



**FINAL RESEARCH FOR MASTER'S DEGREE IN ENERGY ENGINEERING  
TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT**

# **Available energy flexibility: sensitivity study for different climatic conditions**

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## **ABSTRACT**

The present project develops different strategies to implement in a commercial building to provide electrical flexibility to the grid. The project analyses the effect on how these strategies affect the building power consumption, focusing on strategies to modify and obtain the flexibility with the cooling system. The case study day that is analysed with EnergyPlus and MATLAB is July 10<sup>th</sup>, a typical day in summer. The two-demand response applied in the electrical consumption are related with the chiller set point.

The first demand response implemented is the increase of the set point, obtaining different results for each weather, but it shows how the flexibility is obtained during the building operational hours, also the efficiency of this flexibility is analysed, obtaining a flexibility for each hour and his efficiency, to develop this, it is need to implement the demand response in 1h timesteps, to be able to compare in a proper way the flexibility obtained, it is going to applied the demand response each hour and compare the 24 different cases, this is going to be reproduce for all the weathers considers, after a deep analysis is going to discover how the best flexibility is provided for weathers with an outdoor temperature near the new set point, also it is discovered the efficiency in this down flexibility is going to be related with the hours where the flexibility is provided.

Once the increase set point demand response is implemented and analysed, the methodology is reproduced for the second demand response consisted of decreasing the set point temperature. This new strategy is up flexibility and provides the efficiency to the grid incrementing the commercial building consumption. The results obtained from this demand response are different to the other strategy, results prove how the strategies analysed can provide electrical flexibility to the grid during all day, also it demonstrates how the strategy cannot be efficient even if it is providing flexibility.

## **KEY WORDS:**

Energy flexibility, efficiency, demand response, savings, comfort, energy, temperature, weather, cooling, heating and building.



## **STATEMENT OF ORIGINAL AUTHORSHIP**

I hereby certify that the submitted work is my own work, was completed while registered as a candidate for the degree stated on the Title Page, and I have not obtained a degree elsewhere on the basis of the research presented in this submitted work.



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## NOMENCLATURE

### *Acronyms*

EU	European Union
UN	United Nations
DOE	Department of Energy
HDD	Heatings Degree Days
CDD	Cooling Degree Days
DR	Demand Response
AEEF	Available Electrical Energy Flexibility
$\eta_{AEEF}$	Energy flexibility efficiency
PMV	Predicted Mean Value
ISO	International Organization for Standardization
HVAC	Heating, ventilation and air conditioning
P	Power consumption
kW	Kilowatts
kWh	Kilowatts hour



## 1. INTRODUCTION

The present thesis is submitted to University College Dublin (UCD) for the Erasmus master program, as the final research for the master's degree in energy engineering technologies for sustainable development granted by Polytechnic University of Valencia and attended in the College of Architecture and Engineering at UCD.

In an energy context, the need of provide flexibility to the electrical grid and develop technologies and strategies to facilitate this is one of the mains goals for the European Union considering increasing penetration of renewable energy. To solve this problem, the actual use of the energy (on the demand side) must change, in this context, the present research develops a model to control the actual commercial buildings energy consumption and provide energy flexibility to the electrical grid. reducing in this way the peaks loads in the electrical daily consumption and decreasing the emissions.

With the control of the electrical consumption the primary energy can be chosen by the user, trying to adapt the commercial building demand to the most cheap and clean energies. Even if the total control is far in this moment, some models and strategies can help reducing the difference and buildings can be approached to a more controllable consumption.

Through the present work is going to develop and analyse different strategies with the goal of provide flexibility, these strategies will play an important role in the commercial building consumption, focusing in the cooling, the strategies that are developed are the increase and decrease of the chiller set point, providing the flexibility changing the electrical consumption in heating and cooling.

### 1.1. BACKGROUND:

The present research is included in electricity efficiency and building construction, with the aim to get a mathematical model to increase the flexibility in one building in the electrical energy consumption.

#### 1.1.1.ENERGY CONTEXT:

In the Energy context the need of sustainability is clear, an energetic problem exists, there are not enough energy for future generations, because of the overuse of the energy and the small resources of some energy founts, a solution must be found, a guarantee to cover all the actual needs and the environmental necessities [1].

The renewable energy sources are presented [2] as the solution for the energy green generation but made them match with the electrical grid is a problem, the renewable energies are dependants of the natural source, the photovoltaic generation can be produced just in the sunny hours, the Eolic generation can't be produced when the consumer need either, it is a windy dependant energy fount.

The energetic problem increase with the increasing demand [3], the unacceptable environmental impact, the contaminants gases accumulation, the greenhouse effect and the global warming[4],[5]. All the impacts are effects of the climate change, and independent of these consequences, the energy consumption is a need. Population have the right of a quality energy access, so, it is need find an environmental friendly solution to cover the energy problems respecting the environment and trying to cause the minimum effect on it while cover the consumers' needs.



The actual electricity production is centralized[6], and the key to prevent and decrease the climate change is decentralized electricity production and increment the renewable sources[6]. The electricity grid uses nowadays as a virtual storage, providing the energy demanded and forcing providers to adapt at consumers necessities, if this fact change the energy production will be easier to adapt to some new technologies environmental friendly.

### **1.1.2.WORLD CONTEXT:**

On 11 December of 1997, in Kyoto, Japan, there was an international agreement [7]. United Nations meet in Kyoto to get an agreement with the aim of reduced the international binding emissions. The goal is reduced the actuals (2012) emission levels of CO<sub>2</sub> and another greenhouse effect gas to the levels of 1990[8].

The Kyoto protocol [9]was adopted for several developed countries, including European Union, who compromised to reduce in an 8% them emissions respect 1990 emission[10], which means a reduction of 346 million of CO<sub>2</sub> tons[10]. But the use of the primary resources in EU until 2030 [11]does not guarantee the Kyoto agreement compliment [12].

Paris 2015, The “Paris Agreement”[13], more than 55 countries that represents the 55% of the global emissions takes an agreement to treat the climate change. Paris Agreement is a Kyoto Protocol ratification, where some goals are include and the emissions target is discuss. [10]

There are some solutions that must be evaluated from the technological scenario, searching for the solution that solve better the energy needs respecting the environment. Also, there are some systems based on renewable energies, and them grid incorporation, trying to improve the energy efficiency and control the demand in all the sectors, in this research the demand control is going to be studying and developed, focusing in the domestic buildings demand.

### **1.1.3.EUROPEAN CONTEXT:**

European Union proposed on 3 March of 2010 a 10 years strategy to develop EU during a decade (2010-2020) [7]. The aims are to advance in economic crisis and solve some defect of the growing model, the strategy focus in a sustainable growing based in a Green economy[14]. To achieve that it focuses in 5 main points, highlighting the climate change and energy. Related with that achieve, EU try to get in 2020 a new energy scenario, with main points[14]:

- 20% of the primary energy must be renewable
- Energy efficiency must improve in a 20%
- 20% of the emissions of CO<sub>2</sub> must be reduced

In a middle term the aims go to 2030 EU plan[15], which consider a green scenario with multiple energies resources, no one resource with a contribution bigger tan 30-35%[15]. The electricity is consider the last final energy form and the energy resources must be distributed, also the energetic demand must have participated in the energy market as an active agent.

In the energetic context buildings have a significant role, the European buildings represent the 40% of the energy use[16]. The consume is electricity and thermal energy, in order to reduce the buildings



consumption, the EU has imposed the “European Performance of Buildings Directive”[17]. New buildings must be nearly zero energy buildings, nZEB buildings[16]. To make the new buildings nearly zero energy it is combined with passive solutions with more efficient energy systems or self-renewable sources in the buildings[18]. This measure reduces the consumption of the new buildings, but it has not influenced the electrical grid, the next step to overcome the imbalance between demand and supply in the grid is to make consumers participate in the energy market, that means a new market structure, for example Smart Grids.[19]

### 1.1.4. ENERGY PRODUCTION IN IRELAND:

The Ireland energy production is shown during the period 1990-2015 in the following figure,

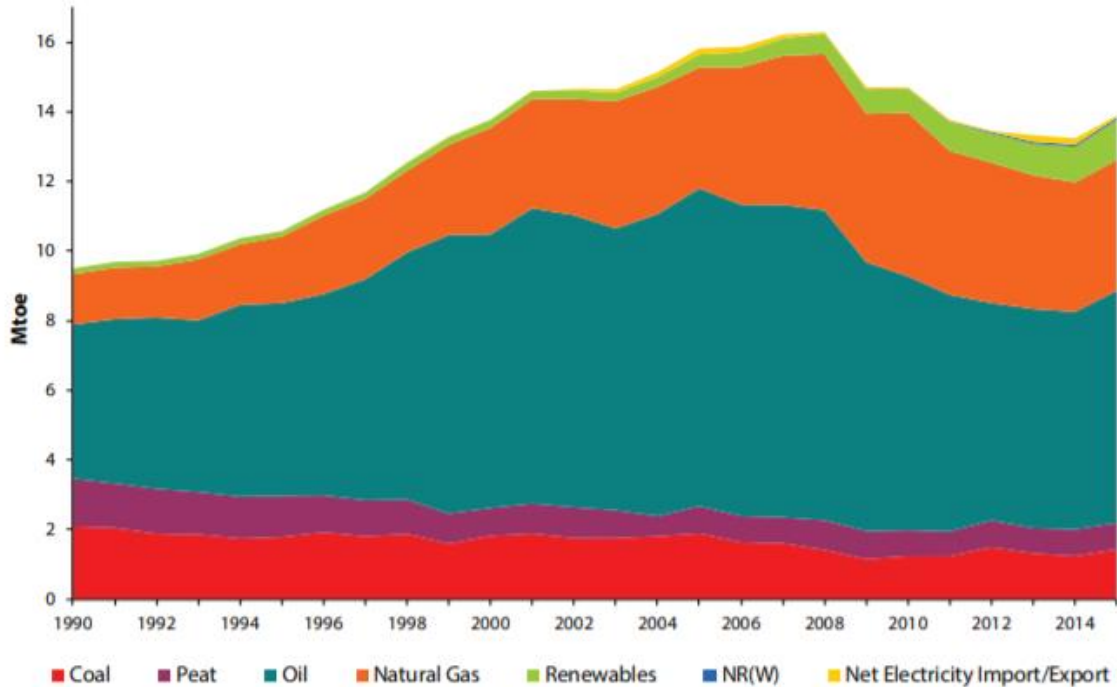


Figure 1: Ireland energy production 1990-2015[20]

In 2015 the 90.9% of the energy comes from fossil fuels (contaminants). Ireland[20] is importing these fossil fuels as the country doesn't have natural fossil resources in his territory. Ireland is buying the primary resource, and just the 8.3% comes from renewable resources in 2015 January[20]. These data has change, increasing until 12,5% in 2015 December, emphasizing the wind energy as the most renewable used, with the half of the renewable production.

The efficiency of electricity supply has experimented a growth in 1990-2015 period[20]. The electricity efficiencies are defined as the final consumption of electricity divided by the fuel inputs. As renewable sources has no inputs, increasing the renewable use this efficiency also increases, getting in 2015 a 49% of efficiency in energy supply and a 54% in energy generation[20].

Since the 2015 Paris Agreement [13] Ireland is progressing to reduce and decarbonised their energy. The EU target 2020 is approaching[14], the new goals are the 2030 target[15], the Irish economy is growing since 2015 and the energy use is also increasing. Despite the energy consumption grow up,



in 2015 Ireland research the half targets for 2020 UE, with a 9.1% of the generation in 2015 based on renewable sources[21].

Ireland is an energy dependence country, this dependence has increase since 2005, incrementing the energy production in Ireland, also increments the energy independence[21].

SEAI's (*Sustainable Energy Authority of Ireland*) [21]has approved a strategy for 2017–2021 in the context of European vision for energy sustainability. The government plans increment the renewable production from 23% to a 40% until year 2020 [21], where these technologies must cover the 16% of the electricity, heat and transport consumption in Ireland[21].

This new polities comes incentivized by the European Project of 2020[14]. The compromises that Ireland has get with EU. SEIA has approved a 5 years strategy to change the actual situation (2017) to a new one, where the great majority of the population participate in a more sustainable energy future, the aim is achieved the EU 2030 climate change agreement[15]. The energetic SEAI's goals are: empowered citizens and communities at the centre of the Irish sustainable energy transition, foment a positive energy sustainability conscience, increment the grant impact in renewable energies, further step-changes in Public Sector, industry and SME sustainable energy activity and the last aim is increase the invest in energy innovation and research [21].

#### **1.1.5.IMPACT OF CLIMATE CHANGE ON BUILDINGS**

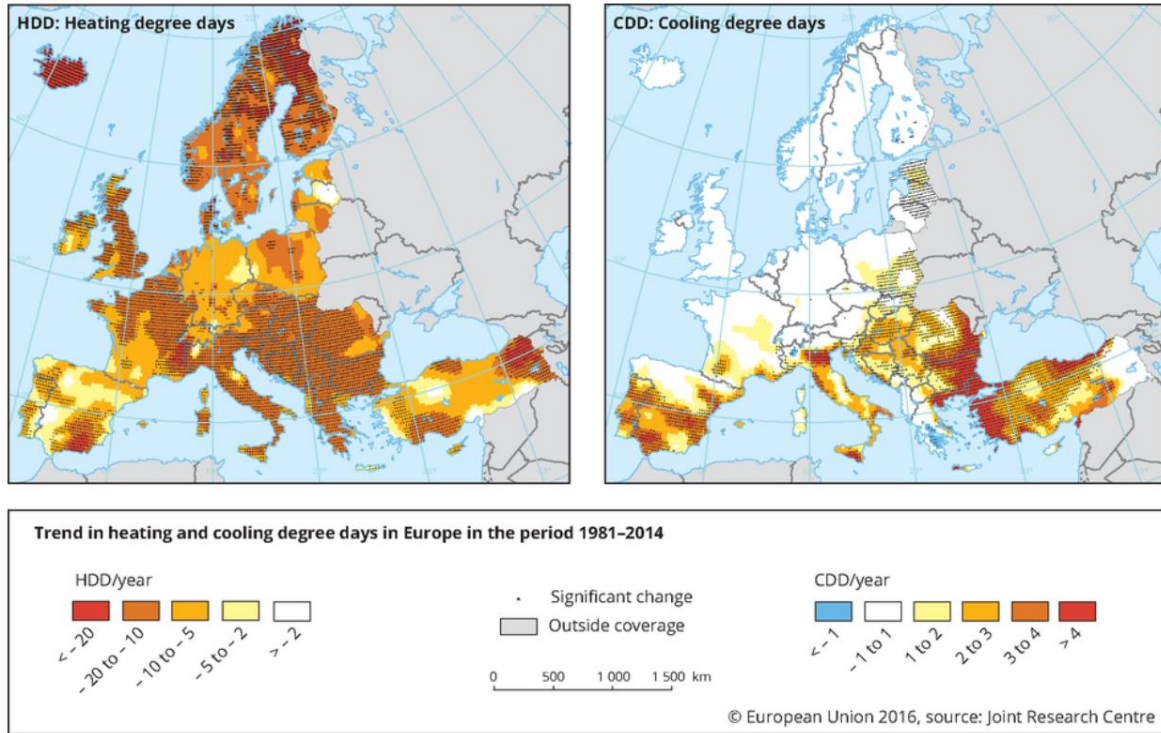
The climate change affects directly to the use of energy in terms of cooling and heating, the change in the demand has been studied by [22], climate change increases the demand of cooling and the heating is becoming less significant, but it depends on the location, there still having locations that are completely heating dominated.

The analysis of the energy demand evolution is based also in the buildings evolution, but global warming is affecting the energy use in buildings, it has been demonstrated in several countries as Sweden, United Emirates, UK and Ireland.

The impact of climate change is undeniable, the energy efficient designs get special importance, the use of different insulation walls, windows and radiation barriers must be considered, the prediction of energy demand have a heavy dependence on the climate energy polities applied, considering different levels of CO<sub>2</sub>. The existing buildings have a potential to save more than the 50% of the energy waste and emissions.

In 2010 the third of global energy use was expending by buildings[23]. In generally developed countries waste great part of this energy, supposing the developing countries have the same consumption, the emissions related by buildings are going to experiment a huge increase[24]. Buildings represent a critical piece of energy consumption and gas emissions, the impacts of climate change in buildings infrastructures and services are alarming[25]. Buildings also show a multiple climate change impact, as the urban heat island effect, they also are vulnerable to the climate change impacts effects, as the increased rain and storms, the wildfires[26]. In Europe Climate change increase the intensity of heat waves[27]. Adaptive strategies should be implemented, including the use of ventilate cooling and solar shading, also the Climate change affects to the buildings materials, damaging them.

As it can be observed in the figure 2, during the last 25 years [15], the heating and cooling degree days (the sum of the different between the real temperature and one reference temperature) are changed in Europe because of the climate change[15]. That means that the global temperature is increasing.



**Figure 2: Trend in heating and cooling degree days (1981-2014) [15]**

It can be observed how the heating degree day and the cooling degree day have increase, having more extremes temperature nowadays than before. The HDD means the hourly temperature for one year comparing with the reference temperature at which the cooling should be program to goal the comfort. As HDD number has increase, that means that the difference between the hourly temperature and the reference during the year is bigger, so during the cold days, the temperatures are lower. Also analysing the CDD it shows exactly the opposite, how the warm days are hotter in 2014 than in 1981 [15], that means that the temperatures have change getting more extreme.

### 1.1.6. BUILDING CONTEXT

Building sector is a significant consumer of the energy[23]. It has been found that energy can be saved in the building demand, controlling and monitoring the use and consumption. An energy benchmarking is really important to detect abnormal energy consumption or estrange energy behaviour in a building [28]. There are a lot of method to research a building process to monitor, the first step to develop a building energy manage is the knowledge of how is using the building this energy.

Also, in the new constructions the energy efficiency is consider, and the new buildings can be constructed thinking in the user needs, taking advance of the orientation, the solar irradiation and





about the light needs implementing energetic passive solutions during the construction [29]. But the majority part of the domestic buildings are buildings already builds.

In 2010 the world's buildings consumed the 32% of the global final energy, and they produced the 19% of the greenhouse gas emissions[20]. In 2015 the average Irish household emitted 5.5 tonnes of CO<sub>2</sub> of which 61% [30]. The emissions came from direct fuel use in the home and the remainder from electricity use, that shows the important place that domestic buildings have in the gas emissions reduction.

## **2. LITERATURE REVIEW**

Buildings represent the 40% of the world-wide energy[16], that shows the important role that building play in the energy consumption control, the buildings consumption is divided in thermal energy and electrical energy. The research goals are find the relationship between the location, building properties and energy strategies in a domestic building consumption with the energy efficiency. Develop a model to reduce the domestic building consumption by the building energy control, moving the demand from the energy market picks to the loads using different energy strategies. There are a lot of researches previous this one related with the topic to threat: the behaviour of the energy domestic building consumption and the commercial buildings consumption [31],[28].

There are many research and articles that introduce and develop that concepts, to understand the importance of that and to see which points the most focused ones are, a sum of the research is going to be introduce.

### **2.1. SMART GRIDS**

The smart grids are presented as a monitoring energy flow to supply energy demand. Consumers can adapt their energy use depending on the energy price during the day, saving money and linearizing the electrical grid demand[32]. The smart grids are a good tool also to integrate renewable energy to balance the net. The final consumer is who decides their own energy response, use and price. The final consumer that has also a renewable source can sell the excess to the grid (that depends in the country law, different for each country). They are a way to change the traditional energy grids for a more digital infrastructure that allows to monitor and steering in real-time[6]. The smart grids try to take advance of the potential energy flexibility to reduce costs and emissions. To integrate more decentralised energy generation system the consumers-producers must be modernising of the role of Distribution Systems Operators, for a more proactive grid the management and operation must change, becoming more flexible and efficient [19].

The EU pretend to replace the 80% of electricity with smart grids in 2020[33], controlling the consumption and electricity production the emissions are reduced. On 30 November 2016, the European Commission made a proposal to request a smart meter that allows consumers to take benefit of the energy market[14]. The aim is get in 2020 almost the 72% of European consumers with a smart meter for electricity, that small meter has a cost between 200€ and 250€ [10], but the annual savings are around 300€ per year, having a payback period smaller than a year [10].

### **2.2. COMFORT ANALYSES**

The thermal comfort is defined as the conditions needs to satisfied buildings occupants. The conditions which expresses satisfaction with the thermal environment, it includes heating, ventilation and air conditioning. The thermal comfort is defined and calculated by ASHRAE as standard according to the most part of the population. As buildings are designed for people, the aim is get



comfort inside, keeping people comfortable while the building should be efficient, healthy and safe [34].

The impact of climate and temperature on health is receiving more attention. Indoor thermal comfort has great importance in European countries. It has been demonstrated the evidence of the temperatures impact on health by [35].

An optimization framework is analysed by [36] to evaluate how affects relax the comfort effect on the energy demand. It is used percentages and economics constrains to observe the energy demand with a comfort variability, using temperatures and relative humidity controllers.

Demand flexibility can be achieved relaxing comfort conditions, thermal comfort and air quality are important points. The traditional systems fix the set-point for the equipment, these control use models to predict the conditions and needs. This system also let predict and manipulate the comfort and control the price. It is an economical control that it has not taken into account the users' needs. Find the balance between the comfort and the price can be complicated. Different measure that reported economic and energy savings are evaluated considering the system behaviour under relaxed comfort conditions[36].

The objective is evaluating the impact comfort relaxation on energy demand. It is demonstrated that significant energy reductions by users are gets with small relaxation of air quality conditions. The comfort base model is based on the ASHRAE standards [34], it is going to change this comfort model to analyse the effect of different control variable, the CO<sub>2</sub> concentration, humidity and pressure.

### **2.3. BUILDING ENERGY ANALYSIS**

Nowadays, the grid flexibility is supplied by conventional power plants. The demand side management is defined as the energy management for the end-user electricity consumption. The consumers response to financial or other incentives. The buildings play an important role in this consumption, representing the 40% of the energy consumption [16]. Buildings should be taken into consider, the commercial building have specially importance but, they use to have implemented a Building Automation System integrated that can be no changed [37]. Furthermore, domestic buildings individually are not representative, but as a group, the residential buildings offers a great potential to work and manage the energy consumption.

Basing the research on the lumped parameter modelling framework calibrated on [38] with synthetic data obtained using Energy Plus to represent a semi-detached house. Representative of Ireland residential buildings, the research starts from a building model with an acceptable accuracy[39]. The model has been calibrated using three methodologies: sequential, simultaneous and ensemble calibration [39]. It is observed that the parameter model has potential to integrate in an electricity grid model a computationally-efficient management of the energy consumption.

Based on [38] model, the research accomplished on [40]. Presents a simple Dynamic model able to simulate heating/cooling energy consumption in buildings, based on the electrical analogy. Developing energy balance equations for external and internal conditions, the consumption is analysed concluding that the inertia effect has importance especially for the cooling demand. A MATLAB/Simulink model able to predict the heating and cooling energy demands accurately has





been developed. The model is compared in different parts of Europe and concludes that the solar irradiation has a direct effect on the cooling demand, also it compares the energy demand in Europe. The MATLAB model works well, and it can predict the energy consumption and the heating demand, which is linearly correlated with HDD (Heating Degree Days).

A model based on domestic grid integration to control the building energy demand and implementing renewable energies with photovoltaic programmable system and an energy storage based on batteries has been developed by Also [31]. But this control uses the energy generation to control the demand, not the building needs.

Some studies affirm that the energy thermal flexibility in the building has the most operational range on weekend days at afternoon/night. Also, the energy storage is proposed, but thermal storage has a short operational time. 1-2h, it has been simulated, and the peaks can be moved using storages, so the research is going to take into consideration focussing in the most operational points to improve.

Moreover, the energy storage has an influence on demand system. A lot of studies compare storage demand systems: batteries, plug-in electric vehicles (EV), commercial building thermal mass and thermostatically controlled loads. But the aim is control the consumption since the consumer point, not from the generators.

The Building demand load management has been studied by [32] with algorithms for a Smart House. The compromise between comfort and energy cost has been gotten, but the present research tries to not change the consumers behaviour. It tries to develop an optimal solution to the prediction of the energy building demand. Also, the most part of the Irish domestic Buildings are not Smart House where implement the [32] with method could be an option.

