RETROFITTING TOWARDS NZEB THE CASE OF RESIDENTIAL BUILDINGS IN THE MEDITERRANEAN CLIMATE

POLITECNICO DI TORINO

Master Degree in Building Engineering

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“It has been said that something as small as the flutter of a butterfly’s wing can ultimately cause a typhoon halfway around the world”

“Si dice che il minimo battito d’ali di una farfalla sia in grado di provocare un uragano dall’altra parte del mondo”

(The Butterfly Effect)

To my family.

ABSTRACT

The idea of designing Zero Energy Buildings (ZEBs) has been gaining international interest in recent times because it seems the perfect solution to make buildings more independent of the electric grid considering the growing energy demand and the climate change. Either way, before being completely introduced in the national building regulations and international standards, the ZEB concept claims a solid and clear definition and a shared energy calculation methodology by all the Member States of the EU. [1] In a period of significant climate change and awareness, the improving of technologies and materials for constructions and the Energy Performance of Building Directive (EPBD), that sets the standards for new and renovated buildings across Europe, might play a key role for the improvement of the building stock and to reduce the greenhouse gas emissions in the atmosphere.

This work aims at presenting a retrofit of an existing building towards nZEB standards (Portugal and Italy), creating a dynamic model of the building via *Energy Plus* that is able to simulate its behaviour in relation to the changes applied, lowering the energy demand of the building and improving the flexibility of the electrical system by taking advantage of renewable energy generation capacities.

L'idea di progettare Edifici a Energia Zero (ZEB) sta guadagnando interesse internazionale negli ultimi tempi perché sembra la soluzione perfetta per rendere gli edifici più indipendenti dalla rete elettrica in vista della crescente domanda di energia e dei cambiamenti climatici. Ad ogni modo, prima di essere completamente introdotto nei regolamenti edilizi nazionali e negli standard internazionali, il concetto ZEB necessita di una solida e chiara definizione e una metodologia di calcolo dell'energia condivisa da tutti gli Stati Membri dell'Unione Europea. In un periodo di significativo cambiamento climatico e presa di coscienza, il miglioramento delle tecnologie e dei materiali per le costruzioni e la direttiva sul rendimento energetico nell'edilizia (EPBD), che stabilisce gli standard per gli edifici nuovi e rinnovati in Europa, potrebbe rivestire un ruolo chiave per il miglioramento del patrimonio edilizio e per ridurre le emissioni di gas serra e anidride carbonica nell'atmosfera.

Questo documento mira a presentare un esempio di riqualificazione di un edificio esistente secondo gli standard nZEB (Portogallo e Italia), creando un modello dinamico dell'edificio tramite ENERGY PLUS in grado di simularne il comportamento in relazione ai cambiamenti applicati, diminuendo il fabbisogno energetico dell'edifici e migliorando la flessibilità del sistema elettrico sfruttando le capacità di generazione di energia rinnovabile.

[1] A.J. Marszal, P. Heiselberg, J.S. Bourrelle, E. Musall, K. Voss, I. Sartori, A. Napolitano. (2010). "Zero Energy Building – A review of definitions and calculation methodologies"

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INTRODUCTION

In Europe, the 40% of the total energy demand comes from building sector. Thus, measures for this sector, especially concerning energy savings, has been introduced by European Directives 2002/91/EC and 2010/31/EU for the design of the buildings or their technical equipment. [2] The EU has set targets for 2020 and goals for 2030-2050 to cut 20% of greenhouse gas emissions (comparing to the level of 1990), to increase the energy use from renewable sources by 20% and to raise energy proficiency by 20%. The primary tool to reach the targets in Architecture and building sector is the Energy Performance of Building Directive (EPBD) that sets the standards for new and refurbished buildings across Europe. The Directive at Art. 9 specifies that Member States (MS) which are part of EU must make sure that by 2021 all the buildings of new construction, and by 2019 all new public buildings, will be nearly Zero Energy Buildings (nZEB) and Member States should outline initiatives and "encourage best practices as regards the cost-effective transformation of existing buildings into nearly zero-energy buildings". [3]

Therefore, most Member States reviewed their existing regulations, norms and guidelines in addiction to start to draw up the resources to increase the spreading of this kind of high-energy performance buildings by making clear the nZEB definitions on the national-wide. Nonetheless, there are critical points in the progress and establishment of nZEBs across the 28 Member States. On the one hand, Northern Member States succeeded to elaborate or adjust principles, definitions and construction technologies of nZEBs that are efficient and fit to their heating dominated climatic conditions; on the other hand, Southern Member States are still trying to find the most suitable solutions considering the climate and local architecture, as well aesthetic, technical and economic context. [4]

In this thesis, the case study examined is a residential building, located in Lisbon (Portugal), object of a project for which the Department of Civil Engineering of the University NOVA of Lisbon (PT) collaborated with the Massachusetts Institute of Technology (MIT) (FIRST [5]). The aim of the project is

[2] D. D'Agostino, C. Marino, F. Minichiello, F. Russo. (2017). "Obtaining a NZEB in Mediterranean climate by using only on-site renewable energy: is it a realistic goal?"

[3] B. Atanasiu, T. Boermans, K.E. Thomsen, J. Rose, S. Aggerholm, A. Hermelink,M. Offermann. (2011). "Principles for Nearly Zero Energy Buildings"

[4] S. Attia, P. Eleftheriou, F. Xeni, M. Rodolphe, C. Mènèzo, V. Kostopoulos, L. Pagliano, M. Cellura, M.G. Almeida, M.A. Ferreira, T. Baracu, V. Badescu, R.G. Crutescu, J.M. Hidalgo Betanzos. (2017). "Overview and future challenges of nearly Zero Energy Buildings (nZEB) design in Southern Europe"

[5] C.A. Santos Silva, C. Sousa Monteiro, D. Aelenei, F. Costa, H. Gonçalves, J. Martins, L. Aelenei, N. Madjalani, R.A. Lopes, T. Simoes. (2018). "FIRST - Mapping flexibility of urban energy systems"

to design a retrofit towards nZEB, changing the stratigraphy of the components of envelope, fixtures and equipments in order to lower the Energy demand. Each component after retrofit has to reach the U-values of the Italian existing regulation about Nearly Zero Energy Buildings.

Despite being the building in question located in Portugal, which enjoys a “Hot-Summer Mediterranean Climate”, we started modelling the building via *Energy Plus* [6] with all the information (location, envelope, fixtures, HVAC system, thermal zones, thermostat temperatures) and then, using an iterative methodology, we calculated the energy demand of the building in different configurations. The next step was to simulate a retrofit of the building envelope and the fixtures, and the energy demand were calculated so that the consumptions of the building were lower than the original model. The simulations done were made at first considering the building located in Lisbon, and then in Turin, and the results were compared.

The data provided about the building showed graphic results of indoor temperature and energy demand in different periods of the year, comparing the results of the original model having multiple thermal zones to the new configurations with only a single thermal zone and with different weather files and configurations, launched through *Energy Plus*.

Another relevant handled topic is the Energy Flexibility which allows the building to use the energy produced on-site from renewable sources like Photovoltaic systems in the hours of the day when there is a peak of energy demand; in fact as regards heating flexibility, this means to heat the building when there is solar energy available that can cover or reduce the energy demand in the mid part of the day. Being the case study building residential, in this work Energy Flexibility has led to lower the energy demand of the building shifting the consumption of the heating system into the period of the day in which the generation of energy onsite reaches a peak. That way, in the middle hours the consumptions are totally covered by generation of energy and the house stores the heat or the cold in the walls decreasing the peaks of demand in latter times of the day.

The project aims to achieve greater environmental sustainability due to lower energy consumption, better indoor air quality and lower carbon dioxide emissions through the exploitation of the building's thermal inertia and the use of renewable sources.
The EPBD requires all new buildings from 2021 (public buildings from 2019) to be nearly zero-energy buildings (NZEB) and a proper design and retrofit of the building stock could be the start point for a big

[6] U.S. Department of Energy. “EnergyPlus Version 8.9.0 Documentation- Getting Started”

change towards a future in which the buildings have to be increasingly independent from the electric grid.

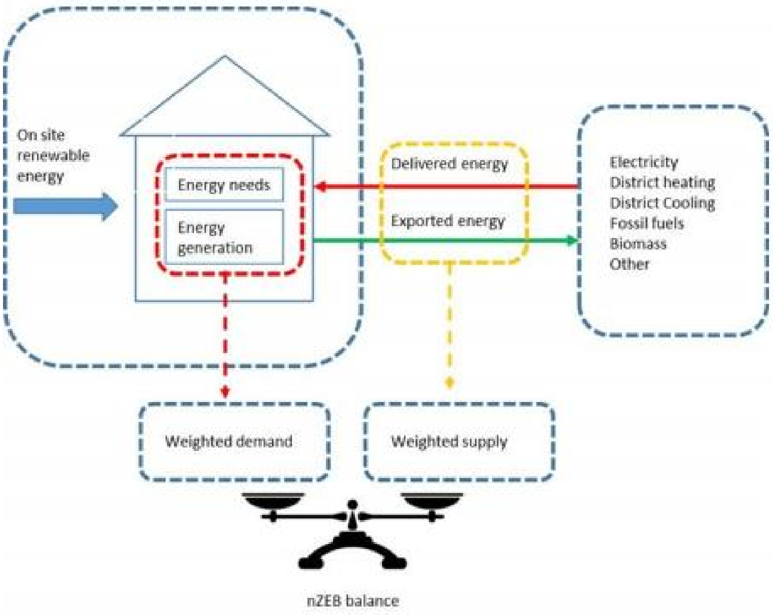

Figure 1 - Graphic definition of a nZEB (Source: AIMS Press, "Energy efficient measure to upgrade a multistory residential in a nZEB")

1. Climate change and building sector

The human activity seems to be the most likely cause of the actual warming trend since the mid-20th century and it's moving forward at a rate that has never reached in the past millennia. Indeed, carbon dioxide and other gases are capable to trap the heat creating a greenhouse effect. Their ability to compromise the transfer of infrared energy through the atmosphere is the scientific base of many instruments conducted by NASA. [9]

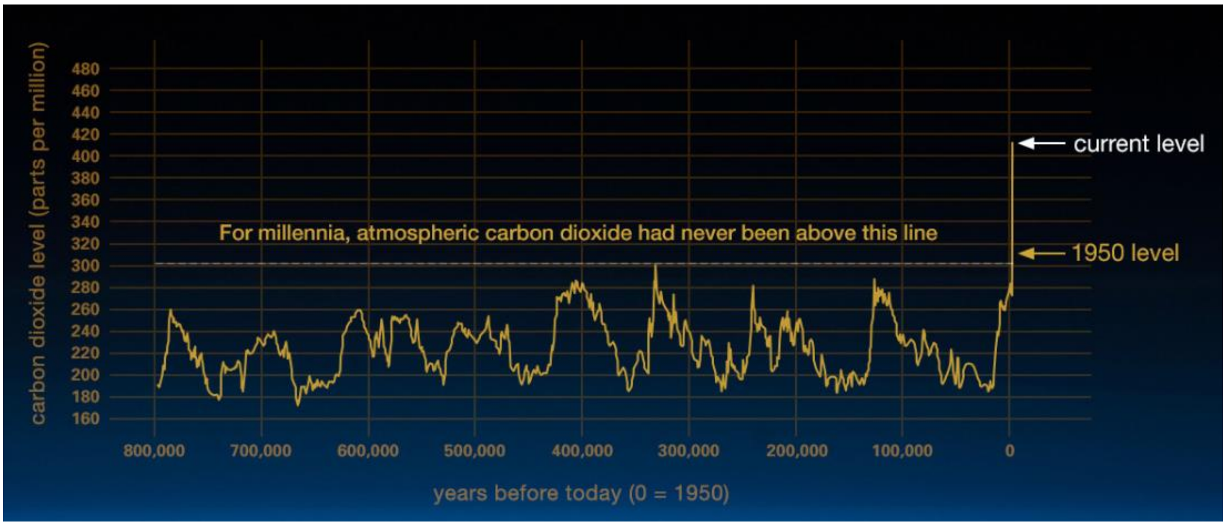

Figure 2 - Graph comparing carbon dioxide level in the past millennia (Source: NASA, "Climate Change: How do we know?", Credit: Luthi, D., et al. 2008; Etheridge, D.M., et al. 2010; Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO2 record.)

The increasing of carbon dioxide and human emissions into the atmosphere as well as the increasing of the energy demand, has driven the planet's average surface temperature to a surge of about 1.62 degrees Fahrenheit (0.9 °C) since the late 19th century. The last ten years was the warmest on record since 2010, but most of the warming occurred in the past 35 years.

This rise in temperatures has led to a shift in the seasons, with anomalous periods of heat during the winter, an equatorial-style rain and unusual disturbances. [7]

[7] H. Shaftel, R. Jackson, S. Callery, D. Bailey. (2019). "Climate Change: How do we know?"

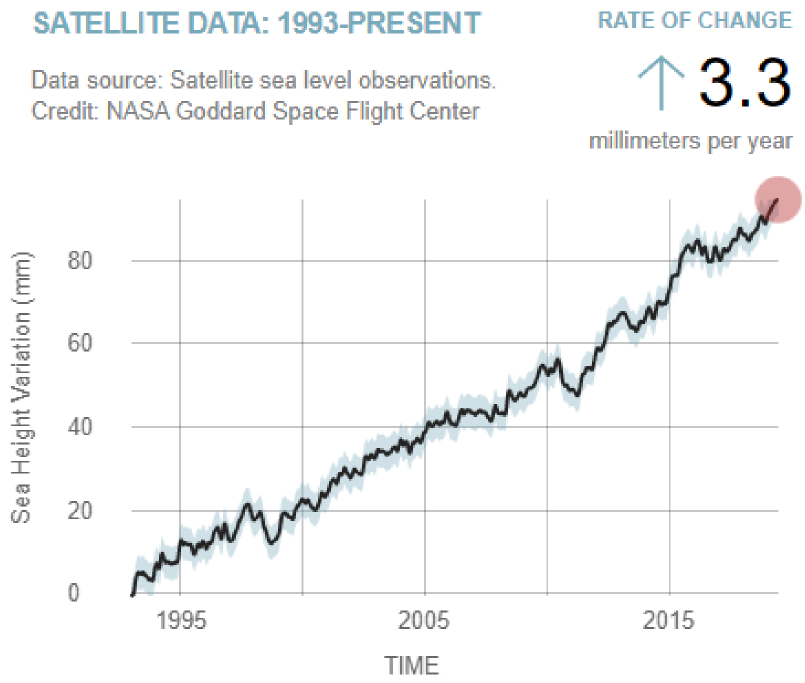

Figure 3 - Sea level (Source: NASA, "Sea level", Last access 07/02/2020)

The Greenland and Antarctic ice caps have been decreasing in mass in the last two decades, in fact NASA's Gravity Recovery and Climate Experiment prove that Greenland lost an average of 286 billion tons of ice every year between 1993 and 2016, while Antarctica lost about 127 billion tons of ice per year during the same time period. In the last decade the Antarctica has tripled its ice loss. [10]

The sea level has been rising primarily for two reasons related to global warming: the dilatation of sea water caused by its warming and the added water from melting ice caps. Figure 3 shows the rise of the sea level since 1993 as observed by satellites. [8]

The continuous growth of the population and the rising temperatures will lead to ever greater energy demand and in most countries of the world, buildings will need more energy for cooling. [9]

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[8] H. Shaftel, R. Jackson, S. Callery, D. Bailey. (2019). "Climate Change: How do we know?"

[9] The IPBES Media Team. (2018). "Media release: Worsening worldwide land degradation now critical, undermining well-being of 3.2 billion people"

Changing the current attitude of building to reduce our emissions and introduce energy savings on many different levels of our daily life could be a small step to contribute to slow down the anthropic climate change taking place on our planet . It is estimated that about 4 billion people will live in barren areas within the next 50 years, the issues of continuous land degradation will push up to 700 million humans to migrate, 18% of mammals will be in danger of extinction, the combination of land degradation and climate change could decrease agricultural production by 10% to 50%.
It is therefore necessary to implement a change in our daily lives, starting from the way we design our houses. With the current economic system, in the immediate future, 4.3 Italy will be needed to cover the Italian's energy demand. [10]

In the following a brief description of the main consequences is given.

Rising temperatures:
The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) states that the climate change is clear and unmistakable, and that human activities, the use of fossil fuels, old equipment as like the emissions of CO_2 are probably the principal causes. Changes are visible: the atmosphere and oceans are warming up, weather conditions are changing, the sea level is rising, the ice caps are melting, the wildfires are becoming increasingly extensive and intensive. [11]

Projections for the future:
Computer models show that changes will continue at a faster rate and that the emissions of greenhouse gases grew faster in the last decade than in the previous ones.
If emissions keep on rising at the running rate, effects by the end of this century are estimated to include a global average temperature 2.6 to 4.8 degrees Celsius (°C) higher than present, and sea levels 0.45 to 0.82 metres higher than the current level.

The Paris Agreement, which was an international reunion taking place in Paris on the 12nd December 2015, where Parties to the UNFCCC (United Nations Framework Convention on Climate Change) reached an agreement to fight and prevent the climate change and to accelerate the actions needed for

[10] The IPBES Media Team. (2018). "Media release: Worsening worldwide land degradation now critical, undermining well-being of 3.2 billion people"

[11] R. Van Staden, University of Cambridge. (2014). "The Physical Science of Climate Change"

a future with lower carbon emissions and to set a target for keeping the global temperature rise below 2°C, and to consider lowering the target to 1.5°C soon. [12]

DATA

When we talk about carbon pollution, we usually have the tendency to think that the main cause the transportation sector. We can imagine streets and cities plenty of vehicles stuck in traffic, releasing in the atmosphere a big quantity of gases and CO_2. Even if is less evident, the building sector has a higher environmental footprint than transportation.

As shown in Figure 4, buildings produce pollution both directly and indirectly; building operations, the processing of products, the stock and the construction are representing the 39% of the national carbon dioxide emissions. Industry activity is in second place with 32% of emissions, and transportation is in third place with 23%.

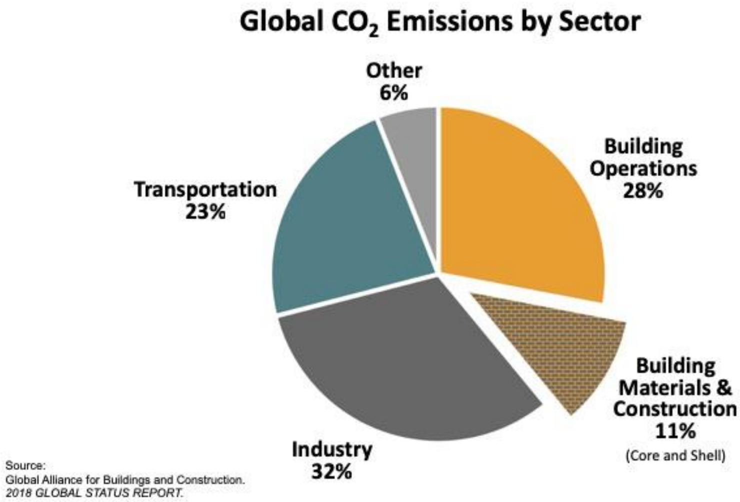

Figure 4 - Carbon Footprint (Source: Global Alliance for Buildings and Constructions, "Global status report", 2018)

Direct Building Emissions

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[12] The IPCC's Fifth Assessment Report, C. Symon. (2013). "Climate change: Actions, trends and implications for business"

Buildings usually produce carbon dioxide directly when they use equipment based on combustion. Carbon emission for space heating are produced by:

- Boilers and furnaces that burn fuels like natural gas and heating oil;
- Water heaters also use fossil fuel combustion as a heat source;
- Power generated on-site also contributes to building emissions if the energy used is a fossil fuel.

All the equipment mentioned could be realized not using fossil fuel combustion. For instance, heat pumps could replace boilers, furnaces and conventional water heaters could use only electricity in order to avoid local emissions. Moreover, wind turbines and solar photovoltaic systems are useful for on-site generation of electricity, and they can be associated to batteries for storing the electricity in the period of excess and using it when the building needs.

Indirect Building Emissions

In addition to the direct emissions released by buildings, there are indirect emissions associated to transportation of fuels and materials, extracting raw materials, processing products and delivering to the construction site.
Each material bring with it incorporated CO_2 emissions, but they are never considered. [13]

1.1 NZEB ACROSS EUROPE

According to the agreed definition of the term, *"A zero-energy building (ZEB), also known as a net-zero energy building (NZEB), is a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site",* or in other definitions by renewable energy sources off-site. These buildings release to the atmosphere less greenhouse gas comparing to non-ZE buildings. [14] [15]

[13] C. Bipat. (2019). "How Buildings Produce Carbon Emissions... And How to Stop Them"

[14] Paul Torcellini, Shanti Pless, Michael Deru National Renewable Energy Laboratory; Drury Crawley, U.S. Department of Energy. National Renewable Energy Laboratory report. (2006). "Zero Energy Buildings: A Critical Look at the Definition"

[15] US Department of Energy. (2015). "A Common Definition for Zero Energy Buildings"

Recent data show that buildings complying with the building code, consume 40% of the national fossil fuel energy in the US and European Union and are considerable contributors of greenhouse gases. [16] The zero-energy consumption criterion is viewed as a way to decrease carbon emissions and decrease dependence on electric grid and fossil fuels.

Many zero-energy buildings utilizes the electric grid to store the energy, some are independent to the grid instead and others harvest and store the energy onsite. Energy can be harvested onsite exploiting solar energy or wind, through photovoltaic system or wind turbines but the energy demand has to be reduced using highly efficient HVAC technologies (Heating, Ventilation and Air Conditioning) and highly efficient lightning or a proper insulation of the envelope and airtightness. The zero energy standards are becoming increasingly easier to realize and to design as long as the costs of these technologies decrease and the costs of traditional fossil fuel increase.

New construction technologies and techniques as well as the evolution and advances in new energy made the development of zero energy building ever more possible. nZEB construction technologies usually include high efficiency solar panels, double or triple low emission glazed windows, proper exterior insulation and heat pumps.[17]

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[16] Baden, S., et al. (2006). "Hurdling Financial Barriers to Lower Energy Buildings: Experiences from the USA and Europe on Financial Incentives and Monetizing Building Energy Savings in Private Investment Decisions."

[17] Yatish T, Shah. (2020). "Modular Systems for Energy Usage Management"

1.1.1 Definitions

Electrical grid

An electrical grid is an interconnected network for delivering electricity from producers to consumers.[18]

Zero net site energy use (ZNE)

In this kind of Zero Net Energy building, the amount of energy harvested onsite through renewable sources is even to the energy demand of the building.

Zero net source energy use

In this kind of Zero Net Energy building, the energy generated is even to the energy used, including the energy used to bring the energy to the building. The amount of energy that these ZNE buildings has to produce is higher than zero net site energy buildings.

Net zero energy emissions

In some countries, a ZEB is generally associated to the definition of zero net emission building or zero-carbon building (ZCB).

Carbon emissions and energy saving are two different topics but sometimes the emissions released by the building through equipment or fossil fuel use can be balanced by the quantity of energy produced onsite through renewable sources. Other definitions take into account also the emissions generated during the construction and the incorporated energy of the structure (the emissions connected to the extraction of the raw materials, the process and the transportation).

Net off-site zero energy use

A building can be defined a Zero Energy Building if the total amount of the energy it uses comes from renewable energy sources produced onsite, or also produced offsite.

Net Zero Energy Building or Nearly Zero Energy Building

The NZEB can be described as a grid-connected building that produce the same amount of energy by renewable sources onsite than its own energy demand; the building becomes an active part of the energy infrastructure exchanging energy to the grid.

[18] Kaplan, S. M. (2009). “Smart Grid. Electrical Power Transmission: Background and Policy Issues. The Capital.Net”

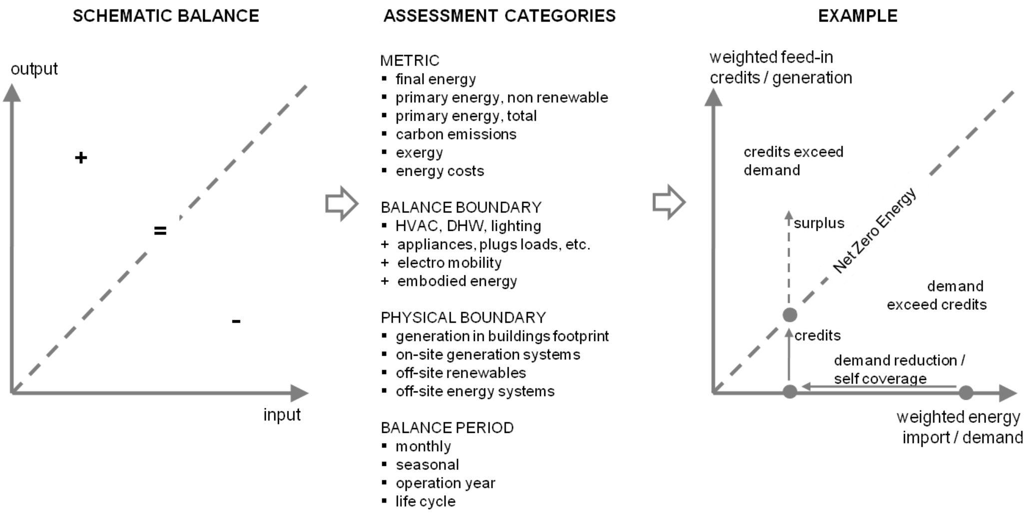

Figure 5 - Net ZEB balance concept: balance of weighted energy import respectively energy demand (x-axis) and energy export (feed-in credits) respectively (on-site) generation (y-axis) (Source: EMusall, University of Wuppertal, 2013)

1.1.2 Design and construction

Zero Energy Buildings are typically designed to use passive solar heat gains and shadings, combined with thermal inertia and super insulation to decrease diurnal temperature variations during the day. [19]

ZEBs are designed for having significant energy-saving features.

High-efficiency equipment are used to reduce heating and cooling loads; for instance, heat pumps which are four times more efficient than furnaces, thick insulation, double or triple low-E glazing, LED lighting, high efficiency appliances, natural ventilation, passive solar gains in winter and shading in the summer.

These features can be different according to the climate zone in which the construction is based. Water store fixtures can be used to decrease the water heating loads, or heat recovery units on wastewater or also using solar water heating. Moreover, daytime illumination could be ensured into the house during all day using skylights or solar tubes.

Night-time illumination is normally provided by LED lighting that consume 1/3 or less power than incandescent lights, not adding unwanted heat.

[19] Frej, Anne, editor, Urban Land Institute. (2005). “Green Office Buildings: A Practical Guide to Development”

Once the energy demand of the building has been reduced to the minimum is possible to generate all that energy on site through photovoltaic panels on the roof or wind turbines.

1.1.3 Energy Harvest

Zero Energy Buildings harvest energy to cover their electricity need and heating or cooling energy demand. Most of the time, energy is harvested through solar photovoltaic panels installed on the roof that transform the sun's light into electricity. Energy can also be harvested through solar thermal collectors that use the heat of the sun to heat the water for the building. Heat pumps or geothermal can also harvest heat and cool from the air or ground next to the building.
The difference between heat pumps and geothermal is that the heat pumps move the heat rather than harvest it, but the impact of decreasing the energy demand and carbon footprint is very similar.
Talking about individual houses, to provide heat or electricity to the building, can be used microgeneration technologies like solar cells or wind turbines for generating electricity, and biofuels or solar thermal collectors connected to a thermal energy storage useful for space heating. This thermal energy storage can also be used in winter storing the cold from the underground. Zero Energy Buildings are usually connected to the electric grid in order to export electricity when there is a surplus and draw electricity when the one produced is not enough to cover the energy demand. [20]

1.2 EPBD (Energy Performance Building Directive) and ZEBRA2020

The Energy performance of buildings directive (EPBD) and the Energy Efficiency Directive are the main legislative tools to spread the energy performance of buildings and to raise the renovation within the European Union.

