MOEEBIUS

Modelling Optimization of Energy Efficiency in Buildings for Urban Sustainability

D3.6 Local and Global Energy performance models

Version number: 1.0
Dissemination Level: PU
Lead Partner: TECNALIA
Due date: 31/03/2017
Type of deliverable: Other
STATUS: Delivered

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 680517

Published in the framework of:

MOEEBIUS - Modelling Optimization of Energy Efficiency in Buildings for Urban Sustainability

MOEEBIUS website: www.moeebius.eu

Authors:

Víctor Sánchez, Pablo De Agustín, Ignacio Gomis, Ander Romero - TECNALIA

Francisco Javier Royo, Manuel Sáenz- SOL

Peet Van Tooren- ALM

Revision and history chart:

VERSION	DATE	EDITORS	COMMENT
1.0	27/04/2017	TECNALIA	Submitted to the EC

Disclaimer:

Table of content

List of tables

List of figures

Glossary

Acronym	Full name
API	Application Programming Interface
BEPS	Building Energy Performance Simulation
BAS	Building Automation systems
BCVTB	Buildings Control Virtual Test Bed
DAE	Dynamic Assessment Engine
DHW	Domestic Hot Water
DER	Distributed Energy Resources
ERL	EnergyPlus Run Time Language
EMS	Energy Management System
FMI	Functional Mockup Interface Standard
FMU	Functional Mockup Unit
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Internal Air Quality
IDF	Input Data File
MOC	Model of Computation
RES	Renewable Energy Sources
XML	Extensible Markup Language

1 Executive summary

In this task the local (building level) and global (district level) energy performance models required by the Enhanced BEPS, the building and district level DAE-s and by the Integrated MOEEBIUS DSS to represent, simulate and evaluate the energy performance of buildings and complete districts, according to the the *Building and District performance assessment methodology and respective Key Performance Indicators* specified in task T2.3, have been developed.

This required the integration into to the BEPS' calculation engine (EnergyPlus) of the models developed in Tasks 3.3, 3.4 and 3.5. Additionally, going beyond the information provided by the static BIM models, the procedure to dynamically update the values of the key thermal parameters of the EnergyPlus models with the actual information of each specific building has been defined.

This provides the ability to building models to exactly reproduce the complexities of the actual buildings by addressing areas and aspects that are dominated by assumptions (e.g. infiltrations, etc.). With this approach MOEEBIUS ensures the delivery of more dynamic and representative holistic models (without increasing significantly the introduced complexity) with the capacity to minimize deviations between predicted and actual building performance.

As a starting point, taking into account the existing constraints (complexity level of the mathematical models) direct incorporation of the models into EnergyPlus IDF files using the advanced ERL programing language functionality and EMS programs, has been identified as the most suitable approach to integrate the models developed in Tasks 3.3, 3.4 and 3.5.

For each of the models, the EMS programs necessary to implement their integration into EnergyPlus have been defined and the EnergyPlus class instances needed to enable the interaction of these models with the relevant standard models of EnergyPlus identified.

Similarly, specific EMS programs have been defined to produce the KPI-s as specified in the methodology defined in Task 2.3, from the comprehensive outputs provided by EnergyPus for DER-s .This work has also been addressed in parallel in Task 5.1 as both task are closely related, and, as a consequence further information about these developments will be provided in D5.1.

The relevance of having a **Weather Data File Generation Engine,** with the capacity to generate EnergyPlus weather data files for different simulations purposes using data from different sources (historic data for calibration and forecasted data for predictions) has been identified and the designed implementation approach developed.

Finally the EnergyPlus models and the Integrated District Model of each pilot, have been produced, when necessary taking advantage of the Subsystem Modelica models included in the **MOEEBIUS Modelica Library**.

2 Introduction

In order to provide the modelling capacities required by the BEPS Engine, the building and district DAE-s and the Integrated MOEEBIUS DSS, to produce accurate demand, local production, IAQ and comfort predictions, in this task all the models developed in previous tasks of WP3 have been incorporated to the calculation engine of the **BEPS** (EnergyPlus).

Additionally, the procedure required to dynamically update the information of the EnergyPlus models related to the key thermal modelling parameters (initially coming from the static BIM models), with building specific values identified by the building **DAE** during the model calibration stage to minimize the differences between simulated and actual building behaviour, have been defined.

In order to identify the most suitable procedure the existing possibilities for the integration of additional modeling capacities into EnergyPlus through the advanced EnergyPlus runtime language functionality or alternatively through co-simulation schemes (Using the Functional Mockup interface standard and FMU-s or using the BCVTB middleware) have been analyzed.

Taking into account that the complexity level of the mathematical description of the models to be incorporated is compatible with the capabilities of the ERL programing language the direct incorporation of the models to the code of the IDF files of the EnergyPlus models has been identified as the most efficient approach.

As part of the implementation procedure of the integration of the models into EnergyPlus, the required EMS programs have been defined and the EnergyPlus class instances required to implement the EMS programs have been identified.

Similarly, specific EMS programs have been defined to produce the KPI-s as specified in *D2.3 MOEEBIUS Energy Performance Assessment Methodology*, from the comprehensive outputs provided by EnergyPus for DER-s .This work has also been addressed in parallel in Task 5.1 as both task are closely related, and, as a consequence further information about these developments will be provided in *D5.1 MOEEBIUS Building Energy Performance Simulation System*.

On the other hand, another key aspect to enable the reliable operation of the **BEPS**, is the availability of building specific EnergyPlus weather data files to be used for different types of simulations (calibration and predictions), and generated from different weather data sources (historic data for calibration and forecasted data for predictions). Therefore, in this task the **Weather Data File Generation Engine** has been defined and described (concept, functionalities, architecture, etc.).

Finally the modelling criteria used to develop the EnergyPlus models and when necessary the Modelica models used to generate the Integrated District Model of each pilot, have been described.

Pilot simulation models have been uploaded to the Google Drive of the Project (goo.gl/weXBHI) to be publically available. These models will be updated until the completion of the project as necessary, to adapt them to any possible modification that might be required along the different stages of the project to guarantee the best possible deployment of the MOEEBIUS Platform in all the pilots.

2.1 Relevance with other tasks

In this task the building level DER models developed in Task 3.3, the comfort model developed in Task 3.4 and the IAQ model developed in Task 3.5 have been be integrated into EnergyPlus models to provide the modeling and simulation capabilities required by:

- The Enhanced BEPS (Task 5.1).
- The Building Dynamic Assessment Engine (Task 5.3).
- The District Level Dynamic Assessment Engine (Task 5.4).
- The Integrated MOEEBIUS DSS (Task 6.4).

On the other hand, the local (building level) and global (district level) models of the pilots have been developed taking advantage of the information gathered in the frame of Task 7.2.

2.2 Structure of this deliverable

In the following lines a short description of the structure of the document is provided in a compact shape:

- Chapter 2 gives an overview of the objectives of the task, and the scope and structure of this deliverable.
- Chapter 3 identifies the existing procedures to integrate the models developed in the previous tasks of WP3 into EnergyPlus, and describes the selected approach based on the advanced EnergyPlus Run Time Language functionality.
- Chapter 4 describes the implementation of the procedure to integrate the IAQ developed in Task 3.5.
- In Chapter 5 all the details about the integration into EnergyPlus of the comfort model, developed in Task 3.4 are given.
- Chapter 6 gives a comprehensive description of the implementation of the integration of the building level DER models developed in Task 3.3, into EnergyPlus through the ERL advanced functionality.
- Chapter 7 describes the procedure to update the critical thermal modelling parameters of EnergyPlus models, to improve the information coming from the static BIM models with building specific actual values.

- In Chapter 8 the process followed to produce the Weather Data File Generation Engine necessary to enable BEPS operation has been included.
- Chapter 9 includes a detailed description of the modelling process followed in the pilots of the project to produce building (EnergyPlus) and district (Modelica) level models.
- Chapter 10 summarizes the conclusions of the activities performed in the frame of this task.

3 Selection of the procedure to integrate new models into EnergyPlus

In this chapter, the existing procedures to integrate the developed models into EnergyPlus will be described and the most suitable one selected.

Two approaches have been identified to incorporate these models into the calculation engine of the BEPS (EnergyPlus). The selection of the most suitable one is mainly affected by the complexity level of the mathematical description of the model.

3.1 Direct integration through EnergyPlus EMS programs

According to this approach, specific EMS programs describing the behaviour of the new models developed using the EnergyPlus **Run Time Language** advanced functionality, would be incorporated to EnergyPlus, along with the additional EMS programs necessary to enable the interaction of the new models with the rest of the EnergyPlus standard components (for input request and output delivery).

As presented in D3.3, the EnergyPlus **Run Time Language (ERL)** functionality enables the definition within EnergyPlus of programs (EMS programs) specifically designed to include additional modelling or control capabilities. The code of these programs is directly entered into the EnergyPlus input data file (IDF).

The ERL is a simplified programming language based on relatively simple rules of syntax and commands, and as a consequence has some limitations (only algebraic statements, no numerical manipulation, etc.). However, when the complexity level of the models to be added is compatible with the capabilities of the ERL language it is the most efficient approach to upgrade EnergyPlus with additional modelling capabilities.

The EnergyPlus runtime language does not provide numerical manipulation capabilities and therefore the models to be incorporated have to be expressed as a group of relatively simple algebraic equations.

3.2 Integration through co-simulation

The integration of behavioural models described by complicated mathematical equations (e.g., differential equationsetc.) through direct integration into EnergyPlus using the ERL advanced functionality can become unpractical or even impossible without a complicated and time consuming pre-treatment process of the mathematical expressions that capture the new physical model.

For these models the most suitable integration approach consists on their implementation on a dedicated simulation and modelling tool (e.g., Modelica, Matblab, etc.), that can provide the required modelling and simulation capabilities, to be coupled to EnergyPlus through a specifically developed co-simulation arrangement.

Depending on the features of the simulation tool selected for the implementation of the new model, different possibilities to solve the co-simulation arrangement have been identified. In the following sections, the existing co-simulation implementation possibilities are described in more detail.

3.2.1 Integration through the Functional Mock Up Interface Standard using functional mockup units

The Functional Mockup Interface standard has been used in the buildings community primarily to link simulation programs for co-simulation. Recent efforts are ongoing in the frame of the IEA EBC Annex 60 to develop the next generation of simulation tools based on the Modelica language and the FMI standards.

The first version of the Functional MockUp Interface standard (FMI 1.0) was originally developed in the Information Technology for European Advancement (ITEA2) project MODELISAR and was published in 2010. In July 2014 it was followed by the FMI 2.0 and is currently supported by over 89 simulation tools. The development of the FMI standard was initiated by Daimler AG, and is still being further developed by 16 companies and research institutes all over the world.

The Functional Mockup Interface Standard is a tool independent and nonproprietary standard that has been developed to export models or whole simulators from one simulation tool into another simulation tool, to perform a coupled simulation of time dependent systems.

Through the use of the FMI standard it is possible to integrate new models developed in advanced simulation tools compliant with the FMI standard, into the available building simulation programs such as EnergyPlus, avoiding the existing difficulties to add new models in this type of tools. In this type of co-simulation arrangement, the simulation tool that imports the other models through the FMI standard is called master and the simulation tools that are exported through the FMI standard are called slaves.

The data exchange between subsystems is restricted to discrete communication points (synchronization points). In the time between two communication points, the subsystems are solved independently from each other by their individual

solver. Master algorithms control the data exchange between subsystems and the synchronization of all slave simulation solvers.

The most common master algorithm stops at each communication point the time integration of all slaves, collects the outputs from all subsystems, evaluates the subsystem inputs, distributes these subsystem inputs to the slaves and continues the co-simulation with the next communication step. However, more sophisticated master algorithms such as communication step size control (adjustment of the communication step size according to the solution behavior) are also supported.

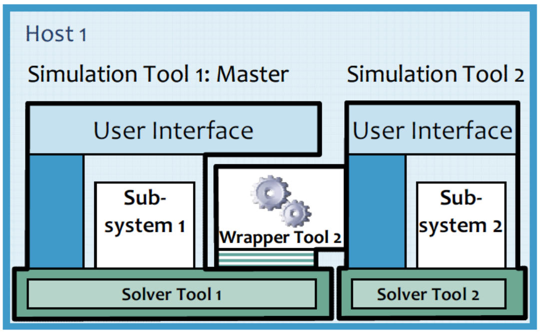


Figure 1 Co-simulation with tool coupling on a single computer

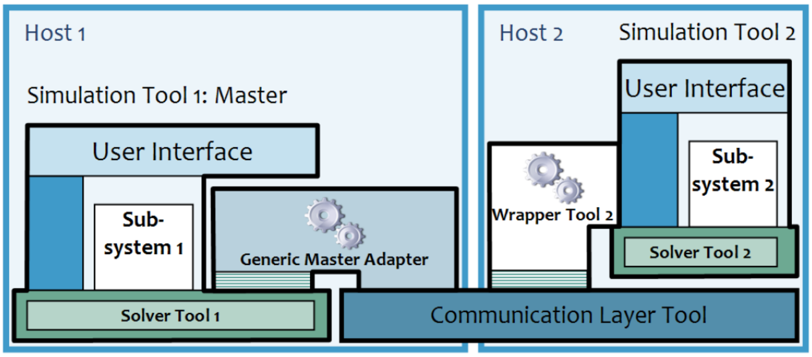


Figure 2 Distributed co-simulation infrastructure

The modular structure of coupled problems allows separate model setup and preprocessing for the individual subsystems in different simulation tools. During time integration, the simulation of each subsystem is performed independently restricting the data exchange between subsystems to discrete communication points. Finally, the visualization and post-processing of simulation data is carried out individually for each subsystem in its own native simulation tool.

The FMI standard supports both model exchange and co-simulation of dynamic models using a combination of a XML-file, C-header files, and C-code in source or binary form.

The Co-Simulation Description Schema is defined in a slave specific XML file, which includes all the information required by the importing tool to inquire

information about the model and its interface variables (input and output variables, parameters, etc.), and the information about the capabilities supported by the simulator (e.g., the ability of the slave to support advanced master algorithms, etc.)

On the other hand, the Co-Simulation Interface is defined by a set of C functions that are necessary to control the slaves, and to perform all the required exchange of status information and input and output values.

From the perspective of the co-simulation arrangement implementation, 2 different FMI standards have been defined, as described below:

- The FMI for model exchange API specifies how a modeling environment can generate C-code of a dynamic system model that can be integrated by other modeling and simulation environments.
- The FMI for co-simulation API provides an interface standard for coupling two or more simulation tools (master and slaves) that contain their own solvers for time integration in a co-simulation environment.

Therefore, the goal of the Functional Mockup Interface for Model Exchange API and of the Functional Mockup Interface for Co-Simulation API are respectively, to give standardized access to simulation model equations, and to provide an interface standard for coupling two or more simulation tools in co-simulation environments.

An implementation of the FMI standard for model exchange or for co-simulation is called Functional Mockup Unit and it is distributed in form of a zip file including the following information:

- The C functions provided in source (including the needed run-time libraries used in the model), and/or binary form to interface with one or more models or simulation programs.
- A model description XML file containing the definition of all variables in the model and other model information needed to simulate the model.
- Additional resource files such as data tables, diagrams, etc.

In the figure below, the existing possibilities, available for simulation tools which support the FMI API, to export a sub-system model as a FMU for model exchange or for co-simulation are displayed.

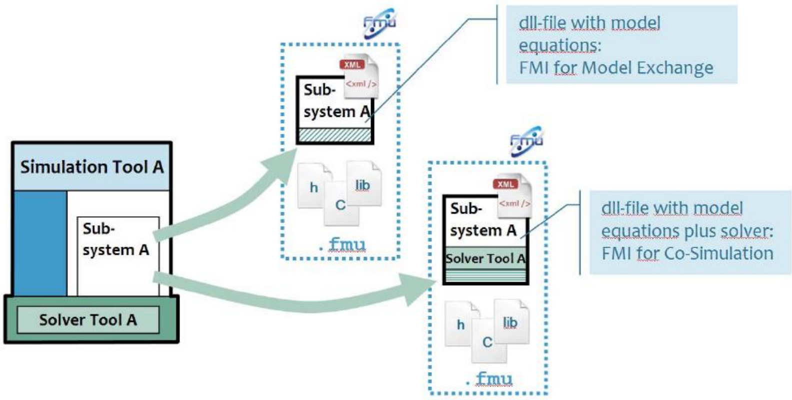


Figure 3 FMU-s produced through the FMI API for model exchange and the FMI API for CO-simulation

If the new models are implemented using a modeling tool that is FMI standard compliant then the new models could be converted into FMU-s to be imported by the EnergyPlus model of the building. More specifically, the development of this co-simulation approach would consist on the following sequence:

- Definition of a EnergyPlus model of the building.
- Definition of each of the new models using the selected simulation tool.
- Definition of the information flow to be exchanged between the building model and the new models.
- Integration of the following objects in the Energy Plus model of the building:
  - An instance of the **ExternalInterface FunctionalMockupUnitExport** object
  - The required number of **ExternalInterface:FunctionalMockuUnitExport:From:Variable** objects
  - The required number of **ExternalInterface:FunctionalMockUpunitExport:To:Schedule** objects
  - The required number of **ExternalInterface:FunctionalMockUpunitExport:To:Actuator** objects
  - The required number of **ExternalInterface:FunctionalMockUpunitExport:To:Variable** objects.
- Exportation of the new models to FMU-s (according to the FMI API for co-simulation).
- Co-simulation model composition. Some form of composition of the slave (new models) and master (EnergyPlus model) simulation models would be necessary to define the structure of the integrated model, including the definition of the topological connections between the master and the FMU-s, instances and the exchanged communication flows.

3.2.2 Integration through the Buildings Controls Virtual Test Bed

The BCVTB is a free modular, extensible open-source software framework available from the Lawrence Berkeley National Laboratory, that allows interfacing different simulation programs with each other and with Building Automation Systems (BAS) for run-time data exchange. Through the BCVTB it is possible to create co-simulation schemes to couple the simulation programs that provide the best capacity to model each specific part of any physical system.

Obviously, the direct implementation of all equations in a single simulation program would provide advantages in terms of computing time and simplicity of use. However, the use of co-simulation through the BCVTB enables extending the capabilities of building simulation programs as EnergyPlus, without the huge effort necessary for the implementation of all the equations in a single program.

Simulation tool coupling can be implemented either locally on a single host computer, or remotely over the internet, if necessary using different operating systems. The user interface of the middleware allows users to couple simulators and control interfaces graphically, and it provides the functionalities necessary to add user developed system models within the middleware.

Below, some additional features of the BCVTB co-simulation middleware are summarized in a compact shape:

- From a numerical point of view, the co-simulation schemes arranged in the BCVTB can be classified as quasy-dynamic coupling co-simulation schemes, with data exchange between simulation tools using a fixed synchronization time step.
- The computing time for data transfer between simulation programs is small compared to the computing time spent in the individual simulation programs.
- The BCVTB is simulation tool independent, and therefore different clients can be coupled to it, such as EnergyPlus, TRNSYS, MATLAB, Simulink, Modelica simulation environments, visualization tools, data bases and building automation systems compatible with the BACnet communications protocol.
- The BCVTB supports the Functional Mock Up Interface Standard for model exchange to import Functional Mock Up Units of models defined in programs that can´t be directly coupled to the BCVTB.
- Adjustable simulation speed.
- The platform provides the libraries necessary to integrate additional or user created simulation programs.
- The BCVTB can be run through the graphical user interface or as a console application without any user interaction.

The BCVTB middleware acts as master of the co-simulation that launches the simulation of all clients and organizes the data exchange between the solvers synchronizing the simulation time and stopping the clients. The interactions between the clients are defined by a Model of Computation (MOC) where the communication semantics among ports are specified (through the Synchronous Data Flow MOC). The BCVTB provides other Models of Computation, such as the Finite State Machines, used to express control logic in which different control laws are used depending on the state of the systems.

The implementation of the BCVTB middleware, was solved through the Ptolemy II software. Ptolemy II is a Java-based open-source software framework developed by the University of California at Berkeley to study modeling, simulation and design of concurrent heterogeneous real-time systems.

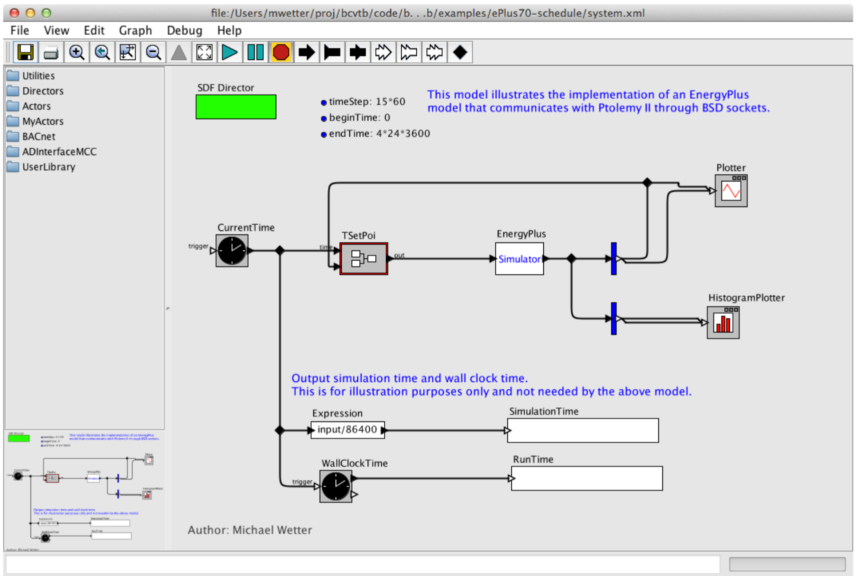


Figure 4 Ptolomy II system that links an actor that computes the room temperature setpoint with the simulator actor that communicates with EnergyPlus

With this co-simulation approach a variable value exchange would take place at calculation time step level, using the BCVTB middleware as master of the co-simulation process, requesting and sending the values of the required variables to the EnergyPlus building model and to the new models. More specifically, the procedure to couple the EnergyPlus building model and the new models through the BCVTB middleware would consist on the following sequence.

- Definition of the Energy Plus model of the building.
- Definition of the new models in the selected simulation tools.
- Identification of the information flow to be exchanged between models.
- Integration of an instance of the **ExternalInterface PtolemyServer** object, and the required number of **ExternalInterface:Schedule,**

ExternalInterface:Variable and **ExternalInterface:Actuator** objects in the EnergyPlus model of the building.

- Definition of the Ptolomy II model through the BCVTB interface, defining the Mode of Computation where the communication semantics among ports are specified.
- Definition of an XML configuration file to include the information necessary to enable the co-simulation including:
  - Identification of the programs to be coupled through the BCVTB, in this case, EnergyPlus and the modelling and simulation tools selected for the new models.
  - Definition of the vector of the variables (number and order) that will be exchanged between the EnergyPlus model and the BCVTB
  - Definition of the vector of the variables (number and order) that will be exchanged between the modelling and simulation environments used for the new models and the BCVTB.

Obviously, in order to have the choice to use this co-simulation implementation procedure, the simulation tools used for the implementation of the developed new models would have to be FMI standard compliant or alternatively, one of the clients supported by the BCVTB.

4 Integration of the improved IAQ model

The predictions provided by the Building Performance Simulation engine must incorporate the delivery of a satisfactory level of internal air quality as an additional constraint, to be maintained after the implementation of the optimized control strategies.

Therefore, it will be necessary to integrate the internal air quality models developed in Task 3.5 in the calculation engine of the BEPS (EnergyPlus).

The developed IAQ model provides the capacity to evaluate the expected production and decay rates for the contaminants relevant in the frame of the project (e.g. CO2, etc.), for each specific thermal zone, according to the evolution over time of the zone, subsystem and system variables identified in Task 3.5. as the most influential in the final IAQ.

Additionally, the model allows setting optimized internal air quality target/setpoints (concentration for the contaminants relevant to the project) that in comparison with currently available standards and good practice could, simultaneously, guaranty user satisfaction and good health, and minimize the required levels of ventilation and energy consumption.

4.1 Implementation of the IAQ model integration

All the procedures described in Chapter 3 to integrate the IAQ model into EnergyPlus, present advantages and disadvantages. However, taking into account the existing constraints, the direct IAQ model incorporation into EnergyPlus using the advanced ERL functionality has been selected as the most suitable approach, as the complexity level of the mathematical description of the developed IAQ model is compatible with the capabilities provided by the ERL programing language.

In this section all the details regarding the implementation of the integration of the IAQ model into EnergyPlus through the EnergyPlus Run time language will be provided.

The EMS programs used to capture the physical behavior of the IAQ model and to enable the interaction of this model with the relevant standard EnergyPlus models will be described in full detail

The IAQ model developed in Task 3.5, can provide the concentration at any given moment for any contaminant for each of the zones of any building where IAQ has to be evaluated.

However, due to some of the limitations existing in the ERL programming language (e.g. maximum number of characters per code line, etc.), a separate instance of the IAQ model has to be integrated into EnergyPlus for each zone and

contaminant, in order to evaluate the evolution over time of the concentration of all the contaminants present in all the relevant zones of the models.

In order to illustrate the procedure followed to integrate the model, in the following lines, the EMS programs to be included in the IDF-S to integrate the IAQ model for a single zone and a single contaminant are described. More specifically:

- **The contaminant increase/decrease component calculation program (zone i and contaminant j):**
    - This programs calculates for each calculation time step:
        - The contaminant presence increase due to the ventilation air (mechanical, natural and infiltration) entering the zone during the calculation time step. This component is mainly affected by the flow of ventilation air entering the zone and by the concentration of the contaminant on the outdoor air.
        - The contaminant presence increase due to the recirculated air flow entering the zone during the simulation time step. This component is mainly affected by the recirculated flow and the concentration of the contaminant on the zone at the end of the precedent time step.
        - The contaminant presence decrease due to the exhaust air flow leaving the zone during the simulation time step. This component is mainly affected by the exhaust flow and the concentration of the contaminant on the zone at the end of the precedent time step.
        - The contaminant presence decrease due to the contaminant sticking to the walls. This component is mainly affected by the concentration of the contaminant on the zone at the end of the precedent time step and the specific decay rate factor.
        - The contaminant presence decrease due to the adsorption of contaminant by walls. This component is mainly affected by the concentration of the contaminant on the zone at the end of the precedent time step, the internal surface of the walls and floors of the zone, and the specific adsorption rate.
    - This program is called and executed at the beginning of each simulation time step.
- **The zone contaminant balance calculation program**
    - Taking advantage of the outputs produced by the previous EMS program, this program calculates the contaminant balance and concentration for each simulation time step.
    - The calculated contaminant concentration values are used as input for the next simulation time step.
    - This program is called and executed at the end of each simulation time step.

More specifically, according to this approach the implementation of the IAQ model for a specific zone and contaminant will require the integration of the following class instances on the IDF file:

- An instance of the **EnergyManagementSystem:Program** to define **The contaminant increase/decrease component calculation program**.
- An instance of the **EnergyManagementSystem:Program** to define **The zone contaminant balance calculation program**.
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of **The contaminant increase/decrease component calculation program**
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of **The zone contaminant balance calculation program**.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the infiltration.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the natural ventilation.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the recirculated air.
- An instance of the **EnergyManagementSystem:GlobalVariable** class to capture the value of the intake ventilation air flow to the zone. This value will be calculated by specific a EMS program defined to evaluate the evolution over time of the required ventilation air flow rate.

Finally it is necessary to mention, that for the evaluation of IAQ in the case of CO_2, the standard models already available in EnergyPlus, provide enough modeling capabilities to address CO_2 concentration evaluation. Therefore, the IAQ aspect related to CO_2 will be analyzed using the standard models.

5 Integration of occupants comfort modelling

Comfort is a key constraint that has to be incorporated to the predictions of the BEPS Engine and therefore it is necessary to incorporate into the calculation engine of the BEPS (EnergyPlus), the information regarding comfort preferences of the occupants provided by the **Behavioural Profiling Engine**. This is actually a main innovation of the MOEEBIUS project as we are not defining static occupancy and behavioural profiles, rather these will be dynamically updated by taking into account at the simulation process the updated behavioural profiling values as defined by the associated models presented in D3.4.

Overall, MOEEBIUS building energy performance simulation is performed on the basis of dynamically updated occupancy profiles and thus behavioural profiles should be also incorporated in the simulation process.

5.1 Implementation of occupants comfort modelling integration

In this section, the details regarding the implementation of the integration into EnergyPlus through the ERL language of the information provided by the **Behavioural Profiling Engine** regarding the comfort preferences of users is described.

The role of the **Behavioural Profiling Engine** as defined in D3.4 is twofold.

Firstly, the engine will provide fine grained occupancy profiles (historical and predicted) as periodically updated by taking into account the raw occupancy formation from building premises. These fine grained occupancy profiles will be further utilized by the **BEPS engine** as the main objective of the simulation engine is to dynamically update EnergyPlus building models with actual occupancy and comfort preferences to be further used in the simulations for calibration and performance predictions (consumption, comfort and IAQ).

