Africa-Europe **BioClimatic** buildings for **XXI** century

FINAL REPORT ON UPDATED TRAINING TOOLS

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ABC 21 project

This document has been developed as part of the project titled "**ABC 21 – Africa-Europe BioClimatic buildings for XXI century**".

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Document information

Name:	**D3.13** Final Report on updated training tools
Date:	31.12.2022
Work Package:	WP3 Performance indicators and guidelines for XXI century bioclimatic buildings and districts
Task:	Task 3.6 – Update and specialisation of training tools

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Revision

Version	Date	Author	Description of changes
0.1	10.06.2022	C. Del Pero, F. Leonforte	First draft
0.2	21.06.2022	All authors	First full version
0.3	26.07.2022	S. Erba	Quality review
0.4	28.07.2022	S. Kuchar	Quality review
1.0	09.01.2023	C. Del Pero, F. Leonforte	Final version

Executive summary

This document aims at describing the final support materials and tools developed within the ABC 21 project, to design new buildings characterized by low energy consumption.

In detail, an **open-access handbook targeted to consultants/designers** (engineers and architects) and other stakeholders (public authorities, financers, real estate managers, etc.), was prepared on the basis of the publication "*Sustainable building design for tropical climates - Principles and Applications for African Countries*" [1], also integrating relevant information from "*Energy and Resource Efficient Urban Neighborhood Design Principles in Tropical Countries - A Practitioner's Guidebook*" [2]. The results is a comprehensive and updated new publication with design concepts that can be applied to all African countries.

The second activity described in this deliverable consists in the improvement and adaptation of a **Building Energy Simulation (BES) tool**, already developed by POLIMI and UN-Habitat for the East African Community, which has the potential to become a reference tool for energy design and certification in African Countries, reaching a wide range of users.

As a third activity, this deliverable describes the preparation of **a MOOC (Massive On-line Open Course)**, summarizing the main contents of the handbook. The MOOC represents an update of the existing version prepared by POLIMI for the East African Community.

Lastly, the document describes the outcomes of the testing session with students, with the scope to gather feedback to further improve the tools.

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[1] https://unhabitat.org/sustainable-building-design-for-tropical-climates
[2] https://unhabitat.org/sites/default/files/2020/06/gh046e_compressed.pdf

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1 Handbook

This section describes the structure of the new handbook that has been developed within ABC 21 project. Specifically, the current version of the publication was implemented and tailored according to the target countries of the project. In detail, for each chapter a brief description of the contents, the list of sections and the specification of updates/modifications currently implemented is provided.

1.1 Chapter 01: Introduction

Starting from background information on climate change and its relation to building energy efficiency, chapter 1 provides designers with information on different phases of the building design and the integrated design process for sustainable buildings. Further, some inherent issues on building design are briefly discussed, mainly in relation to architecture, the use of materials and energy systems.

Table 1: Sections of Chapter 1 with updates/modifications

Sections	Updates/modifications
1.1 Background	Updated data on GHG emissions and ecological footprints.
1.2 The building sector	Updated data on world GHG emission flow-chart.
1.3 Integrated design	Updated design strategy methodology and related schemes. The role of "Energy and Building's Metabolism" which takes into account the embodied energy of buildings, has been introduced.
1.4 Architecture in Tropical climates	Updated with motivation of the extension to all relevant climates of Africa.
1.5 A new energy system for settlements	Minor updates and modifications.

1.2 Chapter 02: Climates and building design

In order to be low energy and sustainable, buildings must be climate responsive, which means that their design must be climate dependent. The climate classification developed for the Handbook is based on the effect of the climatic context on building energy performance and occupant comfort conditions.
In detail, Chapter 2 begins with a description of the main climatic parameters for building design and the methodology for climate classification; subsequently, it provides a climatic classification of Africa, describing features and comfort conditions of each relevant climatic zone.

Table 2: Sections of Chapter 2 with updates/modifications

Sections	Updates/modifications

2.1 Climatic parameters	Updated by including all relevant African locations in the following: - Figure 2.1-17 Monthly irradiation in three sites - Table 2.1-2-4 Radiation square - Figure 2.1-19 Monthly pattern and temperature variation - Figure 2.1-26 Relative humidity vs. dry bulb temperature
2.2 Climatic classification	Updated and extended for whole Africa; in particular, 2 additional climatic zones were added and described.

1.3 Chapter 03: Climate responsive building design

The energy efficiency level of a building is determined by how it is designed, built and operated and the way it is integrated into the urban layout. To reduce its energy consumption and be sustainable, a building must be designed and constructed using shapes, technologies and materials most appropriate to the specific context. Passive cooling techniques like natural ventilation and natural cooling can be used to reduce and, in some cases, eliminate mechanical cooling requirements in areas where cooling is a dominant problem such as Africa. To control heat gains and light provided by the sun it is necessary to rely on a good knowledge about its apparent paths and amount of energy supplied.

Chapter 3 addresses and describes in detail the above aspects related to "Design with climates". Moreover, it also provides a set of design guidelines and some examples of vernacular, colonial and pre-colonial architecture in African countries.

Table 3: Sections of Chapter 3 with updates/modifications

Sections	Updates/modifications
3.1 Passive Design	Minor updates and modifications.
3.2 Bioclimatic charts	Extended for additional African locations based on new climatic zones.
3.3 Site planning	Updated and extended according to the climates.
3.4 Building design	The section "The Kitchen" was removed.
3.5 Natural Ventilation	Minor updates and modifications.
3.6 Daylighting	The Section 3.6.2.3 "Systems with Anidolic Ceilings" was excluded.
3.7 Shading	Minor updates and modifications.
3.8 Natural cooling	Minor updates and modifications.
3.9 Building materials	Updated including more local materials and techniques.
3.10 Design guidelines according to African climates	Updated for additional relevant climatic zones.

3.11. Lessons from the past	The section has been removed.

1.4 Chapter 04: Energy efficient buildings design

For buildings in African climates equipped with HVAC systems (heating, ventilation and air conditioning), a substantial part of the energy consumption is due to summertime air conditioning needs. Chapter 4 describes in detail the design of building envelope (opaque and glazed components), HVAC and lighting systems. Moreover, the strategies for effective energy retrofit of existing buildings are discussed.

Simulation tools are shown to play a critical role for assisting the designer to optimise the energy and comfort performances in designing new buildings and in the retrofit of existing buildings, for such a reason, this chapter also provides the description on various dynamic simulation tools currently available in the market.

Lastly, the energy performance certification and green building rating systems currently used in different countries are presented.

Table 4: Sections of Chapter 4 with updates/modifications

Sections	Updates/modifications
4.1 The envelope	Minor updates and modifications.
4.2 Building services	Updates on: - Energy supply systems, with more recent technological solutions (e.g. heat pumps for domestic hot water production) and solutions suitable for new climatic zones; new schemes and figures were added accordingly. - Lighting systems, with new lighting fixtures and technologies. - Some rules of thumb to quickly design a lighting system have been provided.
4.3 Hybrid ventilation	Minor updates and modifications.
4.4 Existing Buildings	Update data on energy consumption of existing buildings.
4.5 Simulation tools	The chapter is totally revised in order to provide a methodological approach to BES.
4.6 Certification & energy codes	Update on South Africa Building codes, also citing European and other relevant codes to be used as a reference.

1.5 Chapter 05: Design at community scale

Climate responsive design of buildings is based on the definition of strategies at community scale. For such a reason, Chapter 5 provides the fundamental knowledge on the process of designing sustainable communities considering different aspects from energy and water

use to waste management. This chapter has been updated with the detailed contents reported in "*Energy and Resource Efficient Urban Neighborhood Design Principles in Tropical Countries - A Practitioner's Guidebook*", providing a synthesis of the most relevant design principles and an extension to all African reference climates.

Table 5: Sections of Chapter 5 with updates/modifications

Sections	Updates/modifications
5.1 Energy and the urban metabolism	Updated with contents of the Guidebook, extended to the whole Africa.
5.2 Water and sanitation	Updated with contents of the Guidebook, extended to the whole Africa.
5.3 Solid waste management	Updated with contents of the Guidebook, extended to the whole Africa.

1.6 Chapter 06: Renewable energy technologies

Renewables can be used for both electricity and heat generation. There is a wide range of renewable energy technologies suitable to be implemented in African countries for a whole variety of different applications; thus, the designer must have a good knowledge of common renewable energy technologies and their potential contribution to an energy efficient building design. For this purpose, Chapter 6 aims to provide designers with basic knowledge on common renewable energy technologies (solar, wind, biomass, hydro) currently available in the market, their possible application and sizing methods.