The EPBD (2010/31/EU) has been in operation since 2010 and helps users to design buildings in the right way in order to save energy and money. Through it, has been a good change of trends in the energy performance of buildings and its development; in fact, in the EPBD introduction about energy efficiency requirements, the new buildings compliant to the building code are two time more efficient than the typical buildings from the 1980s, and consume half of the energy.

[20] Yatish T, Shah. (2020). "Modular Systems for Energy Usage Management"

The European building sector is responsible for about a third of CO_2 emissions, and the European Union has established a target of 20 % reduction by 2020 and 60 % by 2030, from a 1990 level. Reaching these targets means to reduce the energy demand of the building through retrofits of the existing building stock and to use high efficiency equipments to decrease the carbon footprint. [21]

In Europe, the 40% of the total energy demand comes from building sector. Thus, measures for this sector, especially concerning energy savings, has been introduced by European Directives 2002/91/EC and 2010/31/EU for the design of the buildings or their technical equipment.
The Directives foster the improvement of the energy performance of the building sector through different points, i.e.:

- use of renewable energy sources;
- high energy efficiency technologies for Heating, Ventilation and Air Conditioning systems;
- passive approaches, like solar shading devices or super insulation;
- heat recovery on the ventilation system;
- lighting with high energy efficiency such as LED of fluorescent;
- high efficiency vehicles or transport systems.

Also, there are so many other things upon which to pay attention for an ideal building performance like indoor air quality, thermal and acoustic comfort, enough natural light and airtightness.

In cold climates, to design and a high energy performance building is easier and simpler compared to hot climates. This is because it's easier to store the heat inside the building instead of dissipating it; in fact, in cold climates, thermal insulation and low specific weight have a key role. On the other hand, in hot climates, high thermal insulation can produce negative effects restraining the dissipation of heat. [22]

The Energy Performance Building Directive (EPBD) sets standard for all new buildings from 2021 (and already from 2019 for public buildings) to be nearly zero-energy buildings (NZEB).
The Directive requires that the nearly zero or very low amount of energy demand of the building should be covered from the energy produced or harvested onsite through renewable sources.

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[21] European Commission. (2017). "Buildings"

[22] D. D'Agostino, C. Marino, F. Minichiello, F. Russo. (2017). "Obtaining a NZEB in Mediterranean climate by using only on-site renewable energy: is it a realistic goal?"

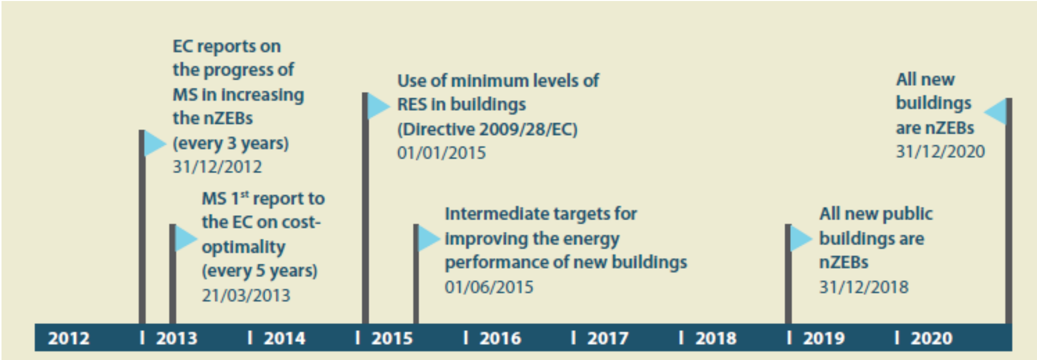

Figure 6 - Key years for nearly Zero-Energy Building (Directive 2010/31/EC) (Source: EPISCOPE)

According to a recent EU project (ZEBRA2020), which is aimed at tracking the market transition to nearly Zero-Energy Buildings (nZEBs) and provide recommendations and guidelines for the building sector to accelerate the market spread of nZEBs across Europe, building are analysed and catalogued in 4 different energy efficiency categories, defined by experts:

1. Better than nZEB standard;

2. nZEB buildings compliant to the national official nZEB definition;

3. Buildings with an energy performance better than the building code (2012);

4. Buildings constructed/renovated according to building code (2012).

The following figure shows the uptake of nZEB in the building sector. The diffusion of nZEBs varies a lot between countries. In fact, in France, the nZEB definition correspond to the current thermal regulation and the primary energy performance of residential buildings has to be below 50 kWh/m^2/year. Therefore, all new buildings are already nZEB (since 2013). In other countries, the diffusion is slower because the nZEB standards are more severe compared to the building code requirements. [23]

[23] Agne Toleikyte, Lukas Kranzl, Raphael Bointner, Frances Bean, Jordi Cipriano, Maarten De Groote, Andreas Hermelink, Michael Klinski, David Kretschmer, Bruno Lapilonne, Ramón Pascual, Andrzej Rajkiewicz, Jose Santos, Sven Schimschar, Carine Sebi, Jonathan Volt (2016). "Zebra 2020 – Nearly Zero Energy Building Strategy 2020"

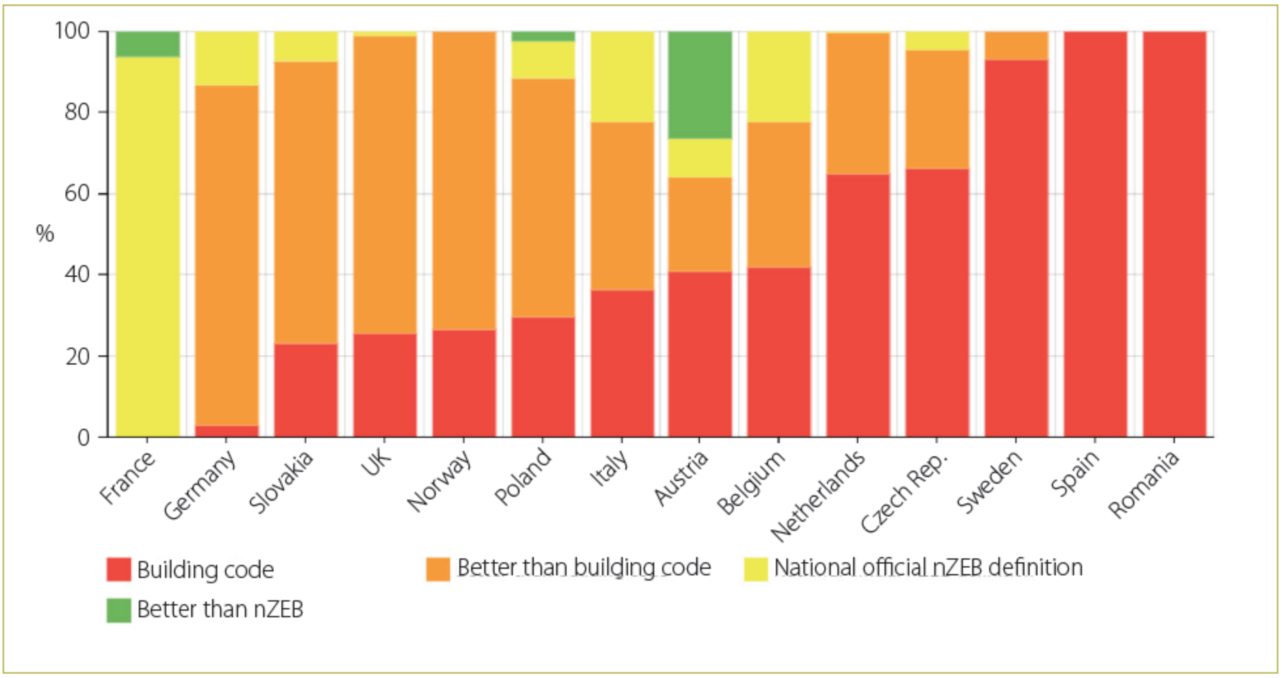

Figure 7 - Distribution of new buildings according to different building standards (Source: ZEBRA2020, "Nearly Zero Energy Building Strategy 2020")

For residential buildings, most jurisdictions move towards having a primary energy use lower than 50 kWh/m²/year. For non-residential buildings instead, the standards are less strict in the same country, depending on the type of building. Generally, because of different calculation methodology, climate conditions and building typology in the different countries, the maximal primary energy level for non-residential buildings in Europe stands from 0 to 270 kWh/m²/year.

The Directive describes only the big picture giving the right of expression to Member States to refine it. Thus, the Nearly Zero Energy Building concept is very flexible with no single definition across the EU. Member States are responsible to define their own definition of nZEBs in their national plans and national contexts, improving their standards for constructions. [24]

[24] Building Performance Institute Europe (BPIE). (2015). "Nearly Zero Energy Buildings definitions across Europe"

1.3 EPBD implementation in Italy

Decree 192/2005 , modified by Legislative Decree 311/2006, establishes the basis for the Energy Performance Building Directive implementation in Italy. After the decree was set, many acts updated the decree about the minimum standards for buildings, building systems and components, guidelines for energy certification and calculation for cooling and lighting systems.

Law 90/2013 implemented Directive 2010/31/EU instead, adding important changes to the first 2005 implementation. Later, on the 26th of June 2015, the EPBD was implemented with 3 inter-ministerial decrees which set stricter minimum requirements for new buildings and significant renovations, made a definition for nZEBs and they set rules for Renewable Energy Sources for buildings.

Italian regions (21 in total) have then a clear definition on nZEB and standards in energy topics. The recent legislation provided, with a unanimous consensus of all the regions, an agreeded implementation of the EPBD all over the national country and took implementation a step forward:

- The six regions that had independently implemented the EPBD before October 2015 (Liguria, Emilia Romagna, Tuscany, Val d'Aosta, Piedmont, Lombardy and the provinces of Trento and Bolzano) have a period of two year to align their EPC (Energy Performance Certification) system to that required by national law;
- Five more regions/autonomous provinces have already proven their EPC database since 2014 (15/21).

1.3.1 Energy performance standards: NEW BUILDINGS

The new decree 26/06/2015 "Minimum Requirements" enhanced the previous acts and provided an updated energy performance calculation methodology, minimum standards for high efficiency buildings, building systems and components, guidelines for energy certification and calculation for cooling and lighting systems, as well as conversion factors. The new legislation also defined NZEB.

Current calculation methodologies are proceeding from the national standard UNI/TS 11300 (series from 1 to 6), and the calculation of artificial lighting from the standard UNI EN 15193:20086 .

The main changes from 2015 are the following:

1. Updated methodology for the calculation of energy performance, in accordance with EPBD Annex I:

- The total annual energy demand is calculated for each energy service monthly and indicated in primary energy;

- The energy produced onsite through renewable sources is calculated in the same way;

2. For the energy services taking into consideration like heating, cooling, ventilation and domestic hot water for residential buildings, and lighting and internal transports (lifts, escalators) for non-residential buildings, the new energy performance standards for new buildings (and significant renovations) are based on the application of the cost-optimal methodology results (EPBD, Article 5), with the use of a "Reference Building".

3. Factors for the conversion of delivered energy to primary energy.

1.3.2 Format of national transposition and implementation of existing regulations

Minimum standards are defined in accordance with the **"reference building"**.

Energy parameters of the reference building will require more strict standards from 2021 and from 2019 for public buildings. *(Table 1,2)*

The new legislation in operation requests the calculation of the next energy performance benchmarks:

- Specific Energy demands for heating ($EP_{H,nd}$), cooling ($EP_{C,nd}$) and domestic hot water ($EP_{W,nd}$);
- Energy performance indicators for heating (EP_H), cooling (EP_C), domestic hot water (EP_W), ventilation (EP_V), lighting (EP_L) and transport (EP_T) for non-residential buildings, for non-renewable and total primary energy [kWh/m^2];
- Global energy performance indicator $EP_{gl} = EP_H + EP_C + EP_W + EP_V + EP_L{*} + EP_T{*}$ for non-renewable and total primary energy [kWh/m^2].

A new building (or significant renovated building) complies with the minimum standards if the Specific Energy demands for heating and cooling ($EP_{H,nd}$, $EP_{C,nd}$) and the Global energy performance EP_{gl} are lower than the values of the "reference building". Also, new buildings are required to have a minimum percentage of Energy produced through Renewable Energy Sources for the supply.

In the evet that the required RES addiction should not be achievable, the building has to comply with a proportionally lower Global Energy performance indicator (EP_{gl}) limit value.

Elements /Components	Validity period	Thermal transmittance U [W/m².k] (including thermal bridges)				
		Climatic Zone				
		A and B	**C**	**D**	**E**	**F**
Envelope – walls	From 2015	0.42	0.36	0.32	0.28	0.26
	From 2019/2021	0.38	0.32	0.28	0.24	0.22
Envelope – roofs	From 2015	0.36	0.36	0.28	0.25	0.23
	From 2019/2021	0.34	0.34	0.24	0.22	0.20
Envelope – floors	From 2015	0.46	0.40	0.32	0.30	0.28
	From 2019/2021	0.42	0.36	0.28	0.26	0.24
Doors, windows and shutter boxes	From 2015	3.20	2.40	2.00	1.80	1.50
	From 2019/2021	3.00	2.20	1.80	1.40	1.10
Indoor partitions	From 2015	0.80	0.80	0.80	0.80	0.80
	From 2019/2021	0.80	0.80	0.80	0.80	0.80
		Total solar energy transmittance g_{gl+sh} [-]				
		A and B	**C**	**D**	**E**	**F**
Windows with shading devices	From 2015	0.35				
	From 2019/2021					

Table 1. Reference building – Performance of single building elements (Source: Ministry of Economic Development)

Components	Validity period	Thermal transmittance U [W/m².K] (including thermal bridges)				
		Climatic Zone				
		A and B	**C**	**D**	**E**	**F**
Envelope – walls	From 2015	0.45	0.40	0.36	0.30	0.28
	From 2021	0.40	0.36	0.32	0.28	0.26
Envelope – roofs	From 2015	0.34	0.34	0.28	0.26	0.24
	From 2021	0.32	0.32	0.26	0.24	0.22
Envelope – floors	From 2015	0.48	0.42	0.36	0.31	0.30
	From 2021	0.42	0.38	0.32	0.29	0.28
Doors, windows and rolling shutter boxes	From 2015	3.20	2.40	2.10	1.90	1.70
	From 2021	3.00	2.00	1.80	1.40	1.00

Table 2. U-value limits for Second level Major renovation and Minor renovation (Source: Ministry of Economic Development)

1.3.4 Energy performance requirements: EXISTING BUILDINGS

The building sector in Italy has the biggest impact of total energy demand with a percentage of 37.1%. The non-residential sector revealed a decrease in consumption (- 6.7%) in 2015 for the first time in the past 20 years. The annual rate of energy refurbishment of existing residential buildings is esteemed to be about 0.5%.

Energy performance standards for existing buildings are equal regardless of they are residential or non-residential buildings. Minimum standards are differentiated in accordance with the size of the renovation intervention:

- **Major renovations – 1st level** ("renovation of at least 50% of the envelope and renovation of the heating and/or cooling plant of the whole building"). Standards for new buildings consider the whole building, limited to the concerned energy services. For building enhancements (new volume >15% of the existing volume or >500 m3) these standards apply to the new volume.

- **Major renovations – 2nd level** ("refurbishment of at least 25% of the exterior surfaces of the building with or without renovation of the heating and/or cooling plant"). The U-value of each surface is lower than the limit values.

- **Minor renovations** ("refurbishment of less than 25% of the external surfaces of the building and/or variation of the heating and/or cooling plants"). The performance of single components or of the technical building systems must enforce necessarily the limit values.

2. Data acquisition and Original model

The building examined in this thesis is an existing residential building, located in Lisbon (Portugal), object of a project for which the Department of Civil Engineering of the University NOVA of Lisbon (FCT) collaborated with the Massachusetts Institute of Technology (MIT). The building is situated in the Encarnação Neighbourhood (Lisbon) that was built around 1940 thanks to the "Social Quarters Programme" promoted by the City Administration. The social quarters were an archetype of *Estado Novo* urbanism policy and were intended to build neighbourhoods of social housing to receive families of lower classes. Associated was also a formal model of property by which the families could own the property of the house after a 25 years period of monthly rates.[25] Normally, these kinds of neighbourhoods were built in the border of the city, in suburban areas, and were characterised by symmetry and wide distribution. These neighbourhoods featured also green areas, covering about 20-25% of the total area, the apartments were small, and the street network was organized in a hierarchical way. [26]

As regards to the architectural context, the period between 1940 and 1950 was known as "*Português Suave"*. This architecture period enclosed a mix of different genres and ideas like the modernists engineering features, disguised by a blend of exterior aesthetic elements based on Portuguese Architecture of the XVII and XVIII centuries and on traditional houses across Portugal. [27] Today, Encarnação Neighbourhood is a low-density residential area composed by semi-detached houses on two elevations. Most part of the neighbourhood has already been renovated (Figure 8).

Figure 8 - Encarnação Aerial View (2005) and Encarnação Initial Plan (1940)

[25] M. C. Teixeira. (1992). "As estratégias de Habitação em Portugal, 1880-1940"

[26] M. Salgado. (2006). "Atlas Urbanístico de Lisboa"

[27] J. M. Fernandes. (2003). "Portugês Suave - Arquitectura do Estado Novo"

2.1 Methodology and tools

EnergyPlus, an open source software for dynamic energy simulation, developed in the United States in 2001 by the Department of Energy (DOE), was used in this thesis to evaluate the energy performance of the building and the internal temperature of the thermal zone/zones in operating conditions in the various configurations; *EnergyPlus* performs integrated simulations between the environment and the system, that is, the information relating to the load which the system must be able to balance, is used to determine the temperature conditions of the air in the environment through an iterative process.

The software is divided into 3 main interconnected blocks: the Surface Heat Balance Manager which solves the thermal balance at the surfaces, the Air Heat Balance Manager which solves the balance of the environment by simulating the radiative and convective heat exchanges, and the Building System Simulation Manager that deals with the simulation of plant components, be they hydronic or air systems. These main modules, part of the Integrated Solution Manager, interact with other secondary modules in such a way that all the elements of the model are solved simultaneously, and not sequentially, to obtain a simulation as realistic as possible. [28]

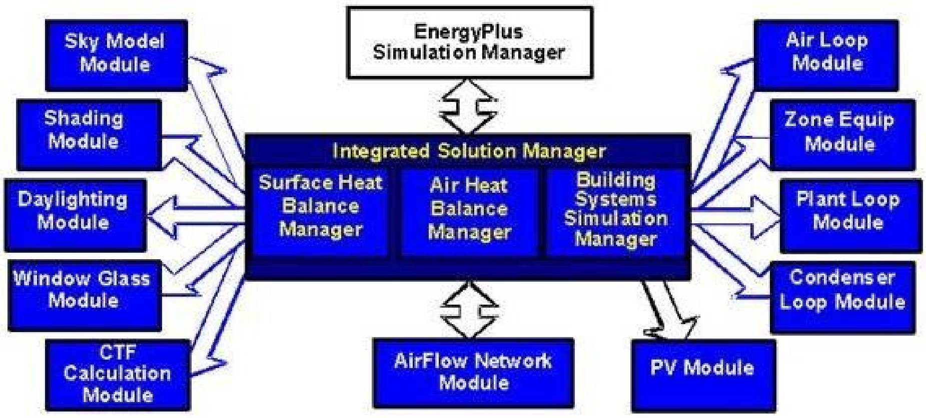

Figure 9 - Energy Plus internal elements (Source: U.S. Department of Energy, EnergyPlus Version 8.9.0 Documentation- Getting Started)

[28] U.S. Department of Energy. "EnergyPlus Version 8.9.0 Documentation- Getting Started"

The case study building is divided into different areas and the project in which I took part already provided the energy performance and internal temperatures of each area at different times of the year. In order to use the data, the geometric model of the building was created on *Energy Plus* considering as in the original project each zone as a thermal zone and then the results were compared.

Having noticed that the results were almost similar, the geometric model was redesigned in such a way as to have a single heated or cooled thermal zone that grouped all the areas of the building and another not air-conditioned (that of the attic). The energy simulation of the single thermal zone building was carried out with both the annual Lisbon and Turin weather conditions. Once this was done, a redevelopment of the original building was envisaged, aimed at enforcing the thermal transmittance values required by law from each element of the building envelope. Energy demand and indoor temperature were then calculated and compared for each city with the values of the original model.

2.2 The Original Building

The case study building has two floors above ground plus attic, but only the first floor and the attic were taken into consideration for the simulations in the thesis.

The steps preceding the simulation are:

1. create the three-dimensional geometric model to identify the thermal zones;
2. assign materials and stratigraphy to the various components;
3. choose a meteorological file of the place.

Location: Lisbon

Latitude: 38.73 deg

Longitude : -9.15 deg

Elevation: 2 m

2.2.1 Geometric model

The geometric model of the building was created directly on *EnergyPlus* by assigning to each element the number of vertices and their respective coordinates in space; the coordinate system is Relative, the direction chosen for the coordinates is counter clockwise and the first vertex to be inserted is the upper left corner.

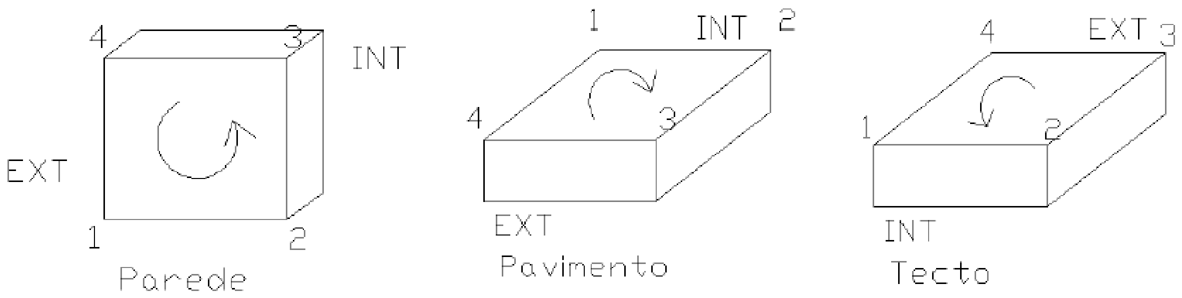

Figure 10 - Graphic example for each element (Wall, Floor, Roof)

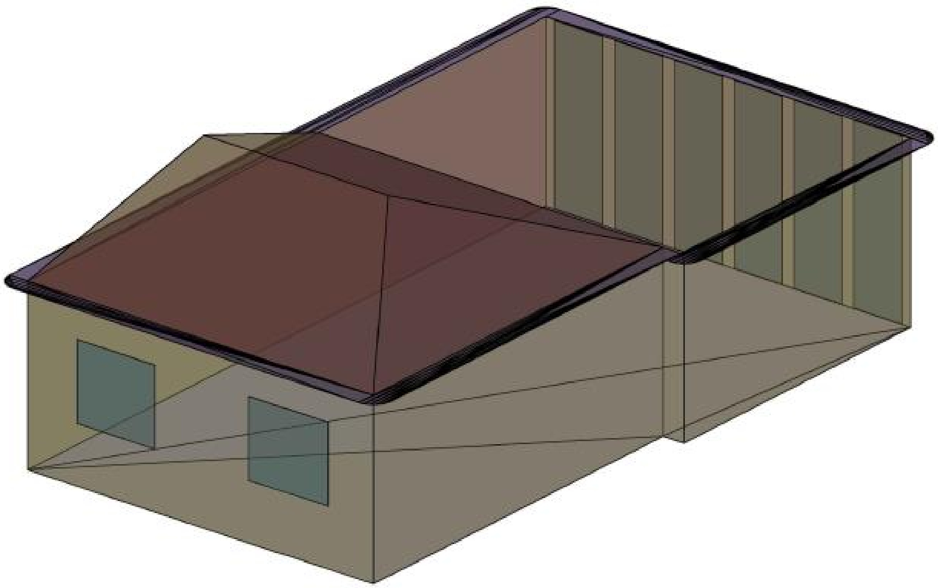

Figure 11 - Geometric model

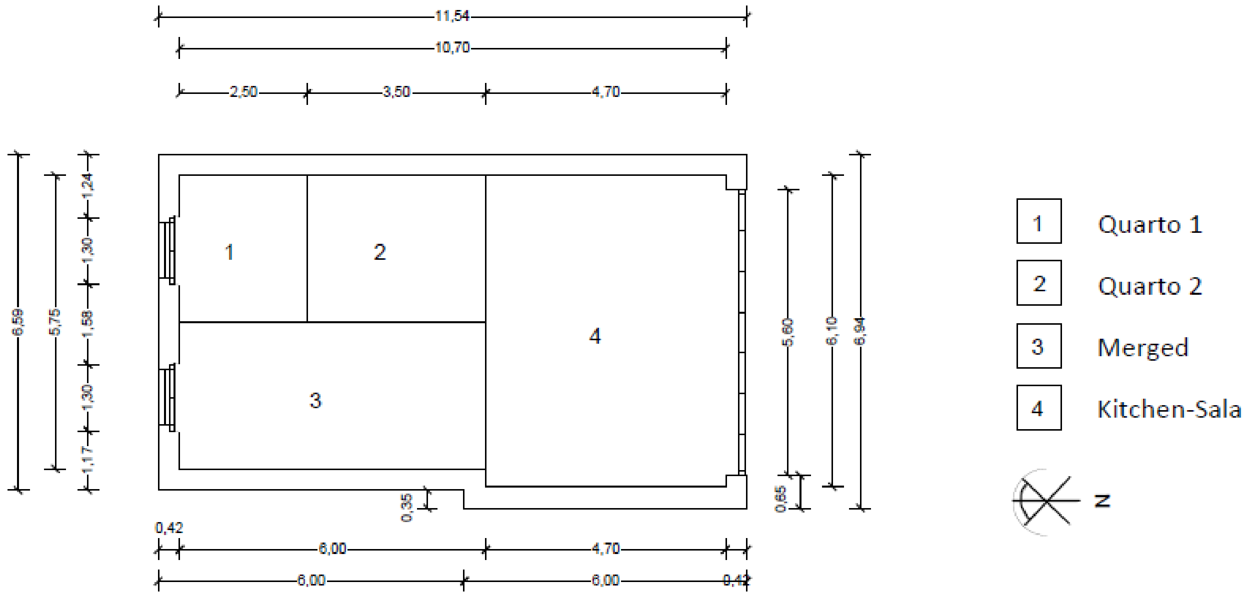

Figure 12 - Plan of the building (Floor 1)

The building consists of 4 rooms: 2 bedrooms, a kitchen-living room and an area called "Merged" which includes 3 spaces. Zones 1, 2, 3 have a pitched roof that houses an attic underneath; the kitchen-living room area instead has a flat roof on which a photovoltaic system is installed.

In the South side of the building there are 2 windows while on the North side there is a curtain wall that covers all the facade.

2.2.2 Envelope and Components

At this point, the stratigraphy and the thermophysical values of the materials have been inserted for each surface. The U-Factor of each surface has been calculated automatically by the software *Energy Plus*.