As presented in D3.4 we have defined the interfaces towards specifying the data structures that incorporate occupancy profiling parameters required for the simulation process and associated methods. In summary, we are presenting the methods defined as part of the BEPS framework for accessing the updated parameters of Behavioural Profiling mechanism.

Method	Description
getOccYearAvg (depth=null)	Returns hourly occupancy average for a period of one year. Depth is the number of years to consider for the avg. calculation. If null last year
getOccSeasonAvg (season= <val>,depth=null)	Returns hourly occupancy average for a certain season. Depth is the number of years to consider for the avg. calculation. If null last year

getOccMonthAvg (months= <listval>,depth=null)	Returns hourly occupancy average for certain months. Depth is the number of years to consider for the avg. calculation. If null last year
getOccMonthAvg (stardate= <val>,enddate=<val>)	Returns hourly occupancy average between certain dates.
getOcc24h ()	Returns the hourly occupancy forecast for 24h ahead

Table 1 BEPS tool & occupancy modeling incorporation

As stated in D3.4 this list is an indicative one, while the actual implementation of these interfaces will be performed in WP5 along with the development of Building Energy Performance Simulation System Enhancement (T5.1) & Occupant Profiling Mechanism (T5.2).

Along with the incorporation of the updated occupancy profiles, the **Behavioural Profiling Engine** will provide information about the comfort boundaries of the building occupants for each thermal/visual zone. As presented in D3.4 and the definition of the modelling framework about the behavioural profiling engine, the role of this mechanism is to define accurate comfort profiles by taking into account the building context conditions (temperature, humidity etc...) and the interaction of building occupants with heating, cooling and lighting devices.

In general, for buildings where a BMS system is available, the profiles about comfort settings defined in the simulation models will be updated with the actual values set for the zones of the building, according to the information available in the BMS further fine grained by the analysis performed by the behavioural profiling engine. However, for buildings without BMS system in place, the comfort boundaries and model parameters included in the simulation models will be updated using the information provided by the behavioural profiling engine regarding the specific comfort preferences of the users of each building zone.

The next table depicts the methods to be incorporated in BEPS tool for accessing the updated behavioural profiling values, while the detailed presentation of .xsd schema to be considered for interfacing the tools is available in D3.4.

Method	Description
getThermal (stardate= <val>,enddate=<val>)	Returns profiling values about thermal comfort associated with a previous period
getVisual (stardate= <val>,enddate=<val>)	Returns profiling values about visual comfort associated with a previous period
getThermal ()	Returns the latest profiling values about thermal comfort
getVisual ()	Returns the latest profiling values about visual comfort

Table 2 BEPS tool & behavioural profiling model incorporation

Each request is associated with a specific occupancy profile and building zone, considering the definition of the different semantic attributes that consist of the holistic Local (and Global) Energy Performance Modelling framework of MOEEBIUS.

More specifically, the following EnergyPlus instances have been integrated for each thermal zone in the models to address thermal profile settings update.

- An instance of the **EnergyManagementSystem:Program** to define the **Thermal Zone Thermal Comfort Profile Definition Program**.
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of the **Thermal Zone Thermal Comfort Profile Definition Program** (this program will be called at the beginning of each simulation time step).
- An instance of the **EnergyManagementSystem:Actuator** class to set the value of the Heating temperature set point schedule of the thermal zone.
- An instance of the **EnergyManagementSystem:Actuator** class to set the value of the cooling temperature set point schedule of the thermal zone.

The same approach should be considered for the incorporation of the visual comfort attributes in the building energy performance simulation engine, by exploiting the methods presented above about interfacing with the MOEEBIUS behavioural profiling engine.

We presented above the framework towards integrating the fine grained occupancy and behavioural profiles (as derived from Behavioural Profiling Engine) in the MOEEBIUS Building Energy Performance Simulation engine, focusing mainly on occupants comfort modelling.

The incorporation of the dynamically updated profiling models in BEPS engine is a heavy task, though will enable a more accurate simulation of building energy performance through the delivery of more dynamic and representative holistic models which stands as the project’s flagship towards holistically diminishing deviations between predicted and actual performance in building.

6 Integration of new building level DER models

As described in D3.3, in order to enable an accurate modelling of the energy demand associated to swimming pools and the impact of swimming pools on the comfort and IAQ conditions of swimming pool rooms it was necessary to develop some specific DER models:

- **The Swimming pool room thermal balance model**.
- **The Swimming pool water heating and makeup water system demand model**.

In this chapter the integration into EnergyPlus of these building level DER models will be described in full detail.

6.1 Implementation of Building level DER model integration

In this section all the details regarding the implementation of the integration of the building level DER models, into EnergyPlus through the ERL language will be provided.

Therefore, the EMS programs used to capture the physical behavior of the models and to enable the interaction of this models with the relevant standard EnergyPlus models will be described in full detail. Additionally, all the required auxiliary EnergyPlus object instances will be described. More specifically, the implementation of the building level DER models into EnergyPlus, will be based on the following elements, for a swimming pool with a single pool:

As described in D3.3, the implementation of the **Swimming pool thermal balance model** is enabled through the implementation of an **Energy Exchange Calculation EMS Program** and of an **Energy Balance Calculation EMS program**.

The Energy Exchange Calculation EMS Program will carry out the calculation of the different components of the energy exchange between the swimming pool and the swimming pool room, using the model equations described in D3.3, as well as, the instantaneous values of all the environmental variables of the swimming pool room (temperature and humidity) and the temperature of the swimming pool.

The program will be called and executed at the end of each simulation time step, in order to calculate all the energy exchange components that will impact the thermal balance of the swimming pool room in the next calculation time step.

Taking advantage of the calculations performed by the **Energy Exchange Calculation Program, the Energy Balance Calculation program** will populate the value for the ongoing time step of the internal gain objects used to transfer to

the swimming pool room zone thermal balance, the impact of each of the components of the energy exchange between the swimming pool and the swimming pool room.

This program is called and executed at the beginning of each simulation time step, and will use the results calculated by the **Energy Exchange Calculation Program** for the precedent time step.

More specifically the implementation of the **Swimming pool Room thermal balance model** requires the integration of the following classes on the IDF file:

- An instance of the **EnergyManagementSystem:Program** to define the **Energy Exchange Calculation EMS Program**.
- An instance of the **EnergyManagementSystem:Program** to define the **Energy Balance Calculation EMS program**.
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of the **Energy Exchange Calculation EMS Program**
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of **Energy Balance Calculation EMS program**.
- An instance of the **OtherEquipment** class to integrate the impact of the sensible gains associated to the pool on the thermal balance of the swimming pool room.
- An instance of the **OtherEquipment** class to integrate the impact of the latent gains associated to the pool on the thermal balance of the swimming pool room.
- An instance of the **OtherEquipment** class to integrate the impact of the radiant gains associated to the pool on the thermal balance of the swimming pool room.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the temperature of the pool water.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the humidity of the swimming pool room.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the air dry bulb temperature of the swimming pool room.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the mean radiant temperature of the swimming pool room.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the number of pool users.
- An instance of the **EnergyManagementSystem:Actuator** class to set the value of the **OtherEquipment** class instance used to integrate the

impact on the thermal balance of the swimming pool room of the sensible heat gains of the pool.

- An instance of the **EnergyManagementSystem:Actuator** class to set the value of the **OtherEquipment** class instance used to integrate the impact on the thermal balance of the swimming pool room of the latent heat gains of the pool.
- An instance of the **EnergyManagementSystem:Actuator** class to set the value of the **OtherEquipment** class instance used to integrate the impact on the thermal balance of the swimming pool room of the radiant heat gains of the pool.

On the other hand, regarding the implementation of **the swimming pool thermal load calculation program,** as was introduced in D.3.3 it is carried out through the definition of the following EMS programs:

- **The pre-heated makeup water temperature Calculation Program**
- **The swimming pool thermal load calculation program**.

The pre-heated makeup water temperature Calculation Program calculates the temperature of pre-heated makeup water, using the model equations described in D3.3, as well as the following variable values.

- The swimming pool water temperature at the end of the previous simulation time step.
- Mains water temperature at the beginning of the simulation time step.
- Makeup water mass flow rate scheduled for the current simulation time step.

This program is called and executed at the beginning of each simulation time step, in order to calculate the value of the pre-heated makeup water temperature to be used in the current simulation time step.

The swimming pool thermal load calculation program, using the mathematical equations described in D3.3, performs the calculation of the makeup water heating energy demand and the energy loss through the walls and the floor of the swimming pool. In this calculation the following variable will be necessary.

- The air temperature of the thermal zone below the swimming pool at the end of the previous time step.
- The Swimming pool water temperature and the end of the previous time step.
- Mains water temperature at the beginning of the current simulation time step.
- The makeup water mass flow rate scheduled for the current simulation time step.

The rest of components (evaporation, convection and radiation losses) will be already available from the **Energy Exchange Calculation Program** of **the swimming pool room thermal balance model**.

Additionally, the **swimming pool thermal load calculation program** will use the values calculated for the current time step, to populate the objects used to transfer the impact of the calculated swimming pool thermal load to the heating plant of the building.

This program will be called and executed at the beginning of each simulation time step after the execution of **The pre-heated makeup water temperature Calculation Program**.

From a numerical point of view, this is equivalent to a loose co-simulation approach, and therefore, in order ensure high accuracy and minimize the existing time-lagged data a very short simulation time step will be necessary.

More specifically the implementation of **The Swimming pool water heating and makeup water system demand model** requires the integration of the following classes on the IDF file:

- An instance of the **EnergyManagementSystem:Program** to define the **The pre-heated makeup water temperature Calculation Program**.
- An instance of the **EnergyManagementSystem:Program** to define the **The swimming pool thermal load calculation program**.
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of **The pre-heated makeup water temperature Calculation Program.**
- An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of **The swimming pool thermal load calculation program.**
- An instance of the **LoadProfile:Plant** class to transfer the thermal load associated to the renovation and heating system of the pool to the heating plant of the complex.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the make water flow.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the temperature of the makeup water flow.

- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the temperature of the thermal zone located below the pool.
- An instance of the **EnergyManagementSystem:Sensor** class to capture the value of the temperature of the pool water.
- An instance of the **EnergyManagementSystem:Actuator** class to set thermal load value of the defined **LoadProfile:Plant** class instance.
- An instance of the **EnergyManagementSystem:Actuator** class to populate water flow rate value of the defined **LoadProfile:Plant** class instance.
- An instance of the **EnergyManagementSystem:Actuator** class to set the value of the makeup water temperature after the preheating effect produced by the heat recovery system.

As described in D3.3, the rest of the DER systems (thermal loads, electric loads and distributed generation systems) present in the pilots will be modeled using the standard models already available in EnergyPlus.

The DER systems existing in each of the pilots, are described in detail in specific sections included in Chapter 9.

7 Integration of calibrated thermal modelling parameters

Besides the integration into EnergyPlus of the new models developed in Tasks 3.3, 3.4 and 3.5, it is also necessary to identify the most suitable procedures, for incorporating in the building energy performance simulation model building contextual parameters, the information provided by the **Behavioural Profiling Engine** (as presented in section 5) and the results of the calibration process of the models to be provided by **the building DAE**.

Along with the data provided by additional monitoring equipment (building BMS, etc.), the information coming from the static BIM models, regarding occupants' behaviour, activity description and thermal modelling can be updated considering the actual information about the building. Among the BIM input parameters to be updated, we are highlighting the following:

- Thermal modelling improvement:
    - Thermal envelope thermal and optical properties
    - Infiltration values.
    - Capacity of generation, distribution and emission systems.
    - Performance of generation, distribution and emission equipment.
    - Presence/absence of natural ventilation.
    - Etc.
- Activity description:
    - Equipment internal gains.
    - Lighting internal gains.
    - Metabolic rates.
    - Etc.
- Occupants behaviour:
    - Activity profiles.

All the required information and the most suitable ways to integrate this information into the standard models of EnergyPlus will be studied in parallel with the final selection of building zones in WP7 and the development of the BEPS component in task 5.1. Though, an overview of the modelling incorporation as part of the Local and Global Energy Performance Modelling, is presented in the next section. Here, an indicative example is provided mainly on the way to improve of the thermal modelling data (initially defined as part of the static BIM models) by defining the procedure to incorporate the actual data streams to the relevant standard EnergyPlus thermal models (information flow within EnergyPlus).

In relation to this specific issue, the following procedure is proposed.

- Definition of a **Thermal Modelling Program** that will receive the values of the key thermal parameters of the model (infiltration, etc.) that enable the minimization of the gap between simulated and actual building behaviour,

and will perform all the required modifications on the relevant models of the EnergyPlus buildings to update the information coming from the static BIM models.

- The following EnergyPlus class instances have been identified as necessary to implement such program.
    - An instance of the **EnergyManagementSystem:Program** to define the **Thermal Modelling Program** (to be called at the beginning of each simulation time step).
    - An instance of the **EnergyManagementSystem:ProgramCallingManager** to define the calling point of **Thermal Modelling Program.**
    - The number of instances of the **EnergyManagementSystem:Actuator** class necessary to update with actual values the key thermal modelling parameters of the EnergyPlus model.

The details about the interaction between the **BEPS** and the rest of the modules of the platform that will update the building context parameters (Behavioural Profiling Engine about occupancy profiling as presented in Section 4 and Building DAE about calibration of building contextual parameters) and the required information flows within the EnergyPlus models (related to occupancy behaviour and activity description) are presented in task 5.1, along with the development of the overall **BEPS** engine. In any case, if necessary according to the final outcomes of D5.1, the procedure described here will be updated, as required.

8 Weather Data File Generation Engine

8.1 Introduction

In this chapter a description of the **Weather Data File Generation Engine** is provided.

This component provides the following functionalities, necessary to enable **BEPS Engine** operation:

- Generation of the EnergyPlus weather data files necessary for the building model calibration process, to be produced from the historical weather data available from a local weather station or weather forecast services.
- Generation of the EnergyPlus weather data files necessary for building level prediction generation, to be produced using data collected from weather forecast services.

An important context for the successful simulation of the energy performance of buildings is given by the climate and actual weather that surrounds the given structures. Energy plus already contains a separate manager that is used to provide this data to the engine. Within the project the goal is to provide more accurate simulation results, and the ability to use current information pertaining to the pilot sites is part of the strategy to improve the results. To that end a number of sources regarding this information must be identified, and these sources must then be adapted in such a way that they can be used in the simulator. This is what the weather data file generation engine is for.

The implemented solution should be capable of using weather forecast data as well as historical information, and the user should be able to choose.

8.2 Current data file contents

The weathermanager that is part of the energy plus simulator uses a so-called comma separated file format. This basically puts all the parameters read on a line each field delimited by a comma. A CR closes the line. This is a format used frequently in older programs using 3d generation languages.

What follows is a sample of the timeseries data incorporated in a WPE file:

```
1994,2,22,18,60,A7A7E8E8*0G9G9G9I9I9I9I9A7A7A7A7A7A7*0E8*0*0,1.5,0.7,94,100000,14,1398,286,1,0,1,1
00,0,100,30,80,3.6,10,9,2.0,90,0,909999999,0,0.0940,2,88,0.000,0.0,0.0

1994,2,22,19,60,A7A7E8E8*0?9?9?9?9?9?9?9A7A7A7A7A7A7*0E8*0*0,1.4,0.9,96,100100,0,1398,294,0,0,0,0,0
,0,0,80,3.6,10,10,2.0,90,0,919999999,0,0.0940,2,88,0.000,0.0,0.0

1994,2,22,20,60,A7A7E8E8*0?9?9?9?9?9?9?9A7A7A7A7A7A7*0E8*0*0,1.3,0.5,94,100100,0,1398,293,0,0,0,0,0
,0,0,80,4.1,10,10,2.5,90,0,929999999,0,0.0940,2,88,0.000,0.0,0.0

1994,2,22,21,60,A7A7E8E8*0?9?9?9?9?9?9?9A7A7A7A7A7A7*0E8*0*0,1.3,0.5,94,100000,0,1398,293,0,0,0,0,0
,0,0,80,4.6,10,10,2.5,120,0,909999999,0,0.0940,2,88,0.000,0.0,0.0
```

It is preceded by a general header describing amongst others the location. For a detailed description of its contents the reader is referred to the Energy Plus documentation available online, and particularly to : Auxiliary Programs.pdf

Most of today's information sources use file formats that at least contain more dictionary type information. The most common format encountered is XML. This type of format is well suited to the internet, both in presentation and in cross-platform use. For those sources providing XML or an XML like information format it is convenient to store the information in a database and use an export script to funnel this information to the simulator.

A limitation lies in the granularity of available information and the associated cost. Most data is offered as monthly averages, or at best on a daily scale. Better data can be obtained but requires a subscription . In most cases (even the free ones) offer an API to access the data. The cost of these are generally around 100$ a month.

8.3 Climate and weather sources

Options

https://www.wunderground.com (Weather.com,wunderground.com,google.com)

Free current weather (500 per day), history on request

https://www.apixu.com/api.aspx (Worldweatheronline.com)

Free current weather (5000 calls per month),history free on hourlly basis.

For our purpose we expect the second option to be the most flexible. According to the documentation of Energy Plus the software uses automatic interpolation between the samples of the timeseries to morph the different values. This source can provide us with hourly current data without cost, and can handle a more intense series of requests if needed for a fee.

8.4 Solution architecture

Using the available API's the engine will be polling the service based on a set interval and location and provide the option to generate a WPE format file covering the requested period.

It is a choice to continuously provide this service to all MOEEBIUS users or leave the exploitation of the service to the individual partners. This decision does not impact the chosen technical solution.

The chosen service provider offers the data in a number of diferent forms, XML and JSON amongst them and also provides support in the form of a number of

libraries suitable for the most prominent languages used. For our purpose the JSON format is probably the best suited of them.

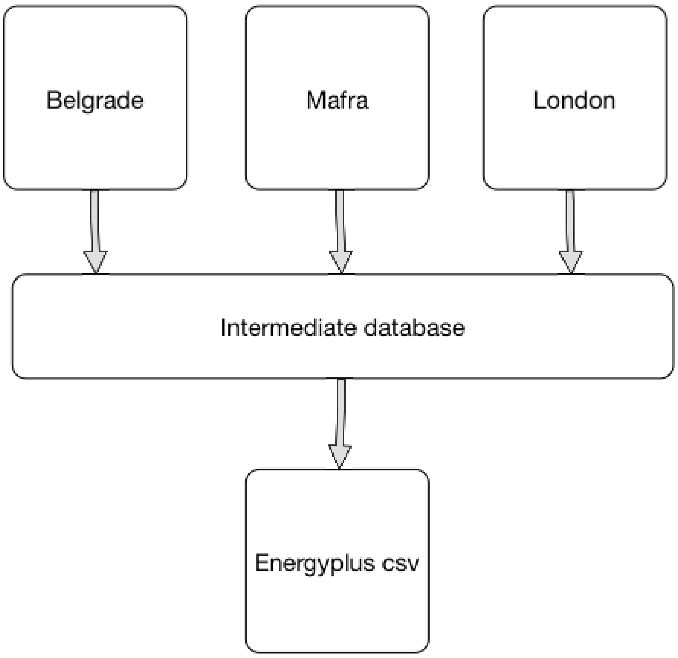


Figure 5 Architecture of the weather data file generation engine

As you can see we are gathering data for three pilot sites, thus requiring all three locations polled for weather data. We can split this over the pilot sites themselves, thus providing 3 instances of the service. The interval for polling the data can be freely chosen within the bounds of the service level contracted. Once per hour, but also once per minute.

This model also allows for easy extension, and in a later stage adoption of the MOEEBIUS tools by other locations than the pilot sites. The use of a local service per pilot site would complicate this. The open nature of the WPE format does not preclude other services from offering the same type of support for Energy Plus.

It is important to guard against accessing incomplete records, thus it makes sense to choose the database from a set offering these mechanics. The service will provide both predictive data and current and historic data but always from the perspective of a single timestamp. The nature of the interface with Energy Plus makes this inevitable. When the file has been generated it is used by the simulator and no longer accessible, once the simulation run has started.

8.5 Adaptation and shortcomings

It is important to understand that the WPE format support a wide variety of data to be included, of which not all can be easily obtained from these services, especially not without accessing the (potentially costly) history services.

Energy Plus has always had to cope with situations like these. In the Energy Plus documentation a special chapter about missing weather data is included. This chapter stimulates a value for those fields signalling to the software that no specific data for this particular purpose is available, thus enabling the software to use an appropriate general model for that.

An example of a field in this category is : nr. of days since last snow. The manual stipulates a value of 88 to signal missing data, a value that can also be observed in the sample of WPE data included above.

The data coming from the sources mentioned above do not cover all requested features. First we show the available data for both:

Wunderground.com:

estimated
station_id
observation_time
observation_time_rfc822
observation_epoch
local_time_rfc822
local_epoch
local_tz_short
local_tz_long
local_tz_offset
weather
temperature_string
temp_f
temp_c
relative_humidity
wind_string
wind_dir
wind_degrees
wind_mph
wind_gust_mph
wind_kph
wind_gust_kph
pressure_mb

pressure_in
pressure_trend
dewpoint_string
dewpoint_f
dewpoint_c
heat_index_string
heat_index_f
heat_index_c
windchill_string
windchill_f
windchill_c
feelslike_string
feelslike_f
feelslike_c
visibility_mi
visibility_km
solarradiation
UV
precip_1hr_string
precip_1hr_in
precip_1hr_metric
precip_today_string
precip_today_in
precip_today_metric
icon
icon_url
forecast_url
history_url
ob_url

Table 3Wunderground.com available data

https://www.apixu.com:

Field	Data Type	Description
time_epoch	int	Time as epoch
time	string	Date and time
temp_c	decimal	Temperature in celsius
temp_f	decimal	Temperature in fahrenheit
condition:text	string	Weather condition text

condition:icon	string	Weather condition icon
condition:code	int	Temperature in code
wind_mph	decimal	Maximum wind speed in miles per hour
wind_kph	decimal	Maximum wind speed in kilometer per hour
wind_degree	int	Wind direction in degrees
wind_dir	string	Wind direction as 16 point compass. e.g.: NSW
pressure_mb	decimal	Pressure in millibars
pressure_in	decimal	Pressure in inches
precip_mm	decimal	Precipitation amount in millimeters
precip_in	decimal	Precipitation amount in inches
humidity	int	Humidity as percentage
cloud	int	Cloud cover as percentage
feelslike_c	decimal	Feels like temperature as celcius
feelslike_f	decimal	Feels like temperature as fahrenheit
windchill_c	decimal	Windchill temperature in celcius

windchill_f	decimal	Windchill temperature in fahrenheit
heatindex_c	decimal	Heat index in celcius
heatindex_f	decimal	Heat index in fahrenheit
dewpoint_c	decimal	Dew point in celcius
dewpoint_f	decimal	Dew point in fahrenheit
will_it_rain	int	1 = Yes 0 = No Will it will rain or not
will_it_snow	int	1 = Yes 0 = No Will it snow or not
is_day	int	1 = Yes 0 = No Whether to show day condition icon or night icon
vis_km	decimal	Visibility in kilometer
vis_miles	decimal	Visibility in miles

Table 4 Apixu.com available data

The most important field not available in any of the services studied is luminance. Most related fields (cloud %, sunshine, etc.) are. The luminance data is also missing in most of the weather files offered by Energy Plus, which makes assessing the importance of this field difficult. It might need attention in the future.

9 Pilot model development

Taking advantage of the information gathered in Task 7.2, in this section the process followed to develop the building and district level models of the pilots has been described.

In the case of the British and of the Portuguese pilots it was be necessary to model all the buildings of the districts. However, in the case of the Serbian pilot, taking into account the high number of buildings connected to the district heating system, modelling of all the buildings with a sustainable effort compatible with the resources available in the frame of the project was not possible. Therefore, some representative building types of the district have been selected and their EnergyPlus models defined.

The selection of the representative buildings takes into account the building type (residential, office, educative), the architectonic characteristics, and the rest of the boundary conditions that might have a relevant impact on the energy demand of the buildings (e.g. orientation, shading by other buildings, occupancy level, user characteristics, etc.).

The total engagement of building owners and/or managers has been a challenge to be overcome in the project. The final selection of buildings to be modelled in the three pilot sites has been performed taking into account the requirements defined in previous deliverables, as the business models to be validated defined in D2.2. This selection is listed in Table 5.

Pilot site	Building types
Mafra (Portugal)	1 Educational&sport complex (school, sport hall, swimming pool) 1 Administrative building (Town Hall) 1 Kindergarten
Belgrade (Serbia)	6 Residential blocks (704 dwellings) 1 School 1 Kindergarten
London (UK)	1 Office block 1 Residential complex (3 blocks)

Table 5 Building Energy Models developed in each pilot

For the development of the architectural modelling of the different pilot sites a thorough revision of available information at the different pilot sites was performed as part of T7.2 work. This information consisted mainly in available BIM models, structural and equipment plans from all the sites.

Originally it was planned to receive directly from the pilot sites a basic BIM model for each of them. It was found out that no BIM models from any of the buildings

acting as pilots in MOEEBIUS project were available, and therefore they had to be completely modelled and build using the available data at each of the pilot sites.

The architectural modelling mainly made use of two sources of information from each of the pilot sites: geometrical information and material information. The geometrical information was obtained directly from the pilot site structural plans as part of the work in T7.2. The material characteristic was also gathered as part of Task T7.2 using a template for the collection of the needed data.

It was decided that the geometrical definition of the modelling needed to reflect reality taking into consideration as well that the computational time should remain within certain boundaries. Simulating buildings with the highest amount of detail do take more than a day of simulation sometimes, and the results obtained do not differ significantly from those obtained in a more simplistic model. In this Task for the geometrical definition, all elements having a direct impact on energy consumption were taken into account while at the same time, part of the geometrical plans were adapted in order to ensure a proper computational behaviour of the models.

As part of the material definition work in T3.6 specific families of components were created in order to introduce the exact characteristics of each of the materials present at the pilot sites.

9.1 MOEEBIUS District Heating and DER Model overview

The **MOEEBIUS District Heating and DER Model** was already described in D3.3. However, to contribute to the completeness of this document and to facilitate the understanding of the process followed to define pilot models in the following lines a summary of the **MOEEBIUS District Heating and DER Model** capable to address building and district level dynamics and distributed energy production, is provided

None of the currently existing modelling and simulation tools is completely suitable to provide all the required modelling and simulation capabilities, and therefore, a co-simulation procedure has been designed as the most suitable approach to produce the integrated district model, where:

- Modelling of the electric and thermal DER-systems deployed inside the physical boundaries of the buildings, will be integrated into the EnergyPlus models of the buildings of the district.
- When necessary, the evaluation of the impact of the production of the DER systems (PV and wind turbines) existing outside the physical boundaries of the buildings of the district, will be evaluated through a statistical modelling approach.
- District heating and thermal DER modelling, will be addressed in Modelica according to a sub-system model based architecture, taking advantage of

the subsystem models developed for generation, storage, and load modelling and integrated in the new MOEEBIUS Modelica library.

Regarding Modelica and EnergyPlus model integration, the interface between the district heating system model and the building models was set in the building thermal substations of the connected buildings. With this co-simulation arrangement the value of the operational variables at the primary and secondary side of the thermal substation are exchanged between the EnergyPlus and the Modelica models, with a calculation time step time resolution.

Different possibilities and procedures to implement the co-simulation arrangement were studied, but considering the existing constraints finally, an offline sequential co-simulation approach was selected.

According to this approach EnergyPlus building models will be simulated for the complete prediction period and the obtained results (heat request profiles and inlet/outlet temperatures on the secondary side of building heating substations), used as input of the district heating model for the complete prediction period.

In other words, buildings will be integrated in the thermal network model as nodes (building heating substations) with a variable energy request profile, distributed according to the topology of the district heating system.

The EnergyPlus building models will be simulated assuming that the energy delivery from the district heating system takes place at nominal conditions of temperature and pressure, which is a realistic assumption for a correctly operated district heating system.

9.2 Portuguese pilot model development

One of the complexities found out when performing the modelling of the Portuguese pilots was related to the fact that only scanned copies of the building plans were obtained from the buildings, since no dwg. files from the original architects were available. This situation required from longer time than anticipated to introduce the geometrical data into the models.

