ePANACEA

Smart European Energy Performance Assessment & Certification

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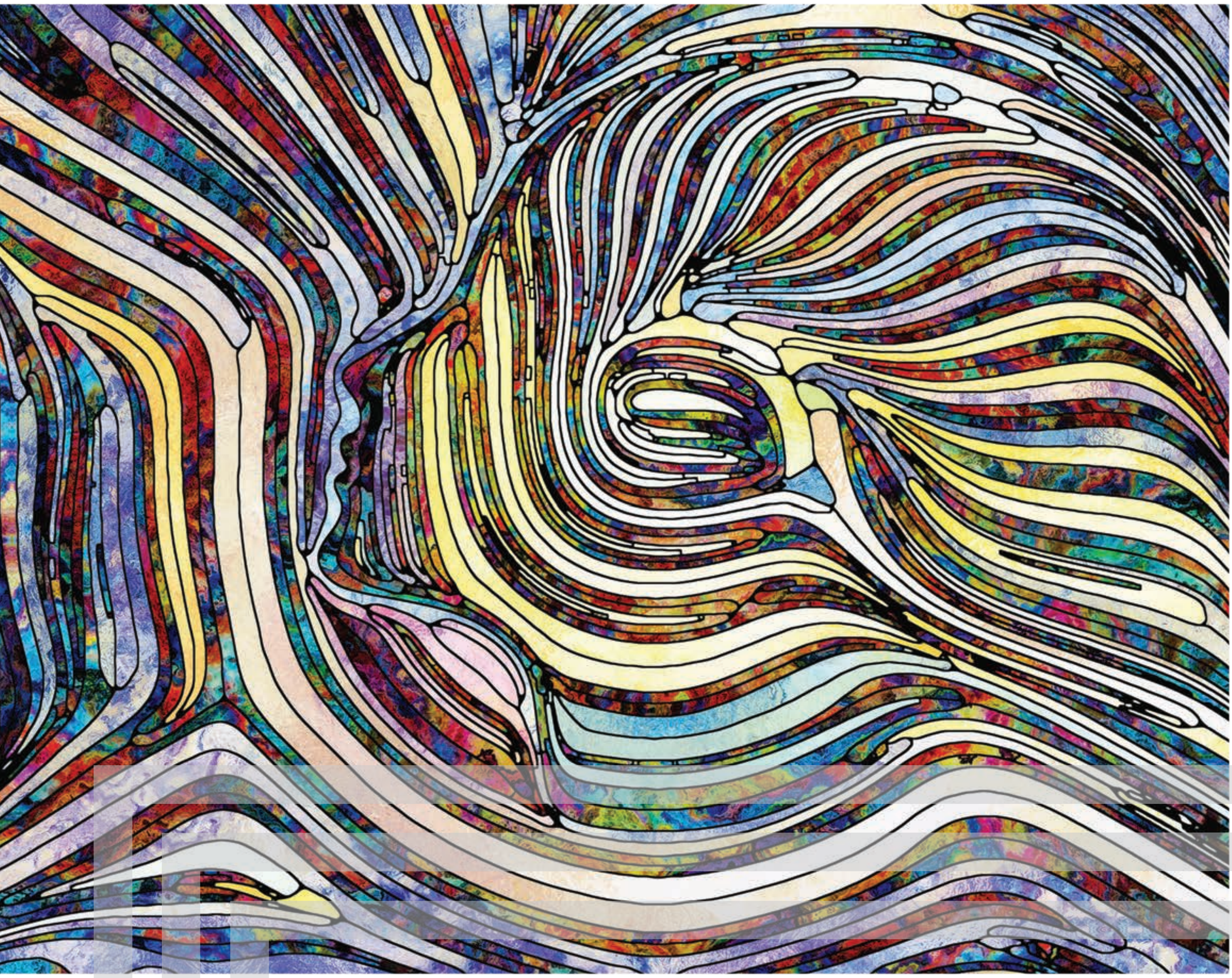

Advanced occupant behaviour patterns for the next generation of Energy Performance Certificates (EPCs)

Report on the selection of advanced occupant models and impact analysis

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Author(s): Marta Sampedro Bores, María Fernández Boneta (CENER)

Reviewer(s): Laura Muhr (IZES), Elpida Polychroni (CRES)

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TABLE OF CONTENTS

OVERVIEW OF THE EPANACEA PROJECT ....- 3 -

EXECUTIVE SUMMARY ....- 4 -

GLOSSARY....- 5 -

1. INTRODUCTION ....- 6 -

1.1. IEA-EBC ANNEX 66. SIMULATION AND DEFINITION OF OCCUPANT BEHAVIOUR IN BUILDINGS ....- 6 -

1.1.1. The DNAS occupant behaviour framework....- 7 -

1.2. IEA-EBC ANNEX 79. OCCUPANT BEHAVIOUR-CENTRIC BUILDING DESIGN AND OPERATION ....- 8 -

2. METHODOLOGY ....- 9 -

3. OFFICE BUILDING USE....- 10 -

3.1. CASE STUDY DESCRIPTION....- 10 -

3.2. BUILDING ENERGY MODELLING (BEM) ....- 10 -

3.2.1. Thermal transmittance of surfaces....- 11 -

3.2.2. Internal Loads ....- 11 -

3.2.3. Ventilation and Infiltrations....- 12 -

3.2.4. System....- 12 -

3.2.5. Schedules ....- 12 -

3.3. IMPACT ASSESSMENT ....- 14 -

3.3.1. Base Case (Case 0) ....- 15 -

3.3.2. Occupancy presence (Case 1) ....- 16 -

3.3.3. Lighting (Case 2) ....- 19 -

3.3.4. Plug-in equipment (Case 3) ....- 22 -

3.3.5. Windows shade (Case 4)....- 23 -

3.3.6. Operable window (Case 5) ....- 25 -

3.3.7. Thermostat (Case 6)....- 26 -

3.3.8. All OB Together (Case 7)....- 27 -

3.4. CONCLUSIONS....- 29 -

4. RESIDENTIAL BUILDING USE ....- 31 -

4.1. CASE STUDY DESCRIPTION....- 31 -

4.2. BUILDING ENERGY MODELLING (BEM) ....- 32 -

4.2.1. Thermal zones ....- 32 -

4.2.2. Thermal envelope ....- 32 -

4.2.3. Domestic hot water need ....- 33 -

4.2.4. HVAC....- 33 -

4.3. METHODOLOGY....- 34 -

4.3.1. Step 1: users' forms....- 35 -

4.3.2. Step 2: data from smart meters ....- 35 -

4.3.3. Step 3: spot measurements and post-processing data....- 38 -

4.3.4. Calibration....- 39 -

4.4. IMPACT ASSESSMENT ....- 41 -

4.4.1. Results and discussion ....- 41 -

4.5. CONCLUSIONS - 45 -

5. REFERENCES - 46 -

5.1. LIST OF FIGURES - 46 -

5.2. LIST OF TABLES - 47 -

5.3. OTHER REFERENCES - 48 -

ANNEX: EU CLIMATE ZONES - 50 -

Occupance Behaviour climates selected - 53 -

OVERVIEW OF THE ePANACEA PROJECT

After 10 years of track record, the current EPC schemes across the EU face several challenges which have led to a not full accomplishment of their initial objectives: lack of accuracy, a gap between theoretical and real consumption patterns, absence of proper protocols for inclusion of smart and novel technologies, little convergence across Europe, lack of trust in the market and very little user awareness related to energy efficiency.

The objective of the ePANACEA project is to develop a holistic methodology for energy performance assessment and certification of buildings that can overcome the above-mentioned challenges. The vision of ePANACEA is to become a relevant instrument in the European energy transition through the building sector.

ePANACEA comprises the creation of a prototype (the Smart Energy Performance Assessment Platform) making use of the most advanced techniques in dynamic and automated simulation modelling, big data analysis and machine learning, inverse modelling or the estimation of potential energy savings and economic viability check.

A relevant part of the project is to have a fluent dialogue with European policy makers, certification bodies, end-users and other stakeholders through two types of participatory actions: a feedback loop with policy makers, carried out through the so-called Regional Exploitation Boards (REBs) covering EU-27+UK+Norway on the one hand, and dialogue with end-users, established by means of specific thematic workshops, on the other.

Thanks to these participatory actions, the acceptance of the ePANACEA approach will be tested and validated in order to become aligned with and meet the needs of national public bodies, end-users and other stakeholders.

ePANACEA will demonstrate and validate reliability, accuracy, user-friendliness and cost-effectiveness of its methodology through 15 case studies in 5 European countries.

EXECUTIVE SUMMARY

Occupant behaviour is now widely recognised as one of the most important factors contributing to the uncertainty of building performance. The operating characteristics and the occupants' use of space are closely related to the energy needs and consumption of buildings. This work was developed in order to explore the possible implementation of advanced occupant models into the Assessment Method 3 developed under the ePANACEA methodology for the use of calibrated models based on dynamic simulation for Energy Performance Certification of buildings.

The work carried out is structured in three clearly differentiated phases:

Firstly, a research has been carried out on the current state of the art in the implementation of user behaviour in dynamic simulation models. In this field, the Annex 66 project in its Subtask D develops a framework for XML schemas and a software module with occupant behaviour models that enables the implementation of stochastic occupant behaviour in dynamic simulation models. Tianzhen Hong (leader of this subtask D) together with his team, have developed the Occupancy Simulator tool that uses Markov chain model to simulate occupancy in office buildings. The application simulates occupant movement and generates occupant schedules for each space. These schedules can be implemented in EnergyPlus which is the tool that will be used in the development of the Assessment Method 3 within the context of the ePANACEA project.

The second part of the work evaluates the energy performance of a static office model (i.e. the common practice in current simulation models) against six stochastic behavioural models. Each of the six stochastic models will evaluate the sensitivity of the results on each of the following variables: (1) Occupancy (presence), (2) Lighting, (3) Plug-in equipment, (4) Window shade, (5) Operable window and (6) Thermostat.

The individualised study of these behaviours has been carried out with an occupant behaviour functional mock-up unit (obFMU) that enables co-simulation with EnergyPlus program implementing functional mock-up interface (FMI). The components detailed in the development of the obFMU include an overview of the DNAS (drivers-needs-actions-systems) ontology and the occupant behavior eXtensible Markup Language (obXML) schema, in addition to details on the creation of the obFMU that contains the co-simulation interface, the data model and solvers [8].

The third phase of the work has been focused on the impact assessment derived from taking actual occupant behaviour into account through a case study of residential typology.

After the research carried out regarding advance occupant modelling and its testing and implementation for an office building case study, due to the difficulty to find existing and robust models for the residential typology because of the variety of scenarios, it is decided to apply a different and cost-effective approach for the residential sector within the ePANACEA project context.

Taking advantage of the ICTs and increasingly common accessibility to actual building data, this approach is focused on the use of smart meter data and some other additional specific measurements, that supported by user interviews, allow a detailed user behaviour modelling for dynamic simulations.

This approach pursues to support the starting point for the calibration procedure implemented within ePANACEA methodology in order to drastically reduce the performance gap between theoretical and actual energy use within the EPC context.

GLOSSARY

ASHRAE:	American Society of Heating, Refrigerating and Air Conditioning Engineers
BEM:	Building Energy Modelling.
BEPS:	Building Energy Performance Simulation
BES:	building Energy Simulation
BMS:	Building Management System
CV(RMSE):	Coefficient of Variation of the Root-Mean-Square Error
DHW:	Domestic Hot Water
DNAS:	Drivers, Needs, Actions, Systems
DSO:	Distribution System Operator
EBC:	Energy in the Buildings and Communities
EEM:	Energy Efficiency Measure
EPC:	Energy Performance Certification
FMI:	Functional Mockup Interface
HVAC:	Heating Ventilation and Air Cooling
IEA :	International Energy Agency
MBE:	Mean Bias Error
NMBE:	Normalised Mean Bias Error
NME:	Normalised Mean Error
OB:	Occupant Behaviour
obFMU:	occupant behaviour Functional Mockup Unit
obXML:	occupant behaviour eXtensible Markup Language
ROV:	Range of variation
XML:	eXtensible Markup Language

ISO 52000-1 definitions

Energy need for heating or cooling: heat to be delivered to or extracted from a thermally conditioned space to maintain the intended space temperature conditions during a given period of time

Energy need for DHW: heat to be delivered to the needed amount of domestic hot water to raise its temperature from the cold network temperature to the prefixed delivery temperature at the delivery point without losses of the domestic hot water system

Non-renewable primary energy use: indicator based on the consumption of non-renewable primary energy, using for calculation the non-renewable primary energy factors for a given energy carrier

Energy use for lighting: electrical energy input to a lighting system

Energy use for other services (electric equipment): energy input to appliances providing services not included in the EPB services

1. INTRODUCTION

One of the most significant barriers to achieving deep building energy efficiency is a lack of knowledge about the factors determining energy use. In fact, there is often a significant discrepancy between designed and real energy use in buildings, which is poorly understood but is believed to have more to do with the role of human behavior than building design. Building energy use is mainly influenced by six factors: climate, building envelope, building services and energy systems, building operation and maintenance, occupants' activities and behavior, and indoor environmental quality [1]. Occupant behaviour implies the major uncertainty source that can conduct up to 30% of variation in building energy performance according to Eguaras-Martínez et al.[2]. Most building energy simulation programs use deterministic models for the variables associated to occupant behaviour (i.e. fixed schedules for occupancy, lighting use, plug loads, cooling/heating set-points, etc.). However, this approach, which is easy to implement, does not represent the complex stochastic nature of human behaviour or its interaction with the building.

This simplification of human behaviour contributes to increase the performance gap between actual energy use of buildings and simulation predicted data. The reality is that user behaviour is not static; it depends on many factors such as outside temperature, radiation, wind, rain, physical and/or psychological state of users, etc. Buildings' users have the ability to open and close windows, deploy or collect sun protection elements, switch lights on and off, activate or deactivate electrical appliances or move between spaces. All these occupant behaviours within the building are a key issue in the evaluation of building performance and energy assessments, due to their important impact on the actual energy use and indoor environmental quality of buildings. Occupant behaviour is complex, stochastic and multidisciplinary.

This report aims to show the results obtained after the research carried out within the context of the ePANACEA methodology development related to the exploration of advanced occupant modelling for dynamic building energy simulations, which can be implemented on energy performance assessments for conducting Energy Performance Certificates (EPCs) of buildings.

The exploration and impact assessments of different advanced occupant models for six occupant-related domains have been carried out (i.e. occupancy (presence), lighting, plug-in equipment, window shade, operable window and thermostat) in order to take decisions regarding next steps of the methodology development.

1.1. IEA-EBC Annex 66. Simulation and Definition of Occupant Behaviour in Buildings

Based on the strong influence of occupant behaviour on building energy use and technology assessment and the lack of quantitative methods and a common language for description and simulation of OB (Occupant Behaviour), Annex 66 was approved at the 74th Executive Committee Meeting of the IEA (International Energy Agency) EBC (Energy in Buildings and Communities) Programme. The Annex aims to set up a standard occupant behaviour definition platform, establish a quantitative simulation methodology to model occupant behaviour in buildings, and understand the influence of occupant behaviour on buildings energy use and their indoor environment.

The project has five subtasks:

- Subtask A - Occupant movement and presence models.
- Subtask B - Occupant action models in residential buildings.
- Subtask C - Occupant action models in commercial buildings.
- Subtask D - Integration of occupant behaviour definition and models with current building energy modelling programs.
- Subtask E - Applications in building design and operations.

1.1.1. The DNAS occupant behaviour framework

As it is mentioned in the ePANACEA's report "The human factor in energy use in buildings (Fact sheet on energy-related behaviour in the context of buildings) | Zenodo" DNAS (Drivers, Needs, Actions and Systems) framework is an ontology to represent energy-related occupant behaviour, providing a systematic representation of energy-related occupant behaviour in buildings by Hong et al. [3]. The DNAS framework was developed following the IEA-EBC Annex 66 project and due to the notion that a reliable energy behavioural model did not exist [4]. Furthermore, Hong et al. [3] developed a XML (extensible Markup Language) schema, with the goal of normalizing energy consumption in buildings for energy-related occupant behaviour [4].

The DNAS framework is based on four main components:

- **Drivers**: represent the stimulating factors that provoke energy-related occupant behaviour. Drivers can come from different sources such as building (properties, location...), occupants (attributes, energy attitude, location, state...), environment (climate, radiation, indoor, outdoor...), systems (properties, state...), time (day, month, season...).
- **Needs**: represent the requirements of an occupant that must be met in order to ensure satisfaction with the environment. There are two types of needs: physical and non-physical. Physical needs include those related to comfort (acoustic, thermal, visual, Indoor Environmental Quality (IEQ)) and biological needs (bathing, hygiene, exercise, food, drink, sleep...). The non-physical ones comprise e.g. privacy, social interactions, entertainment...
- **Actions**: are interactions with building systems or activities that an occupant can conduct in order to satisfy his/her needs. Actions can be: interactions with system/s, movement, inaction, reporting discomfort, etc.
- **Systems**: are the equipment or mechanisms with which an occupant may interact to restore comfort. Common systems that are subject to occupant control and actions include windows, window blind/shades, lights, thermostats, space occupancy and electrical equipment.

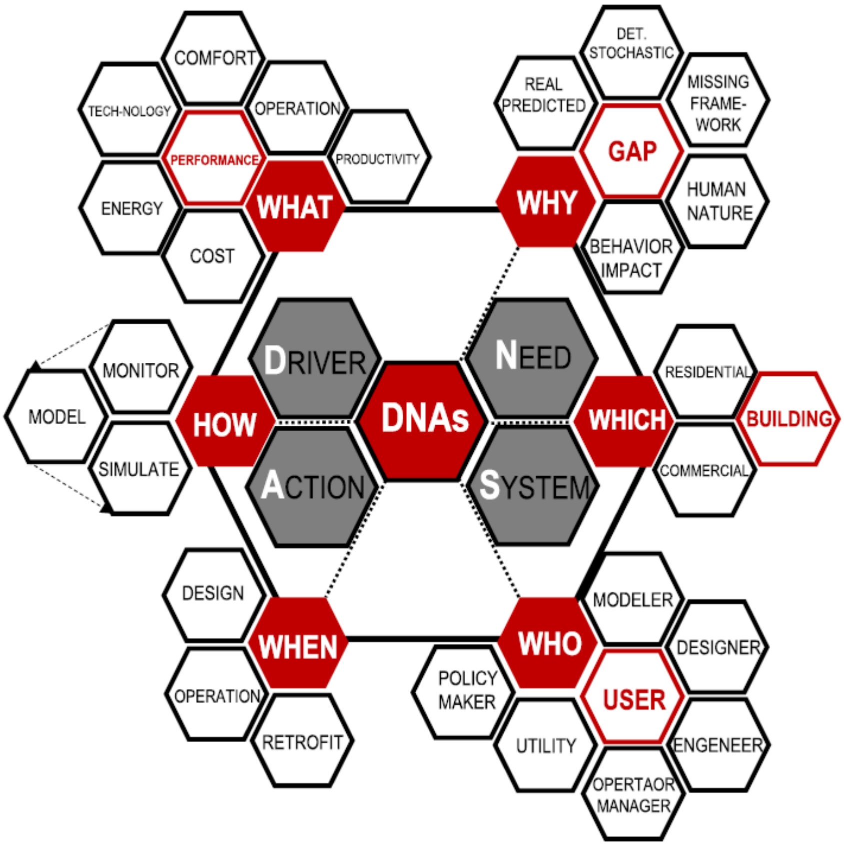

Figure 1. A graphical representation of the DNAS framework applications [3]

The proposed DNAS framework is intended to be integrated into current building energy modelling programs like EnergyPlus and other domains (ESP-r, TRNSYS, IDA ICE, DeST, DOE-2, etc.) or Functional Mock-up Interfaces (FMI) to support both model exchange and co-simulation of dynamic models using a combination of xml-files and compiled codes, within the structure of the XML Schema [3].