Table 6: Sections of Chapter 6 with updates/modifications

Sections	Updates/modifications
6.1 Solar PV	Minor updates and modifications.
6.2 Solar Thermal	Minor updates and modifications.
6.3 Wind energy	Minor updates and modifications.
6.4 Biomass	Minor updates and modifications.
6.5 Hydropower	Minor updates and modifications.

1.7 Chapter 07: Net zero energy buildings and communities

Designing and creating a zero-energy building (ZEB) involves significant changes at technical, economic and cultural levels. For this reason, Chapter 7 provides basic definitions of ZEB, describes principles related to energy balance and load matching. Furthermore, some relevant examples of Net Zero Energy Buildings and Net Zero Energy Communities in tropical and other relevant African climates are presented and discussed.

Table 7: Sections of Chapter 7 with updates/modifications

Sections	Updates/modifications

7.1 Net Zero Energy Buildings	Updated according to more recent directives and definitions; update of NZEB case studies with examples representative for the whole Africa.
7.2 Net Zero Energy Communities	Updated according to more recent directives and definitions; update of NZEC case studies with examples representative for the whole Africa.

1.8 Annexes

To ensure a proper background knowledge and to support the understanding of the 7 above-described chapters, some additional contents are provided, grouped in 4 appendixes. More in detail, the first one contains principles of building physics (heat transfer, building energy balance and primary energy), the second appendix deals with thermal and comfort.

Table 8: Annexes with updates/modifications

Sections	Updates/modifications
APPENDIX 01: Principles of building physics	Minor updates and modifications.
APPENDIX 02: Principles of thermal, visual and acoustic comfort	A specific chapter about "Acoustic Comfort" has been added.
APPENDIX 03: Exercises	Removed
APPENDIX 04: Case studies	Removed
Glossary	Updated
Bibliography	Updated

The handbook can be downloaded at the following link: https://www.dropbox.com/sh/pagnvsxzgt198hy/AADk5QWtrYc7mWjMWL-MpLmfa?dl=0

2 Energy simulation tool

Assessing the energy performance in the design phase of a NZEB requires a detailed dynamic building energy simulation (BES) tool, developed to be used in an intuitive way starting from the architectural concept.

For such aim, an open-source, free-redistributable, intuitive and powerful building energy simulation software (BESTenergy) was developed by POLIMI under an UN-Habitat collaboration, taking into account the main features required in the African context. In particular, the tool has been developed on the basis of NREL OpenStudio platform, which represents the state of the art in terms of Graphical User Interface for building energy simulation; the obtained BES tool has the main key characteristics listed below.

- It runs on the EnergyPlus engine, which is the state-of-the-art tool for dynamic building energy simulation; this ensures an accurate evaluation, especially in cooling-dominated buildings and in hot climates, where dynamic paths heavily affect buildings' thermal behaviour and energy performance. In such a context, designers need accurate, hourly-based simulations, considering the actual building´s thermal response due to the variation of the outdoor conditions through the day.
- It adopts the Sketchup's user interface, to overcome the hardness in compiling a dynamic building energy model; this way, the easiness in geometric modelling of Sketchup is coupled with the reliability and accuracy of EnergyPlus. In fact, users can easily and quickly build an energy model by using the simplified graphical interface, so that the plugin creates the input data file to be processed by the simulation engine with few simple steps. In addition, some macros are developed to generate geometries and to automate modelling process.

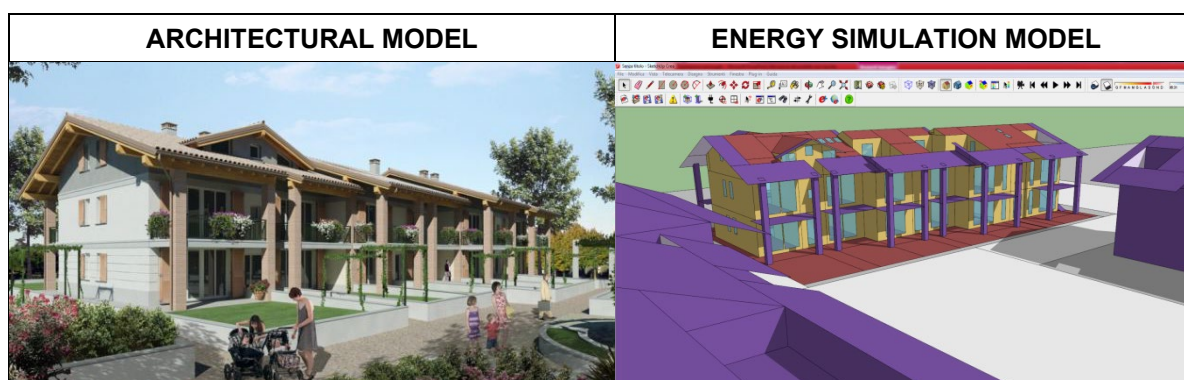| ARCHITECTURAL MODEL	ENERGY SIMULATION MODEL

Figure 1: Comparison between the architectural model and the simulation model in BESTenergy

More in detail, the tool evaluates:
- Heating, cooling and lighting energy consumptions on the same model and their interaction, letting user to interactively optimize overall energy behaviour;
- Effects of movable shading devices;
- Thermal comfort levels, by using both adaptive comfort models and PMV/PPD method;
- The behaviour of each building surface (e.g., surface temperature, amount of heat gain, etc.);
- Daylighting and simple artificial lighting systems;
- Hourly power consumption;
- HVAC systems preliminary sizing;
- HVAC systems hourly performances.

NREL OpenStudio was developed with the goal of allowing third party developers for separated modules and functionalities. However, the lack of intuitiveness in modelling process in such a tool is addressed in the project by developing customized and user-friendly interfaces required to model strategic items in energy optimization design, with specific reference to the African context.

More in detail, BESTenergy provides 3 sections:

- Section 1 contains general commands for managing model files;
- Section 2 provides a step-by-step simple modelling to perform a first thermal simulation of the building, in which users are guided in following a procedure in sequence, by a tailored command menu;
- Section 3 groups additional commands to model advanced issues, such as HVAC systems, lighting, and shading analysis.

According to the above-described structure, users can start from a template, in which the main settings (in terms of user profile, occupancy, heat loads, and so on) are available by default data set according to the building use. Thus, by following guided steps in the command menu, it is possible to build an energy model in a very quick and simple way.

Once the template was loaded, the geometry may be created by adding one or more volumes by using available drawing tools. Such tools are very intuitive, and users may also automatically generate some simple zone geometries by using macros. For instance, one can generate a rectangular-shaped or L-shaped space by only giving dimensions in input, instead of drawing it by using SketchUp drawing commands. Then, automated macros convert geometry in thermal zones and the boundary conditions for thermal surfaces will be created.

Once the geometry is created, the designer can define material properties and assembly constructions to be applied to model surfaces (walls, floors and so on). Materials are also available by one or more libraries which can be loaded, and which include specific technical solutions to be used in African context.

Subsequently, specific settings of each zone can be easily applied, as shown in the following figure.
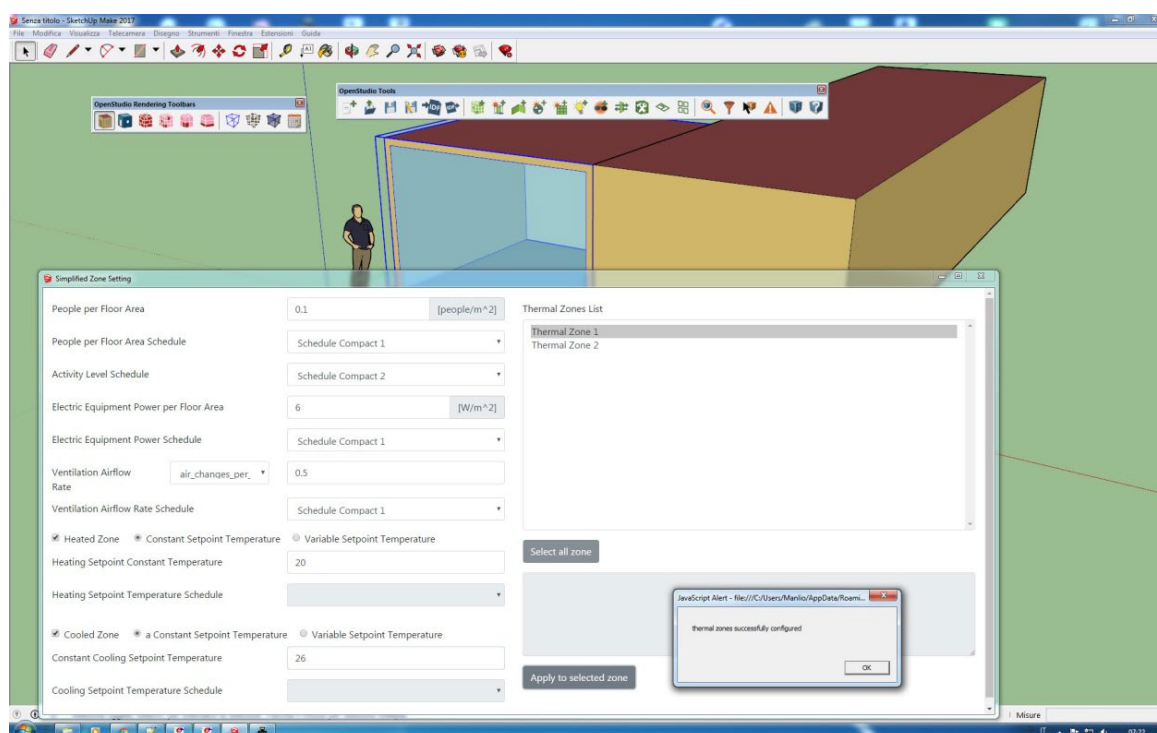