In this section the modeling criteria followed to produce the building and district models of the Portuguese pilot are described in full detail

9.2.1 Educational complex.

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.2.1.1 Architectural modelling specification

For the architectural modelling of the educational complex in Portugal, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following structural plans were used for the definition of the models:

- Cross section
- Elevation 1
- Elevation 2
- Floor 0
- Floor 1

Material and component definition

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template from the Nursery is presented below:

Construction Elements		Layer1 - External layer		Layer2		Layer3		Layer4		Layer5		Layer6	
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]
1.1-1	External Wall 1 - Pe1	Plaster	2,5	Brick	110	Extruded polystyrene	40	Brick	110	Plaster	1,5		
1.1-2	External Wall 2 - Pe2	Plaster	2,5	Brick	150	Air	10	Extruded polystyrene	40	Brick	110	Plaster	1,5
1.1-3	External Wall 3 - Pe3	Plaster	2,5	Brick	150	Air	60	Extruded polystyrene	40	Brick	150	Plaster	1,5
1.2	Below Grade Walls												
1.3-1	Internal Partitions 1 - Pi1	Plaster	2,5	Brick	110	Extruded polystyrene	40	Brick	110	Plaster	1,5		
1.3-2	Internal Partitions 2 - Pi2	Plaster	2	Brick	110	Plaster	2						
1.3-3	Internal Partitions 3 - Pi3	Plaster	2	Brick	150	Plaster	2						
1.3-4	Internal Partitions 4 - Pi4	Plaster	2	Brick	220	Plaster	2						
1.3-5	Internal Partitions 5 - Pi5	Plaster	2	Brick	70	Plaster	2						
1.3-6	Internal Partitions 6 - Pi6	Plaster	2,5	Brick	150	Air	60	Extruded polystyrene	40	Brick	150	Plaster	1,5
1.4	Semi-exposed Walls												
ROOFS													
2.1-A	Pitched Roof (occupied) - CobA	Metal sheet	0,5	Expanded polyurethane	40	Metal sheet	0,5						
2.2-B	Pitched Roof (unoccupied) - CobB	Metal sheet	0,5	Expanded polyurethane	40	Metal sheet	0,5	Air		Waffle slab w/ light concrete	320		
2.3-C	Flat Roof - CobC	Gravel 16/32	100	Extruded polystyrene	35	Waterproof insulation	2	LECA concrete	100	Waffle slab w/ light concrete	480		
2.3-D	Flat Roof - CobD	Ceramic tile	5	Extruded polystyrene	35	Waterproof insulation	2	LECA concrete	100	Waffle slab w/ light concrete	480		
2.3-E	Flat Roof - CobE	Gravel 16/32	100	Extruded polystyrene	35	Waterproof insulation	2	LECA concrete	100	Reinforced concrete slab	200		
2.3-F	Flat Roof - CobF	Gravel 16/32	100	Extruded polystyrene	35	Waterproof insulation	2	LECA concrete	100	Waffle slab w/ light concrete	320		
2.3-G	Flat Roof - CobG	Ceramic tile	5	Extruded polystyrene	35	Waterproof insulation	2	LECA concrete	100	Reinforced concrete slab	200		
FLOORS/CEILINGS													
3.1-A	Ground Floor A	Tout-venant	260	Floor screed	4	Waterproof insulation	4	Reinforced concrete	140				
3.1-B	Ground Floor B	Tout-venant	300	Floor screed	4	Waterproof insulation	4	Reinforced concrete	100				
3.2	External Floor												
3.3-A	Internal Floor A	Waffle slab w/ light concrete	320										
3.3-B	Internal Floor B	Reinforced concrete slab	200										
3.4	Semi-exposed Floor												
3.5	Semi-exposed Ceiling												
OPENINGS													
		Composition [mm]	Solar Factor [%]	Frame Material	U window								
4.1	**External Windows**												
	Je1, Je4, Je5	4|12|6	0,75	Aluminium	3,2								
	Je2, Je3, Je6, Je7	4|12|4	0,75	Aluminium	4								
	Skylights	Alveolate polycarbonate sheet	0,86	Mild Steel	6,89/ 4,44								
		Material	Thickness [mm]	Frame Material	U window	Solar Factor [%]							
4.2	**External Doors**	Glass											
	Pe1, Pe2, Pe3, Pe4, Pe5, Pe6, Pe7, Pe8, Pe8.1, Pe10	Double	4|12|4	Aluminium	4	0,75							
	Pe4.1	Double	4|12|6	Aluminium	3,2	0,75							

Please, leave blank the leftover layers and the non-existent construction elements.
Windows Composition example: 4Neutral+6Air+6Neutral+LowE (=4mmExteriorGlassLayerNeutralColor+6mmAir+6mmInteriorGlassNeutralColor+LowECoating)

Table 6 Thermal envelope of the Mafra educational complex

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site.

Below it is presented the pilot modelled compared with a real life picture.

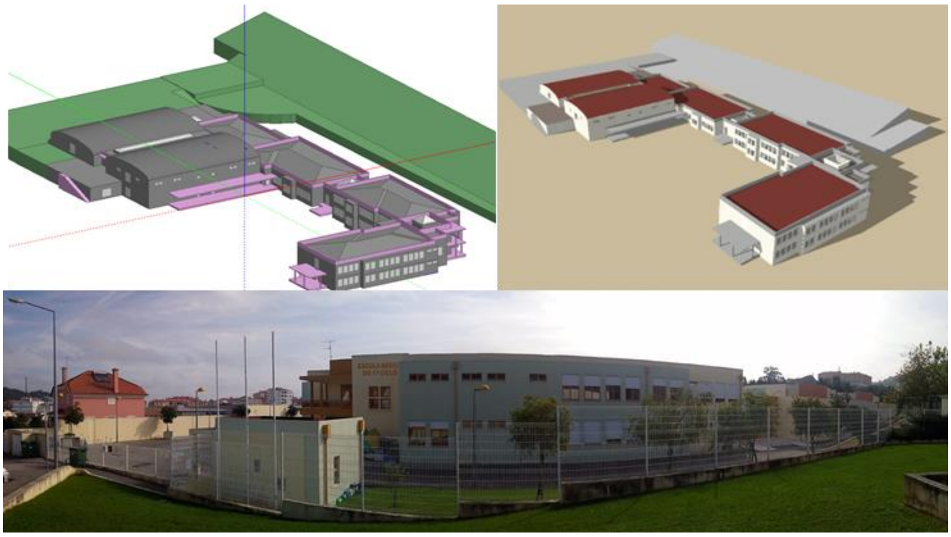


Figure 6 View of the model of the Mafra educational complex

9.2.1.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

More specifically the definition process followed to configure the thermal zones integrated in the model consisted on the following sequence.

- Analysis of the activities existing on the building.
- Identification of the different zone types according to the developed activities.
- Classification/characterization of the zones of the building according to the defined zones types.
- Selection of a zone for each of the identified zone types to be considered directly as thermal zones on the EnergyPlus model (to be monitored in the deployment phase).
- Taking into account, the physical distribution of the zones of the same type within the building, aggregation of the zones of the same type located in adjacent positions and served by the same HVAC system.
- The zones existing at the end of this sequence will be considered the final thermal zones of the building

According to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Rooms with associated occupancy
    - Swimming pool room
    - Multi sports court
    - Gallery for spectators
    - Student locker rooms
    - Swimming pool user locker rooms
    - Classrooms
    - Support classrooms (support spaces for classrooms)
    - Classroom for student with special needs.
    - Dinning hall
    - Administrative premises
    - Teacher room
    - Study room
    - Individual Offices
    - Parent association room
    - Medical room
    - Kitchen and kitchen auxiliary rooms

- Room with no associated occupancy
    - Toilets
    - Corridors and circulation zones
    - Technical rooms
    - Storage rooms

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal air quality setpoints.

After the characterization of the zones of the building, a representative zone has been selected for each of the defined zone types. During the deployment phase of the platform, sensors (NODs and commercial sensors) will be deployed on the selected representative zones to monitor occupancy, thermal comfort, internal air quality and internal gains, to be used by the **Behavioural Profiling Engine** of the MOEEBIUS Platform to produce the actual usage input data (occupancy profiles).

The use description produced for the representative zones, will be used in the model for all the thermal zones of the same type, which will enable to reduce sensor deployment requirements and the input data required to populate the model with information related to the actual and predicted use of the building.

Finally, according to the already described sequence, starting from the characterization of all the zones of the building in relation to the defined room types, the thermal zones to be considered in the EnergyPlus model have been set. In this final step, apart from the room characterization, the HVAC systems serving each zone of the building have been considered. More specifically, the final

thermal zone distribution of the EnergyPlus model is obtained after merging all the zones of the same type that are, additionally, served by the same HVAC system and are physically located next to each other. The following pictures displays the thermal zones of the Energyplus model of the building.

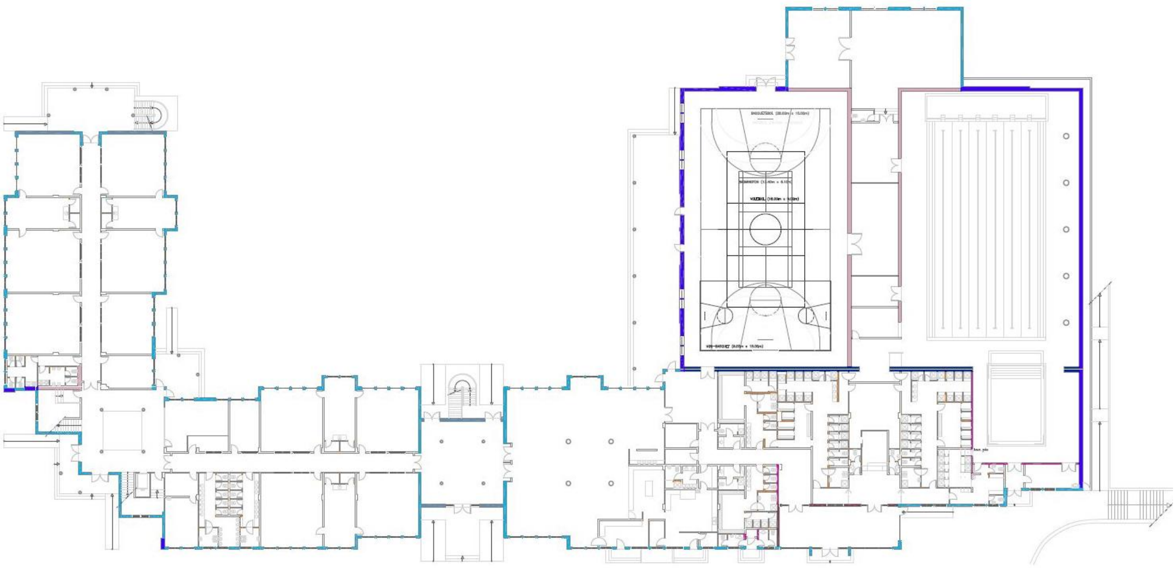


Figure 7 Activity distribution on ground floor (Mafra educational complex)

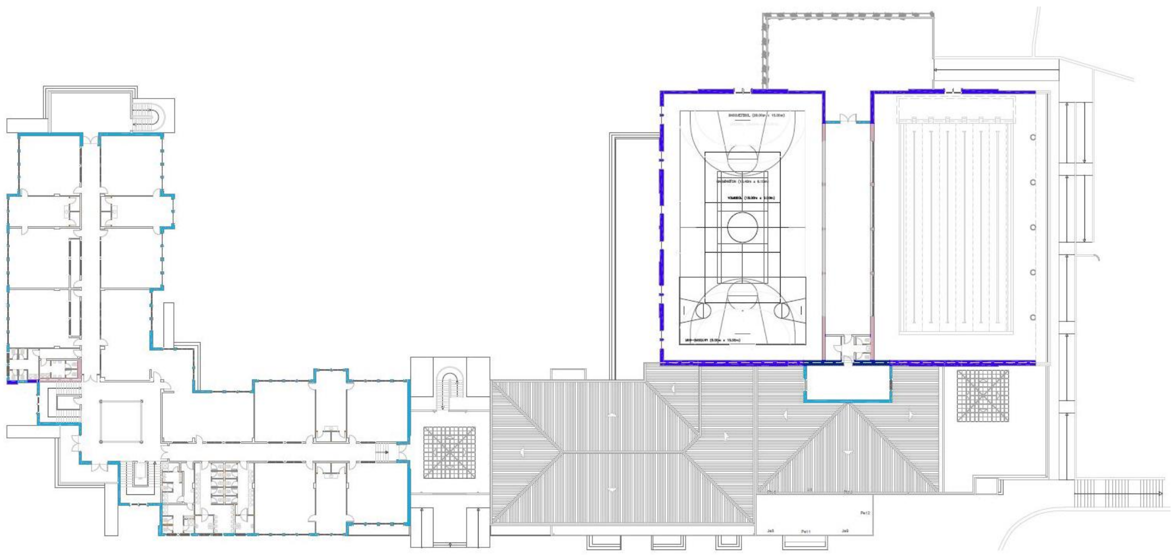


Figure 8 Activity distribution on floor 1 (Mafra educational complex)

Figure 9 Thermal zone definition detail (Locker rooms of the swimming pool. Mafra educational complex)

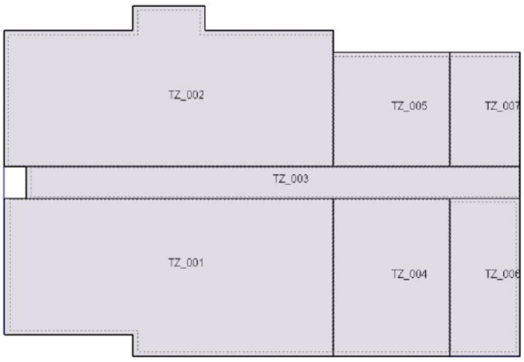


Figure 10 Thermal zone definition detail (classrooms on ground floor. Mafra educational complex)

Figure 11 Thermal zone definition detail (Swimming pool room. Mafra educational complex)

The optimization of the number of the defined thermal zones of the model is a key factor to contribute to reduce the required calculation times. This will be a critical issue during the operational stage of the MOEEBIUS platform.

9.2.1.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main loads present in this building and integrated in the developed EnergyPlus model is included:

- The water renovation and heating system of the swimming pool.
- The humidity control system of the swimming pool room.
- The heating system of the building.
- The domestic hot water production system.
- The mechanical ventilation system.
- The artificial lighting system of the building (indoor and outdoor)
- Small power electrical loads such as computer, IT equipment, etc.
- Thermal and electrical loads of the industrial kitchen.

This educational complex includes a swimming pool room with 2 indoor conditioned pools equipped with a water renovation and heating system that is the biggest single energy consumer of the complex. This system provides the energy necessary to compensate the thermal losses of the pools (evaporation, etc.), and to condition the makeup water (delivered to the pools to ensure satisfactory water quality) up to the setpoint temperature.

Additionally, in order to optimize user comfort, protect the structure of the pool building and to minimize the energy consumption associated to the swimming pool a humidity control system is available. This system keeps the humidity level below the relative humidity setpoint value, and it is formed by a de-humidifying compression cooling air handling unit, that uses the supply air flow as sink of the heat extracted to dehumidify the air of the swimming pool room. The system is completed by an additional hot water heating coil connected to the heating plant of the complex, deployed to provide the additional energy necessary to meet the indoor temperature setpoint of the swimming pool room.

The condensation latent heat recovered from the dehumidifying process is used to preheat the big swimming pool of the complex, through a specific plate heat exchanger. The rest of the energy required to condition swimming pool water and meet the existing swimming pool water temperature setpoint is delivered through a dedicated plate heat exchanger for each pool. In the next figure, the heating system of the big pool of the complex is displayed.

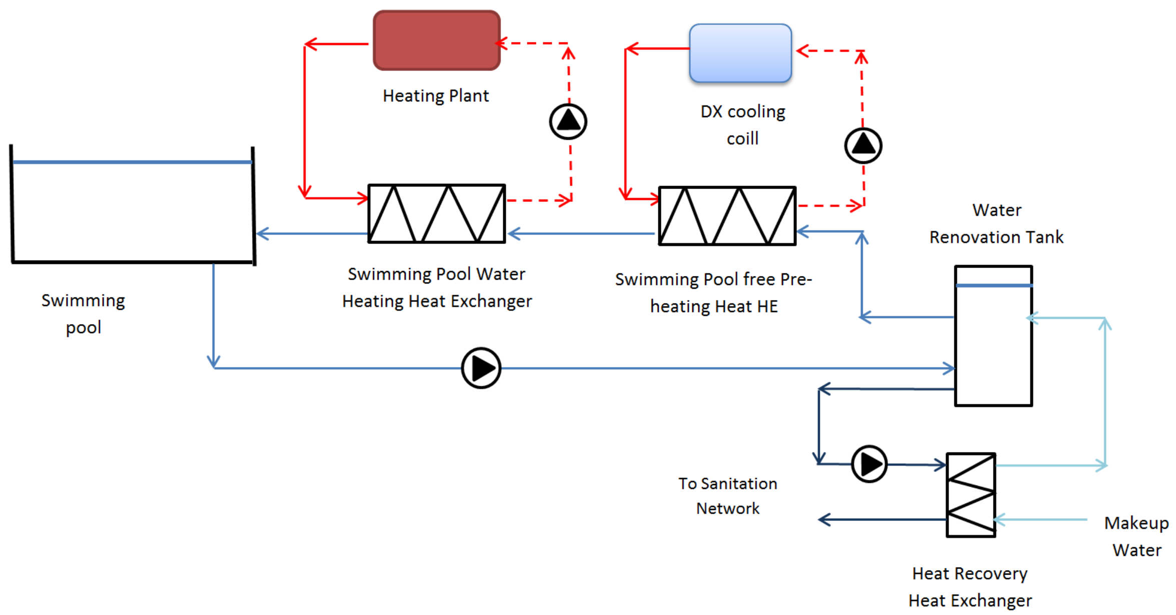


Figure 12 Heating system of the big swimming pool of the complex

The heating plant of the complex produces all the heat energy required by the complex (with the exception of the energy provided by the humidity control system of the SP room), and it is formed by 3 boilers deployed inside a dedicated heating plant room. The figure below shows the source side connection of the heating plant to the main manifold of the distribution system. From there the energy is delivered to the thermal loads of the complex through dedicated distribution loops equipped with constant flow rate twin pumps.

Below the existing distribution circuits are summarized.

- The North building hot water distribution system that feeds the hot water radiators of the north building of the complex.
- The south building hot water distribution system that feeds the hot water radiators of the south building of the complex.
- The swimming pool room hot water distribution circuit that supplies the energy requested by the heat exchangers of the pools and by the auxiliary hot water heating coil of the humidity control system of the swimming pool room.
- The distribution loop that feeds the convectors deployed in the multi sports court.

- The distribution circuits connected to the heating coils of the air handling unit deployed in the school locker rooms and in the locker rooms of the swimming pool room.
- Two dedicated distribution circuits connected to domestic hot water production plate heat exchangers. These heat exchangers produce all the DHW requested by the educational complex (locker rooms, toilets, etc.)

With the exception of the swimming pool room, the locker rooms and the multi sports court, the emission subsystem of the building is formed by hot water radiators distributed as necessary all over the building.

The energy delivery to the swimming pool room is solved through the corresponding supply and return duct networks connected to the humidity control system that additionally, provides the required ventilation air for the swimming pool room.

The multi-sports court is heated through wall mounted water convectors formed by a fan and a hot water heating coil. Additionally, the ventilation of the multi sports court is solved by a dedicated exhaust only AHU that creates a depression inside the sports court room that enables air renovation and an adequate level of internal air quality.

As already mentioned, the locker rooms of the educational complex are conditioned through 2 dedicated AHU-s formed by supply and exhaust fans, water heating coils, heat recovery heat exchangers and all the required air dampers (air intake, air exhaust, and heat recovery bypass damper).

Finally, the ventilation system of the building is completed by the exhaust fan systems coupled to duct networks deployed in all the toilets.

Regarding the electric/thermal loads associated to artificial lighting, food preparation/conservation equipment, and office/IT equipment the nominal power included in the data sheets of each equipment, gathered in the frame of Task 7.2, have been used to characterize them. In any case these values will be calibrated after the deployment of the MOEEBIUS platform in the pilot to capture their actual nominal power.

Regarding the impact of user behaviour on these loads, as a starting point, some static schedules provided by building owners have been considered. In any case, after the implementation of the MOEEBIUS platform in the pilot, actual user behaviour impact on these loads will be provided to the **BEPS** by the **Demand and Flexibility Engine** to update the model of the building accordingly.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems are present on this building.

The modelling criteria considered in the integration of all the DER-s described in the precedent paragraphs into the EnergyPlus model of this building will enable an accurate evaluation of the following dynamics:

- The performance of the boilers.
- The performance of the compression cooling cycle of the humidity control system of the swimming pool room.

- The energy recovered by the humidity control system to be used for pool make up water preheating.
- The performance and behaviour of the plate heat exchangers of the heating system of the pools, if necessary including the impact of energy recovery.
- The performance and behaviour of the DHW production plate heat exchangers.
- Thanks to the accurate modelling of the topology of the distribution subsystem, the thermal losses and water temperature distribution over the distribution loops.
- The energy delivery from the emission subsystem (hot water radiators, and AHU heating coils).
- The performance and behaviour of all the pumping equipment.
- The performance and behaviour of all the components of the AHU-s (fans, heating coils, dampers, heat recovery heat exchanger)
- The performance and behaviour of the auxiliary exhaust ventilation systems.
- The performance and behaviour of the DHW production system.
- The performance and behaviour of the artificial lighting system and its impact on zone thermal balance.
- The energy consumption over time due to electric loads related to food preparation and conservation equipment and their impact on zone thermal balance.
- The energy consumption over time due to electric loads related to office and IT equipment and their impact on zone thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the building.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystems of the buildings.

In summary, the EnergyPlus model of this building includes a detailed modelling of all the DER-s present in the building and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables (performance, consumption, fluid temperatures and flow rates, etc.) of all the systems and equipment existing on the building.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system and the pool water renovation

and heating system, reproducing the typology and topology of the actually deployed systems.

9.2.1.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance
The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
Energy Exchange Calculation Program (one per swimming pool)	Calculation of the thermal loads produced by each swimming pool that have an impact on the thermal balance of the swimming pool room
Energy Balance Calculation program	Value population of the internal gain objects that reproduce the impact of the swimming pool thermal gains on the thermal balance of the swimming pool room
The pre-heated makeup water temperature Calculation Program (one per swimming pool)	Calculation of the impact on the makeup water temperature of the heat recovery system
The swimming pool thermal load calculation program (one per swimming pool)	Integration of the total thermal load of each swimming pool into the heating plant of the building
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU
Humidity control HR calculation Program	Swimming pool room humidity control system modelling
Humidity control condensation latent heat calculation program	Swimming pool room humidity control system modelling
DX coil outlet temperature calculation Program	Swimming pool room humidity control system modelling
Singular thermal/electric loads calculation program (one per singular thermal/electric load))	Singular thermal/electric load modelling

Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 7 Summary of the EMS programs integrated into the EnergyPlus model of the Mafra educational complex

9.2.2 Nursery building

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.2.2.1 Architectural modelling specification

For the architectural modelling of the nursery building in Portugal, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following structural plans were used for the definition of the models:

- Floor 1
- Floor 2
- JI+VP+ALCADOS+6
- JI+VP+ALCADOS+7
- JI+VP+CORTES+5

Material and component definition

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template from the Nursery is presented below:

Construction Elements		Layer1 - External layer		Layer2		Layer3		Layer4		Layer5	
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]
1.1	External Wall	Plaster	2,5	Brick	150	Extruded polystyrene	40	Brick	70	Plaster	2
1.2	Below Grade Walls										
1.3	Internal Partitions	Plaster	2	Brick	110	Plaster	2				
1.4	Semi-exposed Walls										
ROOFS											
2.1	Pitched Roof (occupied)										
2.2	Pitched Roof (unoccupied)										
2.3	Flat Roof	Gravel 16/32	100	Extruded polystyrene	40	Waterproof insulation	2	LECA concrete	100		
FLOORS/CEILINGS											
3.1	Ground Floor	Rockfill	200	Reinforced concrete rigging	100						
3.2	External Floor										
3.3	Internal Floor	Reinforced concrete	150								
3.4	Semi-exposed Floor										
3.5	Semi-exposed Ceiling										
OPENINGS											
		Composition [mm]	Solar Factor [%]	Frame Material	U window						
4.1	**External Windows**			Aluminium							
	Je 1, Je6		0,76		6,2						
	Je2		0,79		6,2						
	Je3, Je4, Je5, Je7, Je8, Je9, Je10, Je11		0,76		6,2						
	Je12 (skylight)		0,79		7,89/ 4,84						
		Material	Thickness [mm]	Frame Material	U window	Solar Factor [%]					
4.2	**External Doors**	Glass		Aluminium							
	Pe 1, Pe 3	Simple	8		6,2	0,76					
	Pe 2	Simple	8		6,2	0,79					
	Pe 4	Double	6|12|6		3,3	0,56					

Please, leave blank the leftover layers and the non-existent construction elements.

Windows Composition example: 4Neutral+6Air+6Neutral+LowE (=4mmExteriorGlassLayerNeutralColor+6mmAir+6mmInteriorGlassNeutralColor+LowECoating)

Table 8 Thermal envelope of the Mafra Nursery building

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site

Below it is presented the pilot modelled compared with a real life picture.

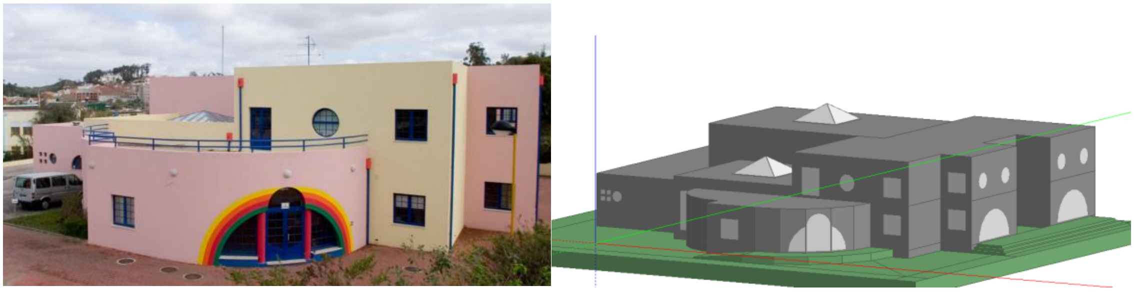


Figure 13 View of the simulation model of the Mafra kindergarten

9.2.2.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

More specifically the definition process followed to configure the thermal zones integrated in the model consisted on the following sequence.

- Analysis of the activities existing on the building.
- Identification of the different zone types according to the developed activities.
- Classification/characterization of the zones of the building according to the defined types.

- Selection of a representative zone for each of the identified zone types (to be monitored in the deployment phase)..
- Aggregation of the zones of the same type located in adjacent positions and served by the same HVAC system.
- The zones existing at the end of this sequence are considered the final thermal zones of the building

According to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Rooms with associated occupancy
  - Class rooms.
  - Activity rooms (including a recreation room)
  - Multipurpose room
  - Secretary office
  - Teacher room
  - Library
  - Food preparation rooms.
- Rooms with no associated occupancy.
  - Toilets.
  - Corridors and circulation zones.
  - Technical rooms
  - Storage rooms
  - Laundry service rooms

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal air quality setpoints.

After the characterization of the zones of the building, a representative zone has been selected for each of the defined zone types. During the deployment phase of the platform, sensors will be deployed on the selected representative zones to monitor occupancy, thermal comfort, internal air quality and internal gains, to be used by the **Behavioural Profiling Engine** to produce the actual usage input data. The use description produced for the representative zones, will be used in the model for all the zones of the same type.

Finally, starting from the characterization of all the zones of the building, the thermal zones to be considered in the EnergyPlus model have been set. In this final step, apart from the room characterization, the HVAC systems serving each zone of the building have been considered. More specifically, the final thermal zone distribution of the EnergyPlus model is obtained after merging all the zones of the same type that are, additionally, served by the same HVAC system and are physically located next to each other.

The following pictures display the thermal zones of the EnergyPlus model of the building.