1.2. IEA-EBC Annex 79. Occupant behaviour-centric building design and operation

The field of occupant modelling emerged over four decades ago; however, it has surged in the past decade, particularly as a result of IEA EBC Annex 66 – “Simulation and Definition of Occupant Behaviour in Buildings”. Annex 66 played an important role in formalizing experimental research methods, modelling and model validation, and occupant simulation. The follow-up Annex 79 - "Occupant Behaviour Centred Building Design and Performance" arises due to the number of unanswered questions on occupant comfort and behaviour and the minimal penetration of advanced occupant modelling in practice.

With the overall goal of implementing occupancy and occupant behaviour into the design process and building operation to improve both energy performance and occupant comfort, Annex 79 is focussing on:

- developing new scientific knowledge about adaptive occupant actions driven by multiple interdependent indoor environmental parameters,
- understanding interactions between occupants and building systems, e.g. how interfaces en-/discourage occupants taking advantage of adaptive opportunities for improving their comfort situation, as well as the impact on building energy use,
- deploying ‘big data’ (e.g. data mining and machine learning) for the building sector based on various sources of building and occupant data as well as sensing technologies,
- developing methods and guidelines and preparing standards for integrating occupant models in building design and operation, and
- performing focused case studies to test the new methods and models in different design and operation phases in order to obtain valuable feedback for the researchers, practitioners, and policy makers.

Annex 79 is currently under development, ending in 2023; therefore, there is no completed documentation on the development of the whole project at the moment that could improve the results obtained in this study.

2. Methodology

In order to study the impact of the possible inclusion of advanced occupancy models into the ePANACEA methodology, the state of the art related to simulation tools that consider user behaviour has been explored. In this context Occupant Behaviour (OB) research conducted by Tianzhen Hong (operating agent of IEA EBC Annex 66 and led Subtask D to integrate occupant behaviour models and tools with building performance simulation) and his team is identified. Funded by DOE's Building Technology Office through the U.S.-China Clean Energy Research Centre one of the primary goals of this research is to simulate and quantify the impact of occupant behaviour on building energy consumption.

To this end, this working team has developed a web application for simulating occupant movement and generating realistic occupancy scheduling considering diverse and stochastic behaviour of occupants, an ontology and XML schema to standardize the representation of occupant energy behaviour in buildings for interoperability and an Occupant Behaviour Software, which redefines, in a more realistic fashion, occupant behaviour inputs and co-simulates with EnergyPlus to capture impact of occupant behaviour on the energy performance of buildings.

Since the ePANACEA's report "Report on the selection of the open-source simulation tool and its compliance with ISO 52000 series | Zenodo" establishes EnergyPlus as the most suitable tool for the development of the assessment method 3 in the framework of the ePANACEA methodology, the above mentioned tool is suited for meeting the study's objectives.

The Occupancy Simulator is a user friendly application that uses Markov chain model to simulate occupancy in buildings. The application takes high level input on occupants, spaces and events, then simulates occupant movement and generates occupant schedules for each space. The generated schedules capture the diversity and stochastic nature of occupant activities. These schedules can be downloaded and used for building simulation.

Three variables have been combined to carry out this study:

a. **Use.** Two building use typologies have been used to explore the influence of user behaviour on buildings energy use; office and residential buildings.

b. **Occupant Behaviours.** To analyse the relative sensitivity of the occupants, six variables were analysed individually so that it can be established which of them can generate more or less uncertainty in the results of a calibrated model. The variables studied are as follows:
    1. Occupancy (presence),
    2. Lighting,
    3. Plug-in equipment,
    4. Window shade,
    5. Operable window
    6. Thermostat

    In order to establish the influence of the results of each of the domains, a Base Case or Case_0, has been developed against which the results obtained for each of the studied occupant –related domains are compared.

c. **Climate.** European climatic zones have been evaluated in the ANNEX: EU Climate zones in order to select four representative weather data files for comparison purposes in the context of this study assessment. In the context of the project, four different climates have been selected that occur in different areas of Europe and are present among the ePANACEA project partner countries. The selected climates, based on the documentation in the ANNEX: EU Climate zones and according to ePANACEA's pilot countries, are: (1) Climate 1 and 2 Madrid (Spain), (2) Climate 3 Vienna (Austria), (3) Climate 4 Brussels (Belgium) and (4) Climate 5 Helsinki (Finland).

3. OFFICE BUILDING USE

3.1. Case study description

An intermediate floor of an office building was selected for this case study. The office floor consists of 776.34 m² of open plan office space, offices, meeting rooms and additional spaces for other services. The office plan is presented in Figure 2.

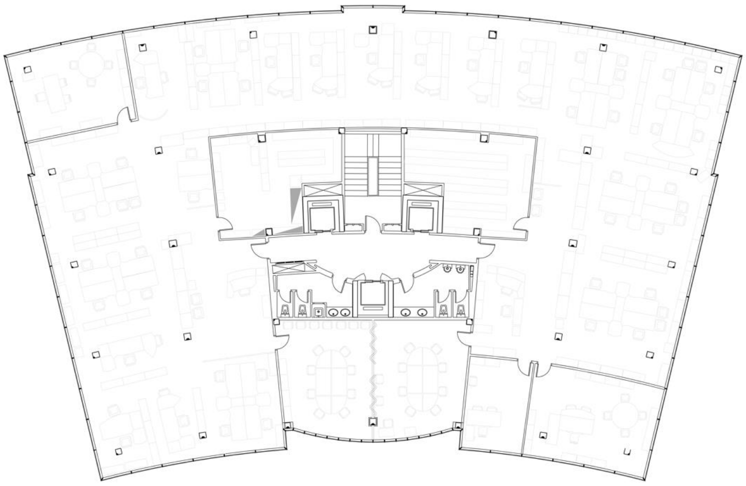

Figure 2. Office plan

3.2. Building Energy Modelling (BEM)

The EnergyPlus office model consists of 12 thermal zones divided into:

- Three open office areas (Office1, Office2 and Office3),
- Two meeting rooms (MeetingRoom1, MeetingRoom2),
- Three offices (managerOffice1, ManagerOffice2, DirectorOffice1),
- Two store zones (Store1, Store2),
- The stairs space to upper and bottom floors (Stairs),
- A distributor (Distributor)

Figure 3 shows the EnergyPlus office model made using the Google SketchUp application.

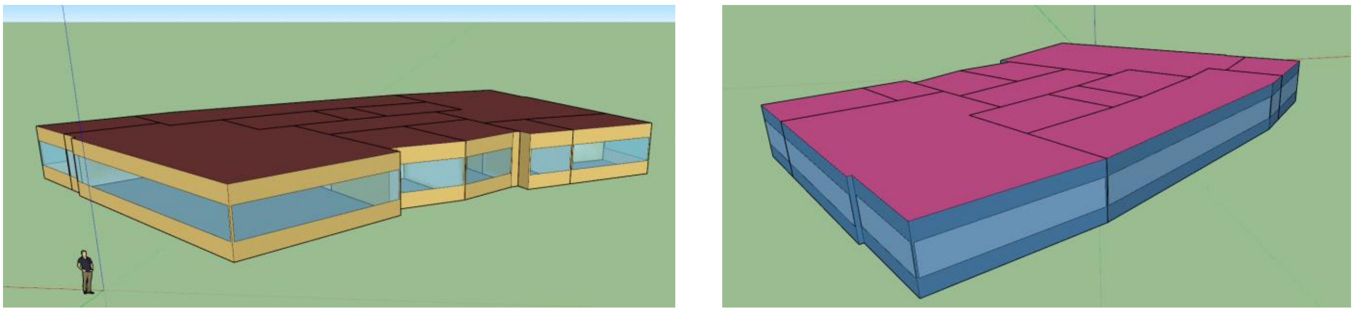

Figure 3. EnergyPlus office model

A large continuous window runs along the entire external wall of the floor. Along this large window there are 2.25 m² casement windows that allow natural ventilation of the spaces. The number of casement windows is distributed according to the surface area of the spaces: 3 units in open-plan office areas and one unit in offices and smaller rooms like meeting rooms.

The list of zones and some basic characteristics related to internal loads are listed in Table 1 and have been entered on the basis of the existing workstations in the office plans.

3.2.1. Thermal transmittance of surfaces

The thermal transmittance of the **external wall** is 0,314 W/m²K and consists of the materials shown in Figure 4.

		Thickness (m)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Thermal transmittance (W/m²K)
External Wall (ETICS)	Rse			0.04	
	MOR01_25mm_Cement_Mortar_1600<d<1800	0.025	1	0.03	
	I03 60mm insulation board	0.06	0.03	2.00	
	M02 115mm brick	0.115	0.694	0.17	
	I05 20mm insulation board	0.02	0.036	0.56	
	F04 Wall air space resistance	0.01	-	0.15	
	G01a 19mm gypsum board	0.019	0.16	0.12	
	Rsi			0.13	
		0.25		3.185	**0.314**

Figure 4. External Wall composition

The composition of the **ceiling** and **floor** is irrelevant because they border other office spaces, so they have been considered adiabatic.

Thermal bridges have not been considered.

Exterior windows construction is composed by shading control solar glass with the following characteristics: $U_{windowr}$=2.8 W/m²K, Solar heat gain coefficient (g) = 0.49 and Visible Transmittance (T_l) = 0.44.

No shading devices have been considered

3.2.2. Internal Loads

Electric equipment loads considered are extracted from 2017 ASHRAE Handbook-Fundamentals (SI), “table 11 Recommended Load Factors for Various Types of Offices” considering a medium use of 11.6 m²/workstation, all desktop use and 1 printer per 10 workstations.

Lighting internal loads in the spaces have been considered according to actual projects built between 2015 and 2020 with similar characteristics (use type and size of the spaces). The installed lighting power per m² and the rest of loads considered are shown in Table 1.

Table 1. Thermal zones of Office building

Thermal Zone Name	Area [m²]	Zone Volume [m³]	Nominal Number of Occupants	Occupant load [W/person]	Lighting load [W/m²]	Equipment load [W/m²]	Ventilation [ach]
OFFICE1	182.23	464.70	18	120	6.75	7.79	1.3
OFFICE2	126.77	323.25	12	120	6.75	7.79	1.3

OFFICE3	182.37	465.04	18	120	6.75	7.79	1.3
MEETINGROOM1	31.01	79.08	3	120	9.00	7.79	1.3
MEETINGROOM2	31.00	79.06	3	120	9.00	7.79	1.3
MANAGEROFFICE1	28.22	71.95	1	120	8.35	7.79	1.3
MANAGEROFFICE2	16.86	42.98	1	120	8.35	7.79	1.3
DIRECTOROFFICE1	34.16	87.11	2	120	8.35	7.79	1.3
STORE1	38.18	97.35	0	120	8.00	0	1.3
STORE2	38.18	97.35	0	120	8.00	0	1.3
STAIRS	17.70	45.14	0	120	6.35	0	1.3
DISTRIBUTOR	49.66	126.62	0	120	6.35	0	1.3

3.2.3. Ventilation and Infiltrations

Minimum mechanical ventilation has been estimated as a mean for the whole floor volume calculated from an outdoor air flow rate of 12.5l/s per person in order to meet IAQ (Indoor Air Quality) requirements.

The Spanish regulation for tertiary buildings establishes this requirement, for which compliance is considered to be valid in accordance with the procedure of UNE-EN 13779. According to this regulation, the office model developed implies a minimum renovation rate with outside air of 1.3 air changes per hour.

Uncontrolled air infiltration of 0.1 air changes per hour in the building has been considered.

3.2.4. System

For this case study, only the impact of Occupant Behaviour on the building's energy needs will be evaluated, for this reason, an HVAC system has not been modelled, but an Idealload system has been used.

3.2.5. Schedules

Static schedules with the operational conditions of building use (e.g. occupancy, use of equipment, lighting system, etc.) are defined for dynamic energy simulation purposes. The schedules used in the definition of the baseline for this case study are shown below.

Occupancy schedule

The occupancy schedule shall govern the other operational schedules of the building. In order to establish the same hours of operation of the building for all study climate zones, the project partners have been asked to provide the typical open office hours in their countries. According to the information provided by the partners, typical office building opening hours are as presented in Table 2.

Table 2 Typical office occupancy schedule

Country	Weekdays	Arrival	Lunch	Departure	Notes
Belgium	Monday to Friday	9:00	12:00-13:00	17:00	Flexible working can be between 7am to 7pm
Finland	Monday to Friday	8:00	0.5 h lunch break between 11:00-13:00	16:15	Clocking in/out is flexible
Spain	Monday to Friday	8:30	1 h lunch break between 13:00-15:00	17:30	30 minutes flexible in/out
Implemented in model	Monday to Friday	8:30	0.5 h lunch break between 12:00-14:00	17:00	30 minutes flexible in/out

Based on these results the weekly schedule implemented in the base case for office use is as shown in Figure 5:

Occupancy schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Labour day	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95	0.75	0.75	0.95	0.95	0.95	0.3	0.1	0.1	0	0	0	0
All other days	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5. Weekly occupancy schedule.

Lighting schedule

Regarding the lighting it is considered that occupants turn on the lights when they arrive at the office in the morning and keep them on until they leave the office between 17:00 and 19:00, keeping a residual percentage of lights on during unoccupied periods, in an attempt to account for occupants who may forget to turn off the lights when they leave and/or the consumption of emergency lights. Figure 6 shows the schedule used in the model.

Lighting schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Labour day	0.05	0.05	0.05	0.05	0.05	0.10	0.10	0.30	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.3	0.1	0.05	0.05	0.05	0.05
All other days	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Figure 6. Weekly lighting schedule

The base case does not have daylight sensors for lighting control in the zones.

Equipment schedule

Considering that some of the equipment is left on during the week (when there is no occupancy) as well as on weekends, the following equipment operation schedule has been considered (as presented in Figure 7).

Electric Equipment schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Labour day	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.90	0.90	0.90	0.90	0.80	0.80	0.90	0.90	0.90	0.50	0.4	0.4	0.4	0.4	0.4	0.4
All other days	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.3

Figure 7. Weekly equipment schedule

Ventilation schedule

It is considered that ventilation of offices is applied during the hours when the office is occupied, between 7:00 and 19:00. The ventilation schedule is presented in Figure 8.

Ventilation schedule	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Labour day	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
All other days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 8. Ventilation schedule on/off

HVAC schedules

To determine the building demands, it has been assumed that the building is heated or cooled all year round according to the thermal needs, regulated by a deadband thermostat during the hours of building occupancy. The heating and cooling set points entered into the model are shown in the Figure 9:

High temperature set-point [ºC]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Weekdays	27	27	27	27	27	27	24	24	24	24	24	24	24	24	24	24	24	27	27	27	27	27	27	27
All other days	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
Low temperature set-point [ºC]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Weekdays	15.6	15.6	15.6	15.6	15.6	15.6	21	21	21	21	21	21	21	21	21	21	21	21	15.6	15.6	15.6	15.6	15.6	15.6
All other days	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6	15.6

Figure 9. Heating and cooling set points

3.3. Impact assessment

Occupant behaviours are grouped into two categories: occupancy and occupants' interactions with building systems [5] [6]. The occupancy simulation determines the location of each occupant during each period and is the foundation of advanced occupant behaviour modelling. When occupants are in a space, they may be able to control its systems (such as lights, HVAC and windows), and therefore influence energy consumption [7].

The procedure used in the office case study to assess the impact of each of the variables is as follows. In each of the cases, the Base Case (or baseline) has been used as a starting point to subsequently compare the results obtained with this case.

Firstly, a variable Occupant Behaviour was generated using the "Occupancy Simulator" tool to simulate the occupant presence and movement and generate occupant schedules for each occupant and each space. This occupant behaviour will be the variable studied in Case 1 (Occupancy), and will be maintained throughout the rest of the cases (Occupants' interactions with building systems), as it is this variable that converts the rest of the behaviours into variables.

Then, in the remaining cases, behaviour related to the variable of analysis of this study will be applied to all occupants of the building. For example, in the case of lighting, it has been considered that users turn on the light when they arrive at their workstations and turn it off when they leave the office at the end of their working day.

The individualised study of these behaviours has been carried out with an occupant behaviour functional mock-up unit (obFMU) that enables co-simulation with EnergyPlus program implementing functional mock-up interface (FMI). As shown in Figure 10, the obFMU contains four main components: the co-simulation interface, the interface description file in XML (eXtensible Markup Language) format, the data model and solvers [8]. The XML file is generated based on an obXML (occupant behaviour eXtensible Markup Language) schema. The obXML schema describes the occupant behaviour by implementing DNAS framework [8]. The Data flow of co-simulation between EnergyPlus and FMU is as presented in Figure 10 and Figure 11.

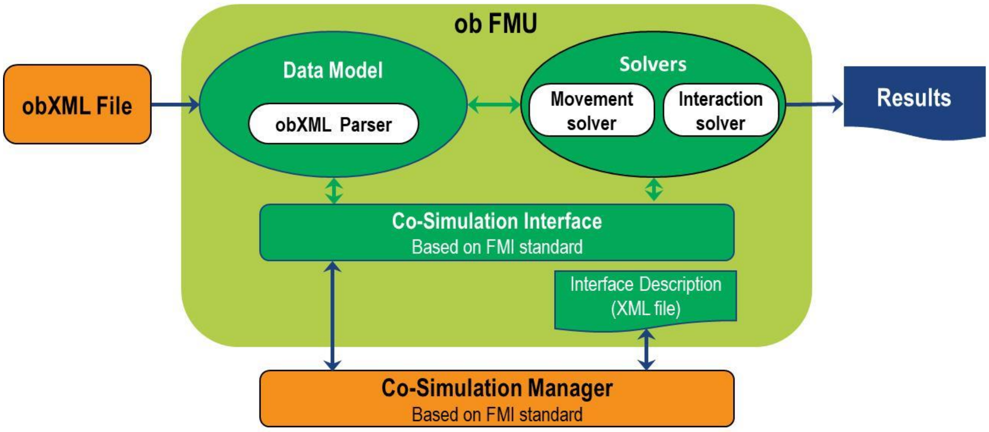

Figure 10. Structure of the obFMU with obXML file inputs and co-simulation manager components [8].

