Validation report of reduced use of Net primary energy

Deliverable Report D3.1

Deliverable Report: D3.1 issue date on 31 August 2018

P2ENDURE
Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 723391.

Disclaimer

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Issue Date	31 August 2018
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Version:	Final
Reviewed by	Marco Arnesano (UNIVPM, Technical Coordinator)
Approved by	Rizal Sebastian (DMO, Project Coordinator)
Dissemination	Public

Colophon

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

Publishable executive summary

One of the main targets of the P2ENDURE research consists in the achievement of a cut in the energy demand of the buildings higher than 60% through the adoption of specific plug and play systems and/or solutions, possibly to be chosen within the basket of options offered by the P2ENDURE Consortium. This document presents the methodology to assess the targeted energy saving and the packages of PnP solutions that can guarantee such objective.

To this end, there is the necessity to define specific instruments to perform the energy analyses and to confirm the attainment of the 60% threshold of the energy savings.

In terms of the methodology that should be used, it is important to underline which are the normative references that should be used in the research and in the calculations: the Description of Action (DoA) states that all the energy analyses shall be performed in a full compliance with European Directive 2010/31/EU and its national secondary derived regulations.

Results as well must be presented in terms of primary energy, that is, scientifically, the more correct approach.

Chapter 1, Introduction, presents the Deliverable, its Topics and the storytelling of its development.

Chapter 2 illustrates the Methodology adopted to perform the analyses and to verify the achievement of the expected targets in terms of savings.

The DoA leaves to the stakeholders that are in charge of the case studies the freedom to choose the preferred tool and/or instrument to make the energy analyses and to test the effect of the retrofit interventions with the only three constraints: i) compliance to the EU 2010/31/EU, ii) results in terms of primary energy ["This tool will validate the 60% threshold in primary energy saving in compliance with European Directive 2010/31/EU"] iii) clear definition of the benefits coming from each single action ["Every single phase of the renovation process will be assessed in terms of the energy balance"].

Nevertheless, a considerable effort had been put to define a common framework for all these activities in order to give a clear overview of the energy analyses and to help in the acknowledgment of the effect of specific retrofit strategy even when applied in different contexts.

Theoretically, the energy analyses could be developed also not considering the support of a BIM (Building Information Model), however since the potential of these instruments and of the correlated patches and tools, BEM (Building Energy Model), a specific input was given to the partners asking them to implement the BIM models prepared in Work Package (WP) 2 and WP4.

In the development of this part of the research, the literature review has not provided evidence of any standardized method in the BIM-BEM implementation. A survey of the available

possibilities was hence executed finding two preferred approaches: the freeware approach and not freeware approach.
Both are presented in Chapter 2, Methodology illustrating all the passages that are necessary in this implementation in a flow chart.
A further possibility to keep the standard methodologies of calculations in the performing of the energy analyse, was left to all the partners that were not in the condition of developing such a composite digital suite.
Chapter 3 reports the energy demands of the case studies in the pre-renovation scenarios for all the case studies. Together with the figures of the energy requirements associated to the major end uses (electricity, heating, cooling), collected though energy bills and other input, this chapter provides a short report on the methodology adopted to prepare a clear set of data for each case study. These data helped in the finishing of the BIM models (WP4, D 4.3), matching the output of the energy analyses of the simulations with the energy data collected from the bills and other data sources
Chapter 4, Energy simulations and validation results, is a report of all the renovation strategies adopted in each selected case studies.
Partners that oversee the case studies present the selected interventions, illustrating the expected benefits coming from “every single phase of the renovation process will be assessed in terms of the energy balance, investigating embodied energy as well.”
The retrofit interventions are presented in terms of their technical specifications and the operations that should put in force to install them. The last are very important in order to demonstrate that these actions are possibly plug and play and lead to lower impacts in terms of both the primary energy associated to the satisfaction of the building end uses and the embodied energy characterizing their materials and their installation.
An omni comprehensive overview of the activities is given also foreseeing the possible “further improvement of the energy performance of the buildings.”
Chapter 5, finally, presents the Handbook of solutions, presenting “recommendations on how to achieve the 60% reduction of net primary energy, compared to the pre-renovation scenario”. These advices are given basing on the results of the energy analyses reported in previous chapters.

List of acronyms and abbreviations

DoA:	Description of Action
BIM:	Building Information Model
EC:	Exploitation Coordinator
GA:	General Assembly
HVAC:	Heating Ventilation Air Conditioning
IEQ:	Indoor Environment Quality
IPR:	Intellectual Property Right
MEP:	Mechanical Electrical Plumbing
PC:	Project Coordinator
PnP:	Plug and Play
R&D:	Research and Development
RES:	Renewable Energy Source
SC:	Steering Committee
SME:	Small and Medium-size Enterprise
TC:	Technical Coordinator
TCP:	Technology Commercialisation Platform
ToC:	Table of Content
WP:	Work Package

Contents

1. Introduction

In P2ENDURE, WP3 represents probably the scientific core of the whole research project, being the section where calculations are provided to give a full demonstration, through numbers, that P2ENDURE ideas are something that can be measured and analytically demonstrated.

In this sense, it is very clear the strong interdependence existing between WP3 and other work packages, especially WP4 in its 4M - Mapping. Modelling, Making, and Monitoring activities. As it will be clearly demonstrated below between WP3 and WP4, there is a general "ping-pong" interconnection, since the output of WP4 deliverables are often the input of WP3 ones, and again the findings of the last are taken back in WP4 to refine its results.

WP3 main goals can be summarized as follows:

- to measure and monitor product and process innovations based on live demonstration projects,
- to provide guidelines for the reduction of 60% of energy consumptions,
- to validate and report the energy performance,
- to test, improve and standardize P2ENDURE solutions for reduction of 60% of energy consumption, reduction of 15% of construction costs, reduction of 50% of construction time and guarantee high level of Indoor Environmental Quality (IEQ),
- to enable residents to maintain optimal performances after deep renovation through advanced monitoring tools

The achievement of the target above represents hence the best demonstration of the effectiveness of the adoption of energy retrofit policy based on the products, the processes and the tools promoted by P2ENDURE.

Each phase of the renovation process will be measured and validated; the results from demonstration cases will be compared to assess achieved performance and clearly reported.

D3.1 focuses on the validation of the achievement of the threshold of 60% savings in terms of primary energy demand, compared to the pre-renovation scenario, according to the requirements given by the European Directive 2010/31/EU.

The goal is reached for each demonstration case, adopting specific plug and play systems, technologies, and/or solutions, possibly to be chosen within the basket of options offered by the P2ENDURE Consortium, according to the site specific needs of the buildings.

Where and when possible the application a BEM, built though the implementation of the demonstration cases BIM, has been used to attest the achievement of the 60% goal. This approach is particularly desirable, since it can take advantage from the huge potential deriving from the BIM platforms, finally helping on the definition of general findings and recommendations that can be addressed to any case studies even beyond the P2ENDURE parterre.

These results are finally presented in form of a commented handbook that summarizing and estimating the potential savings of any given intervention in different geographical areas.

2. Methodology

The targeted reduction of net primary energy use is calculated in accordance with European Directive 2010/31/EU on the energy performance of buildings, which encourage the adoption of a methodology for calculating the energy performance of buildings.

As a reference, a short excerpt of the Directive is given below, providing the rationale and the main requirements of this European Law:

Annex I of 2010/31/EU

1. The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.

3. The methodology shall take into account the following aspects:

(a) the following actual thermal characteristics of the building including its internal partitions:

(i) thermal capacity;

(ii) insulation;

(iii) passive heating;

(iv) cooling elements;

(v) thermal bridges;

(b) heating installation and hot water supply, including their insulation characteristics;

(c) air-conditioning installations;

(d) natural and mechanical ventilation which may include air-tightness;

(e) built-in lighting installation (mainly in the non-residential sector);

(f) the design, positioning and orientation of the building, including outdoor climate;

(g) passive solar systems and solar protection;

(h) indoor climatic conditions, including the designed indoor climate;

(i) internal loads.

The total primary energy demand is then the sum of the primary energy associated with many possible end-uses: heating, electricity, hot water, cooling and ventilation. The numerical indicator of primary energy use is kWh/m2 per year, *id est* the overall primary energy demand, in kWh/year, associated to the fulfilment of the various end uses of interest, divided by the net floor area of the relative demo case (m^2)

The value, assumed as the reference in the calculation of the saving, is, indeed, the one associated to the specific primary energy demand in the pre-renovation scenario.
For each of the case studies, the reference primary energy demand is hence determined is based on the characteristic of the **existing building before the retrofit through the application of P2ENDURE Technologies**:
When direct recordings were not available, an indirect procedure has been adopted to compute the pre-renovation primary energy:

- Electricity needs: the related primary energy is calculated using standard national coefficients (i.e. the average efficiency associated to the transformation of primary energy into electricity, considering the available plants that operate in the country: thermo-electric plants fed by oil, carbon, etc., PV plants, wind farms, etc.);
- Thermal needs for heating: calculated from energy bills and/or through site specific calculation (normally considering a *quasi*-steady state heat exchange between the building envelope during the cold season), also considering the energy vectors involved in the transformation processes (*e.g.,* hot water, air, etc.);
- Hot water demand is computed considering the average usage of hot water for the specific facility and the efficiency of the technology adapted to its production;
- Thermal needs for cooling: it is usually extrapolated from the electricity consumption, isolating the needs that can be referred to the cooling consumptions.

In case of projects where the considered buildings are subjected to a variation in their final use/destination (*e.g.* transformation of an office into a residential building) the energy use before renovation is calculated assuming in the pre-renovation the same final use of the post-renovation, adopting standard/literature data, in case of lack of information, in conformity with the national standards and regulations.

It is clear that the reliability and precision of the calculation are strictly related to the available information and the knowledge of the building, of its activity and, in general, of its energy behaviour:

1st level: a general knowledge of the energy needs is available from the energy bills (it has been recommended to consider at least two years of data, in order to avoid seasonal variation and or demand anomalies); once the electricity consumptions are known, it is possible to calculate

the primary energy, associated to the electricity demand, applying the National Primary Energy Factors.
Historic energy use from bills is, therefore, the first reference used in the analysis of the energy use breakdown. When these documents were not available, the requirements have been reconstructed using similar data taken from scientific literature and/or reports of comparable buildings in the same country/geo-cluster.
Thermal energy demand and hot water needs can be calculated similarly using energy bills through a similar procedure, however considering the efficiency of the thermal plant installed in the building, instead of national factors. Again, some exception could be considered as it happens in case the dwelling is fed by a district heating network.

2nd level: a deeper knowledge of the building is provided by an energy audit: a systematic procedure with the purpose of obtaining adequate knowledge of existing energy consumption profile of a building or group of buildings (Directive 2012/27/EU. The energy audit is the outcome of a deep analysis of the building, its activity and historical energy consumptions; it is provided by a specialist considering the local norms and it can include a site inspection (if needed).

3rd level: the creation of a detailed energy model of the building permits a complete awareness of the building and its energy behaviour though the running of energy simulation and analyses.

In general, primary energy consumption is strictly related to the activities and the occupancy of the building. Therefore, the acknowledgement of some usage information, such as the usage time pattern, or the temperature set-point of the plant is pivotal and might help in finding reliable result, both in the pre and post renovation scenarios.
Since the complexity of the last variables in the energy balance equations, the availability of an energy model of the building highly facilitates the validation of the various selected opportunities to get the energy savings, also helping in the standardisation of the results for future comparison (*i.e.* handbook f solutions).

Calculation of Primary Energy Consumption may be performed through two different methodologies.

i) Manual calculation: many different tools are available on the market for the energy use assessment; each of them required at least a detailed knowledge of historic energy bills and specifications of the installed systems: electricity, natural gas, hot-water plants, and/or others; finally, it is necessary to have a deep knowledge of current lighting and HVAC plants;

ii) Digital model of the building: this methodology is based on the availability of a model of the building, created in a digital environment, where one can simulate the energy behaviour of the subject applying meteorological data, and simulating the operation of the installed on the MEP, in accordance to their given efficiencies. Tools and software yield energy demand through their calculation engines, using heat transfer algorithms, giving very precise results. Different freeware and not freeware software are available on the market and the required input may be substantially different.

BEMs belong to this second category. They have a huge potential in terms of reliability of results and facility in the replicability of the analyses, however they need a considerable amount of input data that are sometimes very difficult to be found and collected.