Figure 2: Customized menu to apply settings of each zone

Such settings may be loaded by a pre-defined dataset, available by importing some profiles and assigned to different zones by selecting them graphically in the model or in the zone list indicated on the side.

Finally, users may run the simulation using specific weather files related to African context (also including outcomes of Task 3.2), which are included in the tool package, and analyse the results.

With respect to the latest BESTenergy software release, specific update/improvement activities were added within ABC21, as listed below:
- Making the current tool compatible with latest simulation engine (EnergyPlus) and modelling interface (SketchUp) releases;
- Adding an information panel about envelope component's main thermal properties;
- Adding an intuitive interface to automatically assign envelope components to group of surfaces;
- Improving shading system modelling options and enhancing its interface;
- Adding information panel to check main thermal zone settings;
- Improving HVAC system modelling;
- Adding interfaces to improve natural ventilation effects assessment;
- Simplifying the visualisation of final results.

The new functions included in the tool are described hereafter.

2.1 Updated compatibility with new releases

As introduced, the simulation tool under development is based on EnergyPlus simulation engine and on the graphical interface provided by Sketchup. The last release of the tool ensures the compatibility with following supporting software versions:
- EnergyPlus 9.2
- OpenStudio 2.6.0
- SketchUp 2017 Make

Since the latest freeware version of the geometrical modeller SketchUp is the 2017 one, this forced to keep the same version compatibility of older release. More recent versions of that modeller are available only in professional releases or web-based released. The professional ones require to buy a licence, so it is not suitable for training purpose. The web-based version has not a full portability because of the need of an internet connection. Moreover, it doesn't support additional interfaces or plugin, so it is not possible to add custom interfaces, as needed to develop the tool. By the way, these more recent versions do not add useful features for building energy simulation modelling: because of the geometry simplicity of thermal models, commands available in the 2017 version are fully adequate.
About the core of the tool, the compatibility was updated to EnergyPlus 9.2 version and to OpenStudio 2.9.1. This variation gave opportunity to make the software working even on latest computers and operative system versions (both Windows and MAC OS) and to develop new modelling features supported by simulation engine and by the OpenStudio middleware.

2.2 More robust geometry modelling

The previous release was largely tested over a large population of users, mainly students of academic courses. Observing most common errors occurring in modelling the building, some improvements were designed in order to avoid them.

First, some problems in dividing surfaces that were in contact with many other thermal zones were noted. More in detail, in case of complex building geometry, with non-regular overlapping between the zones, user had to apply some geometry simplification in order to let the

automated surface splitting in "Step 4 - Surface Boundary Conditions" command to properly work. This operation was not so intuitive. To solve this issue, a more robust automated operation has been introduced after being tested on such complex building geometry.

Another frequent found error consisted in adding some zones that were not populated with building geometry. For this reason, before starting simulation, an automated check was introduced. In case the routine founds some unused zone, it warns the user ant it deletes them.
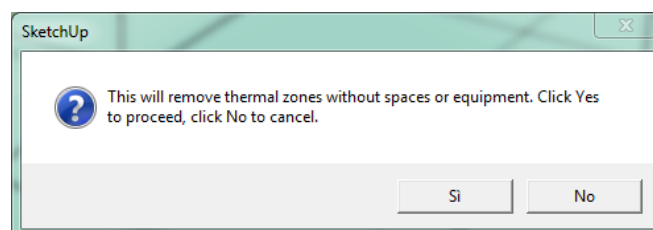
Figure 3: Warning message about the routine launch confirmation to delete unused thermal zones.

2.3 Improving envelope components assignment to model's surfaces

The procedure to assign envelope components to each model surface in the last software version was carried out as explained in the following. Once all constructions were defined, the user had to open the "Inspector" tool, then select one surface at a time and fill the "Construction Name" field with the proper component name shown in the drop down menu (see Figure 4).
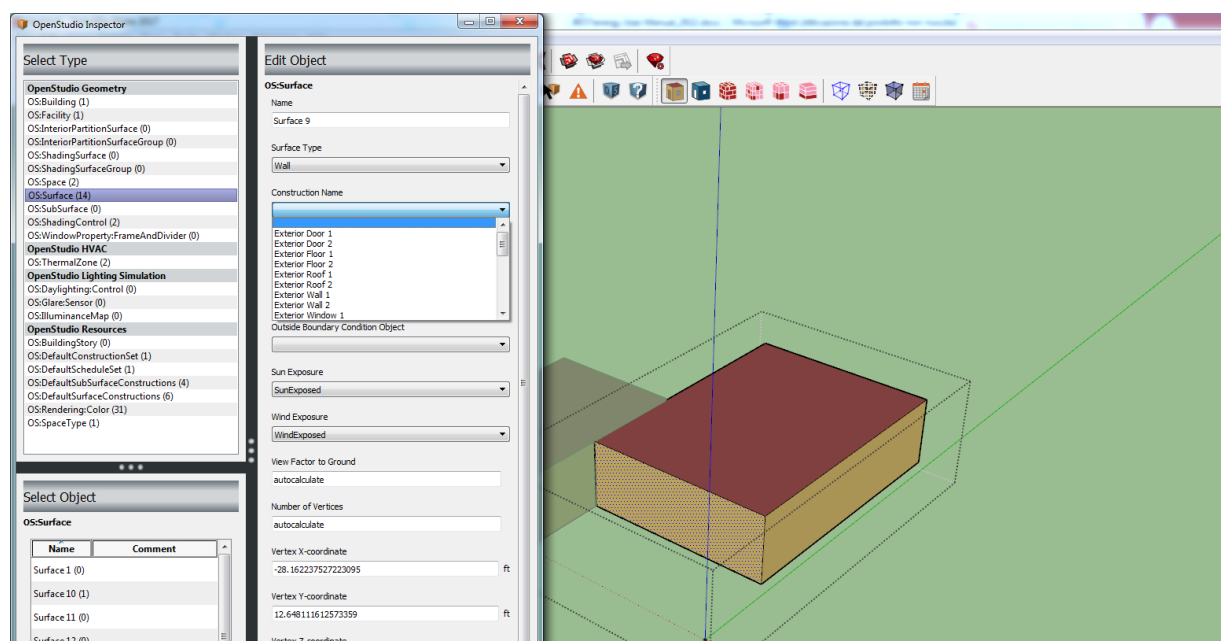

Figure 4: Assigning constructions to surfaces in previous software release.

This time-consuming task was partially solved by introducing in the starting template some default components. They were automatically assigned according to each surface type (i.e. construction "Wall 1" was assigned to exterior wall surfaces, and so on…). By the way, in case of more complex buildings, where each surface type may have different constructions (i.e. exterior walls surfaces may have different components in the model), this issue was not solved.

Thanks to new release features, this problem was solved, since the "Construction Set" object was added. A "Construction Set" is a collection of components, where to each surface type, a

corresponding construction to be assigned is set. By letting the user to add more than one construction set, one can assign a different collection of components for each zone.