A Building simulation has been done with Energy Plus by Cole. It presents a method that generates automatically data to be used in a reduced model studio. The aim is minimize the residential electricity cost during summer. The strategy gives the authors a predictive control reduction, in the research authors focused in summer month because of the Texas weather. But in the study case of Ireland, the summer month do not represent the main energy domestic consumption. This is the reason why, taking in consideration the main parts of the [29] research. The model does not fit with the Ireland domestic energy consumption prediction.

Various demand response strategies are simulated and analysed using EnergyPlus by [41]. The energy daily flexibility is calculated. The total flexibility energy in a commercial building have been calculated by [41] presenting individual and aggregate strategies to increment the electricity energy flexibility. Some of the strategies used are: consider adjust the setpoint of chiller water, thermostat, fan control and modify heat and cooler temperatures.

Also, different types of energy storage are compared, batteries, electrical vehicles, building thermal mass and water tanks. There are considered two supply method, the heat pump and a combined heat and power.

The study made in [41] uses a virtual model to test the strategies and configurations. In first place it is developed the virtual buildings model and simulate using EnergyPlus. Once it is developed, it is analysed to observe the demand responses in each strategy. The flexibility of each strategy is analysed



and finally it is created a daily flexibility profile of the demand response for the different strategies. The flexibility is determinate comparing with an indicator that measures the available storage capacity. With this flexibility daily profile an operator can combined or use individually the strategies that better adapts to the needs of the consumers providing grid flexibility.

#### 2.4. THERMAL BUILDING ANALYSES

Go into detail about the use of commercial buildings to provide management of the energy demand using the thermal inertia of Ventilation, Heating and Air Conditioning[42]. The most common question is how provide an optimally flexibility considering the associated costs and efficiencies, various strategies have been simulated, the total energy flexibility and efficiency is calculated in [43].

The thermal energy is distributed commonly as hot water. This thermal energy can be storage, the impact of use thermal energy storage has been evaluated shifting the peak of the heating demand. Demonstrating that it is possible save costs and have available flexibility, but it depends on each case, the studies cannot be generalized. To analyse the buildings potential for use structural thermal energy storage, a framework should be established to compare the potential and flexibility of the storage. Also, it is needing to be understood how to activate the storage capacity and finally, the impact must be evaluated.

There are a lot of studies that proposed quantify the potential thermal energy storage, and the flexibility available, 3 main characteristics are presented by [43] applied in the Belgian residential sector. There are 3 dimensions of energy flexibility to consider for the storage thermal system: size, time and cost, the storage efficiency is the active thermal storage (with losses) and an activation cost for this storage capacity. This storage capacity depends on the building properties, the climatic conditions and the properties of the ventilation and heating system.

In [40] is quantify the available storage capacity and the heating power is represented by an equation:

$$C_{ADR} = \int_0^{LADR} (Q_{ADR} - Q_{ref}) dt \quad \{Eq. 1\}$$

- $C_{ADR}$  = Capacity of activate demand response
- $Q_{ADR}$  = Heat activate demand response
- $Q_{ref}$  = Heat demand without response

In the research presented by [43] Belgian buildings stock model are taken as the base of the project, the Belgian residential buildings are analysed and simulate. To include different types of building with really different characteristics, it is simulated the quantify of energy storage available and the efficiency.

The boundary condition is analysed and shown to be evaluated in static conditions. Assuming constant outdoor temperature and the absence of gains. It is analysed the effect if storage thermal energy during a period of 4h. It is observed that for long times when the indoor temperature reaches the comfort, the heating must be limited.

Also, comparing different buildings, the houses built before 1945 [21] needs more than the double of energy than the news ones to research the same conditions. On the other hand, the higher ratio of thermal mass losses is obtained for the terraced buildings. Also, the houses with thermal storages



experiments more losses than the houses that provide the heat by radiators. Moreover, it is noticed that floor heating is the most efficient method, with higher storage efficiency and higher available capacity. The study concludes that buildings with higher capacity have higher impact on CO<sub>2</sub> emission [43]. In a new scenario more complete, it is contemplated the solar gains. Resulting higher indoor temperature in spring period until the heating system is not needed. It is noticed that the energy flexibility depends also on the boundary conditions and is also time-dependent.

The impact of structural thermal energy storage has been studied several times. It is based on the available storage capacity, the efficiency, power shifting capability and the state of the charge. It compares the building conditions but also the technologies used to provide the energy, as it was described in the previous paragraph. The floors heated buildings have higher efficiency than the rest of the technologies.

The thermal storage efficiency conversion is one of the less efficient ways of storage energy, around 60% comparing with the 90% of the efficiency in batteries [43]. That means thermal storage can be used when heating or cooling are the end-use of energy but reconvert the thermal energy into electrical energy has no sense. However, multiple researches have demonstrated that thermal energy storage can be cost effective and efficient.

## **2.5. THERMAL AND ELECTRICAL BUILDING ANALYSIS**

An interactive model reduction methodology is presented in [44] to identify potential trade-offs, it describes the results of a model reduction procedure applied in lumped parameter building energy models. This is the first step towards an automated solution, provides guidance on model complexity and its potential problems, this research is based on the reduction of these models, trying to reduce it to obtain accurate and fast results of the simulations, the model is an analysis of multi-energy systems, with occupancies that demand energy, the objective is to get models that would no longer be comparable among themselves. The work done in [44] is the prior step towards a fully automated model reduction tool suitable for providing multi-energy systems researchers with insights into computational trade-offs during the modelling stage.

The energy simulation of the virtual representation of the energy process for a building has been developed by Zheng Yang [art 4], a high accuracy related energy consumption in buildings has been gotten, it has been developed a model to calibrate the building energy efficiency under different control strategies, but do not get the entire energy prediction of the energy building demand.

## **2.6. PRIOR CONCEPTS**

### **2.6.1. ENERGYPLUS**

Energy Plus is a simulation program used to model buildings related with the thermal system, air conditioning and ventilating [45]. Energy Plus is a free professional program designed to describe building conditions and the environment, it is going to be used to compare and simulate different scenarios.

That program is used to simulate a building which is going to be analysed, different demand response, strategies and weather. Obtaining the results from the EnergyPlus model.



### 2.6.2. EFFICIENCY:

The energy efficiency is the comparison between the amount of energy required to use and the amount of energy waste to provide it, improvements in energy efficiency are generally related with more efficient technology, improving the energy efficiency is decreasing the energy consumption and the cost.

### 2.6.3. FLEXIBILITY:

The flexibility is the reference between the base consume and the consume after applying a strategy to reduce it, as much flexibility has a system, as easier is to control the consumption and cost.

### 2.6.4. FLEXIBILITY INDICATOR:

There are a lot of ways to quantify the flexibility, the indicator that is going to be used in this research to analyse the different proposals and how affect the different key points, is defined as[41]:

$$AEEF = \int_j^{lDR} |P_j^{flex} - P_j^{ref}| d \quad \{Eq. 2\}$$

AEEF: Available Electrical Energy Flexibility

$P_1^{h, flex}$  = is the power consumption in the case when the demand response is being applied.

$P_1^{h, ref}$  = is the power consumption in the base case, there is no demand response applying.

To compare easily the individual strategies, apply an analyse, another parameter is going to calculate:

$$\eta_{AEEF} = 1 - \frac{\int_0^{Hor} (P^{flex} - P^{ref})^+ dt}{|\int_0^{Hor} (P^{flex} - P^{ref})^- dt|} \quad \{Eq. 3\}$$

$P^{flex}$ : power consumption with demand response

$P^{ref}$ : power consumption in the reference case

### 2.6.5. COOLING DEGREE DAYS [CDD]

A cooling degree day [CDD in advance] is the energy demand that a building need to cooling [46]. It is related with the outside temperature and it depends directly on the specific location. CDD is defined in relation of the energy need to research a temperature cooling the building and assuming that building need to cool. The reference temperature to obtain the CDD is different depending on the country and his legislation, for the present research the reference temperature chosen is 24°C.

$$CDD = \sum_{n=0}^{n=365} (T_{daily\ average} - T_{base}) \quad \{Eq. 4\}$$



## 2.7. PROJECT AIMS AND OBJECTIVES:

This work is understandable in an electrical grid context. The electrical energy is more and more demanded, and the grid should adapt the load to this demand. But not always is rentable or easy provide this electrical energy. Therefore, a commercial building that can provide some flexibility to the grid can be useful, in the context of decrease the grid peaks. Also, this flexibility can be sold to the grid obtaining economic benefits.

The aim of this project is analysed the available electrical energy flexibility that a commercial building can provide to the grid. The study is developed in several weathers to investigate the weather effect on the flexibility that can be provided. It is based in the HCAV system, in concrete, it is analysed the cooling system. Some of the locations included in this project are Reykjavik, Seville, Athens, Dublin and London, with the aim of analyse different weathers.

The commercial building profile is obtained from a previous work describe in point 3. With the bases of this commercial building, some strategies are analysed to provide this flexibility and they will be examined on EnergyPlus. It is simulated each strategy for a timestep of 1h, because the load of the grid is variable, and the objectives is providing flexibility just when it is need. Each strategy should be analysed for his applied anytime, 24 simulations should be analysed for each demand response in each location. All the results will be compare in MATLAB.

Using demand response strategies is going to provide the flexibility, the main objective of this work is identified the correlation between the demand response strategy and the available flexibility. Another objective is identified how affects the weather to the strategies in order to provide flexibility. Finally, all the strategies in all the locations will be analysed to identify if it is possible.

One important point for this project is obtained the flexibility without affect the inhabitants comfort, this is the reason why a comfort analysis should be done.

To analyse in a proper way the flexibility that can be provided, two strategies are analysed. The main research aims are identifying, and some questions should be answer through this project:

- How affects the weather to the electrical flexibility available?
- Which is the effect of each strategy? How is providing each strategy flexibility?
- Is possible obtained always electrical flexibility with the same strategy?
- Is the comfort compromised if the demand responses are applied?
- Is efficient provide to the grid this flexibility?
- There is some correlation between weather, strategy and electrical flexibility?

### 3. PREVIOUS WORK: MODEL

#### 3.1. REFERENCE MODEL:

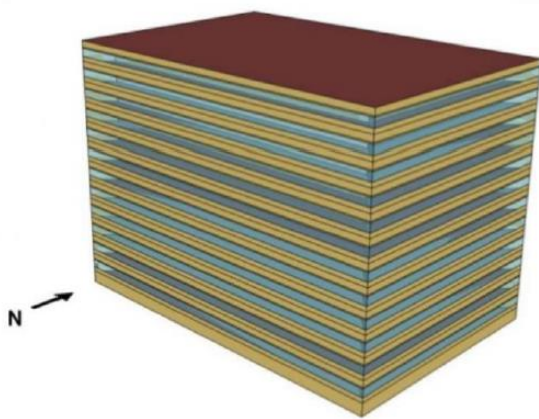
The present research is focusing in the analyses of buildings strategies. The goal is obtained a building that represent the new and existing constructions. Characterizing more than 60% of the commercial buildings [39]. That model is going to be develop in Energy Plus, using the previous research made by [41] and detailed in [47] the reference building to compare and analyses each one of the parameters. The reference model is described as a commercial energy building. The standard model is developed as a representative and realistic commercial building. Moreover, it is going to be used as a reference in the research to analyzes technologies, location and optimize designs. This model is a representative base model to analyse the energy consumption and the flexibility.

##### 3.1.1. BUILDING DESCRIPTION:

The building model has been developed by [41] in the research which is taken as the previous work, to keep the results the same building has been taken, it is a commercial building with the references provided by DOE (Department of Energy) [48] and with the minimum requirements of ASHRAE standard 90.1-2004[49]. It is simulated in EnergyPlus, the building represents the two thirds part of commercial building stock in the USA [41]. It is going to be tested in Europe, with the base case of Dublin, Ireland weather.

The building has 12 floors plus a basement with a total area of 46,320 m<sup>2</sup>. The schedules of the operation time goes from 6 a.m. to midnight during weekdays and 6.00 a.m. to 5.00 p.m. during Saturdays, there is not operating during Sundays. The simulation step are 15 minutes.

Because of the complexity and size of the building, some model reductions are performed. The floors are considered as a box, including five zones, four perimeters and one mid zone each floor, also the temperature and volume zone is calculated as one.



Floor Area	46,320 m <sup>2</sup>
No. of Floors	12
Heating	Gas Boiler (1,766 kW)
Cooling	Two water-cooled chillers (1,343 kW)
Air Distribution	Multizone variable air volume (MZ VAV)

**Figure 3: Large office Building**

The operation time determinates the internal cooling setpoint temperature in the building for the summer season is determinate by the summer design days, where:



Table 1: Temperature set point in summer season for cooling

TIME PERIOD	TEMPERATURE SET POINT
0.00 – 6.00	26,7°C
6.00 – 22.00	24°C
22.00 - 24.00	26,7°C

The HVAC system in the building consist in a heating system provided by a gas boiler of 1766kW, this gas boiler is electrified in the study to offer electricity flexibility. There are two water-cooled chillers to provide cooling with 1.343kW each one. Also, it counts with a multizone variable air volume for the air distribution. To simplify the system is going to be consider a Heat-pump as a combination of heating and cooling systems to analyse and simulate the building.

Once the building has been described it is going to describe the strategies, also known as demand response (DR). It is developed two average profiles, one for winter and one for summer. The average winter day (weekday) has a consumption dominated by heating with boiler peak around 6a.m. and a peak consumption of the building around 8a.m., the average winter load is show in the figure 4:

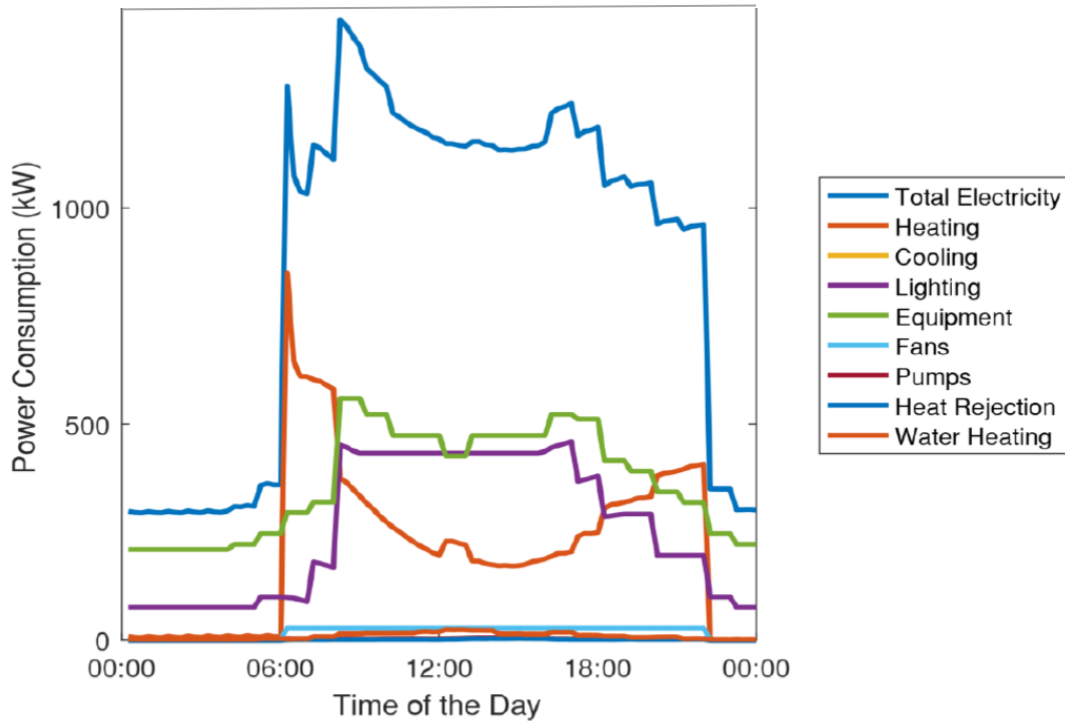
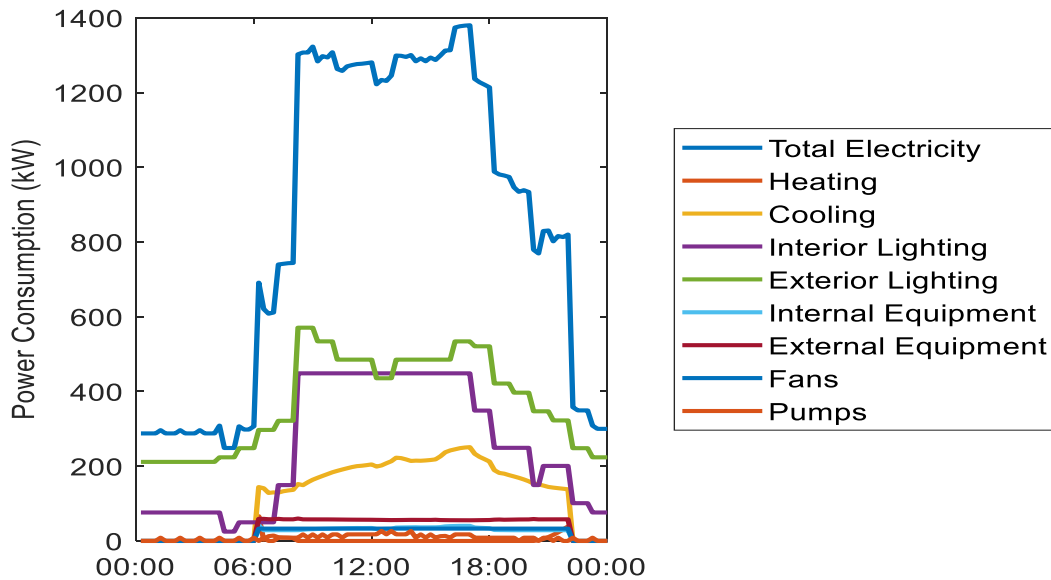


Figure 4: average winter daily load profile

For summer, the load profile on the average of hot day (with a max temperature of 24°C) has a peak because of the chiller (cooling system) around 4.00 to 6.00 pm because of solar gains, the summer load profile is shown:





**Figure 5: summer day load profile**

For both summer and winter days the fan and pump loads are small comparing with the total consumption. The summer peak is the highest, so the day that is possible to obtain the maximum electrical flexibility is the hottest day with the highest peak consumption. That means that has also the highest possible consumption reduction acting in the peak.

But the highest peak doesn't mean the highest consumption, so the coldest and hottest days consumption are going to be compare:

*Table 2: End-use electricity consumption*

<b>END -USE ELECTRICITY CONSUMPTION (KWH)</b>	<b>10<sup>TH</sup> JULY (SUMMER)</b>	<b>20<sup>TH</sup> JAN (WINTER)</b>
<b>HEATING</b>	65	8348
<b>COOLING</b>	2977	0
<b>LIGHTS</b>	6029	6452
<b>ELECTRICAL EQUIPMENT</b>	8918	8918
<b>FANS</b>	526	465
<b>PUMPS</b>	913	16
<b>HEAT REJECTION</b>	529	0
<b>WATER SYSTEM</b>	204	247
<b>TOTAL</b>	20161	24446

Considering the building passive thermal mass as a technology that can provide flexibility. The adjustment of the thermostat temperature setpoint can be used as a demand response strategy. The operative temperatures are given by ASHRAE 2004b standard 55 [49]. Also, if the setpoint change the comfort must be tested.





Table 3: ASHRAE acceptable limits for zone temperature drift [49]

TIME PERIOD	0.25H	0.5H	1H	2H	4H
MAXIMUM OPERATIVE TEMPERATURE CHANGE (°C)	1.1	1.7	2.2	2.8	3.3

Another DR strategy is to adjust the chiller water setpoint temperature. But this strategy is only working with cooling loads, in summer days. The chiller setpoint can be increase from 6.7°C to 12°C. Another DR more extreme is turn off the fans completely, but the thermal comfort and minimum ventilation need to be considered. Also, the addition of thermal store tank is considered. A sum up of the strategies is shown in the table 4:

Table 4: Demand response technologies considered in the previous study.

DEMAND RESPONSE TECHNOLOGY	DR STRATEGY	DETAILS
<b>BUILDING PASSIVE THERMAL MASS</b>	Chiller water setpoint adjustment	Downward flexibility (increases from 6.7°C to 12°C) Upward flexibility (decreases from 6.7°C to 3.3°C)
	Global setpoint adjustment	Downward flexibility: ASHRAE 2004b limits Upward flexibility: ASHRAE 2004b limits
	Fan off	Downward flexibility

The demand response strategies are implemented for the coldest day (January 20<sup>th</sup>) and for the hottest day (July 10<sup>th</sup>) according with the weather file of Dublin, Ireland (base case). The strategies are implemented and simulated with EnergyPlus and the results are compared with the EnergyPlus results without DR implemented. The difference in the building electrical power demand and occupants comfort are the main variables compared.

As the objective is analyse the reduction of the peaks with the implementation of different strategies. The hottest day is the day where are going to probe and test the effect of the different DR.

### 3.2. REFERENCE MATHEMATICAL MODEL:

The model is based in a previous study made by [41], a building simulate in Energy Plus is expose to different climates and demand response. The objective is analysed the flexibility of the electrical energy available under different strategies, for that a new indicator is include:



$$AEEF = \text{Available Electrical Energy Flexibility} = \int_j^{l DR} |P_j^{flex} - P_j^{ref}| dt \quad \{Eq. 5\}$$

$P_j^{ref}$  = power consumption of the building without a demand response

$P_j^{flex}$  = power consumption of the building when the DR is applied

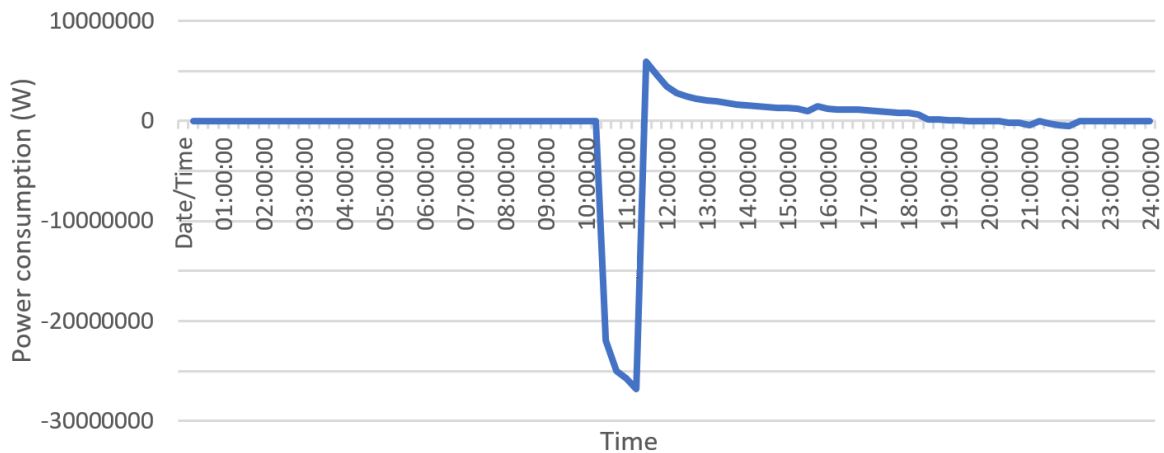
It is reproduce the same results reflected in the mention paper to be ensure that the methodal is the same. The building is simulate in Energy Plus and compare, obtaining the same results.

As the previous study in which is based this document done[41], a demand response is analyse obtaining the hour with most AEEF, the DR selected to this simulation is the set point.

The DR consist in change the temperature set point for 1 hour. 24h are simulated, obtaining 24 different simulations and results. To compare and obtain the results the MATLAB program used in the previous study is used.

Energy Plus program is edit in the energy control program, changing for one hour the set point. This change has an immediate individual effect for the hour analysed. If e.g. the demand response is between 10-11 a.m. the individual effect is show in the next hour. Obtaining an available electrical energy peak during the operation and a rebound effect with a small peak in the next hour, as it can be observed in the following figure:

DR set point apply between 10 and 11 a.m.