In general, they need to be built, starting from a detailed BIM. The last one, again, can be created only once there is a deep knowledge of the building and of its energy behaviour. It is in fact crucial that the digital model, on which the energy assessment is estimate, is as consistent as possible to reality.

This strong interconnection between BIM and BEM emerge if one considers the tight work plans of D3.1 and D4.3.

The modelling in a BIM environment of the case studies developed in D4.3 requires in fact, data from topics previously investigated in other Work Packages (mainly WP1, 2 and 3). WP 3 and D3.1, specifically, provides a lot of information about plants, energy networks, architectonical elements, etc. that are organized and implemented into the BIM models in the pre-renovation status, again of D4.3. These BIM models are given back to WP3 in order to run energy analyses in the pre-renovation scenarios. If the findings of these analyses are then compared to the official recording of the historical energy consumptions from bills, etc., allowing an immediate check on the reliability of the BIM model as a representation of the real case study.

If the findings of the simulations well match with the real energy requirements (a difference of 5 % has been considered as the maximum tolerance), then the model is validated and can be used in the further steps of the research.

On the contrary, if the validation fails, D3.1 of WP3 returns the model to D4.3 of WP4 for a further implementation of the BIMs in an iterative procedure that ends only at the full validation of the case studies BIM model.

This "ping-pong" iterative implementation represents the brightest demonstration of how important BIM an BEM models in are P2ENDURE: "*The results and analyses of the demonstrators in WP4 will be used as feedback for the Work Packages 1, 2, 3 and 5 to adjust and fine-tune the product and process innovation and the supporting tools, services and business models*.".

Once the BIM model of the pre-renovation scenario is complete and validated, and the BEM yield results coherent with the recorded consumptions, it is then possible to run specific energy simulations in the post renovation scenarios, testing the effect of each chosen technology (P2ENDURE or equivalent) in terms of primary energy savings.

The renovation interventions are normally adopted by the stake holders in relations to the typology of their building, the geo-cluster rationale and the specific characteristics of their demonstration case. There is a common understanding that similar case studies will most likely adopt similar retrofit strategy and similar P2ENDURE technologies (see the list below). This is very important in the definition of the handbook of intervention, intended as a *vademecum* of recommendations on how to achieve the 60% reduction of net primary energy, facilitating the replicability of P2ENDURE approach and solutions.

P2ENDURE technologies may be classified as follows:

PnP component for building:

- Multifunctional panel
- Smart window
- Folding balcony
- Rooftop retrofit module
- PnP smart connector

PnP technical systems:

- PnP HVAC control system
- IEQ control system
- Compact energy storage
- Connection to energy grid and RES production

3D technologies:

- 3D printing and robotic

Coming back to the retrofit scenarios, each demonstration case adopts a basket of solutions/technologies to achieve the 60% savings in primary energy demand. The selected interventions, even though shall be considered as a whole thing in the assessment of the 60%, must be investigated considering separately every single action, in order to determine exactly the incremental benefit, in terms of savings, that has to be associated to it.

Analyses are then run for each intervention and their combination. If the 60 % reduction threshold is overcome, then the general goal is accomplished for the specific demonstration case, it is possible to consider this combination of intervention as final and go the construction phase. On the contrary, there is the necessity to add new actions in order to increase the energy savings, as long as the 60% reduction of primary energy is reached.

This is an iterative process that will end only when the goal is finally achieved. In Figure 0 the flowchart of the described process.

2.1 Manual calculation

When simulation software is not available or necessary, other solutions are possible. Many tools are, in fact, available on the market, having the same potential in terms of providing reliable energy calculations under a full compliance with the European Norms.
The DoA, in fact, leaves to the stakeholders that are in charge of the case studies the freedom to choose any preferred tool and/or instrument to make the energy analyses, apart from the necessity of the respect of the EU 2010/31/EU.

The calculation of the primary energy demand is made, by setting up specific energy balances for every single end use: electric, thermal, hot water, *etc*.

Even though they might slightly differ from country to country, varying some coefficients that appear in the formulas especially in relation of the plant efficiencies, the main balance equations are summarized below:

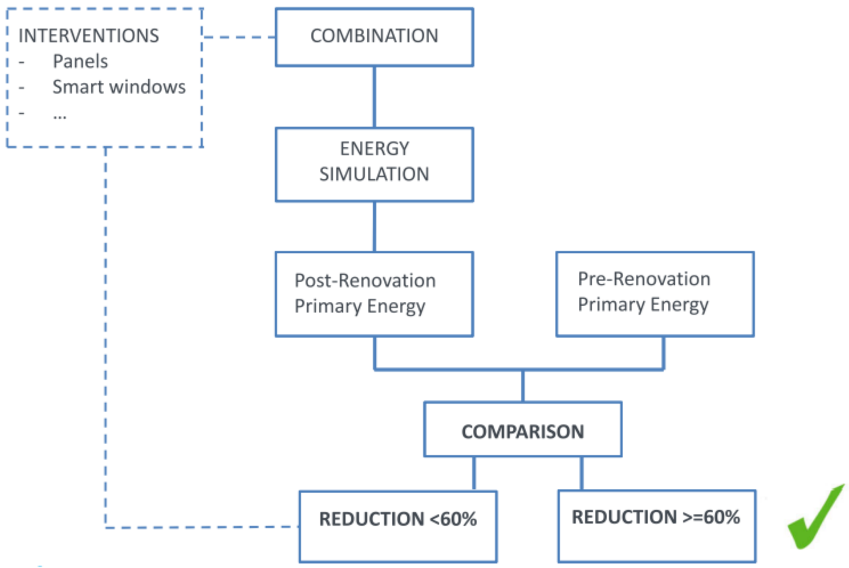


Figure 1: Flowchart of iterative process

- **Thermal requirements (Heating and Hot Water)**
  - Gas fired boilers (Group A)

$$Q_{PA} = Q_{TA}/\eta_{tA}$$

Q_{PA} is the primary energy requirements for buildings in group A;

Q_{TA} is the thermal energy requirements for buildings in group A;

η_{tA} is the thermal efficiency of the gas-fired boilers providing heating to household in group A;

$e_A = 0.236\ kgCO_2/kWh_t$

  - Boilers fed by other fossil fuels (Group B)

$$Q_{PB} = Q_{TB}/\eta_{tB}$$

Q_{PB} is the primary energy requirements for buildings in group B;

Q_{TB} is the thermal energy requirements for buildings in group B;

η_{tB} is the thermal efficiency of the gas-fired boilers providing heating to household in group B;

$e_{B\text{-}gasoline} = 0.318\ kgCO_2/kWh_t$

$e_{B\text{-}LPG} = 0.267\ kgCO_2/kWh_t$

  - Users supplied by district heating (Group C)

    Problems:

    i) when the district heating is fed by CHP plants: i.e. necessity to define a procedure to "allocate" adequately the primary energy and the emission to both electricity and thermal energy production in the Master Power Plants;

    ii) If more plants support the district heating, and if there are different technologies (e.g. boilers, CHPs, etc.) how to compute them? A possibility is to consider the systems as a unique large technological power plant, supplied by different fuels, whose thermal and electric energy productions are equal to the sum respectively of the input and of the output of each power plant;

    iii) Difficulty in finding the energy data of these systems.

<u>*EXERGY ANALYSIS – METHODOLOGY (SHORT SUMMARY)*</u>

Exergy associated to primary energy used = primary energy itself

Exergy associated to electricity production = electricity itself

Exergy associated to thermal energy depends of Carnot Coefficient

$$\tau = 1 - T_{AMB}/T_{MU}$$

T_{AMB} is the ambient temperature, assumed equal to 293 degrees Kelvin;

T_{MU} is the logarithmic mean temperature of the thermal user, assumed equal to 373 degrees Kelvin (assuming, coherently with the study, to use the heat produced by thermal-electric plants only for district heating and not for industrial processes).

- <u>Electric exergy allocation coefficient (sample values: Reggio Emilia District Heating)</u>

$$\alpha_E = \eta_E/(\eta_E + \tau \cdot \eta_T) = \eta_E/[\eta_E + (1 - T_{AMB}/T_{MU}) \cdot \eta_T] = 0.860$$

η_E = 0.341 is the electrical efficiency of the district heating plants park (2006);

η_T = 0.260 is the thermal efficiency of the district heating plants park (2006);

- <u>Thermal exergy allocation coefficient (sample values: Reggio Emilia District Heating)</u>

$$\alpha_T = 1 - \alpha_E = 0.140$$

…

- <u>Users supplied by district heating (Group C)</u>

$$Q_{PC} = \alpha_T \cdot Q_{TC}/\eta_{exc}$$

Q_{PC} is the primary energy requirements for buildings in group C;

Q_{TC} is the thermal energy requirements for buildings in group C;

η_{exc} is the efficiency of the local thermal exchanger between district heating and local building thermal distribution network (≅ 99%);

α_T is the exergy allocation cost for thermal energy provide through district heating.

$e_C = \alpha_T \cdot G / E_T$ 0.140 $kgCO_2/kWh_t$

G over all emission of district heating power plants

- Heat Pump (Group D)

$$Q_{PD} = Q_{TA}/\eta_{el-n} \cdot COP_{HP}$$

Q_{PD} is the primary energy requirements for buildings in group D;

Q_{TD} is the thermal energy requirements for buildings in group D;

η_{el-n} is the average national efficiency associated to the production of electric energy (country specific, e.g. Italy ≅ 40%);

COP_{HP} is the COP of the heat pump (≅ 4).

- **Thermal requirements (Cooling)**
  - Compression chiller

$$Q_{Pcool} = Q_{Tcool}/\eta_{el-n} \cdot COP_{cc}$$

Q_{Pcool} is the primary energy requirements for cooling;

Q_{Tcool} is the thermal energy requirements for cooling;

η_{el-n} is the average national efficiency associated to the production of electric energy (country specific, e.g. Italy ≅ 40%);

COP_{CC} is the COP of the compression chiller (≅ 3).

- **Electricity requirements**
  - Grid Connection (Group alpha)

$$Q_{PE\alpha} = Q_{E\alpha}/\eta_{el-n}$$

$Q_{PE\alpha}$ is the primary energy requirements for electricity requirements;

$Q_{E\alpha}$ is the building electricity requirements;

η_{el-n} is the average national efficiency associated to the production of electric energy (country specific, e.g. Italy ≅ 40%).

- CHP (Group beta)

$$Q_{PE\beta} = Q_{E\beta} \cdot \alpha_E$$

$Q_{PE\beta}$ is the primary energy requirements for electricity requirements;

$Q_{E\beta}$ is the building electricity requirements;

α_E is the exergy allocation coefficient of CHP systems (same procedure of district heating)

An example of existing tools that is able to provide reliable energy calculation is the professional German software "Der Energieberater" is used by architects and engineers to prove that a building is planned according the strict national laws and it has been used for Menden demonstration case.
In Germany for each new construction and deep refurbishments it is asked to provide that the intervention will be in line with the EnEV ("Energieeinsparverordnung"), the Energy Saving Ordinance, a national regulation to save energy. This law determines the maximum heat losses per m^2 and year and also the minimal thermal quality of all building parts that belong to the envelope of the heated volume of a building. According to this obligatory regulation that is updated continuously (last update in 2015), a building is not allowed to consume more than a theoretical reference building that consumes a determined amount of fossil energy. The losses of heat through transmission are limited as well, so the quality of the envelope has to fulfil determined minimum requirements.

The confirmation that the building is in line with the EnEV has to be declared to the Municipality before the construction process begins. There are several programs like "Der Energieberater" available to calculate the energy demand of a planned building and they are all working with the same methodology. Location, type of use, envelope surface separated by orientation to the sun, window surface separated by orientation to the sun, usable and heated floor space, heating system, construction details – thickness, materials, material order and material quality of all envelope building elements are entered into the program. Automatically the program calculates from the entered data the values of the relative annual requirement of primary energy and losses of heat through transmission and compares them to the target reference values of the reference building. The program takes into consideration the heat gains through windows, as well.