To do that, user must open "Inspector" tool and select the wanted zone in the model. In the "Default Construction Set Name" field, user may set the wanted one.
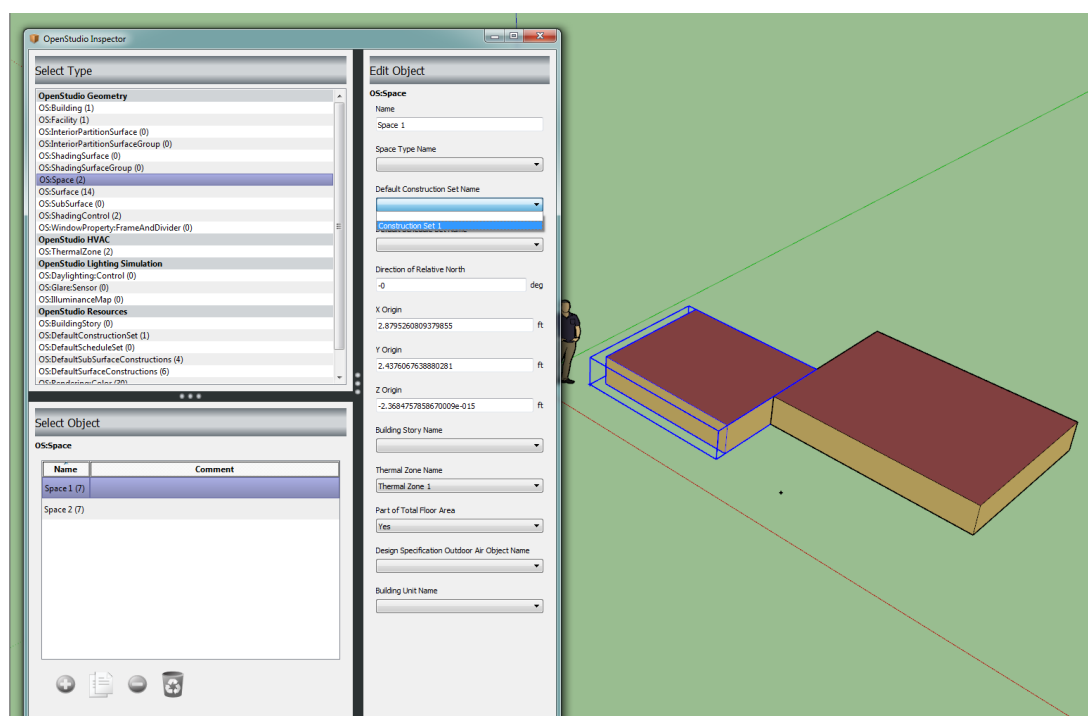

Figure 5: Assigning a different construction set to a zone.

2.4 SHADING SYSTEM MODELLING

The solar control strategy is crucial in properly designing a building.

Most simulation tools only consider fixed shading systems with no opportunity to properly evaluate the effect of movable shadings. The previous version of the tool allowed to set some parameters to take into account for the user behaviour in moving or modulating the shading system, but this feature had to be performed by the modeller, assuming the time when the shading system was deactivated, activated and modulated.

For instance, one needed to set a schedule to define that the shading system was not activated when not useful (i.e. in coldest periods) and when it was activated because of overheating problems (i.e. in warmest periods).

The new release lets users to link the operation of a movable shading system based on the environmental condition that actually occurs at each time-step, simulating, in this way, actions performed by people occupying the building or by automated activators coupled with sensors.

The environmental conditions that can manage the simulation of the shading system operation mainly deals with:
- solar radiation striking on each single window or on horizontal plane;
- outdoor air temperature;
- indoor air temperature;
- room cooling load;
- room illuminance requirement;

- glare occurring.

This automated feature allows to get more reliable information on effects of a movable shading system both on the thermal balance and on the daylighting availability of the room. Moreover, a set of common shading systems and control data is provided in the template file, in order to give some references to the user.
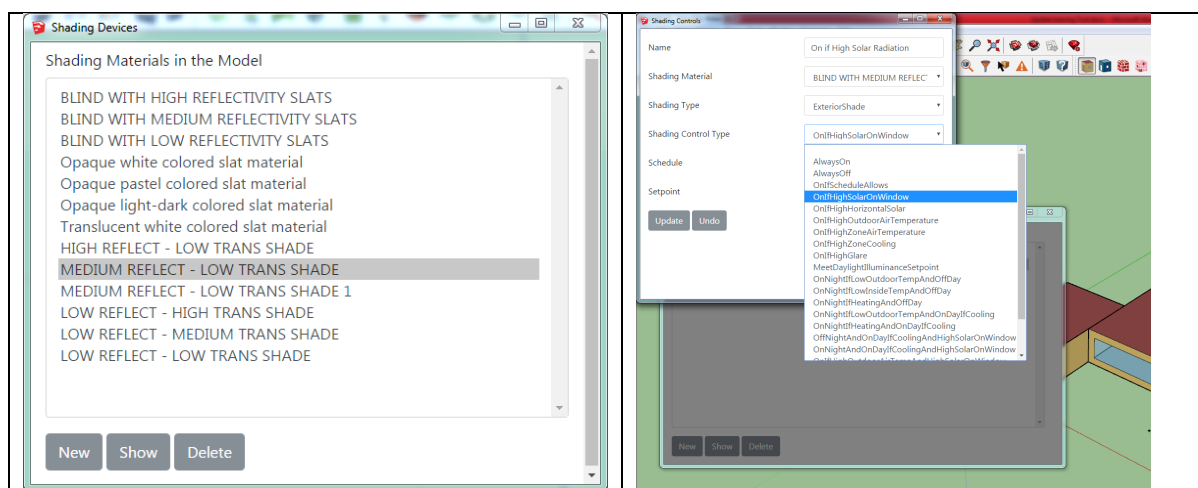

Figure 6: Improved shading system modelling interfaces.

2.5 Model input data double-checking

Another issue that figured out from the beta-testing phase was the lack of double-checking on model data inputs by user, especially about the obtained envelope thermal properties and building user profiles set for each thermal zone.

Thanks to added feature, after a successful simulation, the user can double check input data by mean of the last sheet in the OpenStudioApp (see Figure 7).
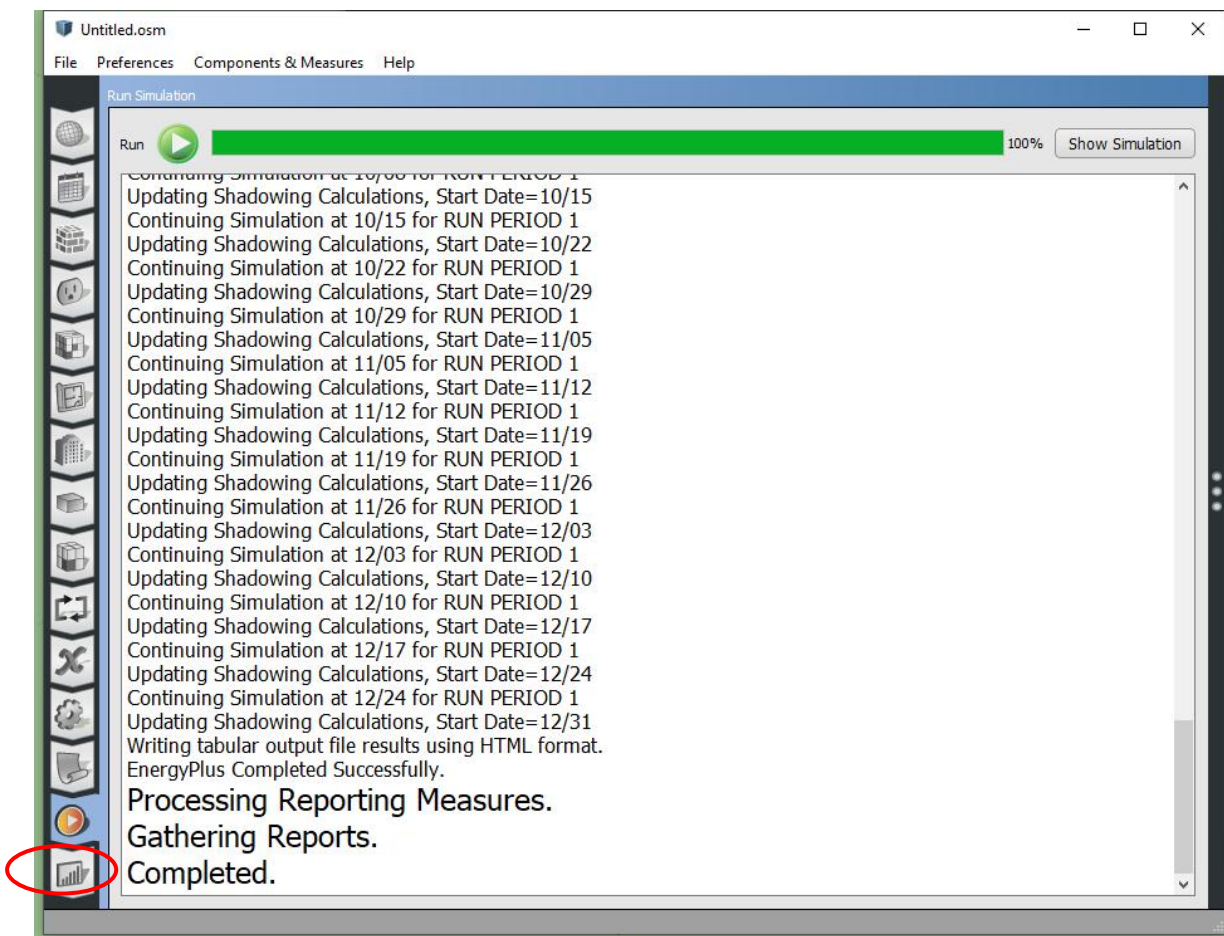
Figure 7: Availability of data summaries, after running a simulation.