Exterior wall				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Plaster	2	1900	1046	1,3
Insulation (EPS)	4	25	1210	0,04
Brick	22	633	790	0,42
Plaster	2	1900	1046	1,3
	U-Factor [W/m² K]			0,587

Table 3. Exterior walls stratigraphy (Original building)

Internal wall				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Plaster	2	1900	1046	1,3
Brick	7	818	790	0,37
Plaster	2	1900	1046	1,3

Table 4. Interior walls stratigraphy (Original building)

Floor				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Wood panel	12	900	820	0,34
Wood panel	3	900	820	0,34
Concrete	15	2300	1000	2
Concrete	5	700	1000	1,3

Table 5. Floor stratigraphy (Original building)

Ceiling				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Wood panel	3	900	820	0,34
Wood panel	12	900	820	0,34
Insulation (Mineral wool)	8	50	1100	0,04
Plasterboard	1	900	820	0,25
	U-Factor [W/m² K]			0,538

Table 6. Ceiling stratigraphy (Original building)

Roof				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Roof tiles	5	907	1000	0,41
Plate	4	900	820	0,025
	U-Factor [W/m² K]			0,538

Table 7. Roof stratigraphy (Original building)

Window		
Layer	Depth [cm]	Conductivity [W/m K]
Glass	0,6	0,9
Air	1,2	0,026
Glass	0,4	0,9
	U-Factor [W/m² K]	1,32

Table 8. Window stratigraphy (Original building)

2.2.3 Assumptions

Since the building is used for residential use, the following hypotheses have been established to launch the energy simulations:

1. In order to simplify the calculation, the lights, equipment and people's metabolic activity were grouped as "Electric Equipment" producing 4 W/m² during all day;
2. The air-conditioned zones are Quarto 1, Quarto2, Merged and Kitchen-Sala, and not the attic under the roof;
3. Each room has the same Thermostat Setpoint temperature;
4. The Design Flow Rate per hour is 0.4 air changes;
5. The house is occupied only in the morning and at night (nobody in the house from 09-18 pm) (*Figure 13*);
6. The heating-cooling system has been programmed to work only in the periods when the house is occupied.

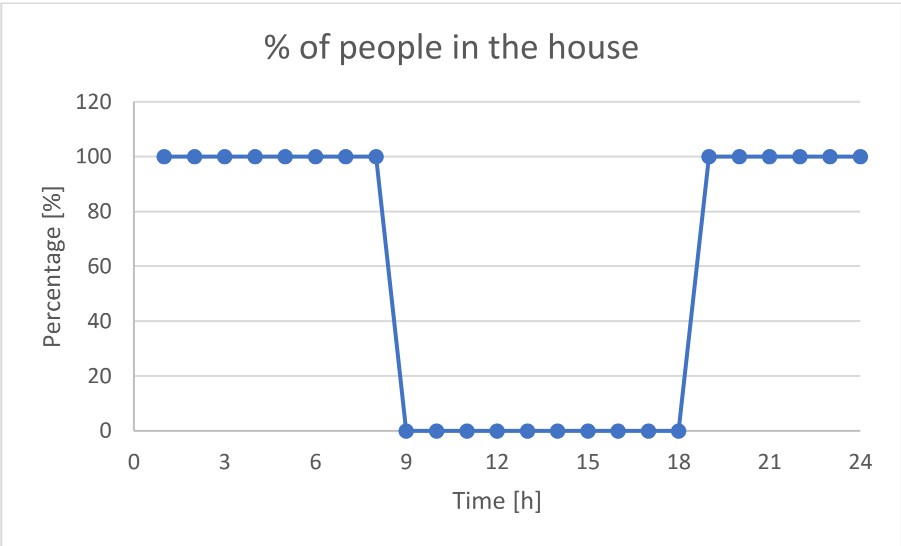

Figure 13 - % of people in the house during the day

2.2.4 Configuration 1. LISBON (Original Model – Multiple thermal zones) / Indoor temperature and Energy Demand

Having as input data all the assumptions made previously, through *Energy Plus* has been possible to obtain the results of indoor temperature and energy demand of the building. In this thesis project two scenarios have been chosen to show the results and to compare them in the different configurations:

- 1 day and 1 week in January
- 1 day and 1 week in August.

In this first configuration, the simulation has been done considering the building with multiple thermal zones and it has been the starting point and comparison for the next configurations.

Figure 20 shows the Energy demand of the original building during the whole year. Energy is expressed in [kWh] and the two colours blue and orange represent respectively the energy demand for heating and for cooling the thermal zones.

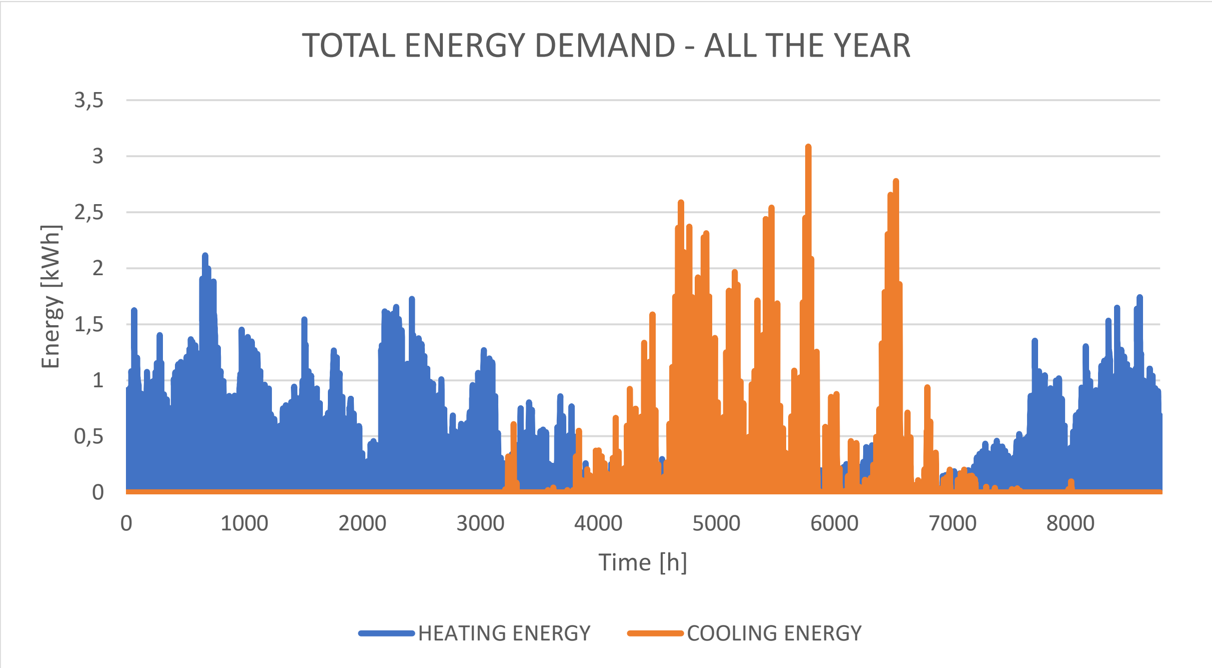

Figure 14 - Total Energy Demand – Multiple thermal zones (Lisbon/Original Model)

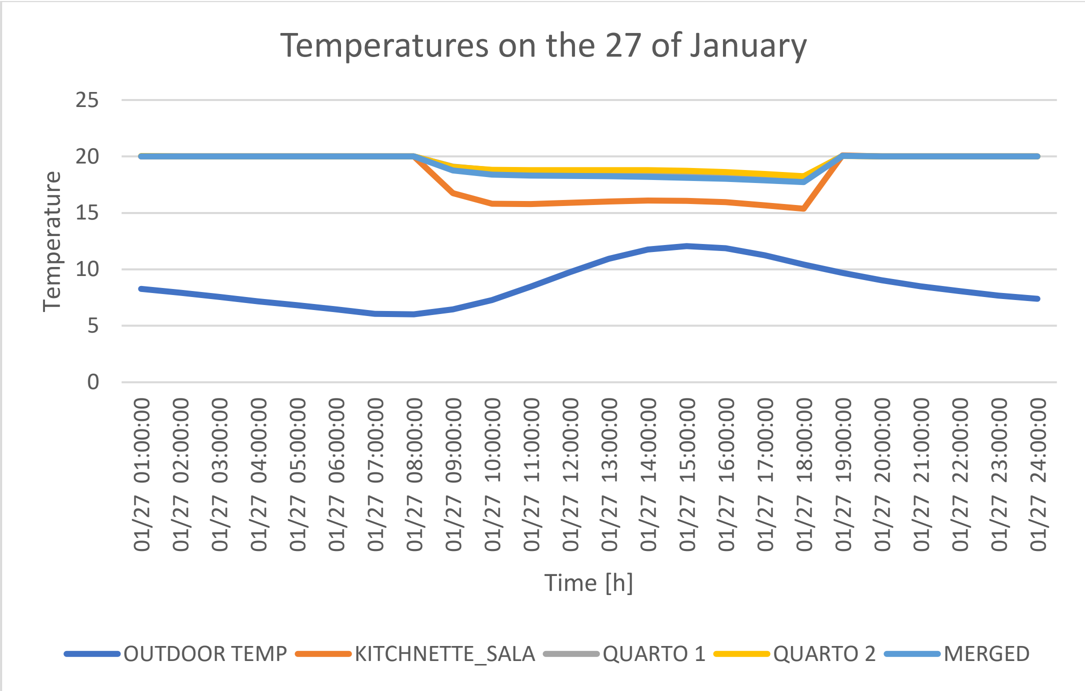

Figure 15 - Outdoor-Indoor Temperature 27th of January – Multiple thermal zones (Lisbon/Original Model)

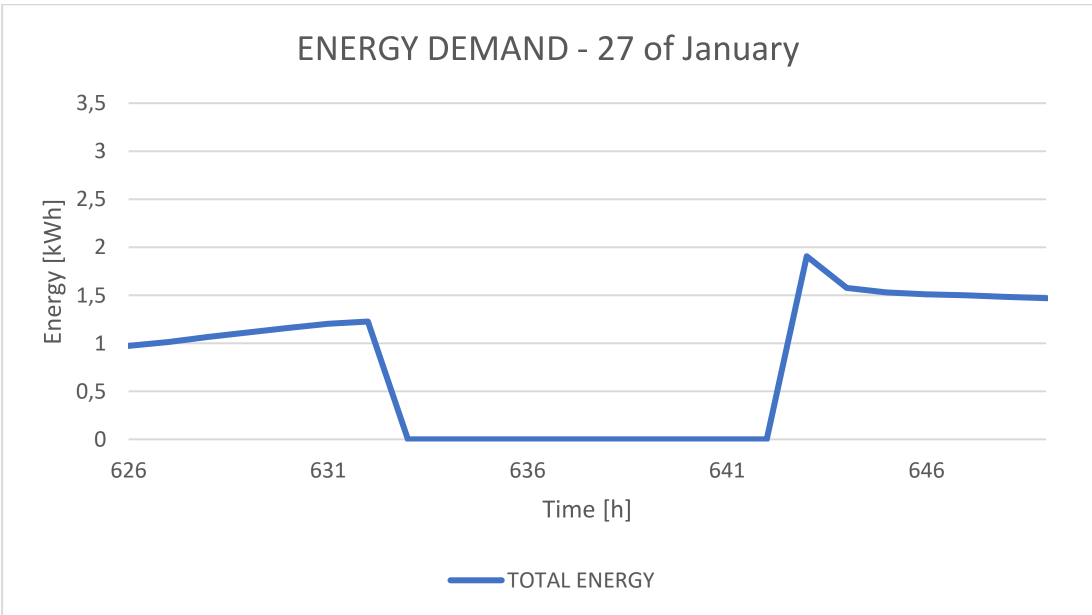

Figure 16 - Total Energy Demand 27th of January – Multiple thermal zones (Lisbon/Original Model)

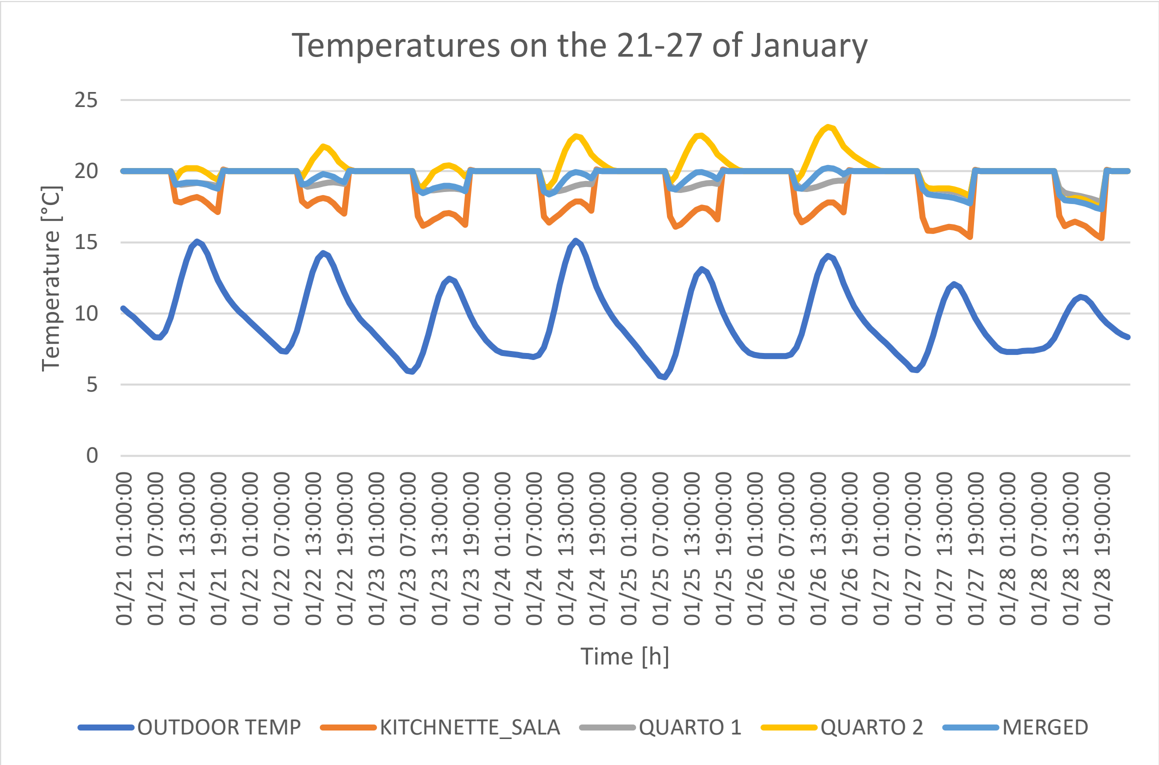

Figure 17 - Outdoor-Indoor Temperature 21-27th of January – Multiple thermal zones (Lisbon/Original Model)

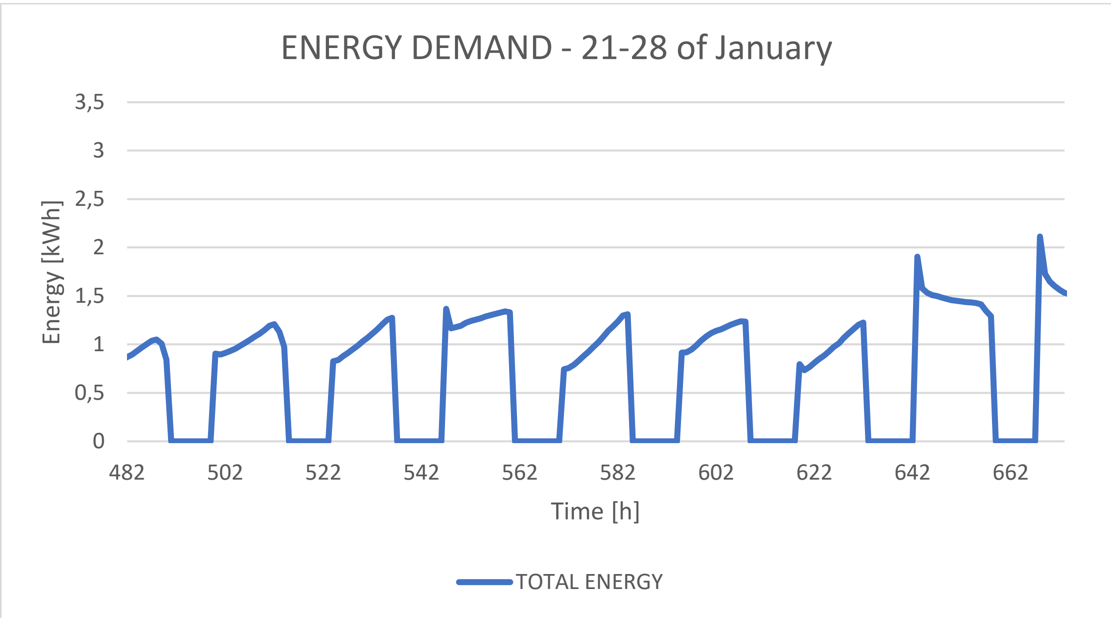

Figure 18 - Total Energy Demand 21-27th of January – Multiple thermal zones (Lisbon/Original Model)

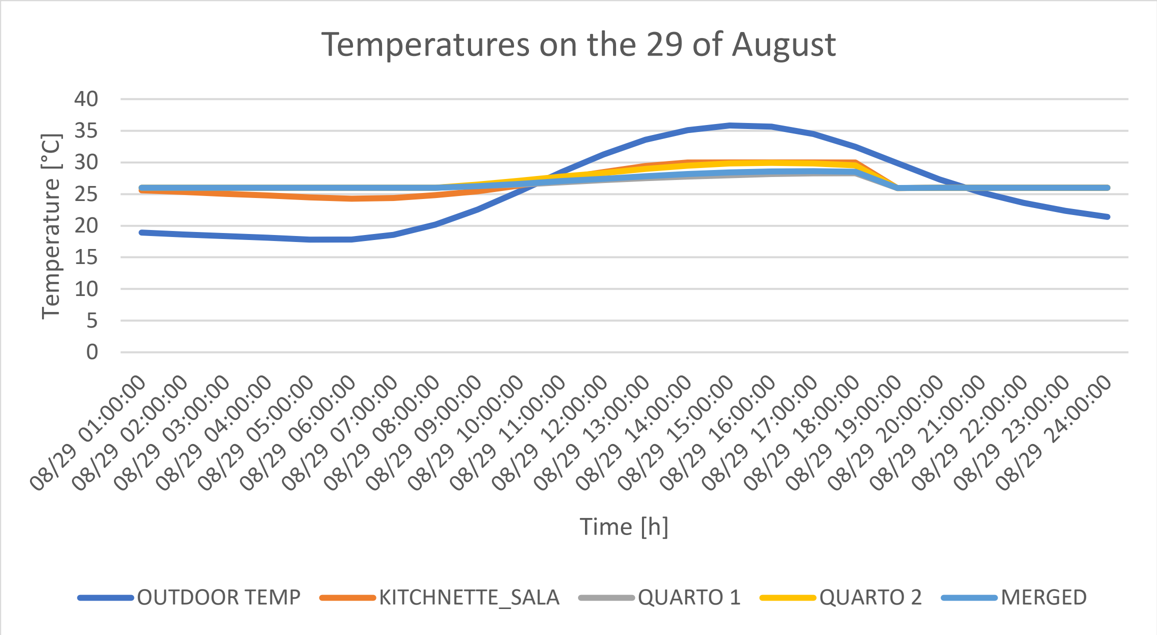

Figure 19 - Outdoor-Indoor Temperature 29th of August – Multiple thermal zones (Lisbon/Original Model)

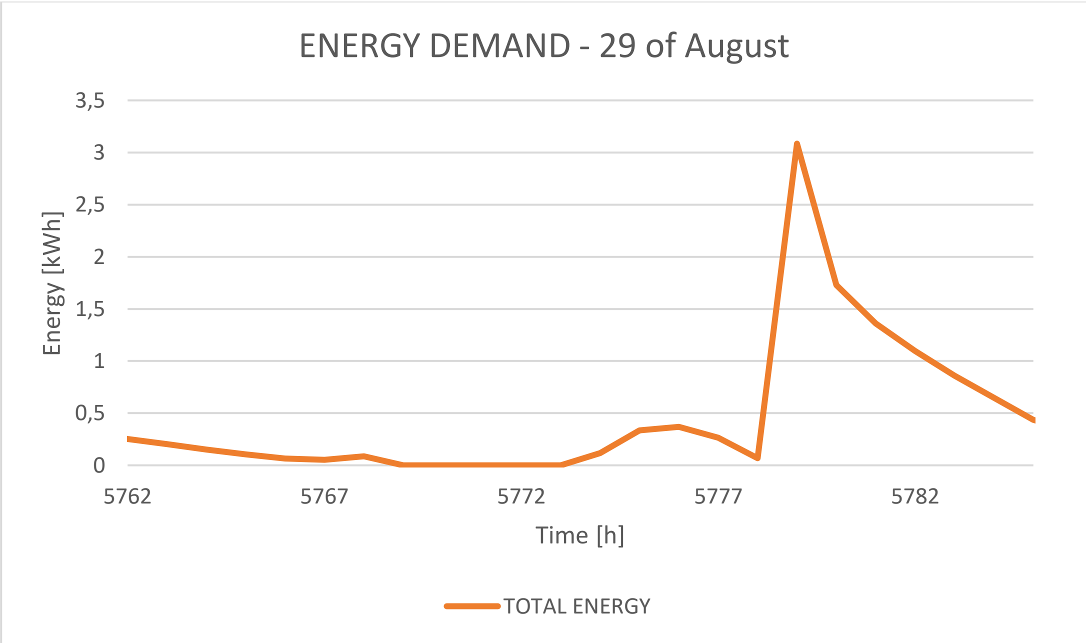

Figure 20 - Total Energy Demand 29th of August – Multiple thermal zones (Lisbon/Original Model)

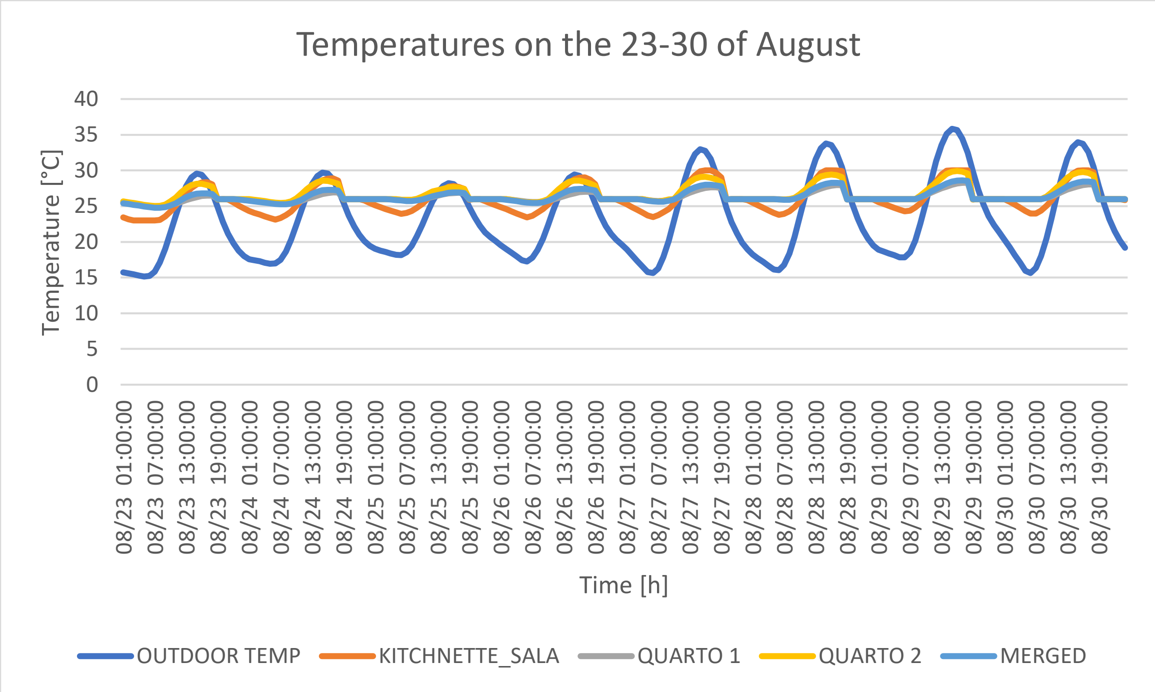

Figure 21 - Outdoor-Indoor Temperature 23-30th of August – Multiple thermal zones (Lisbon/Original Model)

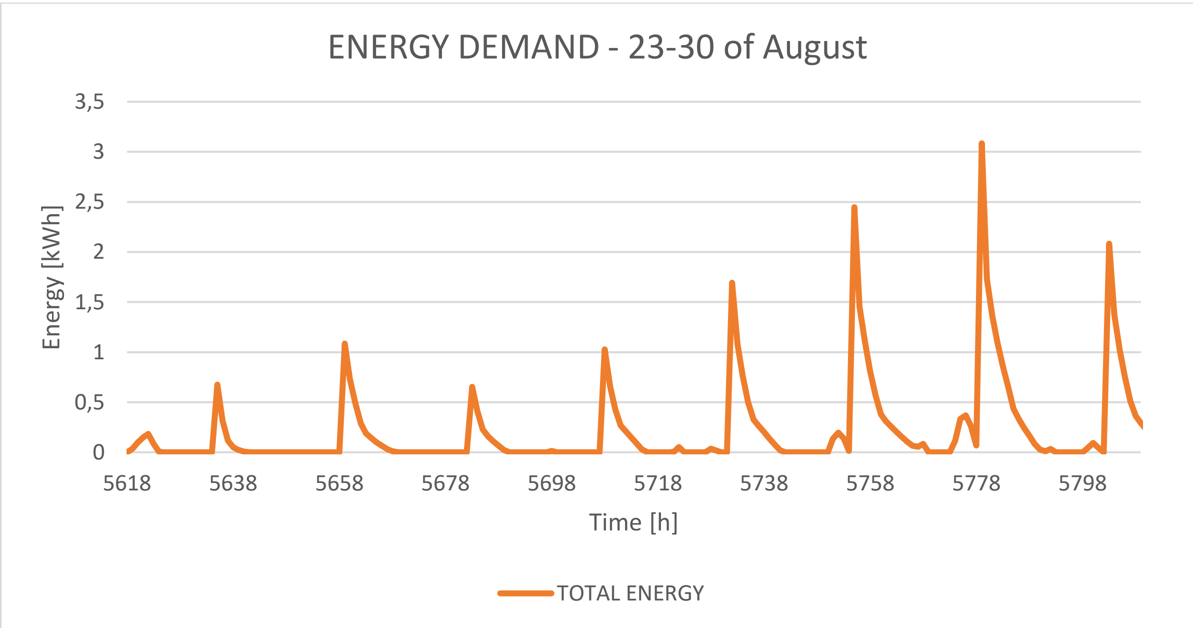

Figure 22 - Total Energy Demand 23-30th of August – Multiple thermal zones (Lisbon/Original Model)

2.2.5 Considerations

As can be seen from the graphs, the indoor temperatures of the various rooms are controlled by the thermostat set point temperatures which are generally more restrictive in the periods of the day when people occupy the apartment.

In January the peak of energy demand reaches a value of 1,9 kWh on the day 27th, while in August, the peak reaches a value of 3,1 kWh on the day 29th.

As for the energy demand necessary to keep the building at the set point temperature, the graphs almost always show energy peaks at 19:00, which is the moment when people return home and the temperature must be brought back within the values required by the thermostat and the heating or cooling system starts to work.

The results of Energy demand are expressed in the form of Total energy, that means heating and cooling energy in the period considered.

3. Data elaboration

After calculating the energy demand and indoor temperature of each room of the building in the different periods of the year with the original configuration, the first experiment was to switch from the "Multiple thermal zones" configuration to the "Single thermal zone" configuration to simplify simulations and control of the results.

The goal of this simplification is to be able to control and compare with the new configurations a single temperature profile, that is that of the single thermal zone, instead of the relative temperatures of each room. Also, for this new configuration the assumptions are the same as the previous one unlike that the building will be composed of the only thermal zone that groups all the rooms, heated or cooled at the same temperature, and the attic, which however is not equipped with air conditioning system.