Bauteil:		Fläche / Ausrichtung:		
	Fassade West, Ansicht 1		51,33 m²	W
	Fassade Süd, Ansicht 2		71,67 m²	S
	Fassade Nord, Ansicht 3		96,40 m²	N
	Fassade Ost, Ansicht 4		85,97 m²	O

Nr.	Baustoff	Dicke	Lambda	Dichte	Wärmedurchlass-widerstand
		cm	W/(mK)	kg/m³	m²K/W
1	Putzmörtel aus Kalkgips, Gips, Anhydrit und Kalkanhydrit	1,50	0,700	1400,0	0,02
2	Beton armiert mit 1% Stahl (DIN 12524)	20,00	2,300	2300,0	0,09
3	Polystyrol PS -Partikelschaum (WLG 030 - > 15 kg/m³)	18,00	0,030	15,0	6,00
4	Putzmörtel aus Kalk, Kalkzement und hydraulischem Kalk	1,50	1,000	1800,0	0,02
	Anforderung nach DIN 4108 Teil 2 ist erfüllt!	$R_{\lambda,zul.}$ = 1,20			R_λ = 6,12

Bauteilfläche		spezif. Bauteilmasse	spezif. Transmissions-wärmeverlust		wirksame Wärme-speicherfähigkeit	
						R_{si} = 0,13
						R_{se} = 0,04
305,37 m²	33,6 %	510,7 kg/m²	48,52 W/K	20,3 %	10cm-Regel: 18365 Wh/K	**U - Wert**
					3cm-Regel: 4708 Wh/K	**0,16 W/m²K**

Bauteil:		Fläche / Ausrichtung:		
	Dach Hauptgebäude		86,83 m²	N
	Dachterassen/Erker		89,08 m²	N

Nr.	Baustoff	Dicke	Lambda	Dichte	Wärmedurchlass-widerstand
		cm	W/(mK)	kg/m³	m²K/W
1	Putzmörtel aus Kalkgips, Gips, Anhydrit und Kalkanhydrit	1,50	0,700	1400,0	0,02
2	Beton armiert mit 2% Stahl (DIN 12524)	20,00	2,500	2400,0	0,08
3	Bitumendachbahn (DIN 52128)	0,50	0,170	1200,0	0,03
4	Polystyrol PS -Partikelschaum (WLG 030 - > 30 kg/m³)	24,00	0,030	30,0	8,00
5	Kunststoff-Dachbahn PVC-P (DIN 16730)	0,50	0,200	700,0	0,03
	Anforderung nach DIN 4108 Teil 2 ist erfüllt!	$R_{\lambda,zul.}$ = 1,20			R_λ = 8,16

Bauteilfläche		spezif. Bauteilmasse	spezif. Transmissions-wärmeverlust		wirksame Wärme-speicherfähigkeit	
						R_{si} = 0,10
						R_{se} = 0,04
175,91 m²	19,4 %	517,7 kg/m²	21,20 W/K	8,9 %	10cm-Regel: 10994 Wh/K	**U - Wert**
					3cm-Regel: 2785 Wh/K	**0,12 W/m²K**

Figure 2: Examples of material order of exterior wall and roof

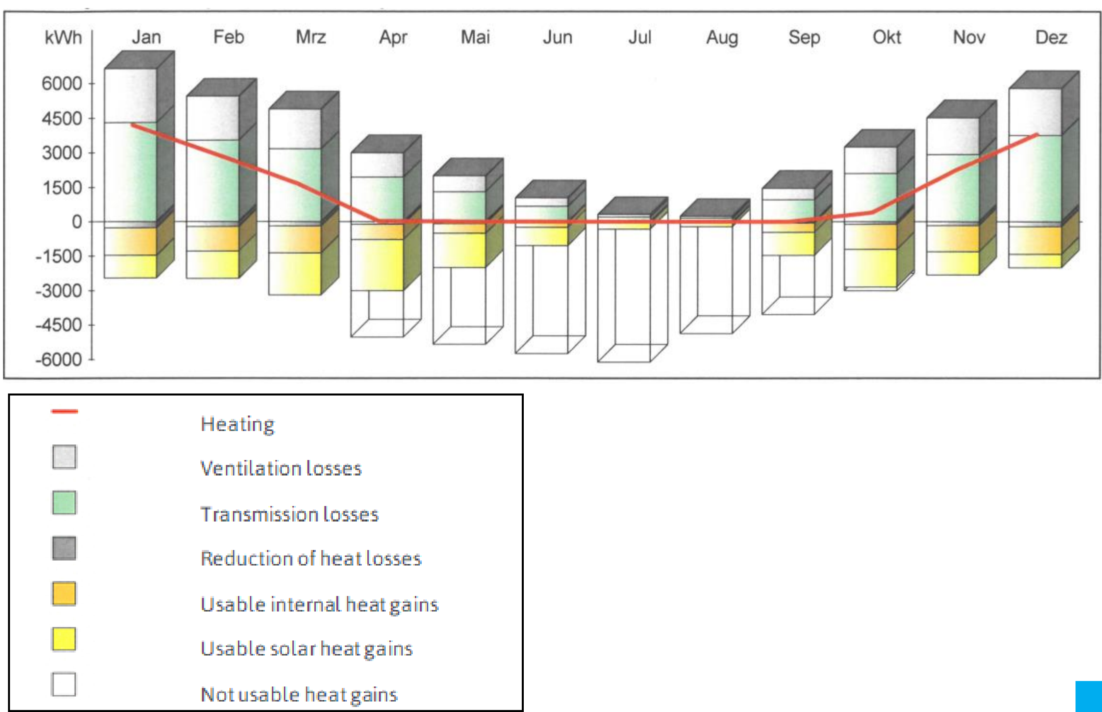


Figure 3: example of monthly balancing of energy gains and losses

The maximum allowed value for losses of heat through transmission according to the EnEV are 0,40 W/(m²K). Additionally, to the analysis of the heat losses through tap water heating and heating of the building the EnEV foresees an analysis of critical rooms concerning summer heat protection. As soon as a certain ratio of window size and floor space is reached, depending on the orientation to the sun, an analysis of the critical room has to be made and, when indicated, measures have to be taken to prevent overheating in summer.

The tolerance of the BIM model's accuracy in terms of geometry is not so strict, as not even e.g. a deviation of 10 cm of a wall's length is playing a decisive role in the final analysis of the energy performance. But the accuracy in terms of material quality and thickness is very important to achieve results that are as good as possible representing the real energy behaviour of the building.

2.2 Simulation Software

In this phase of the project, has been decided to not impose any energy simulation software or procedure. The main idea, in fact, is that the engineers would continue to use the software they normally use, known for their performance and quality, rather than change for software they have not yet mastered.
Many of the demonstration cases, however, have chosen to perform the energy analyses through the development of a BEM. This was the preferred option, since the great potential of BEM in terms of testing many scenarios, in a moderately contained time, under a certain degree of replicability of the analyses.
In the development of this part of the research it has been evident that literature did not provide any standardized method in the BIM-BEM implementation.

A survey of the available possibilities was hence executed finding two preferred approaches, one of those, already investigated while performing the energy analyses of large hospitals, in another European Project: Streamer of Seventh Framework Programme.

- **FREEWARE APPROACH**: Software that permit free access to their contents does not require a licence;
- **NOT FREEWARE APPROACH:** Software requiring the payment of a licence to be used; it is therefore possible the access of a free trial version.

Both the methods are presented in this Chapter and allow a BIM to BEM full export of information and results.

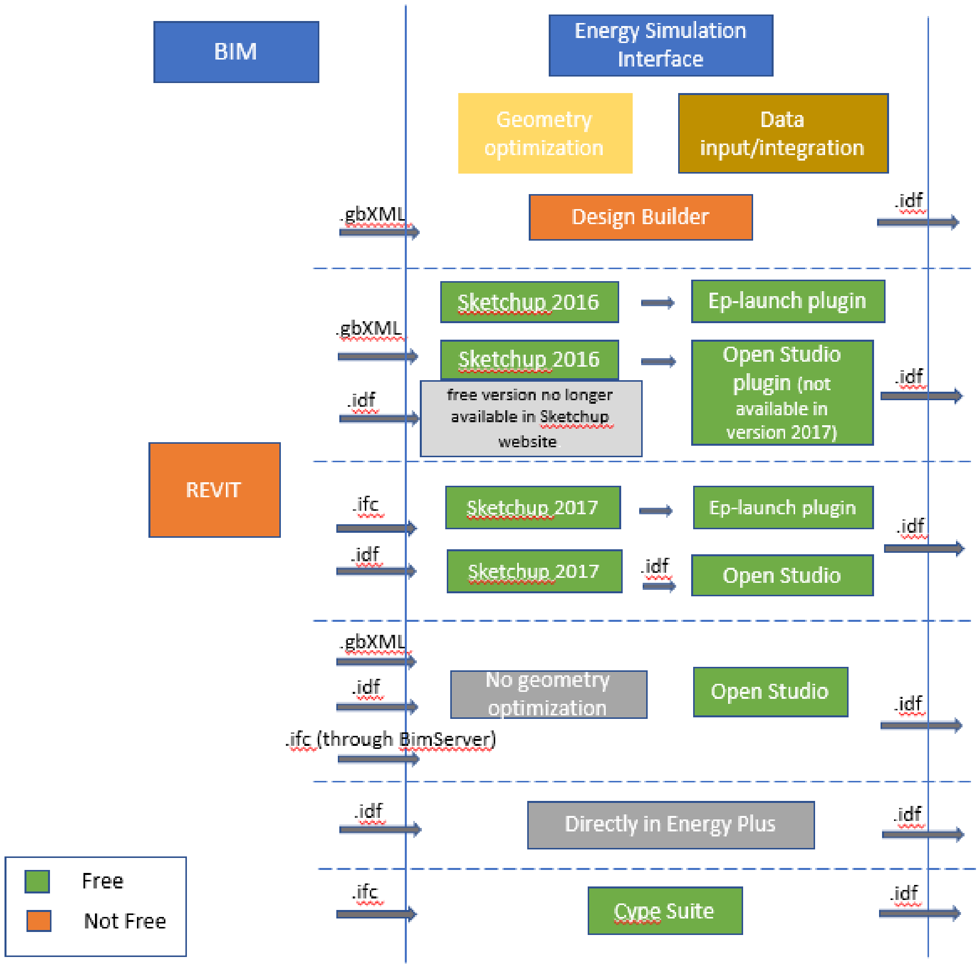


Figure 4: Overview of main simulation software

2.2.1 Freeware Approach

Figure 2: Workflow of freeware approach

This approach considers a combination of software to use their specific potential in order to get the final result. Unfortunately, each one of these has not been developed to interact with the other within a procedure aiming to calculate the energy consumption of buildings and, hence, this results in a very articulate computation roadmap.

The interoperability between Revit, Sketch Up and Energy Plus, in fact, is not automatic: each phase of the process may cause loss of information or a variation of the geometric model. The optimized procedure has been identified as follows:

- REVIT: The preliminary steps of the process are the definition of the geometry of the building in its main features (no internal partition in homogenous thermal zones) and the definition of thermal properties for each component. In this phase of the procedure the openings (windows and doors) are simplified and the HVAC system is not included to avoid difficulties in the export process.

To get an .IDF file from Revit it is necessary to follow the steps below:

- assign the materials and their thermal properties to the constructive elements;
- place spaces to account for the entire volume within the model;
- define thermal zone and set one of the default HVAC systems. The choice of a default HVAC system is important only to obtain the energy model and so to get the .idf file, but the HVAC system has to be more accurately define after the exportation;
- click on "Create Energy Model" and "Run Energy Simulation".

The .idf file imported into SketchUp shows the spaces division previously settled

A critical aspect has been tackled: each opaque element generated by Revit must be shifted to the inside of the model of half of the element width. This is due to the fact that the software generates, for each 3D element, an equivalent surface positioned in the center line of the 3D element.

- EXPORT .IDF: From Revit an .idf file is exported from the section "export and download Data Files" and "Energy Plus File";
- SKETCH UP with LEGACY OPEN STUDIO: importing the .idf file in SketchUp may cause some misalignment in the geometrical model. A general review of the model is therefore necessary to correct some critical issues:
  - division of external surfaces in sub-surfaces possible: separation lines must be deleted;
  - correct geometrical errors (joints between walls);
  - windows are considered as entire glazed surface without framework, the real glazed surface is different from the Revit model.
  - each component must be named and classified by construction type to facilitate a clear identification in EnergyPlus.