Here some summaries are plotted, as reported in the table of contents. For the introduced purpose, the "Envelope Summary" is very interesting; here, the user can double-check, for each model surface, the assigned envelope component and the related thermal properties.

Also, the "Input Verification and Result Summary" can show assigned data for each thermal zone about people occupancy rate, internal heat gains due to lighting and to appliances and the availability of heating and/or cooling system for the space (see Figure 8).

Figure 8: Input Data Summaries

2.6 Improved output data visualization and HVAC consumption calculation

The determination of the energy performance of the building in the previous release of the tool was managed by the user and the calculation of overall energy needs and primary energy uses required an analysis of simulation outcomes and some mathematical operations between given output data.

More in detail, to do this, after the simulation run, the user had to open the "Result Summary" sheet. By clicking on "Open DView for Detailed Reports" button, a visualizer is launched (see Figure 9).
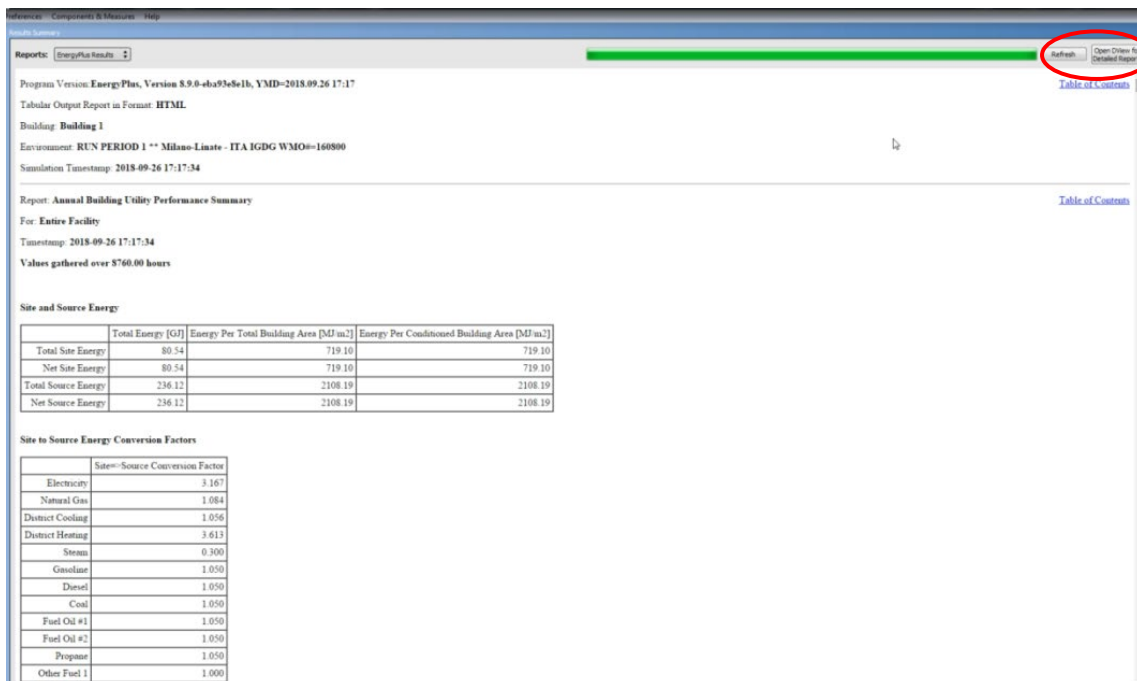
Figure 9: "Result Summary" sheet in OpenStudio App.

Among the graphical and tabular layouts, the "Time Series" sheet, (see Figure 10) provides, on the right, generated output variables. Here, the user may choose which ones to plot over the graphs, referred to the entire simulation period. By selecting the first or the second box, user may choose if plotting the variable on upper or lower graph (or in both).
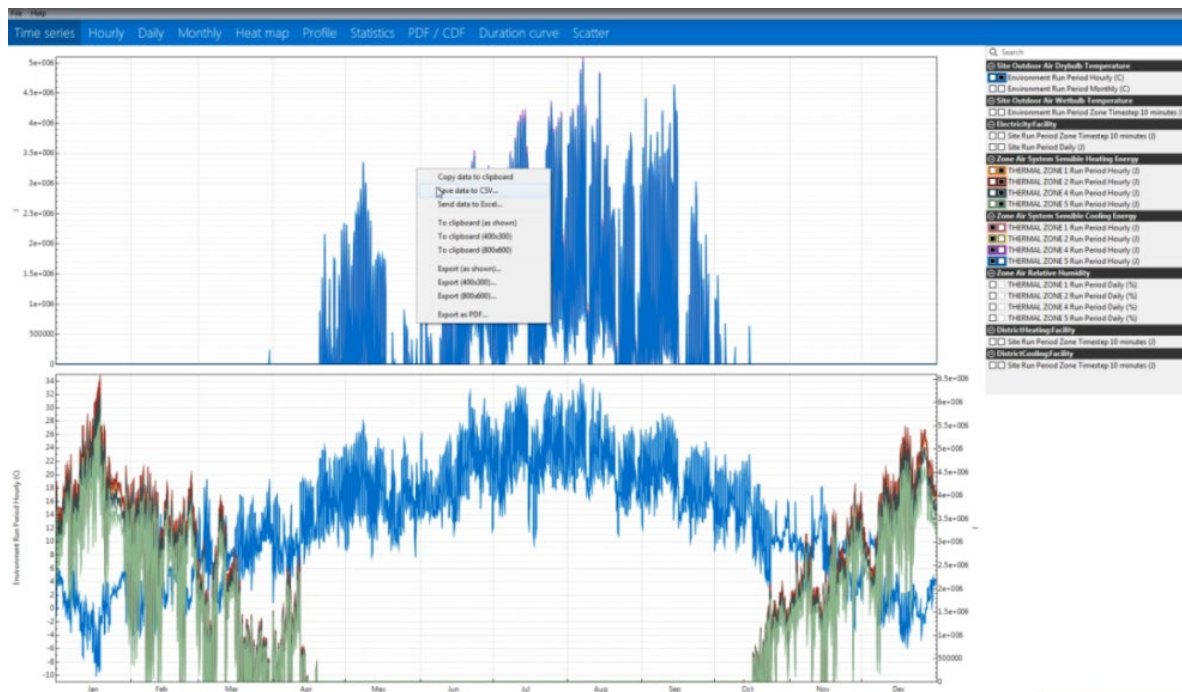
Figure 10: Outcomes analysis and visualization by mean of DView interface.