**Figure 6: DR individual effect expected**

Note the small rebound effect after the demand response event. Due to space con-strains, the results for up flexibility when the chiller water setpoint temperature is decreased are not shown. The plots are similar except inversed from below.

Following this measure, there are undesirable demand spikes which is a rebound effect. Rebound avoidance techniques such as recovery periods were not considered in this study.



Once the individual effect is observed and analyse the daily effect is going to be observed. The day simulate is 10 July, to compare the same as in the previous study. The climate simulate is Dublin, the results are shown:

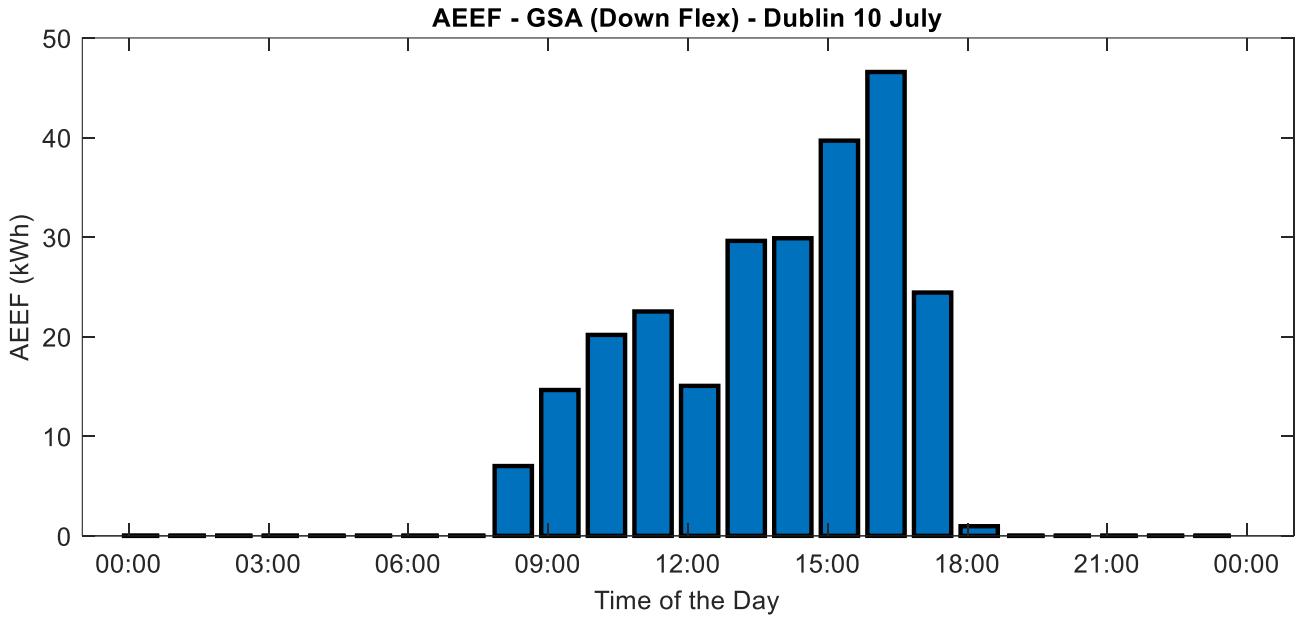


Figure 7: AEEF expected with the DR set point implemented

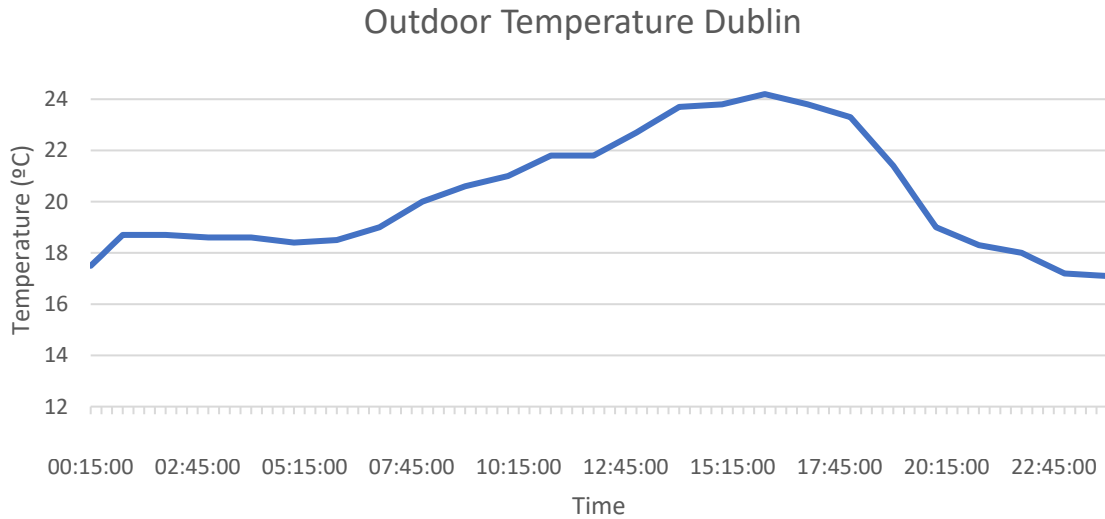


Figure 8: outdoor temperature for Dublin

It is shown the outside temperature in Dublin for the July 10<sup>th</sup>, the flexibility obtained is because of the building systems.



The results are the same than in the previous study, so it is probe that the Energy Plus is the same and the program used in MATLAB obtained the same results. The method can be applied to the rest of the climates to analyse the available electrical energy flexibility applying the same DR to different climates.

On the other hand, another factor should be taken in consideration, the efficiency of the demand response. It is analyzed the efficiency to apply the demand response, to provide the flexibility to the grid it is not need just have savings. Also, the rebound effect and the paying must be considered. A strategy can provide flexibility, but it must also be efficient to put in practice. The aim is providing flexibility reducing the energy consumption. As better efficient is the DR, as better is to implement it from the point of view of the energy cost.

The efficiency depends on the strategy, and it is defined as  $\eta_{AEEF}$  = the efficiency provided for the DR in the electrical flexibility, it is different depending on the DR.

If the strategy is decreasing the consumption, the efficiency will be analysed because of a down-flexibility strategy, what mean that the savings are biggest than the paying:

DOWN-FLEX: It is a strategy that provides flexibility to the grid decreasing the energy consumption. The building can consume less electricity than the expected in the peaks of the load consumption. Providing to the grid an extra electricity available.

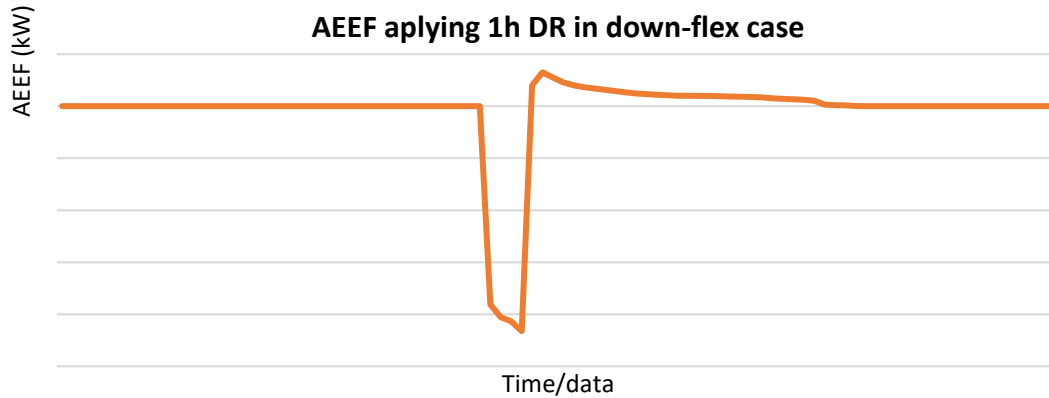
$$\eta_{AEEF} = 1 - \frac{\int_0^{Horizon} (p^{flex} - p^{ref})^+ dt}{|\int_0^{Horizon} (p^{flex} - p^{ref})^- dt|} \quad \{\text{Eq. 6}\}$$

where:  $\int_0^{Horizon} (p^{flex} - p^{ref})^+ dt$  represents the energy consumption required to restore the previous set point conditions, it is the rebound effect.

and  $\int_0^{Horizon} (p^{flex} - p^{ref})^- dt$  represents the energy savings related with the demand response strategy.

The  $P_j^{ref}$  = power consumption of the building without a demand response

$P_j^{flex}$  = power consumption of the building when the DR is applied



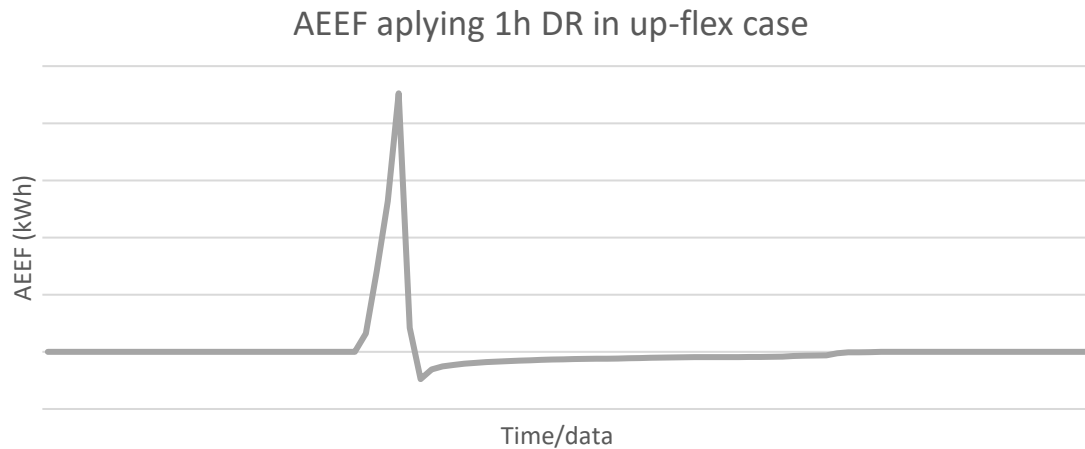
**Figure 9: typical AEF curve in down flexibility DR**

If the strategy is increase the consumption. There are cost than savings, so the efficiency will be analysed due to an up-flexibility:

UP-FLEX: it is a strategy that uses an extra electricity consumption to provide flexibility to the grid. The building can absorb the exceed electricity from the grid.

$$\eta_{AEF} = \frac{|\int_0^{Horizon(pflex-pref)-dt}|}{\int_0^{Horizon(pflex-pref)+dt}} \quad \{Eq. 7\}$$

Where the rebound effect are the savings and the DR is the extra consumption.



**Figure 10: typical AEF curve in up flexibility DR**

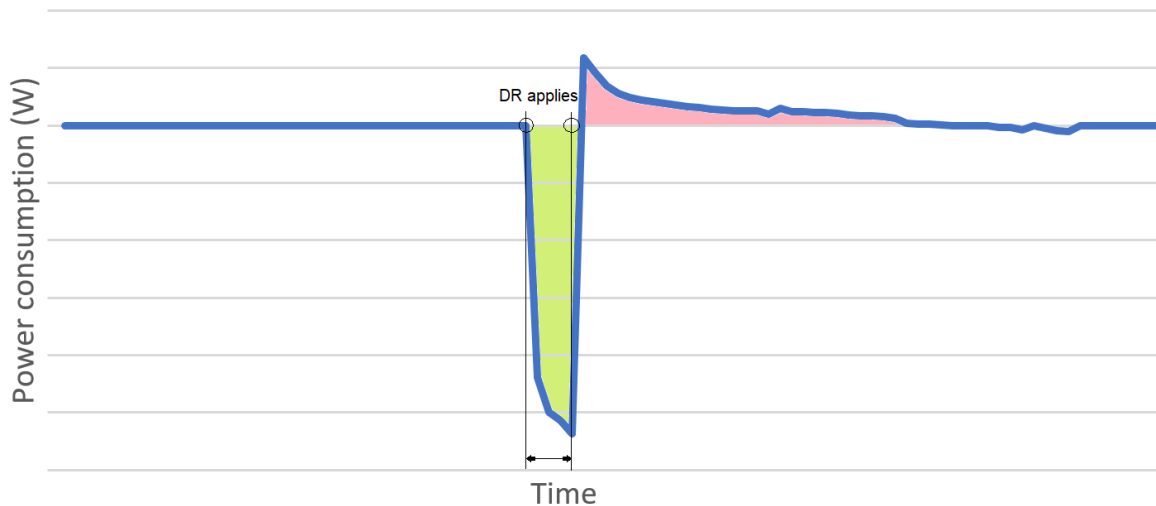
### 3.3. METHODOLOGY TO SIMULATE THE PREVIOUS WORK:

To develops the actual research is starting from the same point as it finishes in the previous work. That is the reason why the simulation of Dublin during the 10<sup>th</sup> of July (day that was selected in the previous work) is the “Base Case” for the present work. To be sure that the model, the demand response and the analysis is the same, the data are reproduced.

On first place, the model without the DR is going to simulate in EnergyPlus, with the power consumption expected as the figure 11.

Then, the DR is reproduced, in time laps of 1h. The DR implemented is the temperature set point. During the not operation hours the expectative is not having any change from the model without DR, to compare and show the results, the AEEF criteria has been selected.

Also, it is expected a reduction of power consumption during the term that the DR is applying. A rebound effect when this DR term finish, as result a graphic as the show in figure 11 is expected:



**Figure 11: AEEF effect expected to apply the DR during 1h term.**

$$AEEF = \text{Available Electrical Energy Flexibility} = \int_j^{l DR} |P_j^{flex} - P_j^{ref}| dt \quad \{\text{Eq. 8}\}$$

$P_j^{ref}$  = power consumption of the building without a demand response

$P_j^{flex}$  = power consumption of the building when the DR is applied

J = time when the DR starts

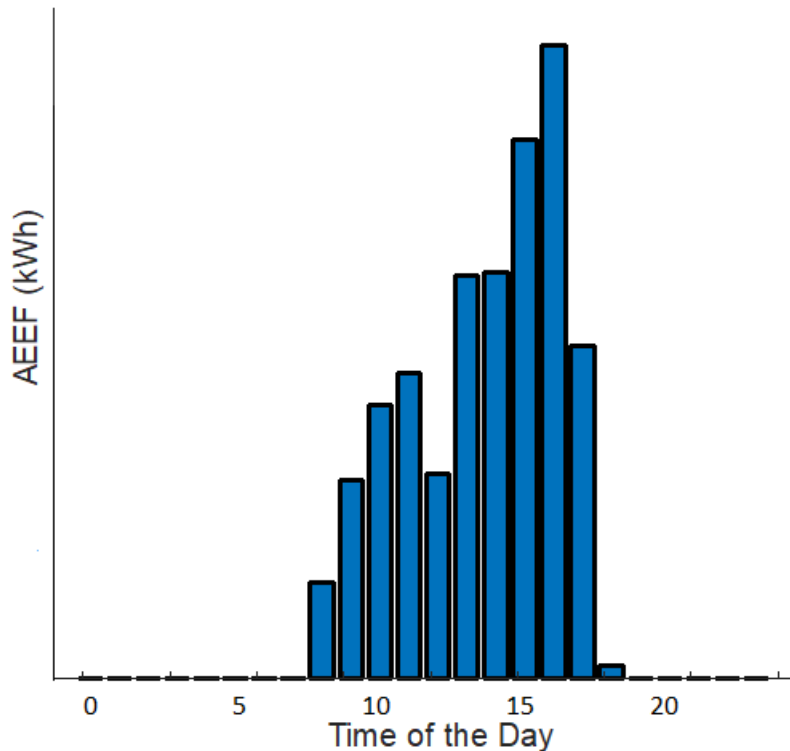
L = time when the DR ends.

The green area represents the gains/ saving obtained in the power consumption when the DR. Reduce the set point is applying. The area is also, the among of energy that can be saved during this hour. Providing to the grid the available electrical energy when the DR is implemented.

The red area corresponds to the rebound effect. This effect is expressed as an increase of the electrical energy needed during the next period. This is the rebound effect, and it is consequence of return to the initial set point. In this study the rebound avoidance techniques are not considered.

Once the individual response has been study, its time to reproduce the DR each hour and observe the effect. Some questions should be respond: Is it able to obtain flexibility any hour? When is it obtained the maximum flexibility?

The DR set point is going to be reproduce for each hour, obtaining at the end 24 simulation in different times. The object is observed in which period is possible offer more flexibility to the grid. That what is expected obtain the maximum flexibility when the consumption is the maximum. That means that for Dublin, the peak is expected at 5pm, as it can be seen in the figure 12.



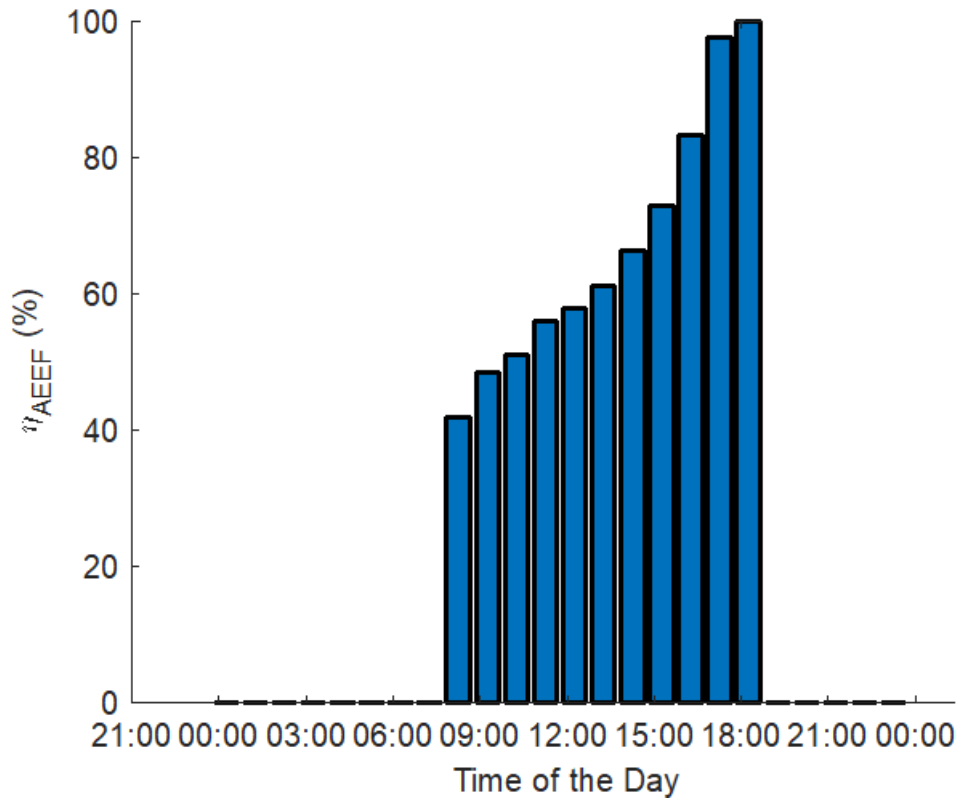
**Figure 12. Typical AEEF if the DR is applied each hour**

As it can be noticed is expected the curve start at 8 a.m. and finish at 19 a.m. Because the operational schedule of the building and because of the internal temperature. The set point consumption increase when the internal temperature should get the set point. But, during the no sun hours the temperature decrease, not being necessary the cooling. In this case the consumption can be reduce because there is no power consumption.

The data obtained in the 24 simulations must be compare with the power consumption profile without the DR applied. To compares and facilitated the comparison MATLAB is used. The code is the same MATLAB file used by the previous work.

As final step the objects resulting for the actual simulation has been compared with the ones obtained by the precious work. Obtaining the same results, as consequence, the research can advance from the base built in the previous work.

In the previous work also is analyse the efficiency of the base case and the 24 simulations. It is expected an efficiency just during the periods where an availability is obtained. As the bases of the wok is to reduce the power consumption the demand response applied is reduce the set point temperature obtaining a down-flex with an expected profile:



**Figure 13. Typical efficiency load when the DR is down flexibility and applied each hour**

As it can be observed is expected obtain efficiency in the same hours than the flexibility is shown. But, it doesn't mean that the efficiency is proportional with the flexibility. This is because the flexibility provided to the grid is an amount of energy and the efficiency is the percentage of energy that can be saved.

### 3.4. GOALS.

The object of the actual research is built a model that provides the availability electrical energy to the grid. To implements this model, it is needing to know if the commercial building can be implemented in different locations with different weather. The goal is demonstrated that the building can be implemented in different locations succeeded and obtaining the electricity flexibility for each location.

As the previous work does, is going to study the implementation of one of the demands response. The set point, as a strategy to provide flexibility, as the chosen day is the hottest during the year in Dublin. Other locations in Europe are going to be choose (location which are in summer season) and different DR are going to be analyse with the aim of answer: Is the set point a good DR everywhere? The electrical flexibility has a similar load everywhere? The flexibility is going to be obtained just during the operational timetable?

To answer all these questions a detail study is shown in 4. Results point.





## 4. METHODOLOGY

### 4.1. ANALYSIS OF IMPACT OF CLIMATE.

#### 4.1.1. Locations.

Location are selected to represent all the weathers and all the climates. The aims in found 15 locations to represent the heating degree days and the cooling degree days covering all the ranges and climates. The location choose has not related with the building model the location is just using to analyse the weather influence in the energy consumption. It is need define zones within European region, each zone contemplates different ranges of heating and cooling degree days and includes common climatic characteristics to facilitate the building energy estimation.

Searching the specific data, a table of Europe is obtained. The table represent the country average, but each specific location can be very different to the others one inside the same country. To calculate the “Heating Degree Days” the hourly temperature during the year 2017 is obtained from the database of Energy Plus and compare with the reference of 20°C for heating. Also, for the calculate of the “cooling degree day” the hourly temperature has been obtained from the same database, but that temperature has been compared with 24°C.

The reference point of 20°C and 24°C are an assumption that it is take into consider to be able to compare different locations. In fact, depending on the country, the reference temperature is different, 20°C and 24°C correspond to a general reference to compare the real weather of the locations.

There are several countries with more heating degree days, but there are less variety on the countries with less cooling degree days. This is because of the weather, it must be observed also the range in the degree days, as in heating degree days the range go from 0 to 5500. In cooling degree days the range is much shorter, from 0 to 700, as in this project it is going to focus in cooling. The most important parameter to choose the locations is the CDD.

In other to cover the biggest range as is possible using Europe as reference. 15 specific location are chosen, the criteria to select the cities is trying to cover the biggest range as possible having also intermediate points to try to have a linearity with the results. To covers all the European climates, the data shown in the table 1 are a country average, in the following table a specific point is studied.

The data are obtained from [50] as the minimum daily temperature for the heating degree days and the maximum daily temperature for the cooling degree days. This is because the data obtained from [50] are in base 20°C, so for HDD can be used but not for CDD. It is choosing the same criteria for both data. How it can be observed, with the minimum daily data the HDD obtained is similar to the HDD calculate as the hourly average (3590HDD/year for hourly average in Milan and 4110HDD/year for minimum daily data in Milan). To calculate the HDD and CDD the reference point is chosen. How is has been explained, as 20°C for HDD and as 24°C for CDD, following the equation 9:

$$HDD = \sum_{n=0}^{n=365} (T_{base} - T_{daily\ average}) \quad \{\text{Eq. 9}\}$$

$$CDD = \sum_{n=0}^{n=365} (T_{daily\ average} - T_{base}) \quad \{\text{Eq. 10}\}$$



Table 5. HDD and CDD in 2017, specific cities in Europe.

	HDD	CDD
<b>Amsterdam</b>	4047	15
<b>Athens</b>	1791	325
<b>Barcelona</b>	2208	89
<b>Canarias</b>	632	116
<b>Kiev</b>	4825	30
<b>Krakow</b>	4751	28
<b>Milan</b>	3590	86
<b>Pisa</b>	2634	119
<b>Seville</b>	1722	464
<b>Bilbao</b>	2659	33
<b>Dublin</b>	4084	0
<b>London</b>	3968	9
<b>Paris</b>	3688	26
<b>Reykjavik</b>	6012	0
<b>Timisoara</b>	3880	112

#### 4.1.2. WEATHER INFLUENCE IN LOAD CURVE.

The influence of the weather on the power consumption is analysed. To compare and analyse is simulated the building in EnergyPlus without the DR in 15 different locations selected in the previous point.