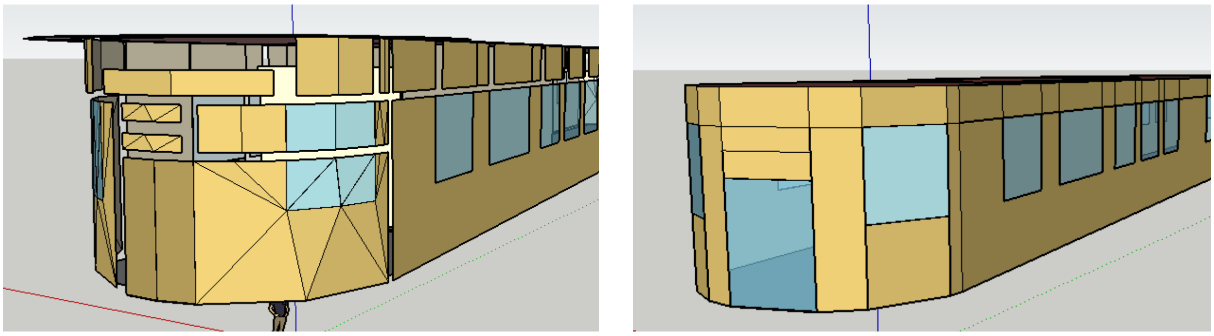


Figure 3: Detail of Genoa demonstration case

- EXPORT .IDF: From SketchUp in .idf file is exported;
- ENERGYPLUS: Import .idf file into IDF Editor, correct some information and insert missing parameters. Following issues have been encountered:
  - presence of additional objects that must be removed;
  - during the export/import process the materials characteristics have been correctly reported but not the names, it is therefore necessary to re-associate the material name to its properties.
  - some data are not correctly imported, it is fundamental to verify and correct the information related to glazing, building components, building surfaces and fenestration surfaces.
- EP-LAUNCH: From SketchUp in .idf file is exported. This phase of the process requires the setting of HVAC characteristics and occupancy schedule; when the model is completed, the energy simulation starts.

2.2.2 Not freeware approach

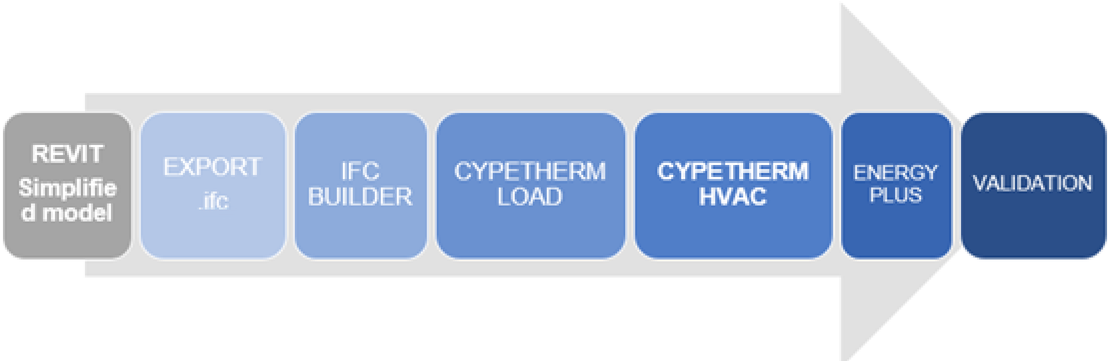


Figure 4: Workflow of not freeware approach

The not freeware approach considers a combination of software as well.
The educational version of Revit 2018 is open source for 3 years, after registration. The CYPETHERM Suite comprises several tools and some of them are available for free while others are provided with a 30 days trial (but completely working) version. In detail, the adopted tools are listed below:

- **Complement Open BIM for Revit**: a free Revit plug-in which allows exporting the BIM model from Revit using the IFC Standard. One copy is saved in a specific folder in the pc, while a file is associated to a project in the BIMserver.centre (i.e. a cloud store for storage and collaboration).
- **IFC Builder**: a free application used to import the IFC files and to define locals and thermal zones of the model.
- **CYPETHERM LOADS**: a free tool adopted to calculate buildings thermal loads (according to the Radiant Time Series Method, proposed by ASHRAE).
- **CYPETHERM HVAC**: a tool used to create and size building heating, cooling and ventilation systems. The tool can be downloadable for free for 30 days.
- **CYPETHERM EPlus**: a tool employed to perform the energy analysis which uses the EnergyPlus cloud simulation engine. The application can be downloadable for free for 30 days.

The entire Suite or the single tools can be downloaded after the registration at the BIMserver.centre (https://bimserver.center/bim_access.asp). This is a cloud-based platform essential for both the download of the tools and their correct operation; it also allows different partners to easily share information and collaborate on the same project.

The **process** is rather intuitive and the data exchange between the tools is excellent; however, some appropriate measures are needed.

- **Revit**: the first step concerns the creation of the *BIM model*. A simplified version, including only the geometrical features, is sufficient for the exportation (**Error! Reference source not found.**). In fact, the Complement Open BIM exports only the geometry, avoiding stratigraphy, materials and systems. All these missing aspects need to be defined within the CYPETHERM tools.

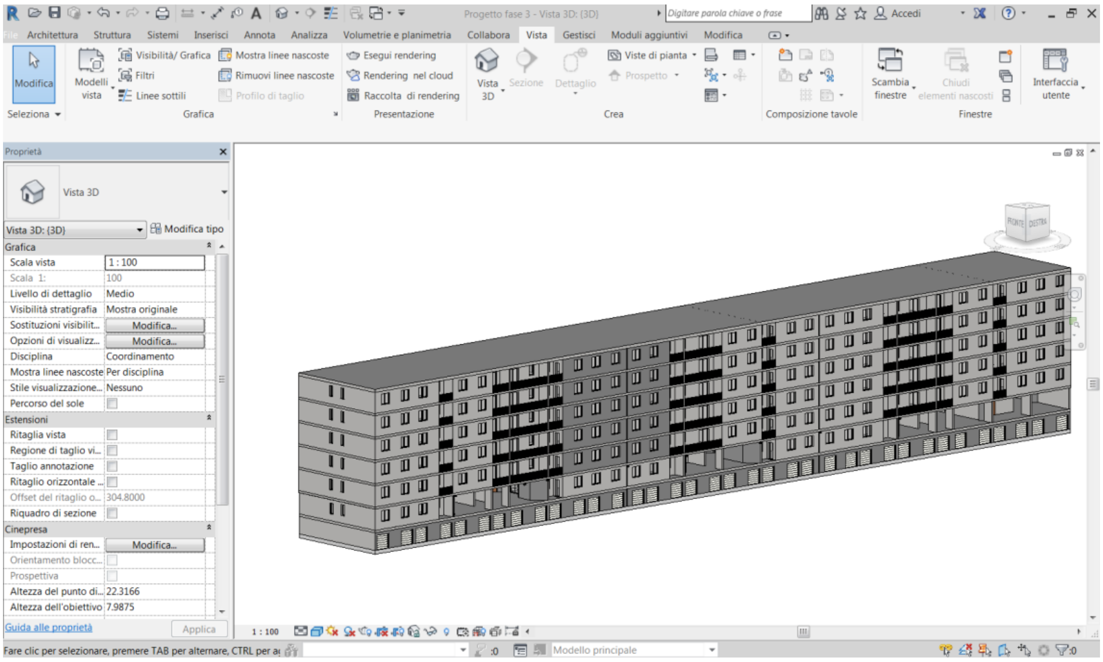


Figure 5: The BIM model in Revit

- **Open BIM plug-in**: the tool exports in a few minutes the model using the *IFC Standard*, saving the file both in the cloud (i.e. BIMserver.centre) and in a PC folder (**Error! Reference source not found.**8).

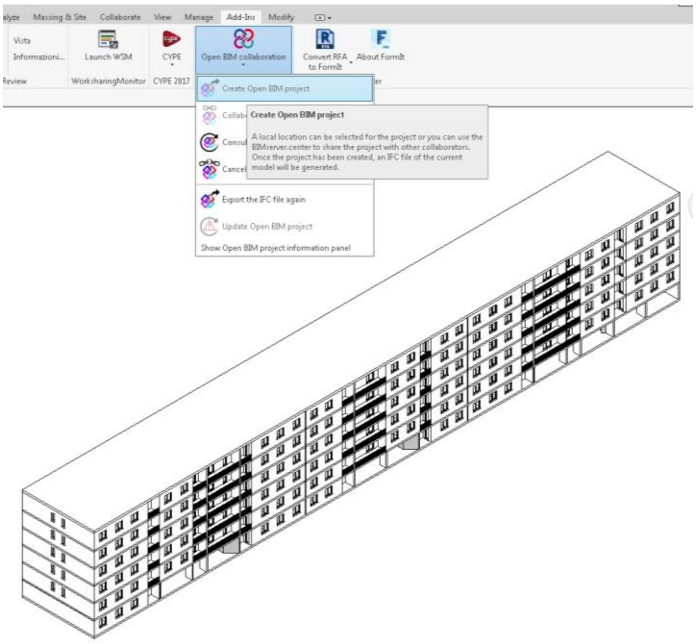


Figure 6: Identification of the Open BIM plug-in

- **IFC Builder**: the importation of the IFC file is very intuitive and guided through every step. The tool correctly recognizes all the elements (e.g. floors, openings) and all the typologies defined in Revit. If any element has not been properly assigned is it possible to change the type or create a new one already in this phase. The tool (Figure 9) is used to check *geometrical errors* (if present) and to *define locals and groups of locals* (i.e. the thermal zones). These will be essential when defining the thermal loads, the systems and when performing the energy analysis. Once these actions are completed, it is necessary to export the file. The exportation (simple and very quick) saves the file both in the cloud and in a specific PC folder.

Figure 7: IFC Builder overview

- **CYPETHERM LOADS**: the guided file import is user-friendly and no information is lost during the transfer. The first step concerns the creation of the *stratigraphy*, the definition of *materials' thermal properties* and the assignment of the stratigraphy to the elements (Figure 10). The layers can be exported from several databases (e.g. according to UNI 10351, UNI-EN ISO 6946) or custom-defined. The program automatically defines the thermal transmittance U and the thermal capacity of the entire element.

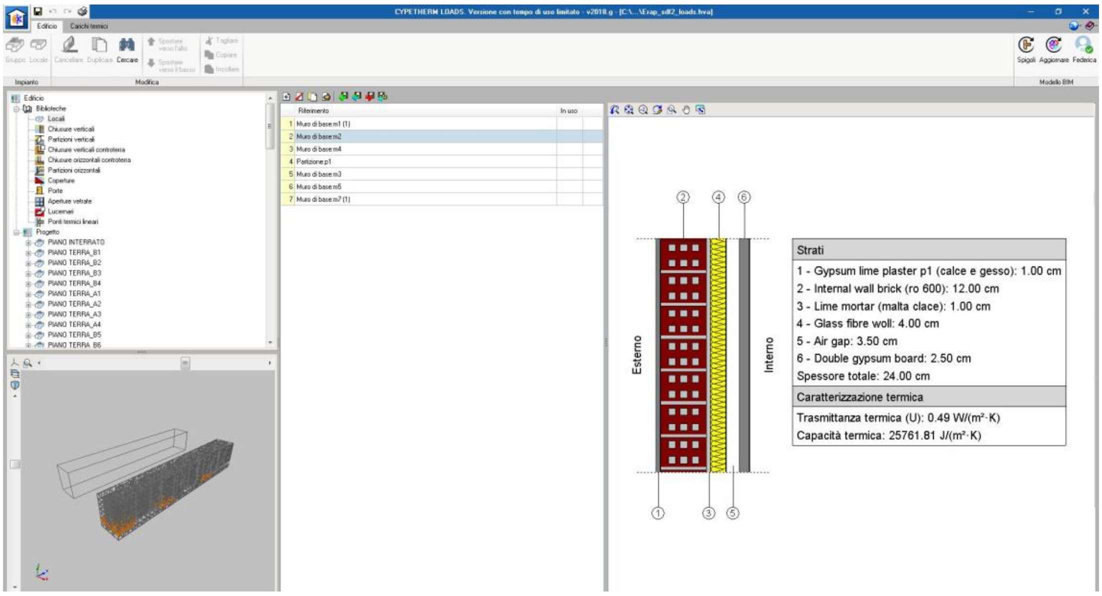


Figure 8: CYPETHERM LOADS interface and definition of the stratigraphy

The second step involves the description of the *thermal loads* (**Error! Reference source not found.**11). It occurs setting the calculation conditions (i.e. only heated, only cooled or both), the project set-points for cooling and heating, the ventilation and infiltration features and the internal loads (i.e. occupancy, lighting, plug loads and further loads). All these characteristics can be included following the suggestion was given by the program (e.g. in relation to the zone end-use) or according to custom settings and profiles.