In this chapter the results obtained from the simulations on different configurations will be shown, made both with the weather file of Lisbon and Turin; in particular, the temperature and energy results of the building before and after the retrofit of the envelope, before and after the change to a “Single thermal zone”, and energy consumption after the installation of a photovoltaic system on the roof will be compared.

Here all the configurations:

1. Lisbon / Original model – Multiple thermal zones;
2. Lisbon / Original model – Single thermal zone;
3. Lisbon / New model (Renovated) – Single thermal zone;
   + Photovoltaic system
4. Turin / Original model – Single thermal zone;
5. Turin / New model (Renovated) – Single thermal zone;
   + Photovoltaic system
6. Turin / New model (Renovated) – Energy Flexibility.

3.1 Configuration 2. LISBON (Original Model – Single thermal zone) / Indoor temperature and Energy Demand

Input data: same assumptions of Configuration 1; only a Single thermal zone

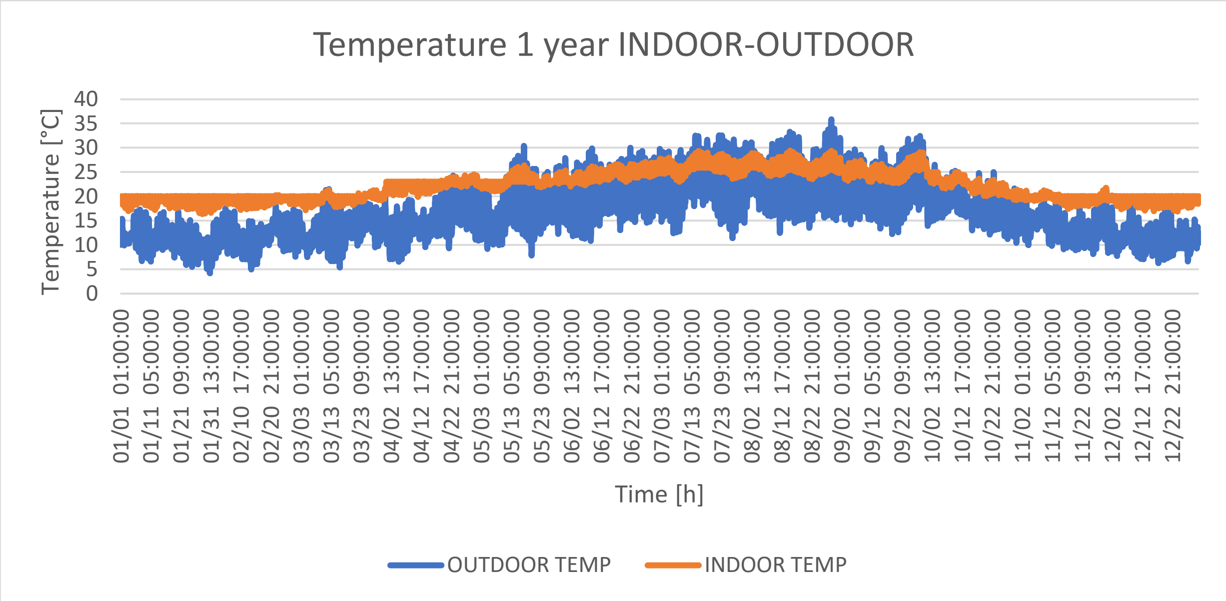

Figure 23 - Outdoor-Indoor Temperature All year – Single thermal zone (Lisbon/Original Model)

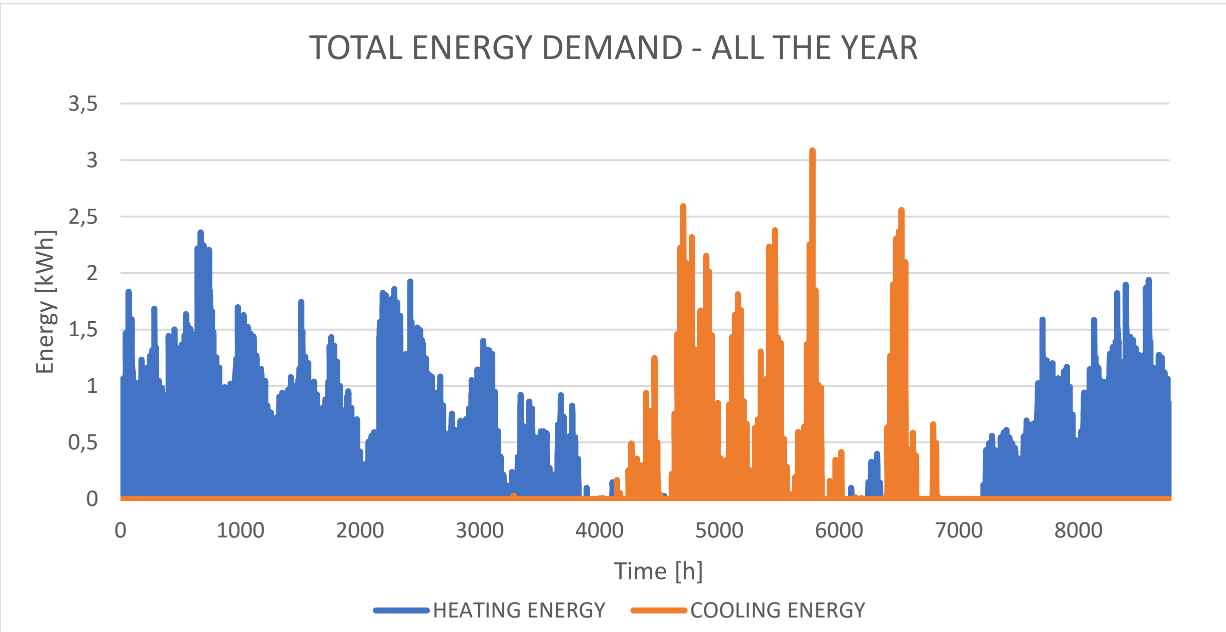

Figure 24 - Total Energy Demand – Single thermal zone (Lisbon/Original Model)

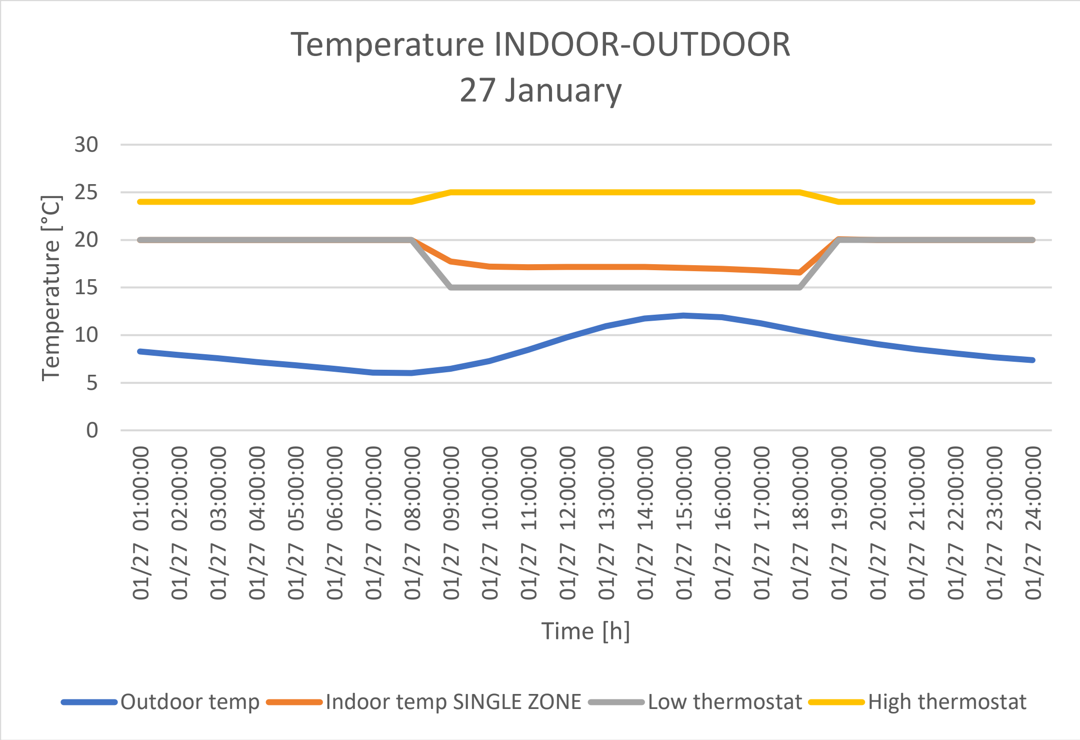

Figure 25 - Outdoor-Indoor Temperature 27th of January – Single thermal zone (Lisbon/Original Model)

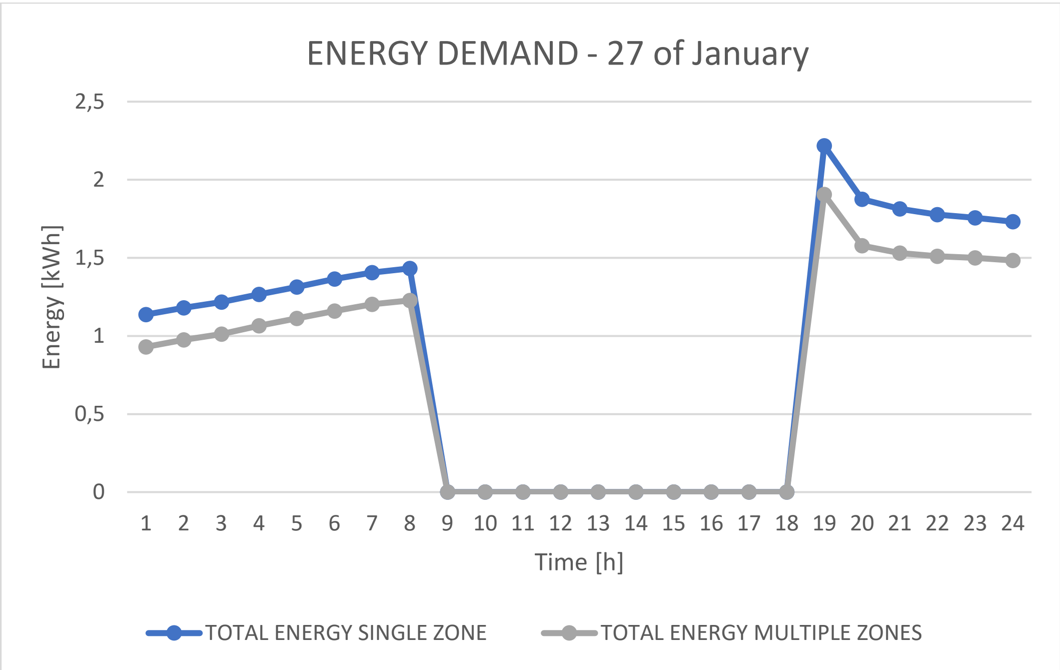

Figure 26 - Total Energy Demand 27th of January – Single thermal zone (Lisbon/Original Model)

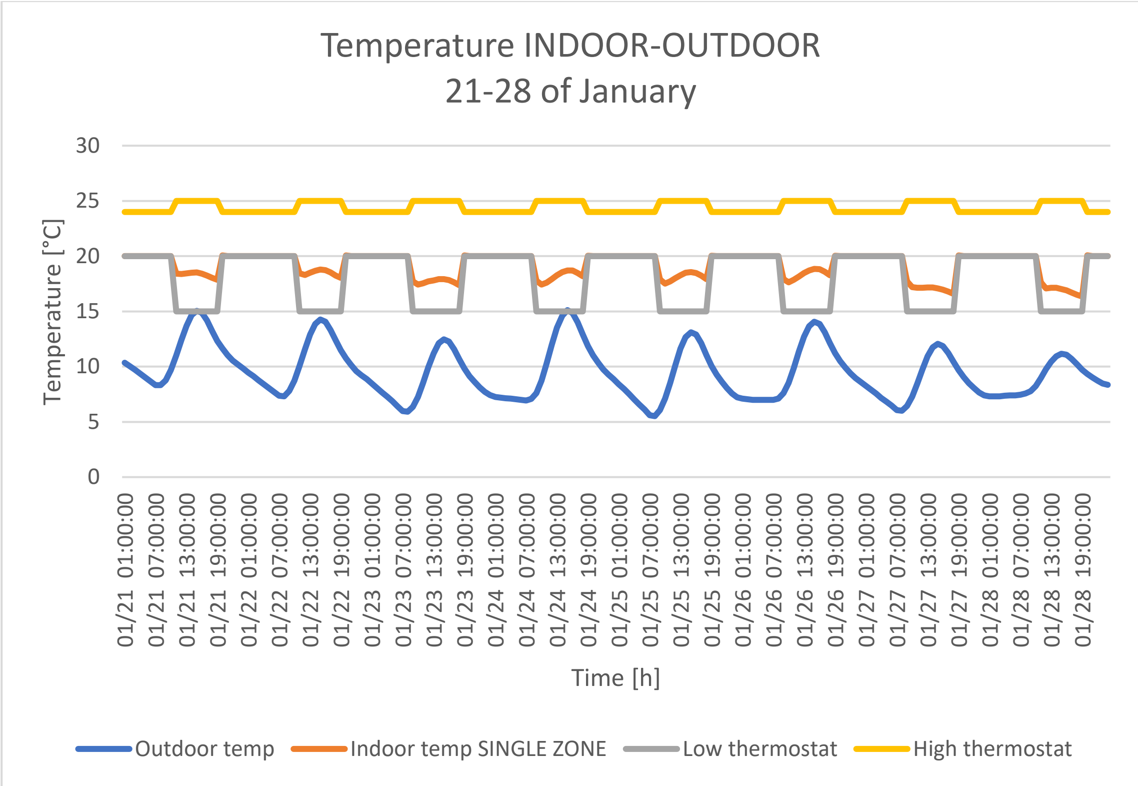

Figure 27 - Outdoor-Indoor Temperature 21-28th of January – Single thermal zone (Lisbon/Original Model)

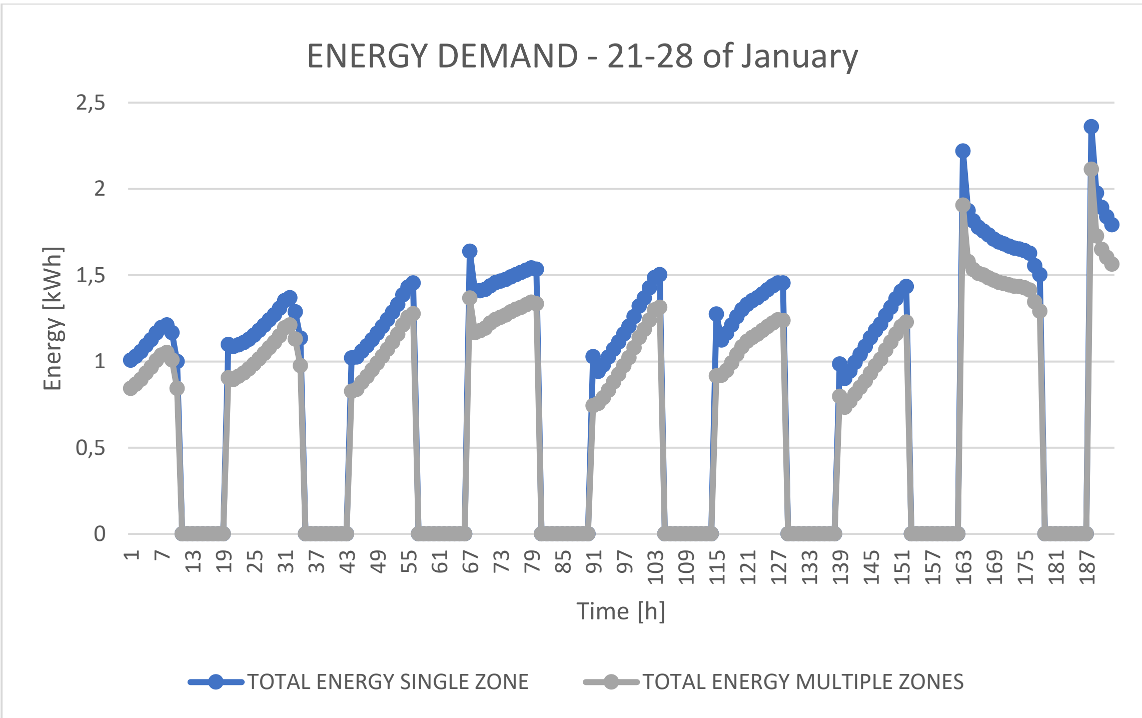

Figure 28 - Total Energy Demand 21-28th of January – Single thermal zone (Lisbon/Original Model)

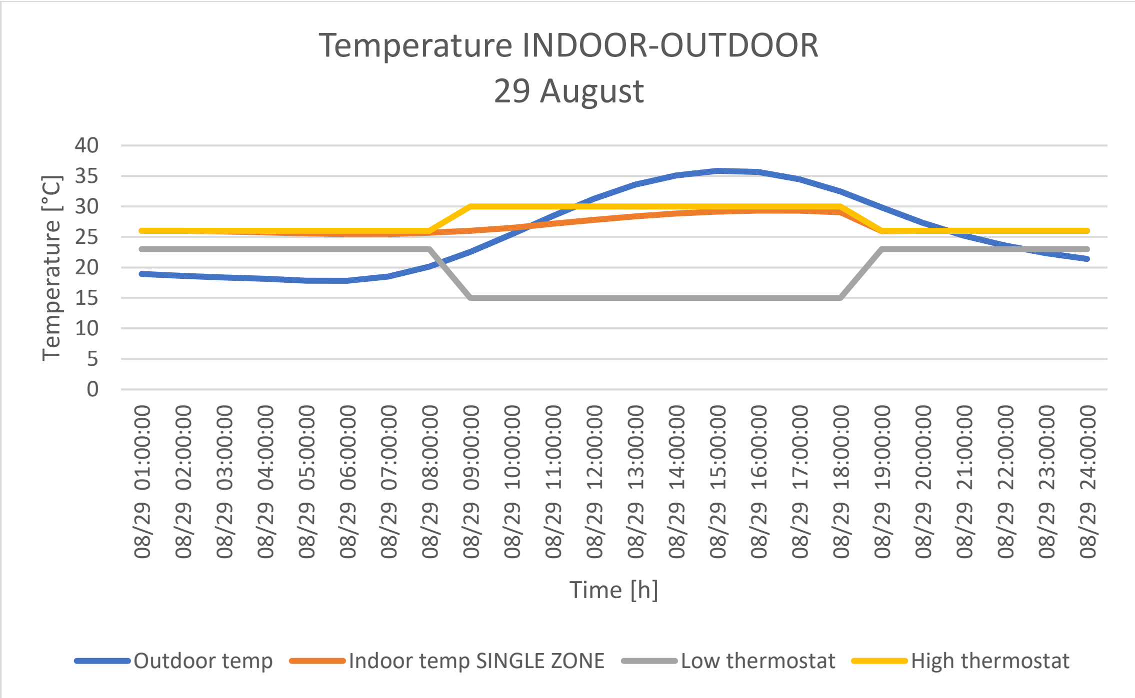

Figure 29 - Outdoor-Indoor Temperature 29th of August – Single thermal zone (Lisbon/Original Model)

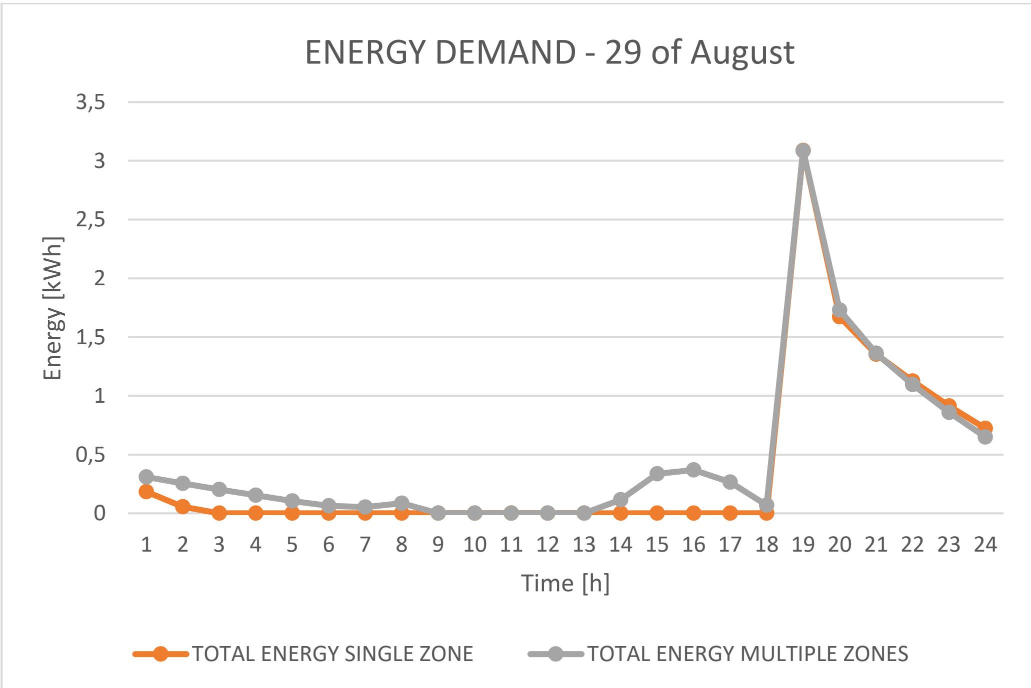

Figure 30 - Total Energy Demand 29th of January – Single thermal zone (Lisbon/Original Model)

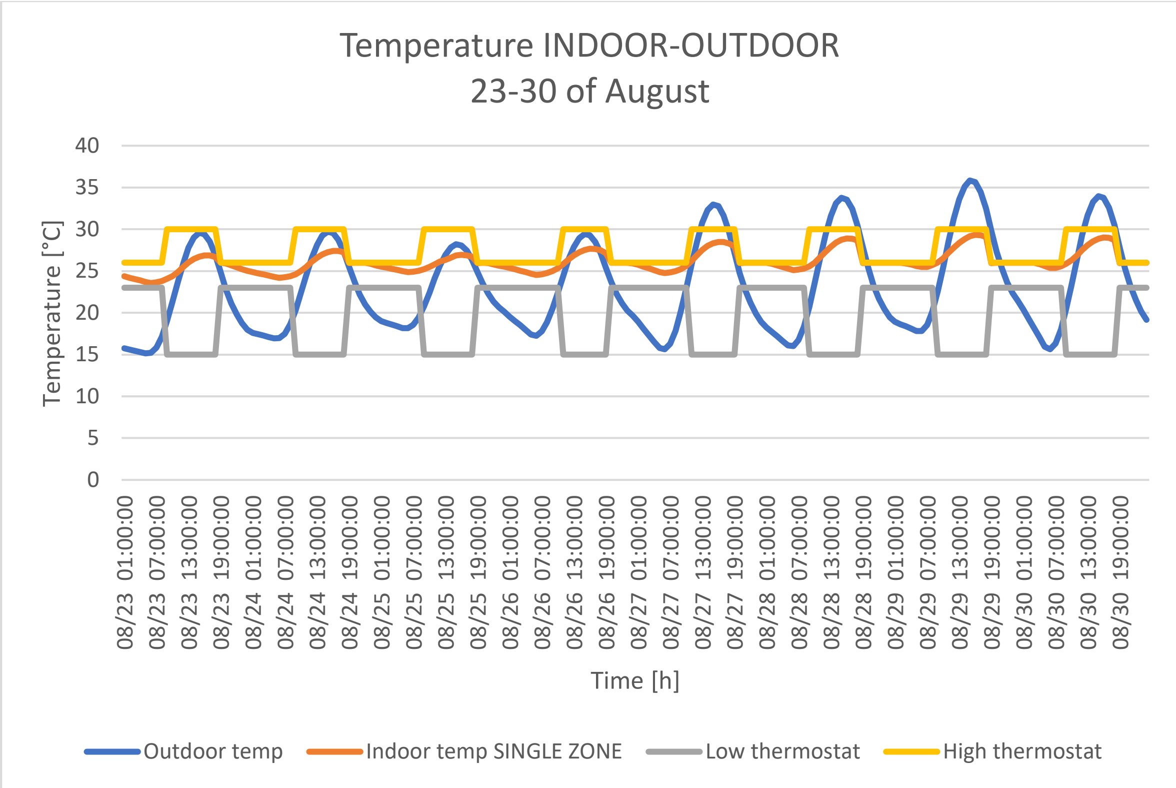

Figure 31 - Outdoor-Indoor Temperature 23-30th of August – Single thermal zone (Lisbon/Original Model)

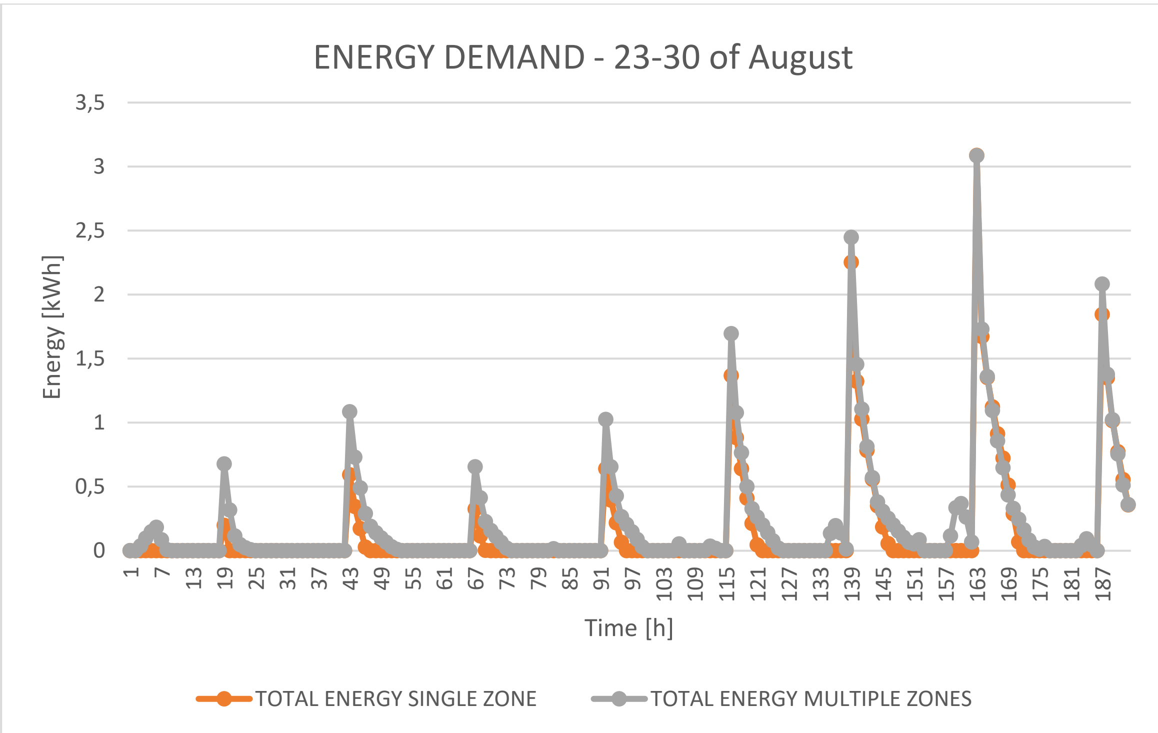

Figure 32 - Total Energy Demand 23-30th of August – Single thermal zone (Lisbon/Original Model)

3.1.1 Considerations

These results are related to the Configuration 2 (Lisbon / Original model – Single thermal zone) and they have been compared with the results of Configuration 1 (Lisbon / Original model – Multiple thermal zones).