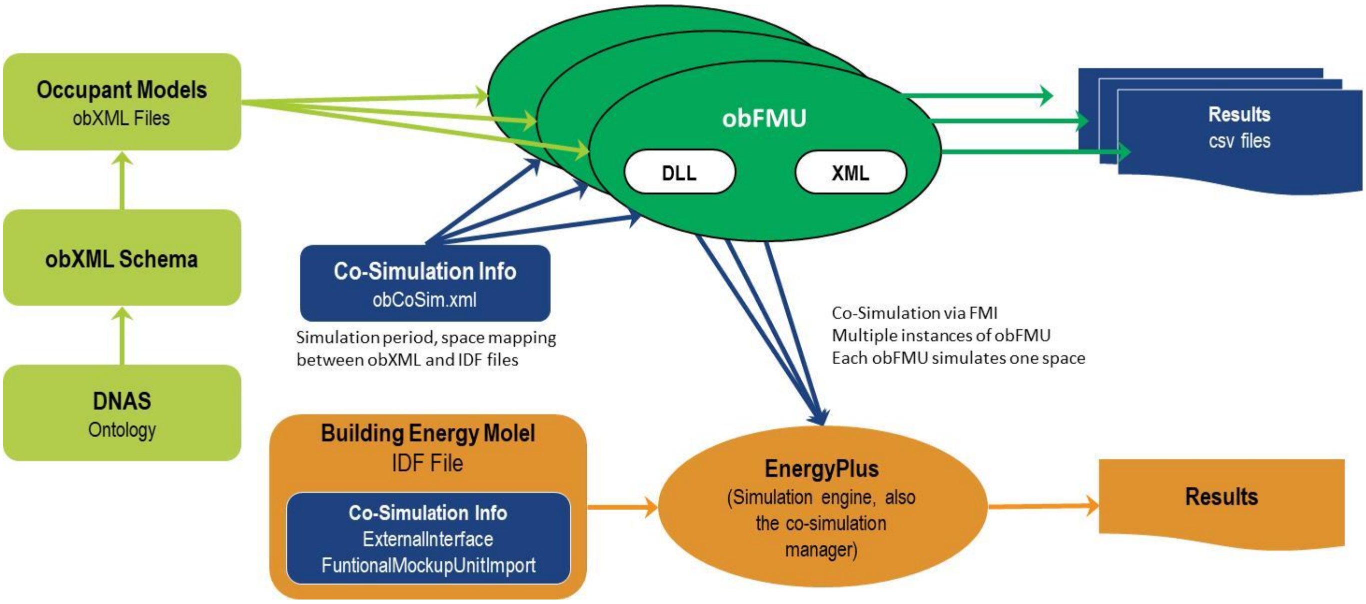

Figure 11. Data flow of co-simulation between EnergyPlus and FMU [18]

Some of the behaviours defined in the obXML schemas and applied in each of the sections refer to published scientific papers while other implemented behaviours are logical and commonplace behaviours such as closing windows when it rains.

Each model run generates different user schedules due to the random nature of the occupancy models and then, each time the model is running; it generates different outcomes (i.e. different values for energy needs and use). In order to obtain an average of results that allows the estimation of each variable's modelling impact, each model has been run 20 times for each variable assessment and climatic zone.

3.3.1. Base Case (Case 0)

The baseline corresponds to the deterministic and static programming commonly used for modelling in current building performance simulation (BPS) software, such as EnergyPlus.

The occupancy, lighting, electrical equipment, ventilation and solar shading data simulated in this base case corresponds to the model description provided in the section 3.2.

Table 3 contains the monthly results for this Base Case.

Table 3. Base Case (Case 0) Energy Demands for different climates

Months	Energy need for Heating (kWh/m²)				Energy need for Cooling (kWh/m²)				Lighting (kWh/m²)				Electric Equipment (kWh/m²)			
Climate	1/2	3	4	5	1/2	3	4	5	1/2	3	4	5	1/2	3	4	5
January	2.45	8.30	6.84	11.77	0.16	0.00	0.00	0.00	1.64	1.64	1.64	1.64	2.33	2.33	2.33	2.33
February	1.07	5.89	4.94	10.12	0.34	0.00	0.00	0.00	1.48	1.48	1.48	1.48	2.10	2.10	2.10	2.10
March	0.29	2.35	2.89	6.94	1.82	0.16	0.00	0.00	1.71	1.71	1.71	1.71	2.37	2.37	2.37	2.37
April	0.09	0.89	0.87	2.28	2.06	1.35	0.19	0.09	1.63	1.63	1.63	1.63	2.28	2.28	2.28	2.28
May	0.00	0.00	0.14	0.03	6.00	4.14	1.68	1.91	1.70	1.70	1.70	1.70	2.37	2.37	2.37	2.37
June	0.00	0.00	0.00	0.00	8.49	5.49	3.31	4.43	1.64	1.64	1.64	1.64	2.28	2.28	2.28	2.28
July	0.00	0.00	0.00	0.00	12.73	7.94	5.69	6.21	1.64	1.64	1.64	1.64	2.33	2.33	2.33	2.33
August	0.00	0.00	0.00	0.00	12.04	7.78	4.99	4.18	1.76	1.76	1.76	1.76	2.41	2.41	2.41	2.41
September	0.00	0.00	0.02	0.24	6.55	2.82	1.16	0.24	1.51	1.51	1.51	1.51	2.20	2.20	2.20	2.20
October	0.03	0.83	0.92	3.25	3.08	0.56	0.49	0.00	1.70	1.70	1.70	1.70	2.37	2.37	2.37	2.37
November	0.62	4.11	3.18	9.35	0.63	0.00	0.01	0.00	1.56	1.56	1.56	1.56	2.24	2.24	2.24	2.24
December	2.33	7.73	5.14	11.16	0.02	0.00	0.00	0.00	1.58	1.58	1.58	1.58	2.28	2.28	2.28	2.28
Total	6.89	30.09	24.94	55.14	53.92	30.23	17.51	17.06	19.55	19.55	19.55	19.55	27.56	27.56	27.56	27.56

3.3.2. Occupancy presence (Case 1)

This first case studies the impact on building energy use of considering the variable presence or movement of occupants inside the building. It is usual to develop the occupancy model based on the information provided by building users through static weekly schedules, assuming an entry, exit, lunch, etc. time for all building occupants and, at most, differentiating between winter and summer time.

The calendar that is implemented in the model usually tries to be as realistic as possible, however it does not reflect the random behaviour of building users: the occupant does not move between different spaces in the office, arrives and leaves always at the same time, there are no delays, is not absent for different random reasons, the meeting room calendars are the same, with the same occupancy, etc. The stochastic behaviour of occupants is what has been implemented in this first model (baseline – Case 0).

The *Occupancy Simulator* tool was used to simulate the occupancy through occupants' movement and generate occupancy schedules for each space as well as for each occupant. Figure 12 shows how the use of the meeting rooms is defined in this tool. Occupants move between spaces, arrive and leave the office earlier and later, have intermediate exits, vary the time they use for lunch, etc. This movement of occupants has a base schedule of occupation, with time of entry and exit from the office, as well as time and average time for lunch, variable number of meetings and attendees, etc., established on the basis of the data used for the Base Case and qualified with a flexible timetable for each of the actions that allows the tool to generate the stochastic calendar that "imitates" reality.

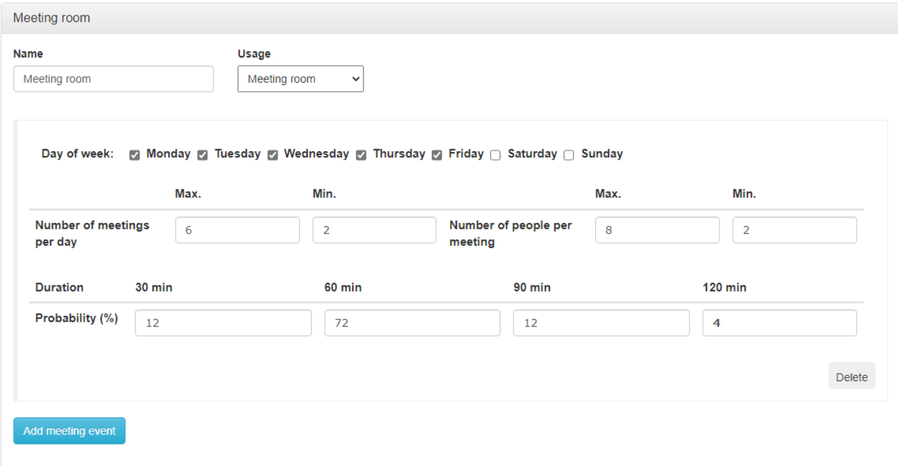

Figure 12. Definition of the meeting room occupancy via the Occupancy Simulator tool

Figure 13 shows the results of the stochastic model for a typical day in the office, showing at each time step (10 minutes) the number of occupants in each space.

Date/Time	OFFICE1	OFFICE2	OFFICE3	MEETINGROOM1	MEETINGROOM2	DIRECTOROFFICE1	MANAGEROFFICE1	MANAGEROFFICE2	STORE1	STORE2	STAIRS	DISTRIBUTOR
04/11 08:00:00	0	0	0	0	0	0	0	0	0	0	0	0
04/11 08:10:00	0	0	0	0	0	0	0	0	0	0	0	0
04/11 08:20:00	0	0	0	0	0	0	0	0	0	0	0	0
04/11 08:30:00	1	0	0	0	0	0	0	0	0	0	0	0
04/11 08:40:00	1	1	3	0	0	0	0	0	0	0	0	0
04/11 08:50:00	7	3	7	0	0	1	0	0	0	0	0	0
04/11 09:00:00	12	7	13	0	0	1	0	0	0	0	1	0
04/11 09:10:00	13	12	17	0	0	2	1	0	0	0	0	1
04/11 09:20:00	14	11	13	0	0	2	0	2	3	0	0	0
04/11 09:30:00	8	11	18	0	0	1	2	2	1	1	1	1
04/11 09:40:00	11	12	16	0	0	3	1	1	0	1	1	1
04/11 09:50:00	10	8	14	6	5	2	1	3	1	0	0	0
04/11 10:00:00	11	7	10	6	5	5	0	3	1	1	1	1
04/11 10:10:00	14	8	11	6	5	0	0	1	2	1	0	0
04/11 10:20:00	13	8	12	6	5	0	2	2	0	0	2	0
04/11 10:30:00	14	8	11	6	5	1	2	1	0	0	2	0
04/11 10:40:00	14	6	10	6	5	4	1	2	3	0	0	0
04/11 10:50:00	12	7	7	6	8	3	2	2	1	1	3	0
04/11 11:00:00	14	8	9	6	8	2	0	3	0	1	0	0
04/11 11:10:00	12	9	7	6	8	2	2	2	0	0	1	1
04/11 11:20:00	13	7	11	0	8	2	3	0	2	0	1	1
04/11 11:30:00	13	9	11	0	8	1	2	1	0	0	0	1
04/11 11:40:00	13	11	9	0	8	2	0	0	0	0	2	0
04/11 11:50:00	15	9	12	5	0	1	1	1	0	0	2	0
04/11 12:00:00	16	6	14	5	0	2	0	1	1	0	1	1
04/11 12:10:00	15	9	12	5	0	1	1	1	2	2	0	0
04/11 12:20:00	14	7	13	5	0	2	0	2	0	1	2	0
04/11 12:30:00	14	7	14	5	0	2	1	1	0	1	2	0
04/11 12:40:00	14	6	15	5	0	1	1	2	0	0	2	0
04/11 12:50:00	14	10	15	0	0	2	0	2	0	0	0	1
04/11 13:00:00	13	9	14	0	0	0	1	1	2	0	0	0
04/11 13:10:00	13	8	9	0	0	1	1	0	0	2	0	1
04/11 13:20:00	9	6	11	5	0	2	2	0	0	1	0	0
04/11 13:30:00	7	7	9	5	0	1	2	2	0	0	0	0
04/11 13:40:00	9	6	11	5	0	0	1	0	1	0	0	0
04/11 13:50:00	11	8	14	5	0	1	1	1	0	0	1	1
04/11 14:00:00	12	13	15	5	0	1	1	0	0	0	0	1
04/11 14:10:00	11	7	13	5	0	2	4	0	2	1	0	1
04/11 14:20:00	10	13	16	0	0	4	3	0	0	0	1	0
04/11 14:30:00	14	12	16	0	0	4	1	1	1	0	0	0
04/11 14:40:00	13	9	17	0	0	1	4	0	2	0	1	1
04/11 14:50:00	20	10	13	0	0	2	1	3	0	2	0	0
04/11 15:00:00	18	6	17	0	0	3	2	1	1	1	0	0
04/11 15:10:00	15	7	18	0	0	1	1	1	0	0	2	2
04/11 15:20:00	15	9	13	0	5	3	2	0	1	0	0	1
04/11 15:30:00	15	8	15	0	5	1	2	1	0	0	0	0
04/11 15:40:00	14	8	11	0	5	4	2	3	1	1	0	1
04/11 15:50:00	12	9	12	5	5	2	0	3	1	0	1	0
04/11 16:00:00	11	9	13	5	5	2	1	1	0	1	0	0
04/11 16:10:00	11	10	11	5	5	1	0	2	0	0	2	0
04/11 16:20:00	11	9	11	5	8	0	2	0	1	0	0	1
04/11 16:30:00	8	10	11	5	8	1	0	0	1	2	0	0
04/11 16:40:00	12	9	8	5	8	1	0	0	0	0	2	0
04/11 16:50:00	11	10	12	0	8	1	0	1	0	0	0	1
04/11 17:00:00	11	8	4	0	8	2	0	1	1	1	0	0
04/11 17:10:00	8	7	5	0	8	1	1	1	0	0	1	0
04/11 17:20:00	7	5	7	2	0	3	1	0	0	0	0	1
04/11 17:30:00	6	4	4	2	0	3	1	0	0	0	0	2
04/11 17:40:00	5	4	3	2	0	2	1	1	0	0	0	0
04/11 17:50:00	4	1	2	2	0	1	0	1	1	1	0	0
04/11 18:00:00	3	3	0	2	0	1	0	0	0	0	0	0
04/11 18:10:00	2	2	0	2	0	1	0	0	0	0	0	0
04/11 18:20:00	0	0	0	0	0	1	0	1	0	0	0	0
04/11 18:30:00	0	0	0	0	0	1	0	1	0	0	0	0
04/11 18:40:00	0	0	0	0	0	0	0	1	0	0	0	0
04/11 18:50:00	0	0	0	0	0	0	0	0	0	0	0	0
04/11 19:00:00	0	0	0	0	0	0	0	0	0	0	0	0

Figure 13. Example of a stochastic movement schedule generated by the Occupancy Behaviour tool for November 4 in one of the models

The occupancy presence, individually studied, only affects the internal loads related to occupancy considered within each space and its energy needs for heating and cooling. Therefore, the electricity use related to the lighting and electrical equipment services are the same as in the Base Case because their loads remain the same. The results obtained in the simulations are shown in Table 4.

Table 4. Results for the Case 1 (Occupant Behaviour with regard to Occupancy Presence)

Months	Energy need for Heating (kWh/m²)				Energy need for Cooling (kWh/m²)			
Climate	1/2	3	4	5	1/2	3	4	5
January	2.69	8.55	7.11	12.05	0.14	0.00	0.00	0.00
February	1.25	6.15	5.20	10.40	0.30	0.00	0.00	0.00
March	0.39	2.59	3.19	7.25	1.69	0.13	0.00	0.00

April	0.15	1.04	1.08	2.53	1.92	1.27	0.17	0.07
May	0.00	0.00	0.20	0.06	5.73	3.90	1.51	1.75
June	0.00	0.00	0.00	0.00	8.24	5.23	3.08	4.17
July	0.00	0.00	0.00	0.00	12.48	7.69	5.44	5.95
August	0.00	0.00	0.00	0.00	11.77	7.50	4.75	3.92
September	0.00	0.00	0.04	0.36	6.32	2.61	1.02	0.20
October	0.07	0.98	1.09	3.56	2.89	0.48	0.44	0.00
November	0.71	4.35	3.37	9.55	0.57	0.00	0.01	0.00
December	2.57	8.04	5.42	11.45	0.01	0.00	0.00	0.00
Total	7.82	31.70	26.69	57.20	52.07	28.81	16.41	16.07
Case1/Case 0 (%)	113.59%	105.35%	107.03%	103.73%	96.55%	95.29%	93.71%	94.19%

The base schedule used in the Occupancy Simulator tool is very similar to the schedule used in the Base Case. Although there is movement of people between spaces in the building and not all users arrive or leave at the same time, the number of hours they occupy each space is practically the same and the number of people in the whole building is very similar. Therefore, the occupancy loads are very similar to those of the Base Case, and the total energy needs for heating and cooling for the case study vary only slightly. This small variation is even smaller if both energy needs are aggregated, since the global indicator would suffer from cancellation effect; deviations regarding energy need for heating and cooling are positive and negative respectively. As it can be seen in Table 4, energy needs for heating are increased between a 4% for the climate 4 and 13.5% for climate 1/2, with reference to the baseline (Case 0). On the other hand, energy needs for cooing are decreased between a 3.4% for climate 1/2 and around 6% for climates 3 and 4.

The stochastic model (advance occupancy model) is considering less occupancy than the baseline schedule and therefore the internal occupancy loads are reduced which leads to an increase in the energy for heating and a decrease in the energy for cooling.

These little deviations regarding the baseline seem reasonable taking into account that appropriate assumptions have been also implemented in the Case 0 regarding occupancy through static schedules.

3.3.3. Lighting (Case 2)

Within the context of Case 2, a series of lighting-related behaviours have been implemented in order to assess the impact on energy use for lighting. Advanced occupant models regarding lighting imply the implementation of advanced models or rules related to the interaction of building users and lighting systems, which include switch on/off patterns according to presence and daylight availability. The implemented lighting related behaviours (and rules), based on scientific papers, are listed below:

- B_Light_Reinhart_Voss_2003_on: Curve determining the probability of occupants switching on lights upon arrival depending on desk illuminance [9]

- B_Light_Newsham_1994_off_illuminance: Occupants turn off the lights when the illuminance in the working plane of the room is above 150 lux. [10].
- B_Light_Newsham_1994_off_leave: The occupant turns off the lights when he/she finishes work and leaves the office for more than 6 hours [10].

Since the lighting system is also an internal load occupant behaviour on lighting also influences energy need for heating and cooling.

The results obtained for the case 2 assessment are shown in the Table 5.

Table 5. Results for the Case 2 (Occupant Behaviour with regard to Lighting)

Months	Heating energy need (kWh/m²)				Cooling energy need (kWh/m²)				Lighting (kWh/m²)			
Climate	1/2	3	4	5	1/2	3	4	5	1/2	3	4	5
January	2.80	8.41	6.89	11.50	0.11	0.00	0.00	0.00	1.61	1.94	2.08	2.33
February	1.38	6.10	5.14	10.16	0.21	0.00	0.00	0.00	1.12	1.67	1.68	1.79
March	0.53	2.72	3.40	7.40	1.28	0.13	0.00	0.00	0.85	1.60	1.49	1.58
April	0.25	1.16	1.38	2.90	1.44	1.13	0.09	0.04	0.72	1.23	0.94	0.98
May	0.00	0.00	0.27	0.12	4.92	3.50	1.06	1.31	0.71	1.17	0.86	0.83
June	0.00	0.00	0.00	0.00	7.37	4.63	2.45	3.41	0.68	0.92	0.82	0.70
July	0.00	0.00	0.00	0.00	11.64	7.02	4.77	5.17	0.69	0.85	0.80	0.73
August	0.00	0.00	0.01	0.00	10.86	6.89	4.06	3.34	0.72	1.05	0.84	0.99
September	0.00	0.00	0.06	0.42	5.72	2.52	0.86	0.15	0.84	1.50	1.28	1.38
October	0.09	0.94	1.07	3.52	2.55	0.48	0.39	0.00	1.17	1.89	1.79	1.90
November	0.69	4.14	3.16	8.95	0.56	0.00	0.00	0.00	1.70	2.00	1.98	2.28
December	2.47	7.55	5.06	10.77	0.02	0.00	0.00	0.00	1.96	2.25	2.26	2.36
Total	8.22	31.02	26.43	55.76	46.67	26.29	13.70	13.41	12.76	18.06	16.82	17.85
Case2/Case 0 (%)	119.39%	103.09%	105.98%	101.11%	86.55%	86.98%	78.20%	78.64%	65.26%	92.40%	86.04%	91.29%

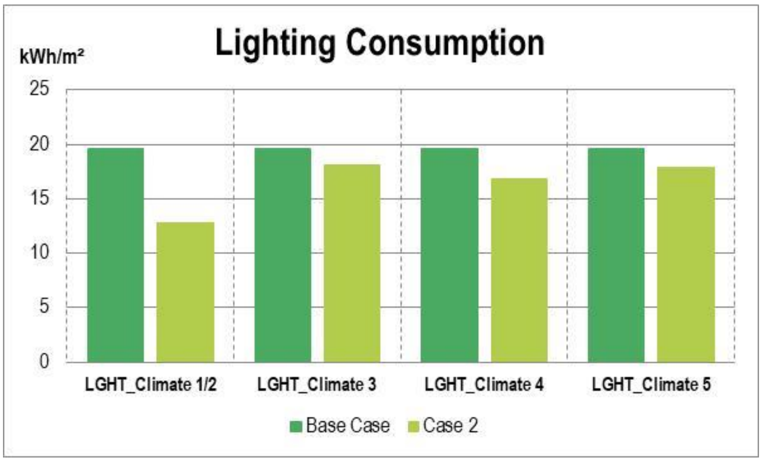

Figure 14. Annual Lighting Consumption of Case 0 and Case 2 by Climate Zone

Analysing the results, deviations when considering a static lighting schedule or stochastic user behaviour are more or less significant depending on the climate or European region considered. Figure 14 and Figure 15 show how lighting consumption varies as a function of climate due to daylight availability depending on latitude. Specifically, compared to the base case, energy consumption for lighting is about 35% lower for the climate 1/2 but only 8% lower for climate 3 (see Table 5). This is consistent because one of the behaviours (advance occupant modelling) implemented in the stochastic model is the influence of daylight on switching on and off of the lighting system.