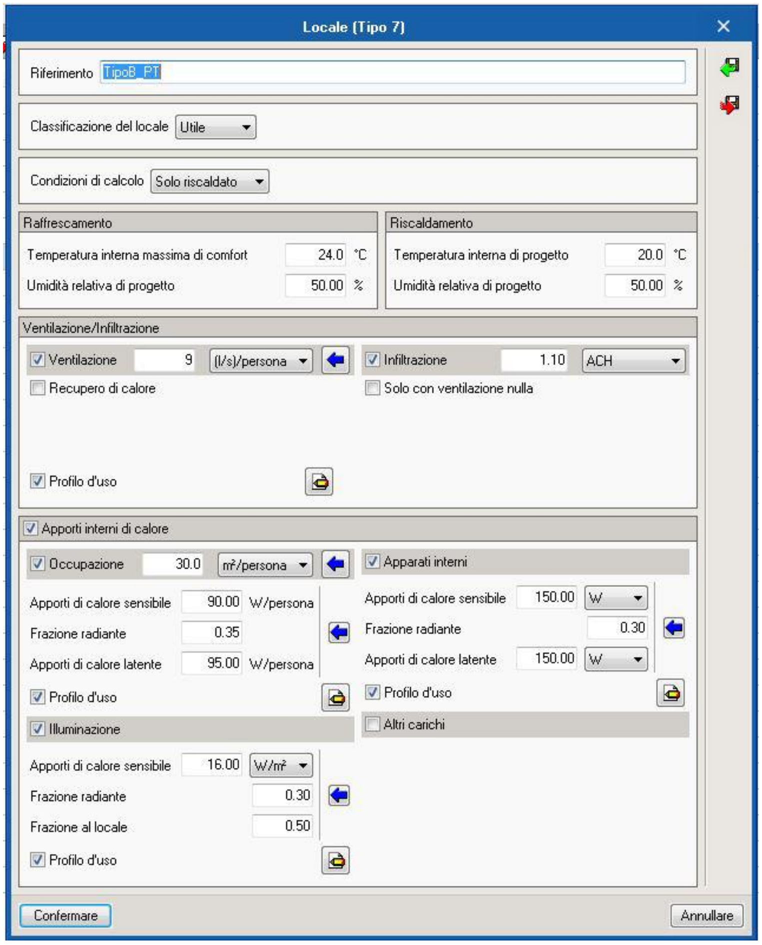


Figure 9: The setting of the thermal loads

The third step is directed to the definition of the outdoor climate conditions. The *weather file* can be selected directly from the ASHRAE Database; however, all the information can be later modified by the user. Finally, the calculation provides the thermal loads for each zone and for the whole building. The results can be displayed and downloaded both in tabular and graphical formats. Once the thermal loads have been calculated, the model needs to be exported following the procedure explained in the previous bullet points.

- **CYPETHERM HVAC**: the file import is simple and guided as for the tools described before. This tool focuses on the *definition of the heating, cooling and ventilation systems*. It can also be used to check whether the defined systems *satisfy the thermal loads* (defined in CYPETHERM LOADS) and, if needed, automatically *size the systems*. The main interface of the program is reported in Figure 12.

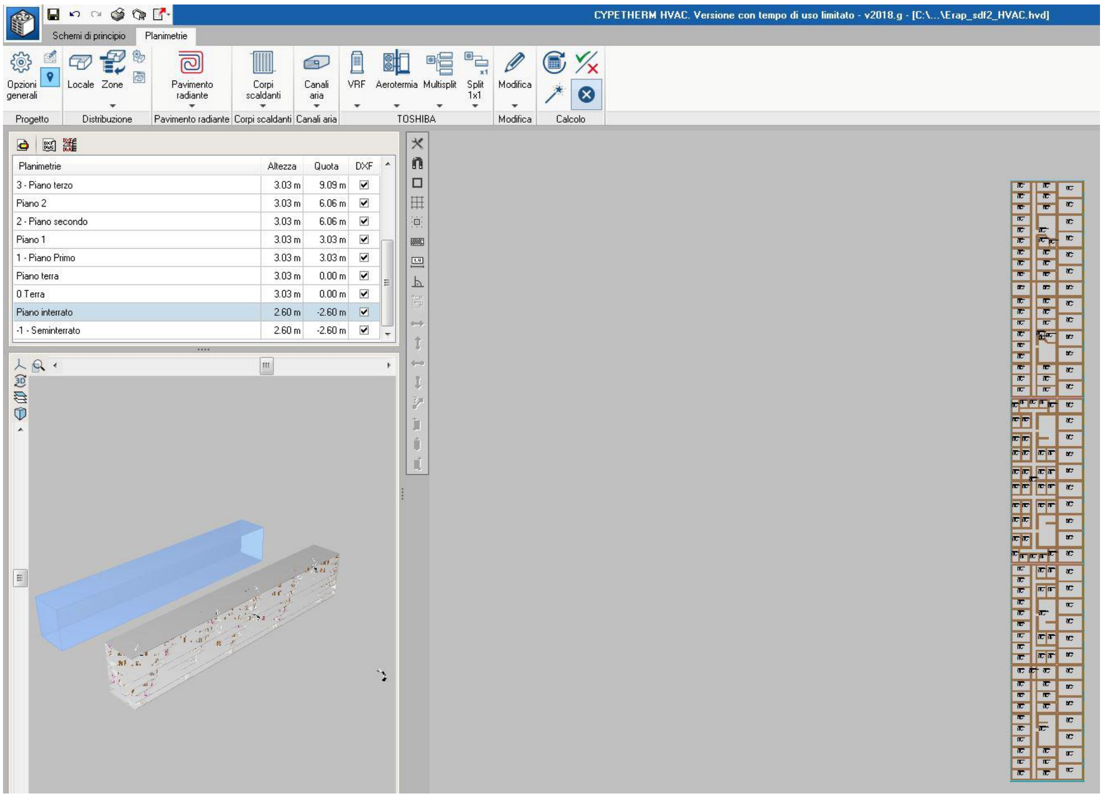
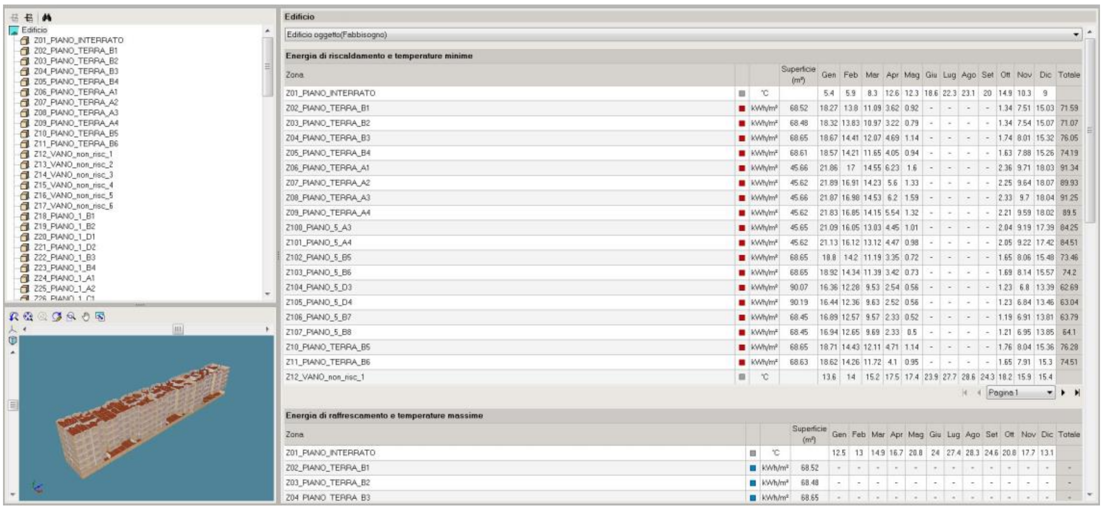


Figure 10: CYPETHERM HVAC interface

The terminals (e.g. radiators, fan coils) are provided by the program but their features can be completely defined by the user. Selecting one element, it is put in the planimetry and it can be copied the required number of times. Once the positioning of the elements is completed, the program calculates whether the system satisfies the loads. Clicking on each room of the model, it appears a flag showing, in summary, the features of the local, the thermal load, the ventilation flow rate and the checks (i.e. if the system satisfies the loads). After this calculation, a report summarizing, for each local, the heating thermal load, the type of emitters, the number of elements, the geometrical features and the power is downloadable in various formats. Once the systems have been set, the model needs to be exported following the usual procedure.

- **CYPETHERM EPlus**: the file import follows the same procedure described in the previous steps. The tool is used to perform the energy analysis of the model using the EnergyPlus cloud engine and according to the thermal loads and the systems previously defined in CYPETHERM LOADS and CYPETHERM HVAC, respectively. All the thermal features of the components and the characteristics of the locals can be modified also in this program. In addition, the user defines the heating and cooling profiles sets ventilation and infiltration features and the DHW needs. Then, the elements concerning the heating/cooling generation (e.g. the boiler) are described through several parameters (e.g. efficiency). The general specifications allow the user to calculate the surface and interstitial condensation, to define the air permeability of the building envelope and to detail DHW properties. Moreover, it is possible to modify the energy conversion factors, proposed by default, according to the type of energy supply. Once the settings are completed, the energy analysis is launched by the user. Depending on the complexity of the geometrical model, the program takes some time to perform the calculation with the EnergyPlus engine. For the Ancona demo case, it takes about 30 minutes. Completed the energy analysis, the user examines the energy demand and consumptions for both the entire building and for each thermal zone (**Error! Reference source not found.**13). The data, listed according to the defined zones, are reported for each month and the total value. It is possible to download (in various formats) the files related to the calculation process while the .idf file is automatically stored in a specific folder in the PC. The directory is reported on the top of the



generated file "EnergyPlus file".

Figure 11: The results after the energy simulation

Strengths of the approach

The proposed approach provides several advantages which are exposed in the following list:

- **Installation:** Three CYPE components (Complement Open BIM for Revit, IFC Builder, and CYPETHERM LOADS) can be downloaded for free, while for the other two (CYPETHERM HVAC and CYPETHERM EPlus) a 30 days trial (but completely functioning) version can be freely downloaded in the BIMserver.centre store.
- **Import from the BIM:** The CYPE software correctly recognizes building geometry and surfaces modeled in Revit.
- **Usability:** the setting of the building features is quite simple and very intuitive, thanks to a clear user-interface. The tools provide 'suggestions' to set the parameters (e.g. occupancy density according to the local end-use) but a good customization is still possible.
- **Reusability:** it is possible to export libraries (e.g. materials, systems) which can be re-used in future modifications of the same project or in different models.
- **Interoperability:** the use of a series of tools provided by the same software house allows a good communication, a smooth import/export and no loss of information between the different steps of the process.
- **Collaborative design:** the use of a cloud-based service improves and simplifies the data exchange and the work between different subjects.

Bottlenecks of the approach

Despite many strengths have been recognized, the procedure presents some bottlenecks. They are recapped in the following list.

- The fact that the CYPE tools recognize only the geometrical features modeled in Revit leads to a waste of time in re-defining features if they were been previously specified in the BIM;
- Since the CYPE tools are mainly targeted for 'new projects', sometimes it is hard modeling old technical systems (e.g. a very old boiler). This target leads to less accuracy in the settings and on the results of existing buildings;
- The energy settings in EPlus are rather fixed since it is not possible to specify simulation and output preferences (e.g. simulation period or the time step). To have an higher flexibility it is necessary to simulate directly using EnergyPlus;
- The 30-day license for two of the CYPE tools limits their usability.

3. Energy consumption before renovation

This chapter provides the estimation of the energy demand of each demonstration case in the pre-renovation scenario.

For each demonstration case the following information will be provided:

- General information of building and building owner;
- Documents that have been considered as the reference of the baseline:
  - energy audit
  - historic energy use
  - energy model
- Geometrical information that have been collected;
- Available energy and indoor environmental data;
- Methodology used for the energy assessment in pre-renovation scenario;
- Results of energy simulation.

In some cases the stake holders have provide further general information on their building on or the procedures they have adopted to collect the necessary data. These have been reported as well.