The graphs show the indoor and outdoor temperature in the different scenarios over the year but has been possible to compare only the results about Energy demand of the two configurations because, in one period, the Configuration 1 with multiple thermal zones provides temperatures of each single room which should have been compared to only one temperature of the single thermal zone of Configuration 2, that it would not make sense.

Concerning temperatures, it is clearly visible that they are free to float within the range imposed by the thermostat that, in the period of the day between 09:00 and 19:00, is less strict; the thermostat require the temperature to be in a smaller range in the period when people occupy the house. *(Figure 25)*

Therefore, the energy demand relies on the path of the indoor temperature respect the thermostat setpoint during the day. Comparing the two configurations, the energy consumption are very similar but, even if the demand of energy of Configuration 1 is lover in some points *(Figure 32)*, it has been decided to carry on the simulations with the Single thermal zone configuration in order to simplify the calculations and to be able to compare also the temperatures.

3.2 Configuration 3. LISBON (Renovated Model – Single thermal zone)

The original building has been improved designing a retrofit of the envelope changing the stratigraphy of each component in order to reach the U-value required by the regulation. In this case, I took in consideration the standards in force for the Italian buildings, especially about renovation of existing buildings *(see section 1.3.4, Table 2).*

The main intervention was to add an external coat of XPS of 10 cm in the exterior walls and both to the pitched roof and plan roof to ensure the building a proper insulation and to lower the loss of heat; the floor that separates the apartment at the ground floor and the one at the first floor was improved and for the roofs has been created an efficient envelope that was missing in the original model.

The assumptions were the same of the other configurations like location (weather file), lights, people occupation, equipment and people's metabolic activity grouped as "Electric Equipment" producing 4 W/m² during all day.

3.2.1 Envelope and Components

Exterior wall				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Plaster	2	1900	1046	1,3
Insulation (XPS)	10	29	1300	0,03
Brick	12	760	1000	0,15
Air	6	1,2		0,026
Brick	22	633	790	0,42
Vapor brake				
Plaster	2	1900	1046	1,3
	U-Factor [W/m² K]			0,19

Table 9. Exterior walls stratigraphy (Renovated Building)

Interior wall				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Plaster	2	1900	1046	1,3
Brick	7	818	790	0,37
Plaster	2	1900	1046	1,3

Table 10. Interior walls stratigraphy (Renovated Building)

Floor				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Concrete	20	2300	1000	2
Insulation (XPS)	10	29	1300	0,03
Acustic panel (rock wool)	3	70		0,037
Vapor brake				
Concrete	8	700	1000	1,3
Ceramic floor	1,5	2300	1000	1,3

Table 11. Floor stratigraphy (Renovated Building)

Ceiling				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Wood panel	3	900	820	0,34
Wood panel	12	900	820	0,34
Insulation (Mineral wool)	8	50	1100	0,04
Plasterboard	1	900	820	0,25
	U-Factor [W/m² K]			0,538

Table 12. Ceilings stratigraphy (Renovated Building)

Roof				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Roof tiles	5	907	1000	0,41
Plate	4	900	820	0,025
Waterproof plastic				
Insulation (XPS)	10	29	1300	0,03
Vapor brake				
Wood panel	3	900	820	0,34
Wood beam	30	608	1630	0,15
	U-Factor [W/m² K]			0,16

Table 13. Roof stratigraphy (Renovated Building)

Plan Roof				
Layer	Depth [cm]	Density [kg/m³]	Specific heat [J/kg K]	Conductivity [W/m K]
Plaster	2	1900	1046	1,3
Lightweight Concrete	15	1280	840	0,53
Waterproof plastic				
Insulation (XPS)	10	29	1300	0,03
Vapor brake				
Wood panel	3	900	820	0,34
Wood beam	30	608	1630	0,15
	U-Factor [W/m² K]			0,18

Table 14. Plan Roof stratigraphy (Renovated Building)

Window		
Layer	Depth [cm]	Conductivity [W/m K]
Glass	0,6	0,9
Air	1,2	0,026
Glass	0,4	0,9
	U-Factor [W/m² K]	1,32

Table 15. Windows stratigraphy (Renovated Building)

3.2.2 Indoor temperature and Energy Demand (Comparison between Original building and Renovated Building)

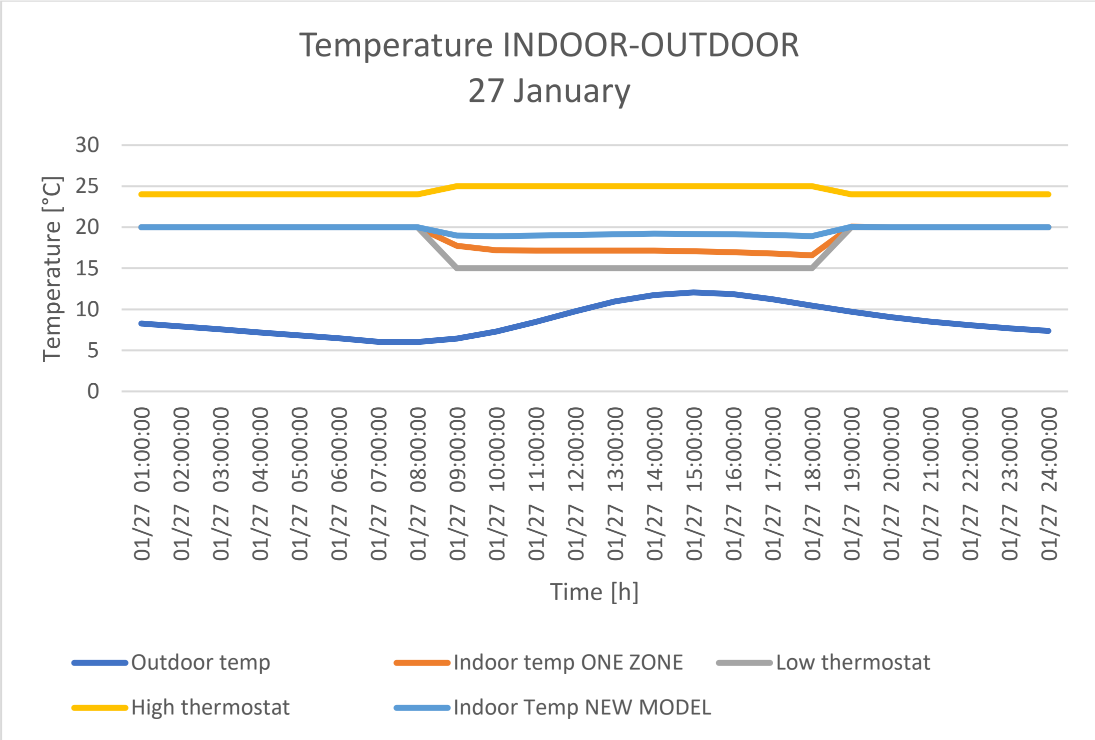

Figure 33 - Outdoor-Indoor Temperature 27th of January – Single thermal zone (Lisbon/Renovated Model)

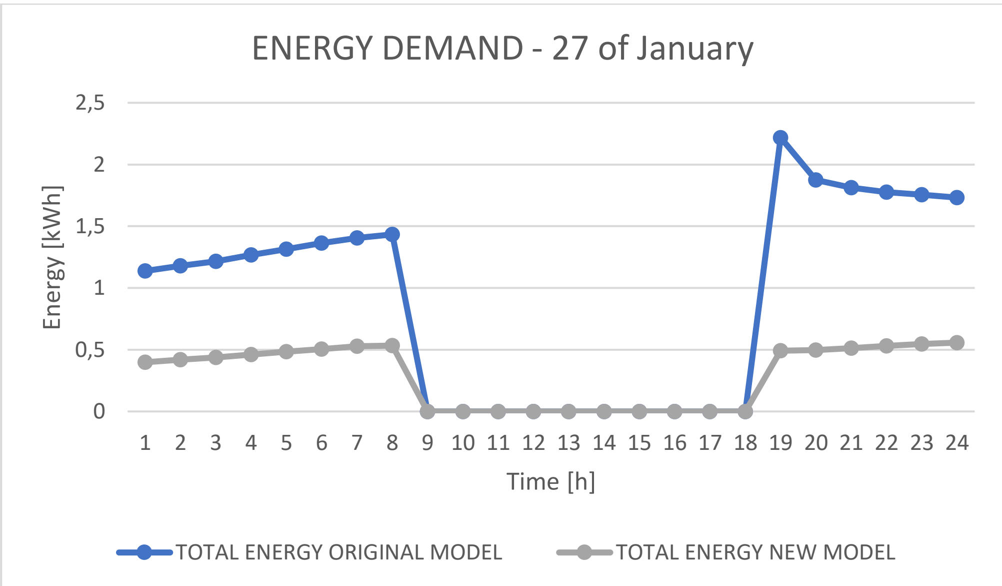

Figure 34 - Total Energy Demand 27th of January – Single thermal zone (Lisbon/Renovated Model)

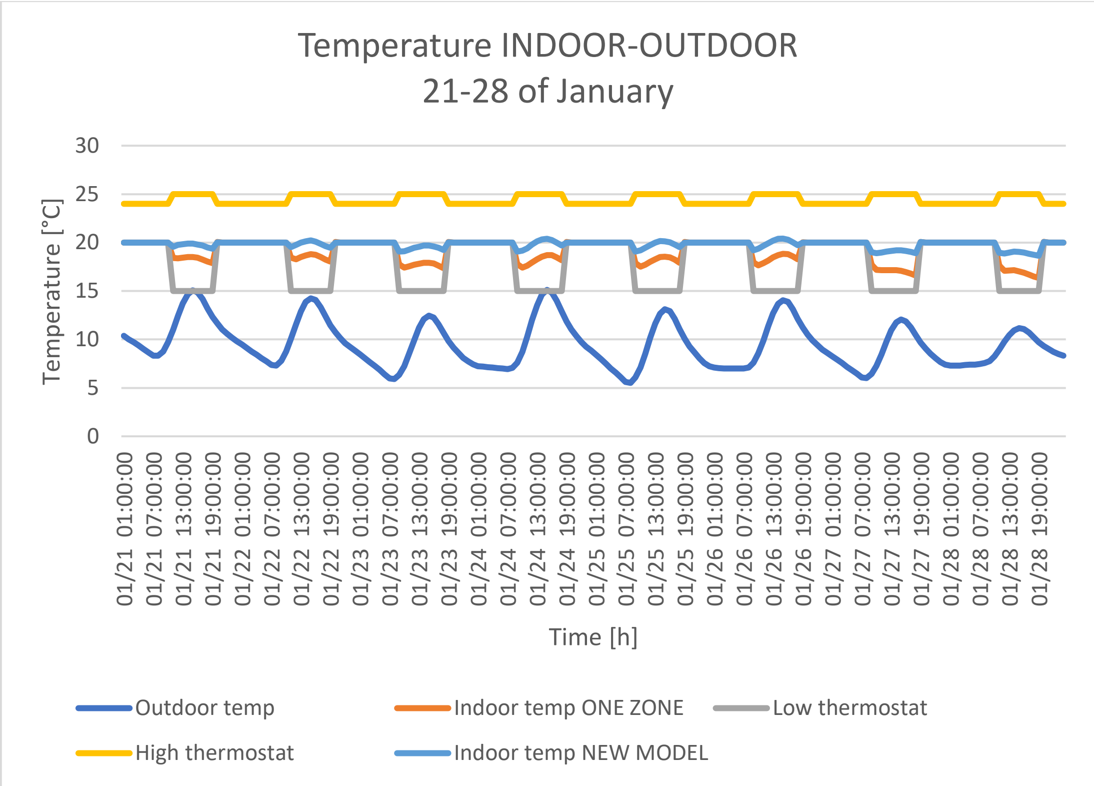

Figure 35 - Outdoor-Indoor Temperature 21-28th of January – Single thermal zone (Lisbon/Renovated Model)

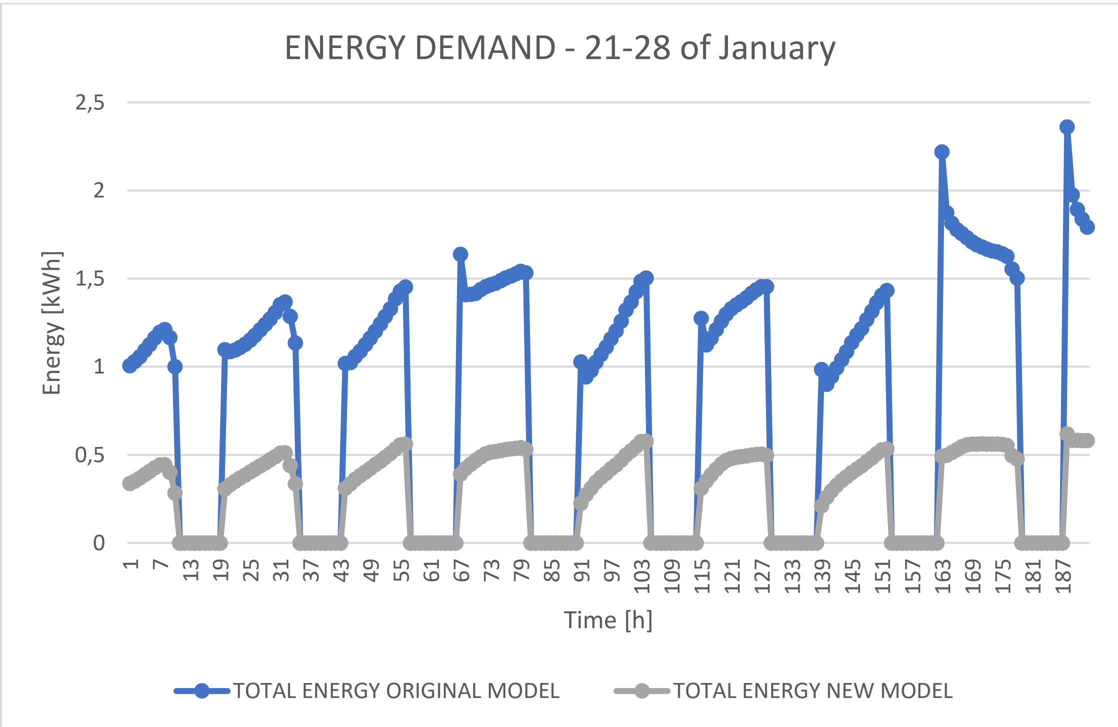

Figure 36 - Total Energy Demand 21-28th of January – Single thermal zone (Lisbon/Renovated Model)

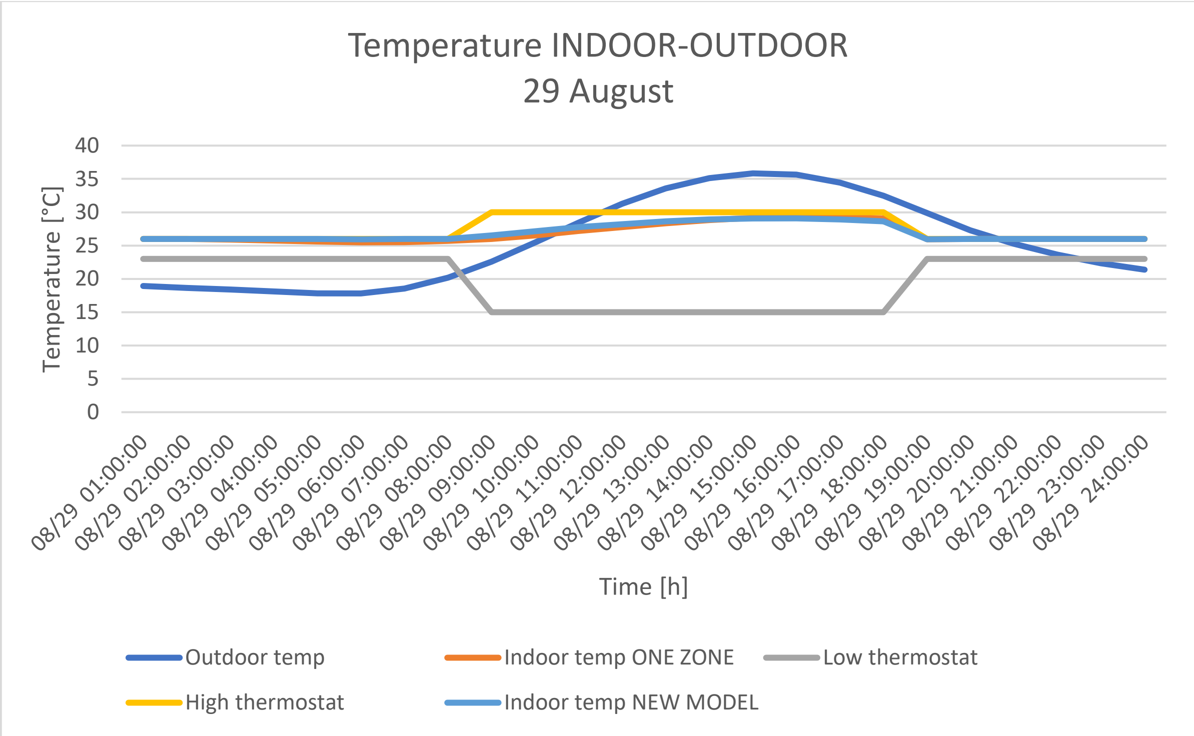

Figure 37 - Outdoor-Indoor Temperature 29th of August – Single thermal zone (Lisbon/Renovated Model)

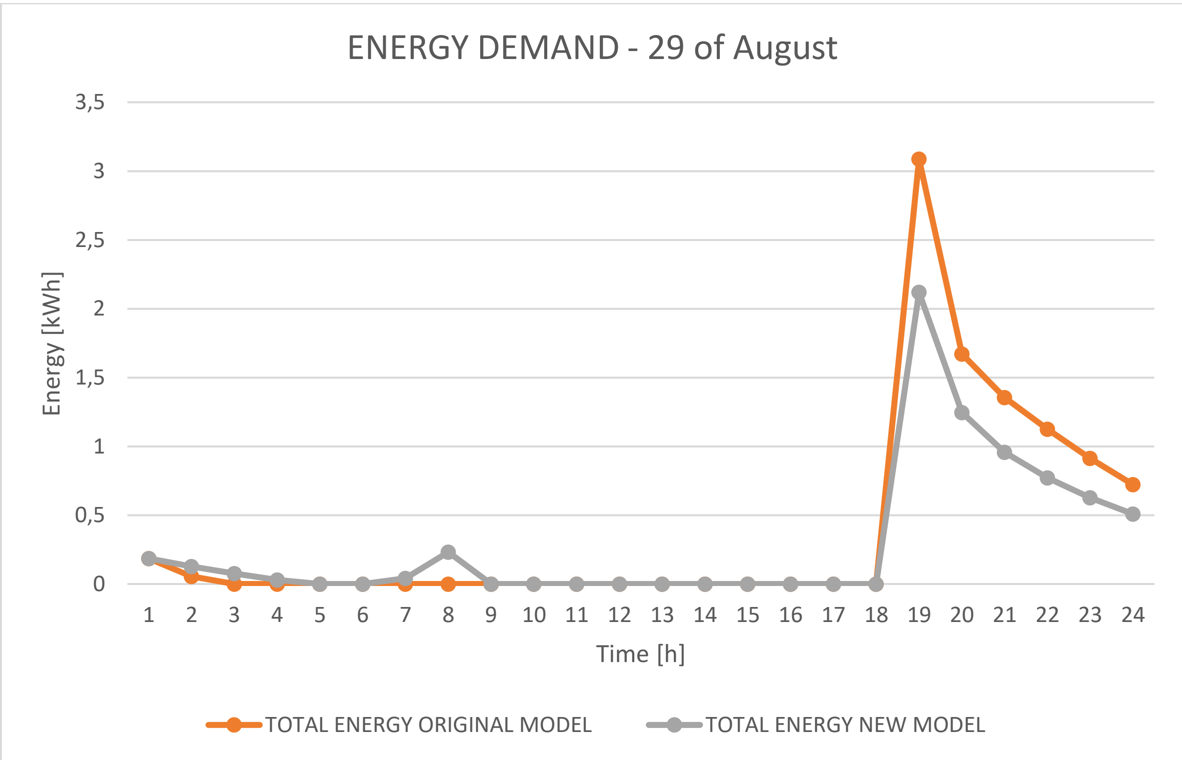

Figure 38 - Total Energy Demand 29th of August – Single thermal zone (Lisbon/Renovated Model)

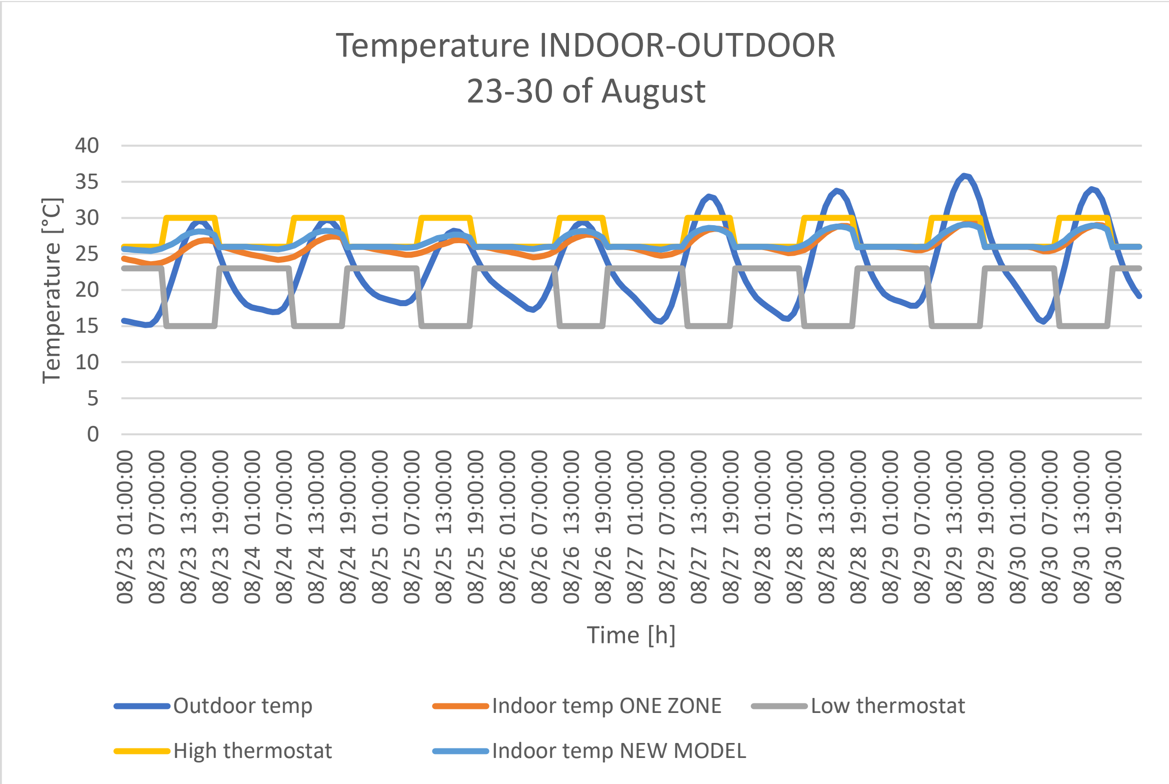

Figure 39- Outdoor-Indoor Temperature 23-30th of August – Single thermal zone (Lisbon/Renovated Model)

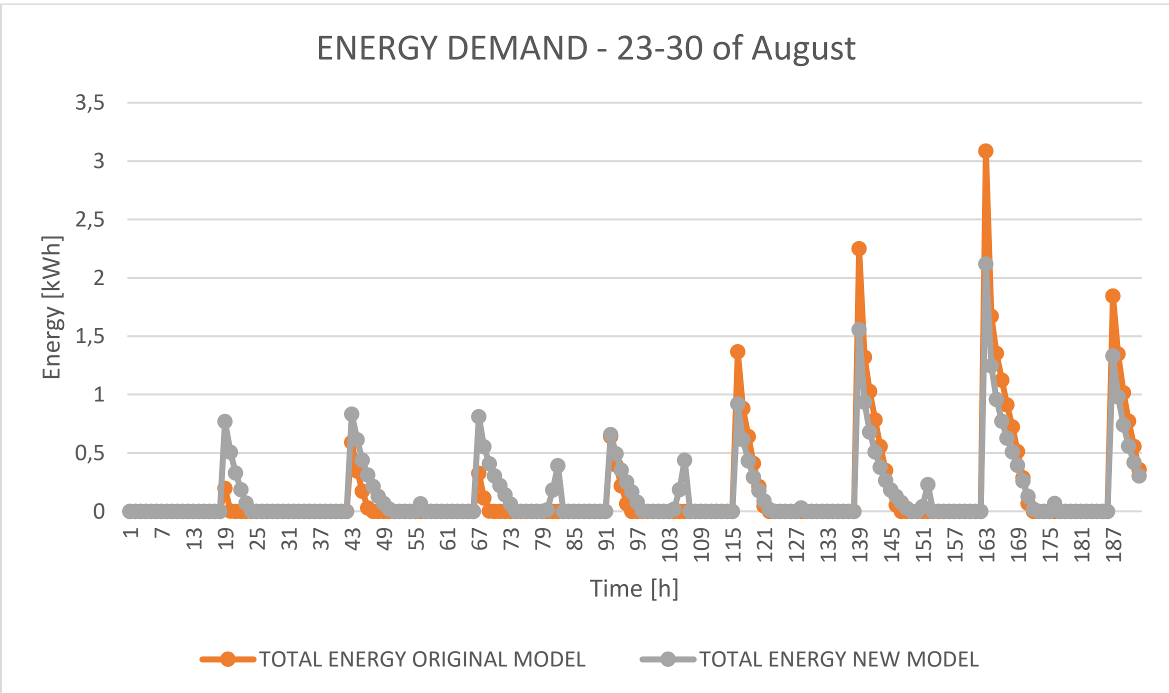

Figure 40 - Total Energy Demand 23-30th of August – Single thermal zone (Lisbon/Renovated Model)

3.2.3 Considerations

These results are related to the Configuration 3 (Lisbon / Renovated model – Single thermal zone) and they have been compared with the results of Configuration 2 (Lisbon / Original model – Single thermal zone); the graphs compare both indoor and outdoor temperatures and energy demand over the year in the different periods analysed.

In January, configuration 3 (Renovated model) provides indoor temperature levels much greater than the indoor temperatures of Configuration 2 (Original model) and consequently the energy demand for heating is lower; in fact, in Configuration 2 the values stand between 1-2.4 kWh while after retrofit they stand between 0.2-0.6 kWh. *(Figure 36)*

In August instead, the indoor temperatures of the two configurations are very similar but, due to the increased thermal mass of the renovated building, the heat loss are lower, and the heat stored tends to stay inside; that's why in some points the energy demand for cooling is higher in the new model instead of the old model. *(Figure 40)*

COLD PERIOD	
TOT OLD [kWh]	TOT NEW [kWh]
2573,96	833,32
DIFFERENCE	1740,65
% SAVINGS	67,6%

WARM PERIOD	
TOT OLD [kWh]	TOT NEW [kWh]
288,71	352,33
DIFFERENCE	-63,62
% SAVINGS	-22,0%

TOTAL ENERGY [kWh]	1185,64
AREA [m²]	63,17
ENERGY [kWh/m²]	18,77

Table 16. Energy accounts of the building in a year (Lisbon)

Looking at the energy accounts in both periods of the year it is clear that in the warm period, which is the period when energy is used for cooling, the renovation did not lead to an higher efficiency but, on the other hand, in the cold period the percentage of savings is around 67% making the building energy-efficient with an energy demand of about 19 kWh/m^2.