By right-clicking on the graph area, user may save data (both in numeric format and in graphical format) in different ways (see Figure 11). Also, he might send all data to Excel: by mean of the "Send to Excel" command, Excel is launched and data are fit in columns automatically.
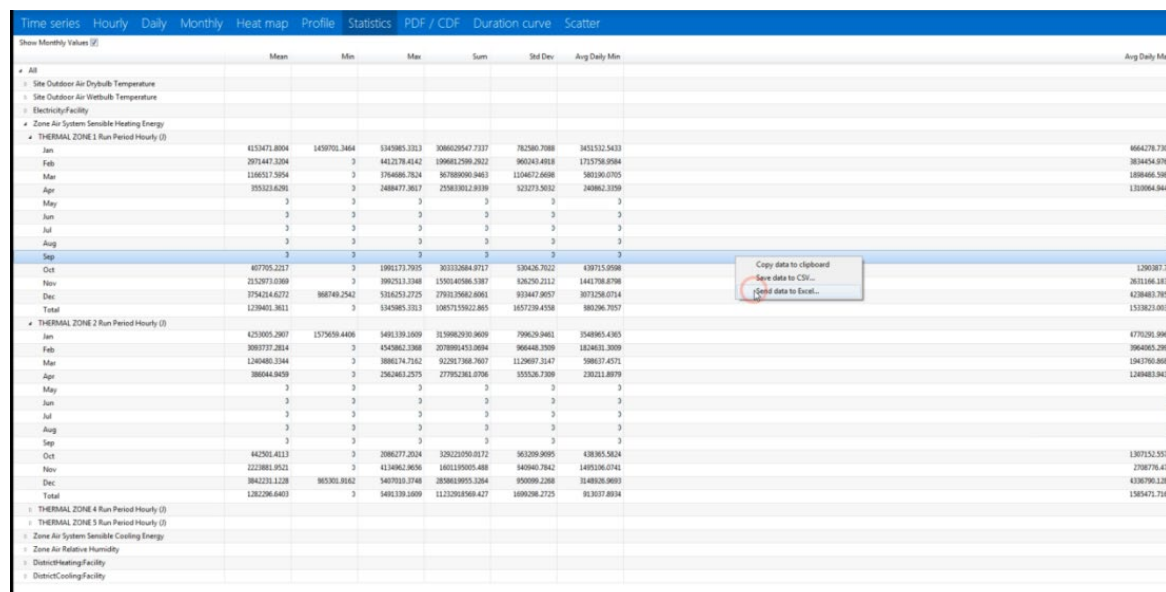
Figure 11: "Statistics" sheet in DView interface and right-click menu.

After that, the user may combine zone output to get the building overall performance for each service.
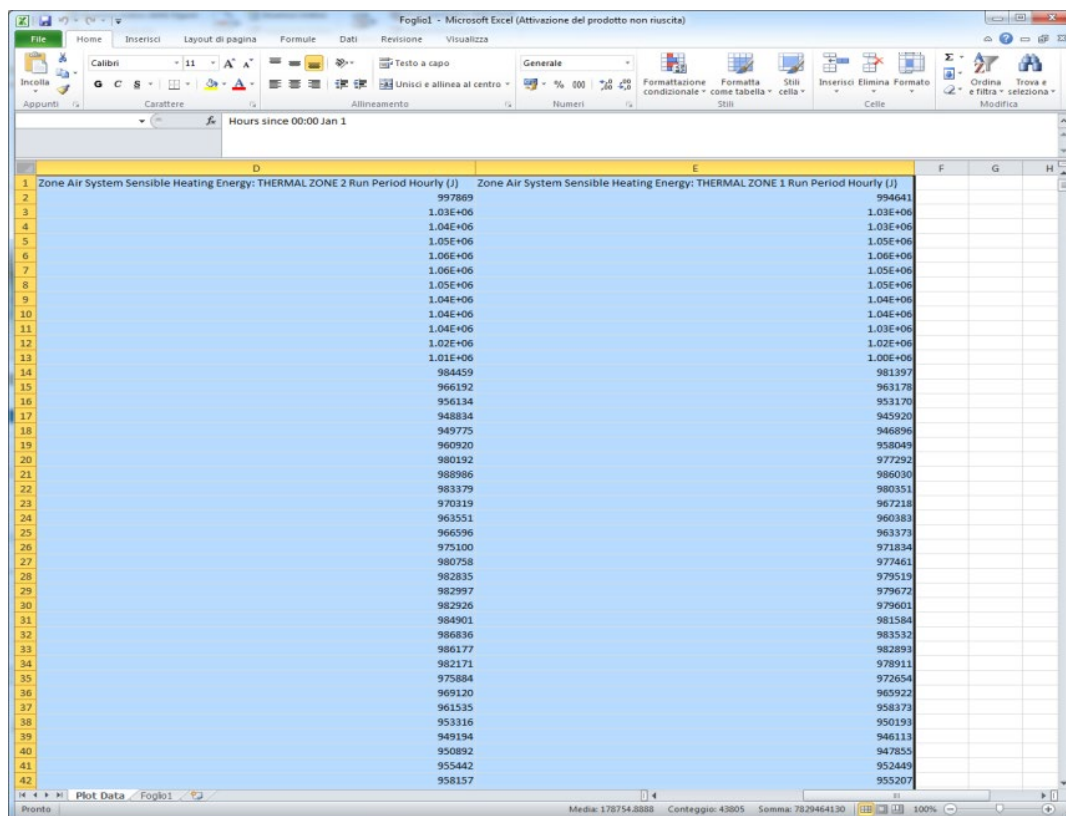
Figure 12: Output data sent to excel

In the new release, the "Step 11 - HVAC and Primary Energy" was introduced. After a successful simulation run, the user may look at main output data in a more intuitive way and set characteristics of HVAC systems, by clicking on "Step 11 - HVAC and Primary Energy" command. By mean of a simple table, one can get the calculation of building energy consumption by source of energy (electricity, gas) and in terms of primary energy. Here, the spreadsheet editor installed on the user's computer will be opened, to show the simulation output. This module is divided in the following sections, where yellow-colored fields mean that the user must input missing data:

- Building data;
- Ventilation;
- Heating System;
- Cooling System;
- Building Energy Consumption.

In "Building Data" section, the user must input the geometric building data. More in detail, it is asked to input the building volume and floor area of zones that are controlled by HVAC systems.

BUILDING DATA		
Heated/Cooled Building Volume (USER INPUT)	500	m³
Heated/Cooled Building Floor Area (USER INPUT)	1500	m²

Figure 13: Building data section in step 11.

The ventilation part requires input for a proper calculation of the latent thermal load in the building.

VENTILATION		
Site Height	0	m
Water Vapour Rate	65	g/(h*person)
People Occupancy Rate	0.04	people/m²
Floor Area	1500	m²
Contemporaneity factor	1	-
Design Air Flow Rate	39.6	m³/(h*person)

Figure 14: Ventilation section in step 11.

The "Heating System" section shows the Net Sensible Heating Energy Demand, in kWh/m³ and the Peak Sensible Heating Power, in kW, obtained from the simulation. This information gives the opportunity to the user to understand at a glance the performance of the designed envelope and to size the generator of the heating system. Moreover, the user may set the characteristics of the heating system.

HEATING SYSTEM		
Net Sensible Heating Energy Demand	5.46	kWh/m³
Peak Sensible Heating Power	27.78	kW
Heating Setpoint Temperature	20	°C
Indoor Relative Humidity Setpoint	50	%
Type of Generation Subsystem	Air Source Heat Pump	
Nominal COP at Source Reference Temperature	3	[-]
Source Reference Temperature for COP Value	7	°C
Distribution Subsystem Efficiency	0.99	[0-1]
Emitting Units Efficiency	0.95	[0-1]
Control Subsystem Efficiency	0.98	[0-1]
Heating System Auxiliary Devices Electric Power	0	W

Figure 15: Heating System section in step 11.

This "Cooling System" section shows the Net Sensible and Latent Cooling Energy Demand, in kWh/m³ and the Peak Sensible and Latent Cooling Power, in kW, obtained from the simulation. This information gives the opportunity to the user to understand at a glance the performance of the designed envelope and to size the generator of the cooling system. Moreover, the user may set the characteristics of the cooling system.

COOLING SYSTEM		
Net Sensible Cooling Energy Demand	7.36	kWh/m³
Peak Sensible Cooling Power	13.89	kW
Net Latent Cooling Energy Demand	0.00	kWh/m³
Peak Latent Cooling Power	0.00	kW
Cooling Setpoint Temperature	26	°C
Indoor Relative Humidity Setpoint	50	%
Type of Generation Subsystem	Air Source Heat Pump	
Nominal EER at Source Reference Temperature	3	[-]
Source Reference Temperature for EER Value	35	°C
Distribution Subsystem Efficiency	0.98	[0-1]
Emitting Units Efficiency	0.97	[0-1]
Control Subsystem Efficiency	0.97	[0-1]
Cooling System Auxiliary devices electric power	0	W

Figure 16: Cooling System section in step 11.

In the "Building Energy Consumption" section, the table shows results about the overall energy consumption of the building, in a form of a balance, considering energy needs outcomes of the dynamic simulation and data input in previous sections. The upper part shows annual electric energy needs figuring out for each service type (heating, cooling, lighting, domestic hot water and other equipment as indoor appliances). Results are shown both in absolute terms (in kWh) and related to the building size (in kWh/m^3). Moreover, the overall electric energy consumption is shown, computed as the sum of electric consumption for all listed services.