Figure 15 shows the monthly lighting consumption by climatic zone and latitude of selected climate cities.

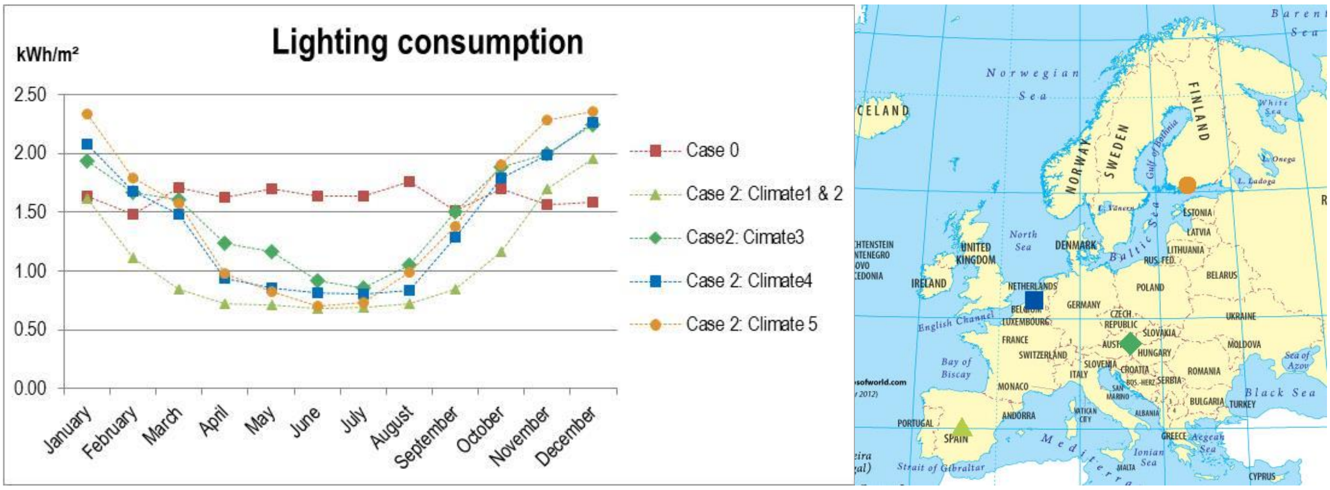

Figure 15. Monthly Lighting Consumption by Climate Zone and Latitude of selected Climate Cities

When lighting consumption is decreased, internal loads decrease as well and then, energy needs for heating and cooling are affected. By reducing lighting loads, heating energy need will increase and cooling energy need decrease, as shown in Table 5. Although the sum of these results may give a global value of energy needs close to that of the base case, the analysis only based on aggregated data is not advisable, as energy saving quantification derived from energy efficiency measures proposed in the EPC will be more accurate as the energy need/use of each service is better calibrated.

3.3.4. Plug-in equipment (Case 3)

Case 3 explores the impact on energy use derived from the implementation of advanced occupant models related to the use of electric equipment. Specifically, two common behaviours of building occupants have been implemented:

- B_ Plug equipment on arrive: all occupants switch on the equipment when they arrive at the office.
- B_ Unplug equipment at departure: 90% of the occupants unplug the equipment when they leave the office for more than 6 hours.

A summary of the results' simulations is shown in Table 6 .

Table 6. Results for Case 3 (Occupant Behaviour on Electric Equipment)

Months	Heating Demand (kWh/m²)				Cooling Demand (kWh/m²)				Electric Equipment (kWh/m²)			
Climate	1/2	3	4	5	1/2	3	4	5	1/2	3	4	5
January	3.18	8.99	7.50	12.42	0.15	0.00	0.00	0.00	1.92	1.91	1.86	1.95
February	1.46	6.45	5.47	10.71	0.28	0.00	0.00	0.00	1.71	1.76	1.74	1.79
March	0.54	2.85	3.44	7.51	1.66	0.13	0.00	0.00	2.07	1.95	1.96	2.05
April	0.27	1.19	1.30	2.77	1.90	1.21	0.17	0.08	2.02	1.96	1.89	1.96
May	0.00	0.01	0.28	0.14	5.49	3.73	1.42	1.67	2.01	2.04	1.99	1.99
June	0.00	0.00	0.01	0.00	7.96	4.93	2.86	3.94	1.98	1.89	1.89	1.94
July	0.00	0.00	0.00	0.00	12.16	7.35	5.17	5.66	1.99	1.93	1.93	1.95
August	0.00	0.00	0.01	0.00	11.50	7.26	4.56	3.76	2.10	2.09	2.01	2.08
September	0.00	0.01	0.11	0.56	6.13	2.51	0.97	0.21	1.93	1.91	1.83	1.89
October	0.12	1.15	1.28	3.82	2.80	0.48	0.41	0.00	2.08	2.06	1.99	2.02
November	0.84	4.55	3.54	9.78	0.60	0.00	0.01	0.00	2.01	1.96	1.99	2.03
December	2.84	8.39	5.73	11.81	0.02	0.00	0.00	0.00	1.84	1.89	1.88	1.91
Total	9.25	33.60	28.67	59.51	50.65	27.59	15.56	15.31	23.65	23.36	22.96	23.57
Case3/Case 0 (%)	134.34%	111.67%	114.95%	107.92%	93.94%	91.27%	88.82%	89.79%	85.81%	84.74%	83.31%	85.52%

In this case, unlike lighting, there is no correlation in the results for plug-in equipment with weather factors outside the building. Workers use the equipment equally throughout the year and this is reflected in the monthly data. As can be seen in the results, the electricity consumption of plug-in equipment has decreased around 15% for all climates (Table 6). However, as internal loads are less than in the base case, energy need for heating increases and energy need for cooling decreases (as was the case with lighting).

3.3.5. Windows shade (Case 4)

The building is equipped with interior blinds in all its windows. In the Base Case, no movement of these blinds has been implemented, considering that they will always be open. The reality is that the occupant usually has access to these blinds and can deploy or retract them according to their needs.

These behaviours are much more difficult to implement in the model as they vary depending on many factors such as weather conditions, physical or psychological state of the occupants, etc. Therefore, to implement this model, the behaviours implemented are based on scientific papers on the prediction of closing and opening of blinds during the day depending on the indoor and/or outdoor temperature. These papers are intended to represent the randomness of this behaviour through specific equations.

The object "MEDIUM REFLECT - MEDIUM TRANS SHADE" from the EnergyPlus libraries (Figure 16) has been introduced to the model in order to determine the influence of user behaviour on this system.

```
WindowMaterial:Shade,
  MEDIUM REFLECT - MEDIUM TRANS SHADE,  !- Name
  0.4,                     !- Solar Transmittance {dimensionless}
  0.5,                     !- Solar Reflectance {dimensionless}
  0.4,                     !- Visible Transmittance {dimensionless}
  0.5,                     !- Visible Reflectance {dimensionless}
  0.9,                     !- Infrared Hemispherical Emissivity {dimensionless}
  0.0,                     !- Infrared Transmittance {dimensionless}
  0.005,                   !- Thickness {m}
  0.1,                     !- Conductivity {W/m-K}
  0.05,                    !- Shade to Glass Distance {m}
  0.5,                     !- Top Opening Multiplier
  0.5,                     !- Bottom Opening Multiplier
  0.5,                     !- Left-Side Opening Multiplier
  0.5,                     !- Right-Side Opening Multiplier
  0.0;                     !- Airflow Permeability {dimensionless}
```

Figure 16. Energy plus object used to represent interior shades

The 3 occupant behaviours considered for this variable's assessment are as follows:

- B_Newsham_1994_Blind_Office_open: Open the blinds in the morning upon arrival [10].
- B_Blind_Haldi_Robinson_2008_Office_Tin: Curve predicting the probability of occupants closing the shades during the day based on indoor temperature [11].
- B_Blind_Haldi_Robinson_2008_Office_Tout: Curve predicting the probability of occupants closing the shades during the day based on outdoor temperature [11].

The deployment or non-deployment of sunscreens will increase the amount of solar radiation penetrating the space through windows. Then, compared to the Base Case that has not included shading devices, heating energy need value increase while cooling energy need value decreases. The deviation's percentages regarding the base case are shown in Table 7.

Table 7. Results for Case 4 (Occupant Behaviour on Shading Devices)

Months	Heating energy need (kWh/m²)				Cooling energy need(kWh/m²)				Average number of hours of window shading devices non-deployed			
Climate	1/2	3	4	5	1/2	3	4	5	1/2	3	4	5
January	2.66	8.45	6.97	11.89	0.15	0.00	0.00	0.00	232	385	327	397
February	1.31	6.04	5.06	10.28	0.29	0.00	0.00	0.00	127	323	273	349
March	0.45	2.56	3.07	7.16	1.42	0.12	0.00	0.00	54	165	245	369

April	0.20	1.05	1.11	2.58	1.55	1.06	0.16	0.08	37	137	153	233
May	0.00	0.00	0.21	0.09	4.82	3.29	1.24	1.24	4	11	36	43
June	0.00	0.00	0.00	0.00	7.06	4.45	2.58	3.23	2	8	8	8
July	0.00	0.00	0.00	0.00	10.96	6.61	4.68	4.95	1	2	4	4
August	0.00	0.00	0.00	0.00	10.41	6.63	4.16	3.36	1	3	6	7
September	0.00	0.00	0.03	0.39	5.48	2.29	0.93	0.16	3	6	20	61
October	0.08	0.92	1.02	3.43	2.51	0.43	0.42	0.00	18	91	85	272
November	0.73	4.17	3.22	9.37	0.54	0.00	0.01	0.00	76	292	200	360
December	2.51	7.83	5.18	11.23	0.02	0.00	0.00	0.00	207	355	273	362
Total	7.95	31.02	25.87	56.41	45.19	24.87	14.19	13.02	762	1778	1628	2465
Case4/Case 0 (%)	115.44%	103.09%	103.72%	102.29%	83.81%	82.26%	81.00%	76.35%	8.70%	20.29%	18.58%	28.14%

The average number of hours for all windows without any shading device deployed is shown in the right hand columns of Table 7 . As can be seen from the results, during the hot summer months, users deploy sun shading devices in an attempt to prevent solar radiation from entering the building and overheat the spaces. Deviations due to this behaviour can also be observed between warmer and colder climates.

Date/Time	OFFICE1: Shading Device 1	OFFICE1: Shading Device 2	OFFICE1: Shading Device 3	OFFICE2: Shading Device 1	OFFICE2: Shading Device 2	OFFICE3: Shading Device 1	OFFICE3: Shading Device 2	OFFICE3: Shading Device 3	MEETING ROOM1: Shading Device	MEETING ROOM2: Shading Device	MANAGER OFFICE2: Shading Device 1	MANAGER OFFICE2: Shading Device 2	MANAGER OFFICE1: Shading Device 1	DIRECTOR OFFICE1: Shading Device 1	DIRECTOR OFFICE1: Shading Device 2
01/04 01:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 02:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 03:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 04:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 05:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 06:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 07:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 08:00:00	0	0	0	1	1	0	0	0	0	0	1	1	1	1	1
01/04 09:00:00	0	0	0	0.66666667	0.66666667	0	0	0	0	0	1	1	0.833333333	0.833333333	0.833333333
01/04 10:00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
01/04 11:00:00	0	0	0	0	0	0	0	0	0	0	0.333333333	0.333333333	0.333333333	0	0
01/04 12:00:00	0	0	0	0	0	0	0	0	0	0	0.166666667	0.166666667	0	0.333333333	0.333333333
01/04 13:00:00	0	0	0	0	0	0	0	0	0	0	0.333333333	0.333333333	0	0.833333333	0.833333333
01/04 14:00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
01/04 15:00:00	0	0	0	0	0	0	0	0	0	0	0.833333333	0.833333333	0.5	1	1
01/04 16:00:00	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
01/04 17:00:00	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
01/04 18:00:00	0	0	0	0.16666667	0.16666667	0.83333333	0.83333333	0.83333333	1	0	1	1	1	1	1
01/04 19:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/04 20:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/04 21:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/04 22:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/04 23:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/04 24:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 01:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 02:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 03:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 04:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 05:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 06:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 07:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 08:00:00	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
01/05 09:00:00	0.5	0.5	0.5	0.5	0.5	0.33333333	0.33333333	0.33333333	1	0	1	1	0.833333333	0.166666667	0.166666667
01/05 10:00:00	0	0	0	0	0	0	0	0	1	0	0.166666667	0.166666667	0.333333333	0.166666667	0.166666667
01/05 11:00:00	0	0	0	0	0	0	0	0	1	0	0.166666667	0.166666667	0	0	0
01/05 12:00:00	0	0	0	0	0	0	0	0	1	0	0	0	0.166666667	0.333333333	0.333333333
01/05 13:00:00	0	0	0	0	0	0	0	0	0.666666667	0	0	0	0	0.166666667	0.166666667
01/05 14:00:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
01/05 15:00:00	0	0	0	0	0	0	0	0	0	0	1	1	0	0.666666667	0.666666667
01/05 16:00:00	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
01/05 17:00:00	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
01/05 18:00:00	0.16666667	0.16666667	0.16666667	0	0	0	0	0	0.833333333	0	1	1	1	1	1
01/05 19:00:00	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1
01/05 20:00:00	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1
01/05 21:00:00	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1
01/05 22:00:00	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1
01/05 23:00:00	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1
01/05 24:00:00	1	1	1	0	0	0	0	0	1	0	1	1	1	1	1

Figure 17. Example of on(1)-off(0) result for shading devices during two days of a simulation

Figure 17 shows when occupants have deployed each shading device in the building (value 1) and when the device is retracted (value 0). The intermediate values represent the times when the device is not deployed during the entire one-hour time step.

In general terms, it is observed that the implementation of these occupants' behaviours related to manual control of shading devices implies very little variation in terms of heating energy need (among other things because due to the low temperatures and the low radiation, occupants deploy the curtains for fewer hours), but they can substantially reduce energy need for cooling in summer.

3.3.6. Operable window (Case 5)

Most buildings, including office buildings, have operable windows that can be opened and closed according to the wishes or needs of occupants. Case 5 described under this section aims to model and assess this occupant behaviour.

In order to ensure the air renewal to meet the Indoor Air Quality (IAQ) requirements, the minimum ventilation, mandatory by Regulation, is introduced into the building through the HVAC system. This means that the opening of windows by building users introduces uncontrolled additional ventilation into the building. However sometimes, the minimum ventilation airflow rate required by regulation does not always guarantee the Indoor Air Quality (IAQ) requirements in the spaces because of uncontrolled factors, e.g. varying occupancy in the space. Therefore, the occupant behaviours implemented in Case 5 are:

- B_Window_Open_IAQ: Predicting window opening when the room CO_2 concentration is higher than 750ppm.
- B_Window_Close_IAQ: Predicting window closing when the room CO_2 concentration is less than 500ppm.
- B_Window_Close_Rain: Predicting window closing when is raining.
- B_Window_Close_Leave: Predicting window closing when occupants are leaving the office for more than 6 hours

In open plan offices, these window opening and closing behaviours have been contucted when the majority of occupants are in agreement. The results obtained are shown in Table 8.

Table 8. Results of Case 5 (Occupant Behaviour on Operable Window)

Months	Energy need for Heating(kWh/m²)				Energy need for Cooling(kWh/m²)			
Climate	1/2	3	4	5	1/2	3	4	5
January	3.53	10.69	8.69	14.74	0.12	0.00	0.00	0.00
February	1.71	7.86	6.49	13.34	0.24	0.00	0.00	0.00
March	0.59	3.51	4.24	9.32	1.56	0.12	0.00	0.00
April	0.27	1.45	1.55	3.47	1.79	1.23	0.15	0.06
May	0.00	0.05	0.28	0.23	5.60	3.78	1.38	1.58
June	0.00	0.00	0.02	0.03	8.18	5.14	2.95	3.98
July	0.00	0.00	0.00	0.01	12.60	7.65	5.36	5.84
August	0.00	0.00	0.01	0.01	11.80	7.52	4.69	3.77
September	0.00	0.01	0.13	0.57	6.19	2.46	0.92	0.14
October	0.09	1.43	1.53	4.51	2.73	0.41	0.41	0.00

November	0.99	5.59	4.35	12.08	0.49	0.00	0.00	0.00
December	3.24	9.82	6.52	13.71	0.01	0.00	0.00	0.00
Total	10.42	40.42	33.81	72.01	51.32	28.31	15.85	15.39
Case5/Case 0 (%)	151.33%	134.31%	135.57%	130.59%	95.17%	93.65%	90.48%	90.21%

As can be seen from the results, window opening during the cold months, the heating energy need of the building increases as additional outside air (the temperature of which is lower than the heating setpoint) is being introduced. However, the extra ventilation will help to reduce cooling energy needs during the warmer months, mainly in cold climates. Opening window while heating (among the cases studied) has the greatest impact on heating energy need compared to the Base Case.

It is unusual to implement this type of occupant behaviour in static simulation models. The regular practice is to implement minimum requirements by regulation (mechanical ventilation) and an additional amount of renewal air through infiltration (i.e. due to envelope airtightness). However, it can be concluded that window opening behaviour can be relevant for model calibration, purposes when the objective is to develop accurate models and energy disaggregation by services in order to obtain proper energy saving quantifications for suggested EEMs.

3.3.7. Thermostat (Case 6)

For the Base Case (static model), the heating set points has been set to 21ºC, while the cooling setpoint has been set to 24.5ºC. However, occupants can usually adjust indoor temperatures by 2ºC to suit their needs. Although setpoints are set for winter and summer, when occupants have the possibility to vary the thermostat, the change of setpoint from winter to summer is usually not so abrupt. Therefore, occupants are assigned behaviours that set the setpoints according to the seasons of the year, while at the same time assigning them a behaviour based on an S Shaped Curve Probability Function where the thermostat is set to 23ºC. The behaviours implemented in the occupants for Case 6 are:

- B_Therm_Winter: Winter set thermostat to 21.10 deg.C
- B_Therm_Spring Autum: Spring and Fall set thermostat to 22.5 deg.C
- B_Therm_ Summer: Summer set thermostat to 23.90 deg.C
- B_Therm4: Set thermostat to 23 deg.C based on the probability curve (S Shaped Curve Probability Function)

These variations in thermostat settings affect the thermal demand of the building. The results of applying these behaviours to occupants in the different climate zones are presented in Table 9.

