BIMERR
RENOVATION 4.0

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Building resident energy-related behaviour profiling framework 1

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The BIMERR project consortium is composed of:		
FIT	Fraunhofer Gesellschaft Zur Foerderung Der Angewandten Forschung E.V.	Germany
CERTH	Ethniko Kentro Erevnas Kai Technologikis Anaptyxis	Greece
UPM	Universidad Politecnica De Madrid	Spain
UBITECH	Ubitech Limited	Cyprus
SUITE5	Suite5 Data Intelligence Solutions Limited	Cyprus
HYPERTECH	Hypertech (Chaipertek) Anonymos Viomichaniki Emporiki Etaireia Pliroforikis Kai Neon Technologion	Greece
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AUTHORS LIST

Leading Author (Editor)			
Surname	First Name	Beneficiary	Contact email
Giannakis	Giorgos	HYPERTECH	g.giannakis@hypertech.gr

Co-authors (in alphabetic order)				
#	Surname	First Name	Beneficiary	Contact email
1	Athanasiadou	Georgia	UOP	gathanas@uop.gr
2	Gonzalez-Gerpe	Salvador	UPM	sgonzalez@delicias.dia.fi.upm.es
3	Katsos	Marios	HYPERTECH	m.katsos@hypertech.gr
4	Kontaxis	Dimitrios	UOP	dkontax@uop.gr
5	Papapolyzos	Thomas	HYPERTECH	thomas@hypertech.gr
6	Poveda-Villalón	Maria	UPM	mpoveda@fi.upm.es
7	Prekas	Georgios	CONKAT	gprekas@konkat.gr
8	Tsoulos	George	UOP	gtsoulos@uop.gr
9	Zarbouti	Dimitra	UOP	dzarb@uop.gr
10	Zielinski	Marcin	BX	drmarcin.zielinski@budimex.pl

REVIEWERS LIST

List of Reviewers (in alphabetic order)				
#	Surname	First Name	Beneficiary	Contact email
1	Lampathaki	Fenareti	SUITE5	fenareti@suite5.eu
2	Hanel	Tobias	FER	thanel@ferrovial.com

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ACRONYMS

Acronym	Meaning
AC	Air Conditioning
API	Application Programming Interface
BEP	Building Energy Performance
BICA	Building Information Collection Application
BIF	BIMERR Interoperability Framework
BIMERR	BIM-based holistic tools for Energy-driven Renovation of existing Residences
BIM	Building Information Modelling
GUID	Global Unique Identifier
HTTP	Hypertext Transfer Protocol
HVAC	Heating Ventilation and Air Conditioning
IFC	Industry Foundation Classes
IoT	Internet of Things
IP	Internet Protocol
IR	InfraRed
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
LOS	Line Of Sight
LTE	Long-Term Evolution
obXML	Occupant Behaviour XML
PRUBS	Profiling Residents Usage of Building Systems
RAT	Radio Access Technology
RenoDSS	Renovation Decision Support System
SCADA	Supervisory Control and Data Acquisition
SenML	Sensor Measurement Lists
TCP	Transmission Control Protocol
WoT	Web of Things
XML	eXtensible Markup Language
XSD	XML Schema Definition

EXECUTIVE SUMMARY

The BIMERR Deliverable D5.7 - *Building resident energy-related behaviour profiling framework 1* aims at documenting the Profiling Residents Usage Building Systems (PRUBS) module and reporting on the first iteration of BIMERR Task T5.3 - *Profiling Residents Usage Building Systems* design and development activities.

The PRUBS module attempts to address the topic of how the occupant behaviour models, that mimic and predict the residents' actions upon building's operable elements and the resident thermal comfort bounds under certain environmental conditions, are to be trained and communicated to the BIMERR Interoperability Framework (BIF). The BIF hands these models over to the Renovation Decision Support System (RenoDSS), that in turn propagates them to the Building Energy Performance (BEP) modelling component to compute the Energy Key Performance Indicators (KPIs) that have been defined in D3.3.

This Deliverable constitutes the first version of the PRUBS module documentation, where: (a) the design and the installation plan of the Wireless Sensor Network that capture the indoor environmental conditions of the building, (b) the implemented algorithmic approaches for the occupant behaviour modelling and training, (c) the delivered data pre-processing, mapping and post-processing methods, (d) the technology stack that the PRUBS module builds upon, (e) the APIs that are exposed and (f) the installation instructions are reported.

Since this work reflects the activities that have been undertaken for the initial release of the module, it adheres to certain assumptions/restrictions and does not fully implement all the fine-grained functionalities that will be issued in the PRUBS module's final version (e.g. a full integration with the BIMERR Middleware and the BIMERR Interoperability Framework is still under development). The final documentation of the PRUBS module, anticipated to be released on M30 of the BIMERR project implementation, shall focus on enhancing the module performance based on the feedback acquired during the BIMERR integration, pre-validation and validation activities, introducing a set of already planned extensions and new functionalities.

1. Introduction

1.1 Scope and Objectives of the Deliverable

The accuracy of the BIMERR Energy KPIs values, that are calculated by the Building Energy Performance Module [1], is highly affected by the level of detail of its input data, where recent studies have shown that the occupant behaviour data constitutes the major cause of uncertainty in the building energy performance simulation results [2]. Hence, having a deeper understanding and properly modelling the occupant behaviour have been of paramount importance within IEA EBC Annex 66 [3], where data, methods and models have been developed and applied to understand and reduce the gap between simulated and measured building energy performance by representing occupant behaviour in a standardized XML schema (obXML) [4].

The PRUBS module leverages the outcomes of Annex 66, adopting obXML as its output data model, and applying Machine Learning algorithms on IoT data streams provided by Wireless Sensor Networks (WSN) that are designed for and installed in the pilot sites, it generates occupant behaviour profiles that mimic the inhabitants' actions. These profiles are subsequently used to project the building system (e.g. heating/cooling) utilization boundaries to maintain the comfort zone of the residents.

The PRUBS module is not being developed from scratch. It comprises and extends the HYPERTECH's THOR User Profiling Engine, which embeds and trains enhanced comfort models using information streams from sensor networks or other devices about the indoor environmental conditions, being already validated in several projects (H2020 MOEEBIUS[1], ORBEET[2], to name but a few) in other sectors.

Within BIMERR, the main objectives of HYPERTECH's THOR User Profiling Engine's extension and advances beyond the PRUBS module's state of the art are to: (a) investigate additional occupant behaviour models, focusing on residential buildings and forecasting

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[1] Modeling Optimization of Energy Efficiency in Buildings for Urban Sustainability https://www.moeebius.eu/

[2] ORganizational Behaviour improvement for Energy Efficient adminisTrative public offices https://orbeet.eu/

resident actions upon the Heating Venting Air Conditioning (HVAC) system (e.g. thermostat setpoint temperature) and openable windows, and (b) develop functionalities that automatically populate obXML files, intended to be used for increasing the BEP simulations accuracy.

This deliverable aims at reporting on the work that has been conducted up to M22 on the PRUBS module, being developed in the context of T5.4 – *Profiling Residents Usage of Building Systems* [5], providing a comprehensive overview and documentation of the PRUBS module's first version, and as a "Demonstrator" type deliverable, reporting on the actual services that have been developed and delivered.

1.2 Relation to other tasks/deliverables

Table 1 depicts the relations of this document to other deliverables within the BIMERR project, that should be considered along with this document for further understanding of its contents.

Table 1: Relation to other BIMERR project's deliverables

Del. Number	Deliverable Title	Relations and Contribution
D3.1 [6]	Stakeholder requirements for the BIMERR system	Analysis of the end-user requirements in order to create the necessary inputs for defining the different components of the BIMERR, along with a thorough description of the business scenarios, use cases and system requirements tailored to the project's goals and therefore setting the skeleton for the BIMERR framework.
D3.3 [7]	BIMERR evaluation methodology	The evaluation methodology is designed based on well-established international methodologies and protocols, reviewing the state of the art and relevant BIM projects, as well as relevant renovation works and expertise of the BIMERR constructor partners. The energy KPIs are documented here.
D3.6 [8]	BIMERR system architecture final version	The final version of the BIMERR architecture is delivered. The structural view, describing the core components of the system in the form of software modules, and the dynamic view, which presents the already defined use cases with the corresponding sequence diagrams are described highlighting the data exchange and interoperability requirements of each tool.
D4.2 [9]	BIMERR Ontology and Data Model 1	The initial BIMERR ontology and data model structure is developed to address the various semantic interoperability challenges for BIM-related data in an efficient manner.
D4.8 [10]	Integrated BIMERR Interoperability Framework 1	An overview of the Integrated BIMERR Interoperability Framework in terms of the interaction and communication of the several subcomponents which compose its overall architecture with reference

		to both D4.4 BIMERR Building Semantic Modelling tool 1 and D4.6 BIMERR Information Collection & Enrichment Tool 1.

Functionalities that are introduced in this document will be deployed to also address the aspects relevant to the scope of T7.3 – *Building Energy Performance Modelling module* [5, 1], since the obXML files, being generated by the PRUBS module, capture the dynamic data (schedules and thermal comfort preferences) that are required to perform the BEP simulation for the Energy KPIs calculation.

1.3 STRUCTURE OF THE DOCUMENT

To address the aspects relevant to the scope of T5.4, Section 1 introduces the work performed and the scope of this deliverable, along with its relevance to other BIMERR tasks and the deliverable's structure.

As a short introduction to the BIMERR PRUBS module data requirements and the IoT solution to meet them, the final version of the Wireless Sensor Network Design for the CONKAT pre-validation site and a draft version for the Polish validation site (final version of both validation-sites to be thoroughly described in D5.8), along with a questionnaire that has been designed to expedite the building characteristics collection process, are reported in Section 2.

Section 3 summarizes the software development work that has been conducted up to M22 within T5.4. Having concluded to the PRUBS module architecture, a transformation process that converts the data obtained from the Middleware to the PRUBS internal data models is required; rules embedded in the Middleware-to-PRUBS data mapping process, are presented in Section 3.1. For the sake of completeness, the most promising Occupant Behaviour Models to be used within BIMERR are briefly introduced in Section 3.2. The Occupant Behaviour Models outputs need to be further processed to automatically populate the obXML data model. Such a data post-processing functionality is reported in Section 3.3. The remaining parts of Section 3 present the technology stack, assumptions, restrictions, installation instructions and licensing that have been considered in the first release of the PRUBS module.