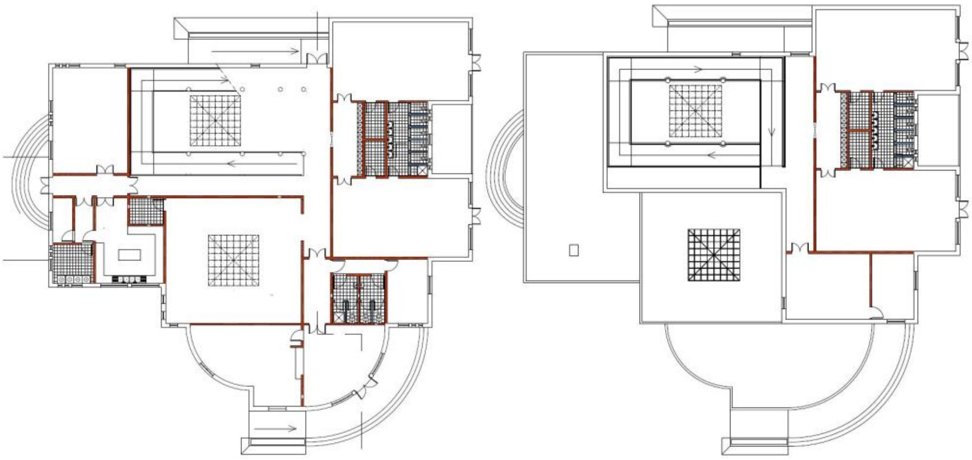


Figure 14 Activity distribution on floors 0 and 1 (Mafra kindergarten)

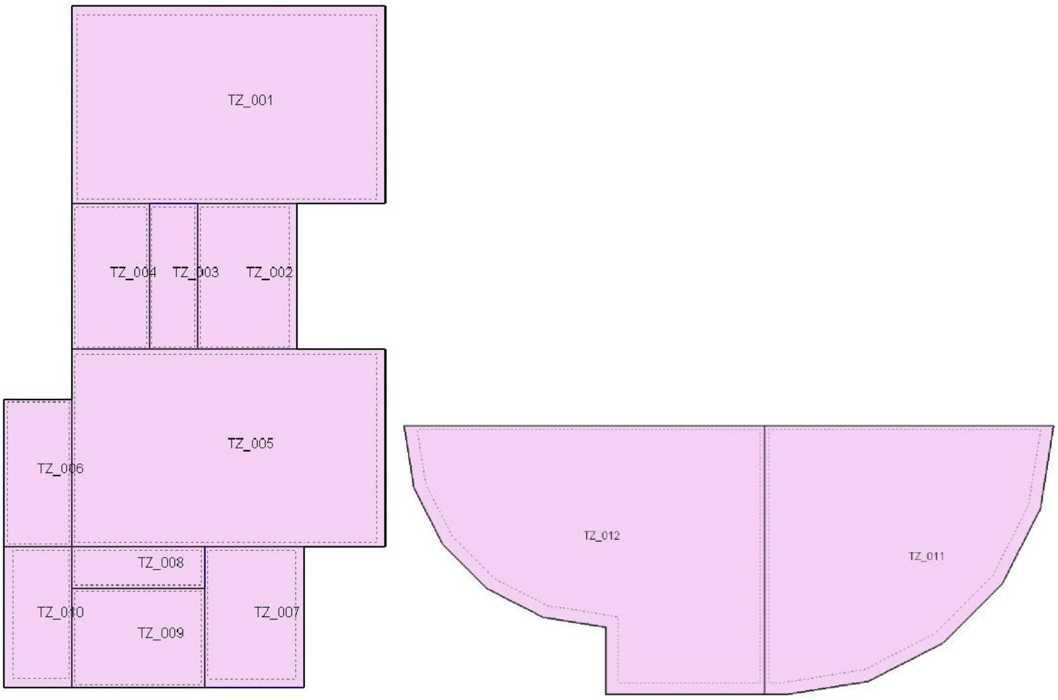


Figure 15 Detail of thermal zone definition (Classrooms Secretary area on ground floor. Mafra kindergarten)

9.2.2.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main loads present in this building and integrated in the developed EnergyPlus model is included:

- The heating and cooling system of the building (5 small capacity split heat pump units).
- The domestic hot water production system.
- The artificial lighting system of the building (indoor and outdoor)
- Small power electrical loads such as computers, IT equipment, etc.
- The thermal and electrical loads of the food preparation/conservation rooms (cooking equipment, fridges, etc.)

The heating and cooling system of the building is formed by 5 small capacity split heat pump units deployed as necessary on the relevant zones.

On the other hand, the DWH demand of the building (toilets and single shower deployed on one of the toilets) is covered by a dedicated domestic electric water heater with a capacity of 200 litres.

The ventilation system of the building is formed by the exhaust systems of the toilets and the exhaust hood deployed on the food preparation room to evacuate the fumes produced by cooking equipment. The ventilation of the rest of the zones of the building takes place through natural ventilation.

Regarding the electric/thermal loads associated to artificial lighting, food preparation/conservation equipment, and office/IT equipment the nominal power included in the data sheets of each equipment, gathered in the frame of Task 7.2, have been used to characterize them. In any case these values will be calibrated after the deployment of the MOEEBIUS platform in the pilot to capture their actual nominal power.

Regarding the impact of user behaviour on these loads, as a starting point, some static schedules provided by building owners have been considered. In any case, after the implementation of the MOEEBIUS platform in the pilot, actual user behaviour impact on these loads will be provided to the **BEPS** by the **Demand and Flexibility Engine** to update the model of the building accordingly.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems are present on this building.

The modelling criteria considered in the integration into the EnergyPlus model of this building, of all the DER-s described in the precedent paragraphs will enable an accurate evaluation of the following dynamics:

- The performance of the small capacity split heat pump units.
- The performance and behaviour of the DHW production system.
- Thanks to the accurate modelling of the topology of the distribution subsystem, the thermal losses over the distribution loops (refrigerant loops of the split heat pump units).
- The performance and behaviour of the auxiliary exhaust ventilation systems of the toilets and of the exhaust hood of the food preparation rooms.
- The performance and behaviour of the artificial lighting system and its impact on zone thermal balance.
- The energy consumption over time due to electric loads related to food preparation and conservation equipment and their impact on zone thermal balance.
- The energy consumption over time due to electric loads related to office and IT equipment and their impact on zone thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the building.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystems of the building.

In summary, the EnergyPlus model of this building includes a detailed modelling of all the DER-s present in the building and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables (performance, consumption, fluid temperatures and flow rates, etc.) of all the systems and equipment existing on the building.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system, reproducing the typology and topology of the actually deployed systems.

9.2.2.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance

The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling
Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 9 Summary of the EMS programs integrated into the EnergyPlus model of the Mafra nursery building

9.2.3 Mafra city council

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.2.3.1 *Architectural modelling specification*

For the architectural modelling of the City Hall from Mafra in Portugal, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following structural plans were used for the definition of the models:

- Floor -1
- Floor 0
- Floor 1

- Floor 2
- CMM – Cross section A-B
- CMM – Cross section C-D
- CMM – Elevation – East façade
- CMM – Elevation – North facade
- CMM – Elevation – South facade
- CMM – Elevation – West facade

<u>Material and component definition</u>

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template from the City Hall is presented below:

Construction Elements		Layer1 - External layer		Layer2		Layer3		Layer4		Layer5	
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]
1.1	External Wall	Plaster	2,5	Brick	150	Air-box	10	Brick	150	Plaster	2,5
1.2	Below Grade Walls										
1.3	Internal Partitions	Plaster	2,5	Brick	150	Plaster	2,5				
1.4	Semi-exposed Walls										
ROOFS											
2.1	Pitched Roof (occupied)										
2.2	Pitched Roof (unoccupied)										
2.3	Flat Roof	Ceramic tile	50	Waterprof insulation	2	Thermal insulation XPS	30	Concrete slab	300	Plaster	2,5
FLOORS/CEILINGS											
3.1	Ground Floor	Concrete slab	300	Thermal insulation XPS	60	Waterprof insulation	2	Ceramic tile	50		
3.2	External Floor										
3.3	Internal Floor	Concrete slab	300	Thermal insulation XPS	60	Waterprof insulation	2	Ceramic tile	50		
3.4	Semi-exposed Floor										
3.5	Semi-exposed Ceiling										
OPENINGS											
		Composition [mm]	Solar Factor [%]	Frame Material	U window						
4.1	**External Windows**										
	Windows	Double: 6|16|6	0,56	Aluminium	3,3						
	Skylights		0,79		7,89/ 4,84						
		Material	Thickness [mm]	Frame Material	U window	Solar Factor [%]					
4.2	**External Doors**	Glass									
	External doors	Double	6|16|6	Aluminium	3,3	0,56					

Please, leave blank the leftover layers and the non-existent construction elements.
Windows Composition example: 4Neutral+6Air+6Neutral+LowE (=4mmExteriorGlassLayerNeutralColor+6mmAir+6mmInteriorGlassNeutralColor+LowECoating)

Table 10 Thermal Envelope of the Mafra kindergarten

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site

Below it is presented the pilot modelled compared with a real life picture.

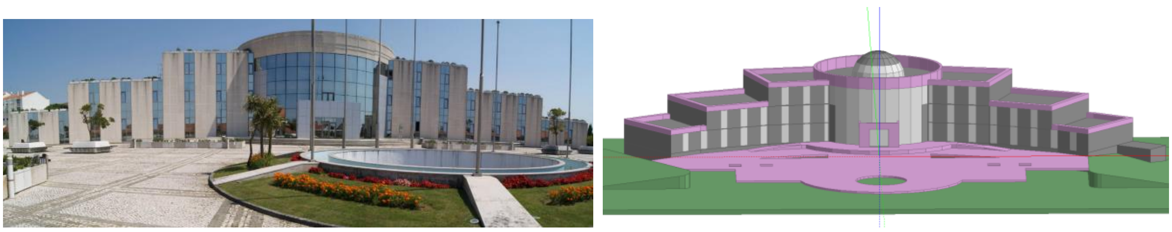


Figure 16 View of the simulation model of the Mafra City Council

9.2.3.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

More specifically the definition process followed to configure the thermal zones integrated in the model consisted on the following sequence.

- Analysis of the activities existing on the building.
- Identification of the different zone types according to the developed activities.
- Classification/characterization of the zones of the building according to the defined zones types.
- Selection of a zone for each of the identified zone types to be considered directly as thermal zones on the EnergyPlus model (to be monitored in the deployment phase)..
- Aggregation of the zones of the same type located in adjacent positions and served by the same HVAC system.
- The zones existing at the end of this sequence will be considered the final thermal zones of the building

According to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Rooms with associated occupancy
  - Meeting rooms.
  - Waiting rooms.
  - Atriums.
  - Reception desks.
  - Individual office rooms.
  - Collective office rooms.
  - Library.
  - Archives and storage rooms.
  - Auditorium.
  - Office equipment room (Reprography room, Plotters room, etc.).
  - IT equipment rooms (computer services room, CCTV room, etc.).
  - Economat.
  - Resting rooms (Lunch room and bar).

- Rooms with no associated occupancy.
  - Toilets.
  - Corridors and circulation zones.
  - Technical rooms

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal quality setpoints.

After the characterization of the zones of the building, a representative zone has been selected for each of the defined zone types. During the deployment phase of the platform, sensors will be deployed on the selected representative zones to monitor occupancy, thermal comfort, internal air quality and internal gains, to be used by the **Behavioural Profiling Engine** to produce the actual usage input data.

The use description produced for the representative zones, will be used in the model for all the thermal zones of the same type, which will enable to reduce sensor deployment requirements and the input data required to populate the model with information related to the actual and predicted use of the building.

Finally, starting from the characterization of all the zones of the building, the thermal zones to be considered in the EnergyPlus model have been set. In this final step, apart from the room characterization, the HVAC systems serving each zone of the building have been considered. More specifically, the final thermal zone distribution of the EnergyPlus model is obtained after merging all the zones of the same type that are, additionally, served by the same HVAC system and are physically located next to each other.

The following pictures display the thermal zones of the EnergyPlus model of the building.

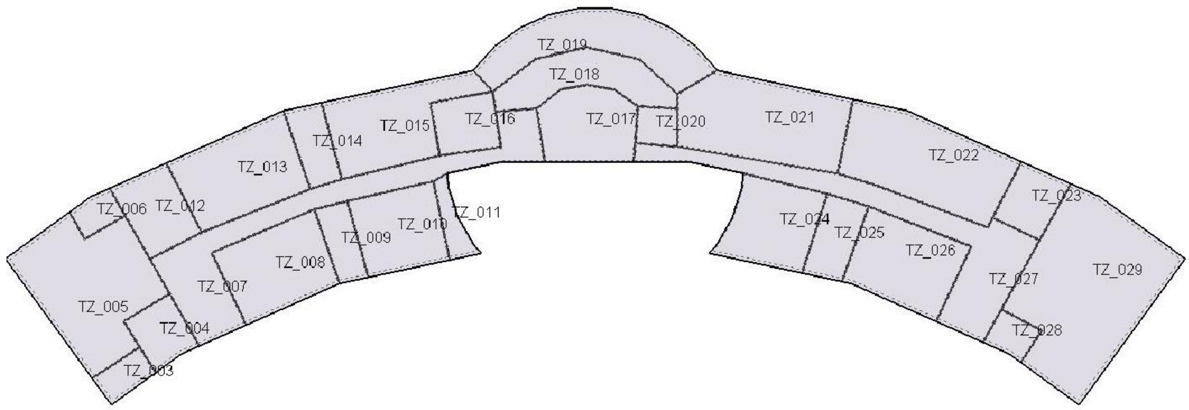


Figure 17 Thermal zone definition on ground floor (Mafra city council)

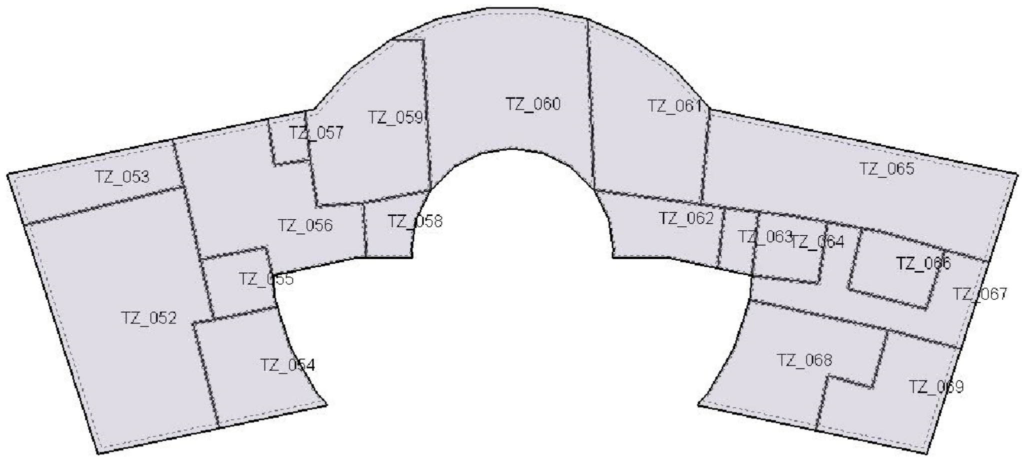


Figure 18 Thermal zone definition on floor 2 (Mafra city council)

9.2.3.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main loads present in this building and integrated in the developed EnergyPlus model is included:

- The heating and cooling system.
- The ventilation system.
- Office equipment such as computers, printers, etc
- IT equipment.
- The artificial lighting system (indoor and outdoor).
- The cafeteria electric equipment (food conservation chambers, etc.).

The heating and cooling system of the building is formed by 8 variable refrigerant volume units that can provide heating and cooling simultaneously according to the specific needs of each of the spaces of the building.

Each of the VRV system is formed by an external unit, connected to several internal units deployed at zone level that can provide independent temperature control to each of the conditioned rooms.

These VRV systems can operate according to a heat pump mode where all the internal units connected to the same external unit will deliver heating or cooling according to the prevailing thermal load (or the thermal load existing in the thermal zone defined as master of each VRV equipment). Additionally, the systems can operate according to a heat recovery mode that allows the simultaneous delivery of heating to some of the connected rooms and cooling to other zones (the heat that is extracted from the cooled zones is delivered to the zones that request heating).

Depending on the size of the zones, the deployed internal units are of the cassette type with direct energy discharge, or internal units with energy delivery through small duct networks to ensure an even delivery of the energy.

The ventilation system of the building is formed by several independent supply and exhaust fans connected respectively to supply and exhaust duct networks that enable internal air renovation, but can´t provide exhaust air heat recovery functionalities. All of them operate according to constant air volume control strategies.

The basement floor ventilation system is formed by 2 supply ventilation systems and two exhaust ventilation systems. The rest of the floors of the building are served by two supply ventilation systems and two exhaust systems that provide the required air renovation through dedicated supply and exhaust duct networks.

Finally, the ventilation system of the building is completed by the exhaust fan systems coupled to duct networks deployed in all the toilets.

There is not a relevant domestic hot water production demand. Only some small very specific DHW consumption points (cafeteria etc.), solved with locally deployed small domestic water heaters.

Regarding the electric/thermal loads associated to artificial lighting, cafeteria equipment, and office/IT equipment the nominal power included in the data sheets of each equipment, gathered in the frame of Task 7.2, have been used to characterize them. In any case these values will be calibrated after the deployment of the MOEEBIUS platform in the pilot to capture their actual nominal power.

Regarding the impact of user behaviour on these loads, as a starting point, some static schedules provided by building owners have been considered. In any case, after the implementation of the MOEEBIUS platform in the pilot, actual user behaviour impact on these loads will be provided to the **BEPS** by the **Demand and Flexibility Engine** to update the model of the building accordingly.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems are present in this building.

The modelling criteria considered in the integration into the EnergyPlus model of this building, of all the DER-s described in the precedent paragraphs will enable an accurate evaluation of the following dynamics:

- The performance of the VRV systems.
- Thanks to the accurate modelling of the topology of the distribution subsystem, the thermal losses over the distribution loops (refrigerant fluid circuits).

- The energy delivery from the emission subsystem (VRV system internal units).
- The performance and behaviour of all the supply only ventilation systems.
- The performance and behaviour of all the exhaust only ventilation systems.
- The performance and behaviour of the auxiliary exhaust ventilation systems of the toilets.
- The performance and behaviour of the DHW production system.
- The performance and behaviour of the artificial lighting system and its impact on zone thermal balance.
- The energy consumption over time due to electric loads related to cafeteria equipment and their impact on zone thermal balance.
- The energy consumption over time due to electric loads related to office and IT equipment and their impact on zone thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the building.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystems of the buildings.

In summary, the EnergyPlus model of this building includes a detailed modelling of all the DER-s present in the building and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables (performance, consumption, fluid temperatures and flow rates, etc.) of all the systems and equipment existing on the building.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system, reproducing the typology and topology of the actually deployed systems.

9.2.3.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance

The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU
Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling
Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 11 Summary of the EMS programs integrated into the EnergyPlus model of the Mafra city council

9.2.4 Integrated district model

In this section the modelling specification of the integrated district model for the Portuguese pilot is included in a compact shape.

In this case, at this stage of the project all the DER-s (loads and distributed generation systems) are physically deployed at building level and a thermal supply from a district heating system is not available.

Therefore, at this stage of the project there is not any district level dynamics or infrastructure to be modelled in order to enable district level aggregated thermal, electricity and gas demand prediction delivery.

In summary, the aggregation of the predictions provided by the EnergyPlus models of the buildings of the pilot, can provide all the DER system modelling capabilities required by the district level DAE to operate successfully.

9.3 Serbian pilot model development.

In this section the modeling criteria followed to produce the building and district models of the Serbian pilot are described in full detail.

One of the characteristics of the Serbian pilot is related to the fact that it is a district. As it was explained before, due to the amount of buildings that are part of such district and te calculation complexity, timing, and available resources to perform the work, it has been decided to select representative buildings from such district to be modelled and simulated.

A full representation of the district with appropriate coordinate system has been developed in order to ensure that the impact from other buildings and the terrain are taken into consideration during the simulation from the whole district.

The representative buildings modelled do have assigned location coordinates and orientation, and therefore can be introduced in the Neighbourhood model for simulation in an efficient manner. The reasoning behind this approach was to ensure that the models are not too heavy and work can be done in them without increasing dramatically the computation time.

Below it is presented a general representation of Serbia district scenario:

Figure 19 Stepa Stepanovic neighborhood

9.3.1 Residential buildings

In this section the modelling criteria used to generate the EnergyPlus models of these buildings is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

The buildings have been selected taking into account typology of geometry, typology of construction materials, affecting shadows, and equipment present in each of the residential scenarios.

Below the selected buildings are presented:

Figure 20 Modelled buildings of the Stepa Stepanovic neighborhood

As it can be extracted from the figures at least 1 building block has been modelled from each of the groups from the Serbian district. All groups are represented except Group 5 due to the buildings block similarities to Group 1 and Group 6 since it is the same group as Group 7.

The selected residential building blocks are:

- 1D (1 building)
- 2A (3 buildings)
- 3G (4 buildings)
- 4E (5 buildings)
- 6D (2 buildings)
- 6L (1building)

As it can be observed a total number of 16 representative residential buildings have been modelled for the Serbian district in MOEEBIUS.

9.3.1.1 Architectural modelling specification

For the architectural modelling of the residential buildings in Serbia, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following structural plans and information were used for the definition of the models:

1D

- 1D energy passport
- 1D residential block study
- 04- Garage
- 05– Lower Ground Floor
- 06– Ground Floor
- 07- Standard Floor
- 08- Fifth Floor
- 09- Sixth-retracted Floor
- 12- Cross section 1-1 2-2
- 12- Cross section 3-3 4-4
- 15- Entrance Façade
- 16- Yard Façade
- 17- Sideways Façade

2A

- 2A- L1 – Basis
- 2A- L1 – Cross section
- 2A- L1 – Facade

- 2A- L2 – Basis
- 2A- L2 – Cross section
- 2A- L2 – Facade
- 2A- L3 – Basis
- 2A- L3 – Cross section
- 2A- L3 – Facade

3G

- 3G- L1 – Basis
- 3G- L1 – Cross section
- 3G- L1 – Facade
- 3G- L2 – Basis
- 3G- L2 – Cross section
- 3G- L2 – Facade
- 3G- L3 – Basis
- 3G- L3 – Cross section
- 3G- L3 – Façade
- 3G- L4 – Basis
- 3G- L4 – Cross section
- 3G- L4 – Facade

4E

- 4E- L1 – Basis
- 4E- L1 – Cross section
- 4E- L1 – Facade
- 4E- L2 – Basis
- 4E- L2 – Cross section
- 4E- L2 – Facade
- 4E- L3 – Basis
- 4E- L3 – Cross section
- 4E- L3 – Façade
- 4E- L4 – Basis
- 4E- L4 – Cross section
- 4E- L4 – Façade
- 4E- L5 – Basis
- 4E- L5 – Cross section
- 4E- L5– Facade

6D

- 6D- Building design
- 6L residential block 1 energy passport
- 6L residential block 1 study

6L

- 6L- Building design
- 6L residential block 2 energy passport
- 6L residential block 2 study

Material and component definition

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template for the different residential blocks is presented below:

Construction Elements		Layer1		Layer2		Layer3		Layer4		Layer5		Layer6		Layer7	
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]
1.1	External Walls														
	FZ2	mortar	20	concrete	200	mineral wool	80	air	20	brick tiles	70				
	FZ4	mortar	20	concrete	250	polystyrene	30	air block	100	mortar	25				
	FZ3	mortar	20	hollow block	200	mineral wool	80	air	20	silicate brick	80				
	FZ1	mortar	20	air block	380	mortar	25								
1.2	Below Grade Walls														
1.3	Internal Partitions														
		mortar	20	hollow block	200	mortar	20								
1.4	Semi-exposed Walls														
	UPZ1a	mortar	20	hollow block	200	mineral wool	30	mortar	20						
	UPZ1c	mortar	20	air block	300	mortar	20								
	UPZ2b	mortar	20	mineral wool	50	concrete	200								
ROOFS															
2.1	Pitched Roof (occupied)														
	KK1	mortar	20	concrete	200	mineral wool	150	air	40	wood	24	bitumen	2	metal	1
2.2	Pitched Roof (unoccupied)														
2.3	Flat Roof														
	RK1	mortar	20	concrete	200	bitumen	5	polystyrene	150	cement screed	40	ceramic tiles	10		
FLOORS/CEILINGS															
3.1	Ground Floor														
3.2	External Floor														
	MKT7	parquet	25	cement screed	45	polystyrene	10	concrete	250	mineral wool	150	mortar	5		
3.3	Internal Floor														
3.4	Semi-exposed Floor														
	MKT8	parquet	25	cement screed	45	polystyrene	10	concrete	200	mineral wool	70	mortar	5		
	MKT8a	ceramic tiles	8	cement screed	45	polystyrene	10	concrete	200	mineral wool	70	mortar	5		
3.5	Semi-exposed Ceiling														

OPENINGS				
		Composition [mm]	Solar Factor [%]	Frame Material
4.1	External Windows	4Neutral+12Air+4Neutral+LowE	0,567	PVC
		Material	Thickness [mm]	
4.2	External Doors	Wood-metal	50	

Please, leave blank the leftover layers and the non-existent construction elements.
Windows Composition example: 4Neutral+6Air+6Neutral+LowE (=4mmExteriorGlassLayerNeutralColor+6mmAir+6mmInteriorGlassNeutralColor+LowECoating)

Residential 1D | Residential 2A | Residential 3G | Residential 4E | Residential 6D | Residential 6l | Kindergarten | School Stepa Stepanovic

Table 12 Thermal envelope of the residential buildings of the Stepa Stepanovic district

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site

All residential Serbian pilots modelled compared with a real life picture of the building are presented below.

1D

Figure 21 Simulation model of the 1D residential building

2A

Figure 22 Simulation model of the 2A residential building

3G

Figure 23 Simulation model of the 3G residential building

4E

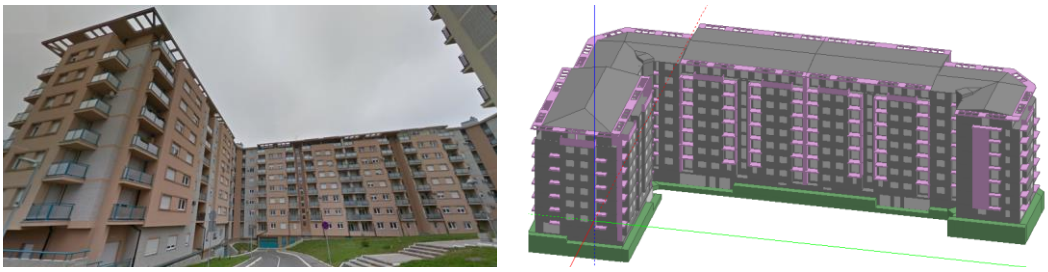


Figure 24 Simulation model of the 4E residential building

6D

Figure 25 Simulation model of the 6D residential building

6L

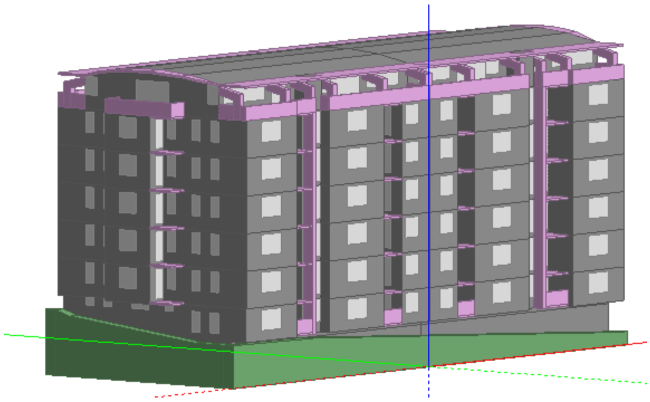


Figure 26 Simulation model 6L Simulation model of the 2A residential building

9.3.1.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

In the case of the residential buildings the thermal zone definition process can be greatly simplified, as according to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Zones with residential activity
- Common areas and other non-residential activities.

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal quality setpoints.

The optimization of the number of the defined thermal zones of the model is a key factor to contribute to reduce the required calculation times. This will be a critical issue during the operational stage of the MOEEBIUS platform. As a consequence, the following thermal zone definition criteria was adopted:

- Each apartment will form and independent thermal zone.
- All the common areas of each floor will be merged into a single zone

The following pictures display the thermal zones of the EnergyPlus models of the buildings.