Once the base case for each location during the July 10<sup>th</sup> is simulated, the power load is observed. There is expected high cooler consumption in warmer places, and have heating consumption in the coldest places, as in Reykjavik.

On the other hand, the indoor temperature inside the building is going to compare. The places with a weather like Dublin must have a time profile of the cooling like Dublin during the operational hours. But, the hottest places as can be Seville, should show a different profile, having the cooling working also out operational time. Furthermore, in the places with cold temperature is expected have less operational time for the cooling, include not the use of this one.

#### 4.2. METHODOLOGY TO IMPLEMENT THE DEMAND RESPONSE.

Once the weather has been analysed, to keep with the simulation, after comparing the base case, it is simulated the demand response during 1h time laps, for one day, each hour. Obtaining 24 simulations per location, with the DR simulations is possible to obtain the AEEF profile for each location.

The AEEF profile for each location is obtained following the same methodology as in the previous work. Comparing the power consumption with the DR each hour with the power consumption in this location without the strategy.



It is expected obtain a load like the temperature, in the places where inside temperature is over the set point. There are an electricity flexibility during this period, but in the places where the indoor temperature is always under the set point, will be no flexibility.

To solve the 24 simulations per location, it is created groups in EnergyPlus, which let simulate at the same time the 24 DR cases for the same weather. Once the simulations are taken, it is used the same MATLAB file than in the previous work, changing the data.

It is drawn the AEEF profile for the 15 locations and compare. It is expected different types of profiles, but that is not enough to know if the model is available for all the locations. The summer design set point is shown in [Table 1](#).

**4.2.1.DR: INCREASE THE SET POINT**

During the present research some demand response are contemplated. The increase set point is proved and simulates, it is the same that has been explained in the previous work. It is chosen the same DR to compare the expected results with the actual ones, also it is important compare this DR in the 15 locations. This DR with the increase of the set point suppose a consumption reduction in the cooling, simulating for the July 10<sup>th</sup> it is expected obtained saves when the strategy is applied. Due to the nature of the DR it is catalogued as down-flex strategy, and the methodology to develop the efficiency is going to follow that description.

To decide the increase of the set point is going to follow the ASHRAE acceptable limits for zone temperature drift (ASHRAE 2004b Standard 55. Thermal Environmental Conditions for Human Occupancy, 2004[49]), which determinate the maximum variety in the indoor temperature as:

*Table 6: Acceptable variety in indoor temperature*

<b>TIME PERIOD</b>	<b>MAXIMUM VARIETY INDOOR TEMPERATURE ACCEPTABLE</b>
<b>15 MINS</b>	1,1°C
<b>30 MINS</b>	1,7°C
<b>45 MINS</b>	2,2°C
<b>60 MINS</b>	2,2°C

The increase of the set point strategy implies a change in the design days:



Table 7: New summer design days increasing set point temperature

TIME PERIOD	TEMPERATURE SET POINT
0.00 – 6.00	28.9°C
6. 00 – 22.00	26.2°C
22.00 - 24.00	28.9°C

#### 4.2.2.DR: DECREASE THE SET POINT.

Looking for other strategy to compare and analyse the influence not only of the strategy but also for the weather influence it is going to be apply a set point temperature decrease. This strategy should affect to the heating, having more sense during the winter season. But, it is compared with the other strategy through the strategy is going to cause cost in the cooling and saving on the heating. It is expected obtain more costs than saving. That mean that the flexibility provided by the strategy it is going to be provided with an extra consumption cost. The flexibility is the capacity to provide a variation of electrical energy to the grid, in this case this variation in increment the consumption of the building in case the grid has an exceed. This strategy must be analysed as an up-flex strategy.

As it happens with the previous strategy, to decrease the set point temperature it is going to follow the ASHRAE acceptable limits for zone temperature drift [49]. Which determinate the maximum variety in the indoor temperature as [Table 6](#).

The decrease of the set point strategy implies a change in the design days:

Table 8: New summer design days decreasing set point temperature

TIME PERIOD	TEMPERATURE SET POINT
0.00 – 6.00	24.5°C
6. 00 – 22.00	21.8°C
22.00 - 24.00	24.5°C

#### 4.2.3.METHODOLOGY TO ANALYSE DR: AVAILABLE ELECTRICITY ENERGY FLEXIBILITY

To analyse the available electricity the first step is catalogized the demand response in down-flex or up-flex. Which kind of flexibility offer the strategy to the grid? Absorbing exceeds or provide more energy?

Once the DR is cataloged it is going to simulate the strategy during 1h time lapses and it is going to draw the flexibility provided. This flexibility is the result between the electrical power consumption with the DR applied and the original power consumption.

#### 4.2.4. METHODOLOGY TO ANALYSE THE EFFICIENCY.

It is catalogued the demand response strategy in down-flex or up-flex, depending of the origin of this flexibility. If the flexibility is provided by a reduction of power consumption the strategy will be catalogued as down-flex. In the case of the electrical flexibility will be provided by an extra energy consumption the strategy will be catalogued as up-flexibility. The first question to analyse the efficiency that need to be solved is: Which type of strategy is?

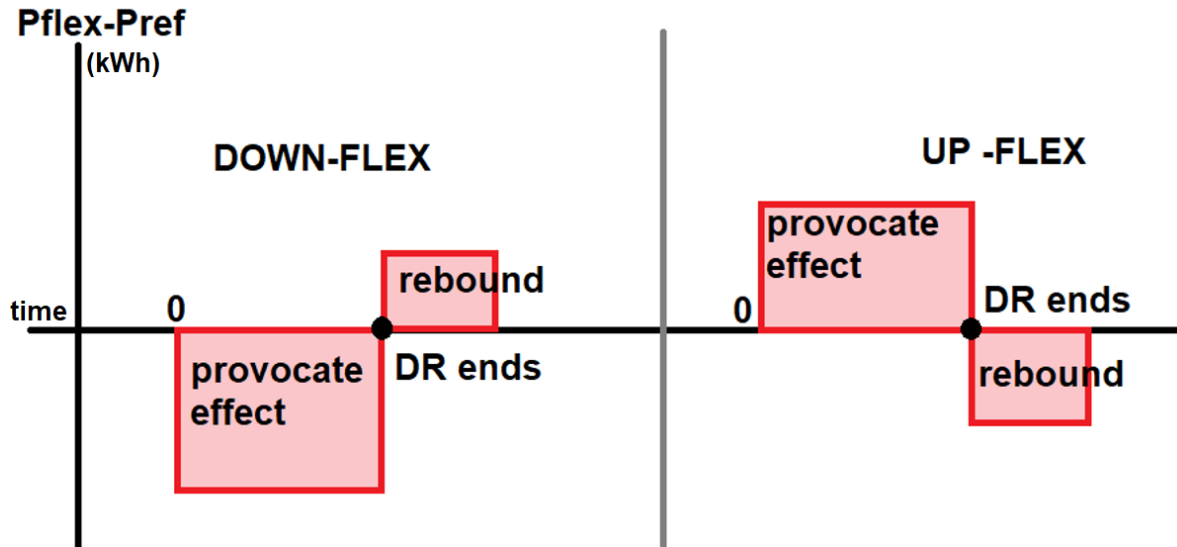


Figure 14. Down and up flexibility loads

DOWN-FLEX: when the power consumption is decreasing providing the flexibility.

UP-FLEX: when the power consumption increases to provide the flexibility to the grid.

Once it is classified the strategy, it is going to analyse mathematically following the MATLAB model developed in the previous work. Where the efficiency will be defined:  $\eta_{AEFF}$  = the efficiency of the flexibility provided for the DR in the electrical grid.

To develop and analysed each case it has been developed in MATLAB a code to simulate the flexibility and efficiency depending on the type of flexibility.

#### 4.2.5. METHODOLOGY TO ANALYSE THE COMFORT.

The implementation of each strategy is initially determinate by the electrical flexibility provided to the grid. But, there are other main variables to consider, and it is needing to follow the ASHRAE restrictions [51], to analyse how the DR strategy influence on occupants' comfort.

There are six factors implies in thermal comfort, they are: metabolic rate (energy generated by the human body) it depends on the activity, clothing insulation, air temperature, radiant temperature (the weighted average of all the temperatures), air velocity, relativity humidity (percentage is water vapor in the air).



Thermal comfort is calculated as the heat transfer energy balance, the heat transfer between the environment and the human body. If the heat leaving is greater the perception is cold, if the heat receiving by the environment in the human body is greater than the leaving, the perception is hot. There is a method to describe and predict the thermal comfort: the PMV. It is going to consider the predicted mean vote (PMV), that is an index of the Fanger thermal comfort model [52]. The indexes predicts the mean response of a group of people according the ASHRAE thermal scale:

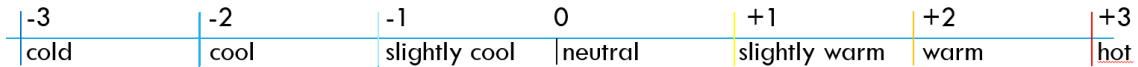


Figure 15: PMV index

PMV is the most used thermal comfort index, the ISO Standard 37730 [53], uses limits on PMV as a definition of comfort zone. The equation only applies to humans exposed to a constant metabolic rate, it means, to the same human activity (e.g. work in an office, do sport). The recommended acceptable PMV range in previous work, and in this one, is -1 and 1 for an interior space.

The PMV simplify index is express as the follow equation:

$$PMV = (0.303 e^{-0.036M} + 0.028) L \quad \{Eq. 11\}$$

PMV = Predicted Mean Value Index

M = metabolic rate

L = thermal load, defined as the difference between the internal heat production and the heat loss to the actual environment, for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level

To know if the comfort is gets in the different location applying the DR, it includes this calculation in EnergyPlus. It is analysed, to make a real impression about how affect the DR to the comfort, it is simulate also the comfort without the DR strategy.

After the calculate of this ratio, it is drawn by MATLAB following the code specify and the results will be compare in [8.3.3. Appendix PMV results](#).

In base case, it is expected get the comfort once the DR is applied. Different space comfort are show as it was specified in the model description. The building has 12 floors, but it can be reduced in basement, bottom floors, middle floors and the top one, because the spaces are calculated as one, with the average of the spaces.

It is expected different values, the basement as the less refrigeration, so it will be the space with less comfort. Also, it is expected less comfort in the peaks of consumption.

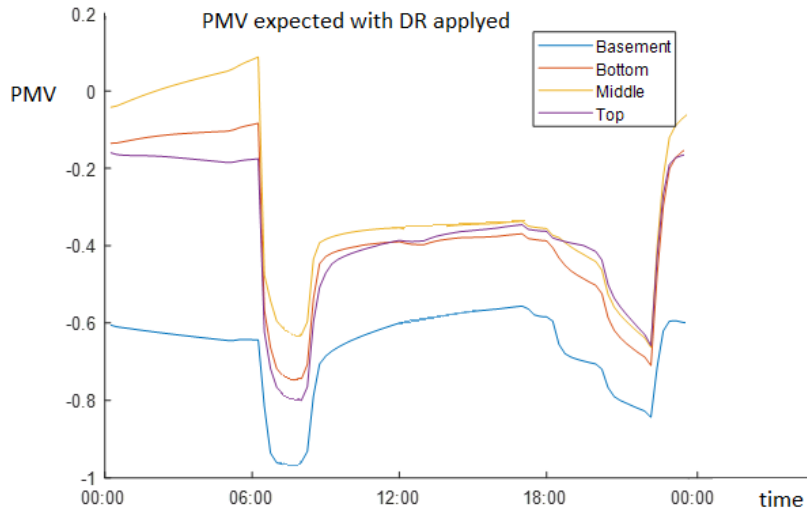


Figure 16. PMV expected with DR

## 5. RESULTS

### 5.1. RESULTS OF INFLUENCE OF WEATHER

Firstly, it is analysed the location temperature during the day.

Firstly, it is check the temperature in Athens and Seville, both should show temperature over 26,7°C to confirm that the AEEF has effect also in this hourly range.

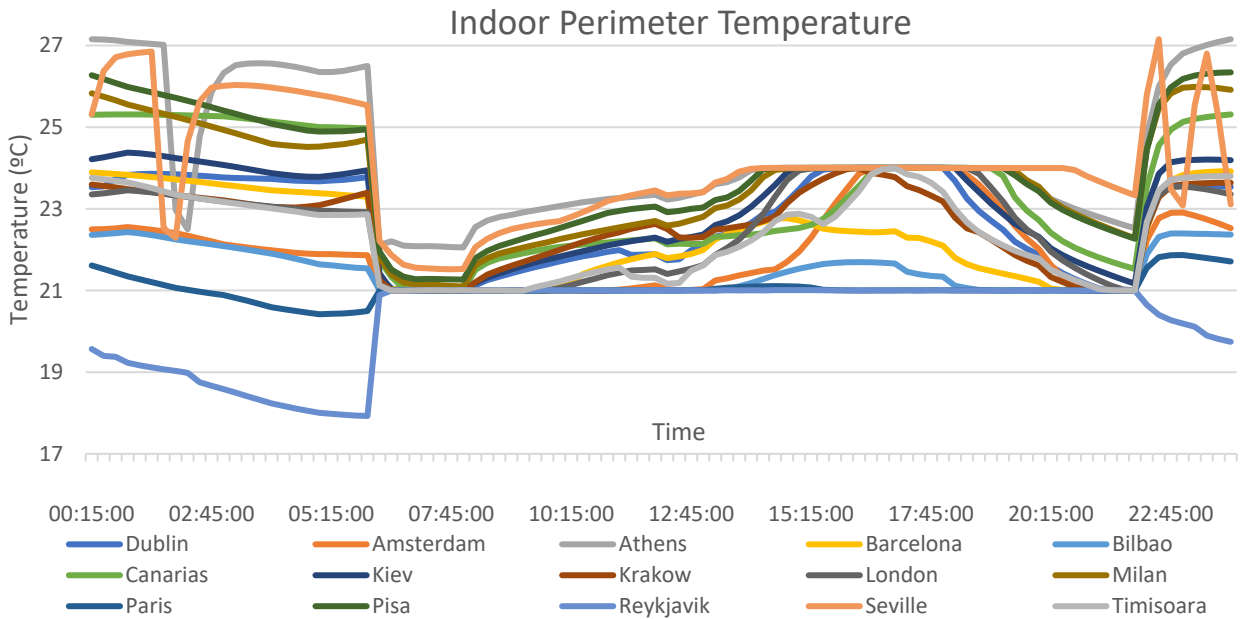


Figure 17. Indoor temperature in the perimeter



Taking in to consider the range of temperatures in Seville, during the time that the cooling in not program in the schedule (22p.m.-6a.m.). In Seville the temperature research the maximum set point (26.7°C), so the cooling system works also during this range, obtaining different profiles to the AEEF.

Observing the indoor temperature for the 15 locations during July 10<sup>th</sup> in the figure 17. There are climates where the temperature is over the design day temperature, that means it is hottest than the limit stablishes. Also it can be observed another climate, as Reykjavik where the temperature is under the design day, that means that during this term the indoor temperature is cold. A result can be deduced: not the same DR strategy obtains the same results. Increasing set point temperature must obtained better flexibility in warm weathers and the decreasing set point will obtain better results in coldest places.

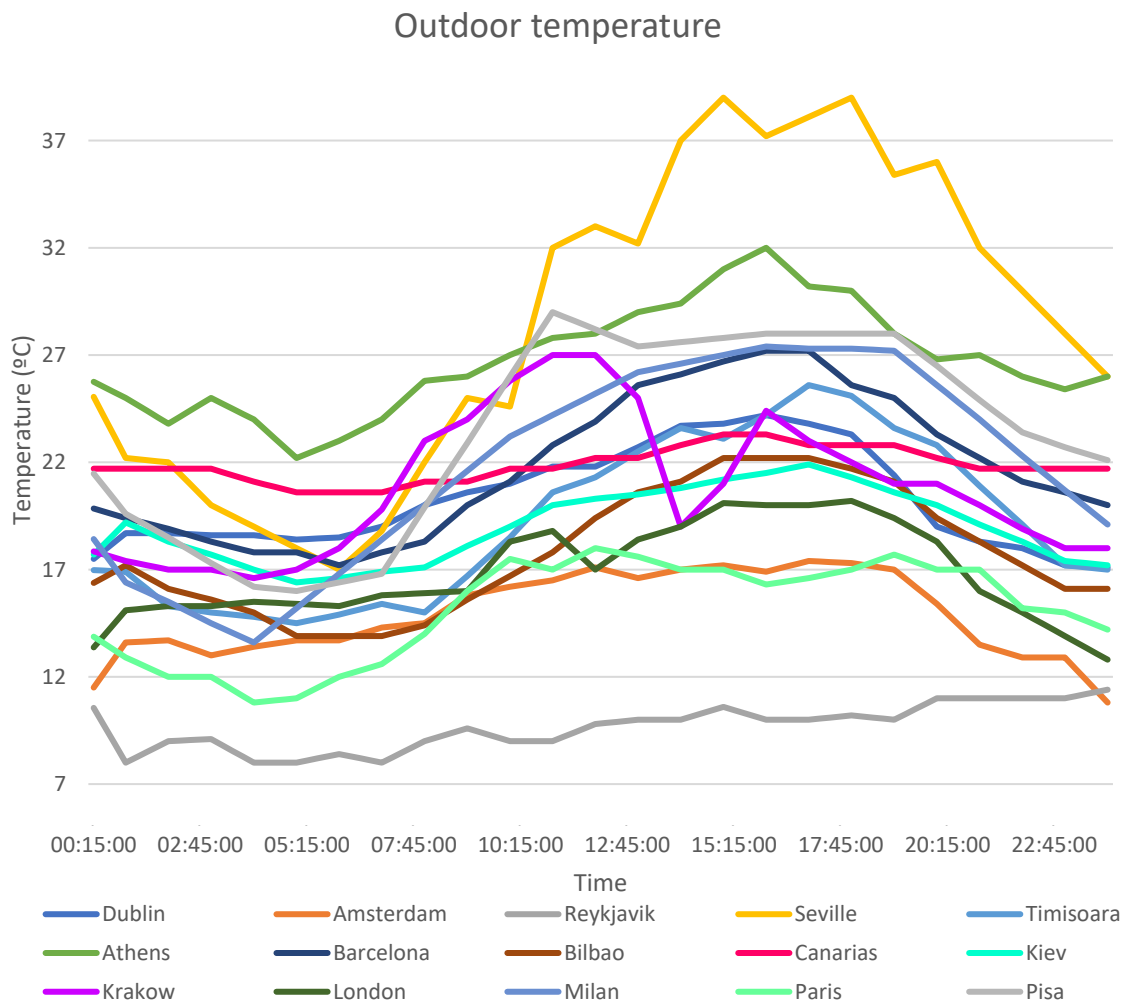


Figure 18. Outdoor temperatures

As it can be observed, there are climates where the building refrigeration system is not working properly. It can be observed just with a look, Reykjavik, obviously is not using the cooling system.





But, the users are going to research the comfort, because the heating system is working. The results in Reykjavik will no show any change in the cooling system, as in this summer day the interest is on the cooling, Reykjavik is not going to provide information.

It is expected that the PMV factor show the discomfort in some location when it is needing to heat. This is because the PMV parameter has been implemented for cooling, where the comfort is in 24°C and is not a good parameter to compare in heating where the comfort should be at 21°C. Also, it is expected a discomfort peak during the morning in Paris. Where the site temperature between 3 am-5 am is under 12°C. Some specific indoor temperature for the locations than need heating are shown in [8.1.1. Appendix indoor temperatures.](#)

As I can be observed in Dublin during the time 0 a.m. to 6 a.m. the temperature is under 26,7°C (set point when the cooling should start working). No cooling system is need at that time in Dublin.

The results in Seville shows if its possible use the DR without affect the users comfort. it is simulated the PMV. If the results are between 1 and -1 the comfort is not affected, and the DR can be applied. The zones less affected by the outdoor temperature are the midzone but, if the climatic system is adequate for the weather, even in the perimeter the comfort should be research.

The outdoor temperature is just reflecting the weather condition. But the building has a thermal inertia and the refrigeration system is working. It should be compare also the indoor temperature, the heaviest weather effect will be noticed in the perimeter zones. Where the heat transfer with the environment is higher.

Once the outdoor and indoor temperature have been analysed, it should prove if the expectation become in a reality. To probe it the comfort is mathematically analysed, it is check all the PMV for each hour of each location, paying attention in the hours and locations with a range over [1,-1].

Now, the results are evaluated to be ensure that the DR can be apply without affect the human comfort. This is the reason why limit of PMV is established in 1 as it was specified in the [3.3.4 comfort analysis methodology](#) of this present research. To check the comfort is analysed the midzone areas where the outdoor temperature has less influence and the results are going to show if the system is getting the expected results. The main evaluated areas are: basement, bottom, middle and top.

This analysis can be observed in [8.1.3. Appendix Dublin PMV hour by hour.](#)

## **5.2. RESULTS OF INCREASE SET POINT DEMAND RESPONSE:**

After applying and simulating the increase demand response the results are going to be shown and analysed.

### **5.2.1. AEEF: INCREASE SET POINT**

Observing each location, it is possible to observe the time at what the location offers the peak of flexibility. The simulations have been developed on MATLAB and they are representant in [8.2.1. Appendix increase set point flexibility results:](#)



Initially, it is observed how the coldest place (Reykjavik) has no effect with the set point. This is because the temperature in Reykjavik is under the objective, and cooling is no need. Even it can be observed also how the actual HCVA system is not using the cooling at this weather, and the heating set point even if this set point is increasing is lower than the set point to cooling. This means, that during the summer day, it is not possible to obtain flexibility using the cooling system in Reykjavik, as it can be observed in the results.

There are two climates which response out of the time programming, checking the reason, it is concluded it's because the temperature. In Athens and in Seville the temperature is over 26.7°C out the schedule of 8 am – 20 pm, that why there are also availability in the electrical efficiency. Checking a cold climate as Reykjavik is also observed how the cold climate doesn't need cooling, having an AEEF near 0.

It is going to be probed in the figures 20 and 22 showing the temperature in Dublin (reference case), Athens and Seville.

But to compare in a better way, all the simulations are drawn in the same graphic:

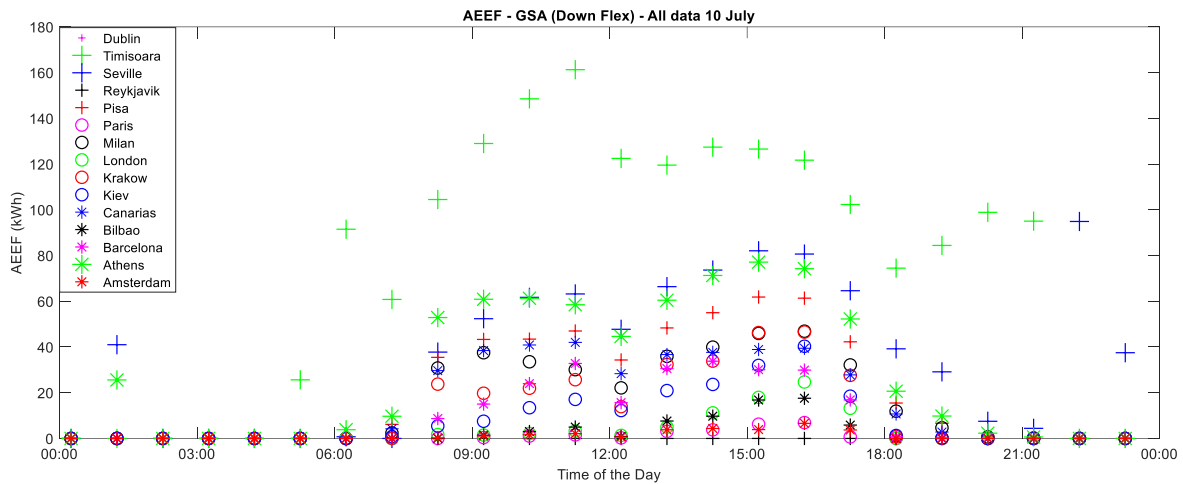


Figure 19: All the AEEF obtained applying the DR in each location, each hour

As it can be observed in Dublin indoor temperature in figure 39 during the time 0 a.m. to 6 a.m. the temperature indoor in the midzone is under 26,7°C (set point when the cooling should start working), so no cooling is need.