Finally, in Section 4, conclusions are provided along with the release plan for the 2nd iteration of the BIMERR PRUBS module.

2. Wireless Sensor Network

The PRUBS module implementation is accompanied by specific IoT data streams requirements that must be fulfilled before applying any innovative methodology to generate Occupant Behaviour models/profiles. To this direction, the IoT streams data model must include measured data for the following parameters: (a) room air temperature – the indoor temperature measurements from two specific sensors installed in each room; (b) room air relative humidity – the indoor relative humidity measurements from two specific sensors installed in each room; (c) room occupant presence – the occupancy inside a room based on motion detection provided by a motion sensor installed in each room; (d) Heating Ventilation and Air Conditioning (HVAC) system's thermostat setpoint temperature – apartments' desired temperature for HVAC device configured by the end user if applicable; (e) HVAC equipment's mode – apartments' HVAC device mode (heating, cooling, fan, etc.) configured by the end user, if applicable; (f) HVAC equipment's status – apartments' HVAC device status (on/off) configured by the end user if applicable; (g) opening elements (exterior operable/ not-fixed windows and doors) status (open/ closed); (h) weather conditions – outdoor dry bulb temperature, relative humidity, wind speed, wind direction, direct and diffuse normal radiation; (i) apartment and/or building level energy metering – metering data for power consumption will be collected from smart energy meters.

Subject of this section is to draft the critical IoT infrastructure to be installed at the pilot sites to meet the aforementioned requirements, as well as to report on the methodology that has been followed in order to: (a) collect information about the building characteristics; (b) select the proper IoT devices; and (c) proceed with the WSN design, tailored to each pilot-site.

2.1 Pilot Sites Audit Questionnaire and Installation Guidelines

To expedite the building characteristics collection process, a building audit questionnaire has been sketched, comprising tables and forms, aimed to facilitate the compilation of information. The audit questionnaire's scope has been to become a useful tool in the hands of the building auditors and guide them to collect the necessary information.

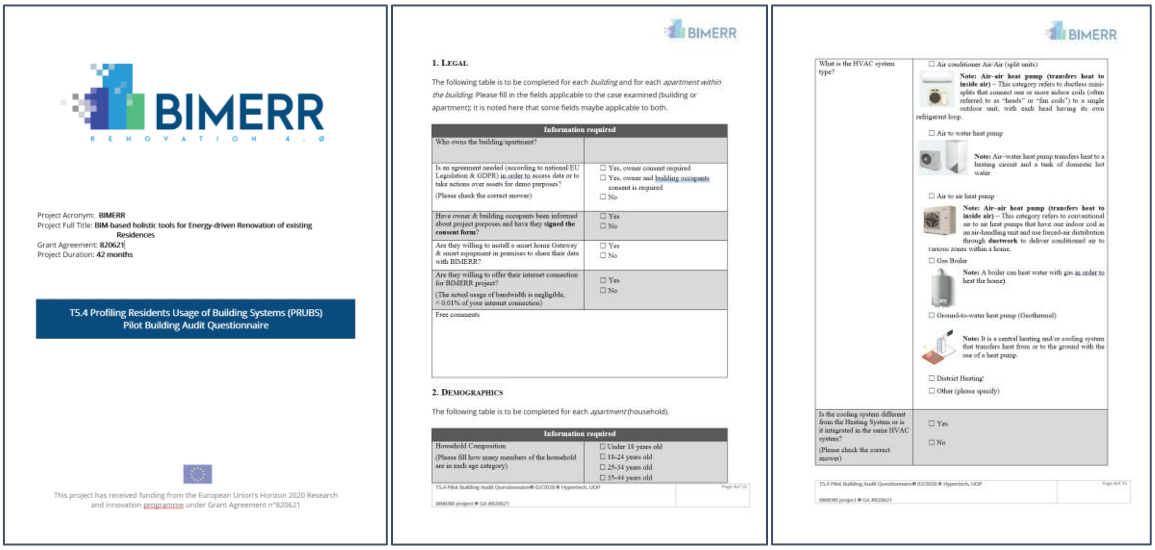

Figure 1: BIMERR Pilot Building Audit Questionnaire (Annex I)

From a technical perspective, the existence (or not) of a Building Energy management System, smart meters, HVAC system demand and supply side, thermostats, hot water loop system, domestic hot water system, smart home/IoT devices and control/monitoring equipment, accessibility of circuit panel, renewable Energy Sources, and their characteristics, to name but a few, are data that the auditor should collect through the questionnaire. Furthermore, legal information (consent for participation in BIMERR project), building general information, structural information, demographic information, Internet connectivity, building annual consumption, frequency of readouts usage patterns (e.g. daily or weekly) is supplementary information which should be provided. Annex I presents a subset of the forms and tables that have been included in the questionnaire.

2.2 IoT INFRASTRUCTURE

The IoT devices that are listed in this section constitute the IoT infrastructure anticipated to be installed to the pilot sites, so that the PRUBS IoT data streams requirements are met, and they have been tested in lab conditions to ensure their compatibility with the overall WSN solution that is presented in Section 2.3.

The required devices are being divided to the following categories: (a) Sensing Devices, responsible for monitoring building's ambient conditions, including indoor temperature, humidity, illuminance, CO_2 levels, door/window status (open/closed) and occupancy (via motion sensors); (b) Monitoring Devices, capable to capture the HVAC system's control actions; (c) Metering Devices, responsible for collecting data about the energy consumption and performance of heavy load building assets; and (d) Gateway, the connection point between the cloud and the Sensing, Metering and Monitoring devices.

2.2.1 Sensing Devices

For the rooms' occupancy and temperature measuring, a FIBARO Motion sensor will be installed at each room. The FIBARO Motion Sensor is a universal Z-Wave multi-sensor that measures the temperature and light intensity and detects motion. It is battery powered device, with a LED indicator that signals motion, temperature level and operating mode, being also used to check whether the device is within the Z-Wave network or not.

Figure 2: FIBARO Motion sensor

Figure 3: MCO Home MH9

Due to the high cost of VOC sensors, the MCO Home MH9 device has been selected to be installed in the most frequently occupied room of each apartment. The MCO Home MH9 - CO_2 Sensor can real-time detect & alarm CO_2 in air, and it is built-in with VOC, Temperature & Humidity sensors. They even can be customized with outputs to control air ventilation system directly. These devices are of high reliability and practicability, and able to work in any Z-Wave network with other Z-Wave certified devices.

The opening elements (exterior operable/ not-fixed windows and doors) status (open/ closed) will be detected by FIBARO Door/Window Sensor 2 devices that will be installed at each external opening element. The FIBARO Door/Window Sensor 2 is a wireless, battery powered, Z-Wave Plus compatible magnetic contact sensor. Changing the device's status will automatically send signal to the Z-Wave controller and associated devices. Opening is detected by separating the sensor's body and the magnet.

Figure 4: FIBARO Door/ Window Sensor 2

Note here that the FIBARO Door/Window Sensor 2 is also equipped with a built-in temperature sensor.

2.2.2 Monitoring Devices

Since CONKAT pre-validation site is equipped with typical AC split-units with IR remote controller receiver, which records and controls remotely the ACs thermostat setpoint temperature, mode (heating, cooling, fan) and status (on/off), the [IntesisBox IS-IR-WMP-1 interface]() has been selected to monitor and control the Air Conditioning system, remotely, from the Control Centre, using any commercial SCADA or monitoring software that includes the possibility to communicate through simple ASCII messages/commands on a TCP/IP network.

Figure 5: IntesisBox IS-IR-WMP-1

To monitor the residents' actions (CONKAT pre-validation site) on the hot water central heating system, an [SRT323 Room Thermostat]() has been selected, to be installed to host all functionalities of a water heating thermostat. It is a Z-Wave Plus enabled device for indoor temperature control to be included and operated in any Z-Wave network with other Z-Wave certified devices from any other manufacturers. It is a single-box solution that can be used as a direct replacement for existing thermostats, without the need for wiring changes.

Figure 6: SRT323 Thermostat

The Polish pilot site is connected to a district heating system that provides all apartments with hot water, while rooms heating is achieved through radiators that are connected to the hot water loop. The apartments are not equipped with any room thermostat to control the indoor thermal conditions, since the hot water loop operates according to a predefined operational schedule. Hence, to provide the residents the

Figure 7: FIBARO Heat Controller

possibility to control the heating load on their apartments and monitor relevant control actions, a FIBARO Heat Controller is being installed at each radiator, a remotely controlled thermostatic head (radiator valve) that controls the temperature inside a room. It measures the temperature and automatically adjusts the radiator's heat level. It is also equipped with an additional temperature sensor that can be placed anywhere inside the room and act as the reference point of the indoor temperature that triggers adjustments on the radiator's heat level. FIBARO Heat Controller is compatible with any certified Z-Wave Controller and can interface with a Z-Wave home gateway, allowing remote control of heating from anywhere with an Internet connection. Manual control can be performed by rotating the spherical knob to set the desired temperature. FIBARO Heat Controller is equipped with a built-in battery that can be recharged through a standard micro-USB port.

2.2.3 Metering Devices

To meter the electric power consumption of heavy load equipment (HVAC, electric convectors, electric water heaters, etc.) two devices have been selected: (a) the Aeotec Home Energy Meter Gen5 and (b) the FIBARO Wall Plug.

The Aeotec Home Energy Meter Gen5 device monitors, records and reports the electricity being used in a home, either in total or the portion that is consumed/produced by a specific load, e.g. HVAC device, or a small RES, e.g. rooftop PV. Its current clamps affix around the home's AC Mains and record electricity use wirelessly. It reports wattage and kWh electricity usage.

Figure 8: Aeotec Home Energy Meter

Figure 9: FIBARO Wall Plug

The FIBARO Wall Plug device is a universal, Z-Wave compatible, relay switch in the form of a socket adapter. The Plug may be used to operate any device up to 2500W power output. The Plug features power consumption measuring and uses a crystal LED ring to visualize the current load by colour changing illumination. FIBARO Wall Plug may be operated using the service button located on its casing or via any Z-Wave compatible controller.