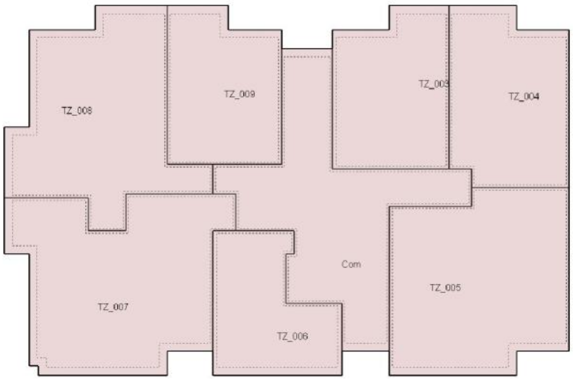


Figure 27 Thermal zone definition on ground floor (1D L1 building of the Stepa Stepanovic neighborhood)

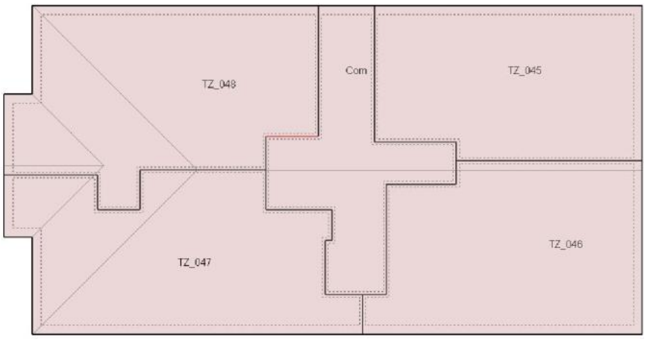


Figure 28 Thermal zone definition on floor 6 (1D L1 building of the Stepa Stepanovic neighborhood)

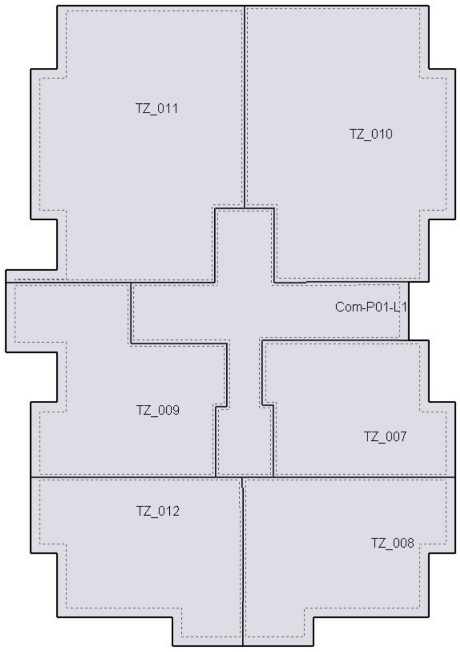


Figure 29 Thermal zone definition on floor 1 (2A L1 building of the Stepa Stepanovic neighborhood)

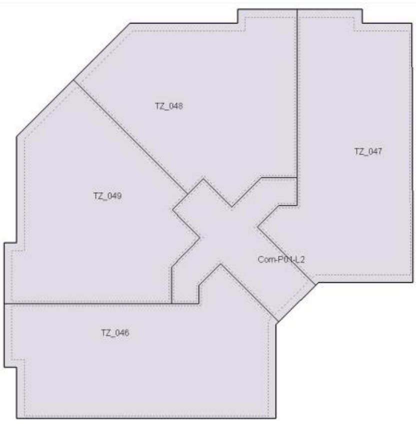


Figure 30 Thermal zone definition on floor 1 (2A L2 building of the Stepa Stepanovic neighborhood)

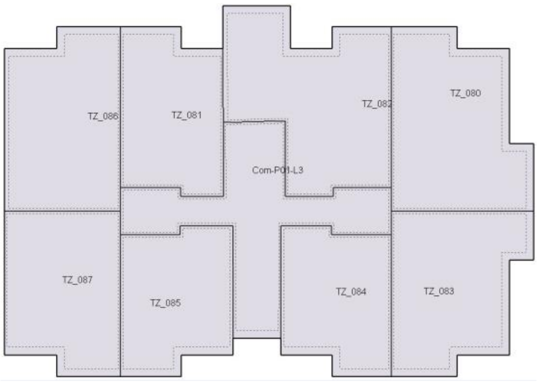


Figure 31 Thermal zone definition on floor 1 (2A L3 building of the Stepa Stepanovic neighborhood)

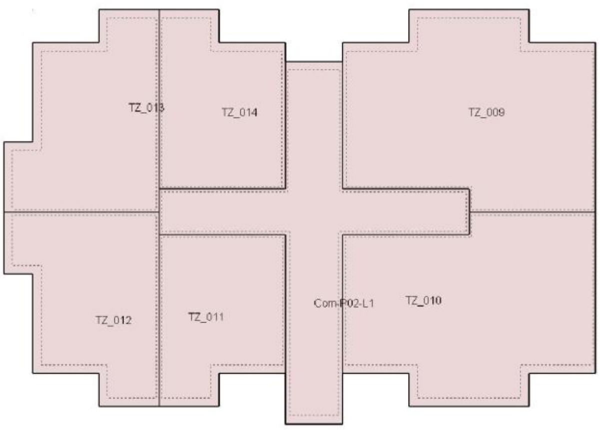


Figure 32 Thermal zone definition on floor 2 (3G L1 building of the Stepa Stepanovic neighborhood)

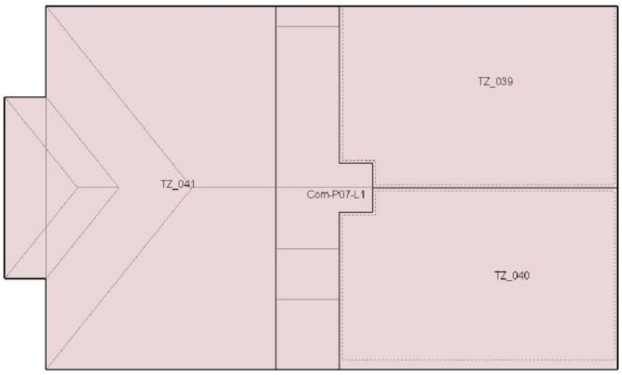


Figure 33 Thermal zone definition on floor 7 (3G L1 building of the Stepa Stepanovic neighborhood)

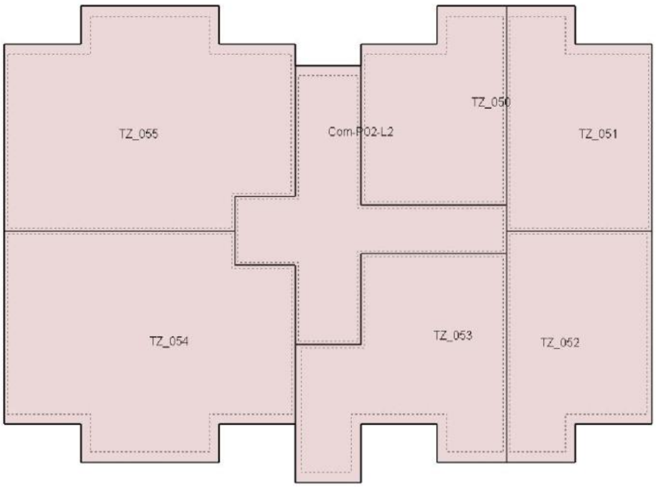


Figure 34 Thermal zone definition on floor 2 (3G L2 building of the Stepa Stepanovic neighborhood)

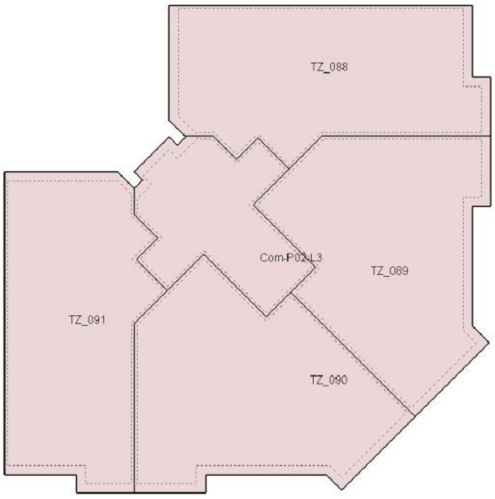


Figure 35 Thermal zone definition on floor 2 (3G L3 building of the Stepa Stepanovic neighborhood)

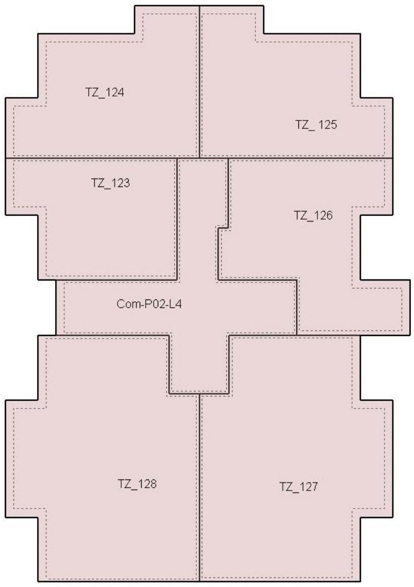


Figure 36 Thermal zone definition on floor 2 (3G L4 building of the Stepa Stepanovic neighborhood)

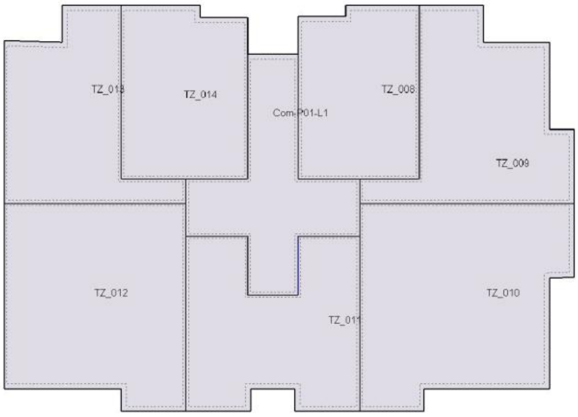


Figure 37 Thermal zone definition on floor 7 (3E L1 building of the Stepa Stepanovic neighborhood)

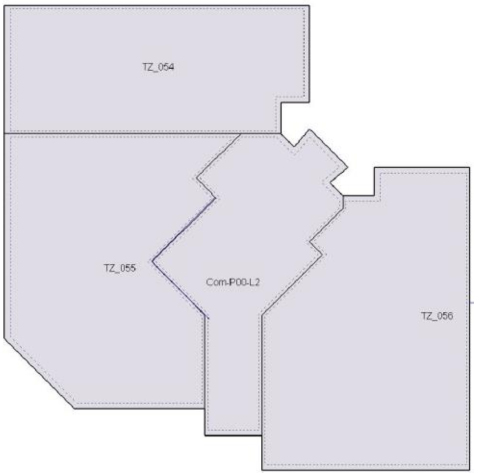


Figure 38 Thermal zone definition on ground floor (4E L2 building of the Stepa Stepanovic neighborhood)

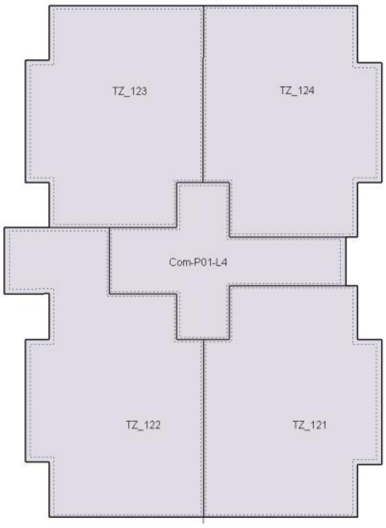


Figure 39 Thermal zone definition on floor 1 (4E L4 building of the Stepa Stepanovic neighborhood)

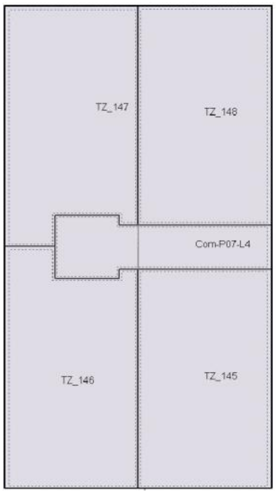


Figure 40 Thermal zone definition on floor 7 (4E L4 building of the Stepa Stepanovic neighborhood)

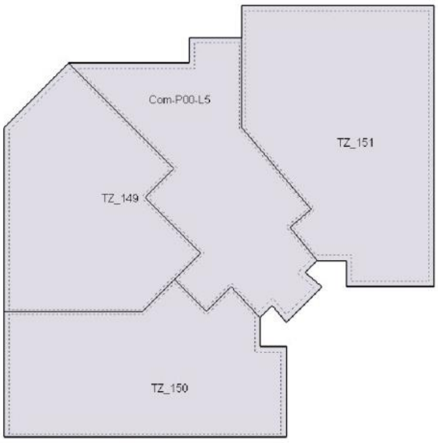


Figure 41 Thermal zone definition on ground floor (4E L5 building of the Stepa Stepanovic neighborhood)

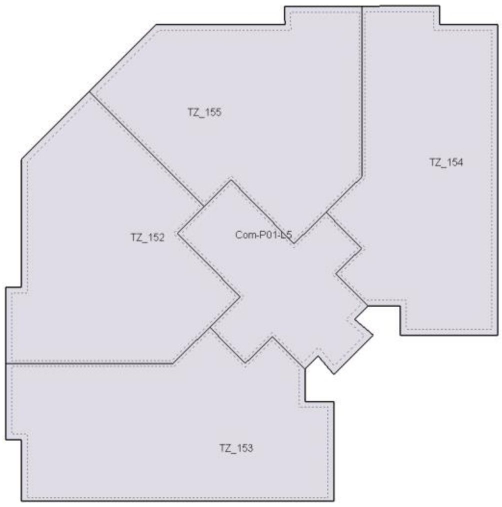


Figure 42 Thermal zone definition on floor 1 (4E L5 building of the Stepa Stepanovic neighborhood)

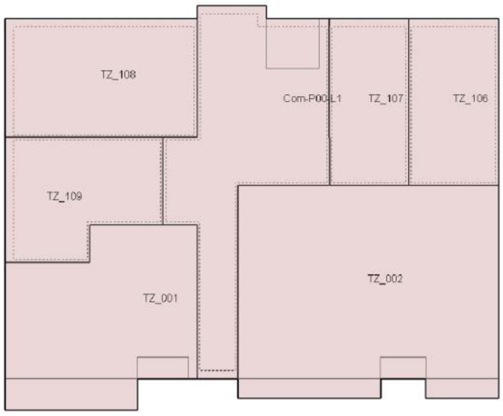


Figure 43 Thermal zone definition on ground floor (6D L1 building of the Stepa Stepanovic neighborhood)

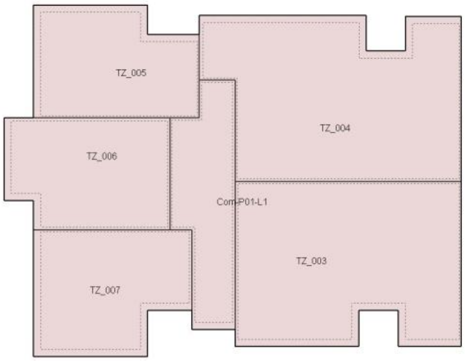


Figure 44 Thermal zone definition on floor 1 (6D L1 building of the Stepa Stepanovic neighborhood)

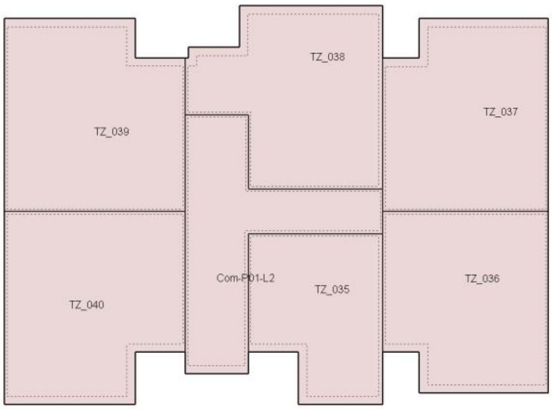


Figure 45 Thermal zone definition on floor 1 (6D L2 building of the Stepa Stepanovic neighborhood)

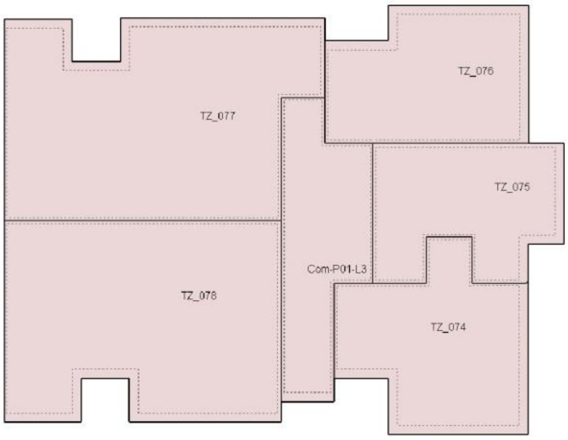


Figure 46 Thermal zone definition on floor 1 (6D L3 building of the Stepa Stepanovic neighborhood)

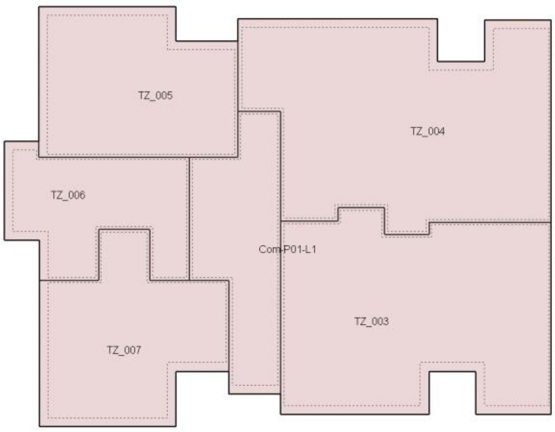


Figure 47 Thermal zone definition on floor 1 (6L L1 building of the Stepa Stepanovic neighborhood)

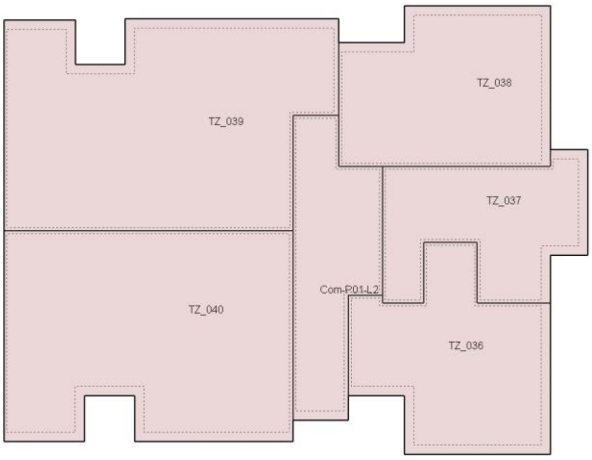


Figure 48 Thermal zone definition on floor 1 (3L L2 building of the Stepa Stepanovic neighborhood)

9.3.1.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in these buildings is provided. Below the summary of the main loads present in these buildings and integrated in the developed EnergyPlus models is included:

- The Heating system.
- The Domestic hot water production systems (one per apartment).
- Domestic electric equipment (washing machines, fridge, tv, domestic computers, etc.).
- The artificial lighting system.

These buildings are connected to the Stepa Stepanovich district heating system and therefore, the energy requested by the heating system of the buildings is supplied by the thermal network. The connection of each residential building is solved through an indirect heating substation formed by a single plate heat exchanger, and all the auxiliary hydraulic, control and monitoring equipment necessary to ensure a satisfactory, reliable and efficient operation. However, local storage capacity is not provided at substation level.

The primary side of the heating substations is connected to the thermal network through 2 way proportional control valves that adjust the amount of delivered energy according to the evolution over time of the heating loads, and ensure adequate values for the return temperature from the substations to the thermal network.

The secondary side of each building substation is connected to the distribution loops of the heating system. Each distribution loop is equipped with variable flow pumps with variable frequency drives, that enable the modulation of the distributed water flow rate according to the evolution of the heating loads of the

connected apartments. The number of distribution circuits deployed in each building varies according to their size and typology.

The distribution loops are connected to floor level manifolds where specific supply/return branches enable apartment level station integration to the distribution subsystem of the building. Floor manifolds include the manual valves required for hydraulic balancing of all the branches, and to isolate specific apartments for maintenance purposes. However, due to the lack of actuated valves it is not possible to isolate specific apartments without human intervention. On the other hand, it is necessary to mention that apartment stations include dedicated energy meters for heating cost allocation.

The emission subsystem is formed by hot water radiators deployed on each room of the apartments including thermostatic valves to control the energy delivered by each radiator according to room temperature, to reduce, as much as possible, energy wastage due to room overheating.

The toilets and kitchens of the apartments include dedicated mechanical exhaust fan systems, but the ventilation of the rest of the rooms is solved through natural ventilation.

In the case of the residential buildings of the Stepa Stepanovic neighbourhood included within the scope the pilot, the energy necessary for domestic hot DHW production is not delivered by the district heating system. Instead, DHW production takes place at apartment level, through domestic electric water heaters.

Regarding the electric loads associated to artificial lighting and household appliances, as it is well known, the deployed systems and their exploitation are strongly affected by user behaviour. As a consequence, several different scenarios have been identified in the apartments of these residential buildings.

Therefore, as a starting point, a baseline has been defined to represent the typical impact of these electric loads on the residential buildings, to be modified to represent the actual impact of each apartment on the total loads of each building, by means of model calibration after the deployment of the MOEEBIUS platform in the pilot.

Regarding RES and distributes generation technologies, it is necessary to mention that at this stage of the project none of these DER systems exist on these buildings.

The modelling criteria considered in the integration into the EnergyPlus models of the residential buildings, of all the DER-s described in the precedent paragraphs will enable an accurate evaluation of the following dynamics:

- The performance of the heat transfer on the building substation and secondary side flow parameter evolution over time (inlet temperature, outlet temperature, inlet water flow rate).
- Thanks to the accurate modelling of the topology of the building level distribution subsystem distribution, the thermal losses and water temperature distribution over the building distribution loops.
- The energy delivery from the emission subsystem (hot water radiators) at zone level.
- The performance and behaviour of all the pumping equipment.
- The performance and behaviour of the artificial lighting system
- The performance and behaviour of the exhaust ventilation systems.
- Performance and behaviour of the DHW production system.
- The energy consumption over time due to household appliances (washing machines, fridge, tv, domestic computers, etc.) and their impact in apartment room thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the buildings.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystem of the buildings.

In summary, the EnergyPlus models of these buildings include a detailed modelling of all the DER-s present in the buildings and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables (performance, consumption, temperatures, water flow rates, etc.) of all the systems and equipment existing on the buildings.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in these buildings, special attention has been paid to provide an accurate modelling of the HVAC system of the buildings, reproducing the typology and topology of their actual heating systems.

Finally, as it will be described in the section related to the definition of the integrated district model for the Serbian pilot, according to the defined offline co-simulation procedure, it is assumed that the water supply from the thermal network to each building model will take place according to nominal operational conditions (supply temperature, return temperature, supply pressure), which is a realistic scenario for correctly operated district heating systems.

9.3.1.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance
The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU
Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling
Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 13 Summary of the EMS programs integrated into the EnergyPlus model of each of the residential buildings of the Serbian pilot

9.3.2 Nursery building

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.3.2.1 Architectural modelling specification

For the architectural modelling of the nursery building in Serbia, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following information was used for the definition of the models:

- KindergartenStepa_PLAN_Ground
- Kindergarten stepa – book 1
- Kindergarten stepa – book 2
- Energy elaborate_Kindergarten Stepa
- Energy Passport_Kindergarten Stepa

Material and component definition

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template from the Nursery is presented below:

Construction Elements		Layer1		Layer2		Layer3		Layer4		Layer5		Layer6		Layer	
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thic
1.1	External Walls	mortar	20	concrete block	200	wool	200	brick	12	mortar	20				
1.2	Below Grade Walls	mortar	20	concrete block	200	EPS	100	air	10	brick	120				
1.3	Internal Partitions	mortar	20	concrete block	200	mortar	20								
1.4	Semi-exposed Walls	mortar	20	wool	50	cast concrete	200								
ROOFS															
2.1	Pitched Roof (occupied)	concrete tiles	20	cast concrete	200	wool	150	air gap	40	wood wool	24	bitumen sheet	2	metal deck	
2.2	Pitched Roof (unoccupied)														
2.3	Flat Roof	roof gravel	80	butadiene	2,3	cast concrete	250	EPS	40	cast concrete	220	mortar	20		
FLOORS/CEILINGS															
3.1	Ground Floor	mortar	75	cast concrete	150	EPS	100	cast concrete	40	gravel	100				
3.2	External Floor														
3.3	Internal Floor	plasterboard	12,5	air gap	400	wool	140	cast concrete	40	mortar	50	aerated concrete slab	3	PVC	
3.4	Semi-exposed Floor	mortar	5	wool board	70	cast concrete	250	EPS	40	mortar	45	timber flooring	25		
3.5	Semi-exposed Ceiling														
OPENINGS															
		Composition [mm]	Solar Factor [%]	Frame Material											
4.1	External Windows	28													
		Material	Thickness [mm]												
4.2	External Doors														

Please, leave blank the leftover layers and the non-existent construction elements.
Windows Composition: 6Neutral+16Argon+6Neutral

Table 14 Thermal envelope of the Stepa Stevanovic nursery building

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site

Below it is presented the pilot modelled compared with a real life picture.

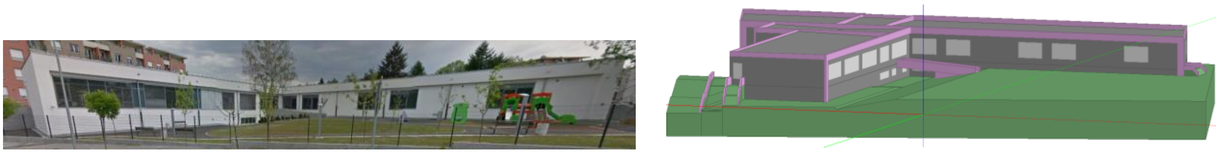


Figure 49 Simulation model of the Stepa Stepanovic Kindergarten

9.3.2.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

More specifically the definition process followed to configure the thermal zones integrated in the model consisted on the following sequence.

- Analysis of the activities existing on the building.
- Identification of the different zone types according to the developed activities.
- Classification/characterization of the zones of the building according to the defined types.
- Selection of a zone for each of the identified zone types (to be monitored in the deployment phase)..
- Aggregation of the zones of the same type located in adjacent positions and served by the same HVAC system.
- The zones existing at the end of this sequence will be considered the final thermal zones of the building.

According to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Rooms with associated occupancy
    - Children rooms and Class rooms.
    - Dinning hall.
    - Individual Offices.
    - Locker rooms.
    - Medical rooms.
    - Nursing rooms.
    - Food preparation rooms.
- Room with no associated occupancy.
    - Toilets.
    - Corridors and circulation zones.
    - Technical rooms
    - Storage rooms
    - Laundry service rooms

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal quality setpoints.

After the characterization of the zones of the building, a representative zone has been selected for each of the defined zone types. During the deployment phase of

the platform, sensors will be deployed on the selected representative zones to monitor occupancy, thermal comfort, internal air quality and internal gains, to be used by the **Behavioural Profiling Engine** to produce the actual usage input data. The use description produced for the representative zones, will be used in the model for all the zones of the same type.

Finally, starting from the characterization of all the zones of the building, the thermal zones to be considered in the EnergyPlus model have been set. In this final step, apart from the room characterization, the HVAC systems serving each zone of the building have been considered. More specifically, the final thermal zone distribution of the EnergyPlus model is obtained after merging all the zones of the same type that are, additionally, served by the same HVAC system and are physically located next to each other.

The following pictures display the thermal zones of the EnergyPlus model of the building.

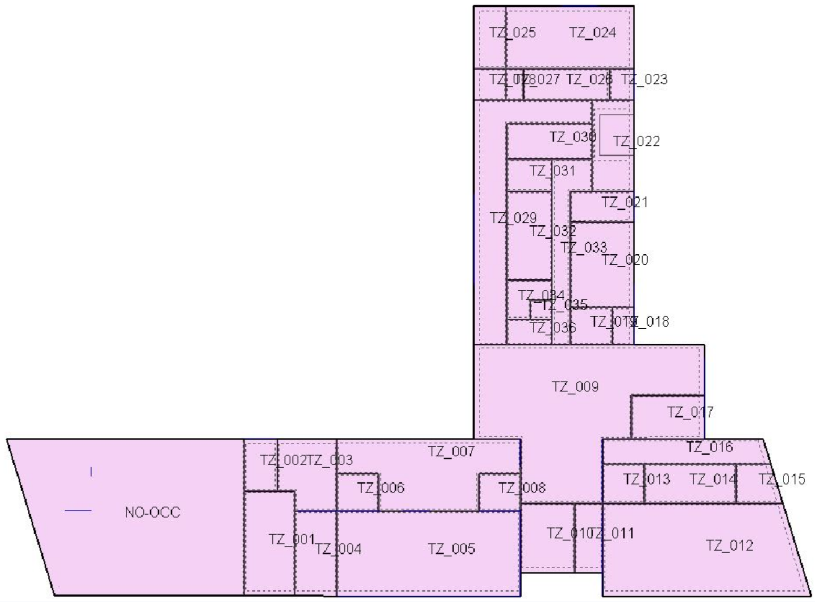


Figure 50 Thermal zone distribution on ground floor (Stepa Stepanovic kindergarten)

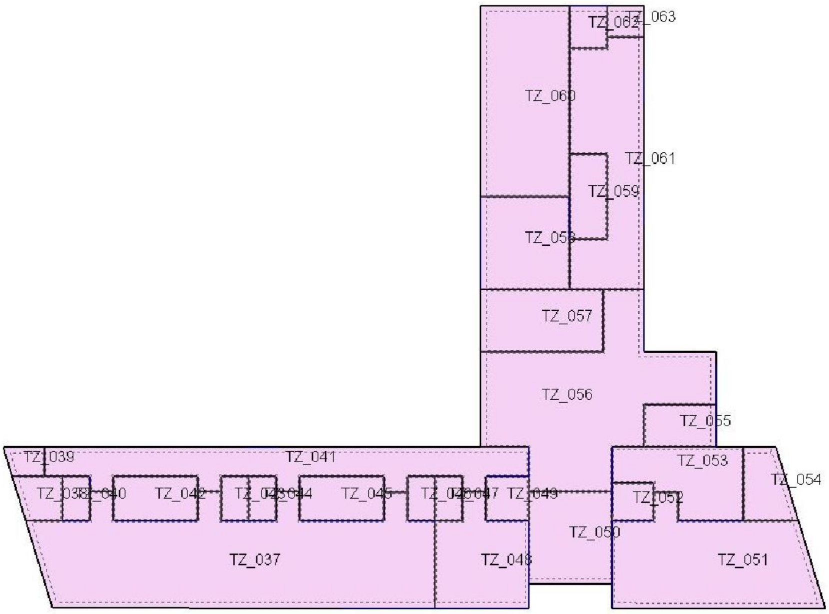


Figure 51 Thermal zone distribution ground floor 1 (Stepa Stepanovic kindergarten)

9.3.2.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main loads present in this building and integrated in the developed EnergyPlus model is included:

- The Heating system.
- The ventilation system.
- The cooling system (small capacity split heat pumps)
- The domestic hot water production system.
- Electric loads related to food preparation and conservation equipment.
- The lighting system (internal and external).