Table 9. Results of Case 6 (Occupant Behaviour on Thermostat) (Case 6)

Months	**Heating Demand (kWh/m²)**				**Cooling Demand (kWh/m²)**			
Climate	**1/2**	**3**	**4**	**5**	**1/2**	**3**	**4**	**5**
January	3.03	9.34	8.50	13.01	0.60	0.05	0.04	0.05
February	1.61	6.35	5.46	10.37	1.03	0.04	0.03	0.04
March	0.83	3.31	3.86	7.96	3.06	0.59	0.13	0.06
April	0.71	1.70	2.02	3.56	2.79	1.83	0.61	0.38

May	0.08	0.16	0.64	0.50	6.65	4.94	2.62	2.73
June	0.04	0.05	0.16	0.08	7.83	5.41	3.56	4.64
July	0.03	0.04	0.07	0.06	11.19	7.28	5.12	5.70
August	0.04	0.06	0.23	0.17	10.84	7.22	4.69	3.95
September	0.05	0.18	0.63	1.31	5.88	2.95	1.50	0.52
October	0.36	1.73	1.78	4.48	3.85	1.01	0.84	0.03
November	1.08	4.54	3.64	9.51	1.76	0.04	0.26	0.04
December	2.90	8.06	5.63	11.08	0.25	0.04	0.04	0.04
Total	10.75	35.53	32.63	62.08	55.73	31.34	19.45	18.19
Case6/Case 0 (%)	156.13%	118.08%	130.83 %	112.58%	103.35 %	103.89 %	111.07%	106.62%

Considering this gradual adaptation of the thermostat setpoint between seasons, as well as a likely behaviour where the user raises the setpoint higher in winter or lower it in summer, leads to an increase in the energy need for heating and cooling of the building.

3.3.8. All OB Together (Case 7)

After analysing the impact of each of the occupant's behaviours independently, the Case 7 aims to analyse what happen in the model if all the behaviours are implemented simultaneously. For this, all the behaviours analysed previously are implemented: the user's movement (which had already been taken into account in all the previous cases) combined with the switching on and off of lights, equipment, opening of windows, deployment of sun protection elements, as well as the setting of different temperatures of the thermostats.

The results are depicted in Table 10.

Table 10. Results for Case 7 (All Occupant Behaviours)

Months	**Heating energy need (kWh/m²)**				**Cooling energy need (kWh/m²)**				**Lighting (kWh/m²)**				**Electric Equipment (kWh/m²)**			
Climate	**1/2**	**3**	**4**	**5**	**1/2**	**3**	**4**	**5**	**1/2**	**3**	**4**	**5**	**1/2**	**3**	**4**	**5**
January	5.32	12.23	10.14	16.27	1.24	0.12	0.20	0.05	1.60	1.97	2.07	2.24	1.89	1.88	1.76	1.92
February	3.58	9.76	8.00	15.36	1.69	0.27	0.24	0.08	1.38	1.68	1.80	1.73	1.75	1.83	1.87	1.77
March	2.52	5.83	6.50	12.03	3.60	1.13	0.50	0.25	1.20	1.71	1.56	1.67	2.04	2.08	1.97	2.03
April	2.31	3.28	4.35	6.38	3.40	2.62	1.18	0.93	1.06	1.51	1.30	1.34	1.89	2.02	1.89	1.96
May	0.78	0.99	1.96	2.44	6.04	4.92	3.18	3.12	0.95	1.60	1.36	1.14	1.84	1.92	2.01	2.04
June	0.27	0.42	1.03	0.98	7.90	5.49	3.55	4.57	1.01	1.34	1.19	1.20	1.81	1.90	1.79	2.03

July	0.10	0.21	0.67	0.61	11.26	6.87	5.03	5.39	0.99	1.32	1.24	1.19	1.94	1.96	1.83	2.01
August	0.21	0.40	1.17	1.15	10.61	7.25	4.51	3.82	0.96	1.60	1.31	1.48	2.04	2.12	1.97	2.01
Septembe r	0.46	1.22	2.08	3.29	6.57	3.44	2.49	1.40	1.29	1.68	1.75	1.82	1.88	1.76	1.87	2.06
October	1.41	3.73	3.95	7.35	4.41	1.65	1.47	0.34	1.78	1.89	1.92	2.04	2.16	2.08	1.98	2.01
November	2.68	7.22	5.93	13.67	2.59	0.34	0.78	0.10	1.66	1.91	2.04	2.30	1.94	1.96	1.94	2.00
December	5.07	11.60	8.00	15.24	0.93	0.09	0.16	0.04	1.97	2.25	2.26	2.50	1.95	1.90	1.87	1.87
Total	24.73	56.90	53.79	94.77	60.24	34.17	23.28	20.08	15.87	20.46	19.80	20.64	23.12	23.40	22.75	23.73
Case7/ Case 0	359.08 %	150.97 %	215.54 %	171.85 %	111.71 %	113.02 %	132.94 %	117.74 %	81.17 %	104.67 %	101.27 %	105.60 %	83.88 %	84.90 %	82.55 %	86.08 %

As expected, when all the behaviours are added together, they influence each other and the results are mixed. Thus, for example, when comparing the lighting consumption of the Base Case, Case 2 (which evaluates the behaviours applied exclusively to this service) and Case 7 (all OB), the results differ between them, as shown in Figure 18. This is presumably the case because the operation of shading devices affects the illuminance on the working plane which in turn influences the occupants' actions on the lighting devices. However, in the case of plug-in equipment, this is not the case, as depicted in Figure 19.

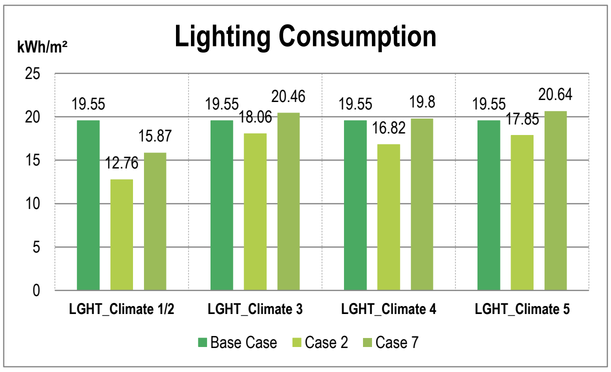

Figure 18. Lighting Consumption comparative among Lighting OB Cases

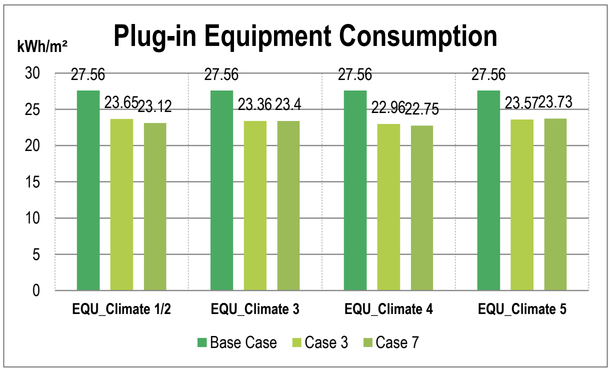

Figure 19. Plug-in Equipment Consumption comparative among Electric Equipment OB Cases

The difference in energy use between applying individual behaviours or the aggregation of all the occupants' behaviours is high and not equivalent to the sum of their results. Therefore, it would be necessary to consider all the behaviours of the building occupants in order to make a reliable assessment of the building.

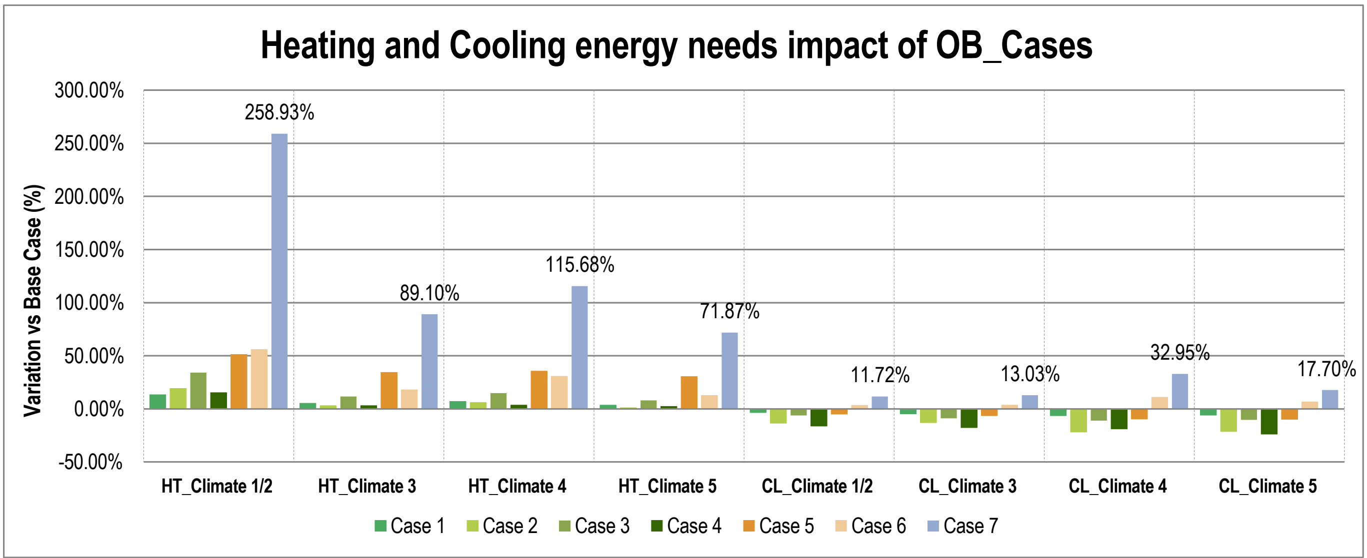

Figure 20. Increase compared to Base Case of the different Occupant Behaviour cases

3.4. Conclusions

In the cases of occupancy (Case 1), lighting (Case 2) and plug-in equipment (Case 3), the difference between the results of the static model and the stochastic models lies in the thoroughness and logic of the simplifications made to introduce the static schedule of the Base model. If the simplifications assumed for the Base Case are consistent (i.e. based on weighted averages, etc.) and their implementation in the static model schedules are sufficiently thorough, the differences in the results will be very small.

The results of Cases 2 and 3 affect both the energy use for lighting and equipment services, respectively, and the heating and cooling energy needs of the building. On the other hand, the Case 4 (shading devices), Case 5 (window opening) and Case 6 (thermostats) only affect the building energy needs (for heating and cooling). The reduction or increase of energy use in the cases of lighting and equipment (cases 2 and 3) is inversely proportional to the increase or decrease of the heating and cooling energy needs of the building, as they are part of the building internal loads. It could be the case that the displacement of these consumptions between services means that the building is consuming the same energy in global terms or a very similar value to that of the Base Case (which does not consider the behaviour of the occupant). This error in the calibration of the energy use of different services of the building leads to errors in the estimation of energy savings that the building may experience after the implementation of energy efficiency measures.

Regarding the Case 4 (shading devices), the occupants' behaviour differs along the year, with the tendency to deploy window shades when the amount of solar radiation is higher. For this reason, this behaviour has a greater impact on the energy need for cooling. Combined with lighting-related behaviours, the operation of window shades has the greatest effect on the cooling of the building (i.e. office typology).

Behaviours that do not have concrete triggers are often not included in static models due to the difficulty of their implementation. The Case 5, which implements the manual opening and closing of windows, which the building occupants do because of random reasons, is the variable that casts the greatest uncertainty on the results of the Base Case (i.e. static schedules).

However, this result is not surprising as the heating energy need in well insulated buildings is mainly due to the ventilation. The results obtained show that if building energy uses are to be properly calibrated; special attention should be paid to this factor.

After window-opening behaviour, adjusting of thermostat set point is the highest impact on energy need for heating. Just as the other behaviours studied have opposite effects on heating and cooling energy needs (e.g. if lighting consumption decreases, its associated internal load decreases and then, increasing energy need for heating and decreasing energy need for cooling), thermostat behaviour has a tendency to increase both heating and cooling energy needs. This is because in the case of thermostat management, the usual tendency of occupants tends to be the opposite, raising the standard setpoint in winter and lowering it in summer.

Figure 21 depicts a graph showing the results obtained for the heating energy needs and cooling energy needs of all the studied cases applied to an office building type.

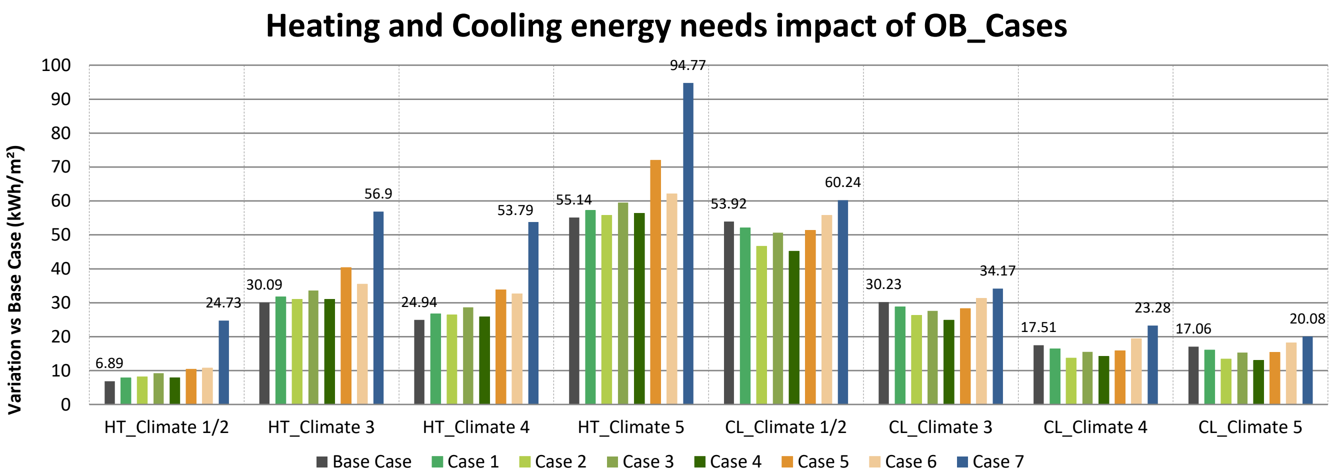

Figure 21. Impact on Heating and cooling demand of the different Occupant Behaviour cases

Since considering all occupant behaviours simultaneously is more realistic than considering them individually, it can be concluded for this case that in global terms user behaviour tends to affect energy need for heating more than for cooling. In any case, in order to make a reliable assessment of the building's energy performance it would be necessary to consider all the behaviours of the building's occupants. However, this requires of a high level of expertise (i.e. academic/researcher), besides having associated a high computational cost and time-consuming, hardly justifiable for the elaboration of an EPC, especially if we consider the current difficulties for harmonization between Member States.

The development of a calibrated model using this methodology would mean assigning different behaviours to each of the occupants, as each occupant is different and reacts differently to the same stimuli. Assuming different behaviours can lead to a substantial variation in the results, while at the same time increasing the work required for the development of the model.

4. RESIDENTIAL BUILDING USE

After the research carried out regarding advanced occupant modelling and its testing and implementation for an office building case study, due to the difficulty to find existing and robust models for the residential typology because of the variety of scenarios, it was decided to apply a different and cost-effective approach for the residential sector within the ePANACEA project context.

Taking advantage of the ICTs and increasingly common accessibility to actual building data, this approach is focused on the use of smart meter data and some other additional specific measurements, that supported by users interviews, allow a detailed user behaviour modelling for dynamic simulations.

This approach pursues to support the starting point for the calibration procedure implemented within the ePANACEA methodology in order to substantially reduce the performance gap between theoretical and actual energy use within the EPC context.

This section shows the description and comparison of this approach through the development of an actual case study located in Spain (Atlantic climate zone).

4.1. Case study description

This case study is focused on the assessment of one individual dwelling located in the third floor of a multifamily apartment block with five floors. The dwelling covers a floor area of 90m^2 and is occupied by a family of three members. Its layout and emplacement are shown in the Figure 22 and Figure 23 respectively.

Figure 22. Apartment layout

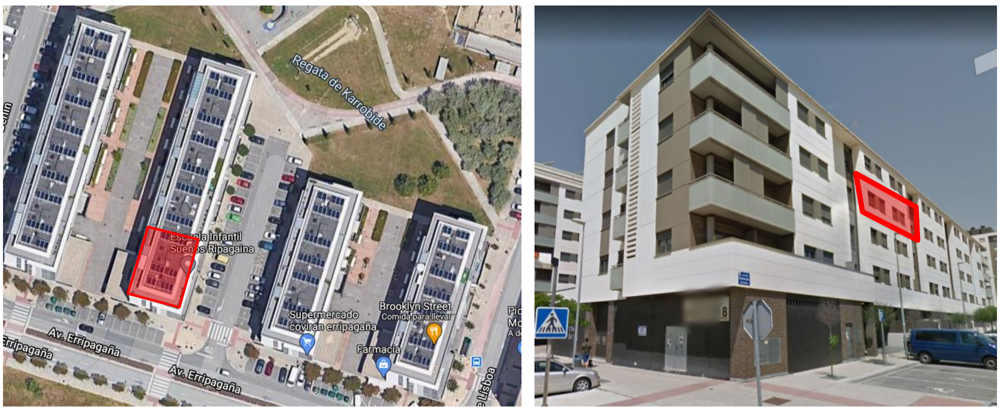

Figure 23. Case study emplacement

4.2. Building Energy Modelling (BEM)

The BEM for this individual dwelling (residential case study) has been modelled through its geometry, space type, thermal zones, envelope thermal characteristics and HVAC systems. Building model geometry is shown in Figure 24 and other characteristics included for dynamic simulation are shown in the following tables.

