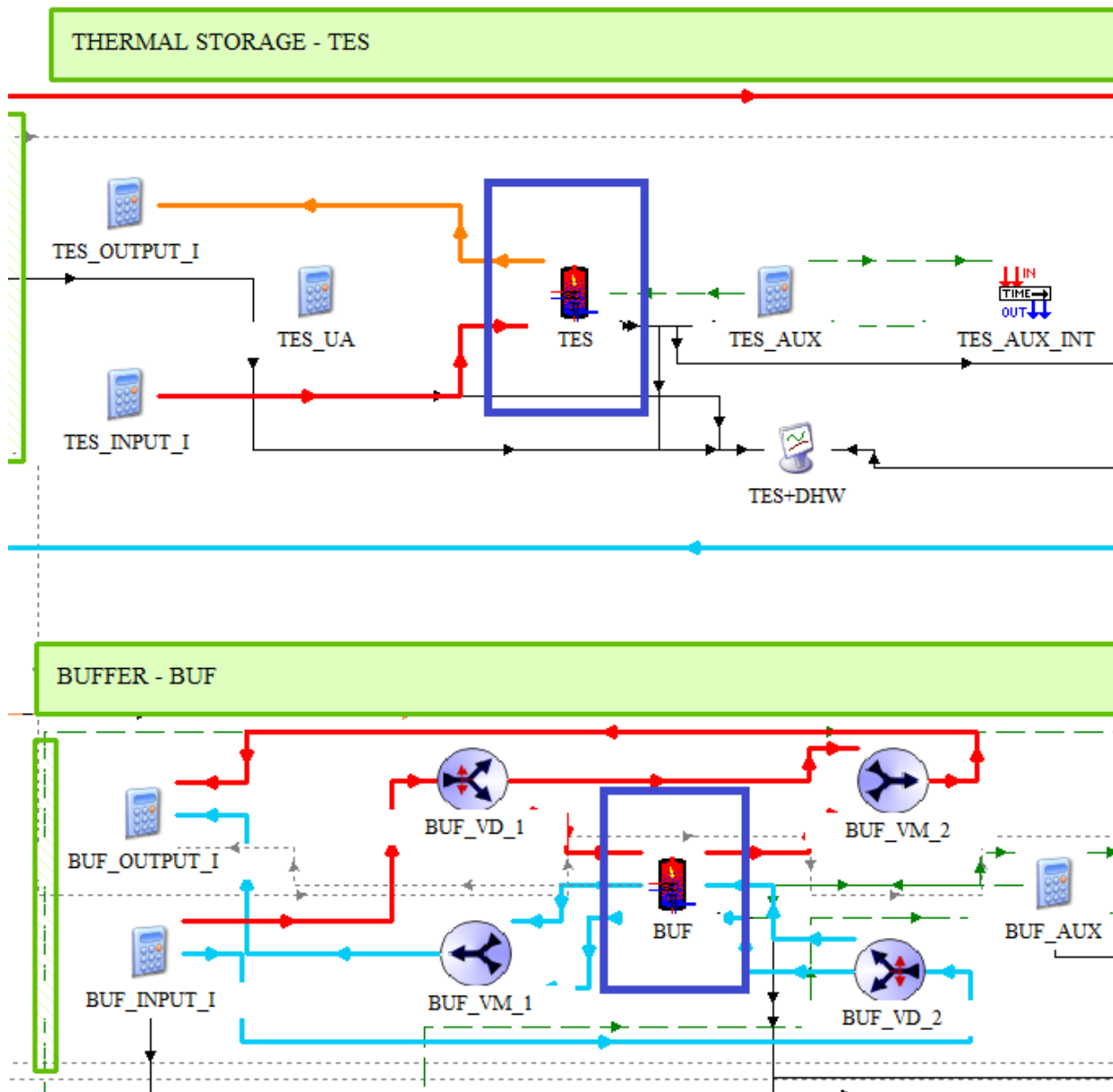


Figure 14: TRNSYS model - thermal storage and buffer

3.8 PV system

The modelled building features a PV-battery system. In fact, the buildings that are part of Cultural-E project aim to reach a positive energy balance target, where feasible.

In Figure 15 it is possible to see the layout of the model section which implements the PV-battery system. There are three TRNSYS types dedicated to the PV panels, one for the panels on the roof and the other two for the panels positioned on the related building facades. Moreover, the "PV_BEES" type models the performance of the battery storage.

The controller prioritizes the direct flow of electricity from the PV panels to the building. If there is a surplus of electricity production the controller sends the electricity in excess to the battery until it is fully charged (90% of nominal capacity). Once the battery is full, the electricity in excess is sent to the electrical grid. When the electricity demand of the building is greater than the PV production, the controller discharges the battery until it is empty (10% of nominal capacity). Once the battery is fully discharged, the electricity to cover the building demand is withdrawn from the electrical grid. Each time that there is an energy flow to or from the battery, some losses due to inverters and rectifiers are considered.