As is the case with the residential buildings, the thermal energy required for heating and ventilation purposes is delivered by the Stepa Spanovic district heating system through 2 dedicated thermal substations.

Both substations are connected to the district heating through 2 way proportional valves that enable the adjustment of the energy delivered to the building for heating and for ventilation air pre-treatment.

The secondary side of the heating substation is connected to the distribution circuit of the building that delivers the hot water to the hot water radiators deployed at zone level.

Similarly, the secondary side of the ventilation thermal substation is connected to the distribution loop of the heating coils of the air handing units of the building.

These heating coils, if necessary, allow ventilation air pre-heating in order to ensure the delivery of the ventilation air at adequate temperatures. The pumps deployed on this distribution circuits operate according to variable flow strategies.

The ventilation system of the building is formed by 2 AHU-s. The first AHU includes supply and ventilation fans, a heat recovery heat exchanger and the dampers necessary to enable the air renovation of the laundry service rooms through the corresponding supply and return duct networks (air intake, air exhaust, heat recovery heat exchanger bypass).

The second AHU is of the supply only type, and provides the ventilation air through a supply duct network to the food preparation rooms (kitchens) and to the individual office room located on the ground floor. This AHU includes a hot water heating coil for supply air pre-heating.

Additionally, in each of the food preparation rooms a dedicated exhaust hood has been deployed to extract all the fumes produced by cooking equipment and allow internal air renovation of these rooms.

Finally, the ventilation system of the building is completed by the following systems.

- The exhaust fan systems coupled to duct networks deployed in all the toilets.
- The exhaust fan systems coupled to duct networks deployed in the locker rooms.
- The exhaust only system coupled to a duct network deployed to renovate the indoor air of the main technical room where the building substations are deployed.

All the deployed AHU-s and the rest of the auxiliary ventilation systems operate according to constant flow control strategies. In the rest of the rooms of the building, natural ventilation through windows is the only available air renovation mechanism.

Additionally, a total number of 17 small capacity direct expansion split heat pump units exist, to provide cooling and additional heating capacity to the following activity zones of the building:

- All the classrooms.
- All the children rooms.
- The dinning hall.
- The technical room on the ground floor

Finally, DHW production is carried out by 2 dedicated electric boilers, each coupled to a storage tank of 500 litres. From there, DHW is distributed to the consumption points existing all over the building.

Regarding the electric/thermal loads associated to artificial lighting, laundry service, food preparation/conservation equipment, and office/IT equipment the nominal power included in the data sheets of each equipment, gathered in the frame of Task 7.2, have been used to characterize them. In any case these values will be calibrated after the deployment of the MOEEBIUS platform in the pilot to capture their actual nominal power.

Regarding the impact of user behaviour on these loads, as a starting point, some static schedules provided by building owners have been considered. In any case, after the implementation of the MOEEBIUS platform in the pilot, actual user behaviour impact on these loads will be provided to the **BEPS** by the **Demand and Flexibility Engine** to update the model of the building accordingly.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems exist on this building.

The modelling criteria considered in the integration of all the DER-s described in the precedent paragraphs into the EnergyPlus model of this building will enable an accurate evaluation of the following dynamics:

- The performance of the heat transfer on the building heating and ventilation substations and secondary side flow parameter evolution over time (inlet temperature, outlet temperature, inlet water flow rate).
- Thanks to the accurate modelling of the topology of the building level distribution subsystem, the thermal losses and water temperature distribution over the building distribution loops.
- The energy delivery from the emission subsystem (hot water radiators, AHU heating coils and split heat pump units).
- The performance and behaviour of the cooling system (split heat pump units)
- The performance and behaviour of all the pumping equipment.
- The performance and behaviour of all the components of the AHU-s (fans, heating coils, dampers, heat recovery heat exchanger)
- The performance and behaviour of the auxiliary exhaust ventilation systems.
- The performance and behaviour of the DHW production system including the thermal losses and stratification on the storage tanks.
- The performance and behaviour of the artificial lighting system and their impact on zone thermal balance.
- The energy consumption over time due to Electric loads related to food preparation and conservation equipment and their impact on zone thermal balance.
- The energy consumption over time due to electric/thermal loads related to laundry service equipment and their impact in zone thermal balance.
- The energy consumption over time due to electric loads related to office and IT equipment and their impact in zone thermal balance.

- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the buildings.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystems of the buildings.

In summary, the EnergyPlus model of this building includes a detailed modelling of all the DER-s present in the building and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables (performance, consumption, temperatures, water flow rates, etc.) of all the systems and equipment existing on the building.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system, reproducing the typology and topology of the actually deployed systems.

Finally, as it will be described in the section related to the definition of the integrated district model for the Serbian pilot, according to the defined offline co-simulation procedure, it is assumed that the water supply from the thermal network to the building model will take place according to nominal operational conditions (supply temperature, return temperature, supply pressure), which is a realistic assumption for correctly operated district heating systems.

9.3.2.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance
The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU

Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling
Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 15 Summary of the EMS programs integrated into the EnergyPlus model of the Stepa Stepanovic kindergarten

9.3.3 Educational building

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.3.3.1 Architectural modelling specification (SOL)

For the architectural modelling of the School in Serbia, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following information was used for the definition of the models:

- 01 – Location
- 02 – Foundation basis
- 03 – Basement
- 04 – Ground Floor
- 07 –Roof
- 08 – Roof 2
- 09 – Cross section 1-1 and 8-8

- 10 – Cross section 3-3 and 4-4
- 11 – Facade – northeast – southwest
- 12 – Facade – northwest – southeast

Material and component definition

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template from the School is presented below:

Construction Elements		Layer1		Layer2		Layer3		Layer4		Layer5		Layer6		
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Material	Thickness [mm]	Materia
1.1	External Walls	mortar	20	concrete block	200	wool	200	brick	40	mortar	20			
1.2	Below Grade Walls	mortar	20	concrete block	200	EPS	100	air gap	40	brick	120			
1.3	Internal Partitions	mortar	20	concrete block	200	mortar	20							
1.4	Semi-exposed Walls	mortar	20	wool	50	cast concrete	200							
ROOFS														
2.1	Pitched Roof (occupied)	gravel	80	butadiene	2,3	cast concrete	250	EPS	300	cast concrete	220	mortar	20	
2.2	Pitched Roof (unoccupied)	gravel	80	butadiene	2,3	cast concrete	250	EPS	300	cast concrete	220	mortar	20	
2.3	Flat Roof	gravel	80	butadiene	2,3	cast concrete	250	EPS	300	cast concrete	220	mortar	20	
FLOORS/CEILINGS														
3.1	Ground Floor	mortar	75	cast concrete	150	EPS	100	cast concrete	100	gravel	100			
3.2	External Floor													
3.3	Internal Floor	plasterboard	12,5	air gap	400	wool	140	cast concrete	220	mortar	50	aereated concrete slab	3	PVC
3.4	Semi-exposed Floor	mortar	5	wool	70	cast concrete	250	EPS	10	mortar	45	timber	25	
3.5	Semi-exposed Ceiling													
OPENINGS														
		Composition [mm]	Solar Factor [%]	Frame Material										
4.1	External Windows	45												
		Material	Thickness [mm]											
4.2	External Doors													

Please, leave blank the leftover layers and the non-existent construction elements.
Windows Composition example: 7Neutral+14Air+12Neutral+12Air+LowE

Table 16 Thermal envelope of the Stepa Stepanovic primary school

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site

Below it is presented the pilot modelled compared with a real life picture.

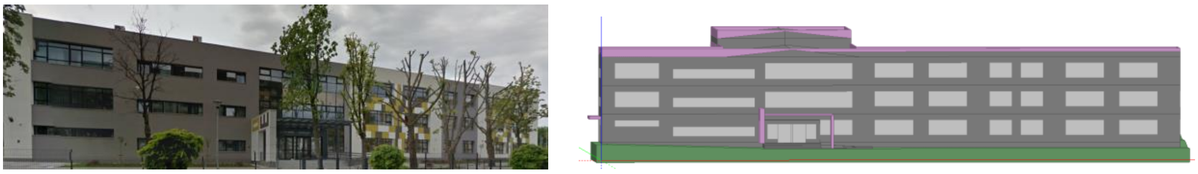


Figure 52 Simulation model of the Stepa Stepanovic primary school

9.3.3.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

More specifically, the definition process followed to configure the thermal zones integrated in the model consisted on the following sequence.

- Analysis of the activities existing on the building.
- Identification of the different zone types according to the developed activities.

- Classification/characterization of the zones of the building according to the defined types.
- Selection of a zone for each of the identified zone types (to be monitored in the deployment phase)..
- Aggregation of the zones of the same type located in adjacent positions and served by the same HVAC system.
- The zones existing at the end of this sequence will be considered the final thermal zones of the building

According to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Rooms with associated occupancy
  - Multi-sports court.
  - Locker rooms.
  - Class rooms
  - Cabinets
  - Dinning hall
  - Individual Offices
  - Administrative premises
  - Library
  - Medical rooms
  - Assembly halls
  - Kitchen.
- Rooms with no associated occupancy.
  - Toilets.
  - Corridors and circulation zones.
  - Technical rooms.
  - Storage rooms.

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal quality setpoints.

After the characterization of the zones of the building, a representative zone has been selected for each of the defined zone types. During the deployment phase of the platform, sensors will be deployed on the selected representative zones to monitor occupancy, thermal comfort, internal air quality and internal gains, to be used by the **Behavioural Profiling Engine** to produce the actual usage input data. The use description produced for the representative zones, will be used in the model for all the zones of the same type.

Finally, the thermal zones to be considered in the EnergyPlus model have been set. In this final step, apart from the room characterization, the HVAC systems serving each zone of the building have been considered. More specifically, the final

thermal zone distribution of the EnergyPlus model is obtained after merging all the zones of the same type that are simultaneously served by the same HVAC system and are physically located next to each other.

The following pictures display the thermal zones of the EnergyPlus model of the building.

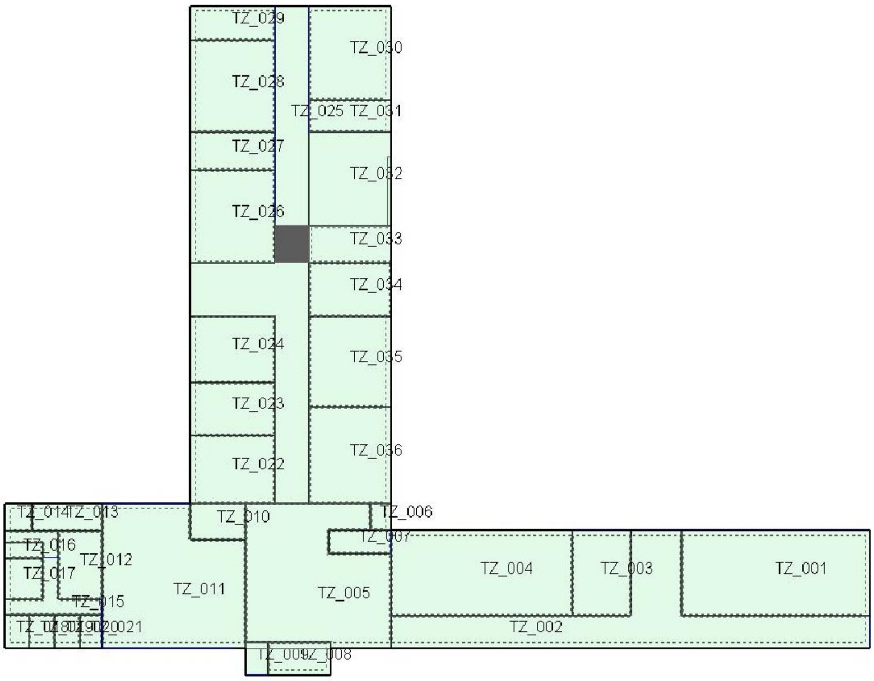


Figure 53 Thermal zone distribution on ground floor (Stepa Stepanovic school)

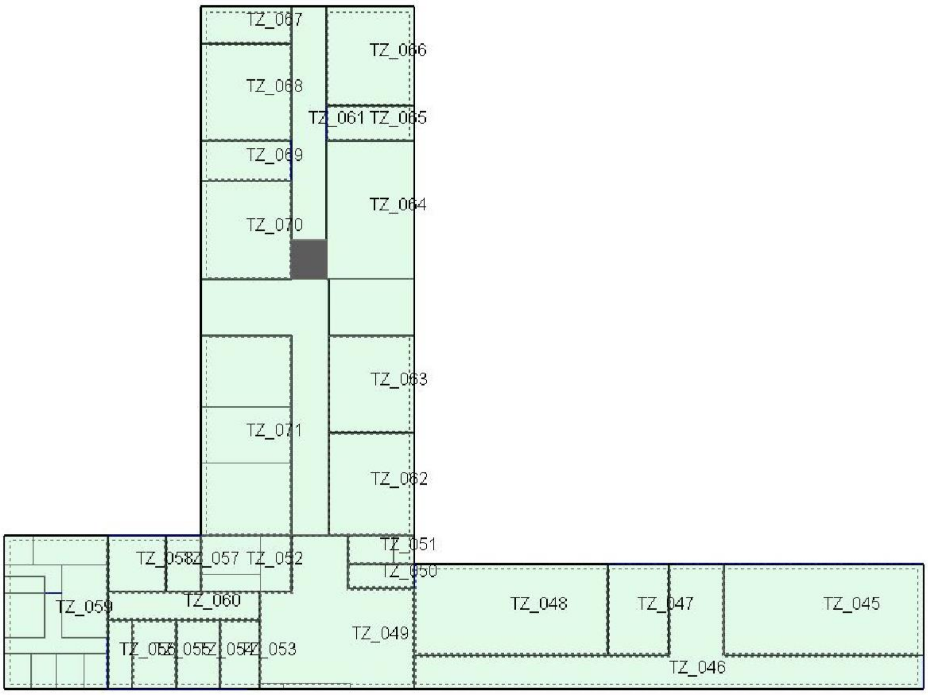


Figure 54 Thermal zone distribution on floor 1 (Stepa Stepanovic school)

9.3.3.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main loads present in this building and integrated in the developed EnergyPlus model is included:

- The Heating system.
- The Heating coils of the ventilation system.
- The domestic hot water production system.
- The cooling system (small capacity split and multi-split heat pump units)
- Thermal/electric loads of the equipment of the kitchen.
- Electric load associated to the educational activities (computers, etc.)
- Lighting system (indoors and outdoors).

As the rest of the buildings of the Serbian pilot, this building is connected to the Stepa Stepanovich district heating system that provides the energy requested by the heating and ventilation systems of the building through two dedicated indirect substations.

The primary side of the heat exchanger of each substation is connected to the thermal network through 2 way proportional control valves that enable the modulation of the delivered energy to adapt it to the evolution over time of the existing thermal loads, and to ensure a satisfactory temperature value of the return flow from the substations to the thermal network.

On the other hand, the secondary side of the heating substation is coupled to dedicated distribution loops connected on the one hand to the radiant floor system deployed on the multi sports court, and on the other hand to the hot water radiator system that forms the main heating emission subsystem in the rest of rooms of the building.

Similarly, the secondary side of the ventilation substation is coupled to the distribution loop that provides hot water to the heating coils of the AHU-s of the ventilation system of the building.

All the distribution loops of the building include dedicated pumps that operate according to variable flow strategies.

The ventilation system of the building is formed by 4 AHU-s that provide preheated ventilation air through specific supply and return duct networks, to the following zones:

- The multi sports court.
- The Locker rooms.
- The dinning hall.
- The assembly hall on the second floor of the building.

All these AHU-s include supply and exhaust fans, a heat recovery heat exchanger and the intake, exhaust and heat recovery bypass dampers necessary to enable the renovation of air in these rooms.

An additional, supply only AHU provides fresh air to the Kitchen through a duct network that, along the dedicated exhaust hood deployed to eliminate the fumes produced by cooking equipment, guaranties the satisfactory air renovation of the kitchen room.

Finally, the ventilation system of the building is completed by the exhaust fan systems coupled to duct networks deployed in all the toilets.

All the deployed AHU-s and the rest of the auxiliary ventilation systems, operate according to constant flow control strategies. In the rest of the rooms of the building, natural ventilation through windows is the only available air renovation mechanism.

Additionally, a total number of 10 small capacity direct expansion split heat pump units and 4 multi-split heat pump units exist, to provide cooling and additional heating capacity to the following activity zones of the building:

- Split units.
  - The 2 informatics classrooms.
  - The ground floor technical room.
  - The technical room on floor 1.
  - The technical room on floor 2.
  - The IT equipment room on floor 2.
  - The office of the director of the school
  - The office of the secretary of the director
  - The medical room on floor 2.
- Multi-split units.
  - The assembly hall on floor 1.
  - The assembly hall on floor 2
  - The office rooms on floor 1 (pedagogue office, psychologist office, administration offices).
  - The library and the medical room on floor 1.

Finally, a dedicated electric boiler produces the necessary domestic hot water. The boiler is coupled to a storage tank with a capacity of 750 litres. From there, the DHW is distributed to the consumption points existing all over the building.

Regarding the electric loads associated to artificial lighting, food preparation/conservation equipment, and office/IT equipment the nominal power included in the data sheets of each equipment, gathered in the frame of Task 7.2, have been used to characterize them. In any case these values will be calibrated after the deployment of the MOEEBIUS platform in the pilot to capture their actual nominal power.

Regarding the impact of user behaviour on these loads, as a starting point, some static schedules provided by building owners have been considered. In any case, after the implementation of the MOEEBIUS platform in the pilot, actual user behaviour impact on these loads will be provided to the **BEPS** by the **Demand and Flexibility Engine** to update the model of the building accordingly.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems are present on this building.

The modelling criteria considered in the integration into the EnergyPlus model of this building, of all the DER-s described in the precedent paragraphs will enable an accurate evaluation of the following dynamics:

- The performance of the heat transfer on the building heating and ventilation substations and secondary side flow parameter evolution over time (inlet temperature, outlet temperature, inlet water flow rate).
- Thanks to the accurate modelling of the topology of the building level distribution subsystem, the thermal losses and water temperature distribution over the building distribution loops.
- The energy delivery from the emission subsystem (radiant floor of the multi-sports court, hot water radiators, AHU heating coils, split heat pump units and multi-split heat pump units).
- The performance and behaviour of the cooling system (split and multi-split heat pump units)
- The performance and behaviour of all the pumping equipment.
- The performance and behaviour of all the components of the AHU-s (fans, heating coils, dampers, heat recovery heat exchanger)
- The performance and behaviour of the auxiliary exhaust ventilation systems.
- The performance and behaviour of the DHW production system including the thermal losses and stratification on the storage tank.
- The performance and behaviour of the artificial lighting system and its impact on zone thermal balance.
- The energy consumption over time due to electric loads related to food preparation and conservation equipment and their impact on zone thermal balance.
- The energy consumption over time due to electric loads related to office and IT equipment and their impact on zone thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the building.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystems of the buildings.

In summary, the EnergyPlus model of this building includes a detailed modelling of all the DER-s present in the building and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables of all the systems and equipment existing on the building.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system, reproducing the typology and topology of the actually deployed systems.

Finally, as it will be described in the section related to the definition of the integrated district model for the Serbian pilot, according to the defined offline co-simulation procedure, it is assumed that the water supply from the thermal network to the building model will take place according to nominal operational conditions, which is a realistic assumption for correctly operated district heating systems.

9.3.3.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance
The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU
Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling
Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values

Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 17 Summary of the EMS programs integrated into the EnergyPlus model of the Stepa Stepanovic primary school building

9.3.4 Integrated district model

9.3.4.1 Introduction

Before explaining the modelling criteria used to define the model of the district heating system of this pilot, in the following paragraphs a description of the typology and an overview of the main technical features of the district heating system will be provided.

The Vozdovac district heating system supplies heat energy for heating and domestic hot water production for different parts of the city of Belgrade (Banjica, Kumodraz, Stepa Stepanovic, and part of the Brace Jerkovic settlement).

The system is formed by a single 2 pipe (supply and return) distribution thermal network that enables energy distribution all over the district, and a district heating plant where the distributed heat energy is produced.

However, as it has already been described, the project pilot will be focused on 46 buildings of the Stepa Stepanovic neighbourhood.

The district heating system operates 24 hours a day all year round. During winter season, the heat energy is used for heating and DHW production, whereas during summer season the district heating plant operates at partial capacity, covering the energy requested by the connected buildings for DHW preparation purposes.

The heating plant is formed by three hot water boilers with a total capacity of 241 MW and by two steam boilers with a unitary capacity of 11 t/h of steam, used mainly for auxiliary technical purposes (fuel oil heating, thermal water treatment, local heating, etc.), and for DHW production in summer season. All the heat generators of the plant operate using natural gas as main fuel, but can also operate using heavy oil as alternative fuel. Additionally, two of the hot water boilers, include economizers deployed for energy recovery from the exhaust fumes to increase boiler output and total efficiency.

More specifically the power output of each of the heat generators is summarized below:

Boiler	Type	Capacity (MW)	Economizer capacity (MW)
HOB1	Hot water	58	3
HOB2	Hot water	58	0
HOB3	Hot water	116	6
SB1	Steam	7.8	0
SB2	Steam	6.5	0

Table 18 Nominal capacity of the heat generators of the Vozdovac district heating system

In the following picture, the monthly aggregated value of the heat energy delivered from the district heating plant in 2014 is displayed. The delivered energy ranges from 4.000 MWh in summer period, to the 35.000 MWh in winter period.

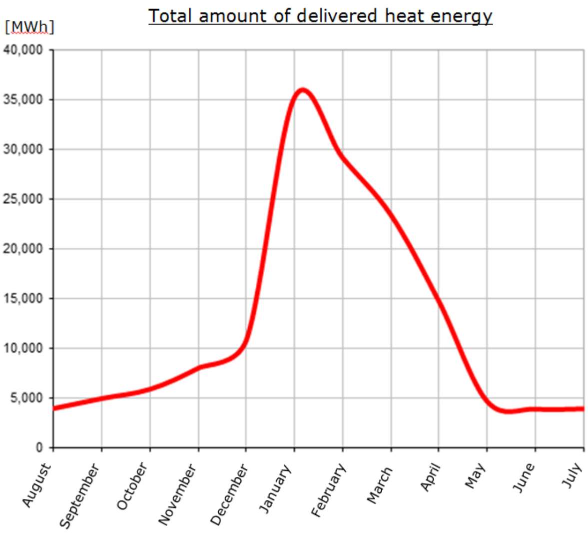


Figure 55 Monthly energy delivery from the district heating plant (2014)

In the following picture, the monotonous curve of the heat energy delivered by the district plant during the 2014/2015 winter season is displayed. The graph shows that the maximum output provided by the plant during this season was of 127 MW.

Load Diagram. Heating Season 2014/2015

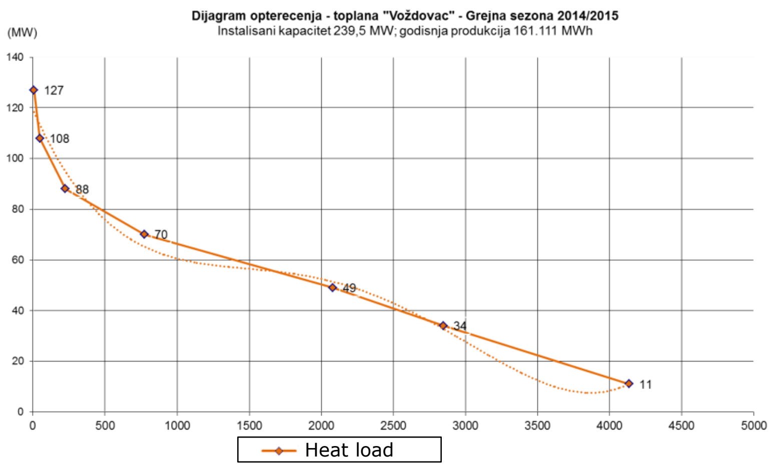


Figure 56 Monotonous curve of the heat energy delivered by the district plant (heating season 2014/2015)

The next graph shows the monotonous curve of the heat energy delivered by the district plant during the 2014 summer season. The picture displays that the maximum output provided by the plant during this season was of 13 MW.

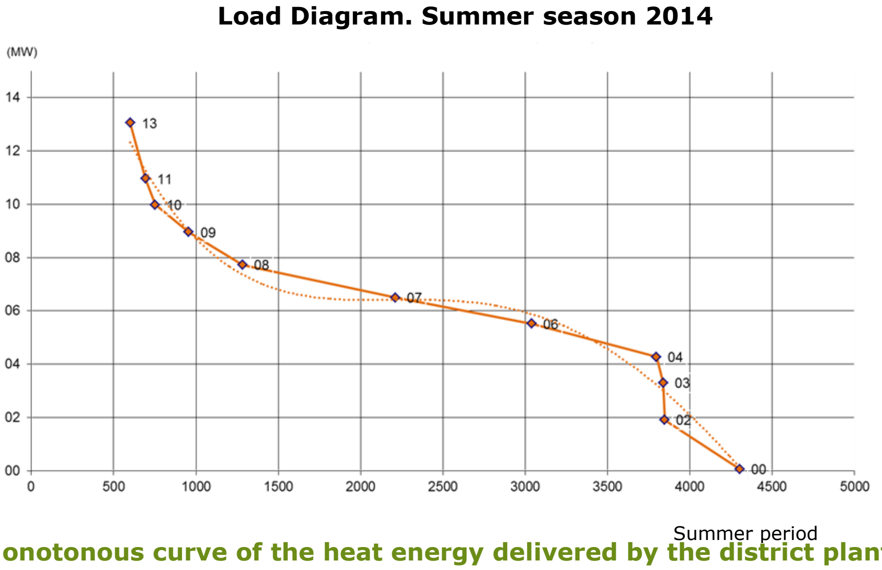


Figure 57 Monotonous curve of the heat energy delivered by the district plant (summer season 2014)

The district heating plant can operate according to a winter mode or according to a heating mode.

During winter season when energy is simultaneously requested for heating and for domestic hot water production the plant operates according to the winter mode and all the required energy is provided by the hot water production boilers. For winter periods without any relevant heating energy request due to high outdoor temperatures, HOB1 and HOB2 will meet all the energy requested by the district for DHW production, and HOB1 will be left out of service in order to operate the plant with satisfactory partial load factor values. For these periods, the use of the steam boilers is not an option due to their relatively low total capacity.

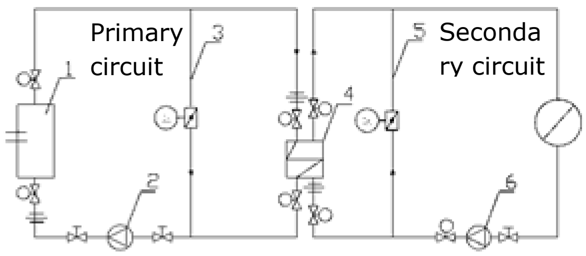
During summer season, DWH production is the only existing heat request and the plant operates according to the summer operation mode and all the heat energy is produced by the, steam boilers. The total capacity of the plant operating according to the heating mode is of 14.3 MW.

The energy delivery from the hot water production boilers to the distribution thermal network is solved through dedicated energy delivery heat exchangers (unitary capacity of 58 MW). A primary side pump produces water circulation from the primary side of each of the energy delivery heat exchangers to the corresponding hot water production boiler.

The circulation of water on the secondary side of the energy delivery heat exchangers is forced by the secondary side pumps deployed to enable heat energy distribution through the thermal network.

In order to prevent corrosion problems due to water vapour condensation inside boilers, the minimum boiler inlet water temperature is of 100 ºC when operating on natural gas and of 130 ºC when operating on fuel oil. Therefore, 3 way proportional mixing valves have been deployed to enable the adjustment of the water temperature entering the boilers, mixing as necessary return flow with supply flow.