2.2.4 Gateway

Figure 10: FIBARO Home Center Lite

The product that has been selected to act as the connection point of the project's control and monitoring system is the FIBARO Home Center Lite. FIBARO Home Center Lite uses wireless Z-Wave technology to manage connected devices simultaneously. It comes with a graphic and user-friendly interface, available through web browser or phone app, that allows for controlling connected devices and creating scenes, and expedites the set up and configuration.

For the needs of local data processing, a Raspberry Pi 4 Model B will be installed. It is the latest version of the popular Raspberry Pi computer series. It offers ground-breaking increases in processor speed, multimedia performance, memory, and connectivity compared to the prior-generation of the series (Raspberry Pi 3 Model B+), while retaining backwards compatibility and similar power consumption.

Figure 11: Raspberry Pi 4 Model B

2.3 WSN DESIGN

Analysing the content of the first version of the filled-out audit questionnaires, a Wireless Sensor Network (WSN) has been designed to be deployed in carefully selected apartments of the pilot sites in Poland, Spain and Greece, designated by BX, FER and CONKAT, respectively. Currently, for the CONKAT pre-validation site, the WSN design and installation have been completed.

The WSN of each apartment will be an autonomous Network based on the Z-Wave Radio Access Technology (RAT). The WSN of each apartment shall include a minimum number and type of Z-Wave enabled sensors, which will be exchanging data over the Internet with the BIMERR Middleware via a local Z-Wave enabled Gateway.

Regarding the connectivity of the Gateways to the Internet, the following technical solution is proposed: all Gateways will be connected via Ethernet cables to a Switch and then the Switch will be connected to the Internet either via a wireless LTE Gateway or a fixed Internet Router. Moreover, for the needs of local data processing, a Raspberry device (mini PC) will be connected to the Switch. The aforementioned network architecture is depicted in Figure 12.

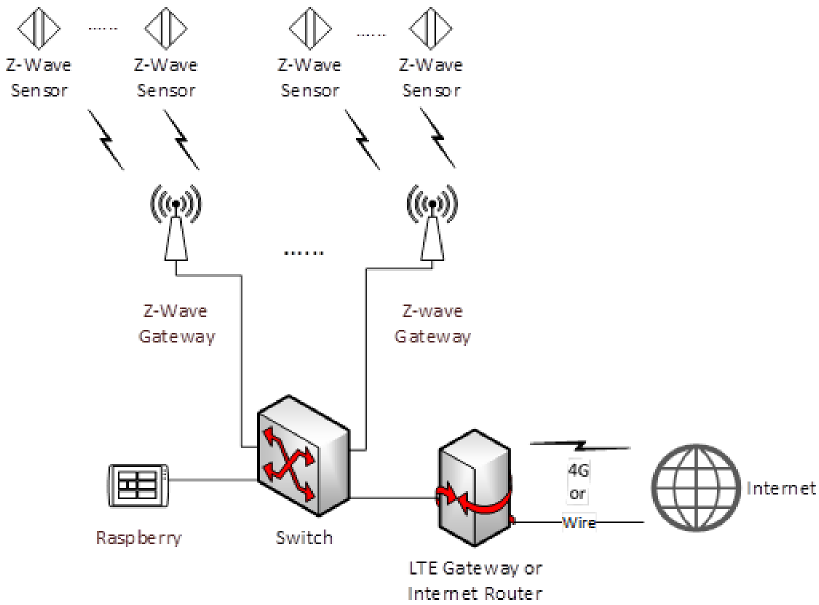

Figure 12: High level architecture of the Wireless Sensor Network

In more detail, the communication of the Home Center Lite Gateway with the sensors will be via the Z-Wave RAT[3]. Z-Wave operates in the unlicensed Industrial, Scientific, and Medical (ISM) band and the frequency used in Europe is 868.42MHz[4]. Z-Wave uses a source-routed mesh network architecture. In such networks, the source device (initiator) uses the wireless interface to transmit messages which are relayed to the destination device via the neighbouring devices, in a wave-like fashion. In the indoor environments of

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[3] The lower layers of Z-Wave, MAC and PHY, are described by ITU-T G.9959. In 2012, the International Telecommunication Union (ITU) included the Z-Wave PHY and MAC layers as an option in its G.9959 standard for wireless devices under 1 GHz. The Z-Wave transceiver chips are supplied by Silicon Labs.

[4] This band competes with some cordless telephones and other consumer electronics devices, but avoids interference with Wi-Fi, Bluetooth and other systems that operate in the crowded 2.4 GHz band.

the BIMERR Project, devices can communicate by using intermediate devices to actively route around and circumvent household obstacles or radio “dead spots” that might occur in the multipath environment. A message from device A to device C can be successfully delivered even if the two devices are not within range, provided that a third device B can communicate with devices A and C. Therefore, a Z-Wave network can span much farther than the radio range of a single device.

According the proposed WSN solution, the Z-Wave Gateway of each apartment is the “Primary Controller” of the Z-Wave network (which can consist of up to 232 devices, with the option of bridging networks, if more devices are required). Each Z-Wave network is identified by a unique Network ID.

A device must be "included" to the Z-Wave Network before it can be controlled via Z-Wave. This process is known as “Commissioning”. Commissioning needs to be performed once (during the set-up of the Network) and after this process the device acquires a Network ID (4 bytes) and a Node ID (1 byte), and is always “recognized” by the Primary Controller.

Practically, in each apartment (of any pilot building) the best location for the installation of the Gateway is the Corridor so that the Gateway can have Line-Of-Sight (LOS) communication with at least one sensor in each room or, even if LOS is not achieved (due to the existence of walls / obstacles), the distance between the Gateway and the sensors will be as short as possible. This is a recommended setup that has been adapted during the WSN installation at the CONKAT pre-validation site, as shown in Figure 13. However, for the Polish pilot-site, the Gateway will be installed at the staircase. Although the LOS condition will not be met in this case, considering that (a) the apartments’ size of the Polish pilot-site is small, (b) the frequency used by the Z-Wave RAT in Europe is relatively low (868.42MHz), and (c) the Z-Wave network is a mesh network (hence, each sensor is a potential signal relay/repeater), communication even in these non-LOS conditions (between the Primary Controller/Gateway and the Sensors) may be feasible. Moreover, additional low-cost Z-Wave sensors, that may act as Z-Wave repeaters, could be installed in the apartments nearby the entrance door, in order to ease the connectivity with the Primary Controllers in case a direct communication is not feasible.

Figure 13 depicts the LOS for the CONKAT pilot-site (left) and non-LOS for a representative apartment of the Polish pilot site (right) conditions between the Z-Wave sensors and the Gateway, where "Sensor" represents any Z-Wave device of the WSN, and the "Gateway" stands for the Z-Wave Primary Controller.

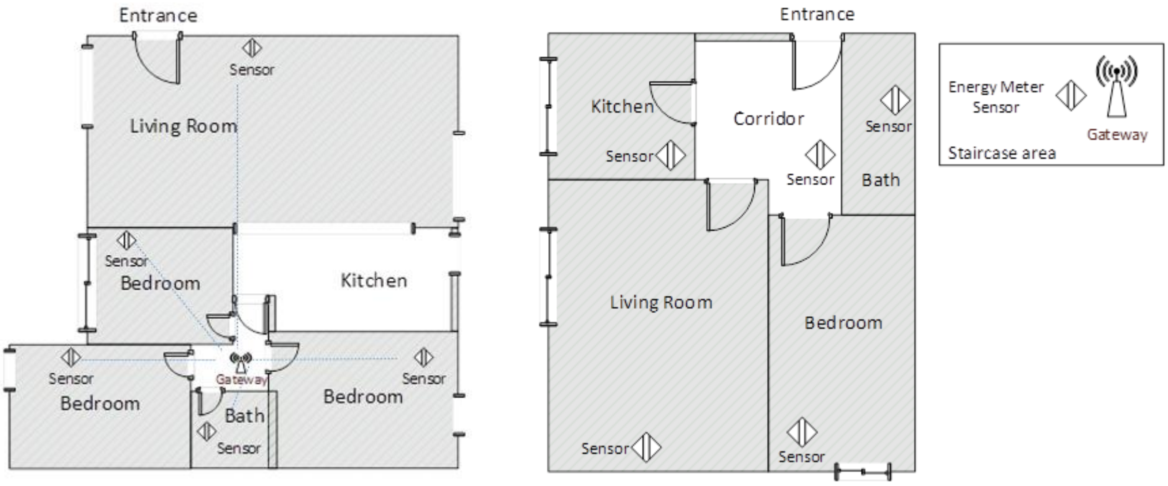

Figure 13: LOS (left) and non-LOS (right) conditions between the Z-Wave sensors and the Gateway

3. Profiling Residents User Building Systems Module

In alignment with the BIMERR architecture [8], the PRUBS module is considered as an "as-is" building information extraction and model population tool, interacting with the BIMERR Middleware and BIMERR Interoperability Framework.

For the occupant behaviour models training, IoT streams data are requested and acquired by the WSN designed for and installed in each pilot site. To receive the IoT data streams, the PRUBS module communicates with the BIMERR Middleware, which is in charge of the buildings IoT data handling. As mentioned above, the PRUBS' output contains data-driven occupant behaviour models and populates a building level obXML file. That file is sent to BIMERR Interoperability Framework [10] to be properly enriched and linked with other data, so that it can be used by the BEP component of RenoDSS.

3.1 Middleware to PRUBS – Data Mapping

According to the BIMERR system architecture [8], the Middleware acts as the IoT data handler and repository. It provides the central Registry that contains metadata to query and access required items, following the W3C Web of Things (WoT)[5] for describing such metadata, and the Middleware's sensor data storage services are microservices that are responsible for the storage and orchestration of sensor measurements data across the edge (building location) and BIMERR cloud; note here that the standardized Sensor Measurement Lists (SenML)[6] is used as the data format for storage and retrieval.

Although the WSN topological representation and the IoT data streams storage of the BIMERR Middleware are based on widely used, standardized data schemas, the PRUBS module comprises and extends the HYPERTECH's THOR User Profiling Engine.

[5] https://www.w3.org/WoT/

[6] https://tools.ietf.org/html/rfc8428

Consequently, it adheres to a tool-specific input data model, resulted by extensive testing and validation that have been performed in the context of other recent projects[7].