By default, the green column is highlighted. It means that the computation is performed assuming values obtained from the simulation. However, the user may want to merge this energy balance with custom calculation (i.e. figuring out from other software or fixing some modeling conventions). To do that, one has to switch from "Simulation Output" to "User Input" in the second line of the table. By clicking on the field containing the option value, a drop down menu is prompted thanks to which, user can switch the option. If "User Input" option is selected the yellow column will be used for calculations. Mind that user may copy some simulation outcomes in this column and modify just the values he need to fix.

Going further, the amount of Electric Energy provided by Renewable Energy Systems (RES) is shown. Even in this field, one can keep simulation output or input custom values from other calculation.

Then, the Net Building Energy Demand is provided as the difference between Total Electric Energy Demand and Electric Energy from RES.

In case of a gas boiler generator, even gas Energy Demand for Heating will be prompted.

In the last section, the user must input the Electric to Primary Energy Factor, according to the national electric generation system. This coefficient is used to convert electric energy consumption into its corresponding value in terms of primary energy, as shown in last two lines.

The Building Total Non-Renewable Energy Use will show the annual primary energy required by the building (both in absolute value, kWh, and related to its volume, in kWh/m^3).

BUILDING ENERGY CONSUMPTION			
ANNUAL ELECTRIC ENERGY NEEDS	**SIMULATION OUTPUT**		
	USER	SIMULATION	
- Heating [kWh]	**1092**	**1092**	kWh
	2.18	2.18	kWh/m³
- Cooling [kWh]	**767**	**767**	kWh
	1.53	1.53	kWh/m³
- Lighting [kWh]	**0**	**0**	kWh
	0.00	0.00	kWh/m³
- Domestic Hot Water **(USER INPUT)** [kWh]	**0**	**0**	kWh
	0.00	0.00	kWh/m³
- Other Equipment [kWh]	**0**	**0**	kWh
	0.00	0.00	kWh/m³
Total electric Energy Demand	**1859**		kWh
	3.72		kWh/m³
	USER	SIMULATION	
Electric energy from RES	**0**	**0**	kWh
	0.00	0.00	kWh/m³
Net Building Electric Energy Demand	**1859**		kWh
	3.72		kWh/m³
ANNUAL ENERGY FROM GAS NEEDS	**SIMULATION OUTPUT**		
	USER	SIMULATION	
Gas Energy Demand for Heating	**0**	**0**	kWh
	0.00	0.00	kWh/m³
Electric to primary energy conversion coefficient	1.95		
Building Total Non-renewable Energy Consumption	3625		**kWh**
Building Total Non-renewable Specific Energy Consumption	7.25		**kWh/m³**

Figure 17: Building Energy Consumption section in step 11, with simulated outcomes.

BUILDING ENERGY CONSUMPTION			
ANNUAL ELECTRIC ENERGY NEEDS	**USER INPUT**		
	USER	SIMULATION	
- Heating [kWh]	**1092**	**1092**	kWh
	2.18	2.18	kWh/m³
- Cooling [kWh]	**767**	**767**	kWh
	1.53	1.53	kWh/m³
- Lighting [kWh]	**0**	**0**	kWh
	0.00	0.00	kWh/m³
- Domestic Hot Water **(USER INPUT)** [kWh]	**0**	**0**	kWh
	0.00	0.00	kWh/m³
- Other Equipment [kWh]	**0**	**0**	kWh
	0.00	0.00	kWh/m³
Total electric Energy Demand	**1859**		kWh
	3.72		kWh/m³
	USER	SIMULATION	
Electric energy from RES	**0**	**0**	kWh
	0.00	0.00	kWh/m³
Net Building Electric Energy Demand	**1859**		kWh
	3.72		kWh/m³
ANNUAL ENERGY FROM GAS NEEDS	**USER INPUT**		
	USER	SIMULATION	
Gas Energy Demand for Heating	**0**	**0**	kWh
	0.00	0.00	kWh/m³
Electric to primary energy conversion coefficient	1.95		
Building Total Non-renewable Energy Consumption	3625		**kWh**
Building Total Non-renewable Specific Energy Consumption	7.25		**kWh/m³**

Figure 18: Building Energy Consumption section in step 11, with customized input.

The installation files of the tool along with the user manual can be downloaded at the following link:

https://www.dropbox.com/sh/2r8930rjt8skcd0/AAA2XU6JHhD2eK83q-ZMhqsDa?dl=0

3. ONLINE COURSES

A MOOC (Massive Online Open Course), already developed by POLIMI, has been updated with new lectures including the main contents added to the handbook presented in Chapter 1. More in detail, the list of lectures of the MOOC and the indication of new contents (underlined) is provided hereafter.

[1]   The global warming issue: the impact of the building sector
[2]   Integrated design concept and Economics of green buildings
[3]   Climatic map of Africa: Climate A
[4]   Climatic map of Africa: Climate B
[5]   Climatic map of Africa: Climate C
[6]   The building's energy balance
[7]   Basic concepts of heat transfer
[8]   Standard and adaptive approach for thermal comfort
[9]   Fundamentals of visual comfort
[10]   Site planning and Building design
[11]   Roof and walls design by climatic zone (mass, insulation, solar protection)
[12]   Embodied energy of materials and life cycle of buildings
[13]   Solar geometry and polar diagrams
[14]   Solar radiation
[15]   Solar shading
[16]   Air movements inside and around buildings
[17]   Cross ventilation and Stack effect: concept and opening sizing method
[18]   Technologies/techniques for enhancing natural ventilation
[19]   Natural cooling: concept and sizing method
[20]   Glass, light and heat - type of glazing
[21]   Window sizing procedure and Tips for window design
[22]   Systems to enhance natural lighting
[23]   Recommendations by climatic zone
[24]   Efficient energy conversion technologies
[25]   HVAC types and features
[26]   Solar PV and Solar Thermal
[27]   Wind Energy, Biomass and Hydro Power

The front cover of the new MOOC, which is reported at the beginning of each lesson, is shown hereafter.
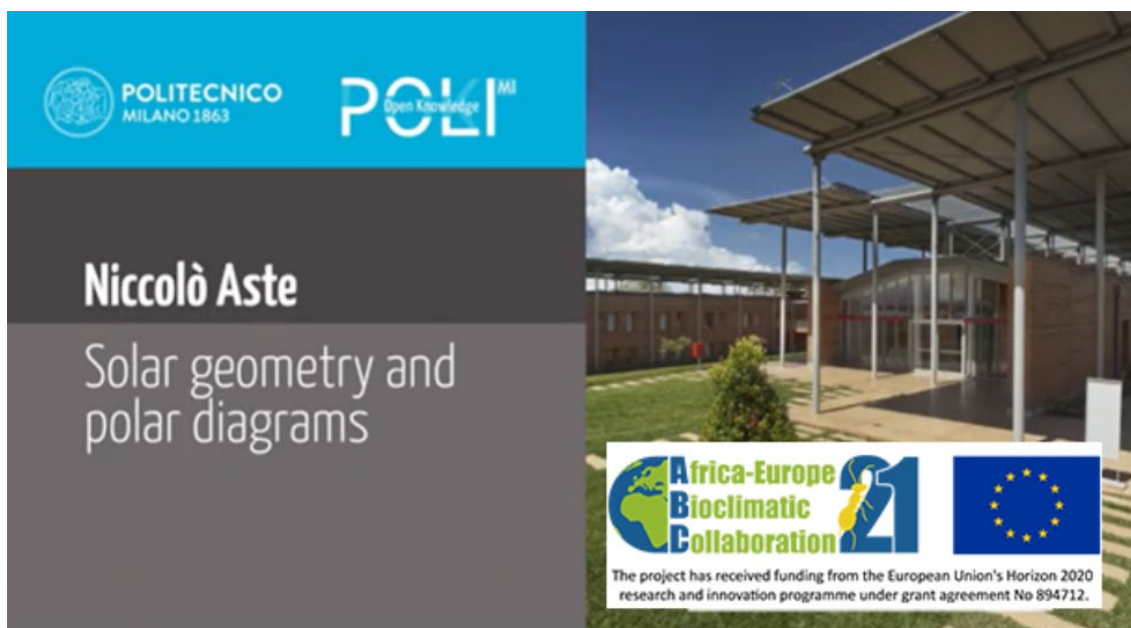
The entire course is available at the following link:
https://www.pok.polimi.it/courses/course-v1:Polimi+SustArch103+2022_M11/about

4. FEEDBACK FROM ATTENDEES

During the development stages, the 3 training tools were tested by students involved in the project. As a result of such testing activity, on-field feedbacks were collected in order to further improve the tools.