Similarly, the supply water temperature set according to weather compensation strategies, can be adjusted through dedicated diverting valves, mixing as necessary district return water with distribution supply flow. A simplified scheme of the hydraulic connection of one of the hot water production boilers to the distribution thermal network is displayed in the following picture

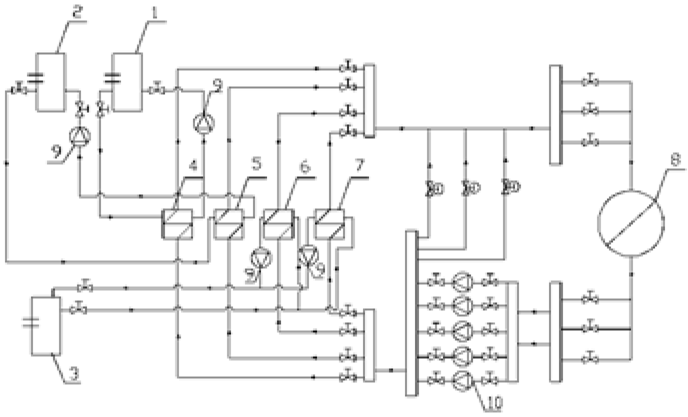


Key

1. Boiler
2. Boiler pump
3. Hot recirculation line
4. Heat exchanger
5. Cold recirculation line
6. Circulation pump for DH network

Figure 58 Simplified connection scheme of one of the hot water production boilers to the thermal network

The following picture displays the hydraulic scheme of the complete connection of the hot water production boilers of the district heating plant to the distribution thermal network through the existing energy delivery heat exchangers. This is the active connection scheme when the plant is operated according to the winter mode.



Key

1. HOB1
2. HOB2
3. HOB3
4. HE1
5. HE2
6. HE3
7. HE4
8. Consumer
9. Boiler circulation pump
10. Circulation pumps for

Figure 59 Connection scheme of the hot water production boilers of the district heating plant to the thermal network

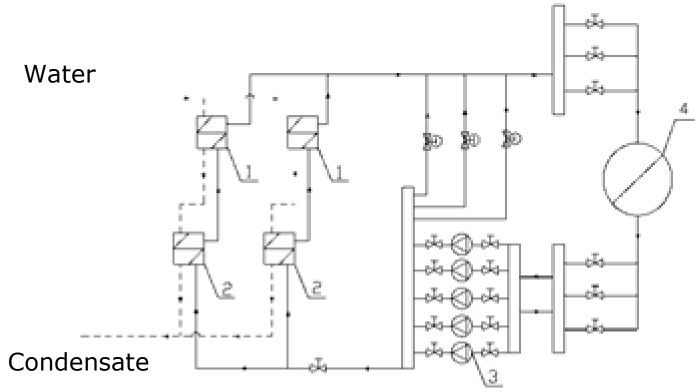
As depicted, the distribution thermal network is formed by three independent loops (two with a nominal diameter of 600 mm and one with a nominal diameter 500 mm), with 5 secondary side pumps deployed to force water flow, as necessary over them.

Energy delivery from the district heating plant takes place through 4 energy delivery heat exchangers. Two of them are connected through specific hydraulic circuits, including primary side pumps (boiler pumps), respectively to boilers HOB1 and HOB2. The last two heat exchangers are coupled to boiler HOB3, through two parallel hydraulic circuits, each including a dedicated primary side pump (boiler pumps).

On the other hand, the two steam boilers are connected in parallel to a common steam production loop that provides the steam required by the primary side of the two existing hot water production lines.

Each of these hot water production lines is formed by a condenser (steam-water heat exchanger) and a condensate sub-cooler (water-water heat exchanger) connected in series in order to maximize the energy extracted from the steam flow and the efficiency of the energy transfer.

The secondary side of the two condenser and sub-cooler couples are connected in parallel to the main supply and return manifolds of the secondary side pumps of the distribution thermal network. The following picture describes the hydraulic connection scheme of the 2 heating lines to the distribution thermal network and to the steam delivery loop. This is the active connection scheme when the plant is operated according to the summer mode.



Key

1. IT-Super heaters
2. IT-Subcoolers
3. Circulation pumps for DH network

Figure 60 Hydraulic scheme of the connection of the condensers and sub-coolers of the district heating plant to the thermal network

The outlet condensate produced by the primary side of the two hot water production lines is connected to the steam production line and conducted to the steam boilers through the existing condensate return pump.

In the following lines the operational criteria of the heating plant for the winter season and for the summer season are displayed in a compact shape.

Winter operational mode:

- The boiler with economizers are used as leading generators of the plant, and are operated at full capacity to take advantage of the 5% performance improvement provided by the economizers.
- The supply and return temperature setpoint values are adjusted according to weather compensation strategies (outdoor temperature and wind speed). The Nominal setpoint values are 120°C for the network supply temperature and 65 °C for the return temperature with an outdoor temperature of -12 °C and wind speed values greater than 10 m/s.
- The primary side plant production temperature is adjusted according to the used fuel type. When the active hot water production boilers operate on natural gas, the SCADA system of the plant sets the outlet temperature setpoint to 150 °C, whereas when boilers operate on fuel oil the value of this setpoint is changed to 180 °C.
- The number of active energy delivery heat exchangers and hot water production boilers is adjusted according to the supply and return water temperature on the distribution thermal network (secondary side) in order to meet the existing setpoint values.
- The water flow rate circulating through the primary side of each energy delivery heat exchanger is adjusted by the primary side pumps equipped with variable frequency drives, according to the evolution over time of the secondary side outlet temperature to meet the existing thermal network supply temperature setpoint value.

- The energy delivered by the burner of each hot water production boiler is adjusted by the management system of the burners, according to the evolution over time of the water flow rate circulating through each boiler to meet the existing boiler outlet temperature setpoint value.
- The inlet water temperature to the hot water production boilers is kept above the minimum values using the existing mixing valves.
- The total secondary side water flow rate that is circulated through the distribution thermal network is adjusted by the secondary side thermal network pumps equipped with variable frequency drives to meet the existing differential pressure setpoint (4.4 bar in the Heating Plant or 5 bar in the hydraulically most unfavourable substations). The maximum water flow value will be of 2.650 m^3/h
  In any case, the variation of the total thermal network water flow rate is produced by the evolution over time of the water flow rate requested by the thermal substation, as the variation of substation primary side flow control valve position will affect the pressure losses at thermal network and substation level.
- The final distribution temperature is adjusted by the diverting valve.

Summer operational mode:

- The supply water temperature setpoint of the thermal network is set constant at 70 °C. (return 45-55 °C)
- The mass flow rate of steam delivered to the hot water production lines is adjusted according to the evolution over time of the hot water produced by the hot water production lines, to meet the setpoint value of the supply water temperature of the distribution thermal network. The value of the mass flow rate supplied to the hot water production lines is modified by a dedicated steam valve controlled by a field controller.
- The Temperature of the condensate from the subcoolers of the hot water production lines returning to the steam boilers is regulated adjusting the inlet water flow rate entering the secondary side of the subcoolers from the thermal network. This enables maximizing the energy extracted from the steam supplied by the boilers.
- The total secondary side water flow rate that circulated through the distribution thermal network is adjusted by the secondary side thermal network pumps to meet the existing differential pressure setpoint (1,8 bar). The water flow value will be adjusted in the range between 550 and 790 m^3/h
- The final distribution temperature is adjusted by the diverting valves.

As has already been described, the connection of the buildings to the thermal network is solved through indirect substations, formed by a plate heat exchanger.

9.3.4.2 Integrated district model definition

In the case of this pilot, the integrated district heating and DER system model, consists in the district heating system and the buildings connected to it. Therefore, the developed model is formed by:

- The EnergyPlus models of the buildings included inside the scope the pilot, modeled according to the criteria described in precedent sections of this chapter.
- The Modelica model of the Vozdovac district heating system, including:
    - A detailed modeling of the district heating plant.
    - A detailed modeling of the topology of the distribution thermal network included inside the scope of this pilot.
    - A detailed modeling of the integration of the thermal network and of the 46 buildings of the Stepa Stepanovic neighborhood included within the scope of this pilot.

As already explained, the energy requested by the buildings of the pilot to the thermal network at the building substation level, is calculated through the EnergyPlus models developed for the buildings of the district.

For each modeled building, the flow conditions on the secondary side of the building substations (inlet temperature curve, outlet temperature curve and water flow rate curve) will be calculated with a calculation time step resolution for the complete prediction period, and used according to the defined offline co-simulation procedure, as inputs in the district heating Modelica model, to evaluate the impact of the dynamics present at district level and calculate the energy actually requested to the district heating plant, and the fuel consumption required to produce that energy.

As previously described, taking into account the number of similar residential buildings included in this pilot, in order to reduce the required calculation time, only some representative buildings will be simulated (6), as the energy request profiles of the rest of the residential buildings can be obtained through post processing of the curves obtained for the actually simulated buildings.

The Modelica model of the Vozdovac district heating system, has been generated connecting, as necessary, the required subsystem models of the MOEEBIUS Modelica Library, to reproduce the typology of the district heating plant and the topology of the thermal network of the Vozdovac district heating system.

As explained in D3.3, these models have been developed, encapsulating the physical behaviour of all the equipment deployed on each of the actual subsystems, reproducing their modularity and connectivity rules.

More specifically, in the case of the Vozdovac district heating system, the following subsystem models from the MOEEBIUS Modelica Library have been necessary to configure the model.

- An instance of the district heating plant model.
- An instance of the pumping station model.
- 47 instances of the building substation model to integrate the impact of the residential buildings of the pilot.
- An instance of the Loop/branch model to represent the main loop of the thermal network included in the scope of the pilot.
- The required number of instances of the Loop/Branch model necessary to reproduce the hierarchy of branches associated to the actual topology of the distribution thermal network, to enable the integration of the energy request profiles according to the actual physical distribution of the buildings over the pilot.
- 2 instances of the building substation model to integrate the impact of the heating system and of the ventilation system of the Stepa Stepanonic Primary School.
- 2 instances of the building substation model to integrate the impact of the heating system and of the ventilation system of the Stepa Stepanonic Kindergarten.

In the following picture a simplified view of the subsystem model connection scheme is displayed, where only a fraction of the branch loop hierarchy and some of the buildings connected to the district heating system are represented. Taking into account the high number of buildings of the pilot connected to the district heating system and the complexity of the topology of the distribution thermal network, due to space limitations the detailed connection diagram is omitted.

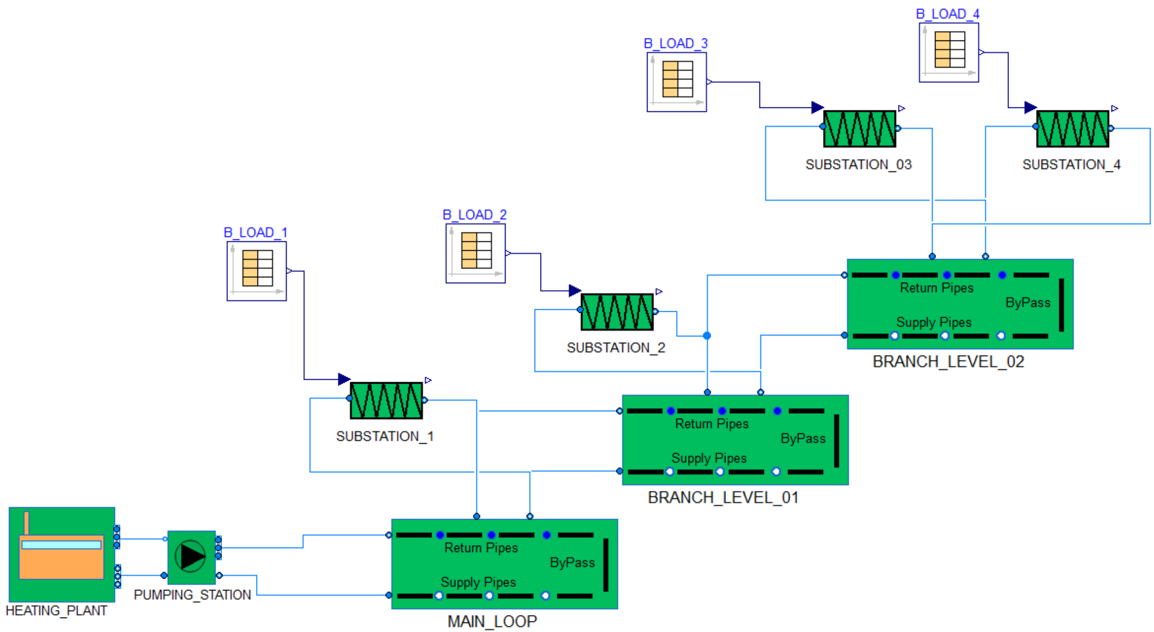


Figure 61 Simplified connection scheme of the subsystem MOEEBIUS Modelica components for the model developed for the part of the Vozdovac district heating system included within the scope of the pilot.

Additionally taking advantage of the flexibility provided by the models, some of them have been configured, giving the adequate value to the relevant input parameters, to adjust them to the specificities, the typology and technical solutions existing on the Vozdovac district heating system. More specifically:

- District heating plant model.
  - Number of hot water generation groups adjusted to 3.
  - Number of hot water generation groups with storage capacity adjusted to 0.
  - Number of Steam boilers adjusted to 2.
  - Number of hot water production lines using steam as energy source adjusted to 2.
  - Number of energy delivery heat exchangers adjusted to 4.
- Pumping station model.
  - Number of pumping groups adjusted to 1.
  - Number of pumps of the single pumping group adjusted to 5.

In the following figure, the physical devices encapsulated within the hot water production plant of the district heating plant of the Vozdovac district heating system are displayed.

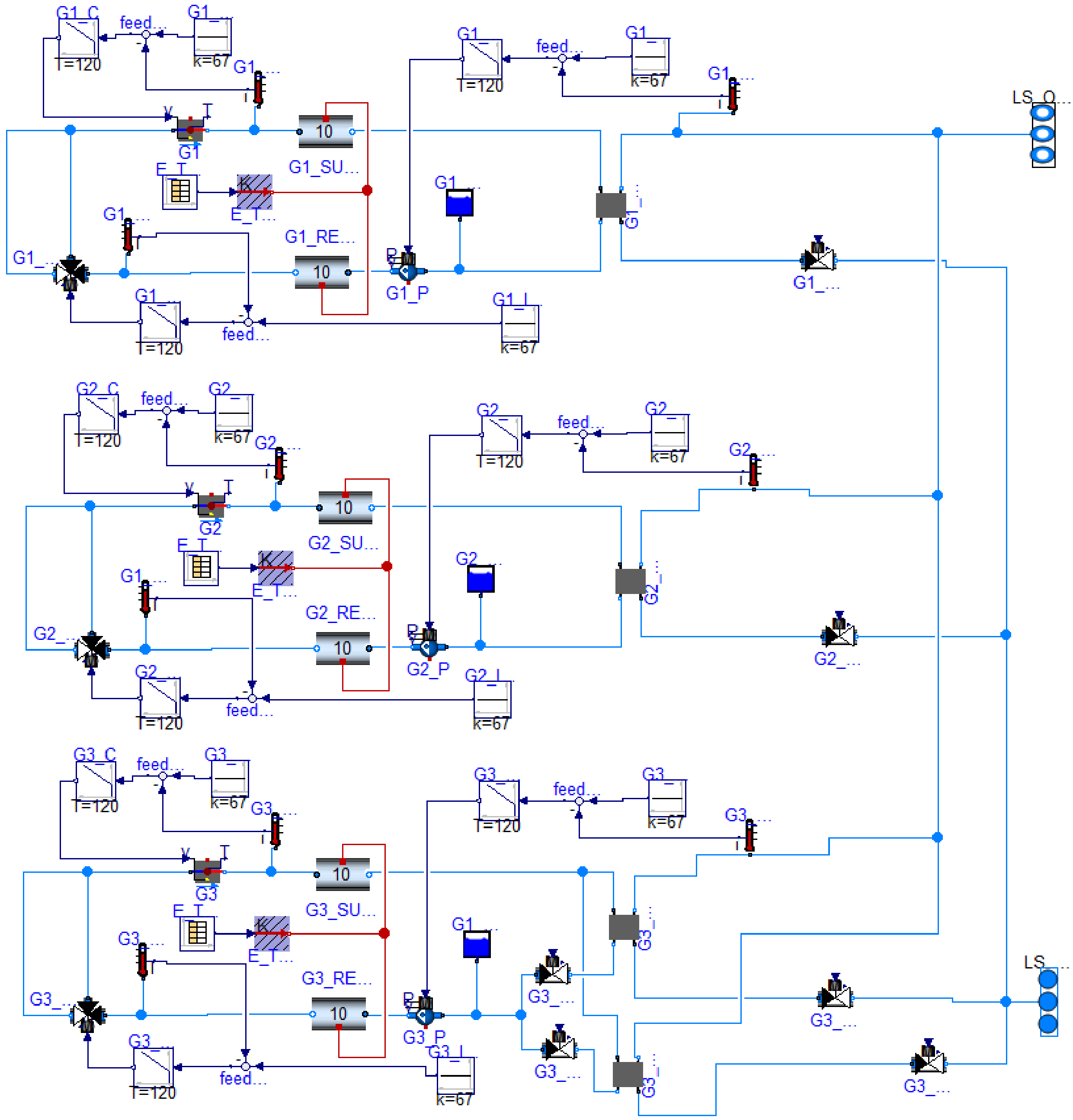


Figure 62 Connection scheme of the component models encapsulated inside the hot water production part of the heating plant subsystem model for the Vozdovac district heating system

Hot water plant	
Component name	**Description**
G1	Generator 1
G1_SUP_PIPE	Generator 1 supply pipe
G1_RET_PIPE	Generator 1 return pipe
G1_M_V	Generator 1 mixing valve
G1_HE	Generator 1 heat exchanger
G1_LS_IV	Generator 1 loads side inlet valve
G1_P	Generator 1 pump
G1_SS_V	Generator 1 source side valve

G1_EB	Generator 1 loop expansion vessel
G1_SSPT	Generator 1 supply setpoint temperature
G1_C	Generator 1 controller
G1_STS	Generator 1 supply temperature sensor
G1_MV_C	Generator 1 mixing valve controller
G1_ITSP	Generator 1 inlet temperature setpoint
G1_ITS	Generator 1 inlet temperature sensor
G1_HE_C	Generator 1 heat exchanger controller
G1_HE_SP	Generator 1 heat exchanger outlet temperature setpoint
G1_HE_S	Generator 1 heat exchanger outlet temperature sensor
G1_P_C	Generator 1 pump controller
G1_DP_SP	Generator 1 pump differential pressure setpoint
DP_S1	Generator 1 differential pressure sensor
G2	Generator 2
G2_SUP_PIPE	Generator 2 supply pipe
G2_RET_PIPE	Generator 2 return pipe
G2_M_V	Generator 2 mixing valve
G2_HE	Generator 2 heat exchanger
G2_LS_IV	Generator 2 loads side inlet valve
G2_P	Generator 2 pump
G2_SS_V	Generator 2 source side valve
G2_EB	Generator 2 loop expansion vessel
G2_SSPT	Generator 2 supply setpoint temperature
G2_C	Generator 2 controller
G2_STS	Generator 2 supply temperature sensor
G2_MV_C	Generator 2 mixing valve controller
G2_ITSP	Generator 2 inlet temperature setpoint
G2_ITS	Generator 2 inlet temperature sensor
G2_HE_C	Generator 2 heat exchanger controller
G2_HE_SP	Generator 2 heat exchanger outlet temperature setpoint
G2_HE_S	Generator 2 heat exchanger outlet temperature sensor
G2_P_C	Generator 2 pump controller
G2_DP_SP	Generator 2 pump differential pressure setpoint
DP_S2	Generator 2 differential pressure sensor
G3	Generator 3
G3_SUP_PIPE	Generator 3 supply pipe
G3_RET_PIPE	Generator 3 return pipe
G3_M_V	Generator 3 mixing valve
G3_HE_1	Generator 3 heat exchanger 1
G3_LS_IV	Generator 3 loads side inlet valve
G3_P	Generator 3 pump
G3_SS_V	Generator 3 source side valve
G3_EB	Generator 3 loop expansion vessel
G3_PS_RV_1	Generator 3 primary side return valve 1
G3_PS_RV_2	Generator 3 primary side return valve 2
G3_SSPT	Generator 3 supply setpoint temperature
G3_C	Generator 3 controller
G3_STS	Generator 3 supply temperature sensor
G3_MV_C	Generator 3 mixing valve controller
G3_ITSP	Generator 3 inlet temperature setpoint
G3_ITS	Generator 3 inlet temperature sensor
G3_HE_C	Generator 3 heat exchanger controller
G3_HE_SP	Generator 3 heat exchanger outlet temperature setpoint
G3_HE_S	Generator 3 heat exchanger outlet temperature sensor

G3_P_C	Generator 3 pump controller
G3_DP_SP	Generator 3 pump differential pressure setpoint
DP_S3	Generator 3 differential pressure sensor
LS_INLET	Load side inlet port
LS_OUTLET	Load side outlet port

Table 19 Component models encapsulated inside the hot water production part of the heating plant subsystem model for the Vozdovac district heating system

In the next figure, the physical devices encapsulated within the steam production plant of the district heating plant of the Vozdovac district heating system are displayed.

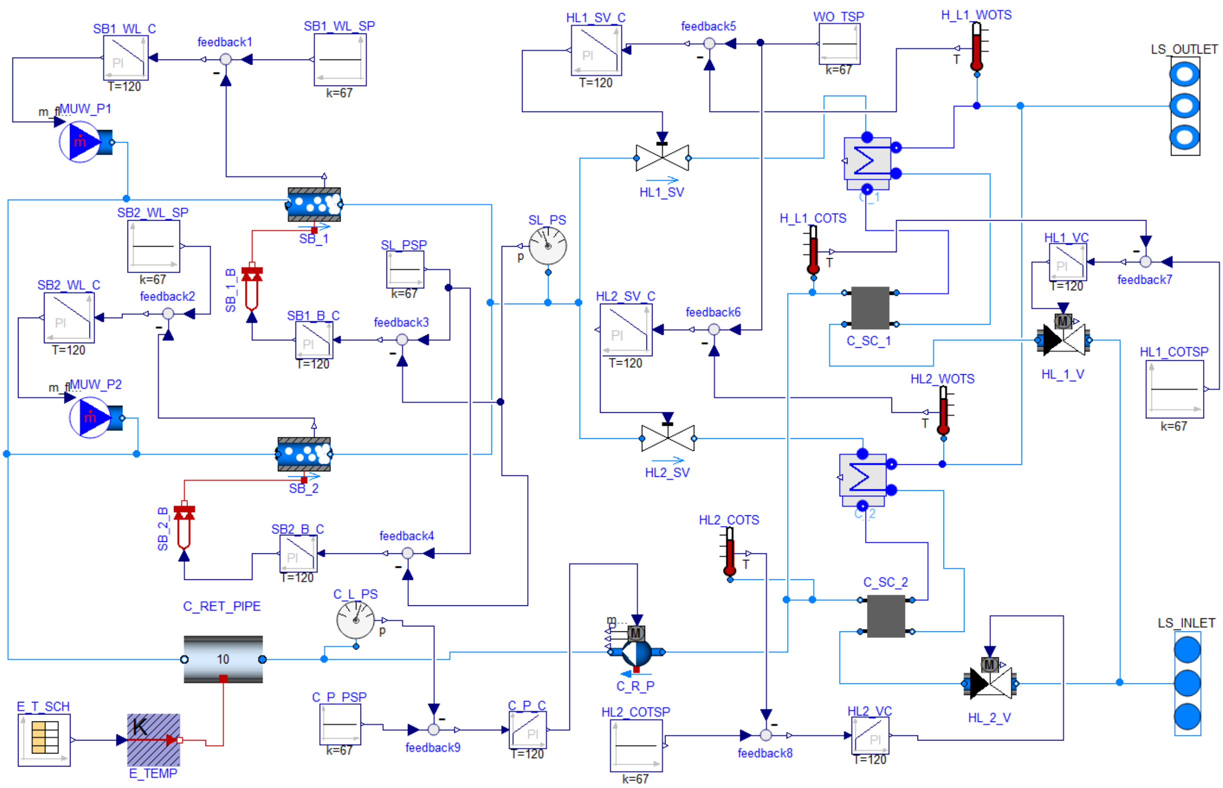


Figure 63 Connection scheme of the Component models encapsulated inside the steam production part of the heating plant subsystem model for the Vozdovac district heating system

Steam production plant	
Component name	**Description**
SB_1	Steam boiler 1
SB_2	Steam boiler 2
SB_1_B	Steam boiler burners 1
SB_2_B	Steam boiler burners 2
MUW_P1	Makeup water pump 1
MUW_P2	Makeup water pump 2
HL1_SV	Heating line 1 steam valve
HL2_SV	Heating line 2 steam valve
C_1	Heating line 1 Condenser
C_2	Heating line 2 Condenser

C_SC_1	Condensate sub-cooler 1
C_SC_2	Condensate sub-cooler 2
HL_1_V	Heating line 1 valve
HL_2_V	Heating line 2 valve
C_R_P	Condensate return pump
C_RET_PIPE	Condensate return pipe
LS_OUTLET	Load Side outlet port
LS_INLET	Load side inlet port
SL_PS	Steam line pressure sensor
C_L_PSP	Condensate line pressure setpoint
C_L_PS	Condensate line pressure sensor
H_L1_WOTS	Heating line 1 water outlet temperature sensor
H_L2_WOTS	Heating line 2 water outlet temperature sensor
H_L1_COTS	Heating line 1 condensate outlet temperature sensor
H_L2_COTS	Heating line 2 condensate outlet temperature sensor
SB1_WL_SP	Steam boiler 1 water level setpoint
SB2_WL_SP	Steam boiler 2 water level setpoint
SB1_WL_C	Steam boiler 1 water level controller
SB2_WL_C	Steam boiler 2 water level controller
SL_PSP	Steam line pressure setpoint
SB1_B_C	Steam boiler 1 burner controller
SB2_B_C	Steam boiler 2 burner controller
WO_TSP	Hot water outlet temperature setpoint
HL1_SV_C	Heating line 1 steam valve controller
HL2_SV_C	Heating line 2 steam valve controller
HL1_COTSP	Heating line 1 condensate outlet temperature setpoint
HL2_COTSP	Heating line 2 condensate outlet temperature setpoint
HL1_VC	Heating line 1 valve controller
HL2_VC	Heating line 2 valve controller

Table 20 Component models encapsulated inside the steam production part of the heating plant subsystem model for the Vozdovac district heating system

Finally, in the following picture the physical devices encapsulated within the pumping station model of the Vozdovac district heating system are displayed. For simplicity, only the control components associated to pumps 2 and 5 have been included in the figure.