In an effort to conceptually gather the data mapping rules that must be performed to transform IoT data that are available through the Middleware to input data that are meaningful for the PRUBS module, a Middleware-to-PRUBS wrapper has been created. In a nutshell, the mapping rules that are applied are summarized in Table 2 and briefly described below.

According to the WoT, a building has a list of items (Things), and each item is accompanied by a Thing description. A thing has four main components: textual metadata about the Thing itself, a set of Interaction Affordances that indicate how the Thing can be used, schemas for the data exchanged with the Thing for machine-understandability, and, finally, Web links to express any formal or informal relation to other Things or documents on the Web. Within BIMERR, a list of metadata properties has been defined to provide characteristics of each item that are meaningful for the BIMERR tools that act as the IoT data streams consumers (e.g PRUBS). In terms of the PRUBS module, the following, relevant to the WoT data, mapping rules are applied:

- Rule 1: projectID (string) – it is generated during a project creation through the Middleware Identity Provider and mapped to the "buildingKey" property's value of PRUBS data model.
- Rule 2: site (string) – it is manually set during the manual commissioning of the IoT devices and mapped to the "site" property's value of the PRUBS data model.
- Rule 3: ifcBuildingID (string) – it refers to the IfcBuilding GUID of the IFC file [11] that is generated by the Scan-to-BIM tool for a specific building and set manually to the Registry. It is mapped to the "ifcBuildingID" property's value of the PRUBS data model.
- Rule 4: apartment (string) – it refers to a representative name of an apartment (group of spaces) of a building. It is mapped to the "prosumerKey" property's value of the PRUBS data model.

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[7] Integrated Modular Energy Systems and Local Flexibility Trading for Neural Energy Islands https://www.merlon-project.eu/

- **Rule 5**: ifcZoneID (string) – it refers to an IfcZone GUID of the IFC file that is generated by the Scan-to-BIM tool to describe a group of IfcSpaces (apartment) for a specific building and it is set manually to the Registry. It is mapped to the "ifcZoneID" property's value of the PRUBS data model.
- **Rule 6**: ifcSpaceID (string) – it refers to an IfcSpace GUID of the IFC file that is generated by the Scan-to-BIM tool to describe a space (room) for a specific building and it is set manually to the Registry. It is mapped to the "ifcSpaceID" property's value of the PRUBS data model.
- **Rule 7**: fibaroGatewayName (string) – it provides the name of the gateway for a specific apartment, mapped to the "smartboxKey" property's value of the PRUBS data model.
- **Rule 8**: id (integer) – it defines the unique id of an item (Thing) and is mapped to the "physicalDeviceKey" property's value of the PRUBS data model.
- **Rule 9**: href (public) (string) – according to the WoT description, it is a target IRI of a link or submission target of a form. In other words, it is the endpoint URL that can be used to query data of a specific property of a unique item, and it is mapped to the "itemKey" property's value of PRUBS data model.

Table 2 Middleware Data Registry and Sensor Data Storage to PRUBS – Properties mapping rules

PRUBS data models	Middleware IoT data models
WSN topology – Data Registry (from WoT to PRUBS)	
buildingKey	projectID
Site	site
ifcBuidlingID	ifcBuidlingID
prosumerKey	apartment
smartboxKey	fibaroGatewayName
ifcspaceID	ifcSpaceID
spaceKey	roomName
physicalDeviceKey	id
Items	Properties
itemKey	href (public)
Historical Data – Sensor Data Storage (from SenML to PRUBS)	
itemKey	n
timeseries	data

Timestamp	t
Value	v

Furthermore, according to the WoT schema, each item has at least one device, each with its own endpoint. For instance, a multisensory item that is equipped with a temperature, a motion, and an illuminance sensor has three devices with different deviceIDs and endpoints that refer to different sensing properties. Each endpoint can be used to query data of a property. The response to each query is a list of sensor measurements that is based on SenML, where each list's element has three properties values:

- Rule 10: n (string) – the name of the sensor (device of an item) that needs to uniquely identify and differentiate the sensor from all others – it is provided by the Thing Description and is mapped to the "itemKey" property's value of PRUBS data model.
- Rule 11: t (double) – the epoch time when the value "v" was recorded – it is mapped to the "timestamp" property's value of PRUBS data model.
- Rule 12; v (double) – the value that has been sensed by the sensor with unique name "n" and recorded at time "t" – it is mapped to the "value" property's value of PRUBS data model.

3.2 Occupant Behaviour Models

Having met the PRUBS module input data format requirement through the Middleware to PRUBS data mapping process, this section introduces the modelling approaches that are most frequently used and have been implemented for modelling occupant behaviour by the PRUBS module. The modelling approaches are divided into two main sections, each corresponding to Needs or Actions such as the occupant's thermal comfort and the HVAC systems' thermostat adjustment.

3.2.1 Thermal Comfort

Within PRUBS, for the occupant thermal comfort modelling the Gaussian Naïve Bayes method is applied, a supervised Machine Learning (ML) algorithm that follows the Bayes' theorem assuming conditional independence between the features, named Drivers in terms of obXML.

According to the Bays' theorem, given a class variable $y \in \{0,1,\dots,m\}$ and a set of Drivers $\boldsymbol{x} = [x_1, x_2, \dots, x_n]$, the conditional probability for each class is given by:

$$P(y = i|\boldsymbol{x}) = \frac{P(y = i)P(\boldsymbol{x}|y = i)}{P(\boldsymbol{x})}, \quad i \in \{0,1,\dots,m\}$$

where, $P(y = i|\boldsymbol{x})$, $i \in \{0,1,\dots,m\}$ are the posterior probabilities, $P(y = i)$, $i \in \{0,1,\dots,m\}$ the prior probabilities, $P(\boldsymbol{x})$ the evidence, and $P(\boldsymbol{x}|y = i)$, $i \in \{0,1,\dots,m\}$ the likelihood functions.

Since the values of Drivers are given, $P(\boldsymbol{x})$ is constant, while $P(y = i)P(\boldsymbol{x}|y = i)$ equals the joint probability $P(y = i, x_1, x_2, \dots, x_n)$, $i \in \{0,1,\dots,m\}$. Hence, considering the conditional independence assumption the following holds:

$$P(y = i \mid \boldsymbol{x}) \propto P(y = i) \prod_{j=1}^{n} P(x_j|y = i) , \qquad i \in \{0,1,\dots,m\}.$$

Prior probabilities $P(y = i)$, $i \in \{0,1,\dots,m\}$ can be uniform, where each prior is equal to $\frac{1}{m+1}$, or non-uniform; here, priors can be estimated from the training set as follows: $P(y = i) = (number\ of\ samples\ in\ class\ y = i)/(total\ number\ of\ samples)$.

Another assumption of the Gaussian Naïve Bayes method is that the Drivers' values associated with each class are distributed according to a normal distribution, with likelihood functions as follows:

$$P(x_j|y = i) = \frac{1}{\sqrt{2\pi\sigma_{j,i}^2}} e^{-\frac{(x_j - \mu_{j,i})^2}{2\sigma_{j,i}^2}} , \qquad i \in \{0,1,\dots m\}, j \in \{1,2,\dots,n\}$$

where, $\mu_{j,i}$ and $\sigma_{j,i}^2$ are the mean and the variance of the values in x_j associated with class $y = i$, respectively.

Having estimated priors and likelihood functions, usually the Maximum A Posteriori estimation is used, and the Bayesian classifier is formed as follows:

$$\hat{y} = \underset{i \in \{0,1,\dots,m\}}{\operatorname{argmax}} P(y = i) \prod_{j=1}^{n} P(x_j|y = i)$$

Previous versions of the Bayesian thermal comfort model response reflected the probability of the occupant thermal satisfaction $y \in \{0,1\}$ being 0, given as single Driver x_1 the space air temperature in $^{\circ}\mathrm{C}$. However, recent updates introduce 3 classes of thermal satisfaction y: $y \in \{0,1,2\}$, where 0 still holds for thermally satisfied occupants, 1 refers to thermally dissatisfied occupant due to hot, while 2 refers to thermally dissatisfied occupant due to cold.

Before training the model, an event generation process is applied to populate the proper training events/dataset expected by the ML model, certain pre-processing rules/steps are applied to sensed data, stored in PRUBS database. For example, for spaces that are heated and/or cooled with air-to-air HVAC systems[8], recorded data that are considered during this process are the following:

- status: the HVAC system's status; values for this data may be ON or OFF;
- mode: the HVAC system's mode; values may be COOL or HEAT;
- setTemperature: the HVAC system thermostat's setpoint temperature in $^{\circ}\mathrm{C}$; and
- temperature: the space dry-bulb air temperature in $^{\circ}\mathrm{C}$.

Initially, after retrieving data for a requested period, a list of recorded data that are sorted based on their timestamps is generated; from that list, data that have been recorded during unoccupied hours are discarded. For the rest entries, the following rules are applied:

- Rule 1: If the value of a "status" entry is "ON" and the previous "status" entry has value "OFF" (in other words, the HVAC system status alters from OFF to ON), an event is generated with $y = discomfort$ – other rules are applied to distinguish the case of discomfort due to hot $y = 1$ from the case of discomfort due to cold $y = 2$ – and $x_1 =$ the most recent value of a "temperature" entry.
- Rule 2: For a "mode" entry the following holds: if its value is "COOL", the previous "MODE" entry is "HEAT" and the value of the latest "status" entry is "ON" an event is generated with $y = 1$ and $x_1 =$ the most recent value of the "temperature" entry. In

[8] Similar events generation rules are applied for other thermostatically controlled HVAC system's types

other words, if the HVAC system operates and a switch from heating to cooling mode occurs, the occupant feels hot.

- **Rule 3**: Similar to Rule 2, for a “mode” entry the following holds: if its value is “HEAT”, the previous “mode” entry is “COOL” and the value of the latest “status” entry is “ON” an event is generated with $y = 2$ and $x_1 =$ the most recent value of the “temperature” entry. In other words, if the HVAC system operates and a switch from cooling to heating mode occurs, the occupant feels cold.

Assuming that there is an “temperature” entry with value B, while the HVAC has been switched ON or its mode has been changed previously.