3.2.4 Photovoltaic system

Part of the retrofit was also the installation of a photovoltaic system on two surfaces: the plan roof above the kitchen and the clove of pitched roof heading the south direction.

Once given the surfaces where to install the PV system, *EnergyPlus* calculated automatically the area and the generated power according to the weather file and location.

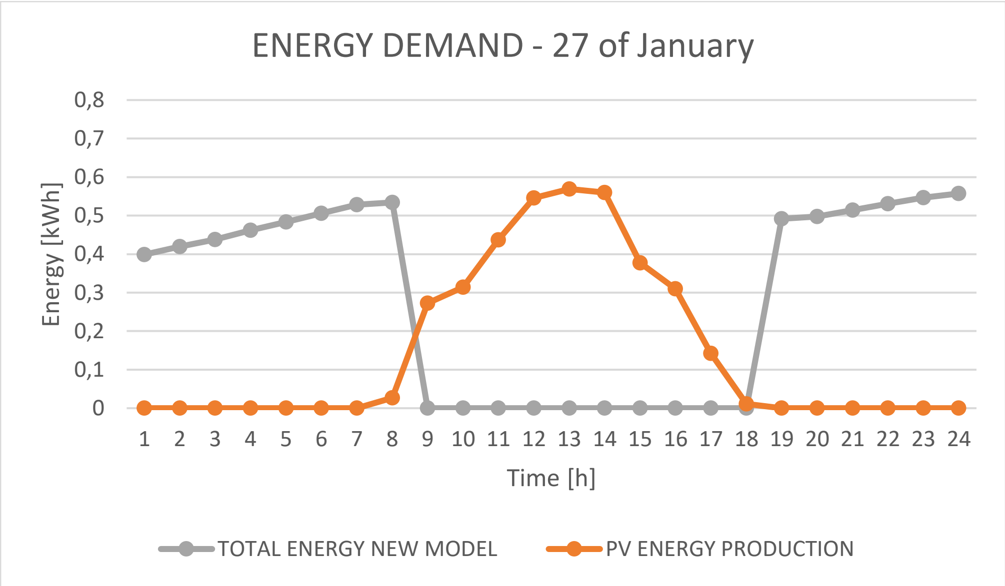

Figure 41 - PV energy production 27th of January (Lisbon/Renovated Model)

27th of January	
Energy Demand [kWh]	Energy Produced [kW]
6,91	3,57

Table 17. PV energy production 27th of January (Lisbon/Renovated Model)

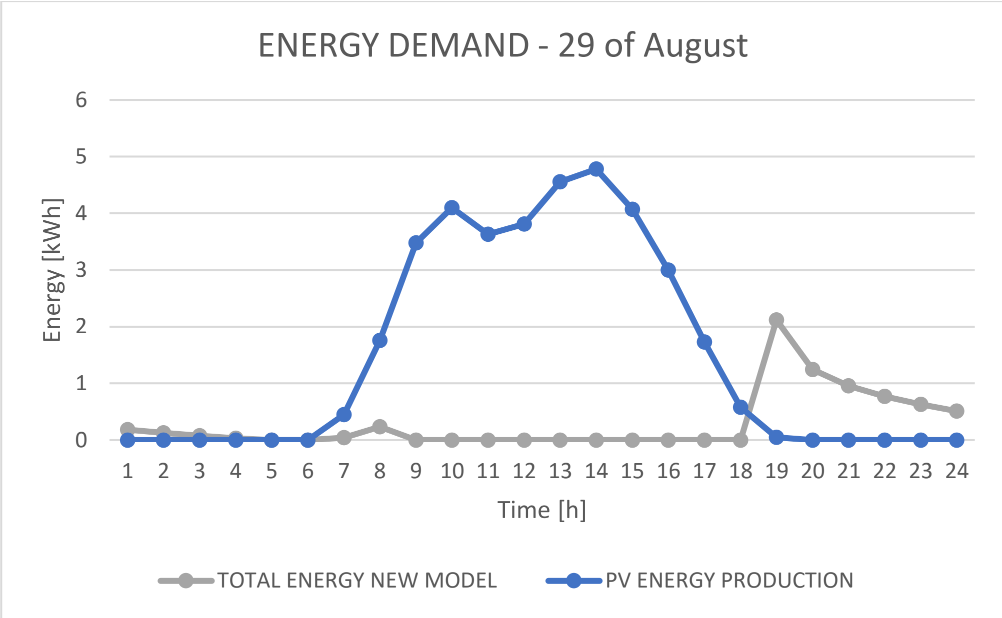

Figure 42 - PV energy production 29th of August (Lisbon/Renovated Model)

29th of August	
Energy Demand [kWh]	Energy Produced [kW]
6,92	35,99

Table 18. PV energy production 29th of August (Lisbon/Renovated Model)

All the year	
Energy Demand [kWh]	Energy Produced [kW]
1185,64	13298,98

Table 19. PV energy production All year (Lisbon/Renovated Model)

The energy produced over the year from the PV system is very much higher than the energy demand of the building but, as shown by the graphs (*Figure 41,42*), the energy produced can cover only a little part of the energy demand during the day. Indeed, being a building of residential use, people is not at home when the production of energy reaches the peak and when people occupy the house, the production is, low in the morning and zero from 18-19 pm.

3.3 Configuration 4. TURIN (Original Model – Single thermal zone) / Indoor temperature and Energy Demand

Input data: same assumptions of Configuration 2; only a Single thermal zone; weather file: Turin

Location: Turin

Latitude: 45.07 deg

Longitude : 7.68 deg

Elevation: 239 m

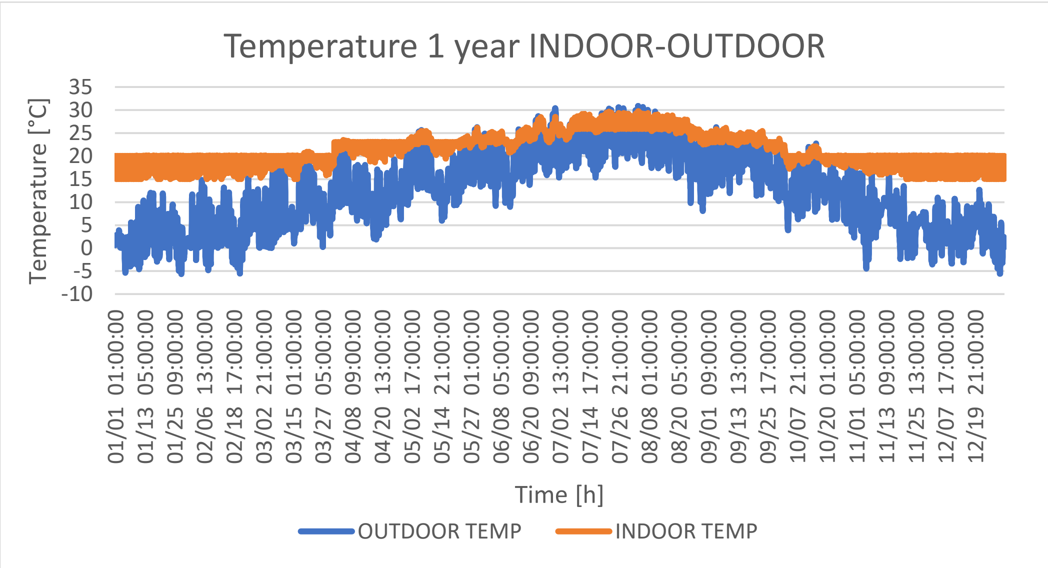

Figure 43 - Outdoor-Indoor Temperature All year – Single thermal zone (Turin/Original Model)

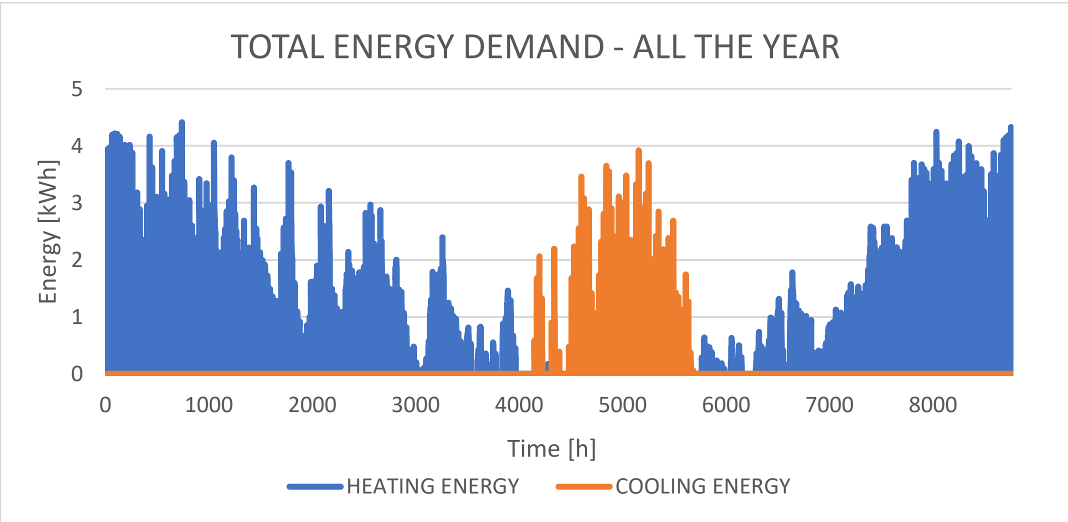

Figure 44 - Total Energy Demand – Single thermal zone (Turin/Original Model)

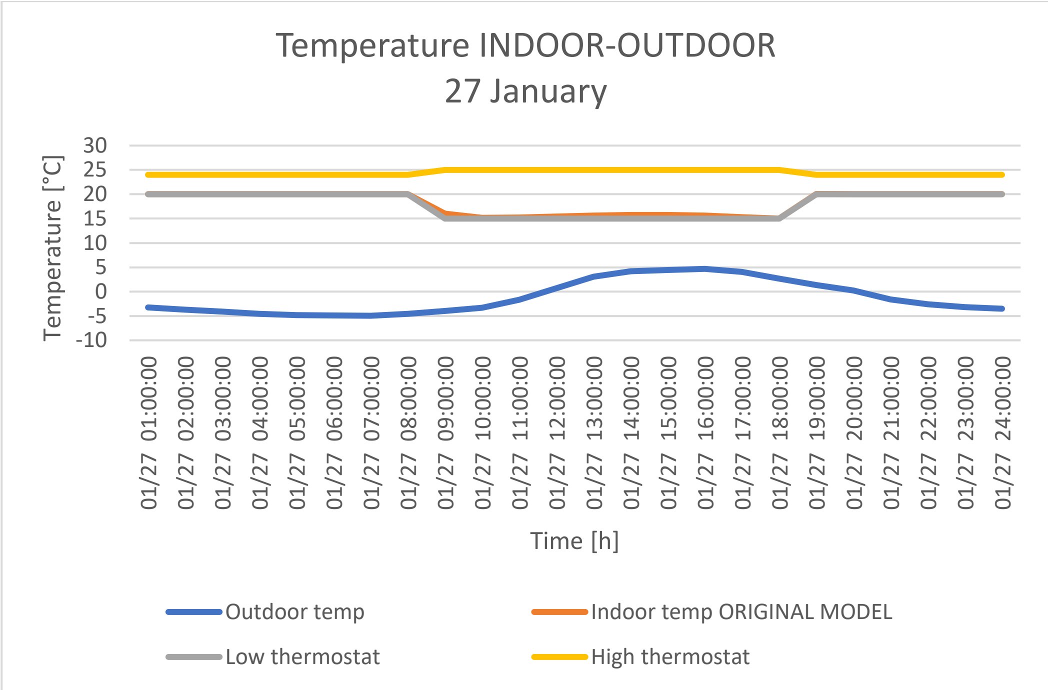

Figure 45 - Outdoor-Indoor Temperature 27th of January – Single thermal zone (Turin/Original Model)

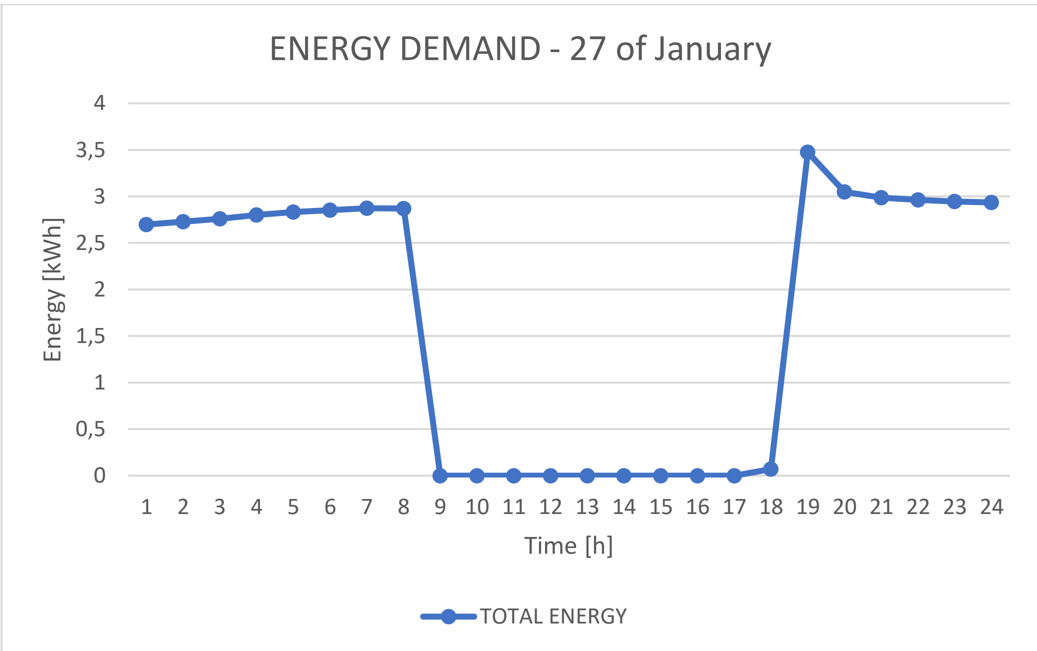

Figure 46 - Total Energy Demand 27th of January – Single thermal zone (Turin/Original Model)

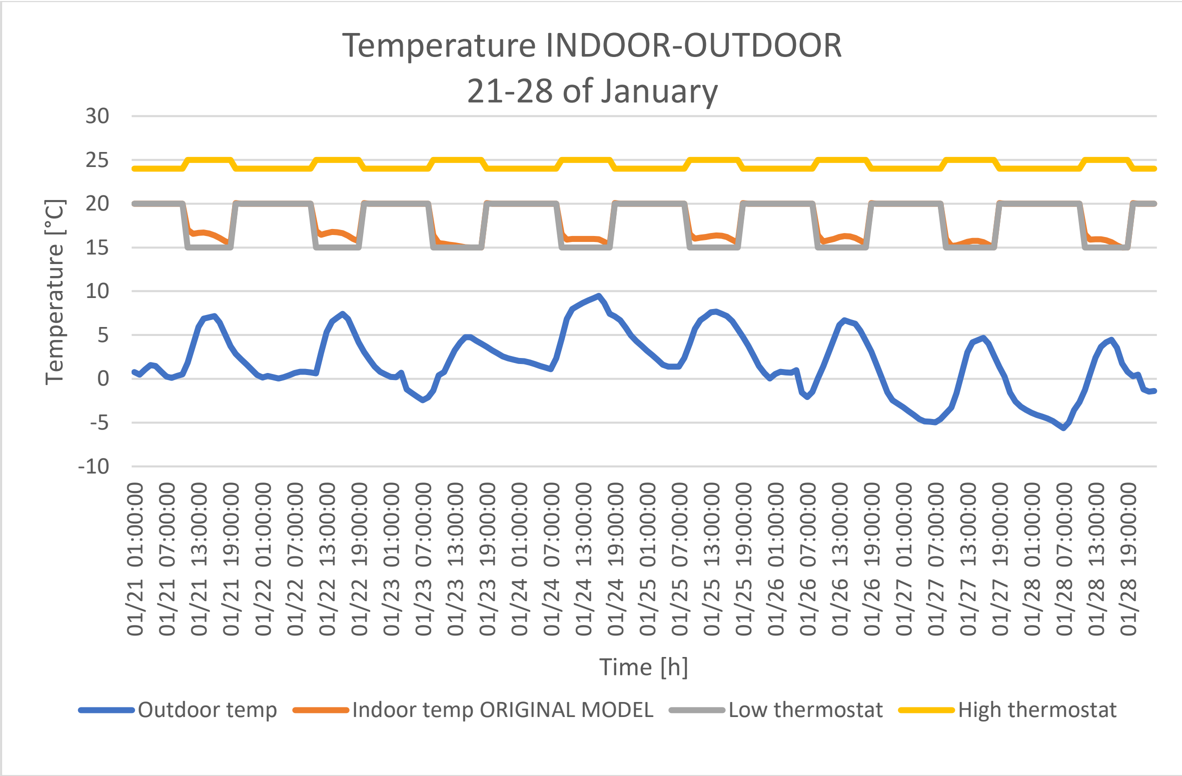

Figure 47 - Outdoor-Indoor Temperature 21-28th of January – Single thermal zone (Turin/Original Model)

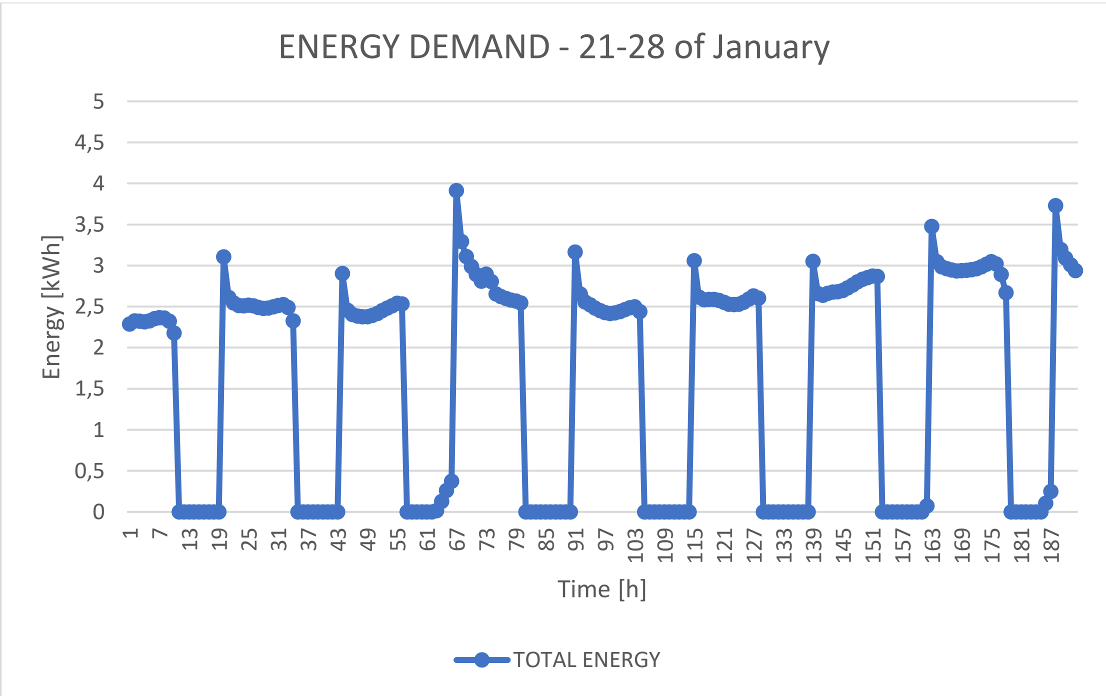

Figure 48 -Total Energy Demand 21-28th of January – Single thermal zone (Turin/Original Model)

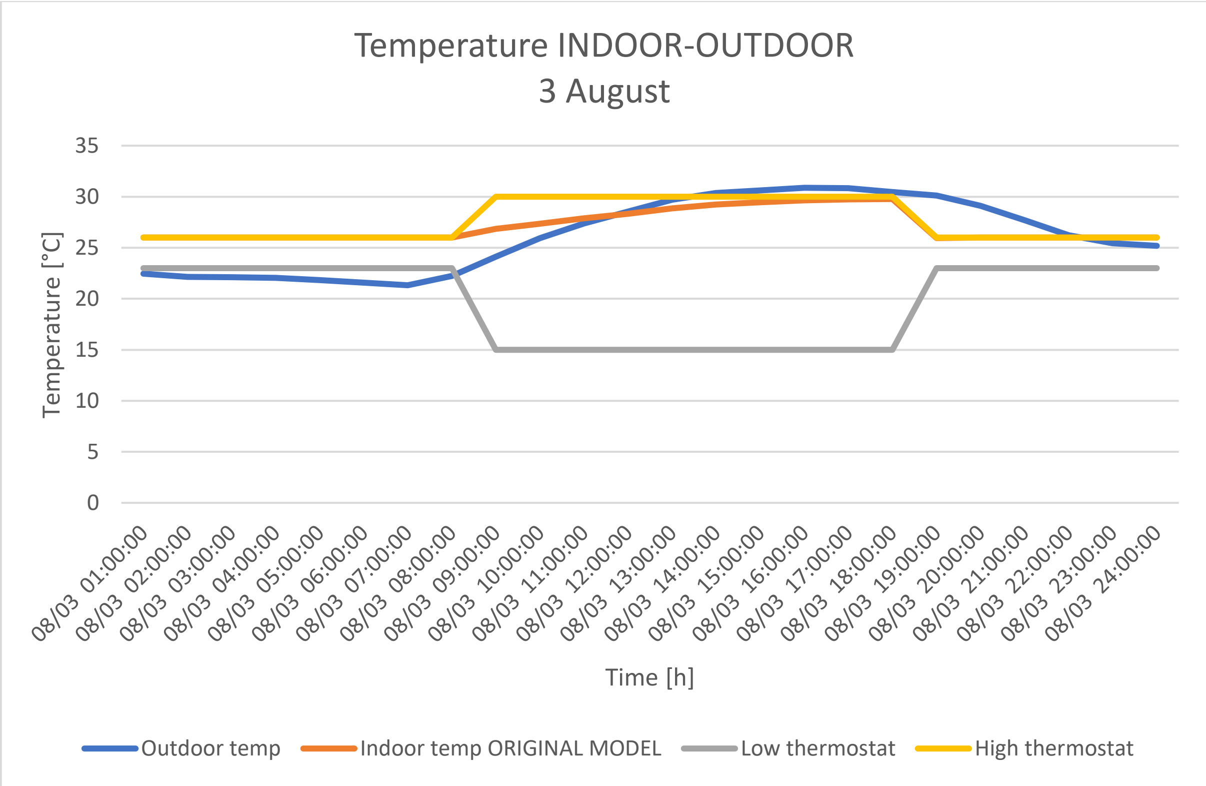

Figure 49 - Outdoor-Indoor Temperature 3rd of August – Single thermal zone (Turin/Original Model)

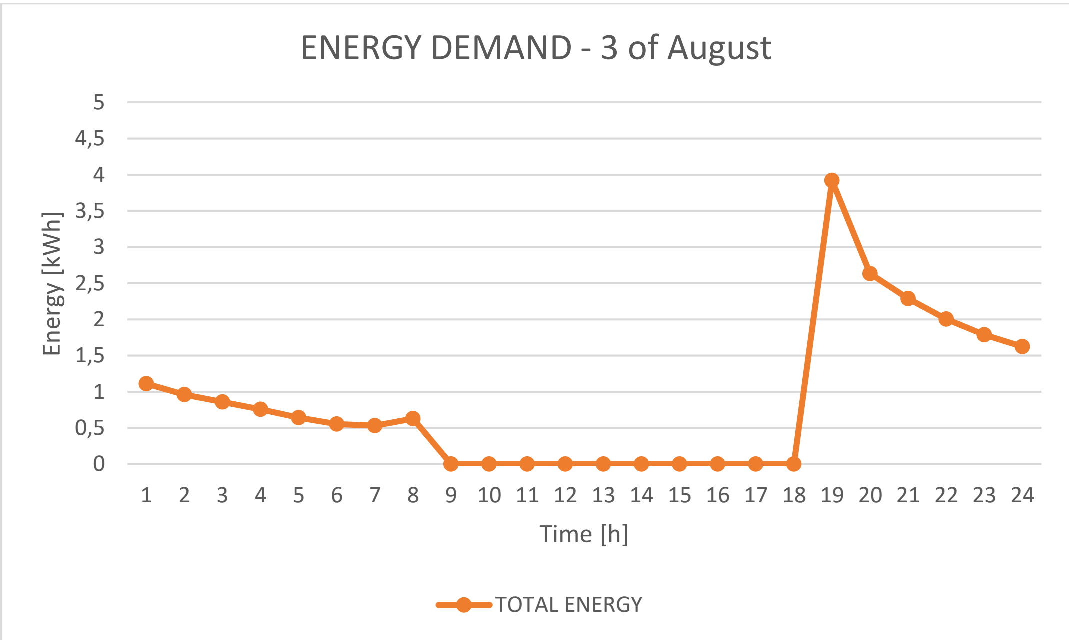

Figure 50 - Total Energy Demand 3rd of August – Single thermal zone (Turin/Original Model)

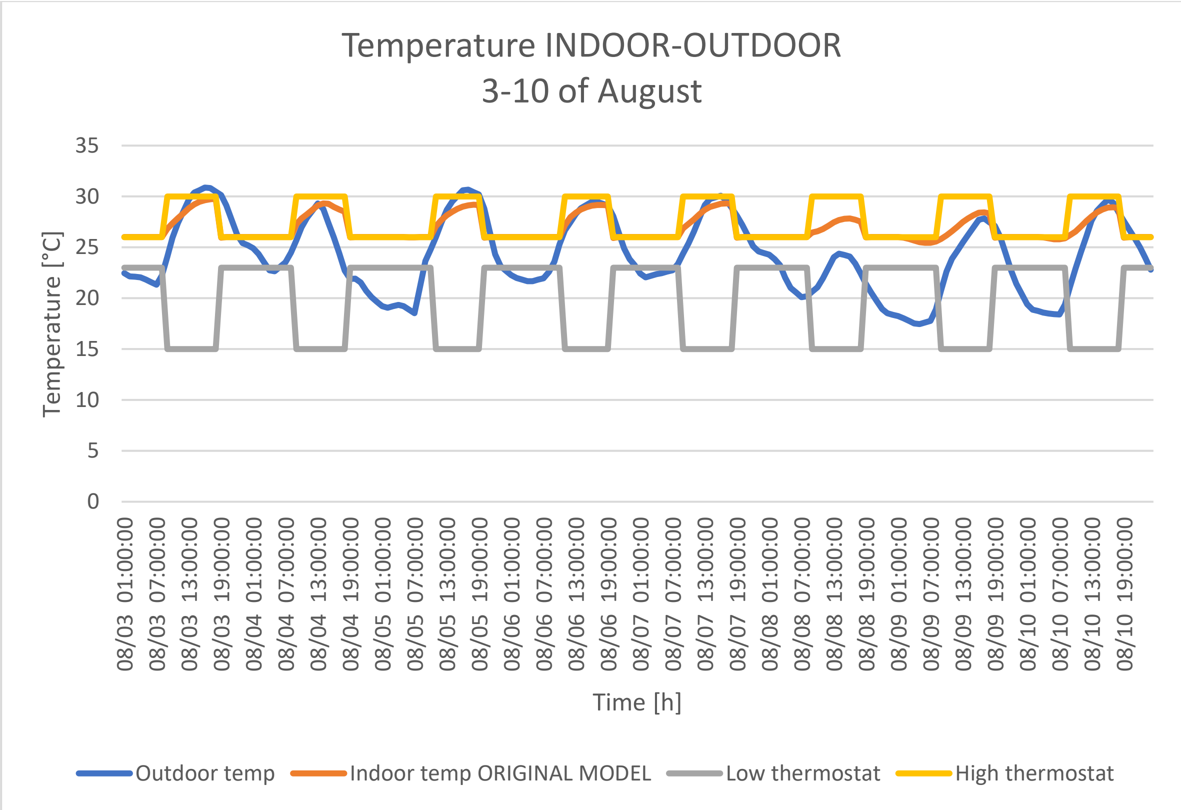

Figure 51 - Outdoor-Indoor Temperature 3-10th of August – Single thermal zone (Turin/Original Model)

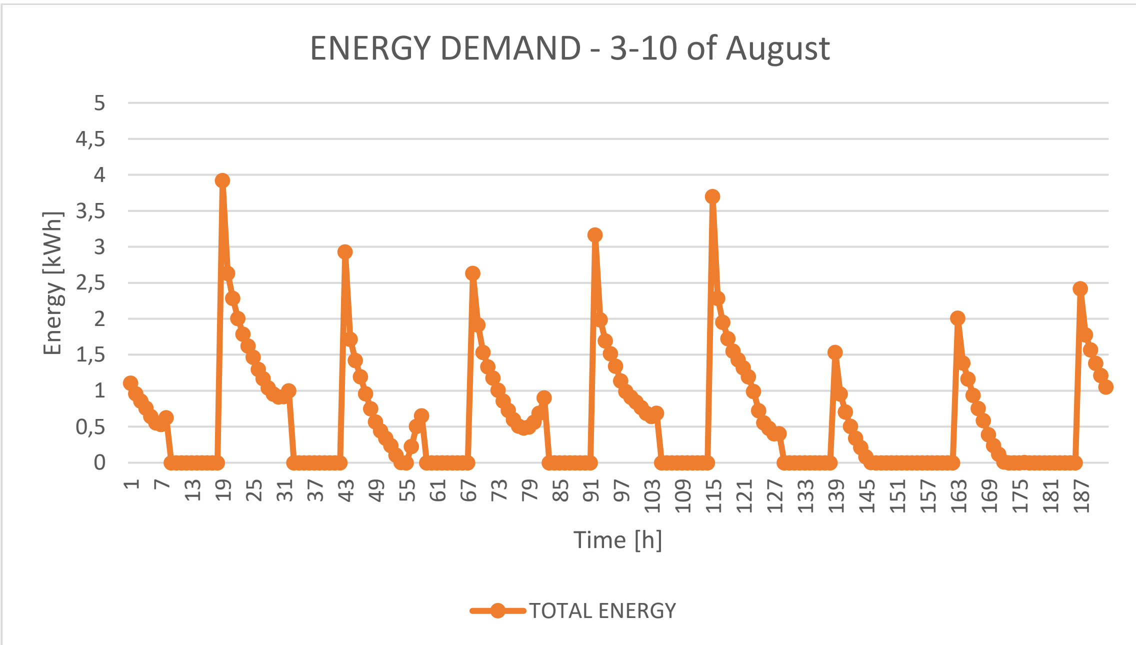

Figure 52 - Total Energy Demand 3-10th of August – Single thermal zone (Turin/Original Model)

3.3.1 Considerations

These results are related to the Configuration 4 (Turin / Original model – Single thermal zone) and they have been obtained running a simulation through *EnergyPlus* using the same assumptions and components' stratigraphy of Configuration 2 (Lisbon / Original model – Single thermal zone) but with a different weather file (Turin).