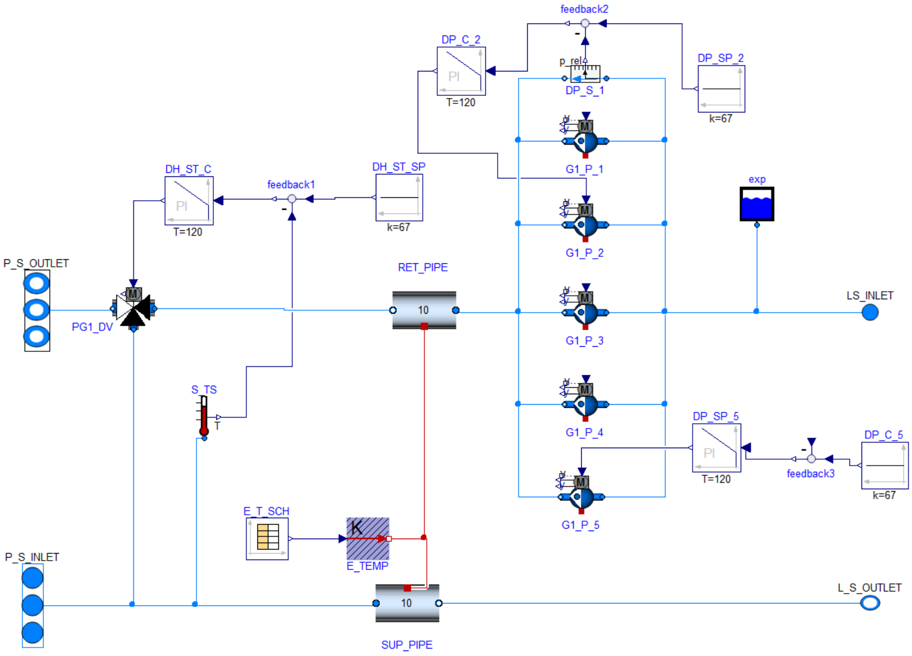


Figure 64 Connection scheme of the component models encapsulated inside the pumping station subsystem model for the Vozdovac district heating system

Pumping station	
Component name	**Description**
P_S_INLET	Plant side inlet port
P_S_OUTLET	Plant side outlet port
LS_INLET	Load side inlet port
L_S_OUTLET	Load side outlet port
SUP_PIPE	Supply pipe
RET_PIPE	Return pipe
Exp	Expansion vessel
G1_P_1	Group 1 pump 1
G1_P_2	Group 1 pump 2
G1_P_3	Group 1 pump 3
G1_P_4	Group 1 pump 4
G1_P_5	Group 1 pump 5
DP_S_1	Differential pressure sensor 1
DP_S_2	Differential pressure sensor 2
DP_S_3	Differential pressure sensor 3
DP_S_4	Differential pressure sensor 4
DP_S_5	Differential pressure sensor 5
PG1_DV	Diverting valve
DP_SP_1	Differential pressure setpoint 1
DP_C_1	Differential pressure controller 1
DP_SP_2	Differential pressure setpoint 2
DP_C_2	Differential pressure controller 2
DP_SP_3	Differential pressure setpoint 3
DP_C_3	Differential pressure controller 3
DP_SP_4	Differential pressure setpoint 4
DP_C_4	Differential pressure controller 4

DP_SP_5	Differential pressure setpoint 5
DP_C_5	Differential pressure controller 5
DH_ST_SP	District heating supply temperature setpoint
DH_ST_C	District heating supply temperature controller
S_TS	Supply temperature sensor
E_T_SCH	Environment temperature schedule
E_TEMP	Environment temperature

Table 21 Component models encapsulated inside the pumping station subsystem model for the Vozdovac district heating system

Finally, and to conclude the definition of the district heating and thermal DER model, all the specifications of the equipment included in the model have been populated through the input menus provided by each subsystem model, including the specification for the following equipment:

- District heating plant model.
    - Hot water production boilers.
    - Primary side pumps.
    - Hot water boiler inlet temperature control valves.
    - Steam production boilers.
    - Stream production boiler burners.
    - Water makeup system for steam boilers.
    - Energy delivery heat exchangers.
    - Condensate return pump.
    - Pipes and fittings of hydraulic loops.
    - District heating plant environmental conditions (monthly evolution of indoor air temperature).
    - Control devices (valves, field controllers, etc.) and operational criteria (control sequences, setpoints, etc.).
- Pumping station model.
    - Secondary side pumps (thermal network distribution pumps).
    - Distribution temperature adjustment mixing valve.
    - Pipes and fittings of hydraulic loops.
    - Pumping station environmental conditions (monthly evolution of indoor air temperature).
    - Control devices (valves, field controller, etc.) and operational criteria (control sequences, setpoints, etc.).
- Main Loop model
    - Supply and return pipes.
    - Bypass pipe.
    - Ground boundary conditions (monthly temperature evolution over time)
- Branch Loops of the branch hierarchy that form the topology of the thermal network.
    - Supply and return pipes.

  - Ground boundary conditions (monthly temperature evolution over time)
- Building thermal substation models.
  - Energy delivery heat exchangers.
  - Primary side energy delivery control, 2 way proportional valves.
  - Pipes and fittings of the hydraulic connections to the thermal network.
  - Control devices (field controllers, etc.) and operational criteria (setpoints, etc.).

The information required to populate each model instance was collected in the frame of Task D7.2. Taking into account the high the number of the equipment involved in the definition of the district model, the details about equipment specifications are omitted here, in order to contribute to the brevity and clarity of this document.

The model developed according to this offline co-simulation procedure enables addressing all the relevant dynamics present in the different subsystems, with a complexity level consistent with the required accuracy.

- Heat generator performance.
- Pressure driven flow control algorithms.
- Pump consumption calculation in all the hydraulic loops.
- Performance of the energy delivery heat exchangers (plate heat exchangers).
- Performance of the condensers and condensate sub-cooling heat exchangers.
- Distribution thermal losses over the thermal network.
- Thermal inertia of the distribution network and detailed thermal network temperature distribution.
- Dynamics present in the interface between the thermal network and the connected buildings (building thermal substation).
- Detailed control algorithms for all the relevant equipment of all the subsystems (heat generators, pumps, valves, etc.).

9.4 UK pilot model development.

In this section the modeling criteria followed to produce the building and district models of the UK pilot are described in full detail.

9.4.1 Moorhouse building

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.4.1.1 Architectural modelling specification

For the architectural modelling of the Moorhouse building, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following information was used for the definition of the models:

- Foster and Partners Architectural Scheme Design
- Site Pictures
- General site information

Material and component definition

The information related to the materials used in the construction and their thermal properties to be added to the model were collected directly using the ThermalLayersInfo template created for such purpose. The completed template from the School is presented below:

Construction Elements		Layer1		Layer2		Layer3		Layer4		Layer5	
WALLS		Material	Thickness [mm]	Material	Thickness [mm]	Material	kness [	Material	Thickness [mm]	Material	Thickness [mm]
1.1	External Walls										
1.2	Below Grade Walls										
1.3	Internal Partitions	Plasterboard A1 (single layer)	12,5	gap - stud	75	Plasterboard A1 (single layer)	12,5				
1.3	Internal Partitions	Plasterboard A2(double layer)	12,5	gap - stud	75	Plasterboard A2(double layer)	12,5				
1.4	Semi-exposed Walls	Double Glazzing		airspace	40	Double glazing					
ROOFS											
2.1	Pitched Roof (occupied)										
2.2	Pitched Roof (unoccupied)										
2.3	Flat Roof	Concrete slab	130	Mastic asphalt	30	Mastic asphalt	30	Polystyrene insulation	120	concrete paviours	65
FLOORS/CEILINGS											
3.1	Ground Floor - Basement	Concrete slab	400								
3.2	External Floor										
3.3	Internal Floor 1 (groundlevel)	Concrete slab	250	Gap-raised floor	300	Floor Finish-Nero Impala granite	41				
3.3	Internal Floor 2 (typical office floor)	Concrete slab	130	Gap-raised floor	150	Floor Finish	41				
3.3	Internal Floor 3 (Level 1)	Concrete slab	250	Gap-raised floor	150	Floor Finish	41				
3.4	Semi-exposed floor (ground floor retail)	Concrete slab	200	Screed finish	80						
3.5	Semi-exposed Ceiling	Plasterboard (double layer)	25	Gap	100						
OPENINGS											
		Composition [mm]	Solar Factor [%]	Frame Material							
4.1	External Windows										
		Material	Thickness [mm]								
4.2	External Doors	Steel									

Please, leave blank the leftover layers and the non-existent construction elements.
Windows Composition example: 4Neutral+6Air+6Neutral+LowE (=4mmExteriorGlassLayerNeutralColor+6mmAir+6mmInteriorGlassNeutralColor+LowECoating)

Facades

Northern Elevation - EWS 1
d) Glass: Double glazed units which will incorporate a neutral low E coating on face [cavity side of inner pane) of the unit. The double glazed unit will comprise an outer monolithic annealed pane with an inner laminated annealed pane and a black non metallic spacer bar .The light transmission for the double glazed unit is 60% minimum. Two glazed panels per floor on the North elevation will be openable for stair pressurization pressure relief.

Western Elevation - EWS 2
b) Glass: Double glazed unitswhich will incorporate a neutral selective performance coated glass-coating used on face 2 (cavity side of outer pane). The unit will comprise a monolithic annealed outer pane with two laminated annealed inner panes and a black nonrnetallicspacer bar. The total energy transmission required from the double glazed unit is 39%. The light transmission required from the double glazed unit is 50-60%.
All Glass panels will ne mechanically restrained.

Southern Elevation - EWS 3
Glass: The double glazed unit will incorporate neutral selective performance coated glass-coating used on face 2 (cavity side of outer pane) of the double glazed unit. The unit will comprise an outer monolithic annealed pane with two laminated annealed inner panes and a black non-metallic spacer bar. The total energy transmission required from the double glazed unit is 39%. The light transmission required from the double glazed unit is 52%. All glass panes are mechanically restrained.

Eastern Elevation - EWS 4
e) Glass: from level 1 to 16 the double glazed unit is a neutral selective performance coated glass. The coating shall be on face 2 (cavity side of the outer pane) ofthe double glazed unit. The unit will comprise an outer monolithic annealed pane and two laminated annealed inner panes, with a black non-metallic spacer bar. The total energy transmission required for the double glazed unit is 390f0. The light transmission required from the double glazed unit is 50-60010

Table 22 Thermal envelope of the MoorHose building

For each of the materials presented a family was created in the model, reflecting the exact properties from the real constructed building site

Below it is presented the pilot modelled compared with a real life picture.

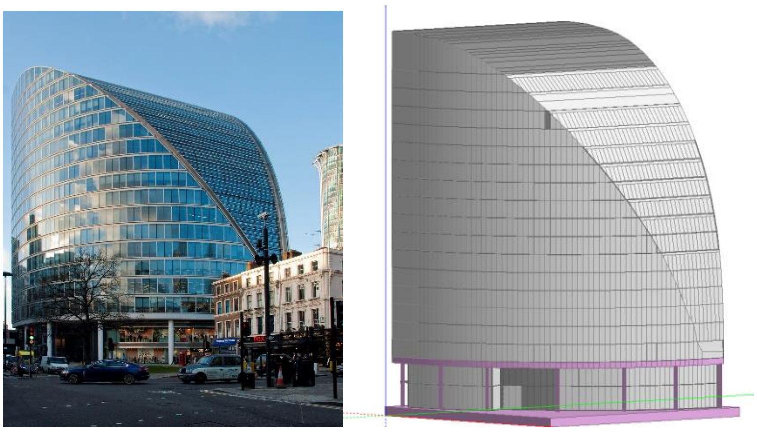


Figure 65 View of the simulation model of the Moorhouse

9.4.1.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

More specifically the definition process followed to configure the thermal zones integrated in the model consisted on the following sequence.

- Analysis of the activities existing on the building.
- Identification of the different zone types according to the developed activities.
- Classification/characterization of the zones of the building according to the defined types.
- Selection of a zone for each of the identified zone types (to be monitored in the deployment phase).
- Aggregation of the zones of the same type located in adjacent positions and served by the same HVAC system.
- The zones existing at the end of this sequence are considered the final thermal zones of the building

According to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Rooms with associated occupancy
  - Small retail center zone
  - Meeting rooms.

- Individual office rooms.
- Collective office rooms
- Archives
- Big Office equipment rooms (semi industrial printers)
- Lobbies
- Resting rooms/coffee rooms

• Room with no associated occupancy.
  - Toilets.
  - Corridors and circulation zones.
  - Technical rooms.
  - Server and IT equipment rooms
  - Storage rooms.

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal quality setpoints.

In the case of this building, due to confidentiality issues, only a limited deployment of sensors will be possible is some specific zone types (a meeting rooms, an office and one of the resting coffee rooms). Therefore, the general procedure of user behaviour evaluation described for the previous buildings will have to be modified as necessary in order to provide the input required by the **Bahavioural Profiling Engine** to produce actual usage input data for the building.

Finally, the thermal zones to be considered in the EnergyPlus model have been set. In this final step, apart from the room characterization, the HVAC systems serving each zone of the building have been considered. More specifically, the final thermal zone distribution of the EnergyPlus model is obtained after merging all the zones of the same type that are simultaneously served by the same HVAC system and are physically located next to each other.

The following pictures display the thermal zones of the EnergyPlus model of the building, including the representative building zones.

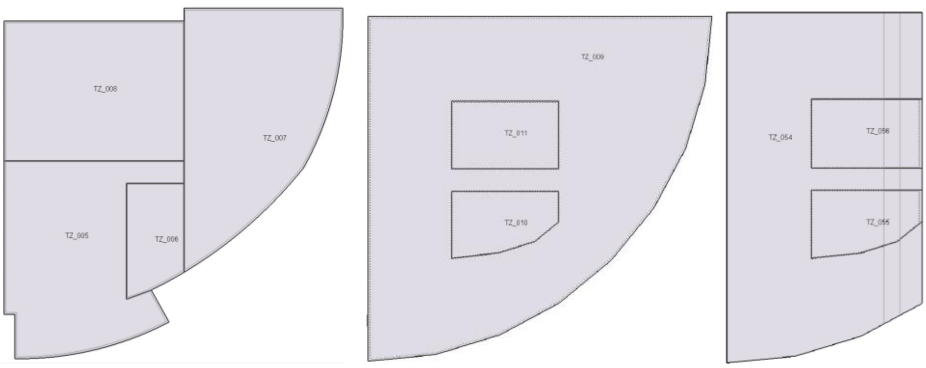


Figure 66Thermal zone distribution on floors 0 and 1 (Moorhouse building)

9.4.1.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main DER systems present in the building and integrated in the developed EnergyPlus model is included:

- The Heating system.
- The cooling system.
- The Ventilation system.
- The Artificial lighting system.
- The cooling system of the server rooms.
- The electric loads associated to the office activities (computers, etc.)
- The Electric loads associated to IT equipment (servers, etc.)
- The electric equipment associated to resting zones (cafeterias, etc.).

A centralized heating and cooling system produces and distributes (using water as energy carrier), the energy necessary to condition the zones of the building.

The cooling plant is formed by 6 air/water compression chillers deployed on the roof of the building. Similarly the heating plant consists on 3 gas fired boilers deployed inside a dedicated boiler room located on the last floor of the building.

The thermally treated water (heated/cooled) is distributed from the generation plants all over the building through a 4 pipe distribution subsystem to the terminal unit (four pipe fancoils) distributed at zone level and to the heating and cooling coils installed in the AHU-s that provide the required ventilation air to the building.

The topology of the heating and cooling distribution subsystem is formed by the following distribution loops, each of them equipped with pumping groups operating according to variable flow strategies:

- Heating distribution subsystem
  - Fan coils and AHU heating coil distribution loop (all the heating coils of fancoils and AHU-s are connected to the same loop)
- Cooling distribution subsystem
  - South riser (dedicated pumping group).
  - North riser (dedicated pumping group).
  - New south riser (pumping group shared with the north riser).
  - New north riser (pumping group shared with the south riser).

The ventilation system is formed by the following air handling units, each covering specific zones of the building:

- The AHU of the north office deployed on the roof.
- The AHU of the south office deployed on the roof.
- The AHU of the north office deployed on the mezzanine.
- The AHU of the south office deployed on the mezzanine.

- The AHU of the lift lobby.
- The AHU of the reception zone.

In the table below, the components of each of the existing AHU-s are summarized:

AHU	Heating coils	Cooling coils	Heat recovery HE
North office (roof)	X	X	X
South office (roof)	X	X	X
North office (mezzanine)	X		X
South office (mezzanine)	X		X
Lift lobby	X		X
Reception	X		X

Table 23 Description of the AHU-s of the Moorhouse building

Finally, the ventilation system of the building is completed by the exhaust fan systems coupled to duct networks deployed in all the toilets and some technical rooms.

As already stated, the emission subsystem is formed by four pipe fancoils, if necessary enabling the simultaneous delivery of heating and cooling according to the specific loads existing in each zone.

The heating and cooling plants provide the energy necessary for heating and cooling of the complete building with the exception of the server rooms located in several floors of the building. Being this, critical equipment, a dedicated cooling plant consisting on 9 medium sized chillers, exists in the building to provide permanent cooling to these rooms that operate according to a 24/365 schedule.

Regarding the electric/thermal loads associated to artificial lighting, food preparation/conservation equipment, and office/IT equipment the nominal power included in the data sheets of each equipment, gathered in the frame of Task 7.2, have been used to characterize them. In any case these values will be calibrated after the deployment of the MOEEBIUS platform in the pilot to capture their actual nominal power.

Regarding the impact of user behaviour on these loads, as a starting point, some static schedules provided by building owners have been considered. In any case, after the implementation of the MOEEBIUS platform in the pilot, actual user behaviour impact on these loads will be provided to the **BEPS** by the **Demand and Flexibility Engine** to update the model of the building accordingly.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems are present on this building. However, according to the existing electricity supply contract the coiling plant of the building is subject to the implementation of demand response strategies in time windows of 30 minutes. In order to enable these strategies, the

chiller plant is equipped with independent real time consumption metering for each chiller, and the hardware necessary to execute the remote deactivation of the required number of chillers.

The modelling criteria considered in the integration of all the DER-s described in the precedent paragraphs into the EnergyPlus model of this building will enable an accurate evaluation of the following dynamics:

- The performance of the boilers.
- The performance of the compression chillers.
- Thanks to the accurate modelling of the topology of the distribution subsystem, the thermal losses and water temperature distribution over the distribution loops.
- The energy delivery from the emission subsystem (4 pipe fancoils and AHU heating and cooling coils).
- The performance and behaviour of all the pumping equipment.
- The performance and behaviour of all the components of the AHU-s (fans, heating/cooling coils, dampers, heat recovery heat exchangers).
- The performance and behaviour of the auxiliary exhaust ventilation systems.
- The performance and behaviour of the artificial lighting system and its impact on zone thermal balance.
- The energy consumption over time due to electric loads related to food preparation and conservation equipment and their impact on zone thermal balance.
- The energy consumption over time due to electric loads related to office and IT equipment and their impact on zone thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the building.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystems of the buildings.
- The dynamics related to the implementation of the demand side management strategies.

In summary, the EnergyPlus model of this building includes a detailed modelling of all the DER-s present in the building and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables of all the systems and equipment existing on the building.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system, reproducing the typology and topology of the actually deployed systems.

9.4.1.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance
The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU
Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling
Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 24 Summary of the EMS programs integrated into de EnergyPlus model of the Moorhouse building

9.4.2 Ernest Dence residential complex

In this section the modelling criteria used to generate the EnergyPlus model of this building is provided, including specific sections related to:

- Architectural modelling
- Activity and thermal zone modelling.
- DER system modelling.
- New model integration (building level DER systems and IAQ).

9.4.2.1 Architectural modelling specification

For the architectural modelling of the residential block in London, data related to the geometry and material definition of the building was extracted from the pilot site as part of T7.2.

Geometry data gathered

The following information was used for the definition of the models:

- EAST-001
- ETDE-022
- ETDE-043
- ETDE-049
- ETDE-051
- ETDE-063
- ETDE-071
- ETDE-083
- ETDE-087

Material and component definition

In this case, the information related to the construction materials and their thermal properties could just be deducted from scattered sources as old documents and on-site visits. This could be a regular scenario for future applications of MOEEBIUS in old buildings, like these residential blocks, where the original construction information is partially or totally missing. Consequently, for cases like this the webtool[1] funded by the European projects TABULA and EPISCOPE can be consulted to extract the common thermal properties for a building depending on its type, age and country.

For a multifamily block in England built between 1919 and 1944, according to TABULA, the usual thermal properties would be as listed in the following table:

[1] http://webtool.building-typology.eu

Construction element	U-value (W/m^2·K)
Pitched roof with glabes	2.30
Solid brick	2.10
Flat floors	0.4
Windows* (wood frame, single glaze)	4.8
External doors (wood)	3.00

Table 25 Thermal envelope of the Ernest Dence residential complex

*During on-site visits, it was observed that the windows had been renovated by standard double glazing ones. Therefore, windows' U-value has been set to 2.20 W/m2·K in the EnergyPlus model of the building.

Below it is presented the pilot modelled compared with a real life picture.

Figure 67 Simulation model of the Ernest Dence residential building

9.4.2.2 Zone and activity modelling specification

In this section, the activities developed in the different zones of the building will be described, along with the criteria used to define the thermal zones considered in the EnergyPlus model of this building.

In the case of the residential buildings the thermal zone definition process can be greatly simplified, as according to the information collected in the frame of Task 7.2 and the input provided by building owners, the following zone types can be found regarding the developed activities.

- Zones with residential activity
- Common areas and other non-residential activities.

The definition of the types of rooms was made taking into account activity schedules, occupancy densities, metabolic rates, equipment internal gains and thermal comfort and internal quality setpoints.

The optimization of the number of the defined thermal zones of the model is a key factor to contribute to reduce the required calculation times. This will be a critical issue during the operational stage of the MOEEBIUS platform. As a consequence, the following thermal zone definition criteria have been adopted:

- Each apartment will form and independent thermal zone.
- All the common area of each floor will be merged into the a single zone

The following pictures display the thermal zones of the EnergyPlus model of the complex.

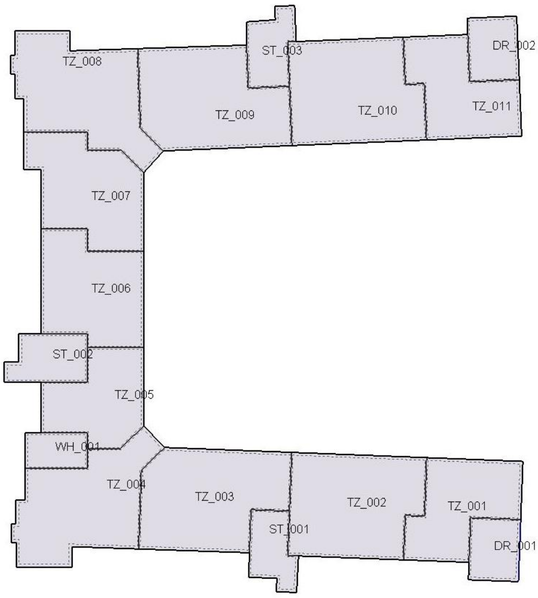


Figure 68 Thermal zone distribution on the ground floor (B1 building of the Ernest Dence complex)

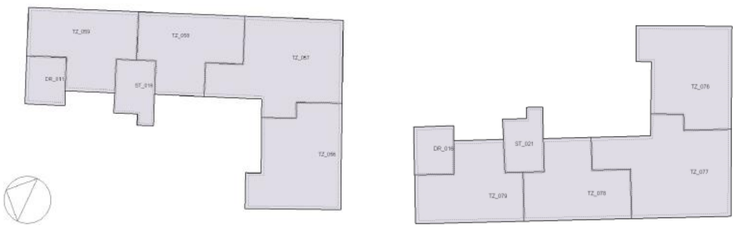


Figure 69 Thermal zone distribution on the ground floor (B2 and B3 buildings of the Ernest Dence complex)

9.4.2.3 DER system modelling specification

In this section the modelling specification of the thermal/electrical loads and distributed generation systems existing in this building is provided. Below the summary of the main loads present in this building and integrated in the developed EnergyPlus model is included:

- Heating.
- Domestic hot water production.
- Artificial lighting system.
- Domestic household appliances (refrigerator, domestic appliances, washing machines, etc.).

A common heating plant deployed on a dedicated plant building and formed by 3 hot water boilers produces the energy requested by the 3 buildings of this residential complex. From there, the produced energy is distributed all over the complex through two distribution loops equipped with specific pumping groups. All these pumps operate according to constant flow control strategies.

The emission subsystem of the heating system of the complex is formed by hot water radiators, deployed on the rooms of the apartments.

The toilets and kitchens of the apartments include dedicated mechanical exhaust fan systems, but the ventilation of the rest of the rooms is solved through natural ventilation.

The energy necessary for DHW production is not generated by the heating plant of the complex, instead, DHW production takes place at apartment level, through domestic electric water heaters.

Regarding the electric loads associated to artificial lighting and household appliances, as it is well known, the deployed systems and their exploitation are strongly affected by user behaviour. As a consequence, several different scenarios have been identified in the apartments of these residential buildings.

Therefore, as a starting point, a baseline has been defined to represent the typical impact of these electric loads on the residential buildings, to be modified to represent the actual impact of each apartment on the total load of the building, by means of model calibration after the deployment of the MOEEBIUS platform in the pilot.

Regarding RES and distributed generation technologies, it is necessary to mention that at this stage of the project none of these DER systems exist on the complex.

The modelling criteria considered in the integration into the EnergyPlus model of the residential complex of all the DER-s described in the precedent paragraphs will enable an accurate evaluation of the following dynamics:

- The performance of the boilers.
- Thanks to the accurate modelling of the topology of the distribution subsystem, the thermal losses and water temperature distribution over the building loops.
- The energy delivery from the emission subsystem (hot water radiators) at zone level.
- The performance and behaviour of all the pumping equipment.
- The performance and behaviour of the artificial lighting system.
- The performance and behaviour of the exhaust ventilation systems (toilets and kitchens).
- Performance and behaviour of the DHW production systems deployed at apartment level.

- The energy consumption over time due to household appliances (washing machines, fridge, tv, domestic computers, etc.) and their impact on apartment room thermal balance.
- The dynamics present in the supervisory control sequences of all the equipment of the different subsystems of the building.
- The evolution over time of room level thermal comfort and internal air quality conditions.
- The impact of user behaviour on room thermal balance and on the operation of all the subsystem of the building.

In summary, the EnergyPlus model of this residential complex includes a detailed modelling of all the present DER-s, and can provide specific outputs with a time resolution of up to 1 minute for all the operational variables of all the systems and equipment existing on the buildings.

Taking advantage of these outputs, as will be described in full detail in D5.1 the relevant KPI-s, as defined in Task 2.3, will be generated by a dedicated EMS program.

As the main load present in the building, special attention has been paid to provide an accurate modelling of the HVAC system, reproducing the typology and topology of the actual system.

9.4.2.4 Model integration through EMS programs

In this section the EMS programs integrated into the model and the provided functionalities are displayed in a compact shape:

EMS Program	Functionality
The contaminant increase/decrease component calculation program (one per thermal zone and contaminant)	Calculation of the different components that affect the room contaminant balance
The zone contaminant balance calculation program (one per thermal zone and contaminant)	Calculation of the room contaminant concentration
Thermal Zone Thermal Comfort Profile Definition Program (one per thermal zone)	Dynamic update of comfort setpoint profiles
AHU Control program (one per AHU)	Definition of the ventilation air to be delivered to the zones served by each AHU
Singular thermal/electric loads calculation program (one per singular thermal/electric load)	Singular thermal/electric load modelling

Thermal modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding some thermal modeling aspects (infiltration values, thermal envelope properties, etc.) with actual values
Activity modelling program	Substitution in the EnergyPlus models of the assumptions included in the BIM models regarding activity description (occupancy profiles, internal heat gains etc.) with actual values
KPI calculation program	Calculation of the KPI-s as defined in Task 2.3 taking advantage of the output provided by the Model

Table 26 Summary of the EMS programs integrated into the EnergyPlus model of the Ernest Dence residential Complex

9.4.3 Integrated district model

In this section the modelling specification of the integrated district model for the UK pilot is included in a compact shape.

In this case, at this stage of the project all the DER-s (loads and distributed generation systems) are physically deployed at building level and a thermal supply from a district heating system is not available.

Therefore, at this stage of the project there is not any district level dynamics or infrastructure to be modelled in order to enable district level aggregated thermal, electricity and gas demand prediction delivery.

In summary, the aggregation of the predictions provided by the EnergyPlus models of the buildings of the pilot, can provide all the DER system modelling capabilities required by the district level DAE to operate successfully.

However, in the last months intensive contacts have been established with several hotel building owners in order to enable the addition of a hotel building to the UK pilot, as an additional added value for the project.

In the case of one of these hotels the activities had a successful outcome and as a consequence, it is expected that this building will be added to the pilot. If these good expectations are definitively confirmed, the corresponding EnergyPlus model will be developed before the deployment phase of the MOEEBIUS platform in the pilots.

Similarly, additional activities are ongoing to complete the currently existing DER-systems with some district level distributed generation systems. As before, according to the outcome of these efforts, the integrated district model will be adapted and expanded, as necessary.

10 Conclusion

In this deliverable, all the activities carried out to integrate the models developed in the previous tasks of WP3 into EnergyPlus, in order to provide the modelling capabilities, required to produce building and district level predictions, have been documented.

As a starting point, direct incorporation of the models into EnergyPlus IDF files using the advanced ERL programing language functionality and EMS programs, has been identified as the most suitable approach taking into account the existing constraints (complexity level of the mathematical models).

For each of the models, the EMS programs necessary to implement their integration into EnergyPlus have been defined and the EnergyPlus class instances necessary to enable the interaction of these models with the relevant standard models of EnergyPlus identified.

Additionally, and taking advantage of the capabilities provided by the ERL language the procedure to, going beyond the information provided by the static BIM models, dynamically update the values of the key thermal parameters of the EnergyPlus models with actual information of each specific building has been defined (EMS programs and EnergyPlus class instances).

On other hand, the relevance of having a **Weather Data File Generation Engine,** with the capacity to generate EnergyPlus weather data files for different simulations purposes (calibration, prediction, retrofitting) using data from different sources (historic data for calibration and forecasted data for predictions) has been identified and the developed implementation approach described.

Finally the modelling criteria used to develop the EnergyPlus and the Modelica models used to generate the Integrated District Model of each pilot, with the information gathered in Task 7.2, have been described. As was defined in D.3.3 the Modelica models have been produced taking advantage of the Subsystem Modelica models included in the MOEEBIUS Modelica Library.

Finally, it is necessary to mention that pilot simulation models have been uploaded to the Google Drive of the project (goo.gl/weXBHI) to be publically available. These models will be updated until the completion of the project as necessary, to adapt them to any possible modification that might be required along the different stages of the project to guarantee the best possible deployment of the MOEEBIUS Platform in all the pilots.