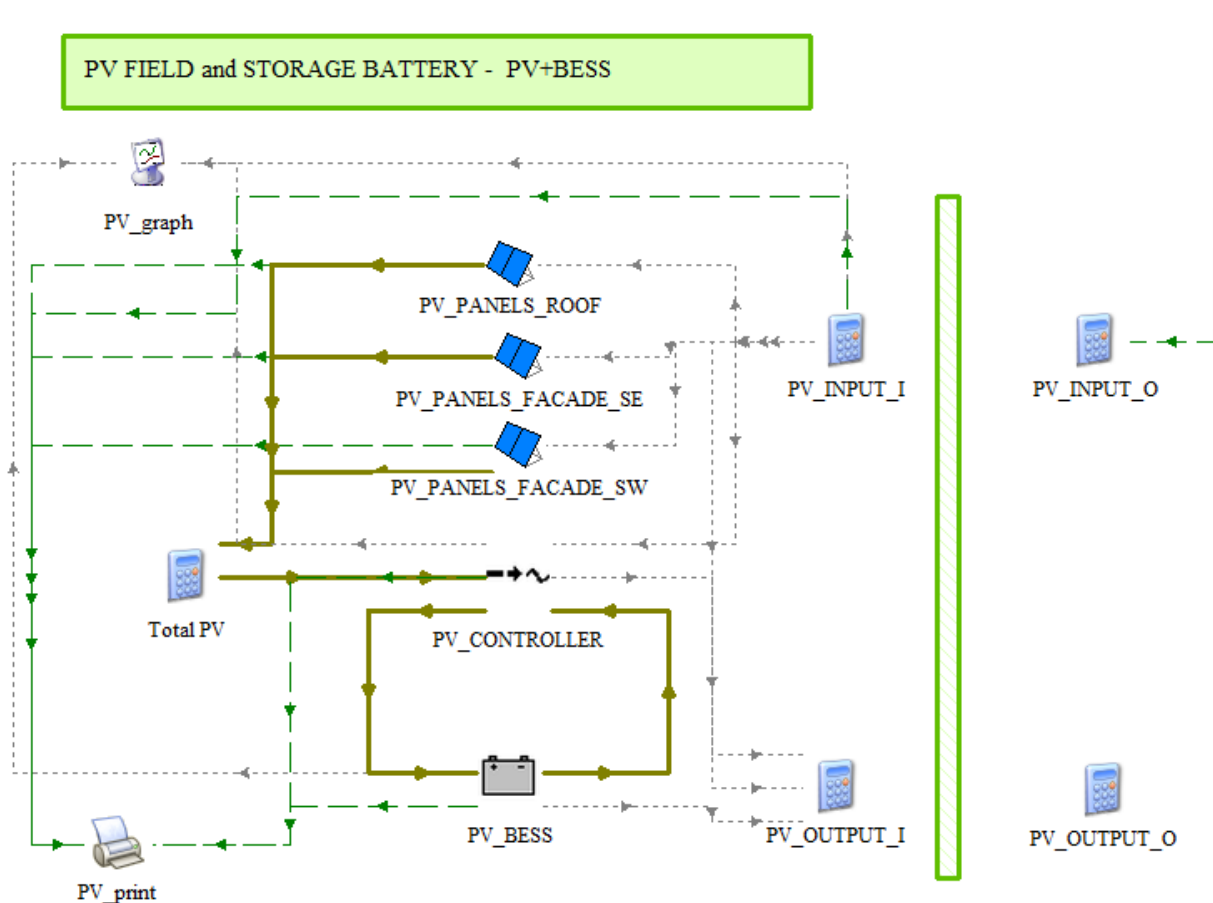


Figure 15: TRNSYS model - PV+battery

3.9 Outputs

The aim of the simulations is to evaluate the energy performance of the analyzed building, as well as the indoor thermal conditions for the occupants' well-being. For this reason, a set of KPIs was calculated from the simulation outcomes.

The energy performance of the building with the selected solution sets can be evaluated by means of the following KPIs (Avella, Mauro, & Belleri, Data Visualization Library, 2021):

- Primary energy consumption
- Final energy consumption
- Annual heating, cooling and domestic hot water demand
- Heating and cooling peak power
- Self-sufficiency and self-consumption
- Plus energy balance
- Electrical consumptions for the appliances, lighting, ventilation systems and HVACs auxiliaries
- Renewable energy generation and installed capacity (i.e. PV plant)
- Imported and exported renewable energy
- CO2 concentration
- Percentage of time with temperature and humidity inside the comfort range

Regarding the quality of the indoor environment, the percentage of discomfort hours are assessed. In particular, this KPI is estimated as the percentage of occupied hours when the operative temperature is outside the recommended range for cat. II of standard EN 16798-1:2019. The higher this KPI is, the worse the indoor thermal comfort is.

As mentioned in the introduction section, these KPIs can also be assessed through the “Data visualization library” (Avella, Mauro, & Belleri, Data Visualization Library, 2021).

4 Conclusions

With the executable files, obtained from the TRNSYS models that have been presented in this document, it is possible to simulate the performance of pre-defined building archetypes. Changing some input parameters, users can observe how these buildings perform under different boundary conditions, varying, for instance, the weather or the properties of the HVAC of the Cultural-E solution sets.

These executable models can be useful to designers or potential customers to evaluate how the technological solution sets of Cultural-E could work in a high-performance building. Using climatic files that take into account the changing climatic conditions, it would also be possible to assess the resilience of the building and if the suitability of some technological solutions changes over time in a given context.

These models could be improved in the future by implementing the performance data of the Cultural-E technologies which have been recently developed into the model. This could be done after laboratory measurements and translating the performance map and the control logics into the TRNSYS model.

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