As we can see in (*Figure 43*), during cold periods of the year, in Turin the temperature goes down to values minus zero comparing to Lisbon where the temperature never goes under zero level; exterior temperature combined with a not adequate envelope of the building make the energy demand higher in order to maintain the indoor temperature within the setpoint range imposed by the thermostat.

Therefore, in January, configuration 4 (Turin/Original model) provides indoor temperature levels worse than the indoor temperatures of configuration 2 (Lisbon / Original model) and consequently the energy demand for heating is lower; in fact, in configuration 2 the values stand between 1-2.4 kWh while in configuration 4 the values stand between 2.3-3.9 kWh. (*Figure 48*)

In August instead, the indoor temperatures of the two configurations are similar but, due to the higher temperature of Italy, the energy demand reaches peaks up to 3.9 kWh while in Lisbon up to 3.1 kWh. (*Figure 52*)

The results of Energy demand are expressed in the form of Total energy, that means heating and cooling energy in the period considered.

3.4 Configuration 5. TURIN (Renovated Model – Single thermal zone)

Input data: same assumptions of Configuration 3 (lights, people occupation, equipment and people's metabolic activity grouped as "Electric Equipment" producing 4 W/m² during all day); only a Single thermal zone; weather file: Turin

The original building has been improved designing a retrofit of the envelope changing the stratigraphy of each component (*see section 3.2.1)* in order to reach the U-value required by the regulation. The standards taken in consideration are those in force for the Italian buildings, especially about renovation of existing buildings (*see section 1.3.4, Table 5*).

3.4.1 Indoor temperature and Energy Demand (Comparison between Original building and Renovated Building)

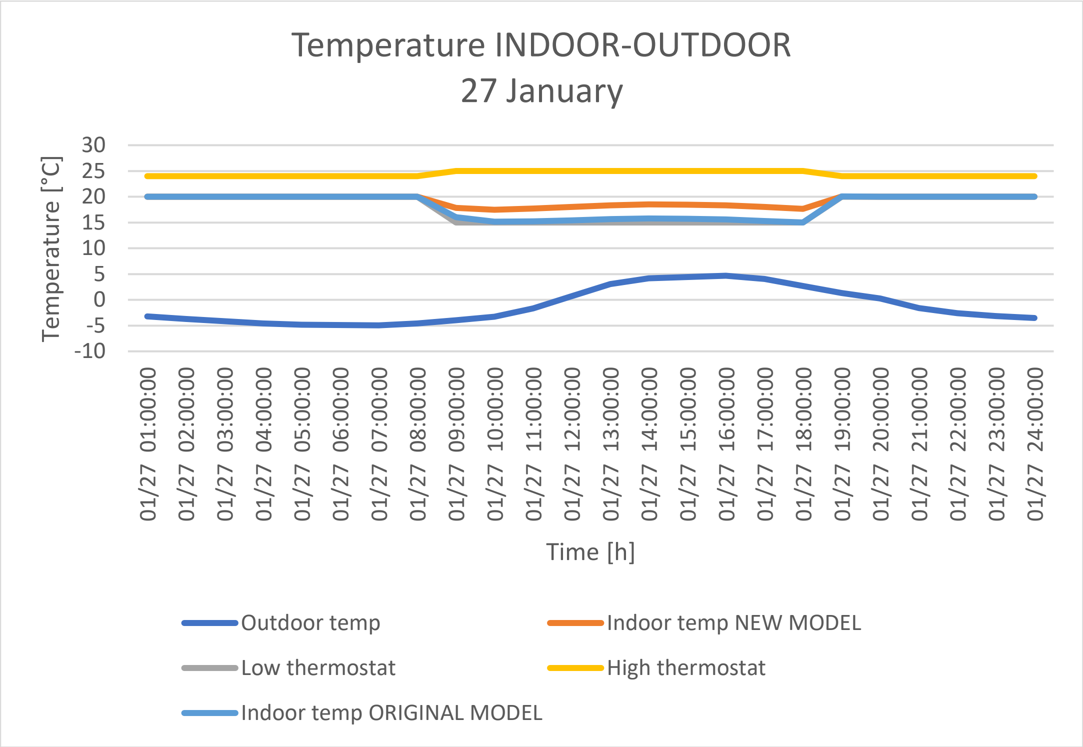

Figure 53 - Outdoor-Indoor Temperature 27th of January – Single thermal zone (Turin/Renovated Model)

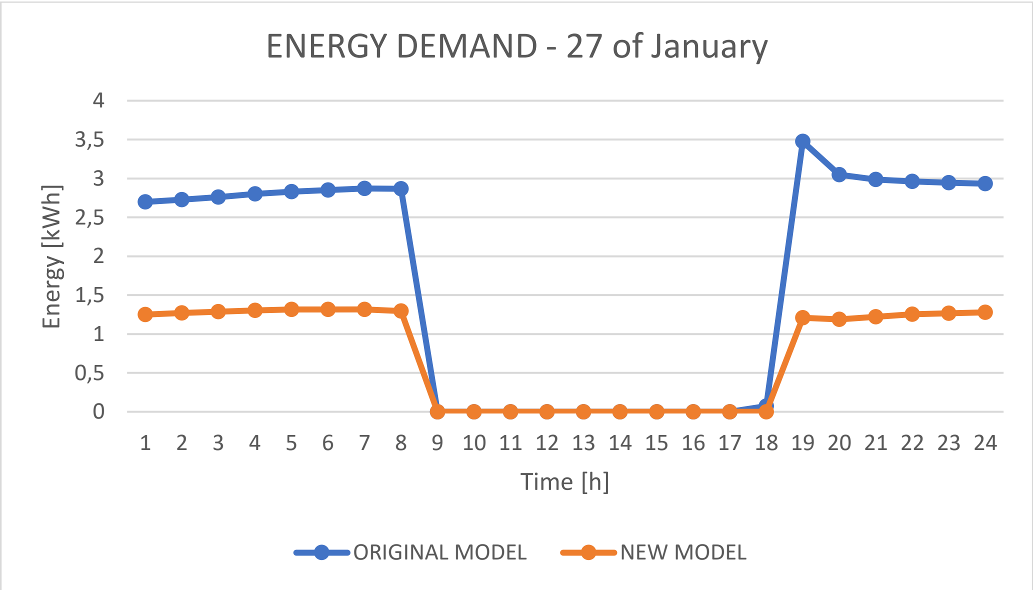

Figure 54 - Total Energy Demand 27th of January – Single thermal zone (Turin/Renovated Model)

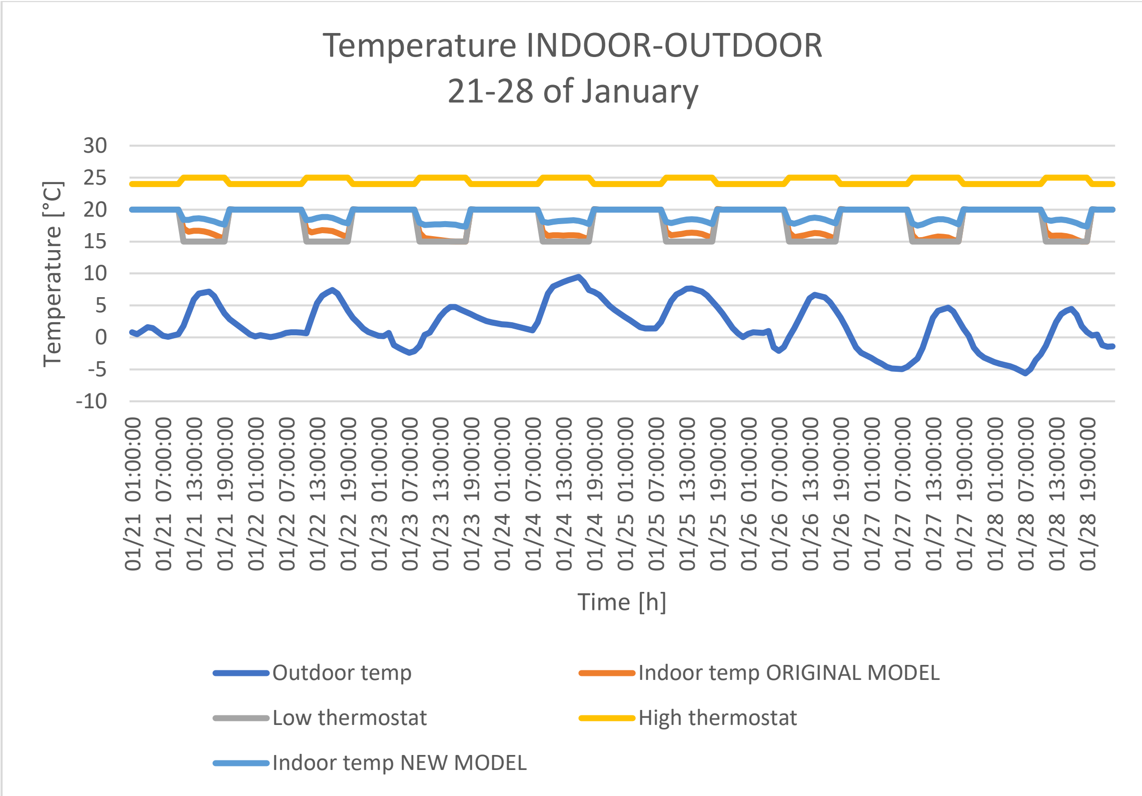

Figure 55 - Outdoor-Indoor Temperature 21-28th of January – Single thermal zone (Turin/Renovated Model)

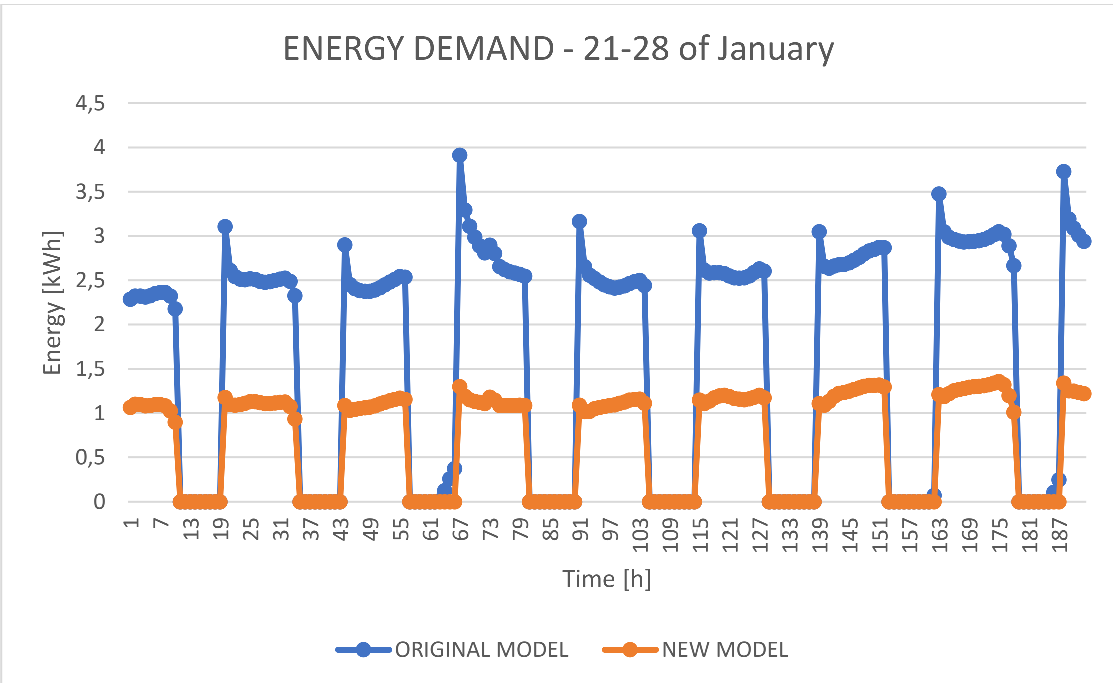

Figure 56 - Total Energy Demand 21-28th of January – Single thermal zone (Turin/Renovated Model)

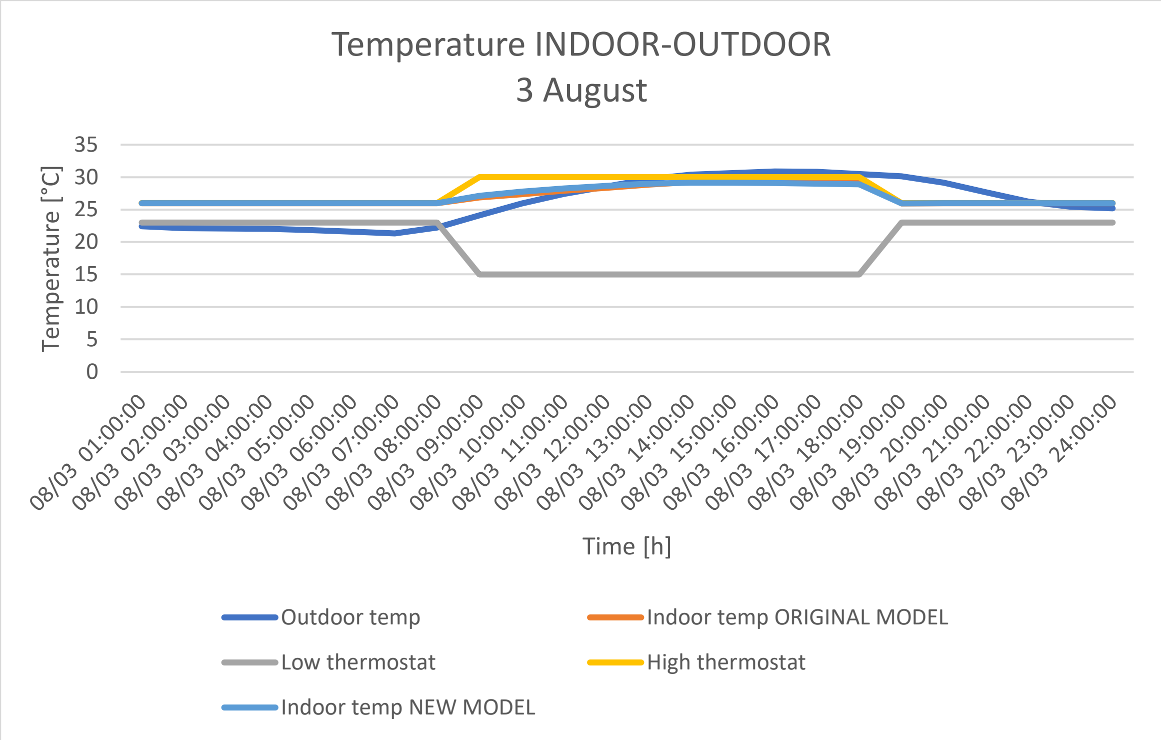

Figure 57 - Outdoor-Indoor Temperature 3rd of August – Single thermal zone (Turin/Renovated Model)

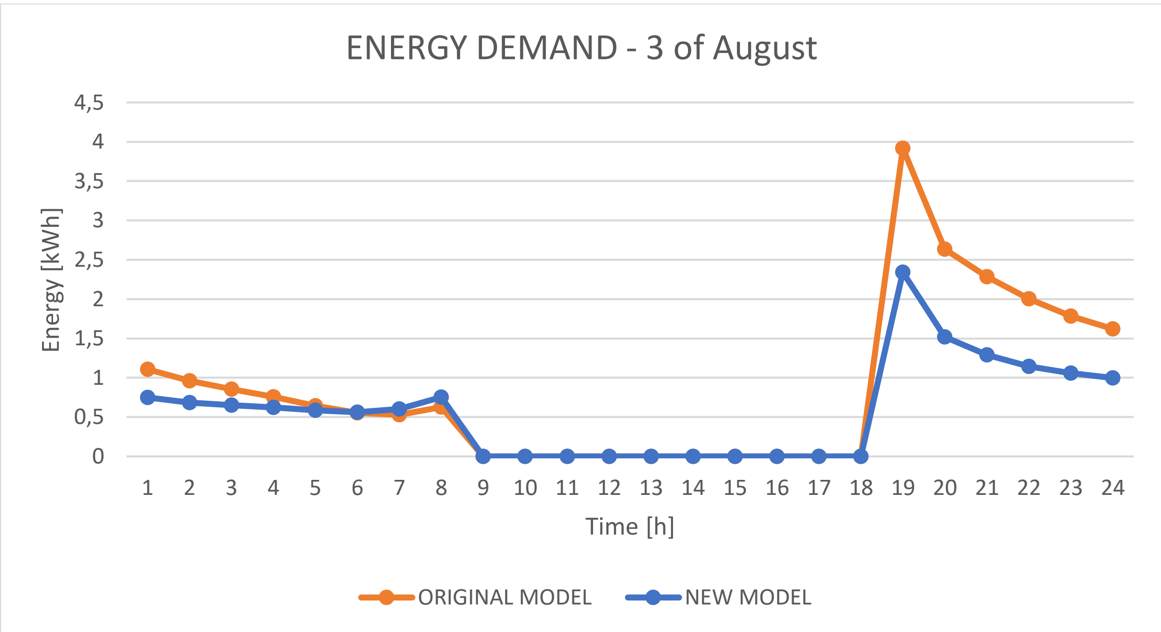

Figure 58 - Total Energy Demand 3rd of August – Single thermal zone (Turin/Renovated Model)

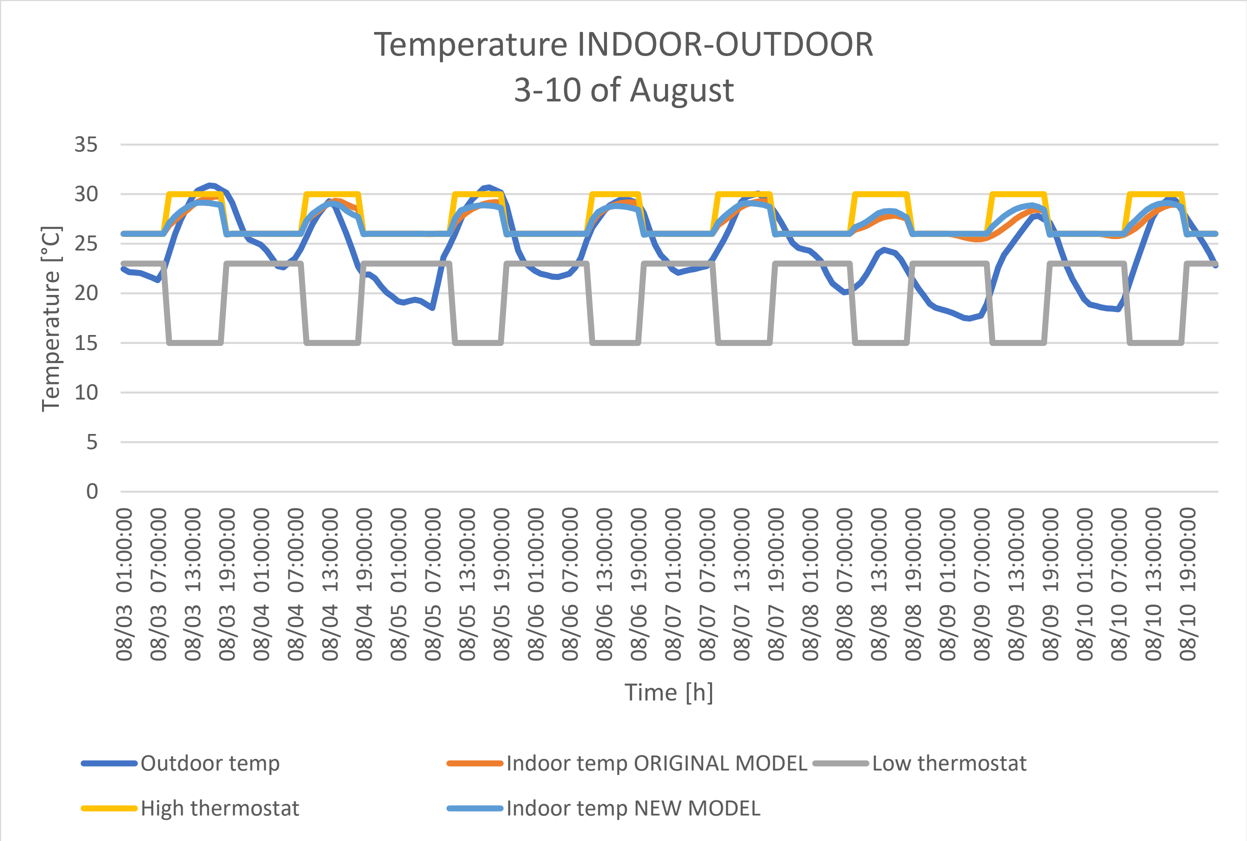

Figure 59 - Outdoor-Indoor Temperature 3-10th of August – Single thermal zone (Turin/Renovated Model)

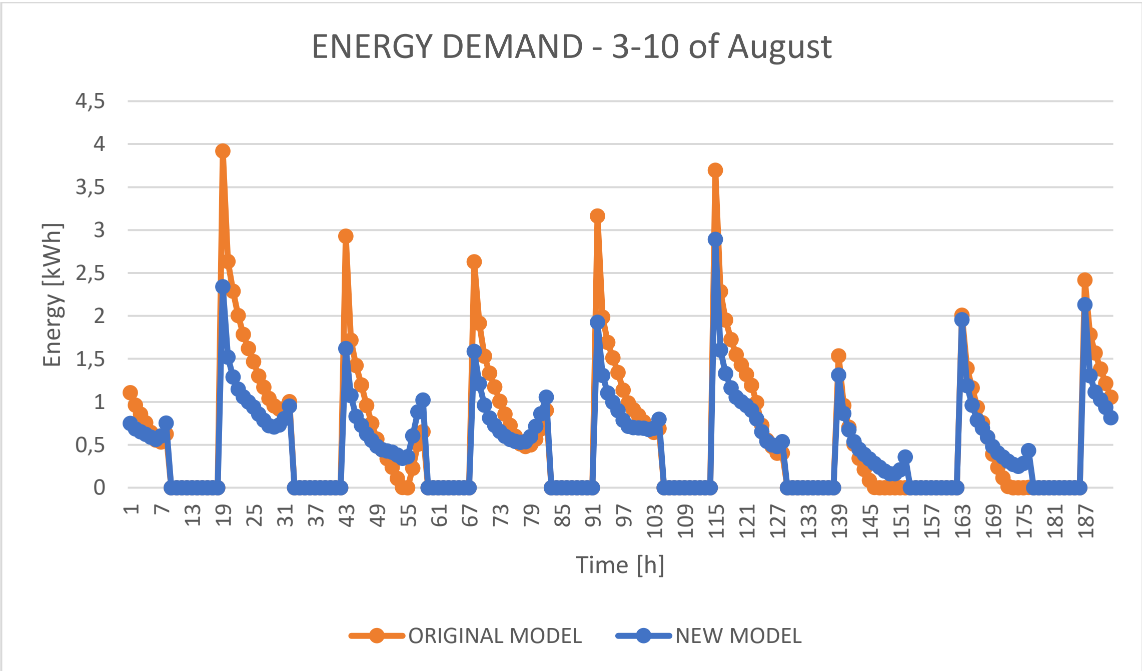

Figure 60 - Total Energy Demand 3-10th of August – Single thermal zone (Turin/Renovated Model)

3.4.2 Considerations

These results are related to the Configuration 5 (Turin / Renovated model – Single thermal zone) and they have been compared with the results of Configuration 4 (Turin / Original model – Single thermal zone); the graphs compare both indoor and outdoor temperatures and energy demand over the year in the different periods analysed.

In January, configuration 5 (Renovated model) provides indoor temperature levels much greater than the indoor temperatures of Configuration 4 (Original model) because of the improved stratigraphy and consequently the energy demand for heating is lower; in fact, in Configuration 4 the values stand between 2.3-3.9 kWh while after retrofit they stand between 0.9-1.3 kWh. (*Figure 56*)

In August instead, the indoor temperatures of the two configurations are still very similar but, due to the increased thermal mass of the renovated building, the heat loss are lower, and the heat stored tends to stay inside; that's why in some points the indoor temperature of the new Configuration is higher and the energy demand for cooling is higher as well. Generally, the peaks of energy demand have been lowered from the maximum of 3.9 kWh to 2.9 kWh. (*Figure 60*)

COLD PERIOD	
TOT OLD [kWh]	TOT NEW [kWh]
6319,47	2562,25
DIFFERENCE	3757,21
% SAVINGS	59,5%

WARM PERIOD	
TOT OLD [kWh]	TOT NEW [kWh]
611,83	468,18
DIFFERENCE	143,66
% SAVINGS	23,5%

TOTAL ENERGY [kWh]	3030,43
AREA [m²]	63,17
ENERGY [kWh/m²]	47,97

Table 20. Energy accounts of the building in a year (Turin)

Looking at the energy accounts in both periods of the year it is clear that in the warm period, which is the period when energy is used for cooling, even if less than in the cold period, the renovation led to an higher efficiency respectively of 23.5% and 59.5%, making the building energy-efficient with an energy demand of about 48 kWh/m^2.