3.1 Overview

PRE RENOVATION																
Country, Partner, Demo case			**Energy Assessment - Primary energy consumption**			**Geometric data and modelling**		**Energy and Indoor environmental data**								**energy consumption**
			reference of baseline			**BIM-to-BEM**		transmittance		indoor usage		systems				
			bills	energy audit	energy model	Completed	Validated	envelope	interior	indoor operating temperature	time pattern	HVAC	lighting	power	other	kWh/m2y
DE	3L	Menden	Y	Y	N	N	N	Y	-	Y	Y	Y	Y	Y	-	255
DK	INV	Korsløkken	N	Y	N	Y	Y	N	N	Y	N	N	Y	Y	-	64
IT	UNIVPM	Ancona	Y	Y	Y	Y	N	Y	Y	N	N	Y	Y	N	-	85.8
IT	SGR	Firenze	N	Y	N	Y	Y	Y	N	Y	N	N	N	N	-	366.3
IT	RINA	Genoa	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	161
NL	HIA	Breda	N	Y	N											501
NL	CAM	Enschede	Y	Y	N											300
NL	PAN	Tilburg	Y	Y	N	N	N	Y	Y	Y	Y	Y	N	N	-	428
PL	FAS	Gdynia	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	-	120.5
PL	WAW	Nursery	Y	Y												137.3

3.2 Denmark, Korsløkken

GENERAL INFORMATION	▪ CLIENT ORGANISATION	Private owner	
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	Private	
	▪ RESPONSIBLE PARTNER	INV	
	▪ COUNTRY, GEOCLUSTER	Denmark	
	▪ BUILDING		
	TOTAL FLOOR AREA [m2]	Not available due to privacy issues	
	TOTAL VOLUME [m3]	Not available due to privacy issues	
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
	▪ HISTORIC ENERGY USE		
	ELECTRICITY	N	
	HEAT	N	
	HOT WATER	N	
	GAS	N	
	...		
	▪ ENERGY AUDIT	Not available due to privacy issues	
GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y	
	▪ BIM MODEL	Y	
ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE	Not available due to privacy issues	
	▪ TIME PATTERN	Not available due to privacy issues	
	▪ HVAC	Not available due to privacy issues	
	▪ LIGHTING	Not available due to privacy issues	
	▪ POWER	Not available due to privacy issues	
	▪ ...		
ENERGY MODEL ASSESSMENT	SPECIFY METHODOLOGY/SOFTWARES		
	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS	
	Due to privacy constraints it is not possible to share this information within P2ENDURE project		

ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	Not available
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	Y
ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**64**

3.3 Germany, Menden

GENERAL INFORMATION	▪ CLIENT ORGANISATION	Private Client	
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	private	
	▪ RESPONSIBLE PARTNER	3L	
	▪ COUNTRY, GEOCLUSTER	Germany, North Rhine-Westphalia	
	▪ BUILDING		
	TOTAL FLOOR AREA [m2]	155	
	TOTAL VOLUME [m3]	682	
	▪ DEMO CASE		
	TOTAL FLOOR AREA [m2]	155	
	TOTAL VOLUME [m3]	682	
	▪ REFERENCE		
	NATIONAL ANNEX:	ENEV 2015	
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
	▪ HISTORIC ENERGY USE		
	ELECTRICITY	N	
	HEAT	N	
	HOT WATER	N	
	GAS	N	
	…		
	▪ ENERGY AUDIT	Y	255
GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y	
	▪ BIM MODEL	Y	
ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE	21°C	
	▪ TIME PATTERN	7:00-16.30 Monday-friday	
	▪ HVAC	Gas boiler	
	▪ LIGHTING	Neon tubes	
	▪ POWER	Basic installation in each room	

<table>
<tr><td rowspan="3">ENERGY MODEL ASSESSMENT</td><td colspan="2">SPECIFY METHODOLOGY/SOFTWARES</td></tr>
<tr><td>WITH SIMULATION SOFTWARES</td><td>WITH MANUAL TOOLS</td></tr>
<tr><td></td><td>The building was captured with the help of laser measurement and then edited in an ArchiCad 3D BIM model. The relevant data of the building parts was processed, calculated and extracted:
- Total heated volume
- Total envelope area
- Different envelope qualities
- Exterior walls assigned to geographic direction (sun orientation)
- Exterior walls assigned to heated neighbour buildings
- Interior floors assigned to unheated basement area
- Heating systems
- other
This data was edited in a professional German software application called “der Energieberater” and the U-Values and the overall energy consumption was calculated</td></tr>
<tr><td rowspan="2">ENERGY MODEL VALIDATION</td><td colspan="2">▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)</td></tr>
<tr><td colspan="2">▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)</td></tr>
<tr><td>ENERGY CONSUMPTION PRE-RENOVATION SCENARIO</td><td>▪ PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]</td><td>255</td></tr>
</table>

3.4 Italy, Ancona

The fulfilment of a valuable energy analysis cannot be achieved without the collection of real data, retrieved in the investigated building. In fact, the installed systems, settings and usage profiles, and material' properties influence greatly the energy demand and the building performance. However, it is hard obtaining such information, especially those related to occupants' behaviours. The collection of these data is even more difficult when the building is not recent since the existing documentation is very old and most of it is on the paper. The lack of these information increases the approximations and the uncertainty in setting material features, systems parameters and profiles in the BEM phase.
The data acquisition in the Ancona demo case was rather challenging. The building is a social housing composed of 100 apartments, owned by the municipality (ERAP). The private end-use made very difficult the collection of real data both in terms of bills and occupants' behaviours (e.g. occupancy patterns, heating/cooling schedules). It was possible to have just a quick walkthrough in one apartment.
The Ancona demo case is connected to a particular condition. In fact, it should be considered that most of the inhabitants live in a semi-poverty situation with economic constraints. As a consequence, the ordinary maintenance of the apartments and the preservation of the thermal comfort are not of a primary importance for the occupants. Usually, they prefer to suffer from cold or heat than increase costs. This condition has a big impact on the indoor conditions, on the usage patterns of the systems and on the heating/cooling set-points; therefore the information retrieved from the occupants have been evaluated in this perspective.
Although most of the features related to HVAC, lighting and power refer to the surveyed apartment (quite representative of the status of the entire building); other characteristics have been set according to Standards (e.g. ASHRAE Standard 90.1) since they could not be recovered.
The following Table reports the information collected to perform the energy analysis of the pre-renovation scenario. In particular, the primary energy consumptions written in bold concern to the whole building; while the values in brackets refer to the apartments which show the greatest and the lowest energy consumptions.

GENERAL INFORMATION	▪ CLIENT ORGANISATION	ERAP (Ente Regionale per l'Abitazione Pubblica)
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	public
	▪ RESPONSIBLE PARTNER	UNIVPM
	▪ COUNTRY, GEOCLUSTER	Ancona, Italy
	▪ BUILDING	

	TOTAL FLOOR AREA [m2]	6807
	TOTAL VOLUME [m3]	18671
	▪ DEMO CASE	
	TOTAL FLOOR AREA [m2]	6807
	TOTAL VOLUME [m3]	18671
	▪ REFERENCE	
	NATIONAL ANNEX:	

		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION	▪ HISTORIC ENERGY USE	N	
	ELECTRICITY		
	HEAT		
	HOT WATER		
	GAS		
	...		
	▪ ENERGY AUDIT	N	

GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y
	▪ BIM MODEL	completed

ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE		N
	▪ TIME PATTERN		N
	▪ HVAC	Y	
	▪ LIGHTING	Y	
	▪ POWER	Y	
	▪ ...		

	SPECIFY METHODOLOGY/SOFTWARES	
ENERGY MODEL ASSESSMENT	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS
	The BIM model has been created using Revit 2018. The geometrical model has been exported using the Complement Open BIM for Revit (IFC standard). The BEM model has been	N

	developed using the CYPETHERM enenrgy simulation tool. Specifically, the adopted tools are: IFC Builder (geometrical check and definition of the thermal zones), CYPETHERM LOADS (definition of stratigraphy and loads), CYPETHERM HVAC (systems definition), CYPETHERM EPlus (energy simulation using EnergyPlus)	
ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	N
ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**85.8** (103.1 - 42.6)

3.5 Italy, Florence

The fulfilment of a valuable energy analysis cannot be achieved without the collection of real data, retrieved in the investigated building. In fact, the installed systems, settings and usage profiles, and material' properties influence greatly the energy demand and the building performance. However, it is hard obtaining such information, when the building is unoccupied in the pre-renovation scenario. This is the case of Firenze. The collection of these data is even more complicated when the building is historical and the existing documentation is very old and most of it is on the paper support. The lack of these information increases the approximations and the uncertainty in setting material features, systems parameters and profiles in the BEM phase.

The Firenze demonstration case is a private historical building realized at the end of '800 and located in the historical downtown of the city in the block bounded by Via della Fornace and via Ser Ventura Monachi and is placed at the confluence of the two streets. The building in the last decades has been abandoned and not used for this reason. Therefore, in order to estimate the energy performance, typical occupants' standard behaviours have been simulated.

From the technological point of view the historical building is realized with load-bearing masonry and wooden floors. The existing windows are in woods frames with a single glazed. Regarding the thermal comfort, the heating systems are composed of boilers and radiators; while no cooling units are installed. The following Table reports the information collected to perform the energy analysis of the pre-renovation scenario.

The primary energy figures resulting from the simulation software coincide perfectly with the one reported in the official energy certification of the building, demonstrating that the BIM and BEM models are coherent and reliable.

GENERAL INFORMATION	▪ CLIENT ORGANISATION	IMMOBILIARETRE S.R.L.
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	Private
	▪ RESPONSIBLE PARTNER	SGR
	▪ COUNTRY, GEOCLUSTER	Italy, Florence
	▪ BUILDING	
	TOTAL FLOOR AREA [m2]	439.82
	TOTAL VOLUME [m3]	1528.47
	▪ DEMO CASE	
	TOTAL FLOOR AREA [m2]	439.82
	TOTAL VOLUME [m3]	1528.47

	▪ REFERENCE NATIONAL ANNEX:		UNI/TS 11300
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
	▪ HISTORIC ENERGY USE	N	
	ELECTRICITY		
	HEAT		
	HOT WATER		
	GAS		
	...		
	▪ ENERGY AUDIT		-for heat 245,32 [kWh/m2y] for hot water 49,9 [kWh/m2y] calculated with simplified method
GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY		Y
	▪ BIM MODEL		Completed
ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE		20°C
	▪ TIME PATTERN	Commercial	9:00-19:00 Monday-Friday
		Residential	N
	▪ HVAC		Y
	▪ LIGHTING		Y
	▪ POWER		N
	▪ ...		

ENERGY MODEL ASSESSMENT	SPECIFY METHODOLOGY/SOFTWARES	
	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS
	After the BIM model has been generated in REVIT 2018 it has been exported using the Complement Open BIM for Revit. Then, with the CYPETHERM energy simulations tools the BEM model has been developed; in IFC BUILDER the geometry of the construction elements, the locals and the thermal zones have been defined; CYPETHERM LOADS allowed the definition of the stratigraphy and the calculation of the building thermal loads; in CYPETHERM HVAC the systems have been created and sized; finally in CYPETHERM EPLUS it has been run the energy simulation using Energy plus.	

ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	< 5%
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	Y
ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**366.3**

3.6 Italy, Genoa

GENERAL INFORMATION	▪ CLIENT ORGANISATION	Genoa Municipality
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	Public
	▪ RESPONSIBLE PARTNER	RINA-C
	▪ COUNTRY, GEOCLUSTER	Genoa, Italy
	▪ BUILDING	
	TOTAL FLOOR AREA [m2]	534
	TOTAL VOLUME [m3]	2190
	▪ DEMO CASE	
	TOTAL FLOOR AREA [m2]	267
	TOTAL VOLUME [m3]	1095
	▪ REFERENCE	
	NATIONAL ANNEX:	

		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION	▪ HISTORIC ENERGY USE		
	ELECTRICITY (electrical Equipment, lighting, DHW)	Y	Y
	GAS (heating)	Y	Y
	...		
	▪ ENERGY AUDIT		

GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y
	▪ BIM MODEL	completed

ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE	Y
	▪ TIME PATTERN	Y
	▪ HVAC	Y
	▪ LIGHTING	Y
	▪ POWER	Y
	▪ ...	

	SPECIFY METHODOLOGY/SOFTWARES	
	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS
ENERGY MODEL ASSESSMENT	**Software used**: Revit2017, SketchUpMake 2016 v 16.1.1449, Open studio v.2.0.047, EnergyPlus 8.4, Legacy OpenStudio v1.0.14 **Methodology:** - creation of the geometrical model with Revit 2017 including the thermal properties of the materials and thermal zones; - import of the BIM model into SketchUP to review and implement the data; - import the modified model into EnergyPlus to correct errors, implement schedules, HVAC data, internal loads (lighting, equipments).	

ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	<5%
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	Y

ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**161**

3.7 Poland, Gdynia

Demo site in Gdynia (Poland) is a building of a kindergarten no 16 located in a city centre at Jana z Kolna Street 29, see. It is a two-storey building, constructed in year 1965 and attended by around 130 children. Building is divided into two parts: one storey administrative part that will be renovated within P2ENDURE project and 2 storey part where the children are staying (this part will be renovated by City of Gdynia). The building has no electrical documentation; only old paper design from year 1965 is available. Exterior walls of the building are not insulated, and in the administrative part of the building there are old wooden windows.

Figure 15: Demo site building in Gdynia

Administrative part that will be renovated within P2ENDURE project is shown in Figure .

Figure 16: Administrative part of the Gdynia demo building that will be subjected to P2ENDURE renovation

GENERAL INFORMATION	▪ CLIENT ORGANISATION	Kindergarten nr 16 in Gdynia, building owner City of Gdynia	
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	Public	
	▪ RESPONSIBLE PARTNER	FASADA	
	▪ COUNTRY, GEOCLUSTER	Poland, Nothern East	
	▪ BUILDING		
	TOTAL FLOOR AREA [m2]	760,22	
	TOTAL VOLUME [m3]	2766	
	▪ DEMO CASE		
	TOTAL FLOOR AREA [m2]	274,57	
	TOTAL VOLUME [m3]	1160	
	▪ REFERENCE		
	NATIONAL ANNEX:	Dz. U. Nr 75, poz. 690 National guidelines for buildings and its surroundings, Dz.U. nr 43 poz. 346.	
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
	▪ HISTORIC ENERGY USE	Y	
	ELECTRICITY	2016	9459,21 kWh/year
	HEAT	Average for 2015 and 2016	119,6 kWh/m2y
	HOT WATER	Average for 2015 and 2016	47,1 GJ/year
	GAS	2016	509m³/year
	...		
	▪ ENERGY AUDIT	y	Primary energy consumption calculated by auditor with simplified method: - for heat 143 [kWh/m2y] -for hot water 11 [kWh/m2y]
GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y	
	▪ BIM MODEL	completed	
ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE	Y	
	▪ TIME PATTERN	6:00-17:00 Monday-Friday	
	▪ HVAC	Only ventilation, no cooling system	
	▪ LIGHTING	Y	
	▪ POWER	Y	
	▪ ...		

	SPECIFY METHODOLOGY/SOFTWARES	
	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS
ENERGY MODEL ASSESSMENT	The final BIM model has been created using Revit LT 2018 . As an addition the first BIM model has been created using SketchUp. After simplifying, the model has been exported to IFC IFC 2x3 Coordination View 2.0 file. The BEM model has been developed with a of CYPETHERM energy simulation tool. First step was the export of the geometrical model with the use of IFC standard to IFC Builder for geometrical check and definition of the thermal zones. Other used tool was CYPETHERM EPlus (energy simulation using EnergyPlus).	Energy Audit according to polish national guidelines was performed (calculations in Excel)
ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	<1%
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	Y
ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**120,5***

*Ventilation performance changed from 4 to 3 l/s.person in group rooms and offices and from 14l/s to 12l/s in toilets and kitchen – this was done in order to simulate ventilation that is not as efficient as it was in the beginning)

3.8 Poland, Warsaw

For this demonstration case the requested information is not available.

3.9 The Netherlands, Breda

For this demonstration case the requested information is not available.

3.10 The Netherlands, Enschede

To ensure the correctness and completeness of the pre-renovation energy assessment it has been preferred to calculate the energy consumptions of the building through manual calculation.

GENERAL INFORMATION	▪ CLIENT ORGANISATION	Camelot Europe
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC	private
	▪ RESPONSIBLE PARTNER	HIA
	▪ COUNTRY, GEOCLUSTER	Netherland
	▪ BUILDING	
	TOTAL FLOOR AREA [m2]	20296
	TOTAL VOLUME [m3]	66977
	▪ DEMO CASE	
	TOTAL FLOOR AREA [m2]	20296
	TOTAL VOLUME [m3]	66977
	▪ REFERENCE	
	NATIONAL ANNEX:	

		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION	▪ HISTORIC ENERGY USE		
	ELECTRICITY	N	104
	HEAT	N	177
	HOT WATER	N	83
	GAS		
	…		
	▪ ENERGY AUDIT		

GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY	Y
	▪ BIM MODEL	completed

ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE	Y
	▪ TIME PATTERN	Y
	▪ HVAC	Y
	▪ LIGHTING	Y
	▪ POWER	Y
	▪ …	

ENERGY MODEL ASSESSMENT	SPECIFY METHODOLOGY/SOFTWARES	
	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS
	Sketchup Pro 7 (remodel project - rough) OpenStudio v2.4.0 EnergyPlus v8.8	

ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	< 5%
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	Y

ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**300**

3.11 The Netherlands Tilburg

GENERAL INFORMATION	▪ CLIENT ORGANISATION		Freshideas
	▪ PRIVATE/PUBLIC/SEMI-PUBLIC		private
	▪ RESPONSIBLE PARTNER		PAN
	▪ COUNTRY, GEOCLUSTER		Netherlands
	▪ BUILDING		
	TOTAL FLOOR AREA [m2]		4380
	TOTAL VOLUME [m3]		13600
	▪ DEMO CASE		
	TOTAL FLOOR AREA [m2]		137
	TOTAL VOLUME [m3]		373
	▪ REFERENCE		
	NATIONAL ANNEX:		
ENERGY CONSUMPTION PRE-RENOVATION - AVAILABLE INFORMATION		REFERENCE OF BASELINE (years of bills)	PRIMARY ENERGY CONSUMPTIONS [kWh/m2y]
	▪ HISTORIC ENERGY USE		
	ELECTRICITY	2014-2017	103 kWh/m2y
	HEAT (gas)	2012-2017	276 kWh/m2y
	HOT WATER (gas)	2014-2016	60 kWh/m2y
	GAS	See above (incl cooking)	
	...		
	▪ ENERGY AUDIT		Y
GEOMETRIC DATA AND MODELLING	▪ PLANS, SECTIONS, INNER/OUTER COMPOMENTS STRATIGRAPHY		Y
	▪ BIM MODEL		Yes completed (first step based on drawings)
ENERGY AND INDOOR ENVIRONMENTAL DATA	▪ OPERATING TEMPERATURE		Y
	▪ TIME PATTERN		Y
	▪ HVAC		Y
	▪ LIGHTING		Y
	▪ POWER		Y
	▪ ...		

	SPECIFY METHODOLOGY/SOFTWARES	
	WITH SIMULATION SOFTWARES	WITH MANUAL TOOLS
ENERGY MODEL ASSESSMENT	Sketchup Pro 7 (remodel project - rough) OpenStudio v2.4.0 EnergyPlus v8.8	EPPD software

ENERGY MODEL VALIDATION	▪ VARIATION OF ENERGY MODEL FROM ENERGY CONSUMPTIONS (BILLS/AUDIT)	<5%
	▪ VALIDATION OF THE ENERGY MODEL WITH ENERGY CONSUMPTIONS (<5%)	Y
ENERGY CONSUMPTION PRE-RENOVATION SCENARIO	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**428**

4. Energy simulation and validation results

This Chapter report the energy simulations that have been developed for the various demonstration cases.

A description of the undertaken actions is given, together with the estimation of the benefits determined from the energy analyses.

The incremental saving that can be expected from the application of the P2-Endure or equivalent technologies is provided as well, in order to describe the full picture of the retrofit strategy, at least from the energetic point of view.

Results confirm the great potential of these technologies and help in the definition of a first short handbook that is presented in Chapter 5.

A large number of stake holders have also succeeded in validating and then using the BIM-BEM suite to run the simulations, this in very advantageous for the proceeding of the research since the very high degree of reliability that accompany these energy assessments, and the possibility of having available a very powerful and quickly instrument to assist the stake holders in weighting the benefits coming from the various options of P2ENDURE basket of solutions, and finally selecting the best combination of them.

The detailed energy simulations are available on the SharePoint, in most of the cases together with all the files and the documents that have been used in the calculation procedures (e.g. for Firenze, all the data have been uploaded: Revit, Cypetherm, and Energy Plus files, theoretically allowing a third part to control and repeat the calculation using, of course, case by case, the same selected software suite).

Unfortunately M24 is only the midterm of theP2ENDURE research, and, notwithstanding the greater effort that has been put in force by all the members of the Consortium, few demonstration cases are not yet in the final steps of retrofit strategy (still in the final phase of the design), and/or have encountered relevant difficulties in the definition of the retrofit interventions: these area the cases of Warsaw (first issue) and Breda and Enschede (second issue). In these cases the available results have been published in this deliverable, whereas the final energy simulations and values will be made in the very near future, giving full evidence of their outcomes and results as soon as they are achieved.

Following pages will provide outcome of those demonstration cases which have achieved remarkable results.

4.1 Overview

PRE RENOVATION				INTERVENTIONS					POST RENOVATION	
Country, Partner, Demo case			energy needs	1st TECHN.	2nd TECHN.	3rd TECHN.	4th TECHN.	5th TECHN.	FINAL COMBINATION	savings
			kWh/m2y	savings [%]	savings [%]	savings [%]	savings [%]	savings [%]	description	[%]
DE	3L	Menden	255	14	28	8	11	-	Fermacell system, roof insulation, triple glazing, thermal insulation basement ceiling	61
DK	INV	Korsløkke	64						3D print design on gables with 200mm insulation	
IT	UNIVPM	Ancona	85.8	30.2	22.8	32.4	-	-	Smart windows BGTEC, Roof and exterior insulation system, condensing boiler serving an apartment block	68.1
IT	SGR	Firenze	366.3	3.2	22.9	14.5	-	-	Smart PnP windows, roof and walls insulation and condensing boiler	60.2
IT	RINA	Genoa	161	21.7	26.7	9.5	12.9	-	Smart Windows BGTEC, Internal insulation, consensing boiler and LED lamps	60.2
NL	HIA	Breda	501							
NL	CAM	Enschede	300	50					Insulation and district heating 2nd phase	62
NL	PAN	Tilburg	428	9	26	44	4	7	Sanitary units, windows, insulation, solar panels, heatpump	71
PL	FAS	Gydnia	120.5	50	11	23			Multifunctional panels and Smart windows, Insulation of basement external walls	67
PL	WAW	Nursery	137.3							

4.2 Germany, Menden

4.2.1 Methodology / Approach

Menden demonstration case has been presented as reference for manual calculation; therefore the methodology used has been fully described in chapter 2.1.

4.2.2 Energy simulation of renovation strategies

		DESCRIPTION	AMOUNT [nr./m2]
INTERVENTIONS	▪ 1st TECHNOLOGY		
	P2ENDURE TECHNOLOGY	Fermacell facade system	96 m2
	OTHER TECHNOLOGY		
	SAVING	**14 %**	
	▪ 2nd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Roof insulation	184 m2
	SAVING	**28 %**	
	▪ 3rd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Triple glazing	25 m2
	SAVING	**8 %**	
	▪ 4th TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Insulation basement ceiling	155 m2
	SAVING	**11 %**	

4.2.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES	Fermacell system
	▪ OTHER TECHNOLOGIES	Roof insulation, triple glazing, tharmal insulation of basement ceiling
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**255 kWh/m2y**
	▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]**	**100 kWh/m2y**
	▪ **SAVING**	**61 %**

4.3 Italy, Ancona

4.3.1 Methodology / Approach

Ancona demonstration case has been presented as reference for not freeware approach, therefore the methodology used has been fully described in chapter 2.2.2.

4.3.2 Energy simulation of renovation strategies

The post-renovation scenario proposed for the Ancona demo case includes three different interventions:

1. Windows replacement;
2. Envelope insulation (roof and facades);
3. Centralized heating system replacing the actual domestic gas boiler installed in each apartment.

In detail, the windows have been modelled with the same parameters of the SmartWIndows BGTEC (i.e. Uglass =1 W/m2K – Uframe =1.5 W/m2K – air permeability = class 4).

The second intervention, targeting at enhancing the envelope, regards the application of thermal insulation system (14 cm of rook wool) on both the facades and the roof.

The third intervention concerns the removal of all the old boilers and the installation of a centralized system for each apartments block. In particular, six high-efficiency condensing boilers, each one supplying group of 15/17 apartments.