- **Rule 4**: If the most recent added event has $y = discomfort,\ x_1 = A$ and its timestamp is at least 20 minutes earlier then: if $|B - A| < threshold$ then, the previous event is discarded; else if $B - A > threshold$ then, for the previous event $y = 2$ and a new event is added with $y = 0$ and $x_1 = B$; else if $A - B > threshold$ then, for the previous event $y = 1$ and a new event is added with $y = 0$ and $x_1 = B$. In our experiments, $threshold = 0.25\ ^\circ\mathrm{C}$.
- **Rule 5**: If the most recent added event has $y = discomfort,\ \ x_1 = A$ and at least 6 minutes have passed since when the HVAC was switched ON or its mode was changed then: if $|B - A| < threshold$ then, the previous event is discarded; else if $B - A > threshold$ and there is not high temperature variance during the last 20 minutes then, for the previous event $y = 2$ and a new event is added with $y = 0$ and $x_1 = B$; else if $A - B > threshold$ then, for the previous event $y = 1$ and a new event is added with $y = 0$ and $x_1 = B$. In our experiments, $threshold = 0.25\ ^\circ\mathrm{C}$.

Within BIMERR, instead of using the previous Bayesian classifier’s equation, a comfort zone is estimated based on the posteriors as follows: the comfort zone is the range of space air temperatures where,

$$P(y = 0 \mid x_1) > P(y = 1 \mid x_1) + P(y = 2 \mid x_1).$$

Note here that the resulted comfort bounds are estimated for each space of a building and are intended to be used to populate the obXML with occupant Needs instances of the relevant occupant behaviour model (see Section 3.3).

3.2.2 *Thermostat Adjustment*

For the HVAC systems' thermostat adjustment behaviour, two statistical modelling approaches that have been introduced in recent studies [2, 12] and seem to be the most applicable to residential buildings, are implemented in the PRUBS module from scratch.

In the first approach [2], occupants are clustered into active, medium, and passive users and multivariate logistic regression models are trained to predict the likelihood of a setpoint increase or decrease.

- For active users' thermostat setpoint behaviour, Drivers are the time of day, the space air relative humidity, and the outdoor dry-bulb temperature, that are used to predict the setpoint increase, while the outdoor global horizontal solar radiation is used as the Driver for the setpoint decrease prediction.
- For medium users' setpoint increase behaviour, Drivers are the outdoor temperature and the wind speed, while their setpoint decrease behaviour is predicted using the time of day.
- For passive users' setpoint increase behaviour, the likelihood is a uniform distribution, and their setpoint decrease behaviour is modelled as a function of the outdoor global horizontal solar radiation.

In the second approach [12], a three-parameter discrete Weibull distribution model is being developed and trained to represent occupants air-conditioning usage, considering indoor temperature, CO_2 concentration, and occupancy state as the model Drivers.

For a thorough description of both methodological approaches, we refer the interested reader to the corresponding publications [2, 12].

Note here that the aforementioned formula-based occupant behaviour models are trained for each space of a building and are intended to be used to populate the obXML with occupant Actions instances of the relevant occupant behaviour model (see Section 3.3).

3.3 PRUBS - OBXML GENERATION

In [4], data methods and models have been developed and applied to understand and reduce the gap between simulated and measured building energy performance by representing occupant behaviour in a standardized ontology and XML schema (obXML).

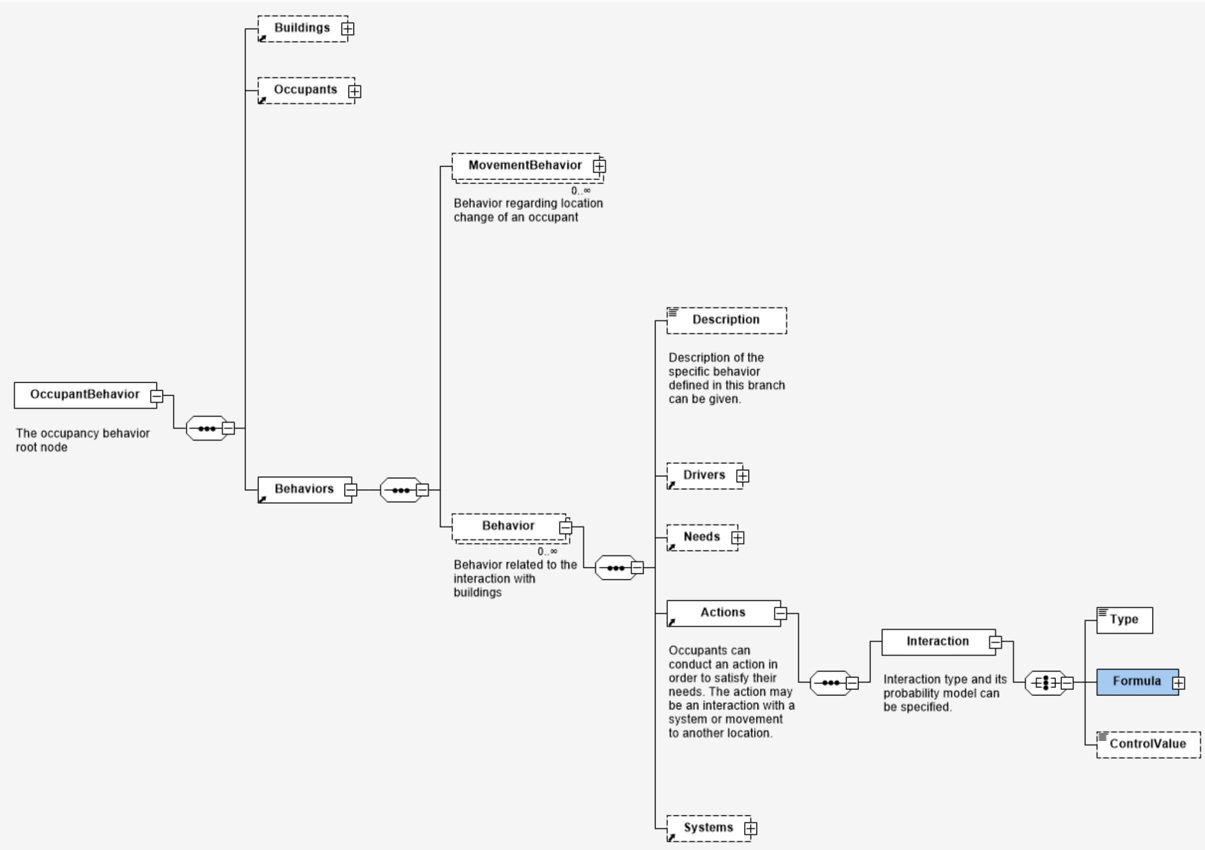

Figure 14: XSD diagram of the main obXML's topology for OB action's modelling

obXML builds upon the Drivers–Needs–Actions–Systems (DNAS) framework to represent energy-related occupant behaviour in buildings. Drivers represent the environmental and other context factors that stimulate occupants to fulfil a physical, physiological, or psychological need. Needs represent the physical and non-physical requirements of occupants that must be met to ensure satisfaction with their environment. Actions are the interactions with systems or activities that occupants can perform to achieve environmental comfort (see Figure 14). Systems refer to the equipment or mechanisms within the building that occupants may interact with to restore or maintain environmental comfort.

Within BIMERR, the obXML schema is adopted to capture information of the occupant profiling usage of building systems for a building as a whole. Thus, the obXML file generation, based occupant behaviour models that have been trained, given the IoT data streams that are received from the Middleware, constitutes a core functionality of the PRUBS module.

The PRUBS module's obXML generation encapsulates a set of rules that are applied to properly populate instances of the obXML classes, accompanied by certain metadata, that are used to build the relations with the building topological information that is provided by the IFC file (IfcBuilding, IfcZone and IfcSpace GUIDs). These rules are briefly described below.

- Rule 1: For each buildingKey of the PRUBS data model, an obXML generation process is initiated and an object OccupantBehavior superclass is populated. The OccupantBehavior has a Building object, with its ID and IfcGuid attributes' values being set to the buildingKey and the ifcBuildingID properties' values of the PRUBS data model, respectively.
- Rule 2: For each prosumerKey (apartment) of the PRUBS data model, a Spaces object is generated, whose ID and IfcGuid attributes' values are equal to the prosumerKey and the ifcZoneID properties' values of the PRUBS data model, respectively.
- Rule 3: For each spaceKey of the PRUBS data model, populated for a specific building, a Space object is generated, whose ID and IfcGuid attributes' values are set to the spaceKey and the ifcSpaceID properties' values of the PRUBS data model, respectively; additionally, a unique OccupantID, that is later used to relate a set of occupant behaviour models with building systems that are located at the specific space, is generated.
- Rule 4: For each OccupantID, child of the Occupants class, that has been generated by applying Rule 3, a list of BehaviorID objects are defined.
- Rule 5: For each BehaviorID the Drivers, Needs and Actions are populated based on the parameters that describe the respective occupant behaviour model, being trained and stored to the PRUBS database. In alignment with the content of Section 3.2, currently occupant behaviour models that act as the thermostat adjustment and the thermal comfort predictors have been developed and properly mapped to BehaviorIDs.

3.3.1 Preliminary Experiment and Results

For a PRUBS module preliminary demonstration, IoT data acquired from the CONKAT pre-validation site through the Middleware were not sufficient to perform the occupant behaviour models' training and the obXML generation. Hence, the IoT data captured from the WSN installed in HYPERTECH premises has been selected as a preliminary testing dataset. To accommodate IFC-wised topological data, required for the obXML generation process, the BIM model (IFC) of the HYPERTECH premises has been designed in Revit 2018 and applying the IFC to IDF mapping process, that has been described in D7.5 [1], IfcSpace, IfcZone and IfcBuilding GUIDs data became available (see Figure 15).