Focusing in the perimeter indoor temperature, figure 17, the worst inside case. It can be observed the influence of the different weather and how the air conditioner system influence and obtain accurate results.

To show if its possible use the DR without affect the users comfort. It is simulated the PMV, if the results are between 1 and -1 the comfort is not affected, and the DR can be applied.



It is check the temperature in Athens and Seville, both should show temperature over 26,7°C to confirm that the AEEF has effect also in this hourly range.

Taking in to consider the range of temperatures in Seville, during the time that the cooling in not program in the schedule (22p.m.-6a.m.) in Seville the temperature research the maximum set point (26.7°C). The cooling system works also during this range, obtaining different profiles to the AEEF.

Secondly, it is check all the PMV for each hour of each location, paying attention in the hours and locations with a range over [1,-1].

After following the methodology, the comfort is check, to be ensure that the DR can be apply without affect the human comfort. For the limit of PMV is stablished in 1. To check the comfort is going to be analysed the areas where there are inhabitants, these areas are: basement, bottom, middle and top.

It is compare some of the results in bars to see it clearly in the figure 21. the highest flexibility is provided by Timisoara, and as it can be observed in the figure 22 the outdoor temperature is near the set point. This is why increasing the set point it is possible to provide more flexibility than in Seville, where the temperature is too hot, and the cooling system is need always. The flexibility that Seville can provide will be smaller than other locations with temperatures nearest to the set point. Also, if the case of Amsterdam is observed, as the cooling is not need during all day. The flexibility would be smaller, also the outside temperature is too similar to the set point. With this results it can be concluded that the highest flexibility is obtained with a weather with an outside temperature around set point temperature +2°C.

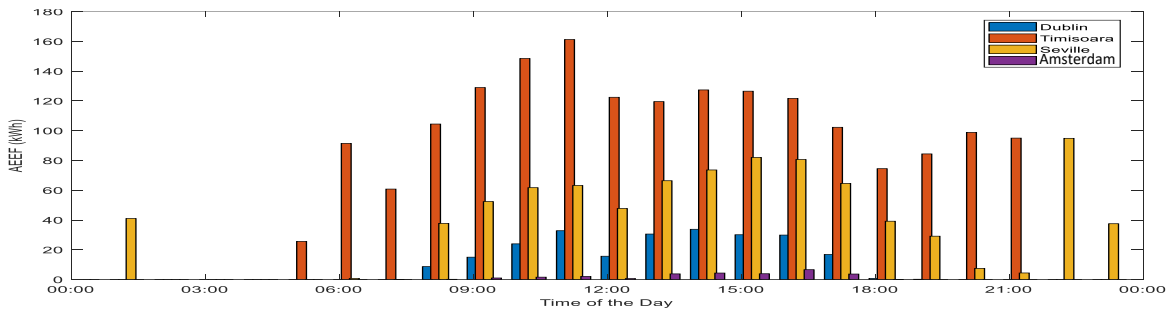


Figure 21: AEEF in 4 Dublin, Timisoara, Seville and Amsterdam

To compare the outside temperature, this for are showed in the figure 22:

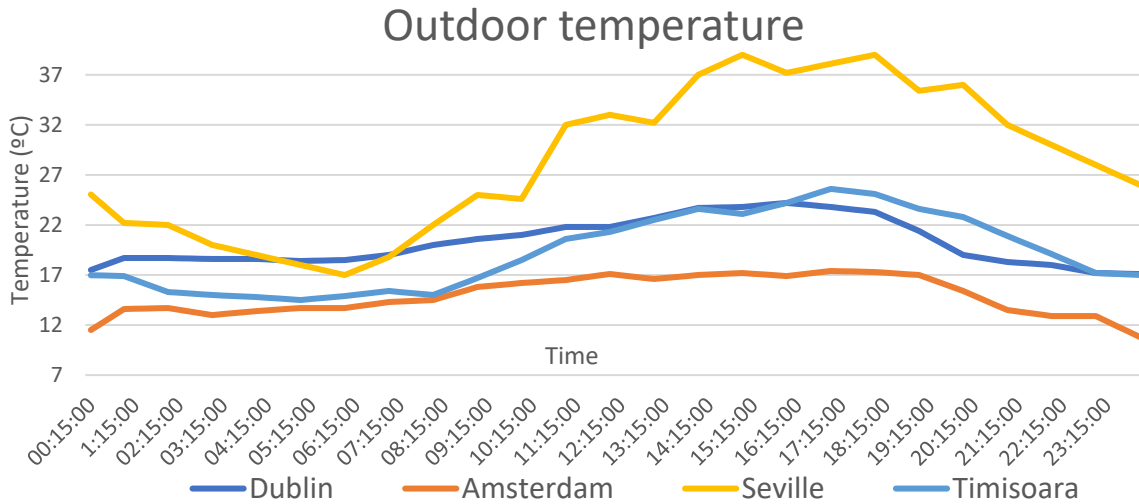


Figure 22: Outdoor temperature in Dublin, Amsterdam, Seville and Timisoara.

### 5.2.2. EFFICIENCY RESULTS

All the results of the increase set point for the efficiency for the different locations are shown in [Appendix 0](#).

As it was expected the efficiency results match in the timetable with the flexibility results, this is because this demand response is down-flexibility one. The efficiency shows the percentage of energy that it can be saved in the cooling system. If there is no saving in the cooling system, the efficiency will be 0. But, the efficiency can reach the 100% also if the flexibility provided to the grid in this location is not the highest. If the cooling system in the base case was consuming a bit of energy, and with the DR all this consumption has been saved. The efficiency would be a 100%, therefore the efficiency load doesn't match with the flexibility load.

### 5.2.3. COMFORT RESULTS

As can be observed, Dublin research the data, following this methodology is going to analyse all the locations. The results can be observed in [8.2.2.PMV increase set point](#).

Analysing all the locations hour by hour is observed how Reykjavik, Bilbao, Paris and Amsterdam have a PMV ratio out of range acceptance in the times the cooling is not needed the heating. Top and basement are the main problems, because are the zones nearest to the external temperature.

As it has been explained in [8.1. Weather effect](#), Reykjavik is specially interest, because there is no DR in this location. The temperatures are under cooling range, so there is no cooling, in consequence there is no AEEF. The discomfort is a model concept, no because the DR.

To prove that the comfort depends more on the correct refrigeration system than in the demand response applied. It is going to show the Dublin comfort profile, hour by hour applying the demand response. Is possible observed the hour influence, making as a result the mail curve, so is going to be observed also the curve with the DR always "ON".



In this point, it is simulated the 15 locations with the base profile, without the demand response, and the profile applying during the hold day the demand response. The simulations have the main goal of compare the comfort and probe that the discomfort is because of the weather and not because of the Demand Response. In all the cases can be observed how it is the initial base data of the place which doesn't research the comfort. The solution can be modified the schedule and increment the heating in the coldest places that need from it. It is demonstrated that the discomfort in the obtained results is because of the HCVA system. This system is not adapted to the locations and it should be, that gives value information. The building model can be use in all the weathers, but the refrigeration system must be evaluated and modified if it is need for each weather. The results of this comparisons can be observed in [8.1.2. Appendix PMV compare all locations.](#)

### 5.3. RESULTS OF DECREASE SET POINT TEMPERATURE.

#### 5.3.1. AEEF RESULTS

Like in the increase set point results all of them are shown. But, in the decrease set point case, the flexibility shows the electrical energy that can absorb the building to provide that flexibility to the grid by consuming more electricity in the building. [8.3.1. Appendix decrease set point flexibility.](#)

This DR is an up-flexibility strategy, the flexibility is provided by increasing the cooling consumption in the building. The commercial building is consuming more electricity to provide this flexibility to the grid. This strategy has the same rebound effect on the consumption, there are some cases where there is not saving with the application of the DR. This strategy is interest from a grid point of view, but economically it is more expensive for the commercial building.

In the next figure all the simulations (350) are shown. It is possible observe the flexibility that the DR can provided to the grid in each location. It has been simulated to apply each hour of the day.

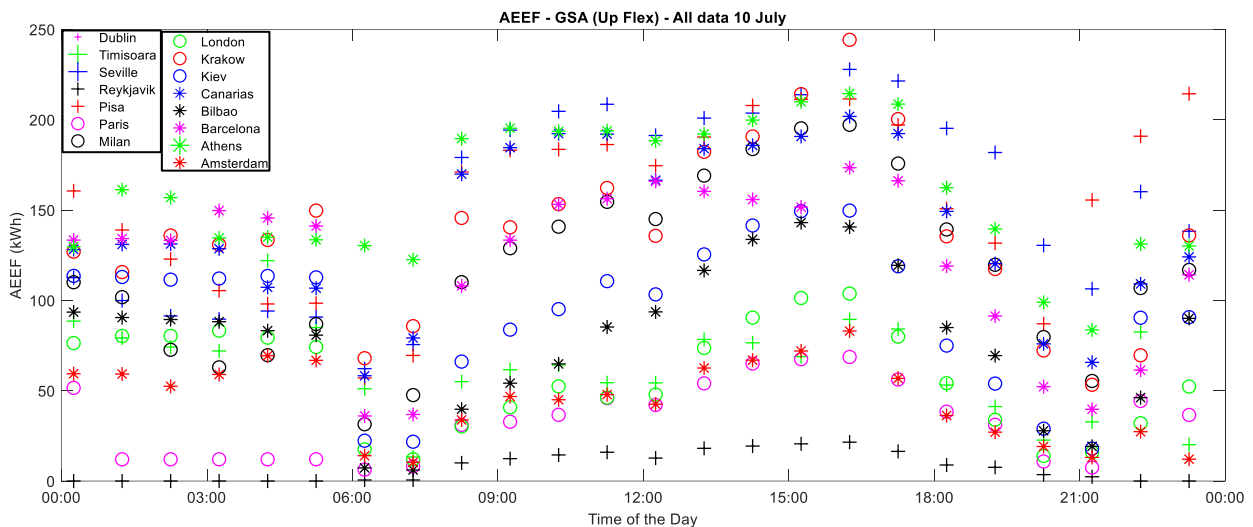
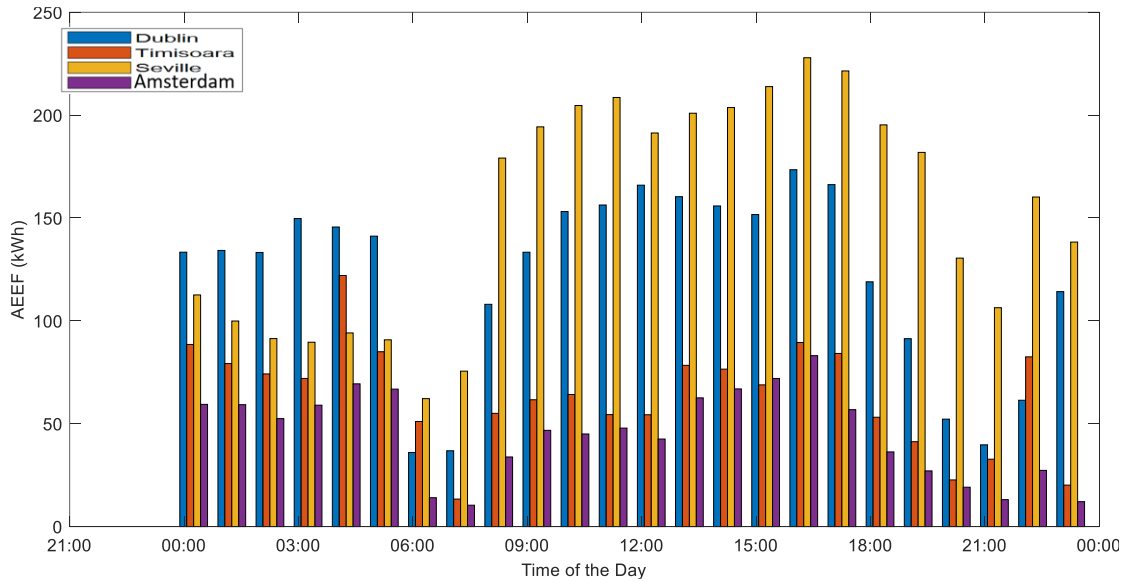


Figure 23: AEEF result up flexibility, decrease set point



**Figure 24: AEEF results decrease set point Dublin, Timisoara, Seville and Amsterdam.**

### 5.3.2. EFFICIENCY RESULTS

The efficiency results are not always in the same time periods that the efficiency. That it is because the flexibility provided to the grid can not be efficient, because the cost is too elevated. The flexibility is provided by increasing the building consumption, and the efficiency shows the percentage of this extra consumption can be reduce in the next hours as a rebound effect. There are times where there is no savings in the next hours, so, even if the commercial building can provided flexibility. This flexibility is not going to be efficient. The results are in [8.3.2. Appendix decrease set point efficiency.](#)

### 5.3.3. COMFORT RESULTS ANALYSES

In the opposite part of the previous DR, when the set point is decreasing the cooling is increasing and heating is reducing. That signify that this measure is an upper-flexibility for the cooling. The cooling system is incrementing the power consumption, using more electricity from the grid. Also, it is a down-flexibility strategy for the heating, it can be observed how in these case, the comfort is research easier. But in the coldest weather the problem persists, the heating system is not being evaluated and the comfort has different set point in heating than in cooling.

The comfort analyses for each location can be observed in [8.3.3. Appendix PMV decrease set point.](#)



#### 5.4. CONCLUSIONS:

As it has been developed over the project, two demand response have been analysed in 15 different locations. The first results obtained is the fact that for extreme cold location the cooling system is not need. The model is not suitable for all the weather, especially for the coldest ones, applying the demand response “set point” in these cold weathers it is not going to obtain a result in the cooling system, because this system it is no need. This fact influence on all the results and it is impossible to research the comfort in the locations and times where the refrigeration is not the needed.

- The first result proved is: **the weather has an influence on the power consumption.**

It is observed in the peak consumption how in each weather the load is quite different, but it can be better observed comparing just the cooling system, that is the only one that change in the different weathers.

The DR has different influences if it is down flexibility or up flexibility. When the outside temperature match with the refrigeration configuration (cooling) it is possible to obtain a huge flexibility. In down flexibility cases the highest flexibility will be obtained in this weather. With an outside temperature between +2-+5 of the set point. With upper flexibility the relation between power consumption and outside temperature is direct. Especially in the warmest places, where the HVAC system is hard working and the set point has a considerable effect on the electricity flexibility. The highest flexibility in the upper flexibility DR is provided by the warmest weather.

- It has been demonstrated that **is possible offer flexibility to the grid in two ways, (increasing or decreasing the building consumption).**

Using the set point to decrease the power consumption in the commercial building in the HCVA system (increasing the set point temperature) or it is also possible to offer flexibility to the grid increasing the consumption inside the building.

The flexibility provided to the grid have a different character in each case. Increasing the set point temperature, the building is reducing his consumption in the cooling system, providing an among of flexibility to the grid, that can reduce the electrical generation in this quantity. On the strategy, decreasing set point, the building is increasing his electrical consumption, providing to the grid flexibility, the building is able to absorb the electrical exceed of the grid.

- The strategies have, also, **different periods where can be applied.**

The increase set point strategy just can be applied in the day times where it is possible obtained this flexibility. If the cooling system is swift off the DR it is not providing flexibility. This is the main reason why increase set point strategy is useful is sunny hours, but this strategy can't be adapted to the grid necessities. If the grid need flexibility at the times that the building has not cooling system working, the building cannot provide flexibility. Also, it is need consider the efficiency of the strategy, there are some hour where the building can provide flexibility but with bad efficiency (less than 20%), it should be consider before applying the DR.



- It is remarked the **importance of made a previous analysis** and catalogued the demand response strategy in **down-flexibility or up-flexibility**.

Decrease the set point is a strategy that can be applied during all day, the building can increase his cooling consumption in any hour of the day. But this increase also has an effect on the consumption in the next hour, that can be observe with the efficiency, and it should be consider before applying the DR and provide the flexibility to the grid. The efficiency of this strategy is not always matching with the flexibility provided. This is because when energy is saving in the building the strategy will always be efficient. But, if the building is increasing his consumption, the efficiency must be analysed in detail.

Also, it is important catalogued in the correct way each strategy, because the down-flexibility efficiency has a different meaning from the up-flexibility efficiency, so the equation is different.

- **The comfort has been analysed** in all the cases. It **is always obtained inside the acceptance range**.

Also, it has been analysed hour by hour in the base case, Dublin, for the base DR, increase set point. And it has been compared the 24 simulations with the building without any strategy, also for the DR increase the set point. The comfort analyses results show that the comfort is not dependant of the DR, it depends more on the base case of the building.

The DR just affect in less that 0.1°C, so the comfort is always research in all the weathers and for all the strategies. In the weathers where the comfort shows results as “too cold” it is because during that hour the cooling system is not working, and the heating system is turn on. For these climes, the reference temperature should be 20°C and not the 24°C of the base case.

- **DR can be applied** to provide the electrical flexibility to the grid and the **inhabitants comfort is not compromised**.

As it has been demonstrated in the results analysed.





### 5.5. FUTURE WORK:

The bases of this project are in a previous work, so it is suggested also, continue with this project in a new study. Once this project has been developed it is discovered that the same building can be simulated in different weathers, obtaining different results and some conclusions about the building.

- **Test the coldest day**

It has been tested just for the warmest day, in summer, so it should also be tested and proved in the coldest day and compare the results between the warmest and the coldest place. The study shows how for the coldest weather the building cannot provide flexibility because the system that has been probed is the cooling one. So, it is suggested to probe the coldest day in winter, to probe the heating system and to analysed if it is obtained the same results, and the warmest places cannot provide flexibility.

- **Test during a year**

Also, in order to obtain a big range of results, it is suggested to analyse the building during a year, and compare in several locations, the results can be useful, because it is need provide the maximum flexibility to the grid, and analysing an entire year it is possible to compare the annual among of energy that each weather can provide to the grid with each DR.

- **Analyse other strategies**

Just the chiller set point strategy has been analysed. It is suggested implement other strategies as the proposed on the previous work to analyse and compare. The weather is influencing in the results obtained, but maybe it has no the same influence if the strategy is other. Also, it is suggested for a future work analyse the new DR strategies in different seasons, and during the year, to obtain annual data about the flexibility that can be provided. It should consider that the same strategy will have a different nature in each season. Increase set point is a down flexibility strategy in summer, but it is a up flexibility strategy during winter.

- **Economic analyses**

Another important point is analysing from the economical point of view. It is suggested considering in a future study, the economic cost of implement these measures, and the economic benefit that it can provided to the building user and to the grid.

The economic study suggest can start with an electricity average cost for all the hours and locations, to make a general idea about the benefits that the DR can provided. If this study shows that it is not profitable, it is not need continue with the study. But, if the first study shows benefit, it is suggested to adapt the real electricity cost to each location and to each hour, to obtain a real result.

It is also suggested once the economic study is ready, implement a new variable in the simulation, providing the flexibility just when it obtains economic benefits. Also, it would be interest if the emissions reduction is analysed. And a market study can be developed, comparing the different weather and obtaining which strategy obtains more benefits in each weather.



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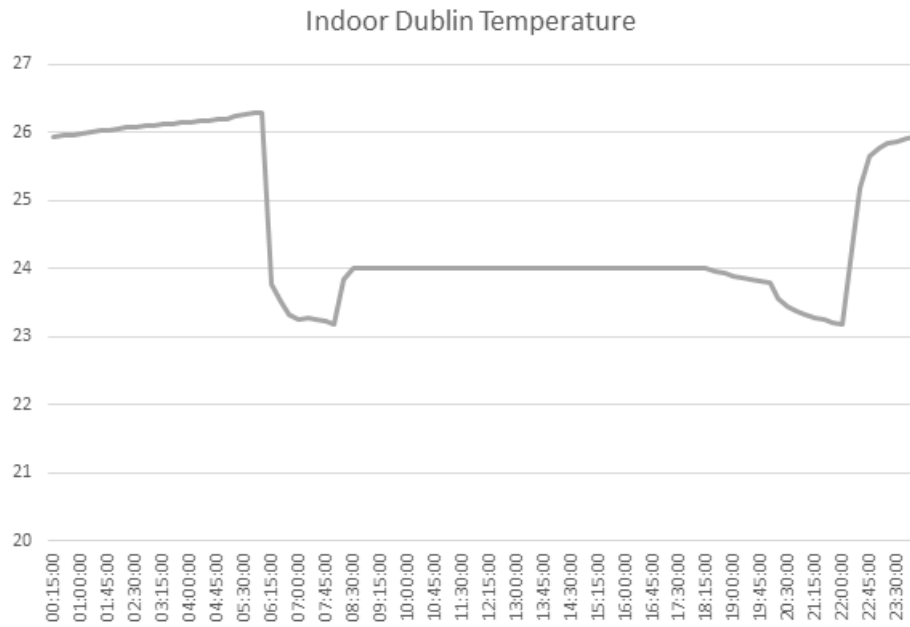


**APPENDIX:**

**A. WEATHER RESULTS: TEMPERATURES**

**A.1. INDOOR TEMPERATURE**

Some of the indoor temperatures are plotted here, the cities more useful in the analysis.