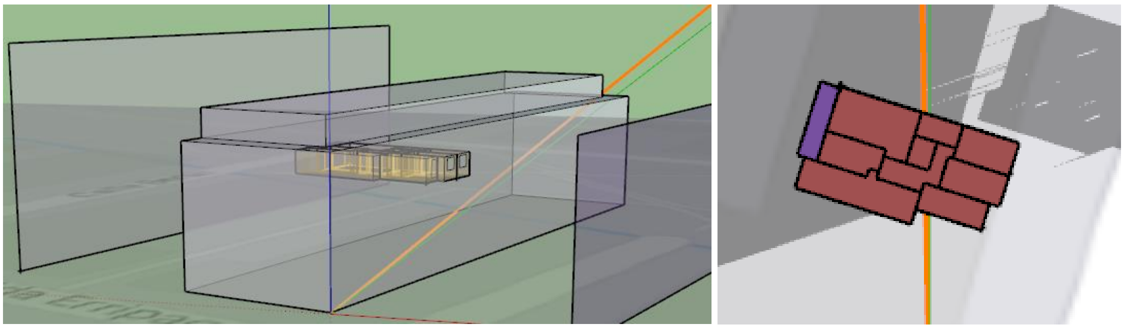

Figure 24. Apartment model for dynamic simulation

4.2.1. Thermal zones

Table 11. List of model's thermal zones in EnergyPlus

Nº	Floor	Zone name	E+ floor area [m2]	Useful height [m]	Useful volume [m3]	Conditioned space?
1	3	F3_Bathroom1	6.01	2.4	14.4	Only heating
2	3	F3_Bathroom2	4.21	2.4	10.1	Only heating
3	3	F3_Bedroom1	11.88	2.4	28.5	Only heating
4	3	F3_Bedroom2	12.37	2.4	29.7	Only heating
5	3	F3_Bedroom3	11.5	2.4	27.6	Only heating
6	3	F3_Corridor	10.68	2.4	25.6	Only heating
7	3	F3_Kitchen	11.48	2.4	27.6	Only heating
8	3	F3_Livingroom	24.29	2.4	58.3	Only heating
9	3	F3_Stairs	24.4	2.4	58.6	Only heating

4.2.2. Thermal envelope

Table 12. Thermal transmittance of the envelope elements

Thermal envelope element	Thermal transmittance (W/m2K)
Exterior Wall (east facade)	0.273
Exterior Wall (west facade)	0.401
Interior Wall	0.411
Interior floor/ceiling	1.036
Window glass (east facade)	1.7
Window glass (west facade)	2.7

4.2.3. Domestic hot water need

Table 13. Annual estimation (based on standards) for the DHW needs

	days	cool water temperature [ºC]	kWh
January	31	7	160.25
February	28	8	142.01
March	31	9	154.20
April	30	10	146.30
May	31	12	145.13
June	30	15	131.67
July	31	17	130.01
August	31	17	130.01
September	30	16	128.74
October	31	14	139.08
November	30	12	140.45
December	31	10	151.18
DHW total need (calculated) [kWh]			1699.03

4.2.4. HVAC

Table 14. HVAC basic characteristics

Service	Description
Supply side/generation	District heating for 206 dwellings (two gas natural condensing boilers)
Demand side/distribution	Water distribution plus radiators
Ventilation	Mechanical ventilation with collective extractors
Monitoring/BMS	Energy need monthly monitoring for energy costs distribution

4.3. Methodology

As it is already mentioned, this approach aims to take advantage of current ICT infrastructures and energy use data available from utility servers thanks to current EU regulation[1], that provide valuable information about occupancy behaviour patterns regarding energy use.

The methodology of this section is divided into three main parts (three-step methodology): (i) data gathering via interviews or forms to end-users, (ii) data gathering and assessment from smart meters available from utility servers and (iii) specific instantaneous measurements. The methodological approach scheme is shown in the Figure 25 and each step is described below.

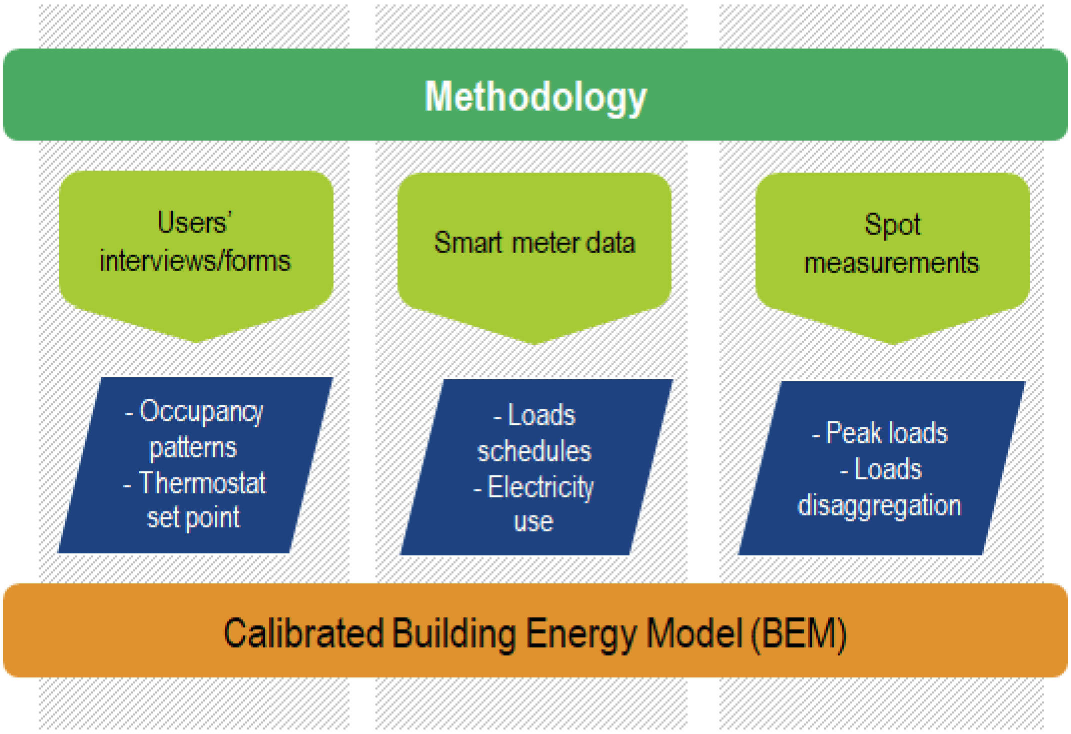

Figure 25. Methodological approach

[1] Regulatory requirements imply that utility companies have to implement web servers in order to provide userful and undestandable data about domestic energy use. This is a valuable source of actual energy data. Specifically, Directive 20112/27/EU requiered to Member States:

Article 9. Metering: *"Member States shall ensure that, … , final customers for electricity, natural gas, district heating, district cooling and domestic hot water are provided with competitively priced individual meters that a**ccurately reflect the final customer's actual energy consumption and that provide information on actual time of use.**"*

*they shall require that **appropriate advice and information be given to customers** at the time of installation of **smart meters**, in particular about their full potential with regard to meter reading management and the **monitoring of energy consumption.***

***Article 10. Billing information:** Independently of whether smart meters have been installed or not, Member States:*

*shall require that, to the extent that **information on the energy billing and historical consumption of final customers is available,** it be made available, at the request of the final customer, to an energy service provider designated by the final customer;*

4.3.1. Step 1: users' forms

Interviews and/or questionnaires to end-users can provide valuable information about parameters related to user behaviour that cannot be measured or monitored. For example, when an advanced building manager system (BMS) is not present in the building (case in most of current dwellings), it is not possible to extract quantified information regarding set-point temperatures.

In this case, the information provided by end-users interviews has been used to model occupancy and HVAC schedules according to the Table 15, based on actual patterns.

Table 15. Actual patterns according to information provided by end-users

	Occupancy				HVAC			
Source:	Interview / survey				Interview / survey			
Hour	Winter week days	Winter weekend days	Summer week days	Summer weekend days	Winter week days	Winter weekend days	Summer week days	Summer weekend days
	Fraction [0-1]				Thermostat setpoint [ºC]			
1	1.0	1.0	1.0	1.0	-	-	-	-
2	1.0	1.0	1.0	1.0	-	-	-	-
3	1.0	1.0	1.0	1.0	-	-	-	-
4	1.0	1.0	1.0	1.0	-	-	-	-
5	1.0	1.0	1.0	1.0	-	-	-	-
6	1.0	1.0	1.0	1.0	-	-	-	-
7	1.0	1.0	1.0	1.0	-	-	-	-
8	0.7	1.0	0.7	1.0	-	-	-	-
9	0.3	1.0	0.3	1.0	-	-	-	-
10	0.0	1.0	0.0	0.0	-	22.0	-	-
11	0.0	1.0	0.0	0.0	-	22.0	-	-
12	0.0	1.0	0.0	0.0	-	22.0	-	-
13	0.0	1.0	0.0	0.0	-	22.0	-	-
14	0.0	1.0	0.0	0.0	-	22.0	-	-
15	0.0	1.0	0.0	0.0	-	22.0	-	-
16	0.6	1.0	0.6	0.0	-	22.0	-	-
17	0.6	1.0	0.6	0.0	22.0	22.0	-	-
18	0.3	1.0	0.3	0.0	22.0	22.0	-	-
19	0.3	1.0	0.3	0.0	22.0	22.0	-	-
20	1.0	1.0	1.0	0.6	22.0	22.0	-	-
21	1.0	1.0	1.0	0.3	22.0	22.0	-	-
22	1.0	1.0	1.0	1.0	22.0	22.0	-	-
23	1.0	1.0	1.0	1.0	-	-	-	-
24	1.0	1.0	1.0	1.0	-	-	-	-

4.3.2. Step 2: data from smart meters

When smart meters for electricity use monitoring are installed, utility web platforms allow to download high quality data. In this case, the utility provides hourly data for the period required (2020 in this case). Data gathering is possible through the utility web platform as it is shown in the Figure 26. Data can be visualized online or downloaded in *.xlsx or *.csv formats, which is very useful for post-processing purposes.

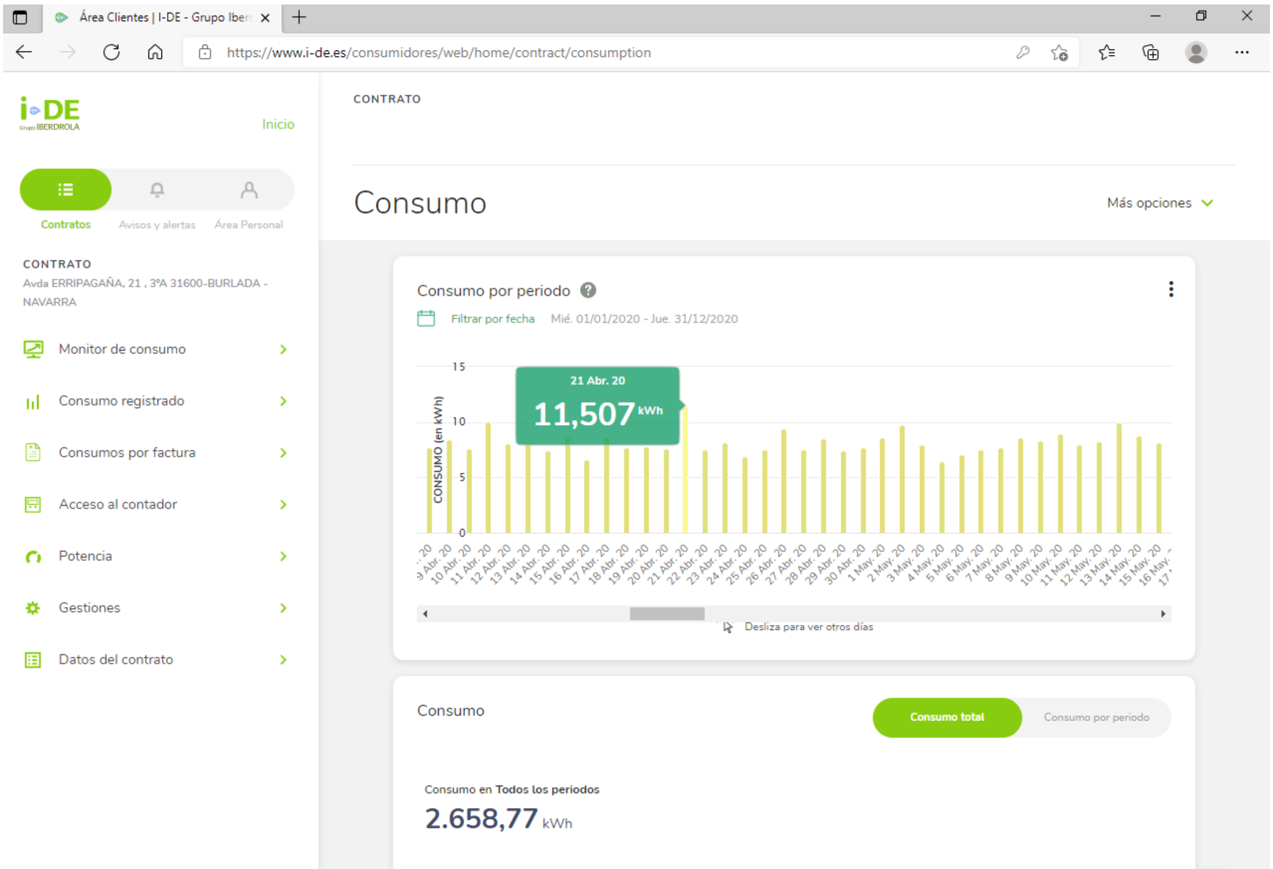

Figure 26. Energy use monitoring via utility[2] web platform

For the case study, a time series of 8784 values of electricity use has been downloaded and represented in the Figure 27.

Data show a peak load of 2.879kW that means 31.2W/m^2 for the model. Since the case study does not include any cooling system, the actual value just covers lighting and electric equipment. Then, this value differs notably from the Spanish standard operational conditions for energy assessments that imply 8.8W/m^2. Actual energy use also shows a minimum electricity use (or base load) of 40W and a total annual energy use of 2,658.8kWh in 2020.

Figure 28 shows annual cumulated electricity use per day hour split per day type (e.g. week and week-end days). This profile provides relevant information about dwelling end-users besides supporting assessment and design of EEMs based on RES technologies such as a PV roof.

[2] Link to the DSO's web platform: i-DE: la empresa de distribución eléctrica del grupo Iberdrola

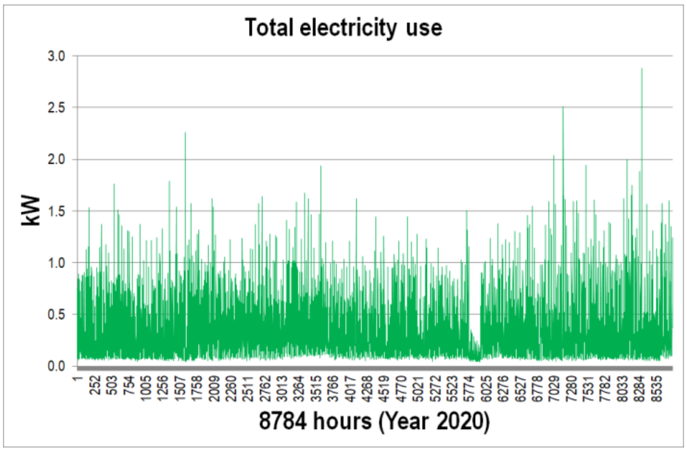

Figure 27. Hourly electricity energy use (actual data)

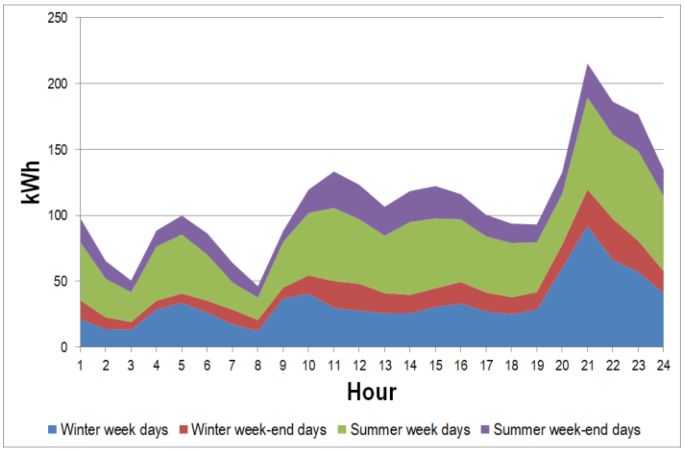

Figure 28. Annual cumulated electricity use per day hour

The comparison of day profiles for several representative day types is shown in the Figure 29. The standard operational conditions for dynamic simulation within the Spanish EPC scheme is highlighted in green colour which allow to highlight the discrepancies between actual mean profiles and standard profiles regarding internal loads associated to lighting and electric equipment

The specific error made when the standard profile is adopted in this case is shown in Table 16 through the Normalised Mean Bias Error. The calculation through the 24 hours for each day type implies an error between 6.4% and 17%, depending on the day type considered.

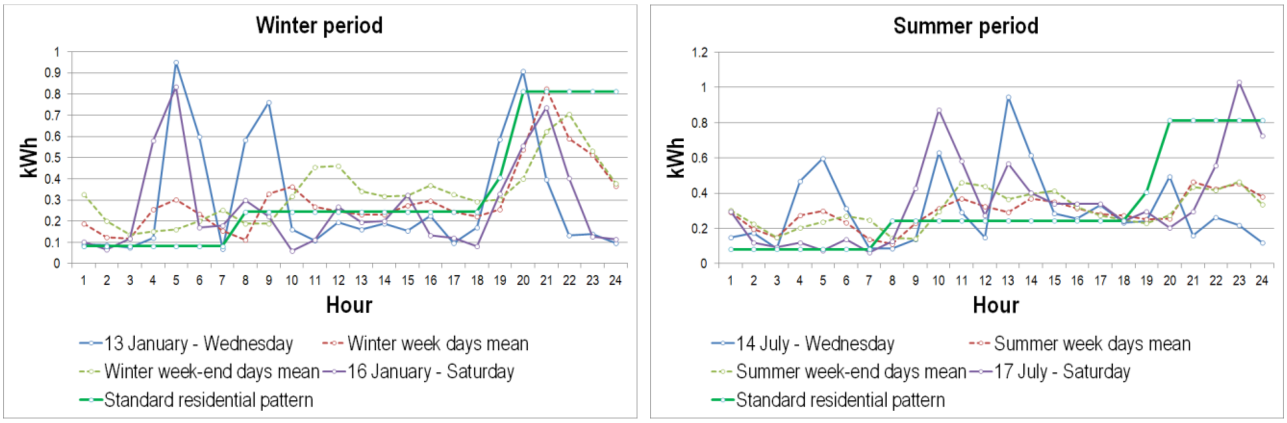

Figure 29. Comparison between different actual day patterns (hourly total electricity use) and standard operational conditions for residential model in Spain

Table 16. Normalised Mean Bias Error for representative days

Mean profile	NMBE (%)
Winter week day	6.42
Winter week-end day	11.61
Summer week day	12.97
Summer week-end day	16.69

Heating and DHW services are covered by a district heating for the assessed case study. In this way, another relevant building data list related to energy use is associated to the district heating energy use. In this case, data monitoring is carried out by a central BMS with an almost monthly frequency with the aim of dividing up energy costs among all dwellings. The specific data gathered for the case study are shown in the Table 17.

Table 17. District heating monitoring data from the BMS (year 2020)

Period	Start of the period	End of the period	kWh	Number of days covered	kWh/day
1	27/12/2019	10/02/2020	739	45	16.42
2	10/02/2020	28/02/2020	169	18	9.39
3	28/02/2020	30/03/2020	370	31	11.94
4	30/03/2020	08/05/2020	297	39	7.62
5	08/05/2020	05/06/2020	130	28	4.64
6	05/06/2020	29/06/2020	109	24	4.54
7	29/06/2020	29/07/2020	88	30	2.93
8	29/07/2020	31/08/2020	46	33	1.39
9	31/08/2020	29/10/2020	370	59	6.27
10	29/10/2020	26/11/2020	269	28	9.61
11	26/11/2020	28/12/2020	506	32	15.81

These data in combination with users´ questionnaires (Table 15) will allow verifying user behaviour regarding HVAC systems (i.e. set-point temperature, DHW use and fractional schedules).

4.3.3. Step 3: spot measurements and post-processing data

The post-processing of hourly electricity use data in combination with spot measurements allow dividing the total electricity use into two data series; one related to the lighting system and another one for the electric equipment currently present in the dwelling.

Table 18. Definition of peak loads

Mean profile	kW	W/m2	Day/Time
Lighting	1.01	10.9	Saturday 12/12/20 at 21.00h
Electric equipment	2.51	27.2	Sunday 25/10/20 at 16.00h

Knowing the peak loads and disaggregated electricity use according to day time due to the day lighting accessibility inside the dwelling, it is possible to generate appropriate and detailed schedules for both internal loads present (i.e. lighting and electric equipment). Then, schedules generated for the assessment object with data from 2020 shown in the Figure 30, have been imported from the dynamic simulation tool in combination with actual peak loads in order to develop a pre-calibrated model.