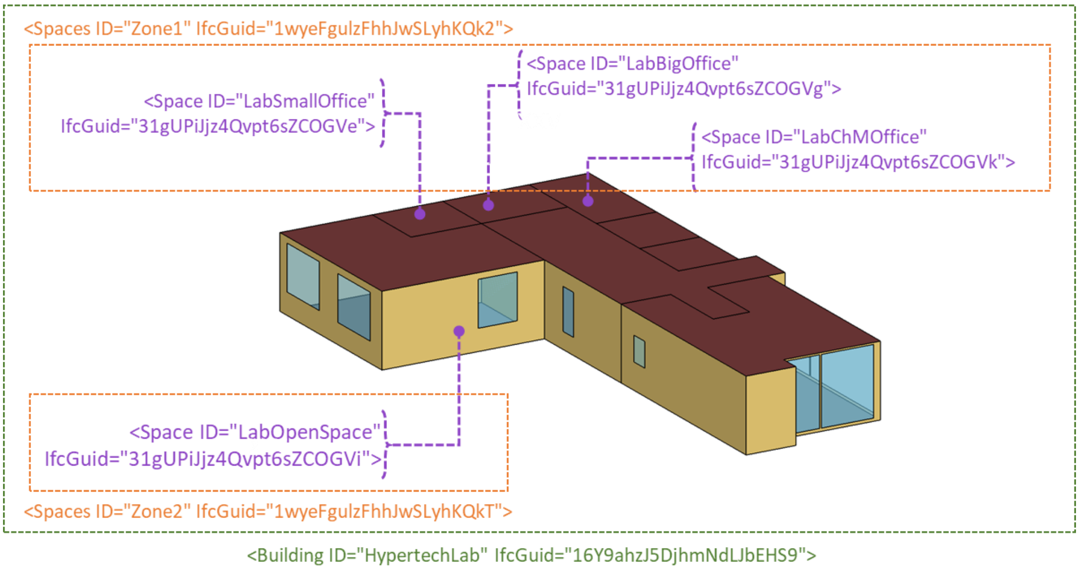

Figure 15: IFC to IDF mapping process result for the HYPERTECH premises – Spaces, group of spaces (zones), building IDs and IfcGuids for the obXML file generation

Based on the aforementioned IoT and IFC data, for the occupant behaviour models training, we assumed that both the thermal comfort and the thermostat setpoint adjustment (for this experiment, the Weibull-based model was chosen) models are being trained for the "master" spaces only, where the thermostats are located. However, the trained models are applicable not only to the master spaces, but also to other spaces, based on the zones and spaces relations that apply and are derived from the IFC data. The resulted obXML file for this preliminary experiment is presented below.

```xml
<Buildings>
    <Building ID="HypertechLab" IfcGuid="16Y9ahzJ5DjhmNdLJbEHS9">
        <Type>Office</Type>
        <Address>Greece</Address>
        <Spaces ID="Zone1" IfcGuid="1wyeFgulzFhhJwSLyhKQk2">
            <Space ID="LabSmallOffice" IfcGuid="31gUPiJjz4Qvpt6sZCOGVe">
                <Type>Office</Type>
                <Systems>
                    <Thermostat><Type>Adjustable</Type></Thermostat>
                </Systems>
                <OccupantID>Occupant_1</OccupantID>
            </Space>
            <Space ID="LabBigOffice" IfcGuid="31gUPiJjz4Qvpt6sZCOGVg">
                <Type>Office</Type>
                <Systems>
                    <Thermostat><Type>Adjustable</Type></Thermostat>
                </Systems>
                <OccupantID>Occupant_2</OccupantID>
            </Space>
            <Space ID="LabChMOffice" IfcGuid="31gUPiJjz4Qvpt6sZCOGVk">
                <Type>Office</Type>
                <Systems>
                    <Thermostat><Type>Adjustable</Type></Thermostat>
                </Systems>
                <OccupantID>Occupant_3</OccupantID>
            </Space>
        </Spaces>
        <Spaces ID="Zone2" IfcGuid="1wyeFgulzFhhJwSLyhKQkT">
            <Space ID="LabOpenSpace" IfcGuid="31gUPiJjz4Qvpt6sZCOGVi">
                <Type>Office</Type>
                <Systems>
                    <Thermostat><Type>Adjustable</Type></Thermostat>
                </Systems>
                <OccupantID>Occupant_4</OccupantID>
            </Space>
        </Spaces>
    </Building>
</Buildings>

<Occupants>
    <Occupant ID="Occupant_1">
        <BehaviorID>B_TC1</BehaviorID>
    </Occupant>
    <Occupant ID="Occupant_2">
        <BehaviorID>B_TC1</BehaviorID>
    </Occupant>
    <Occupant ID="Occupant_3">
        <BehaviorID>B_TC1</BehaviorID>
    </Occupant>
    <Occupant ID="Occupant_4">
        <BehaviorID>B_TC2</BehaviorID>
    </Occupant>
</Occupants>
```

Figure 16: HYPERTECH premises obXML – building, zones, spaces, occupants, and their relations

Figure 16 depicts the relations between building (“Building” class), zones (“Spaces” class) and spaces (“Space” class) that have been properly generated, and their ID and IfcGuid attributes’ values have been properly set. Additionally, an occupant ID has been annotated to each space, while the occupants ("Occupant" class) are also defined, and a behaviour ID has been assigned to each occupant instance.

Each behaviour ("Behavior" class) consists of Drivers, Needs and Actions instances (see Figure 17). For each instance of the "Behavior" class, the comfort bounds, derived from the trained thermal comfort model, have been captured by the " "Min" and "Max" values of the "Thermal" "Needs, while the thermostat adjustment model's parameters and coefficients have been generated under the "Weibull1D" "Formula" of "Actions".

```
<Behaviors>
    <Behavior ID="B_TC1">
        <Drivers>
            <Environment>
                <Parameter ID="TempChMOffice" Name="Room dry-bulb air temperature">
                    <Type>RoomAirTemperature</Type>
                </Parameter>
            </Environment>
        </Drivers>
        <Needs>
            <Physical>
                <Thermal>
                    <OtherComfortEnvelope>
                        <ParameterRange>
                            <ParameterID>TempChMOffice</ParameterID>
                            <Min>24.19</Min>
                            <Max>27.33</Max>
                        </ParameterRange>
                    </OtherComfortEnvelope>
                </Thermal>
            </Physical>
        </Needs>
        <Actions>
            <Interaction>
                <Type>SetToControlValue</Type>
                <Formula>
                    <Weibull1D>
                        <CoefficientA>26.32</CoefficientA>
                        <CoefficientB>5.18</CoefficientB>
                        <CoefficientC>16.54</CoefficientC>
                        <Parameter1ID>TempChMOffice</Parameter1ID>
                    </Weibull1D>
                </Formula>
                <ControlValue>26.47</ControlValue>
            </Interaction>
        </Actions>
        <Systems>
            <Thermostats>
                <ThermostatType>Adjustable</ThermostatType>
            </Thermostats>
        </Systems>
    </Behavior>
```

Figure 17: HYPERTECH premises obXML – Drivers, Needs (thermal comfort bounds) and Actions (Weibull-based thermostat adjustment model) for the Behavior instance with ID: "B_TC1"

3.4 TECHNOLOGY STACK AND IMPLEMENTATION TOOLS

The BIMERR PRUBS module's deployment architecture has been based on state-of-the-art technologies across two layers, as Figure 18 depicts.

The Data Storage Layer utilizes PostgreSQL and MySQL to store project specific IoT data retrieved form the Middleware, obXML files and trained occupant behaviour models for faster access at later usage.

For the the Business Logic Layer, HINERNATE is used to achieve the connection with the Data Storage Layer. Apache Tomcat and Apache 2 HTTP server are acting as the PRUBS module application and web server, respectively. Apache Spark MLlib is utilized as machine-learning framework on top of the Spark Core, that performs the occupant behaviour models training. The Apache kafka platform is adopted and acts as publish-subscribe messaging system. Finally, the Spring Web MVC framework provides ready components that are used to develop the obXML and the thermal comfort J2EE applications.

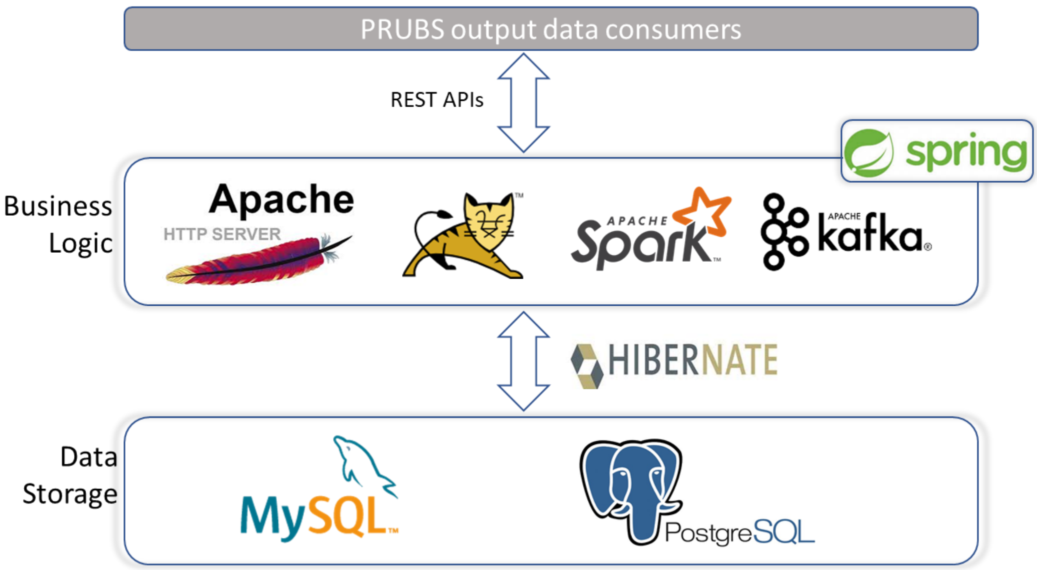

Figure 18: Architecture of the BIMERR PRUBS module

The BIMERR PRUBS module utilizes the open source technologies and libraries as defined in the following table.

Table 3: Technologies and libraries used in BIMERR PRUBS module

Name of the technology/library	Version	License
Apache Tomcat	8.0	Apache License 2.0 license
Apache 2 (HTTP server)	8.0	Apache License 2.0 license
Apache Spark	3.5.3	Apache License 2.0 license
Apache Kafka	8.5.2	Apache License 2.0 license
Oracle Java	1.8	GPLv2 (GNU General Public License)
Spring MVC	2.2.1	Apache License 2.0 license
PostgreSQL	8.0	PostgreSQL License (similar to BSD/MIT)
MySQL	8.0.24	GPLv2 (GNU General Public License)
Hibernate	5.4.8	LGPL 2.1

3.5 APIs Documentation

The PRUBS module APIs have been documented in Swagger[9], as Figure 19 depicts. In the current version, two APIs are exposed:

- *getOBXML*: an API that returns the populated obXML data model in JSON for a building specified by a unique projectId; and
- *getThermalComfort*: an API that returns the forecasted thermal comfort bounds timeseries of a space for a given time horizon in JSON.