**Figure 25: Dublin Temperatures**

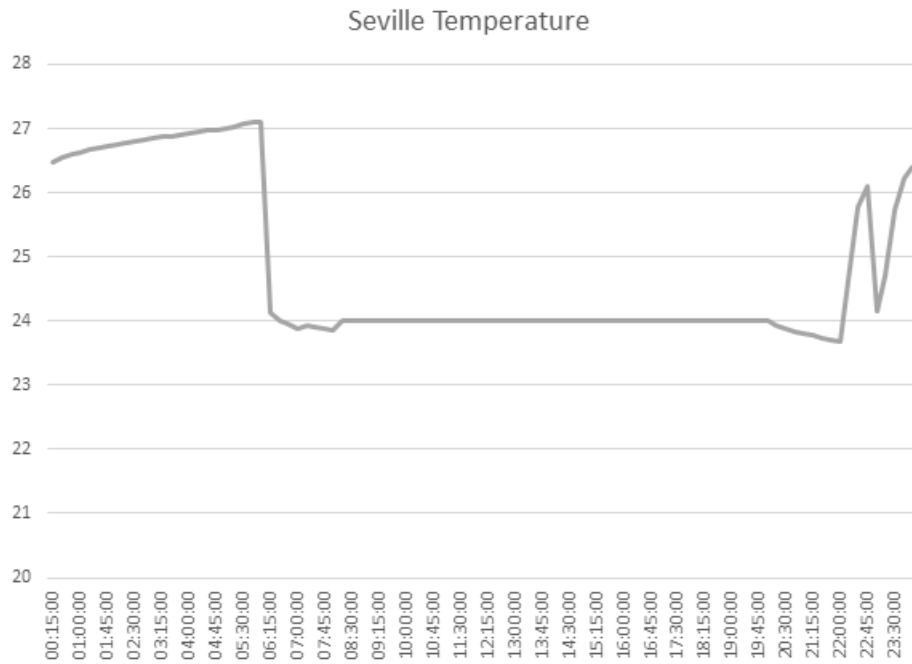


Figure 26. Seville temperature

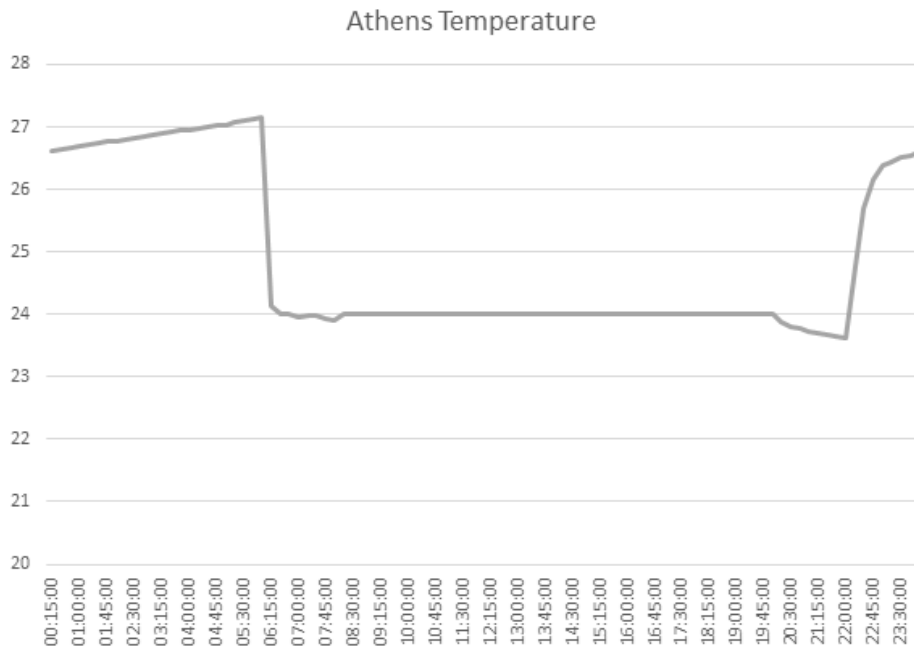


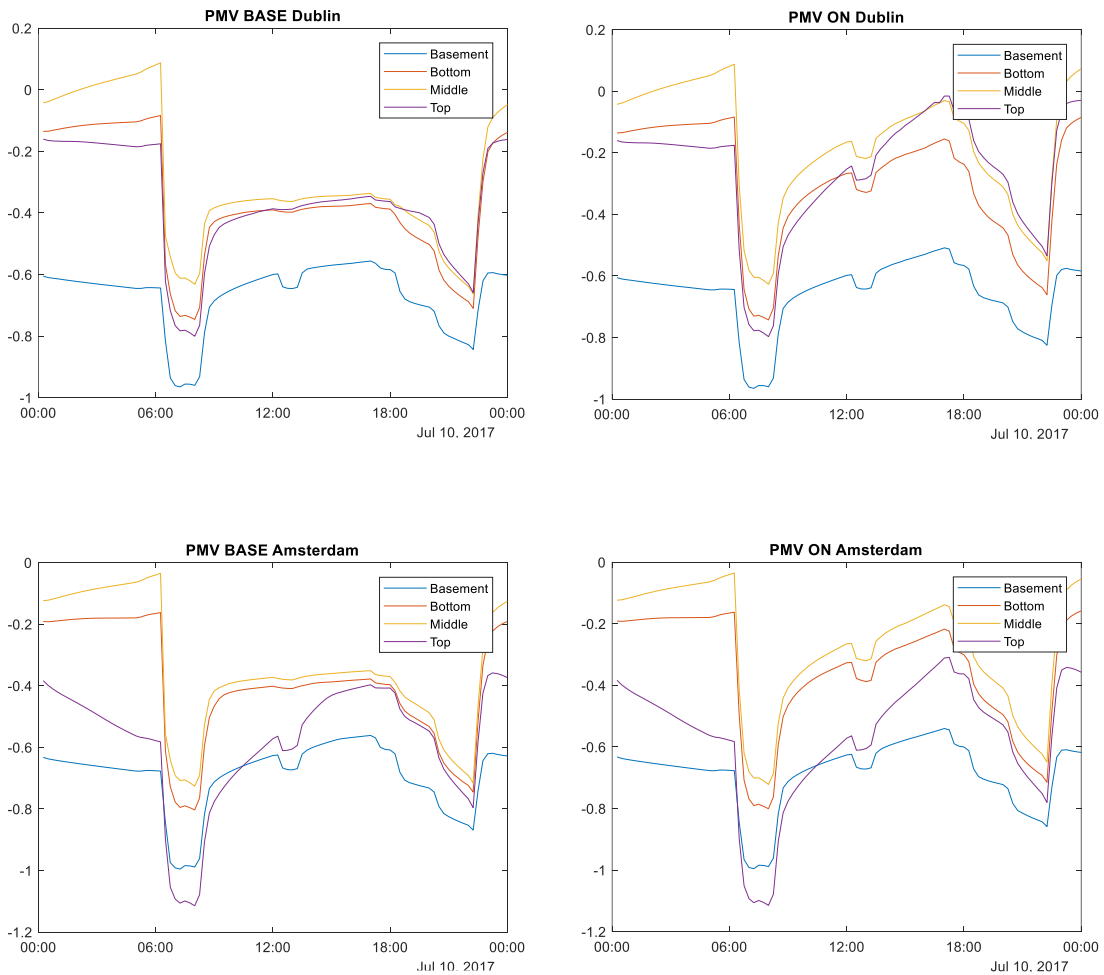
Figure 27. Athens temperature



### A.2. SIMULATIONS WHEN THE PROGRAM IS ALWAYS ON, AND ALWAYS OFF (BASE)

Simulation with the 24h base profile reading to compare the comfort and probe that the discomfort is because of the weather and not because of the Demand Response. In all the cases can be observed how it is the initial base data of the place which doesn't research the comfort. The solution can be modified the schedule and increment the heating in the coldest places that need from it.

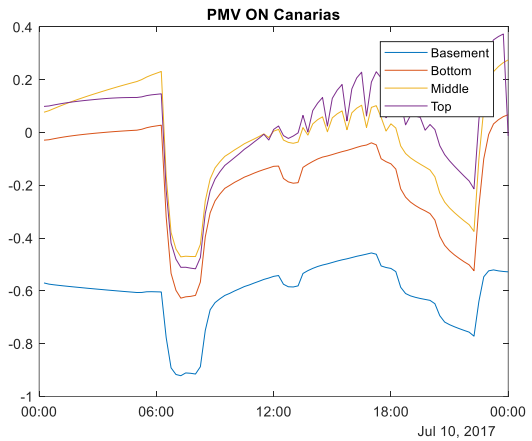
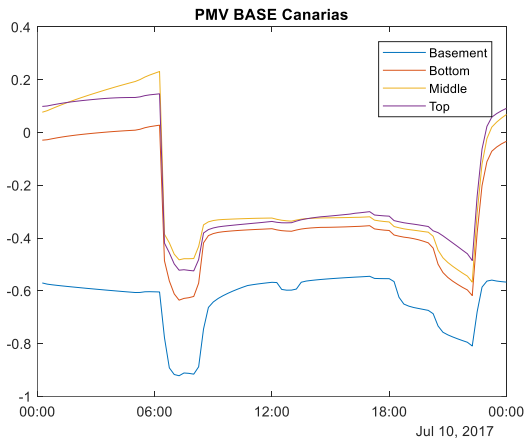
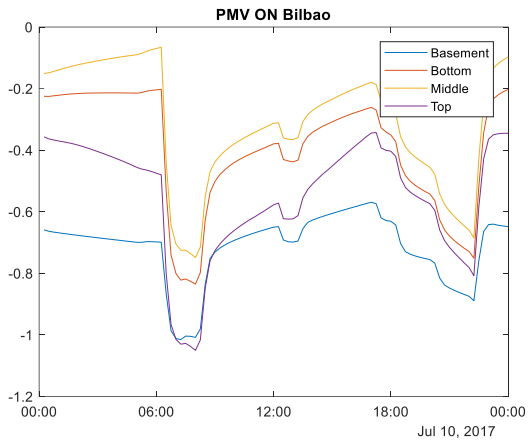
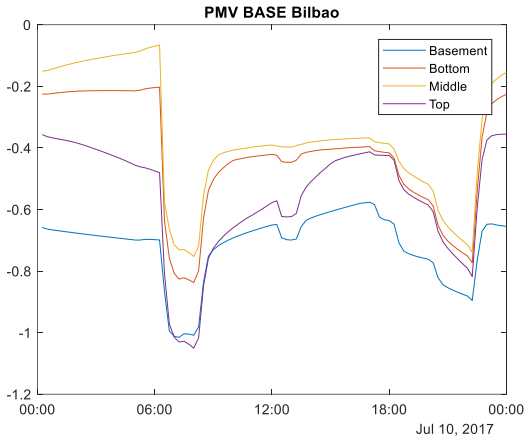
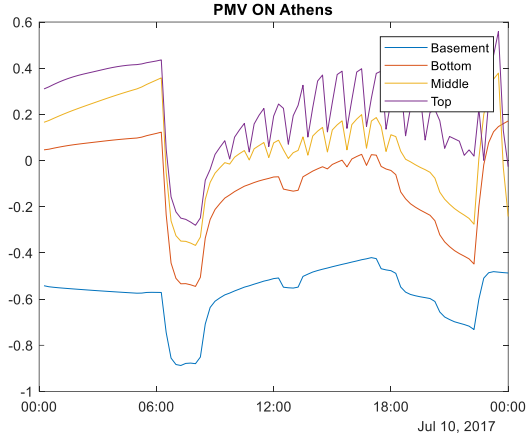
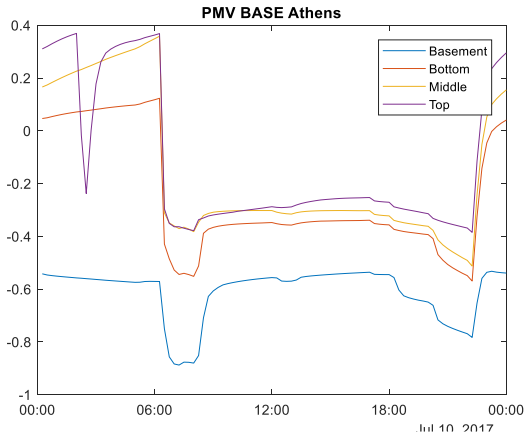
Compare the comfort time with the AEEF, if the comfort is out of the range, at that time is not possible to apply.





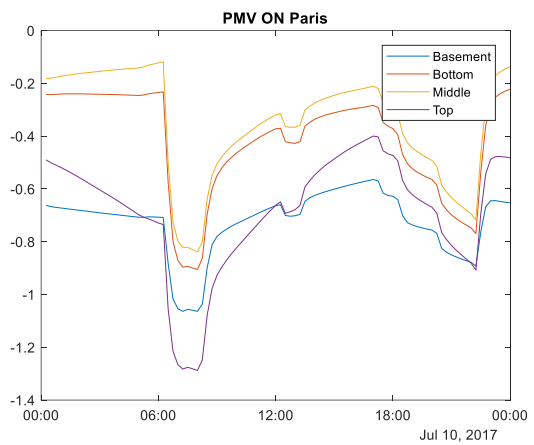
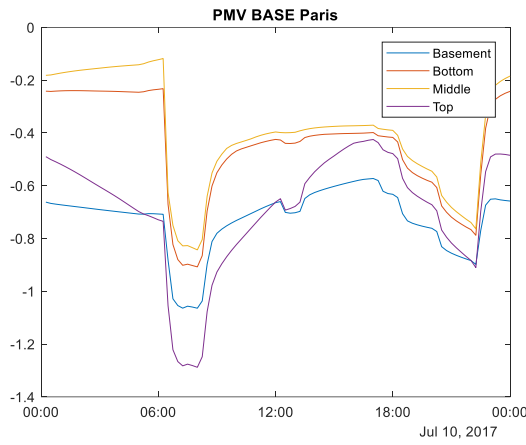
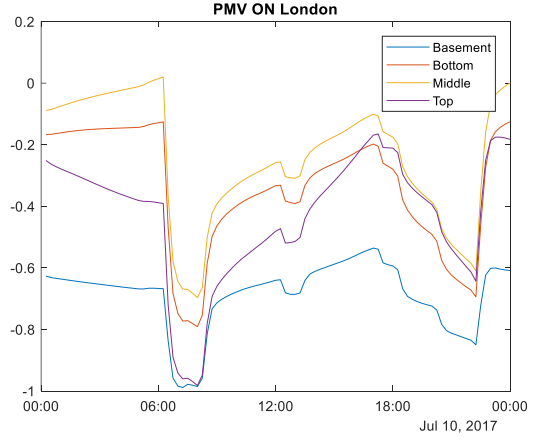
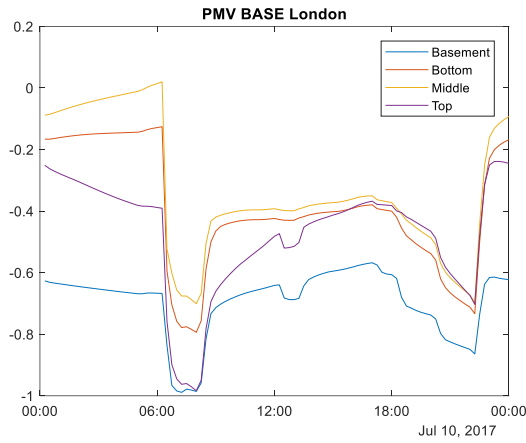
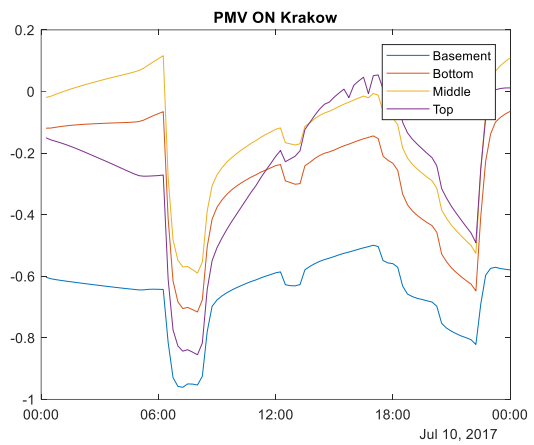
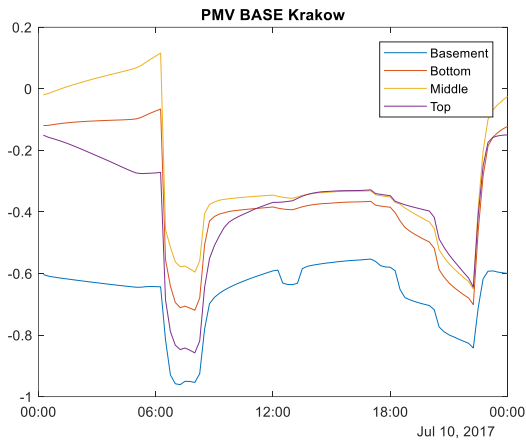


# Available energy flexibility: sensitivity study for different climatic conditions



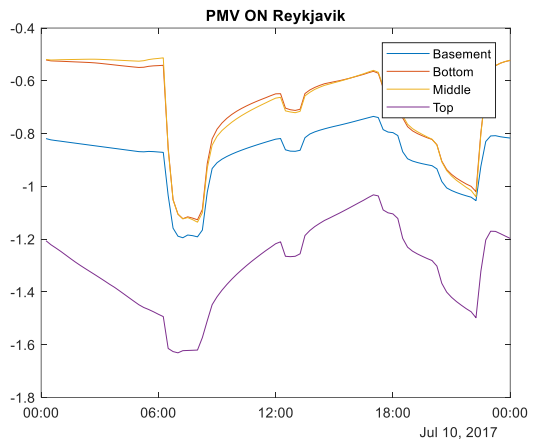
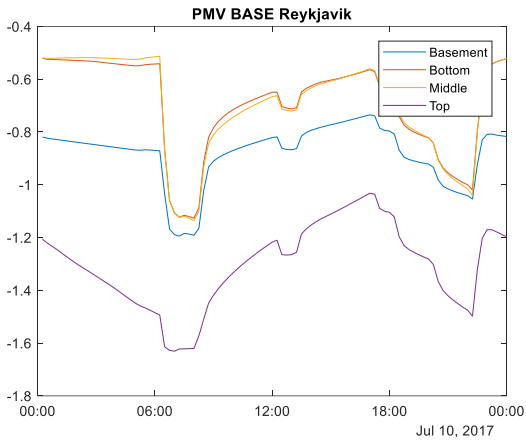
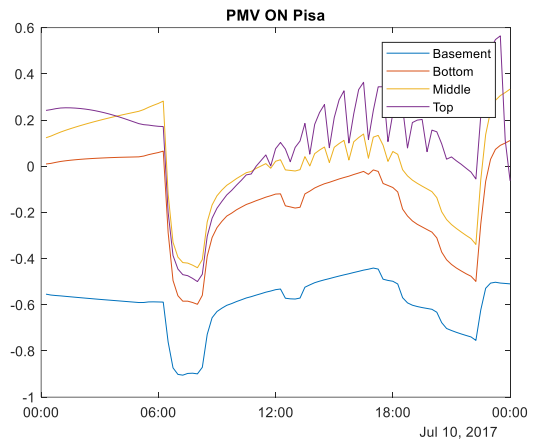
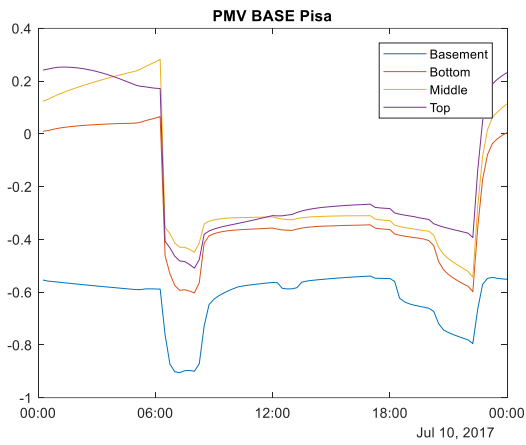
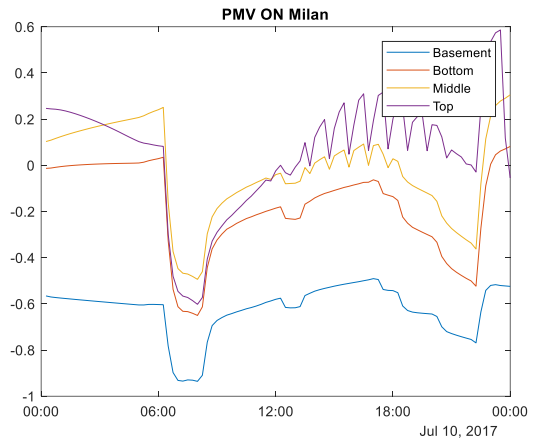
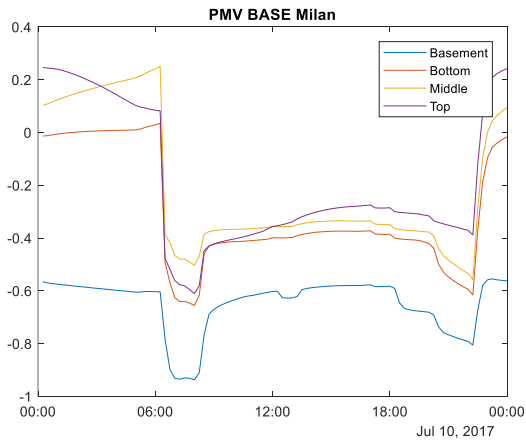


# Available energy flexibility: sensitivity study for different climatic conditions



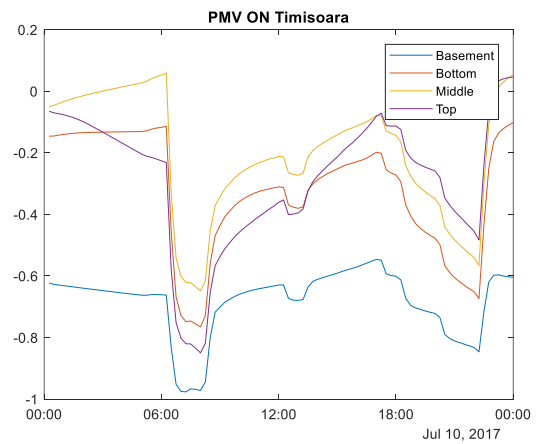
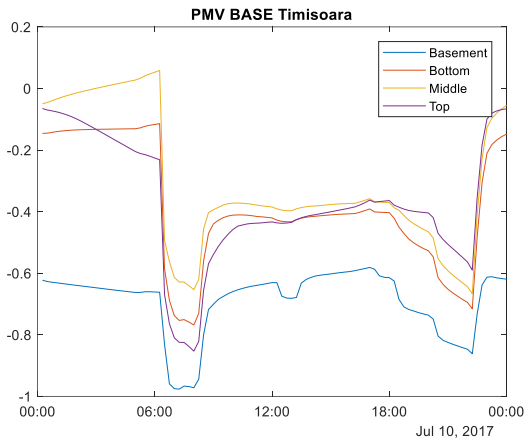
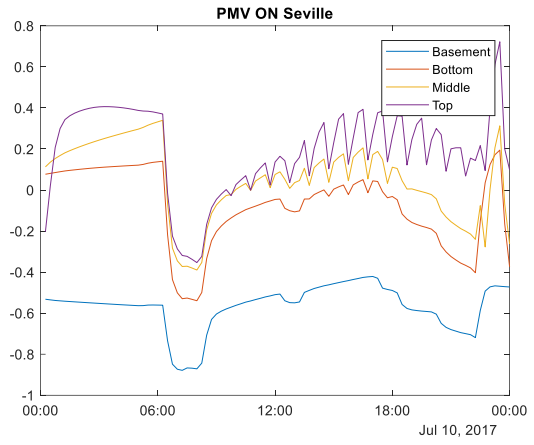
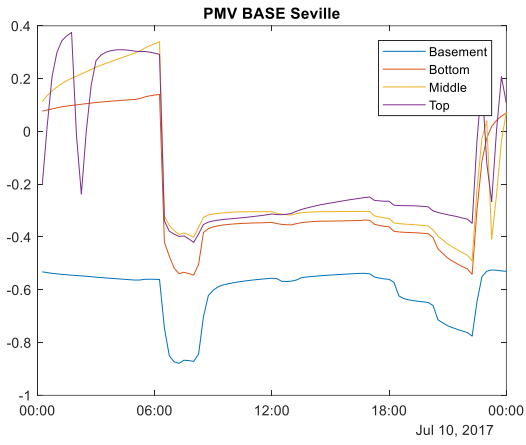


# Available energy flexibility: sensitivity study for different climatic conditions



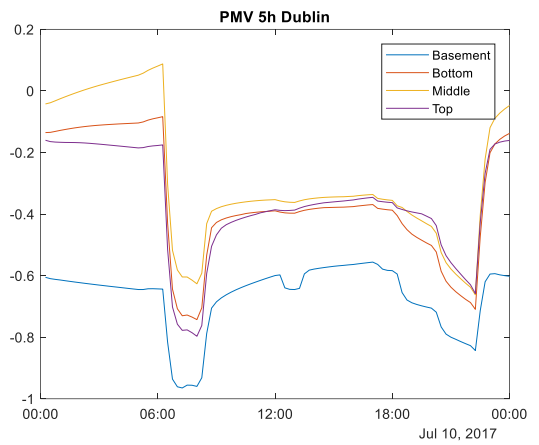
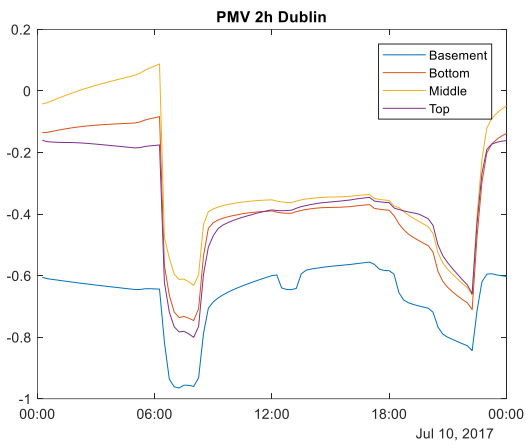
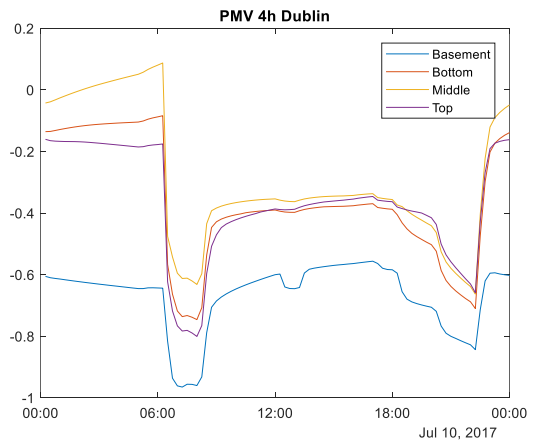
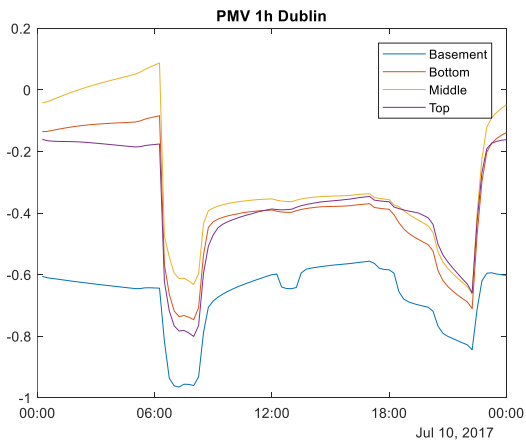
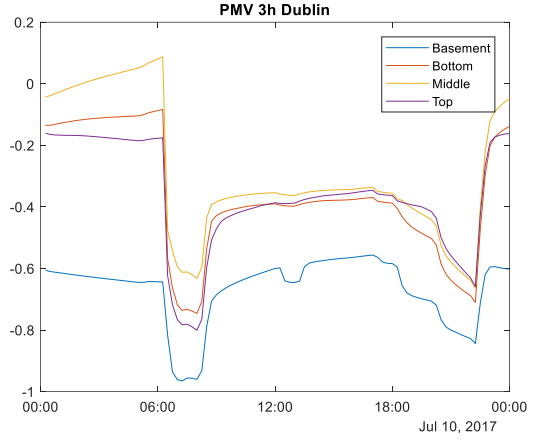
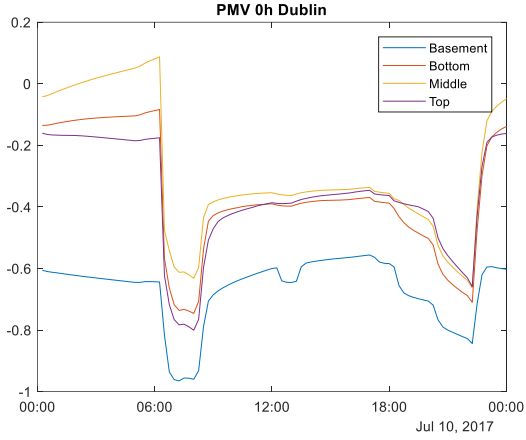