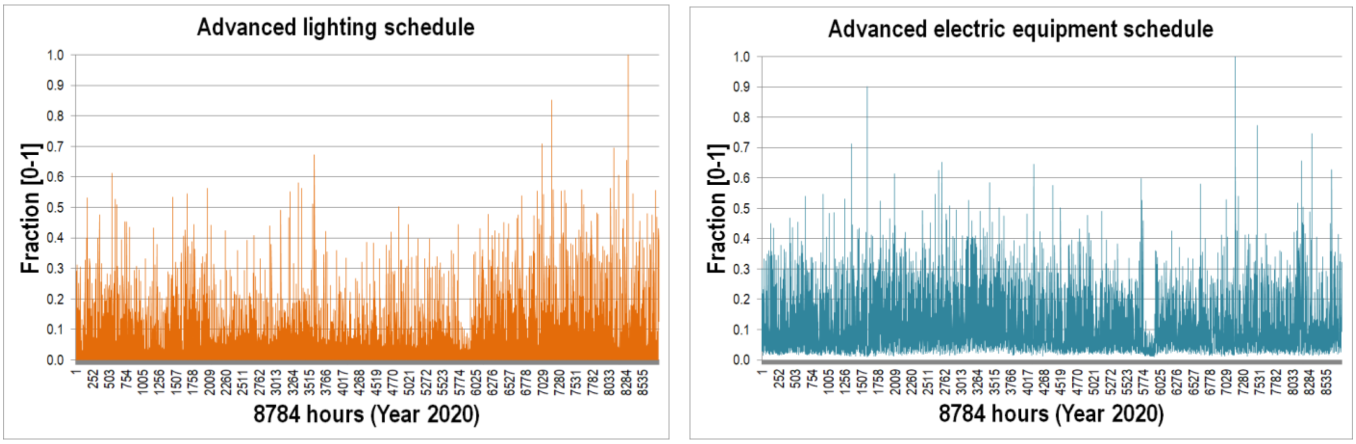

Figure 30. Fractional (0-1) schedules for lighting and electric equipment loads

4.3.4. Calibration

Firstly, since the proposed methodology implies a calibration of the model, it is also needed to gather actual weather data for the year assessed (year 2020 for this case study). Actual weather data from a weather station located in the Public University of Navarre[3] (Pamplona, Spain) have been used (i.e. downloaded and post-processed to develop a *.epw file compatible with dynamic energy simulations in EnergyPlus).

After the application of the three methodology steps (described in the section 4.3.) to the model and proceeding with fine-tuning of calibration through the variation of some un-known thermal parameters of the model (e.g. infiltration air rate), the results obtained regarding the model accuracy are shown graphically in the Figure 31, comparing simulated and actual/measured data.

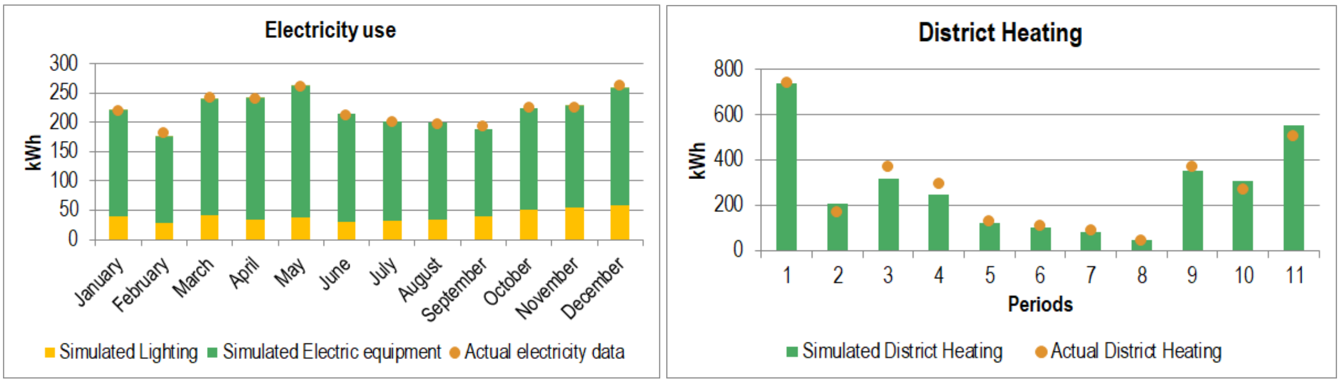

Figure 31. Calibrated simulation results (year 2020)

The calibrated model's accuracy to represent the actual building performance is quantified through the error indices included in the table below, by means of Normalised Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Square Error (CV RMSE). As can be seen, error values comply with the acceptance criteria according to ASHRAE Guideline 14-2014.

[3] Actual weather data (10 minutes frequency) available from an open data source: Datos de la estación - Meteo Navarra

Table 19.Error indices obtained after calibration

Error index (%)	Total Electricity	District Heating	Acceptance criteria ASHRAE 14
NMBE	0.3%	0.5%	<5%
CV(RMSE)	1.3%	11.7%	<15%

The approach scheme for simultaneous calibration and definition of behavioural patterns followed to generate a pre-calibrated and finally a calibrated model that allows the comparison between actual and standard operational conditions is shown in the scheme below (cf. Figure 32).

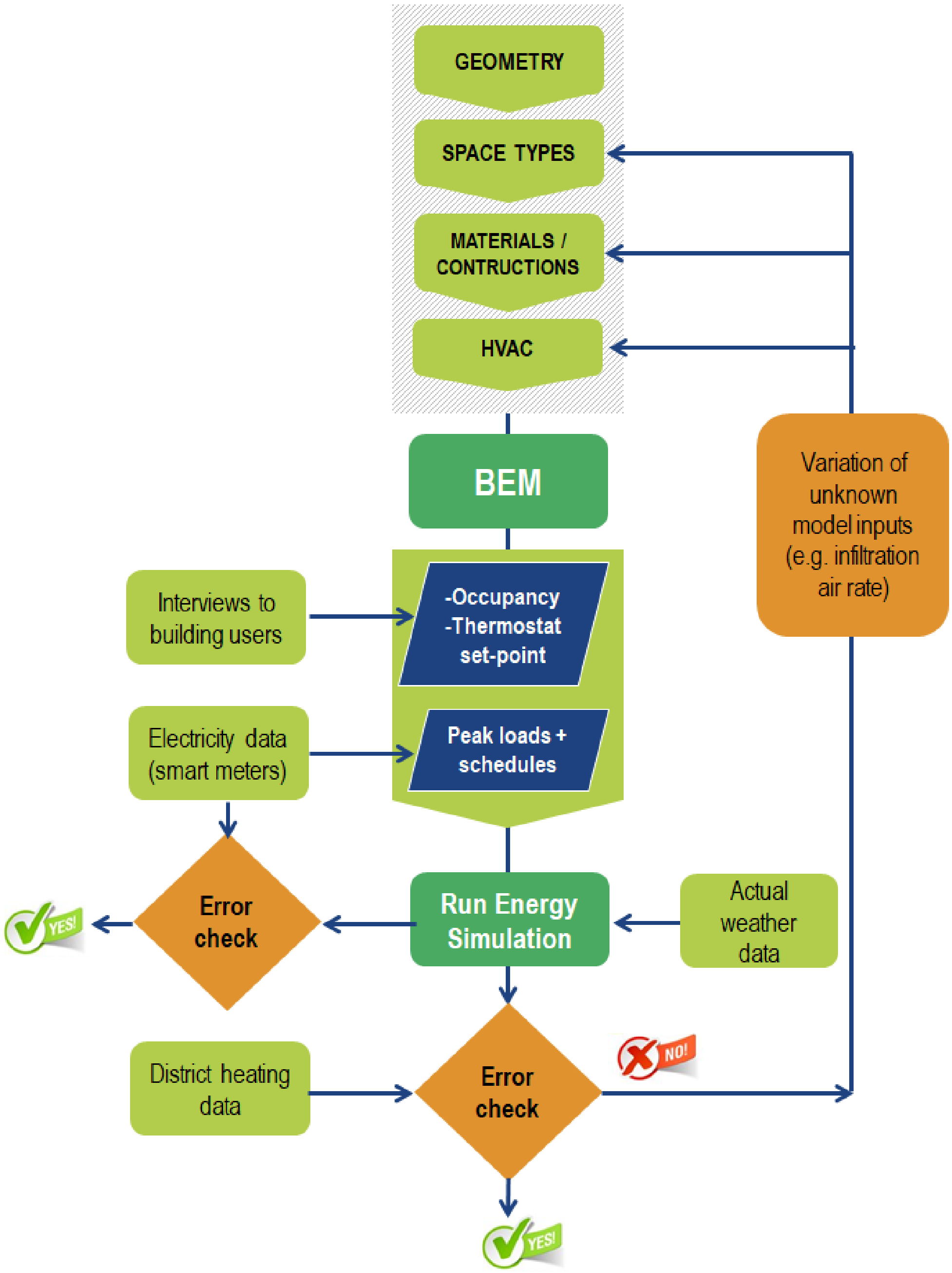

Figure 32. Workflow scheme for simultaneous calibration and advanced end-users behaviour modelling

4.4. Impact assessment

4.4.1. Results and discussion

After the simultaneous calibration and the advanced user behaviour modelling are completed for the case study according to the approach explained in the previous section, the result is a fully calibrated model that accurately represents the energy building performance that allows not only the quantification of global energy use, but also the disaggregation of energy use by service and fuel with a reasonable level of uncertainty.

The impact assessment related to the use of actual operational conditions (i.e. advanced user behaviour modelling) has been conducted through the energy assessment of three calculation scenarios for the same case study according to the characteristics included in the table below (cf. Table 21).

- Actual. Results come from the simulation outcomes for the calibrated model with actual use and actual weather data.
- Climate corrected. Results come from the simulation outcomes when the calibrated model is run under the standard weather data for a whole year.
- Standard. Results come from the simulation outcomes when the calibrated model is run under the standard weather data for a whole year plus standard operational conditions of use.

Table 20. Cases assessed defined according ISO 52000-1:2017

Type	Nº	Subtype	Use	Climate	Building
Measured (operational)	**1**	Actual	Actual	Actual	Actual
	2	Climate corrected	Actual	Corrected to standard	Actual
	3	Standard	Corrected to standard	Corrected to standard	Actual

As a reference, operational conditions of use associated to the standard case are included in Table 21 and Table 22, corresponding to the official procedure of Energy Performance Certification of residential buildings in Spain.

Table 21. Standard operational conditions: temperature set-points

High temperature set-point [ºC]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
January	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
February	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
March	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
June	27	27	27	27	27	27	27	-	-	-	-	-	-	-	-	25	25	25	25	25	25	25	25	27
July	27	27	27	27	27	27	27	-	-	-	-	-	-	-	-	25	25	25	25	25	25	25	25	27
August	27	27	27	27	27	27	27	-	-	-	-	-	-	-	-	25	25	25	25	25	25	25	25	27
September	27	27	27	27	27	27	27	-	-	-	-	-	-	-	-	25	25	25	25	25	25	25	25	27
October	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
November	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
December	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Low temperature set-point [ºC]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
January	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
February	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
March	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
April	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
May	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
June	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
August	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
September	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
October	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
November	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17
December	17	17	17	17	17	17	17	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	17

Table 22. Standard operational conditions: occupancy, internal loads, ventilation and DHW

Occupancy sensible load (W/m2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Labour day	2.15	2.15	2.15	2.15	2.15	2.15	2.15	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	2.15
Saturday	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
Holiday	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
Occupancy sensible load (W/m2)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Labour day	1.36	1.36	1.36	1.36	1.36	1.36	1.36	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	1.36
Saturday	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Holiday	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36
Lighting load (W/m2)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
All days	0.44	0.44	0.44	0.44	0.44	0.44	0.44	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	2.2	4.4	4.4	4.4	4.4	2.2
Electric Equipment load (W/m2)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
All days	0.44	0.44	0.44	0.44	0.44	0.44	0.44	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	1.32	2.2	4.4	4.4	4.4	4.4	2.2
Summer ventilation (ach)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
All days	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Winter ventilation (ach)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
All days	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Domestic hot water (%)*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
All days	12	5	4	2	2	6	27	100	70	75	62	56	48	48	41	33	39	38	52	70	57	63	48	52

*According to national regulation and building typology, DHW demand daily for the case study is 84 l/day at 60ºC

After applying the standard conditions of use and standard weather data according to the Spanish regulation for verification of minimum energy performance requirements and conducting the EPC, the results obtained for the three cases are shown in the figures below for graphical comparison purposes. Figure 33 and Figure 34 show monthly and annual energy use respectively for each service covered.

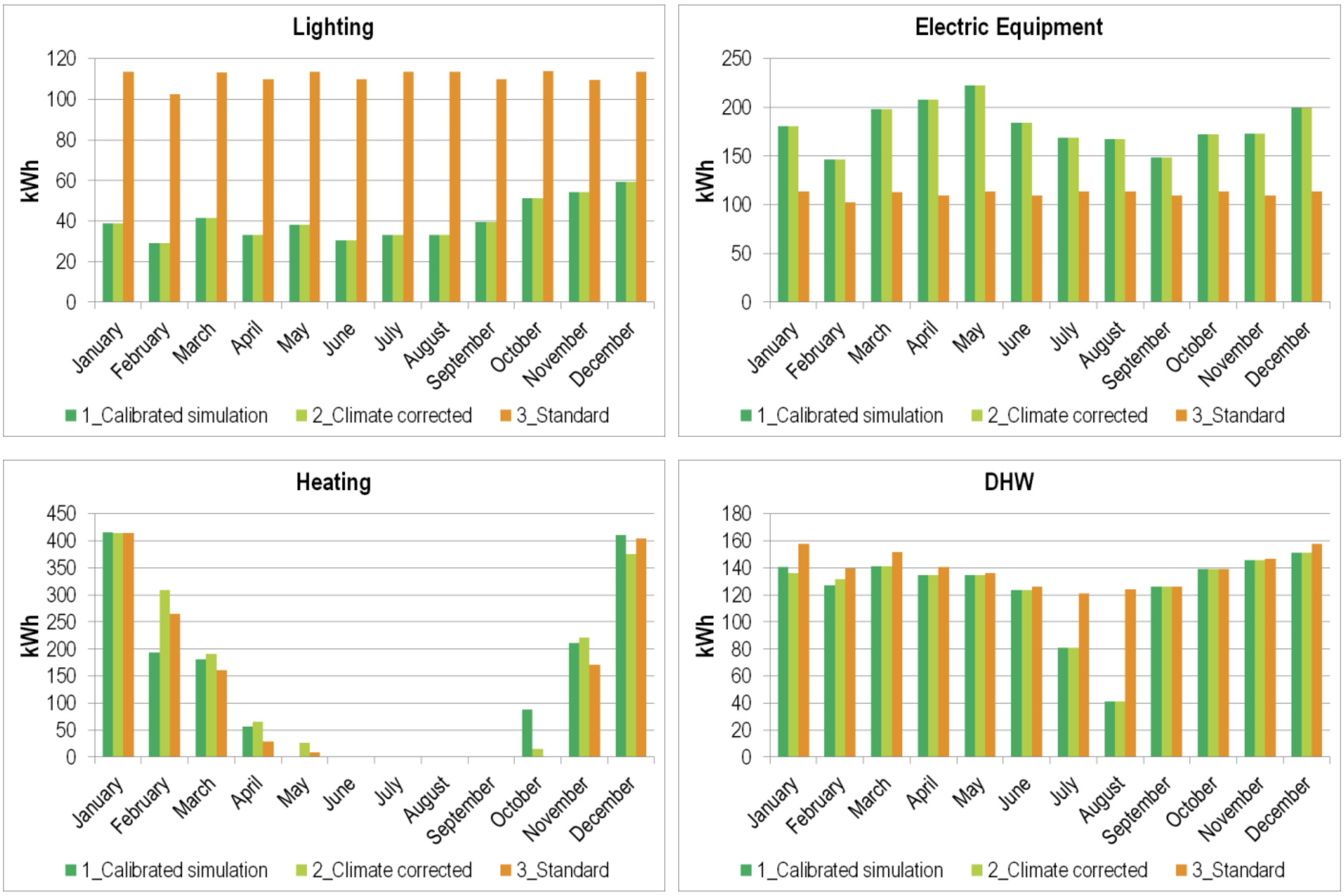

Figure 33. Monthly results comparison per service

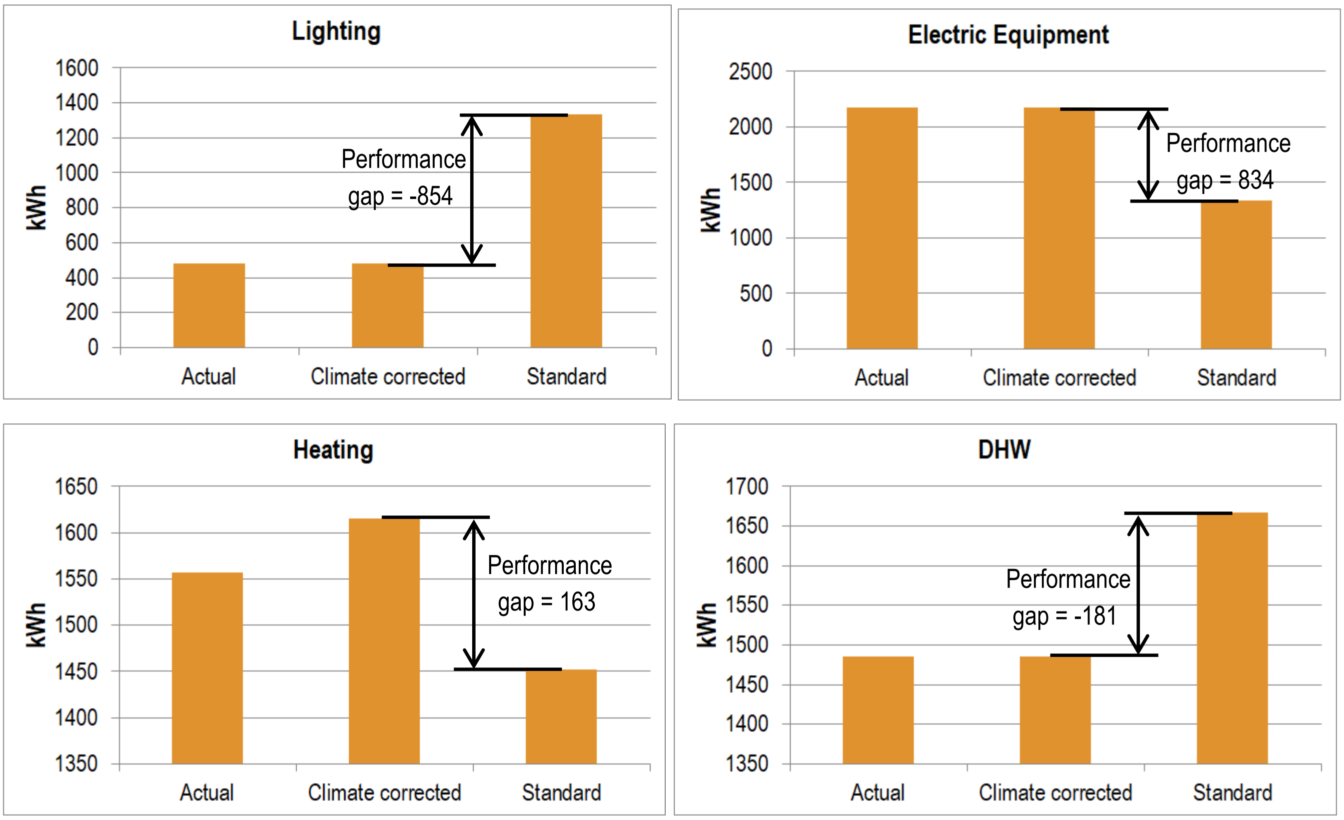

Figure 34. Annual results comparison per service

As can be seen the gap varied for each service, showing higher and lower deviations with different severities. Annual deviations (Table 23) are much higher for electricity use services (i.e. lighting and electric equipment) than district heating services. Although these services (i.e. lighting and electric equipment) are not EPB services for residential buildings at the moment, it is necessary to highlight the fact that within the energy transition framework all energy uses present in the building will be relevant in order to reduce or compensate them with on-site electricity generation through renewable energy sources (e.g. via roof PV installations).