More in detail, regarding the handbook the project team prepared an initial version containing information on the various climates (building a climate map, defining different zones based on the impact of climate on the energy performance of buildings), the relations between the various climates and the energy response of buildings, their energy efficiency, the design methods and the use of various technologies in the field of energy and zero-energy buildings and communities. The contents of the handbook were shared with the consortium partners.

About the software (BESTenergy) a specific online training webinar has been arranged on 14/12/2022 in order to show the main functions of the developed tool as well as to propose a practical exercise, consisting in the energy modelling of a simple building with 2 zones (the text of exercise has been reported in the appendix of the present document).

The webinar was joined by an overall number of 39 students (14 students from FC.ID, 23 from EAMAU and 2 from AUI). The lesson included evaluation questionnaires on the three tools. The questions and the replies are summarized hereafter.

	Average obtained point (1 bad – 3 good)
BESTenergy section:	
Could you easily install the software?	2.1
Could you carry out at least one simulation?	1.9
How do you evaluate the process to create a new material/component?	2.2
How easy is the tool to use?	2.33
Is the HVAC section comprehensive and easy to use?	1.9
Which improvement would you suggest to the developers?	- Add illustration to interface - Just good. - The Best energy can't be used on other software, so you must develop for other software such as ArchiCAD, cinema 4D cause lot of people don't use SketchUp. - After running the simulation, we need to put the volume and area of the building in the resulting excel sheet; it would be better if it is done automatically since this information is already given in Sketchup. - Integrate a graphical view of the simulation data - Useful - Add French translation
Handbook section	
Did you read some chapters of the book?	1.7
Do you consider the topic treated interesting?	2.3

Are the figures clear enough?	2.05
Which are the most interesting topics treated in the book?	1.4. Architecture in tropical climates 3.3. Site planning 3.1. Passive solar 4. Energy efficient buildings design 1.5. A new energy system for cities 3.6. Daylighting 2.1. Climatic parameters 3. Climate responsive building design 3.9. Building materials 2. Climate and Building Design 2. Climate and Building Design 1.4. Architecture in tropical climates 3.9. Building materials 1.4. Architecture in tropical climates 2. Climate and Building Design 3. Climate responsive building design
Which topic, interesting for you, is not adequately treated?	- Very good - According to me, All topics are adequately treated. - Integrated design - Building design - Nothing
MOOK section	
Do you attend the course? ● No ● Yes ● Partially	
Did you complete the course? ● No ● Yes	
What do you think about the quality of the lectures?	2.3

Which suggestion would you provide in order to improve the quality of the course?	- More working with software - Send forward link for students to install Simultaneous translation to French of the course for next time. - to have a translation They must be organised and try to speak a little bit French for more understanding - There is a small mistake in the Climatic Map of Africa Part 3, where it states that Morocco, Algeria and Tunisia are in the North east of Africa while Libya and Egypt are in the North west. - to add readings, and to work on problem not just quizzes - ensure that courses are available in several languages, for a better understanding
Which is the maximum time that you can spend for a single on-line lecture ● 5 min ● 10 min ● 15 min ● 20 min	26,3% 42,1% 26,3%

The evaluations and suggestions were used to improve the contents of the tools and examine a number of issues in more detail, and to fine-tune the outcomes in order to satisfy specific requests that emerged during the webinar.

5. APPENDIX

Hereafter, the content of the exercise shared with the students during the webinar is reported.

1) Exercise object

The following exercise consists in the development of the dynamic energy simulation model, adopting the BESTenergy tool, of a building constituted by two thermal zones: one designated for residential use and the other one for tertiary use (office). The main glazed façade is oriented toward South.
The heating and cooling sensible energy demand is requested for different configurations.
The building will be simulated in different climatic contexts.
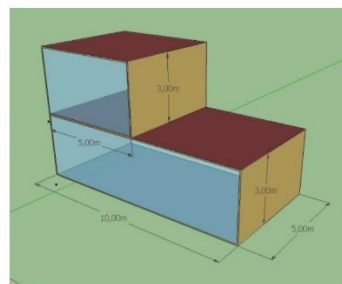
2) Envelope components

In the following sections are shown the compositions of the different envelope components and the thermo-physical properties of the materials.

2.1) Opaque components

The building envelope consists of the following components.

Exterior wall				
Material	Thickness [cm]	Conductivity [W/m K]	Density [kg/m³]	Specific heat [J/kg K]
Exterior plaster (lime-plaster)	1,5	0,7	1400	840
Expanded polystyrene	4	0,036	30	1340
Brick	12	0,8	1800	840
Interior plaster (lime-plaster)	1,5	0,7	1400	840

Exterior ground floor				
Material	Thickness [cm]	Conductivity [W/m K]	Density [kg/m³]	Specific heat [J/kg K]
Ceramic tile	1	1	2300	840
Sand/cement screed	4	0,93	1800	840
Expanded polystyrene	4	0,036	30	1340
Reinforced concrete slab	26	0,74	1800	840
Exterior plaster (lime-sand)	1,5	0,9	1800	840

Exterior roof				
Material	Thickness [cm]	Thermal conductivity [W/mK]	Density [kg/m³]	Specific heat [J/kg K]
Ceramic tile	1	1	2300	840
Sand/cement screed	4	0,93	1800	840
Expanded polystyrene	4	0,036	30	1340
Lightweight screed	10	0,083	600	880
Exterior plaster (lime-sand)	1,5	0,9	1800	840

For each one, the U-value, decrement factor (attenuation) and time lag factor must be calculated.

2.2) Glazing components

The building has two windows facing south with thermal transmittance (U-value) of 2,7 W/m^2K (the value already takes into account the impact of the frame and the junctions between this and the glass). Also, this component has a solar heat gain coefficient of 0,8 and a visible transmittance of 0,7.

3) Defining users' behaviors

In the following table are shown the thermal zone parameters of the operative conditions for the ground floor. The total internal gain is a mean value that takes into consideration the loads from the people occupancy, electric equipment thermal load and the use of the lighting system.

Profile name	Residential	Office
Total internal gain	4 W/m^2 (mean value on the whole year, 24h/24h)	6 W/m^2 (mean value on the whole year, 24h/24h)
Ventilation airflow	0,3 volume/hour (mean value on the whole year, 24h/24h)	0,6 volume/hour (mean value on the whole year, 24h/24h)
Constant heating setpoint temperature	20 °C	20 °C
Constant cooling setpoint temperature	26 °C	26 °C

4) Shading devices

A horizontal overhang to better screen the ground floor during the summer season allowing the penetration of the solar radiation during the winter season (considering the winter and summer solstice) must be designed. The solar elevation angle is:

$$\beta_{max}=(90-\varphi)+23.5$$
$$\beta_{max}=(90-\varphi)-23.5$$

1

Apply an exterior roll-up venetian blind on the window of the office, that is active only in hours when the radiation is over 200 W/m^2. As geometrical and thermal features of the venetian blind, the one already added in the database can be adopted.

5) Calculation of the energy demand and consumption

1. Calculate the heating and cooling sensible energy demand of the building and the maximum dissipated power during the winter and summer season.

2. Calculate the heating and cooling sensible energy demand of the building placing the venetian blind in the interior side of the window.

3. Calculate the heating and cooling sensible energy demand of the building without window blinds.

4. Evaluate the primary energy consumption considering the application of an air source heat pump characterized by the data reported in the following table.

HEATING SYSTEM		
Heating Setpoint Temperature	20	°C
Indoor Relative Humidity Setpoint	50	%
Type of Generation Subsystem	Air Source Heat Pump	
Nominal COP at Source Reference Temperature	3	[-]
Source Reference Temperature for COP Value	7	°C
Distribution Subsystem Efficiency	0,99	[0-1]
Emitting Units Efficiency	0,95	[0-1]
Control Subsystem Efficiency	0,98	[0-1]
Heating System Auxiliary Devices Electric Power	100	W
COOLING SYSTEM		
Coolong Setpoint Temperature	26	°C
Indoor Relative Humidity Setpoint	50	%
Type of Generation Subsystem	Air Source Heat Pump	
Nominal EER at Source Reference Temperature	3	[-]
Source Reference Temperature for EER Value	35	°C
Distribution Subsystem Efficiency	0,98	[0-1]
Emitting Units Efficiency	0,97	[0-1]
Control Subsystem Efficiency	0,97	[0-1]
Cooling System Auxiliary devices electric power	100	W

2