# Available energy flexibility: sensitivity study for different climatic conditions



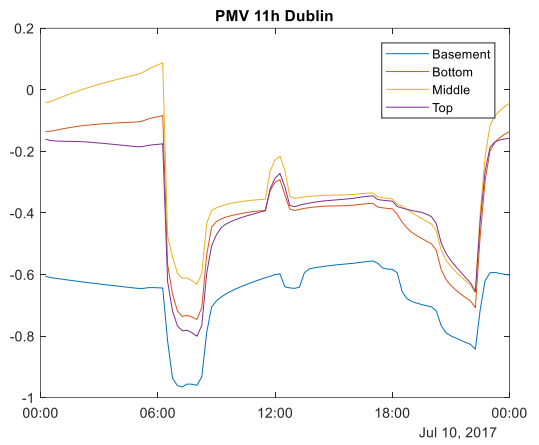
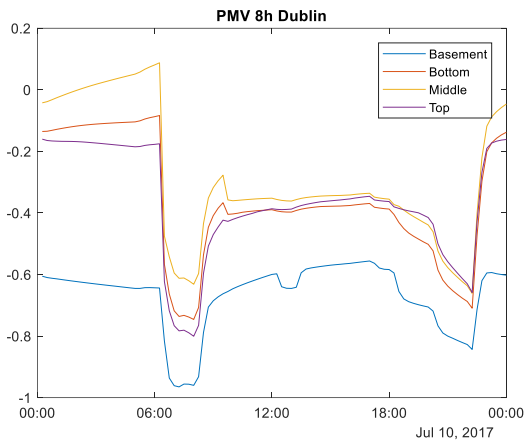
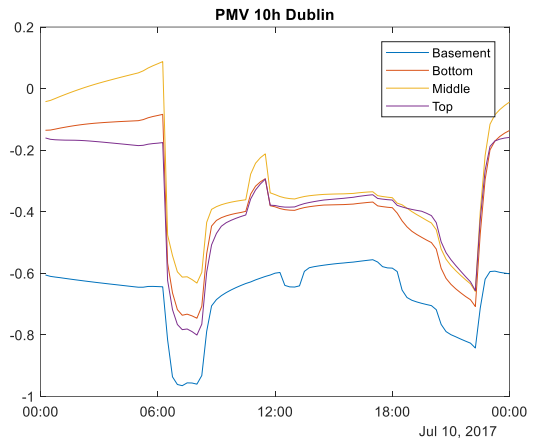
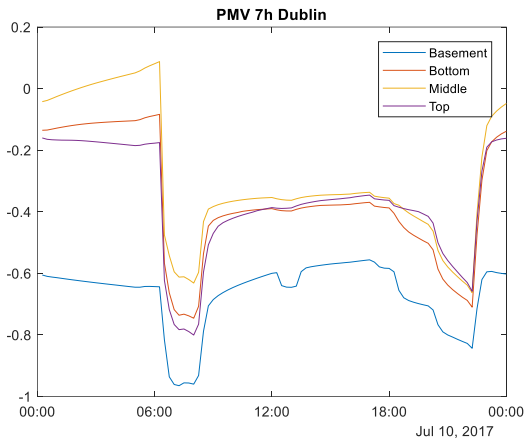
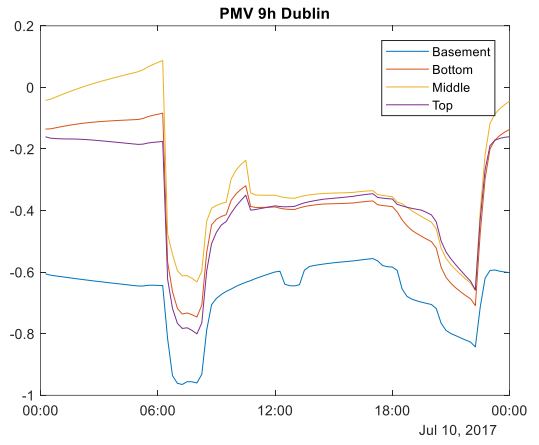
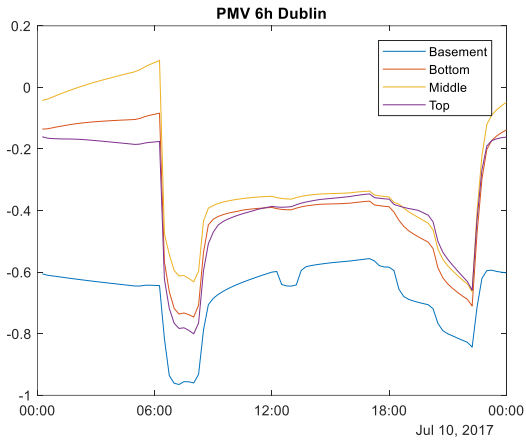


### A.3. PROFILE; HOUR BY HOUR DEPENDING ON THE LOCATION: DUBLIN



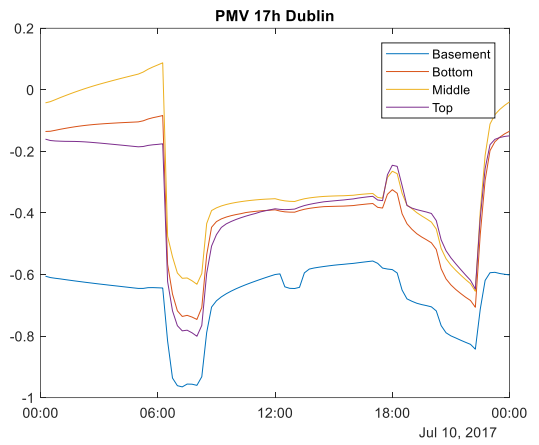
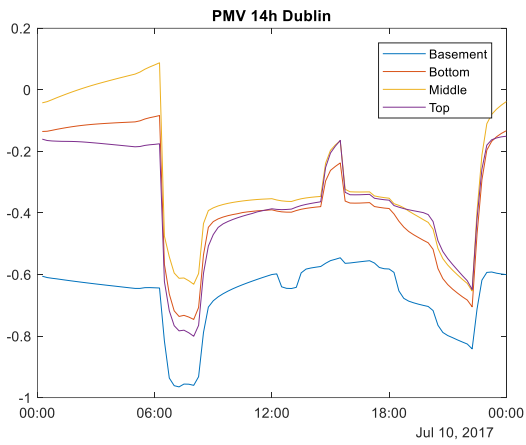
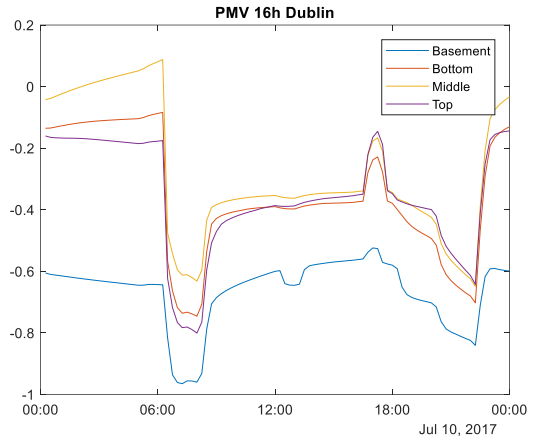
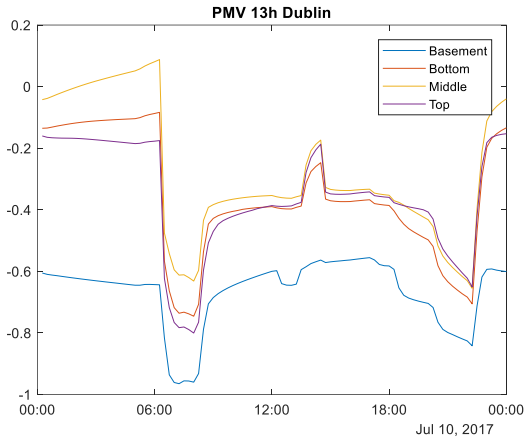
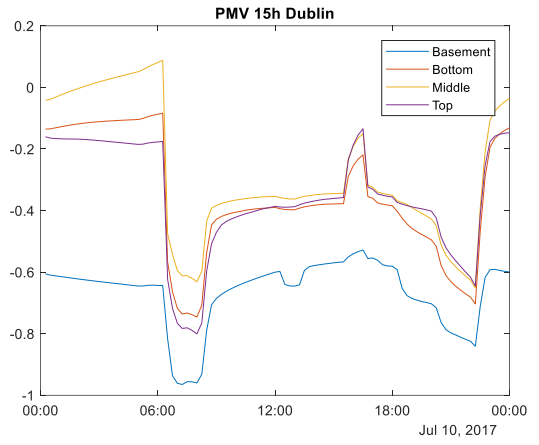
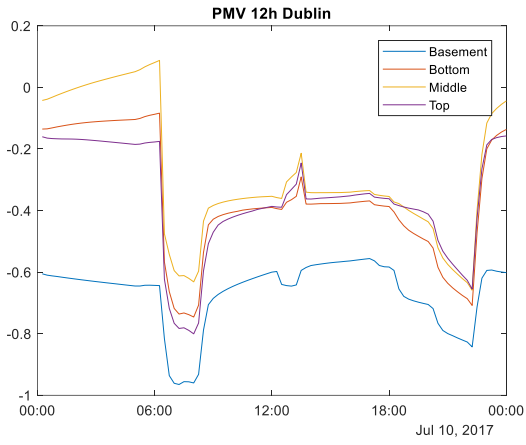


# Available energy flexibility: sensitivity study for different climatic conditions



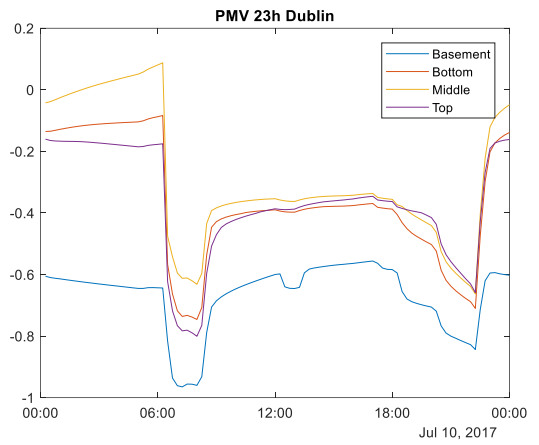
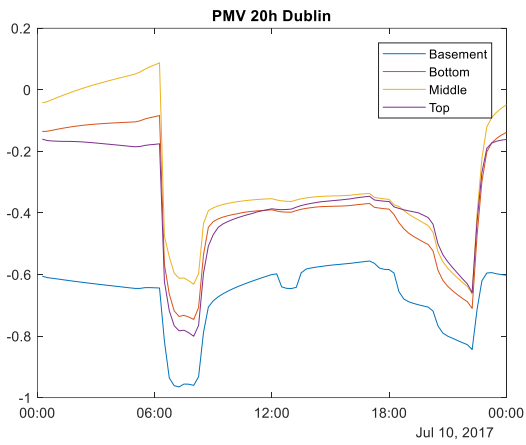
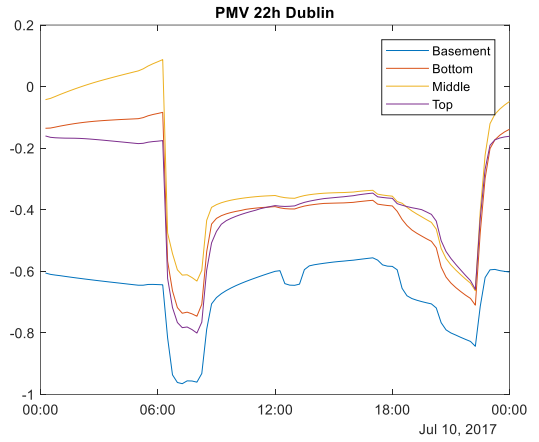
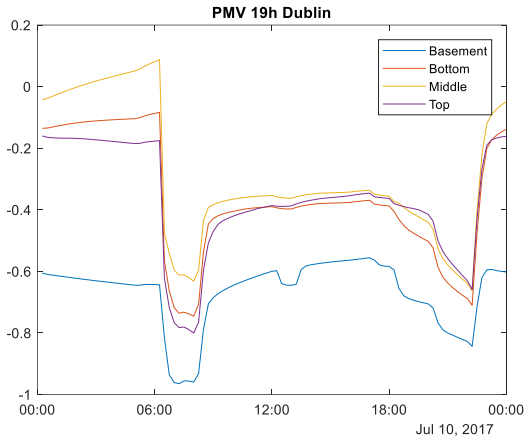
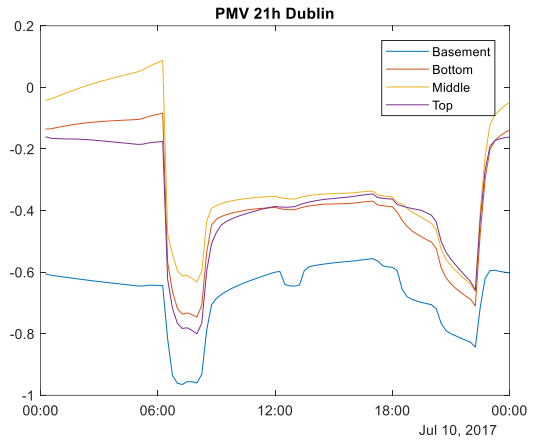
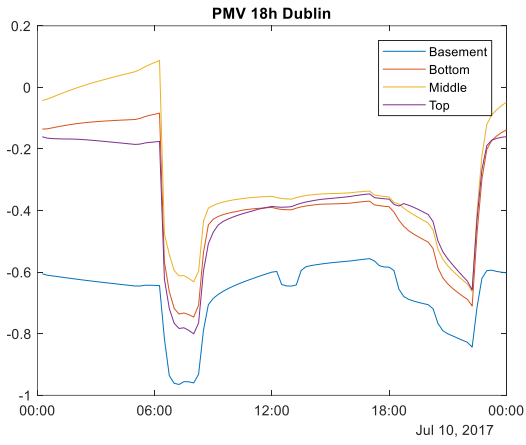


# Available energy flexibility: sensitivity study for different climatic conditions





# Available energy flexibility: sensitivity study for different climatic conditions

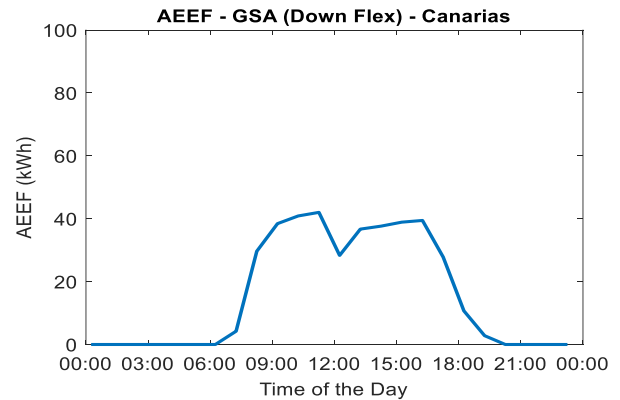
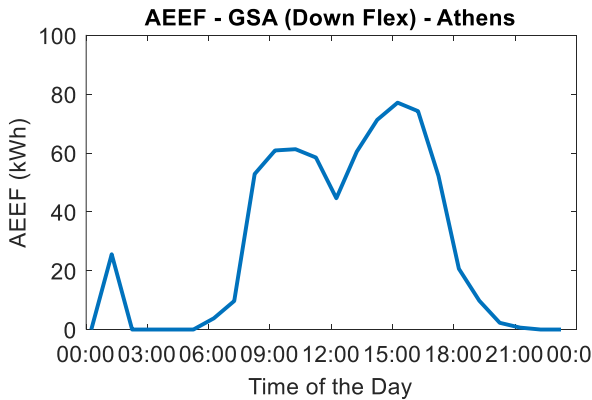
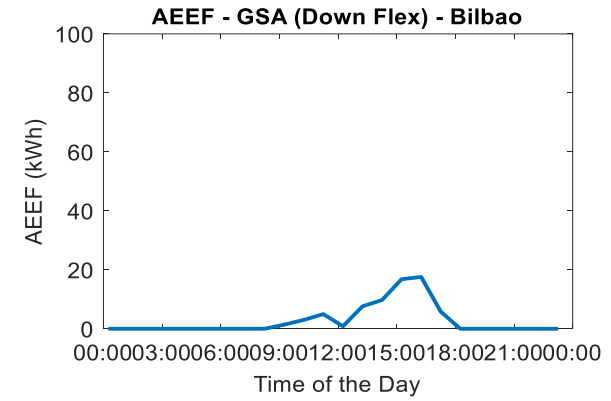
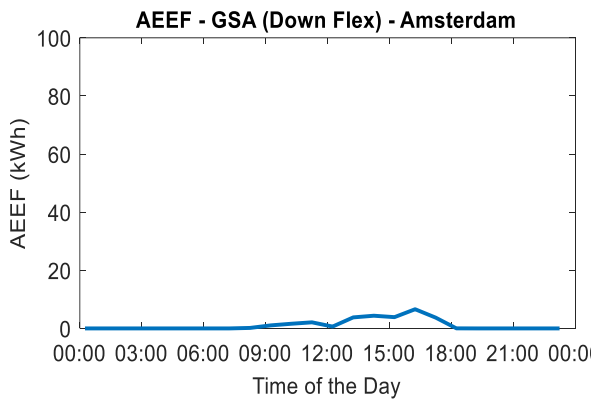
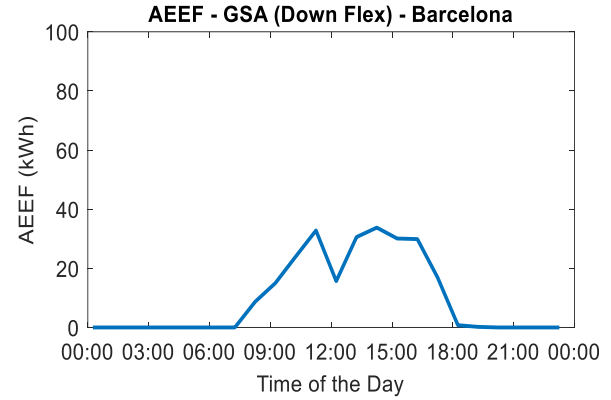
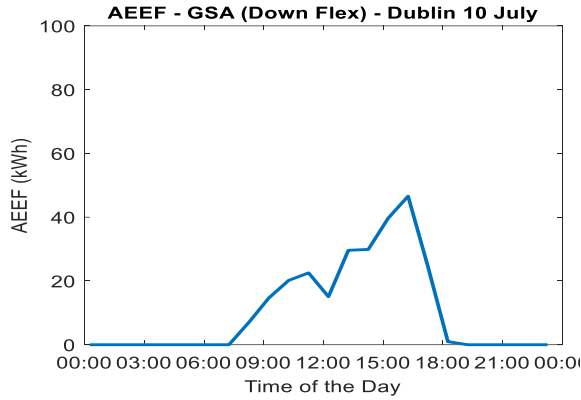






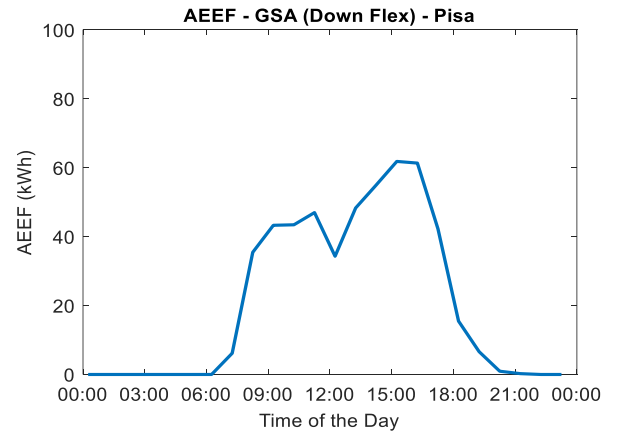
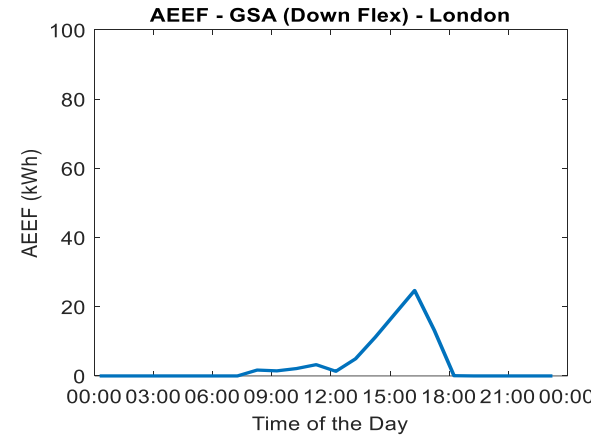
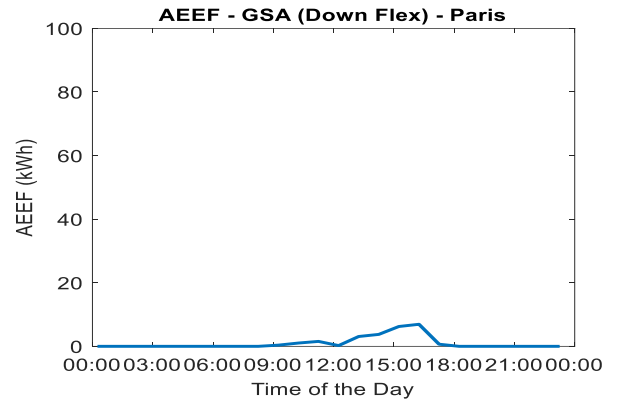
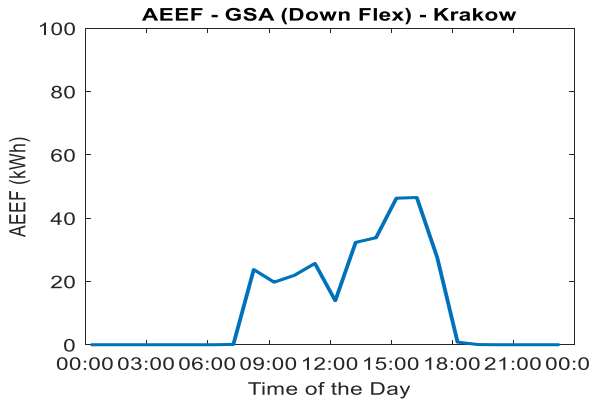
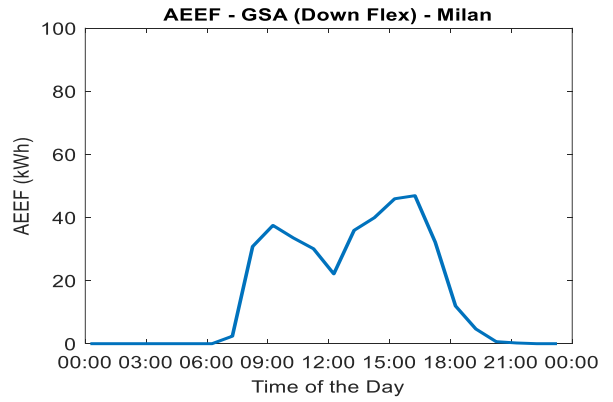
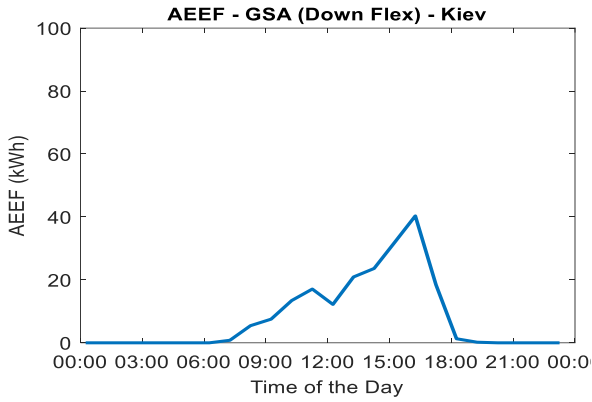
**B. INCREASE SET POINT RESULTS.**