The former had been foreseen from the early stages of the project, while the latter has been recently required to enable certain BIMERR applications (e.g. BICA - Building Information Collection Application) (a) to directly query and display thermal comfort bounds information, and (b) to refine and adjust accordingly the respective entities of the populated obXML data model towards the extraction of more accurate comfort profiles.

The JSON formatted bodies that are used as input for the APIs POST requests, along with the data models that are applied for the response description can be found in the APIs documentation in Swagger, that can be accessed through the following link:

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[9] https://swagger.io/

- http://adsl.hypertech.gr:81/bimerrPRUBS/swagger-ui.html

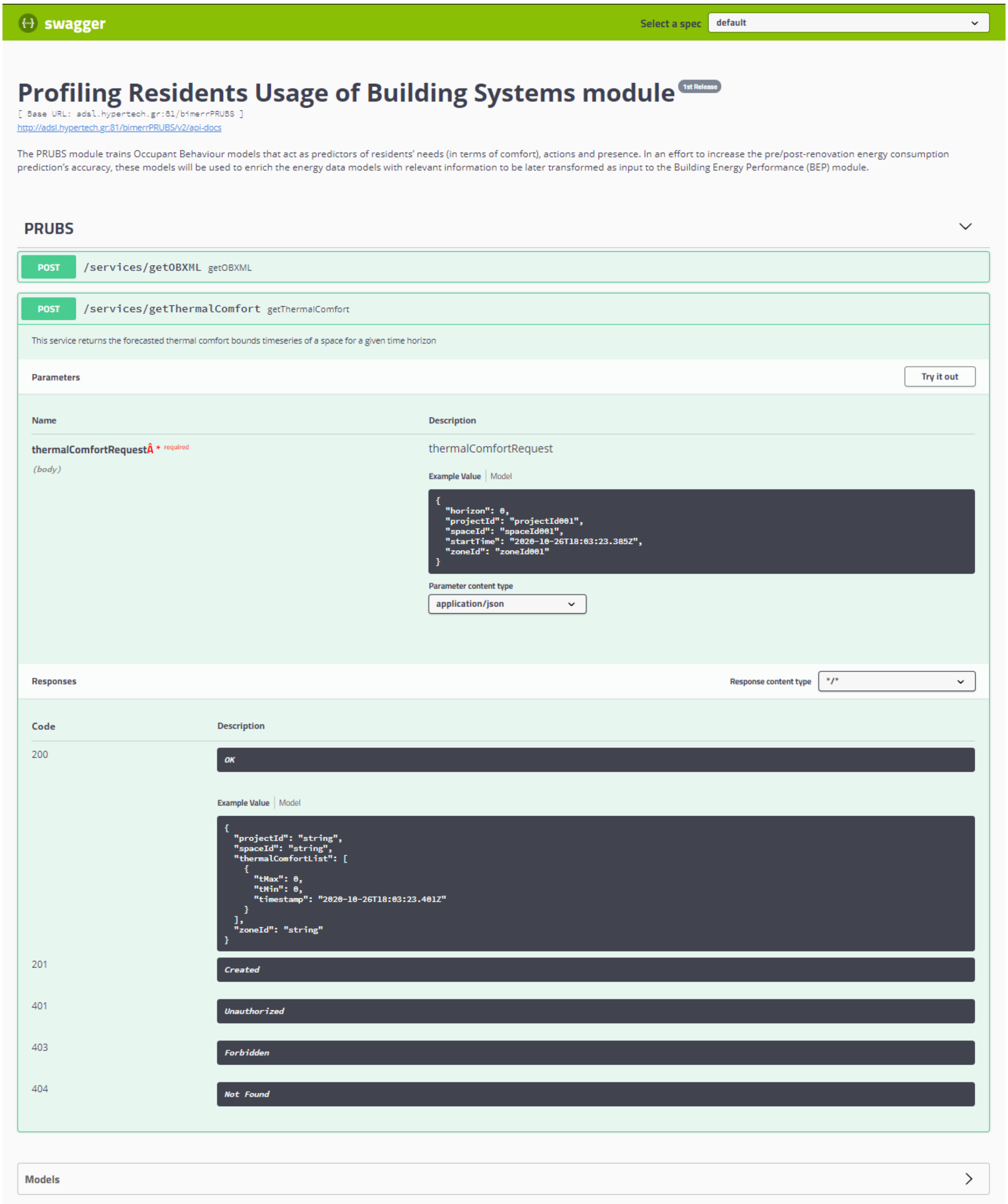

Figure 19: The PRUBS module APIs documented in Swagger

3.6 Assumptions and Restrictions

In alignment with BIMERR DoA, the pre-validation and integration activities are planned for the next period, whose results are anticipated to drive the needs for the PRUBS module's extensions and refinements. Hence, the first release of the BIMERR PRUBS module that is reported in this document, adheres to certain assumptions and restrictions that are listed below:

- WSN design and installation – concerning the validation sites, the WSN design, IoT equipment's procurement and installation is in progress (the Polish pilot site's WSN design is reported below). Due to the ongoing pandemic, collecting detailed information about building characteristics through physical meetings with the residents was impossible and alternatives have been investigated (a thorough description of the pilot sites is anticipated in the deliverable D9.1 – *Pilot renovation sites acquisition/selection process, ex-ante analysis and baseline definition*, to be issued on M29). In addition, both the Polish and Spanish pilot sites are large buildings, consisting of numerous floors and apartments, resulting to a prohibitive total cost for equipping each validation site with IoT devices, which exceeds the available budget. Thus, a careful selection of representative apartments, to be equipped with the proposed IoT infrastructure, has been of paramount importance.
- IoT infrastructure – In the near future, additional IoT equipment from different manufacturers may be required, based on the results of appropriate testing and pre-validation activities. Hence, the BIMERR IoT solution report is a living document that will be regularly updated before submitting the final version of the PRUBS module (M30).
- IFC data as metadata on the Middleware Registry – to perform the co-simulation between EnergyPlus [13] and the obXML [4], as it has been described in D7.5 [1], the obXML must be populated in a way that information about the IfcSpace, IfcZone and IfcBuilding GUIDs is included. According to the respective XSD schema, obXML can capture such data, while PRUBS is capable to populate it, assuming that the BIMERR metadata of the WoT provides information for the relevant attributes (IfcSpaceID, IfcZoneID and IfcBuildingID – see Section 3.1) .
- PRUBS services – In the current version, we assume that the PRUBS module provides services to meet two main functional requirements: a. the obXML population of a

building and b. the thermal comfort bounds estimation for a specific space that is regularly updated. However, additional services that may emerge during the pre-validation phase, to meet other BIMERR tools requirements, will be documented in the final release of the PRUBS module.

3.7 INSTALLATION INSTRUCTIONS

The BIMERR PRUBS module is accessible via rest APIs, thus installation or downloading of any component is not required.

3.8 LICENSING

The BIMERR PRUBS module is a closed source component.

4. Conclusions and Plan for Second Iteration

The focus of this deliverable has been the documentation of the Profiling Residents Usage of Building Systems module; a module that retrieves information for the BIMERR Middleware, transforms that information into meaningful data for PRUBS, launches appropriate Machine Learning algorithms to train individual occupant behaviour models and sends them to the BIMERR Interoperability Framework to make them available to other tools that act as potential consumers of relevant information.

In alignment with T5.4 work-planning, a first version of the WSN design that captures the indoor environmental conditions of a building has been designed and installed at a BIMERR pre-validation site, while the first version of functionalities, data flows specifications, interfaces and messages of the PRUBS module have been delivered as planned, currently being evaluated in the context of WP8 – *ICT System Integration, Testing & Pre-validation.*

Since this work reflects the activities that have been accomplished for the initial release of the module, assumptions and restrictions have been considered and reported in the homonymous section (see Section 3.6). With the WSN design and installation anticipated to be completed in near future (due M24), actions will be taken to overcome those assumptions and restrictions.

During M23-M24, the occupant behaviour models, and the obXML data population tool delivered in this version will be refined. Additionally, functionalities for seamless communication and data exchange with the BIMERR Interoperability Framework will be tested, while due M26, end-to-end testing and validation of the PRUBS module that mainly receives an IoT streams data model, populates the PRUBS output data model (obXML) and send it to the BIF are planned to be performed. Furthermore, in residential buildings, windows manual operation (opening/closing) constitutes the most frequent and preferred behaviour for occupants to control their indoor environmental conditions. Thus, occupant behaviour models that assimilate how the residents manually operate the external windows will be investigated.

During M26-M30, based on the PRUBS module performance on the pre-validation pilot sites and the capability of the occupant behaviour models to capture the occupants' habits, the PRUBS module will be further extended and refined to finally deliver its second version on M30.

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[5] BIMERR, "Description of Action (DoA)," 2018.

[6] BIMERR, "Deliverable D3.1 - Stakeholder requirements for the BIMERR system," 2019.

[7] BIMERR, "Deliverable D3.3 - BIMERR evaluation methodology," 2019.

[8] BIMERR, "Deliverable D3.6 - BIMERR system architecture final version," 2020.

[9] BIMERR, "Deliverable D4.2 - BIMERR Ontology and Data Model 1," 2019.

[10] BIMERR, "Deliverable D4.8 - Integrated BIMERR Interoperability Framework 1," 2020.

[11] ISO 16739, "Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries (ISO 16739:2013)," CEN, 2016.

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ANNEX I - PILOT BUILDING AUDIT QUESTIONNAIRE

Legal Information: The following table is to be completed for each *building* and for each *apartment within the building*. Please fill in the fields applicable to the case examined (building or apartment); it is noted here that some fields maybe applicable to both.

Information required	
Who owns the building/apartment?	
Is an agreement needed (according to national/EU Legislation & GDPR) in order to access data or to take actions over assets for demo purposes? (Please check the correct answer)	☐ Yes, owner consent required ☐ Yes, owner and building occupants consent is required ☐ No
Have owner & building occupants been informed about project purposes and have they **signed the consent form**?	☐ Yes ☐ No
Are they willing to install a smart home Gateway & smart equipment in premises to share their data with BIMERR?	☐ Yes ☐ No
Are they willing to offer their internet connection for BIMERR project? (The actual usage of bandwidth is negligible, < 0.01% of your internet connection)	☐ Yes ☐ No
Free comments	

Demographics: The following table is to be completed for each *apartment* (household).