Table 23. Quantification of the performance gap for each service

Service	Annual gap (kWh)	MBE(%)	CV(RMSE)(%)
Lighting	-854	-177.18	1,066.22
Electric equipment	834	38.45	242.64
Heating	163	10.1	40.85
DHW	-181	-12.16	51.49

In terms of MBE (based on monthly data) the error committed of using the standard case for EPC instead of the climate corrected case (actual use) is practically zero as can be seen in Table 24, since this error function suffers from cancellation effect and positive deviations are compensated with negative deviations. It is the same with the global consumption; for instance in this case study electric services compensate each other (i.e. lighting and electric equipment services) as well as district heating services (i.e. heating and DHW services). This means that the overall performance indicator is quite similar in both cases. However the conclusion is totally different if the assessment is focused on the disaggregation by services and periods, which is very relevant to the actual energy saving evaluation derived from the implementation of EEMs, and where major deviations are found between compared cases (i.e. actual use and standard use); between 10% in the case of heating up to 177% for the lighting system (see Table 23).

On the other hand, if the deviation is analysed with the NME[4] error function instead MBE, although cancelation effect between services is maintained, cancelation effect between monthly data is avoided and the error is higher, as can be seen in the last column of the table below. Results aggregated by energy source (electricity and district heating) used to evaluate these deviations are shown in Figure 35.

Table 24. Quantification of the performance gap for each energy source

Energy Source	Annual gap (kWh)	MBE(%)	NME(%)
Electricity	-19.45	-0.73	8.95
District Heating	-17.56	-0.57	11.5
Total (non-renewable primary energy use)	-67.86	-0.65	7.68

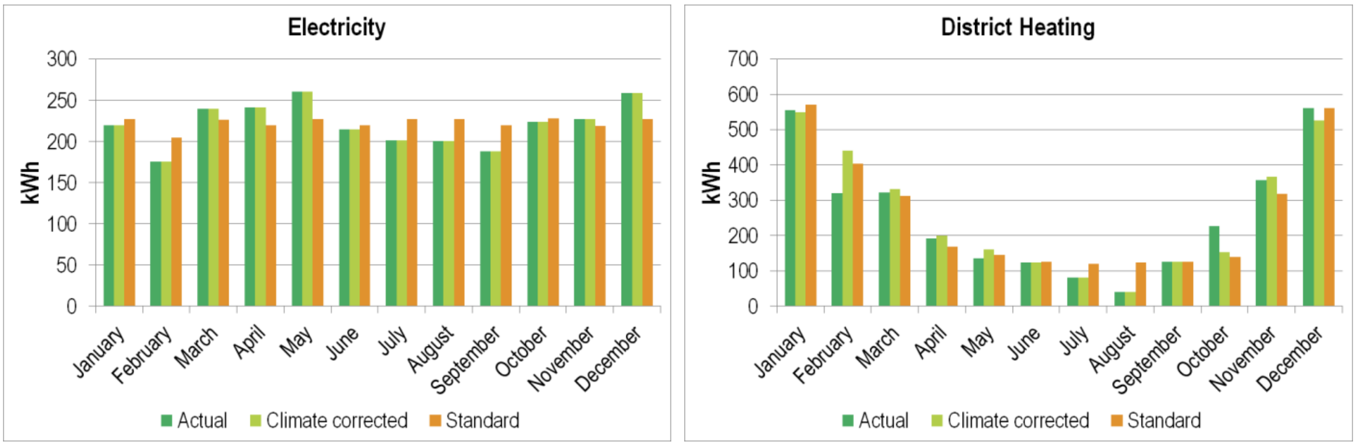

Figure 35. Monthly outcomes for each energy source

Besides, it is important to highlight the fact that the case study assessed under operational conditions in year 2020 is not representative of the regular use of this dwelling, since users' behaviour patterns have been different than regular patterns in due to the COVID-19 crisis. In this case, after post-processing data related to 2021, it is expected that the impact of the consideration of actual operational patterns instead of standard ones will imply a higher impact in global terms, which will be investigated under the testing and demonstration phase of the ePANACEA methodology though the case studies with 2021 building energy data.

[4]Normalized Mean Error (NME) normalizes the sum of the error between the actual behaviour case (climate corrected) and the standard case, being a good indicator for evaluating the perforce gap, avoiding the problem of the cancelation effect as the error is considered in absolute value.

4.5. Conclusions

With the proposed methodology, the use of actual building data (available at the moment thanks to ICTs), including them into the workflow for energy modelling and assessment of buildings, is possible and cost-effective, since a reasonable accuracy can been achieved with a moderate effort if quality data are available.

Although the global (i.e. sum of all energy use per service) and annual overall performance lead to the lowest error (near to 8%), this is mainly due to compensation effects between hourly behaviours, monthly results and opposite deviation for different services. But, for EEMs assessments that need hourly (daily profile) data and an accurate disaggregation by services, the error made will be much higher and can lead to very inaccurate energy savings quantification associated to a specific EEM. This, combined with the fact that the standard calculation procedure which EPCs are based on does not represent the actual building performance, implies a lack of trust in the EPC by different sectors (e.g. market, industry and building end-users).

Then, a simplified approach for modelling advanced occupant behaviour patterns based on actual building data combined or integrated to a calibration process, like it is described in this section, is feasible and will be studied for being implemented into the ePANACEA methodology.

5. REFERENCES

5.1. List of figures

Figure 1. A graphical representation of the DNAS framework applications [3] ....- 7 -
Figure 2. Office plan ....- 10 -
Figure 3. EnergyPlus office model ....- 10 -
Figure 4. External Wall composition ....- 11 -
Figure 5. Weekly occupancy schedule. ....- 13 -
Figure 6. Weekly lighting schedule ....- 13 -
Figure 7. Weekly equipment schedule ....- 13 -
Figure 8. Ventilation schedule on/off ....- 14 -
Figure 9. Heating and cooling set points ....- 14 -
Figure 10. Structure of the obFMU with obXML file inputs and co-simulation manager components [8]. ....- 15 -
Figure 11. Data flow of co-simulation between EnergyPlus and FMU [18] ....- 15 -
Figure 12. Definition of the meeting room occupancy via the Occupancy Simulator tool ....- 17 -
Figure 13. Example of a stochastic movement schedule generated by the Occupancy Behaviour tool for November 4 in one of the models ....- 18 -
Figure 14. Annual Lighting Consumption of Case 0 and Case 2 by Climate Zone ....- 21 -
Figure 15. Monthly Lighting Consumption by Climate Zone and Latitude of selected Climate Cities ....- 21 -
Figure 16. Energy plus object used to represent interior shades ....- 23 -
Figure 17. Example of on(1)-off(0) result for shading devices during two days of a simulation ....- 24 -
Figure 18. Lighting Consumption comparative among Lighting OB Cases ....- 28 -
Figure 19. Plug-in Equipment Consumption comparative among Electric Equipment OB Cases ....- 28 -
Figure 20. Increase compared to Base Case of the different Occupant Behaviour cases ....- 29 -
Figure 21. Impact on Heating and cooling demand of the different Occupant Behaviour cases ....- 30 -
Figure 22. Apartment layout ....- 31 -
Figure 23. Case study emplacement ....- 31 -
Figure 24. Apartment model for dynamic simulation ....- 32 -
Figure 25. Methodological approach ....- 34 -
Figure 26. Energy use monitoring via utility web platform ....- 36 -
Figure 27. Hourly electricity energy use (actual data) ....- 37 -
Figure 28. Annual cumulated electricity use per day hour ....- 37 -

Figure 29. Comparison between different actual day patterns (hourly total electricity use) and standard operational conditions for residential model in Spain ...- 37 -

Figure 30. Fractional (0-1) schedules for lighting and electric equipment loads ...- 39 -

Figure 31. Calibrated simulation results (year 2020) ...- 39 -

Figure 32. Workflow scheme for simultaneous calibration and advanced end-users behaviour modelling ...- 40 -

Figure 33. Monthly results comparison per service ...- 42 -

Figure 34. Annual results comparison per service ...- 43 -

Figure 35. Monthly outcomes for each energy source ...- 44 -

5.2. List of tables

Table 1. Thermal zones of Office building ...- 11 -

Table 2 Typical office occupancy schedule ...- 13 -

Table 3. Base Case (Case 0) Energy Demands for different climates...- 16 -

Table 4. Results for the Case 1 (Occupant Behaviour with regard to Occupancy Presence)...- 18 -

Table 5. Results for the Case 2 (Occupant Behaviour with regard to Lighting) ...- 20 -

Table 6. Results for Case 3 (Occupant Behaviour on Electric Equipment)...- 22 -

Table 7. Results for Case 4 (Occupant Behaviour on Shading Devices)...- 23 -

Table 8. Results of Case 5 (Occupant Behaviour on Operable Window) ...- 25 -

Table 9. Results of Case 6 (Occupant Behaviour on Thermostat) (Case 6)...- 26 -

Table 10. Results for Case 7 (All Occupant Behaviours)...- 27 -

Table 11. List of model's thermal zones in EnergyPlus ...- 32 -

Table 12. Thermal transmittance of the envelope elements ...- 32 -

Table 13. Annual estimation (based on standards) for the DHW needs ...- 33 -

Table 14. HVAC basic characteristics...- 33 -

Table 15. Actual patterns according to information provided by end-users ...- 35 -

Table 16. Normalised Mean Bias Error for representative days ...- 37 -

Table 17. District heating monitoring data from the BMS (year 2020) ...- 38 -

Table 18. Definition of peak loads ...- 38 -

Table 19.Error indices obtained after calibration ...- 40 -

Table 20. Cases assessed defined according ISO 52000-1:2017 ...- 41 -

Table 21. Standard operational conditions: temperature set-points...- 41 -

Table 22. Standard operational conditions: occupancy, internal loads, ventilation and DHW ...- 42 -

Table 23. Quantification of the performance gap for each service - 43 -

Table 24. Quantification of the performance gap for each energy source - 44 -

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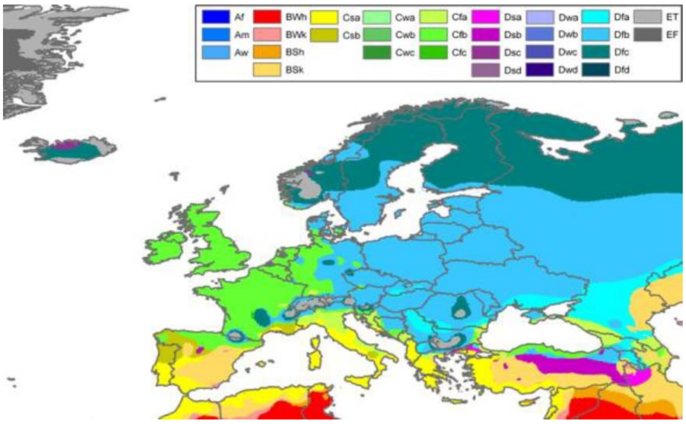
ANNEX: EU CLIMATE ZONES

The selection of the four main climate zones in the European Union is crucial because there is a wide variety of climatic conditions', differing across the EU, that buildings have to cope with and which influence the energy performance of a building.

There are different types of climate classifications depending on different factors. The deliverable "D2.2 European climates zones and bioclimatic design requirements" of the PVsites project includes a classification of the different regions of the EU on the basis of recognised classification systems:

- **Köppen-Geiger classification**

The Köppen-Geiger system is one of the most widely used climate classification systems in the world. Its main climatic groups are based on the main types of vegetation indigenous to each climate.



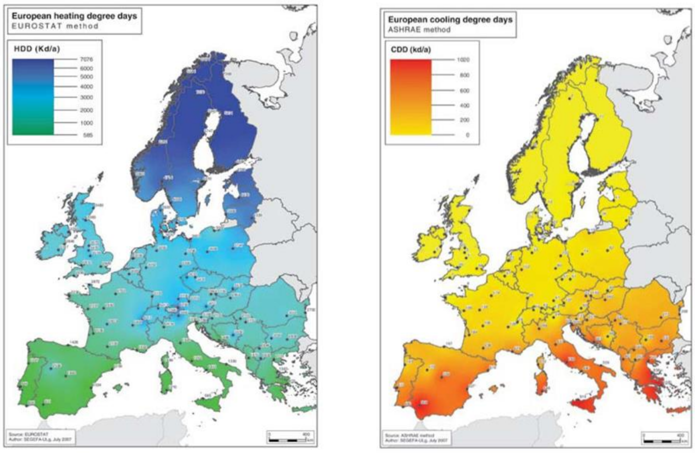
Köppen-Geiger climatic zones [Kottek et Al, 2006]

The Köppen climate classification scheme divides climates into five main climate groups: A (tropical), B (dry), C (temperate), D (continental), and E (polar) [31]. The second letter indicates the seasonal precipitation type, while the third letter indicates the level of heat. [32] Summers are defined as the 6-month period that is warmer either from April–September and/or October–March while winter is the 6-month period that is cooler.

As can be seen in figure above there are countries whose territory shares different climate zones, which can make it difficult to establish the prevailing climate in some areas.

- **Heating and Cooling degree days**

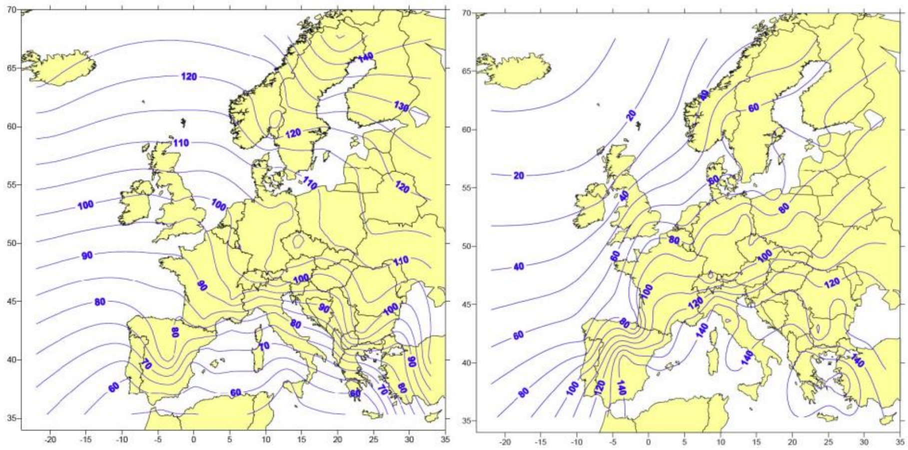
Heating degree days express the severity of the cold over a specific time period taking into consideration outdoor temperature and room temperature. For calculating heating degree days of European cities, weather data were taken from METEONORM and calculated to heating degree days (HDD) using the methodology applied by EUROSTAT, which form a common and comparable basis.



(Left) European heating degree days (Eurostat) [35] (right) European cooling degree days (ASHRAE) [35]

- **European Heating Index (EHI) & European Cooling Index (ECI)**

The HDD and CDD system refers to national regulations to define the set-point temperature indicating optimal comfort conditions. The new European Heating Index (EHI) is developed to make a more consistent system for Europe. The goal was to create an index explaining the demand for environmental heating expected at uniform cost and indoor temperature. The EHI and ECI are normalized, and 100 is equal to an average European condition, while the need for heating and cooling should be proportional to these indexes. Using a reference degree-day number of 2600, corresponding to an annual average outdoor temperature just above 10°C, fulfills this normalization.



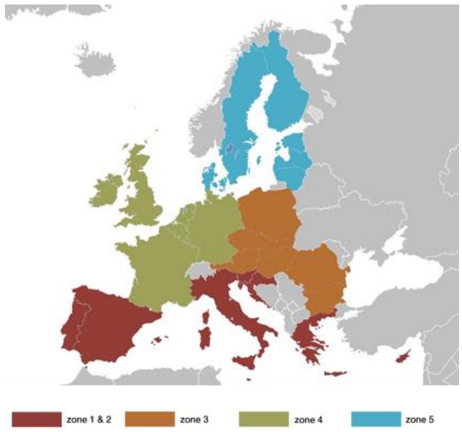
(Left) European heating index (EHI) [33], (right) European cooling index (ECI) [34]

- **Climate chart for NZEB**

As climate charts are independent from political borders, there is another level above the climate classification. That is the political level where borders divide climates and national regulation makes the difference.

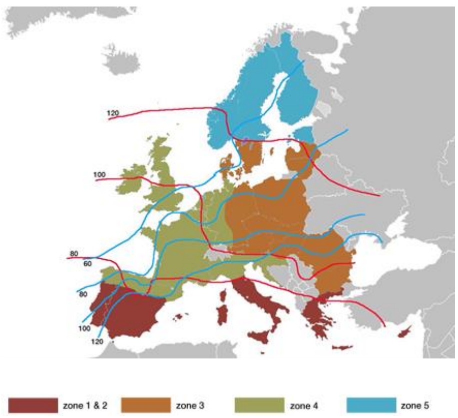
In the report 'Towards an early zero-energy Buildings', Ecofys divided European countries in 5 European climate zones based on global radiation, heating degree-days, cooling degree-days and cooling potential by night ventilation. These overviews result in the following European Climate Chart.

Zone	Cities	Köppen
Zone 1	Athens - Larnaca - Luga - Catania - Seville - Palermo	Csa
Zone 2	Lisbon - Madrid - Marseille - Rome	Csa Cfb
Zone 3	Bratislava - Budapest - Ljubljana - Milan - Venice	Dfb
Zone 4	Amsterdam - Berlin - Brussels - Copenhagen - Dublin - London - Macon - Nancy - Paris - Prague - Waszawa	Cfb/Dfb
Zone 5	Helsinki – Riga – Stockholm – Gdansk - Tovarene	Dfc



NZEB climate zones [Map is redrawn from 3]

When the Köppen-Geiger Classification and the Zoning by ECOFYS are compared, can be seen that most countries get more or less the same classification. A few countries however are divided between two areas according to Köppen-Geiger.



Alternative NZEB climate zones based on Köppen-Geiger and the EHI and ECI

In the report "PVSITES-WP2-T21-D22_M03-BEAR-20160831-v01" the zones in figure above are proposed as alternative NZEB climate zones based on the merging of the zones established in the Köppen-Geiger classification and in the EHI and ECI.

Occupance Behaviour climates selected

Based on the previous climate classifications, for the exploration of the impact and possible inclusion of advanced occupant models, the alternative NZEB climate zones based on Köppen-Geiger and the EHI and ECI **¡Error! No se encuentra el origen de la referencia.**is selected. The simulations will be carried out for the following climates:

Climates zone for occupancy behaviour

	Alternative NZEB Climate Zones	EU City	Weather station file
1	**Zone 1 & 2**	Madrid (Csa, bordering on Bsk)	ESP_Madrid.082210_IWEC.epw
2	**Zone 3**	Vienna (AUSTRIA) (Cfb)	AUT_Vienna.Schwechat.110360_IWEC.epw
3	**Zone 4**	Brussels (BELGIUM) (Cfb)	BEL_Brussels.064510_IWEC.epw
4	**Zone 5**	Helsinki (FINLAND) (Dfb)	FIN_Helsinki.029740_IWEC.epw