The following Table reports the energy savings reached by applying the three technologies both individually and in conjunction.

INTERVENTIONS		DESCRIPTION	AMOUNT [nr./m2]
	▪ 1st TECHNOLOGY		
	P2ENDURE TECHNOLOGY	Smart windows BGTEC	548
	OTHER TECHNOLOGY		
	SAVING	**30.2 %**	
	▪ 2nd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Roof and exterior insulation system	6500 m2
	SAVING	**22.8 %**	
	▪ 3rd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Condensing boiler serving an apartment block	6
	SAVING	**32.4 %**	

4.3.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES	Smart Windows BGTEC
	▪ OTHER TECHNOLOGIES	Roof and exterior insulation system + condensing boiler serving an apartment block
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**85.8** (103.1 – 42.6) **kWh/m2y**
	▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]**	**27.4** (62.8 – 11) **kWh/m2y**
	▪ **SAVING [%]**	**68.1%**

4.4 Italy, Florence

4.4.1 Methodology / Approach

Florence demonstration case adopted the CYPE-THERM suite, the same described in Chapter 2.2.2.
The building presents a lot of constrains, being protected by the national architectural superintendence. The actions then focus towards the implementation on the thermal resistance of the building envelope, i.e. application of PnP insulation layers on the roof and in the external walls, substitution of windows with energy efficient transparent elements, substitution of thermal elements heating floor versus old radiators, and, finally, upgrade of the existing boiler with a high-efficient gas-fired condensation boiler.
The application of all these retrofit actions allow the achievement of the threshold of 60 %, demonstrating that P2ENDURE or equivalent PnP technologies have the real potential of highly increase the efficiency of a building even in a very delicate scenario such as the one existing in Firenze.

4.4.2 Energy simulation of renovation strategies

		DESCRIPTION	AMOUNT [nr./m2]
INTERVENTIONS	▪ 1st TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Roof insulation	245 m2
	SAVING [%]	**3.18 %**	
	▪ 2nd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	External walls insulation	
	SAVING [%]	**22.85 %**	
	▪ 3rd TECHNOLOGY		
	P2ENDURE TECHNOLOGY	PnP windows	39
	OTHER TECHNOLOGY		
	SAVING [%]	**14.45 %**	

4.4.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES	PnP windows
	▪ OTHER TECHNOLOGIES	Roof and walls insulation and condensing boiler
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**366.26 kWh/m2y**
	▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]**	**145.83 kWh/m2y**
	▪ **SAVING [%]**	**60.18%**

4.5 Italy, Genoa

4.5.1 Methodology / Approach

Ancona demonstration case has been presented as reference for not freeware approach, therefore the methodology used has been fully described in chapter 2.2.1.

4.5.2 Energy simulation of renovation strategies

		DESCRIPTION		AMOUNT [nr./m2]
INTERVENTIONS	▪ 1st TECHNOLOGY			
	P2ENDURE TECHNOLOGY	Smart Windows BGTEC		25
	OTHER TECHNOLOGY			
	SAVING [%]		**21.67%**	
	▪ 2nd TECHNOLOGY			
	P2ENDURE TECHNOLOGY			
	OTHER TECHNOLOGY	Internal insulation		667 mq
	SAVING [%]		**26.70%**	
	▪ 3rd TECHNOLOGY			
	P2ENDURE TECHNOLOGY			
	OTHER TECHNOLOGY	Condensing boiler		1

	SAVING [%]		9.48%	
	▪ 4th TECHNOLOGY			
	P2ENDURE TECHNOLOGY			
	OTHER TECHNOLOGY	LED lamps		About 30 lamps
	SAVING [%]		12.92%	

4.5.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES	Smart Windows BGTEC
	▪ OTHER TECHNOLOGIES	Internal insulation + Consensing boiler + LED lamps
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**161 kWh/m2y**
	▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]**	**64 kWh/m2y**
	▪ **SAVING [%]**	**60.20%**

4.6 Poland, Gdynia

4.6.1 Methodology / Approach

4.6.2 Energy simulation of renovation strategies

		DESCRIPTION		AMOUNT [nr./m2]
INTERVENTIONS	▪ 1st TECHNOLOGY			
	P2ENDURE TECHNOLOGY	Multifunctional panels (Fermacell)		
	OTHER TECHNOLOGY			
	SAVING [%]		**50%**	
	▪ 2nd TECHNOLOGY			
	P2ENDURE TECHNOLOGY	Smart Windows BGTEC		
	OTHER TECHNOLOGY			
	SAVING [%]		**11%**	

	▪ 3rd TECHNOLOGY	
	P2ENDURE TECHNOLOGY	
	OTHER TECHNOLOGY	Insulation of basement external walls (underground) with 14cm Extruded Polystirene
	SAVING [%]	**23%**

4.6.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES	Multifunctional panels and Smart windows
	▪ OTHER TECHNOLOGIES	Insulation of basement external walls
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**118.56 kWh/m2y**
	▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]**	**38.63 kWh/m2y**
	▪ **SAVING [%]**	**67%**

4.7 Poland, Warsaw

4.7.1 Methodology / Approach

For this demonstration case the requested information is not available

4.7.2 Energy simulation of renovation strategies

For this demonstration case the requested information is not available

4.7.3 Validation results

For this demonstration case the requested information is not available

4.8 The Netherlands, Breda

4.8.1 Methodology / Approach

For this demonstration case the requested information is not available

4.8.2 Energy simulation of renovation strategies

For this demonstration case the requested information is not available

4.8.3 Validation results

For this demonstration case the requested information is not available

4.9 The Netherlands, Enschede

4.9.1 Methodology / Approach

The methodology adopted for Enschede demonstration case is similar to the procedure described in chapter 2.2.1 and is summarised as follows:

- Export the BIM model to a .ifc file;
- Load the .ifc file in SketchUp/ OpenStudio;
- Correct the geometrical model in SketchUp/Openstudio if this model differs from the BIM model;
- Export the SketchUp/OpenStudio model to a .idf file;
- Load the .idf file into EnergyPlus;
- Fill in all missing parameters in EnergyPlus and generate a BEM.

The process of review and correction of the model geometry and adjustment of thermal zones may be time- consuming depending on complexity of the building. It has been noticed that this process may be more efficient using a fewer number of software and complete the geometrical model directly in SketchUp.

4.9.2 Energy simulation of renovation strategies

INTERVENTIONS		DESCRIPTION	AMOUNT [nr./m2]
	▪ 1st TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	insulation (cavity, ground floor, roof) and district heating 1st phase	5467 m2
	SAVING [%]	**50**	

4.9.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES	
	▪ OTHER TECHNOLOGIES	Insulation and district heating 2nd phase
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]**	**300 kWh/m2y**
	▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]**	**115 kWh/m2y**
	▪ **SAVING [%]**	**62 %**

4.10 The Netherlands, Tilburg

4.10.1 Methodology / Approach

The method adopted for Tilburg demonstration case corresponds to the procedure described for Enschede demonstration case; refer to previous chapter 4.9.1 for further information.

4.10.2 Energy simulation of renovation strategies

		DESCRIPTION	AMOUNT [nr./m2]
INTERVENTIONS	▪ 1st TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	New glass/windows	13 m2
	SAVING [%]	**9%**	
	▪ 2nd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Insulation of cavity, groundfloor and roof	159 m2
	SAVING [%]	**26%**	
	▪ 3rd TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Semi collective heatpump (optional: ice-storage with energypanel) and decentral ventilation with climarad	1+3
	SAVING [%]	**44%**	
	▪ 4th TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Sanitary units with shower heat	3
	SAVING [%]	**4%**	
	▪ 5th TECHNOLOGY		
	P2ENDURE TECHNOLOGY		
	OTHER TECHNOLOGY	Solar panels	4
	SAVING [%]	**7%**	

4.10.3 Validation results

FINAL COMBINATION	▪ P2ENDURE TECHNOLOGIES ▪ OTHER TECHNOLOGIES — Sanitary units with shower heat + new windows + insuation + semi-collective heatpump (optional: ice-storage with energypanel) + solar panels
ENERGY CONSUMPTION POST-RENOVATION	▪ **PRIMARY ENERGY CONSUMPTION IN PRE-RENOVATION SCENARIO [kWh/m2y]** — **428 kWh/m2y** ▪ **PRIMARY ENERGY CONSUMPTION IN POST-RENOVATION SCENARIO [kWh/m2y]** — **124 kWh/m2y** ▪ **SAVING [%]** — **71%**

5. Conclusions and recommendations – Handbook

In every research the creation of a handbook is, undoubtedly, the most desirable finding.
In P2NDURE case, this handbook should represent a *vademecum* for the designers, giving them possible advice on how to further improve the energy performance of the buildings, basing on the overview of the energy analyses run for similar cases.
The more direct and clearer are these advices, the more useful will result the handbook. It is not by chance in fact, that the DoA says in Task 3 Description: "The findings will be explained in easy understandable reports."

After two years of investigations and researches, some important issues in this sense have started to become evident, helping in the definition of this first version of the handbook.
Below a list of them is reported.

i) BIM-BEM approach must be preferred to manual calculations every time, and it is highly recommended in order to simulate reliable energy balances and get precise findings when determining the savings.
Moreover, BIM and BEM are very powerful instruments to run a considerable amount of simulations in a reasonable time. Once the pre-renovation model is validated, the "digital approach" represents hence the best assistant tool for the designer in the selection of the more appropriate combination of retrofit actions.

ii) In all the cases, two main retrofit strategies might be pursued at the same time: a) the increase of the efficiency of the envelope, through an implementation of the thermal resistance of its elements (passive retrofit), b) the upgrade of the plants that assist the fulfilment of the energy end uses, by a revamping or a substitution of them, using more efficient systems or, when possible, devices fed by renewable energy (active retrofit).

Passive retrofit can be made in several ways. P2ENDURE demonstration cases frequently opted for a substitution of the windows, and/or the application of insulated elements.

iii) In the first case the benefits come from a combination of the reduction of the heat losses for transmission through the transparent elements, and the abatement of the air leakage through the window frames. Since the overlapping of these effects, it is not easy to provide a general parametric evaluation of the benefits. However, there is a general understanding that in a building characterized by large section of transparent vertical closing, the usage of smart and efficient windows might be always considered a priority.

iv) The improvement of the opaque elements of the building envelope, instead, allows the identification of an interesting parameterisation, to correlate actions and benefits.

In particular, under the hypothesis that the retrofit intervention should interest the envelope as a whole, it is true that the ratio expressing the percentage of reduction of the opaque elements thermal transmittance, between pre and post retrofit, substantially coincides with the percentage of energy saving. Id est, if one reduces the average transmittance of the walls of 40 %, it is highly probable that the savings will more or less attest around the same 40 % (at least of the primary energy associated to the heating end use).
This statement is rather logic, if one considers that under a quasi stady state conditions, the heat transferred through the envelope is directly proportional (linear) to the U value of the envelope (assuming that the surfaces and the difference of temperatures do not vary in the time interval). The demonstration cases considered in P2ENDURE fundamentally confirms this correlation.

Active retrofit can be made, independently from the passive renovation, acting on the improvement of the efficiency of the energy transformation processes from sources to end uses.
As a rule of thumb, one might expect a saving that is always proportional to the increase in the efficiency of the power plant.

v) For thermal end use, the implementation of the boiler efficiency returns a correspondent benefit in terms of primary energy saving: i.e. if the seasonal efficiency of the boiler grows from 70% to 95% (+35%), one may expect a benefit correspondent to a 35 % of energy saving compared to the pre-revamping scenario. The last assertion is very important since the benefits are in this case relative: in percentage, in fact, they are fixed, but in their value, they depend if the revamping is made alone or not. In fact, if one combines passive and active actions, the saving from the thermal plant implementation should be discounted by the abatement already gained through the passive retrofit.
vi) Finally, the implementation of electric devices using PnP systems (e.g. led lamps), being those not constrained to the passive retrofit, yields benefits, in terms of reduction of primary energy associated to the electric end use, that are exactly proportionally to the increase of efficiency of the electric appliances.

In conclusion, two years of research already return a lot of interesting information that, notwithstanding the differences existing in the case studies, already help in the definition of the handbook above.
In the remain part of the research, together with the advances in the application of the P2ENDURE technologies, there is a good expectation to make this handbook wider and to start to be able to analyse variables, such as geo-clustering, that so far have not been considered yet.