Information required	
Household Composition	☐ Under 18 years old

(Please fill how many members of the household are in each age category)	☐ 18-24 years old ☐ 25-34 years old ☐ 35-44 years old ☐ 45-54 years old ☐ Over 54 years old
Employment Information (Please fill how many members of the household are in each employment status category)	☐ Employed full time ☐ Employed part time ☐ Self-employed ☐ Unemployed ☐ Student ☐ Homemaker ☐ Retired
Digital skills	☐ Not familiarised at all ☐ PC owner ☐ Tablet owner ☐ Smartphone Owner ☐ Smart home Devices Owner ☐ Other
Free comments	

Building information: The following table is to be completed for each *building* and for each *apartment within the building*. Please fill in the fields applicable to the case examined (building or apartment); it is noted here that some fields maybe applicable to both.

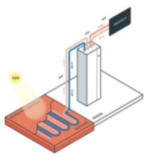
Information required	
Building/Apartment ID	Please identify a unique ID for each dwelling
Location (postal code)	
Dwelling Tenancy regime	☐ Rented ☐ Ownership ☐ Usufruct
Type of dwelling you live in	☐ Detached ☐ semi-detached house ☐ Apartment building
Size of dwelling	☐ Less than 50 m^2 ☐ 50–100 m^2 ☐ 100–150 m^2 ☐ 150–200 m^2, ☐ 200-250 m^2, ☐ More than 250 m^2
Topology plan of the apartment (number of rooms etc) (For each entry please fill the **correct number**)	☐ Floor level (in case of apartment building) ☐ Number of floors ☐ Number of kitchens ☐ Number of bathrooms ☐ Number of living rooms ☐ Number of bedrooms
Number of people in floor / area	

Does the building/apartment have internet connectivity?	☐ Yes ☐ No
Does the building/apartment have wifi connectivity?	☐ Yes ☐ No
Does the building/apartment have already installed any **smart meter**? Please provide information about any energy source (electricity, gas)	☐ Electricity ☐ Gas
Please specify your current electricity, gas tariff scheme (e.g. single rate, time of use, controlled load, etc)	
Approx. building/apartment annual electricity, gas consumption (info can be found from electricity, gas consumption bills)	
Frequency of readouts (info can be found from electricity, gas consumption bills)	
Historical readouts available (historical traces of consumption for baseline)	This info is needed for baseline ☐ No ☐ Yes; For what time period (e.g. one year)
What type of heating system is used? (multiple selection is possible)	☐ Unitary Unit (e.g. a heating/cooling system used/controlled only for one particular room) ☐ Central (e.g. a central heating/cooling system serving the needs of the apartment-dwelling) ☐ District/Collective

What type of cooling system is used? (multiple selection is possible)	☐ Unitary Unit (e.g. a heating/cooling system used/controlled only for one particular room) ☐ Central (e.g. a central heating/cooling system serving the needs of the apartment-dwelling) ☐ District/Collective
What type of water heating is used? (multiple selection is possible)	☐ Unitary Unit (e.g. a heating/cooling system used/controlled only for one particular room) ☐ Central (e.g. a central heating/cooling system serving the needs of the apartment-dwelling) ☐ District/Collective
Local electricity Generation & Storage from RES	☐ Generation ☐ Generation & Storage ☐ No
Free comments	

Available equipment: The following table is to be completed for each *building* and for each *apartment within the building*. Please fill in the fields applicable to the case examined (building or apartment); it is noted here that some fields maybe applicable to both.

HVAC System	
What is the HVAC system type?	☐ Air conditioner Air/Air (split units)  **Note:** Air–air heat pump (transfers heat to inside air) – This category refers to ductless mini-splits that connect one or more indoor coils (often referred to as "heads" or "fan coils") to a single outdoor unit, with each head having its own refrigerant loop.

	☐ Air to water heat pump  **Note:** Air–water heat pump transfers heat to a heating circuit and a tank of domestic hot water ☐ Air to air heat pump  **Note**: Air–air heat pump (transfers heat to inside air) **–** This category refers to conventional air to air heat pumps that have one indoor coil in an air-handling unit and use forced-air distribution through **ductwork** to deliver conditioned air to various zones within a home. ☐ Gas Boiler  **Note:** A boiler can heat water with gas in order to heat the home) ☐ Ground-to-water heat pump (Geothermal)  **Note:** It is a central heating and/or cooling system that transfers heat from or to the ground with the use of a heat pump. ☐ District Heating[i] ☐ Other (please specify)
Is the cooling system different from the Heating System or is it integrated in the same HVAC system? (Please check the correct answer)	☐ Yes ☐ No

Please specify **manufacturer name** and **model** (e.g. GREE Change Ecodesign Series, GRS 101 EI/JCDA-N2)[ii]	
What is the heating/cooling capacity of the system (in BTU or KW)?	
What is the SEER/SCOP (Seasonal Coefficient of Performance) of the HVAC system? (or COP/EER if available)	SEER: EER: SCOP: COP:
Where the HVAC system is located in the building/ apartment? (if multiple devices please indicate where each one is placed)	
Do you have a SG Ready Label Heat Pump?	☐ No ☐ Yes
Which of the following are connected to the HVAC system?	☐ Radiators ☐ Underfloor systems ☐ Hot Water tank ☐ Fan coils ☐ Registers ☐ Other (if any, please specify)
How is the HVAC system controlled? (if multiple devices please indicate for each one)	☐ IR controller for each air-conditioner? ☐ One thermostat for the whole dwelling ☐ One thermostat per room ☐ Thermostat is attached on the emitter (Please write the radiator manufacturer name and its model as well)

	☐ Other (please specify)
For each installed thermostat in the building/apartment, please complete the following table	
Manufacturer Name	
Model (or Serial Number)	
What room / area does this thermostat control?	
Is it possible to remotely capture user setpoints from the thermostat?	☐ Yes ☐ No ☐ I don't know
Is it possible to remotely capture indoor temperature from the thermostat?	☐ Yes ☐ No ☐ I don't know
Is it possible to remotely capture outdoor temperature?	☐ Yes ☐ No ☐ I don't know
Free comments	
Domestic Hot Water	
What type of water heating system do you have?	☐ Electric Domestic hot water (DHW) tanks

	 **Note:** An electric water heater is a storage tank that **heats and stores water** ☐ Electric Boiler  **Note:** An electric boiler can heat water that is used to **heat the home** and **provide hot water** ☐ Tankless heaters  **Note:** Tankless water heaters are devices that instantly heat water as it flows through the device ☐ Domestic hot water (DHW) heat pump  **Note:** In a DHW heat pump device water is feeded from a heat pump ☐ Gas Boiler  **Note:** A boiler that heats water with gas in order to heat the home and provide hot water ☐ District/Collective/Other (please specify)
Please specify manufacturer name and model	
Is your DHW tank connected to your heat pump?	☐ Yes ☐ No

(Please answer this question if applicable)	
What is the nominal power of the system (in KW)?	
What is the tank water capacity?	
How is the Water Heater controlled?	☐ Circuit Breaker ☐ Plug
Please specify the number of phases. (Single Phase / 3-Phase)	☐ Single Phase ☐ 3-Phase
Free comments	

Renewable energy sources: The following table is to be completed for each *building* and for each *apartment within the building*. Please fill in the fields applicable to the case examined (building or apartment); it is noted here that some fields maybe applicable to both.

Information Required	
Local electricity generation from RES	☐ No ☐ Yes; Please specify the RES type (e.g. PV, small wind turbine)
Your RES system is:	☐ grid connected ☐ stand-alone / off grid ☐ N/A
Approx. annual electricity production (please provide info per RES defined above)	

Do you own a battery for RES production storage?	☐ Yes ☐ No
Do you own an EV?	☐ Yes, I have a plug-in hybrid EV (PHEV) ☐ Yes, I have a non-plug-in hybrid EV (HEV) ☐ Yes, I have a battery/pure EV (BEV) ☐ Yes, I have an electric bike ☐ No. I do not have an EV
Free comments	
Available equipment	
Photovoltaics	
Please specify the PV installed capacity (e.g. 10kW)	
Please indicate information about the inverter(s) type and topology	Manufacturer: Model: Number of inverters: Where the inverter(s) are located: Internet connectivity:
Do you have a grid connected inverter with integrated battery (e.g. ABB REACT)?	☐ Yes, please specify the manufacturer and model: ☐ No
Where is the PV electrical panel located?	
Approx. annual electricity production	

Free comments	
Energy Storage System (Batteries)	
Please provide Energy storage system (PV+battery) information (provide information per battery, if applicable)	Manufacturer / Model: Storage Energy (kWh): Usable Energy (kWh): Type of electrode / Technology (e.g. Lithium, Lead Acid):
Please indicate information about the battery inverter(s) type and topology (if applicable)	Manufacturer: Model: Where the inverter(s) are located: Internet connectivity:
Free comments	
Other RES Types (e.g. small wind turbine)	
Please specify the RES installed capacity (e.g. 10kW)	
Please indicate information about the topology and properties of the RES	
Where is the RES located?	
Free comments	

Usage patterns: The following table is to be completed only for each *apartment*.

Information required		
Could you please indicate a rough estimation of the DHW usage schedules on weekdays and weekend?	**Weekdays**	**Weekends**
	From (hour):	From (hour):
	To (hour):	To (hour):
Could you please indicate a rough estimation of the HVAC usage schedules on weekdays and weekend?	**Weekdays**	**Weekends**
	From (hour):	From (hour):
	To (hour):	To (hour):
Could you please indicate a rough estimation of presence and absence schedules on weekdays and weekend? (in case of multiple occupants provide a rough average schedule for all)	**Weekdays**	**Weekends**
	Leaving Home:	Leaving Home:
	Entering Home:	Entering Home:
Free comments		

[i] In case of a District heating system or Gas heating please fill in the corresponding information related with the connected components (e.g. radiators, fan coils) and system control (e.g. thermostats)
[ii] In case the model and manufacturer are not known, a photograph of the device is essential! If not possible at this stage, it can be filled in afterwards during the on-site visit by an assigned expert.