3.4.3 Photovoltaic system

As for Configuration 3, on the building has been installed a photovoltaic system on two surfaces: the plan roof above the kitchen and the clove of pitched roof heading the south direction.

Once given the surfaces where to install the PV system, *EnergyPlus* calculated automatically the area and the generated power according to the weather file and location.

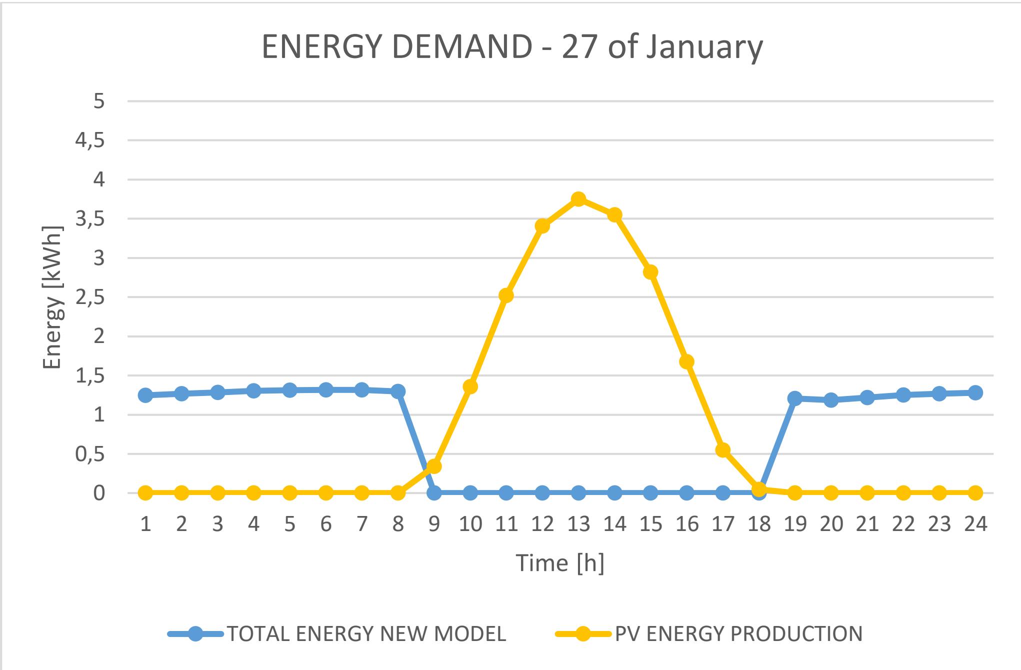

Figure 61 - PV energy production and Energy demand on 27th of January (Turin/Renovated Model)

27th of January	
	NEW MODEL
Energy Demand [kWh]	17,76
PV Energy Produced [kW]	20,03
PV Energy Used [kW]	0,34
Real Energy Demand [kWh]	17,42

Table 21. PV energy production and Energy demand on 27th of January (Turin/Renovated Model)

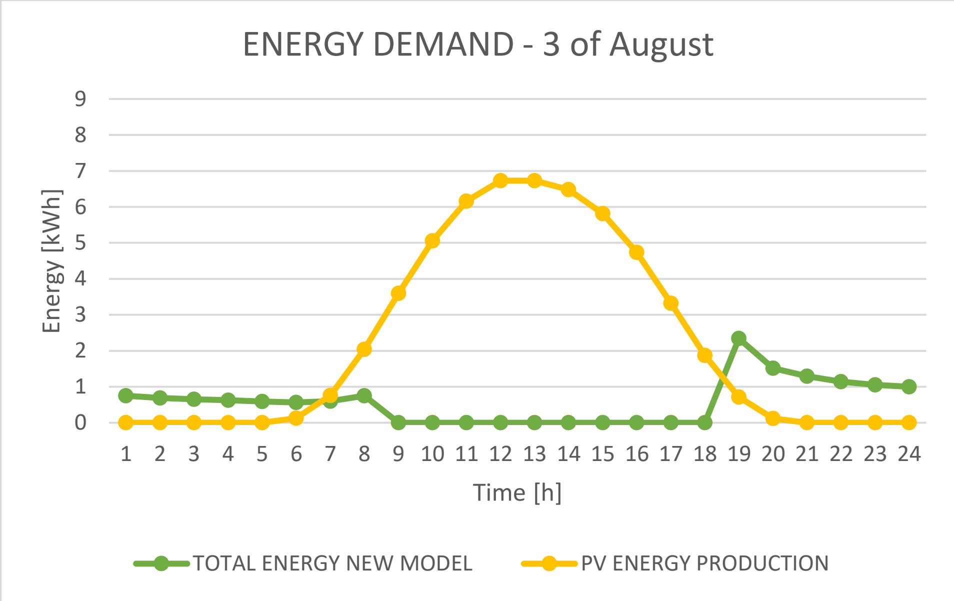

Figure 62 - PV energy production and Energy demand on 3rd of August (Turin/Renovated Model)

3rd of August	
	NEW MODEL
Energy Demand [kWh]	13,57
Energy Produced [kW]	54,28
PV Energy Used [kW]	4,00
Real Energy Demand [kWh]	9,57

Table 22. PV energy production and Energy demand on 3rd of August (Turin/Renovated Model)

All the year	
Energy Demand [kWh]	Energy Produced [kW]
3030,43	7091,56

Table 23. PV energy production and Energy demand on All year (Turin/Renovated Model)

The energy produced over the year from the PV system is more than two times the energy demand of the building but, as shown by the graphs (*Figure 61,62*), the energy produced can cover only a little part of the energy demand during the day. Indeed, being a building of residential use, people is not at home when the production of energy reaches the peak and when people occupy the house, the production is, low in the morning and zero from 18-19 pm. *Energy flexibility* can be used to improve the energy management during the day.

3.5 ENERGY FLEXIBILITY

Flexibility in the building sector means to manage and control the energy loads according to the requirements of the surrounding electric grids. Concerning heating flexibility, this implies to heat-up the building in the period of the day when there is surplus of solar or wind energy available or energy produced by renewable sources decreasing heating power at other times.

Mostly during cold periods, in residential buildings can be used a control system to lower the peaks of energy demand reducing the reliance on heating grids. [29] "*The energy flexibility of heating systems depends on the ability of a building to retain or store the heat inside the building envelope concerning comfort requirements. The amount of insulation, the thermal capacity and the passive solar gains of buildings are crucial for keeping indoor thermal comfort*" [30] [31] [32]

Generally talking about flexibility, two approaches are typically used to stray the electricity consumptions of a building from the normal schedule: thermal energy storage and appliance operation shifting.

The first approach is generally used to anticipate the energy consumption of a determined electrical equipment (i.e. air-conditioner, electrical water tank or heat pumps), in accordance with the thermal properties of the device and the properties of the building (i.e. thermal mass, insulation and sun exposition), to reduce the consumption of electricity on later times.
The second approach shifts the electricity demand of some electrical devices (e.g. washing machines, clothes dryers, and dishwashers) through a control system, to the periods of the day when the price of electricity is lower or in the periods in which the energy demand can be covered by energy generated by renewable energy sources. [33] Another approach for Energy flexibility is to store the energy produced into batteries that allow to use the energy produced in the periods of the day when the building needs;

[29] I. Cardinaels W, Borremans. (2014). "Demand response for families – linear final report," EnergyVille

[30] V. B. J. Six D., Desmedt J., Vanhoudt D. (2011). "Exploring the flexibility potential of residential heat pumps combined with thermal energy storage for smart grids," Explor. Flex. potential Resid. heat pumps Comb. with Therm. energy storage smart grids. Distrib.

[31] J. Le Dréau and P. Heiselberg. (2016). "Energy flexibility of residential buildings using short term heat storage in the thermal mass"

[32] T Weiß. (2019). IOP Conf. Ser.: Earth Environ. "Energy Flexible Buildings - The impact of building design on energy flexibility"

[33] Rui Amaral Lopes, Adriana Chambel, João Neves, Daniel Aelenei, João Martins. (2016). "A literature review of methodologies used to assess the energy flexibility of buildings"

the weakness of these batteries is that their capacity is not enough big to contain all the energy produced and often the cost-effectiveness is not recommended. If only the batteries could store the whole amount of energy produced every day, they would be a great tool for covering the energy demand.

Heating energy flexibility can be defined as “thermal load shifting” that indicated the number of hours the energy system can be delayed or forced to operate in an established period, taking into account the indoor comfort temperature range. For instance, when space heating is switched off at the upper comfort limit of temperature, the indoor temperature stay within the comfort zone for a period of time according to the building insulation, ventilation and thermal mass. As the thermal energy inside the building envelope is fading, the indoor temperature goes down. ΔT indicates the time it takes for the thermal zone to float from the upper comfort limit to the temperature of 19 °C (lower comfort limit) after the heating system is turned off. [34]

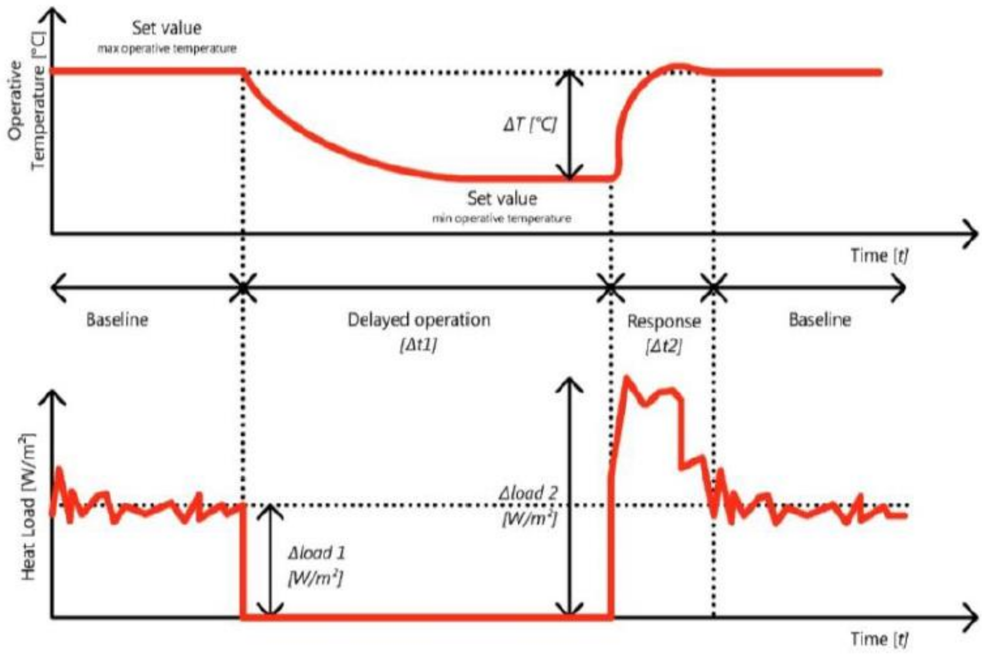

Figure 63 – Demand-side control of set temperatures, representation of the cooling-down curve and heating-up time (Source: T Weiß. (2019). IOP Conf. Ser.: Earth Environ. “Energy Flexible Buildings - The impact of building design on energy flexibility”)

[34] T Weiß. (2019). IOP Conf. Ser.: Earth Environ. “Energy Flexible Buildings - The impact of building design on energy flexibility”

3.5.1 Configuration 6. TURIN (Renovated Model – Energy Flexibility) / Energy Production and Energy Demand

The thermostat sets the set-point temperatures in the different periods of the day and they are stricter when people occupy the house and less when people don't (09:00 – 18:00); also, the set-point temperatures are different in accordance to the seasons of the year.

Based on the occupation of the house, how shown previously in *(Figure 13)*, the thermostat requires the heating or cooling system to work and to set the indoor temperature in order to have an indoor comfort in the hours when people are at home; when people don't occupy the house the temperature is free to float within the range imposed by the thermostat that is wider.

(Table 30) shows the temperature relative to the hours of the day of the original configuration on the 27th of January and *(Figure 64)* the corresponding energy demand for heating the thermal zone during the day, having into consideration these set-point temperatures before people come back home at 19:00.

On 27th of January, the thermostat allows the temperature to drop to 15 °C when the house is empty until 18:00 and requires to reach 20 °C at 19:00 when people come back home; the peak of energy demand between 18-19:00 is related to the fact that in 1 hour the heating system must cover a ΔT of 5 °C to have an indoor temperature comfort.
The problem is that the peak of energy demand stands in the hours when the production of energy from the Photovoltaic system is zero, and, in the event that there is not a battery for energy storage, the energy produced would be wasted or sold to the electric grid. *(Figure 64)*

27th of January	
ORIGINAL	
Time [h]	Thermostat Lower level [°C]
09:00	15 °C
10:00	15 °C
11:00	15 °C
12:00	15 °C
13:00	15 °C
14:00	15 °C
15:00	15 °C
16:00	15 °C
17:00	15 °C
18:00	15 °C
19:00	20 °C

Table 24. Thermostat Lower set-point temperature on 27th of January (Original configuration)

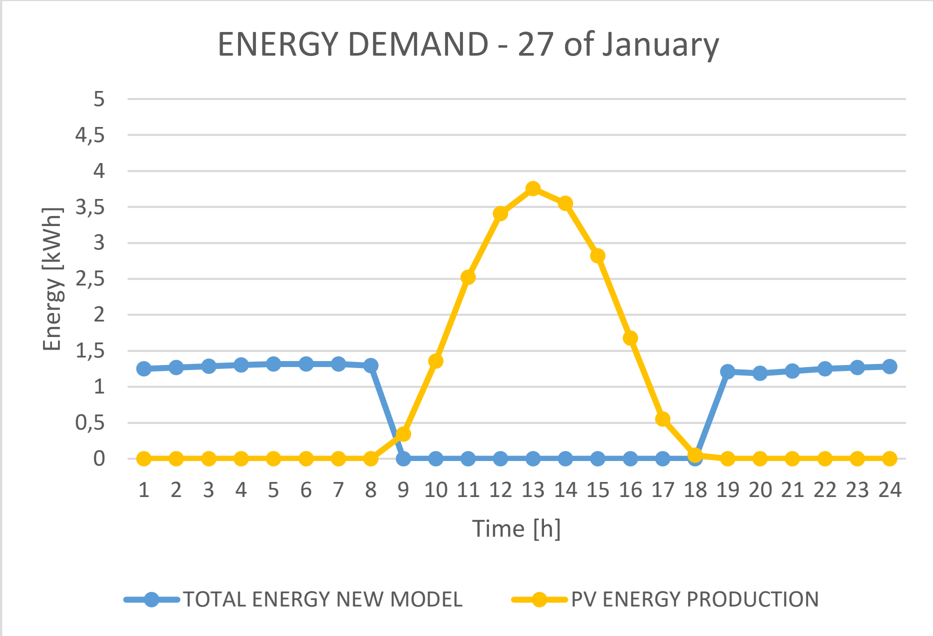

Figure 64 - PV energy production and Energy demand on 27th of January (Turin/Renovated Model)

In Configuration 6 the aim is to heat-up the house from 09:00 *(Table 31)* even if the house is not occupied but taking advantage of the excess of solar energy generated by the photovoltaic system and the thermal mass of the building; in this way from 09:00 -18:00 the house is warm and the energy demand is totally covered by the generation of energy on-site and at 18:00 the house has already reached the temperature of 20 °C and the peak will be lower. *(Figure 65)*

27th of January	
FLEXIBILITY	
Time [h]	Thermostat Lower level [°C]
09:00	18 °C
10:00	21 °C
11:00	22 °C
12:00	23 °C
13:00	23 °C
14:00	23 °C
15:00	23 °C
16:00	23 °C
17:00	21 °C
18:00	20 °C
19:00	20 °C

Table 25. Thermostat Lower set-point temperature on 27th of January (Energy Flexibility configuration)

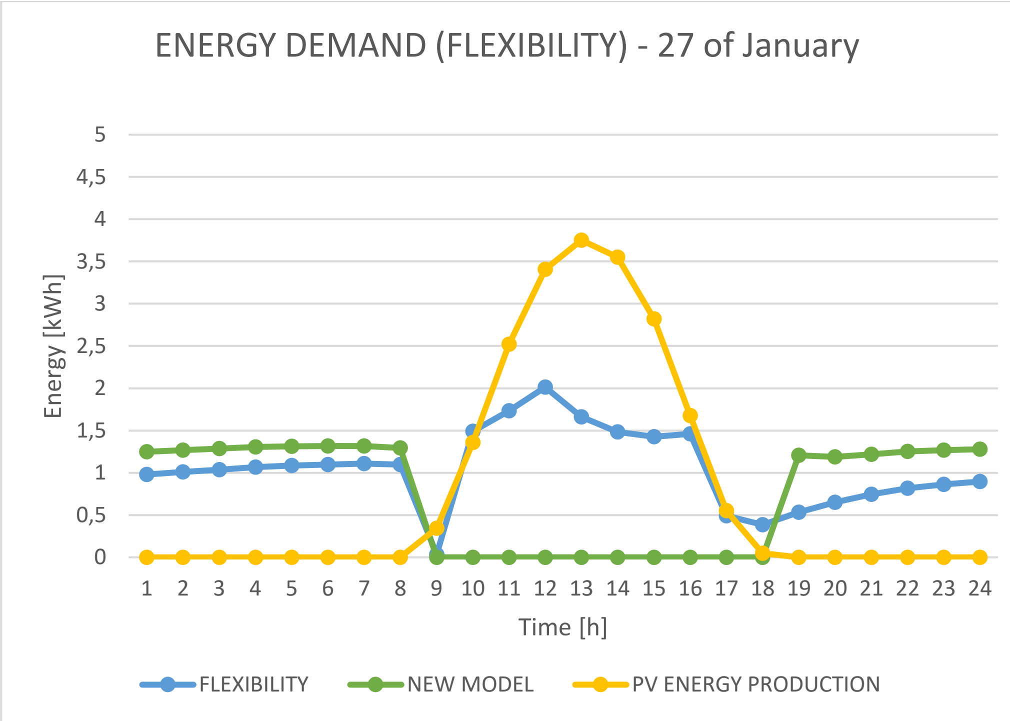

Figure 65 - PV energy production and New Energy demand on 27th of January (Turin/Renovated Model)

27th of January		
	NEW MODEL	SHIFTING LOADS
Energy Demand [kWh]	17,76	25,17
PV Energy Produced [kW]	20,03	20,03
PV Energy Used [kW]	0,34	12,18
Real Energy Demand [kWh]	17,42	12,99

Table 26. Energy demand on 27th of January (Before and after shifting loads)

Even if the energy demand of the building is actually quite far from the Zero, the *Flexibility* has led to a significant decrease of the demand, using the energy generated onsite by the photovoltaic system. Indeed, with the new Configuration, shifting the loads from 18:00 to 09:00 it has been possible to save 4.4 kWh on day 27th of January. *(Table 32)*

Concerning the Summer period, *(Table 33)* shows the temperature relative to the hours of the day of the original configuration on the 3rd of August and *(Figure 66)* the corresponding energy demand for cooling the thermal zone during the day, having into consideration these set-point temperatures before people come back home at 19:00.

On the 3rd of August, the thermostat allows the temperature to raise to 30 °C when the house is empty until 18:00 and requires to reach 26 °C at 19:00 when people come back home; the peak of energy demand between 18-19:00 is related to the fact that in 1 hour the heating system must cover a ΔT of 4 °C to have an indoor temperature comfort.

3rd of August	
ORIGINAL	
Time [h]	Thermostat Upper level [°C]
09:00	30 °C
10:00	30 °C
11:00	30 °C
12:00	30 °C
13:00	30 °C
14:00	30 °C
15:00	30 °C
16:00	30 °C
17:00	30 °C
18:00	30 °C
19:00	26 °C

Table 27. Thermostat Upper set-point temperature on 3rd of August (Original configuration)

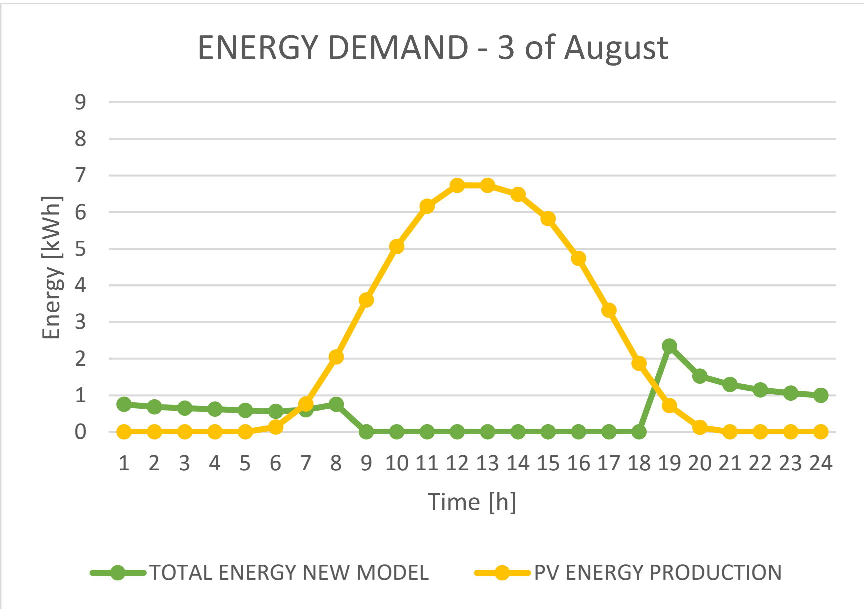

Figure 66 - PV energy production and Energy demand on 3rd of August (Turin/Renovated Model)

As for the Winter period, the aim is to cool-down the house from 09:00 am *(Table 34)* even if the house is not occupied but taking advantage of the excess of solar energy generated by the photovoltaic system and the thermal mass of the building; in this way from 09:00-18:00 the house is cool and the energy demand is totally covered by the generation of energy on-site and at 18:00 the house has already reached the temperature of 25 °C and the peak of energy to reach 26 °C will be lower. *(Figure 67)*

3rd of August	
FLEXIBILITY	
Time [h]	Thermostat Upper level [°C]
09:00	25 °C
10:00	24 °C
11:00	24 °C
12:00	24 °C
13:00	24 °C
14:00	24 °C
15:00	24 °C
16:00	23 °C
17:00	24 °C
18:00	25 °C
19:00	26 °C

Table 28. Thermostat Upper set-point temperature on 3rd of August (Energy Flexibility configuration)

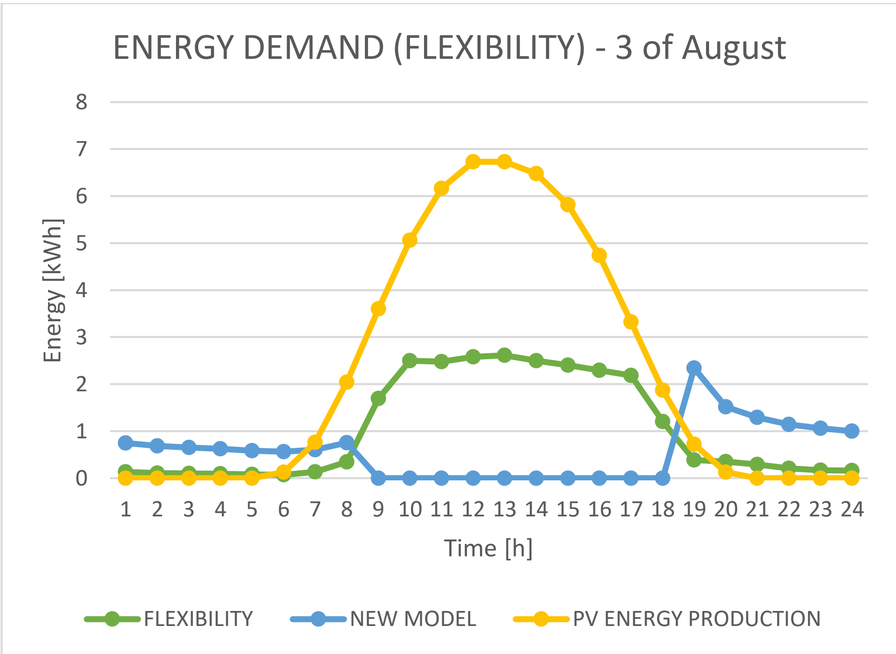

Figure 67 - PV energy production and New Energy demand on 3rd of August (Turin/Renovated Model)

3rd of August		
	NEW MODEL	SHIFTING LOADS
Energy Demand [kWh]	13,57	25,08
Energy Produced [kW]	54,28	54,28
PV Energy Used [kW]	4,00	23,74
Real Energy Demand [kWh]	9,57	1,34

Table 29. Energy demand on 3rd of August (Before and after shifting loads)

Compared these results to the Winter period of the same Configuration, the energy savings after Flexibility are greater, in fact, anticipating the loads for cooling from 18:00 to 09:00, the part of the energy demand has been covered by the production of energy obtained by PV system and the peak has been lowered; the savings in this case amount to 8.2 kWh on day 3rd of August, and the energy demand is nearly zero.

CONCLUSIONS

The existing building stock across Europe is aged, not efficient and not appropriate to face this wave of big climate changes. The world and especially EU are moving towards a green Architecture focusing on NZEBs, setting standards and regulations for new building and renovation of existing building.

The increased awareness and the visible effects of the climate change are pushing the Member States to develop and embrace the standards set by EU in order to decrease the energy consumptions, the carbon footprint and to increase renewable energy production and its manage.
The progress of materials and the lowering prices for renewable technologies make the uptake of NZEBs in the building sector easier and often, incentives are given by governments for installing photovoltaic panels, highly efficient heat pumps, a greater insulation or windows in order to reduce the cost of the construction of a NZEB.

This study provides an example of retrofit of an existing building towards NZEB requirements, starting from the evaluation of the energy demand relative to the original configuration of the building, presenting then a renovation of the envelope and the related energy consumptions, and finally the calculation of the amount of energy generated by Photovoltaic panels installed on the roof and how that energy could be managed during the days.

The case study building energy performance was so poor that the roof didn't even have a real package but after the designed renovation the energy performance improved until having an high-efficiency building; the results show that the energy demand of the new configuration is very low but still far from the NZEB definition.

Therefore, despite being the energy produced through renewable sources higher than the energy demand, given that the building is for residential use, most of the energy generated everyday cannot be used entirely because in the hours of excess solar energy, people don't occupy the house, and the energy risks to be wasted; that's why through *Energy Flexibility* has been tried to shift the loads in the hours of energy generation trying to lower the energy demand in other times.

Final results show that the energy savings after flexibility are less than expected and an explanation for this is that, in order to simplify the calculations, the assumptions given don't take into account the real usage of the house and occupation; for instance, one of the assumption was that "people, lights and equipments" were grouped into a single voice consuming 4 W/m^2 during all day and the energy demand could be lowered considering the real consumption of the equipments during the occupation of the house.

This study integrates the existing literature about the topic and focuses on the retrofit of the envelope and each component in order to have a NZEB without considering the cost-effectiveness of the renovation though; each building needs different types of renovation and the selection of materials is wide but knowledge and commitment are essential for a proper design.

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