**B.1. AEEF RESULTS OF INCREASING SET POINT**



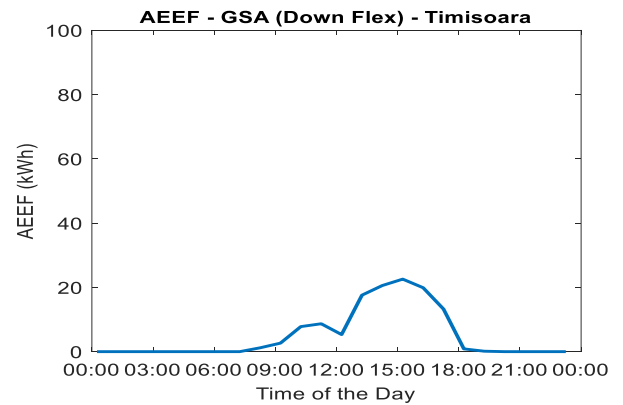
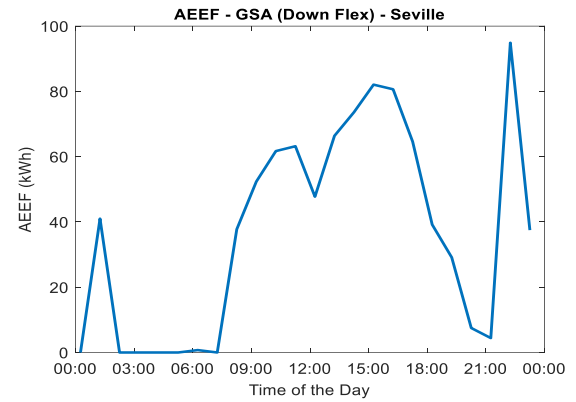
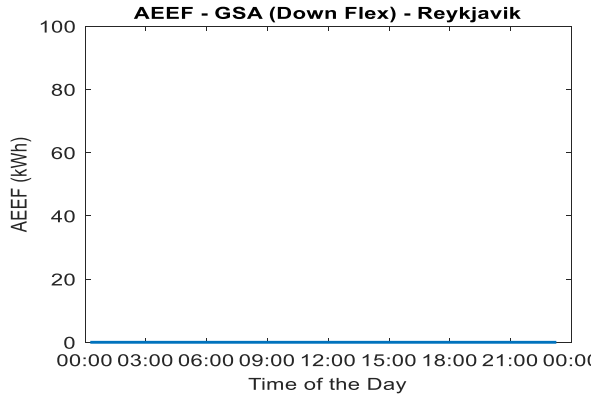


# Available energy flexibility: sensitivity study for different climatic conditions



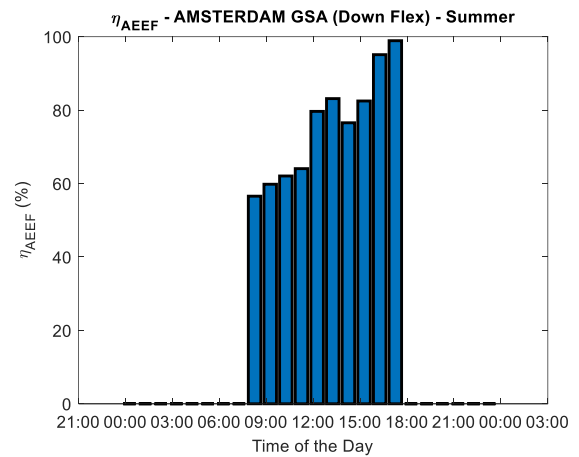
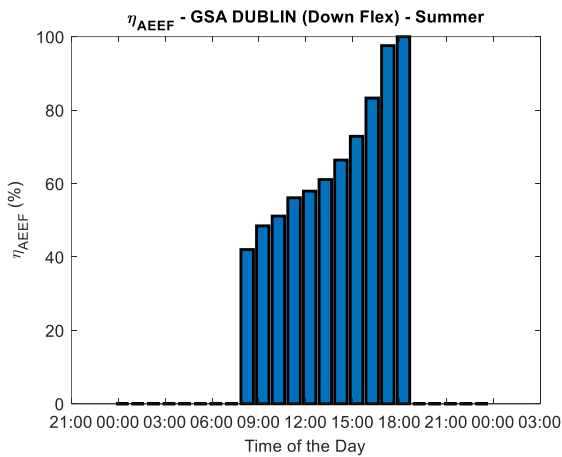


## Available energy flexibility: sensitivity study for different climatic conditions



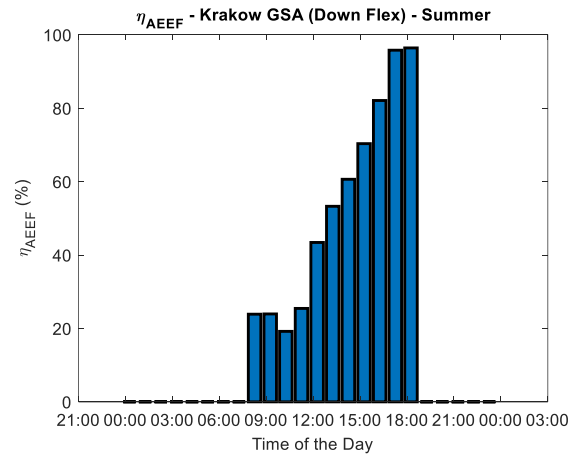
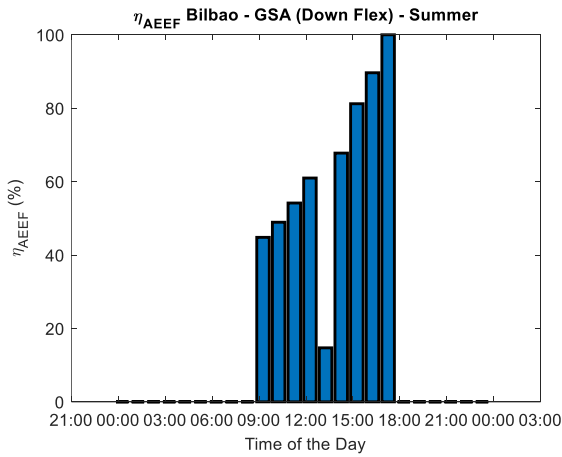
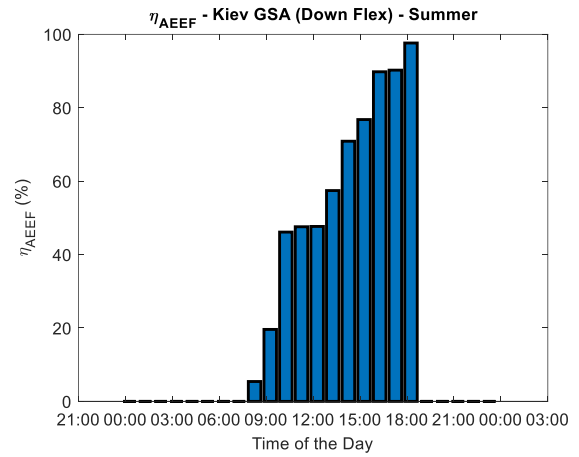
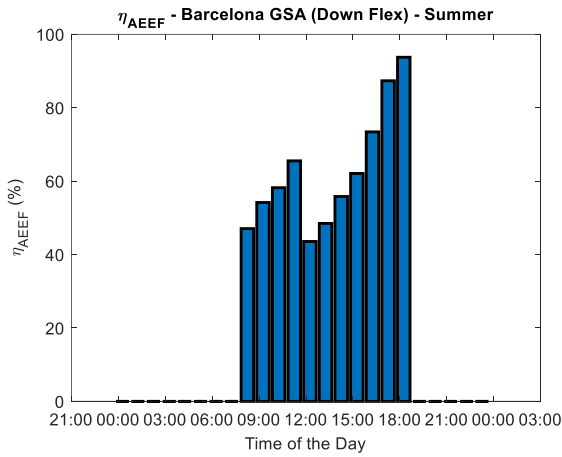
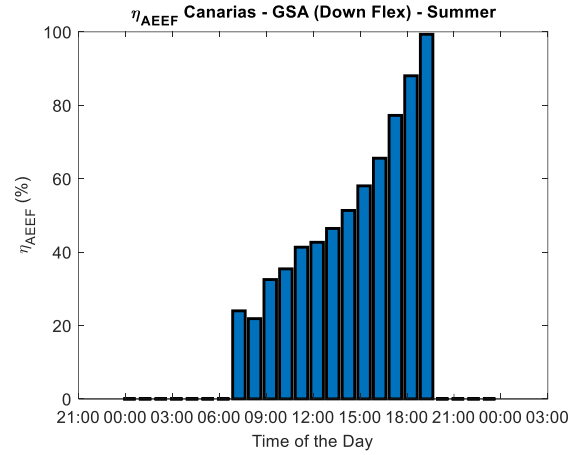
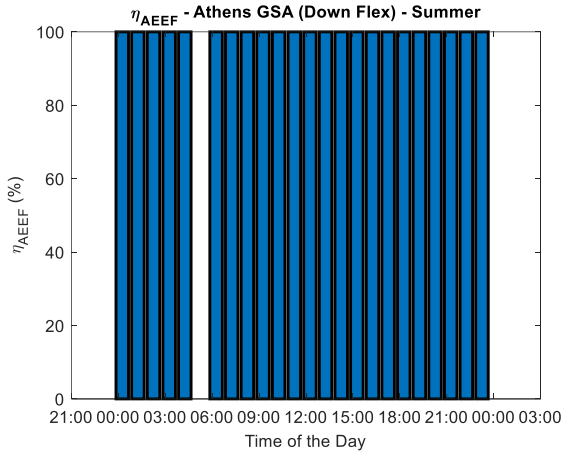
### B.2. EFFICIENCY RESULTS OF INCREASE SET POINT

Efficiency in DR increase set point



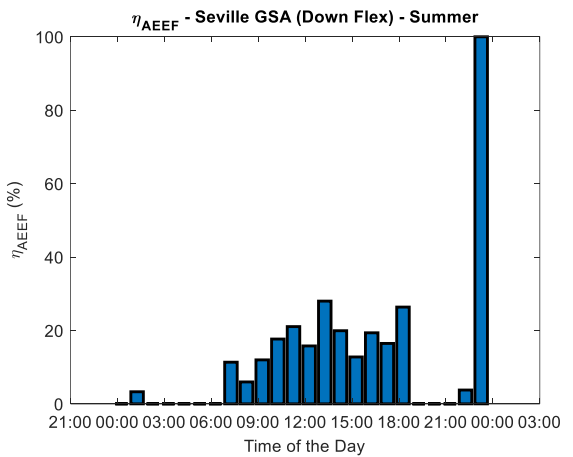
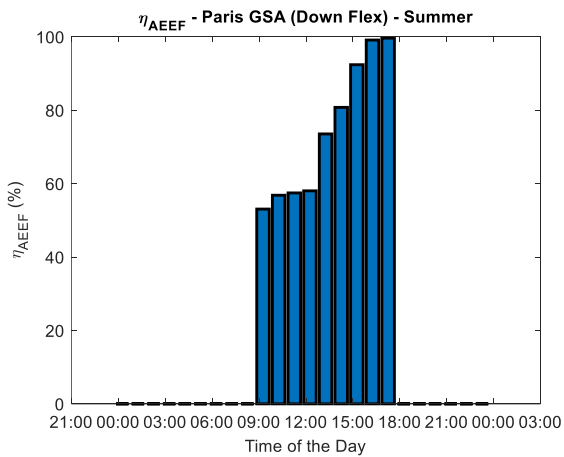
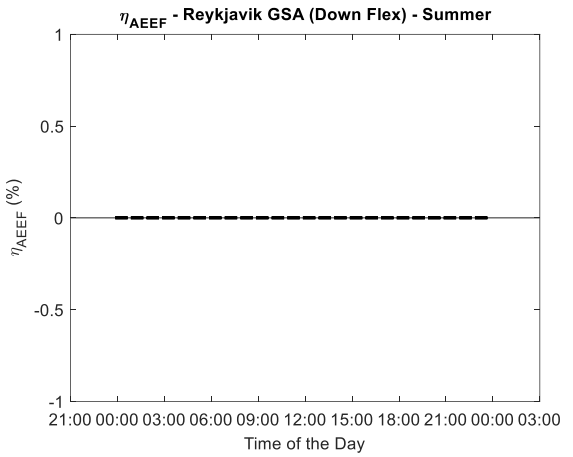
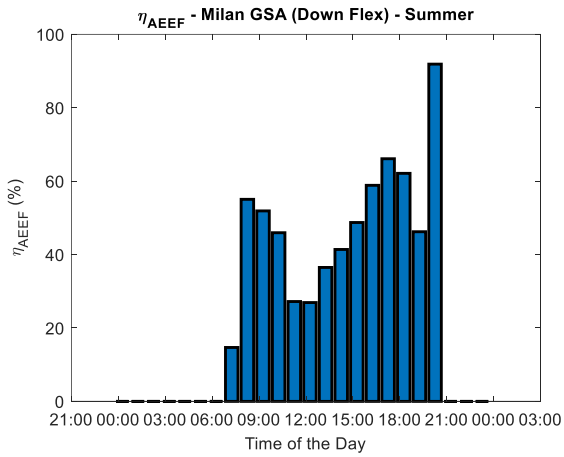
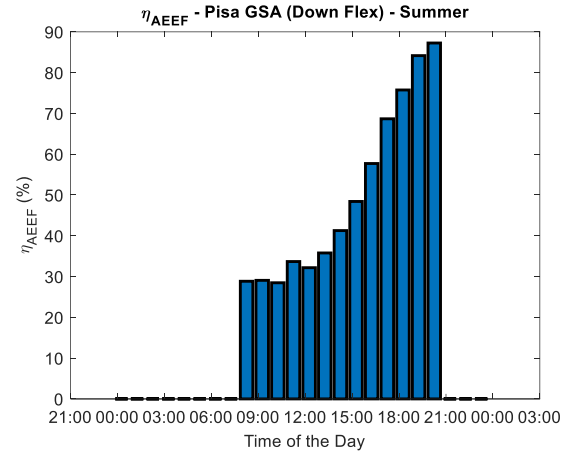
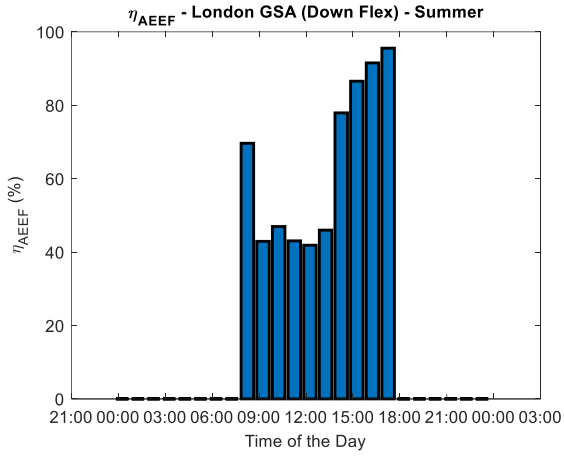


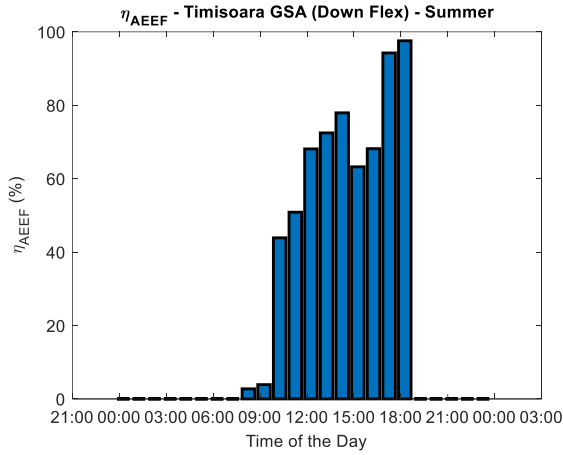
# Available energy flexibility: sensitivity study for different climatic conditions



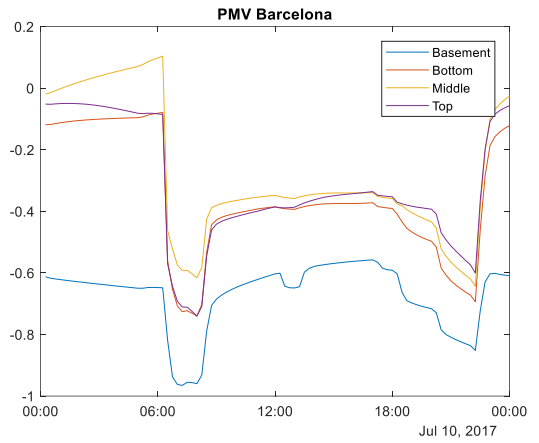
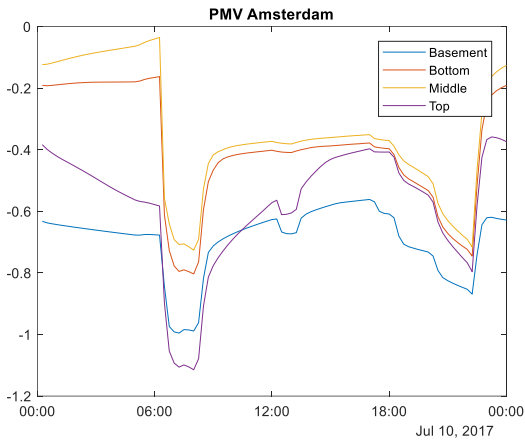
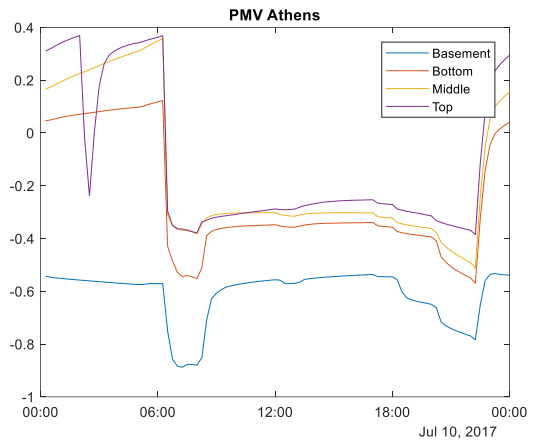
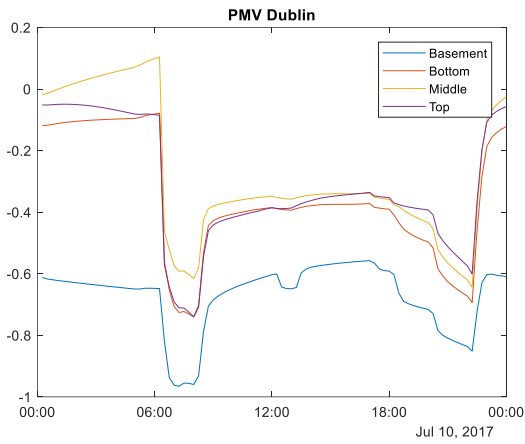


# Available energy flexibility: sensitivity study for different climatic conditions



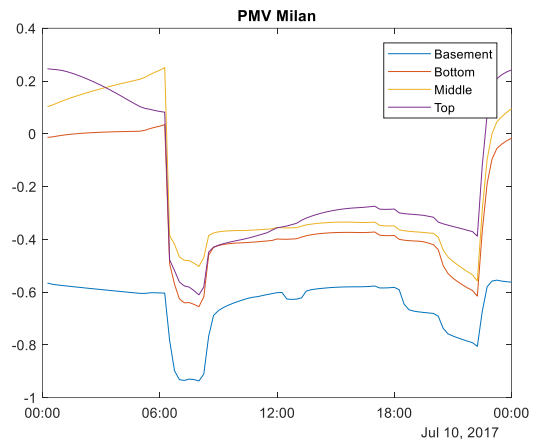
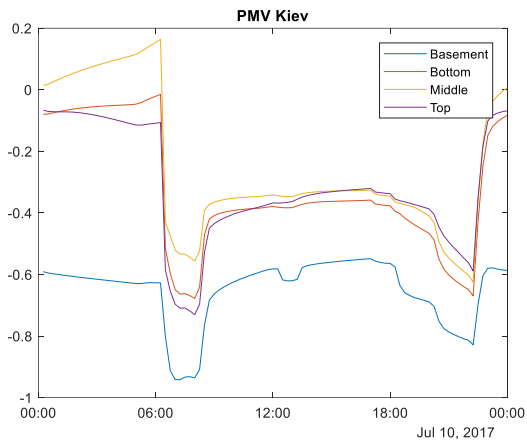
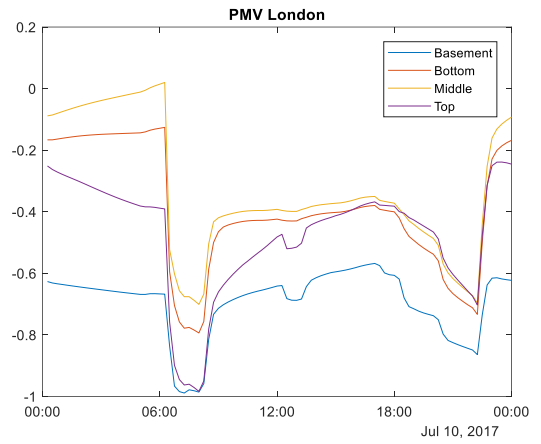
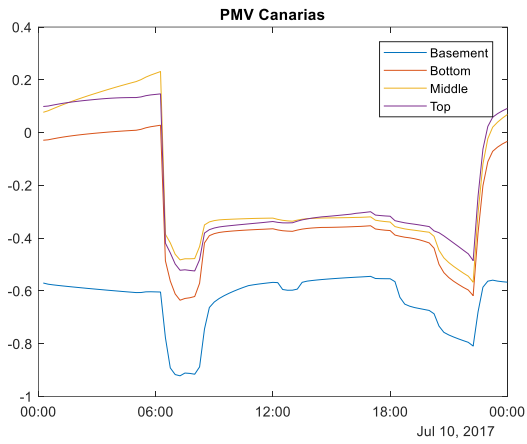
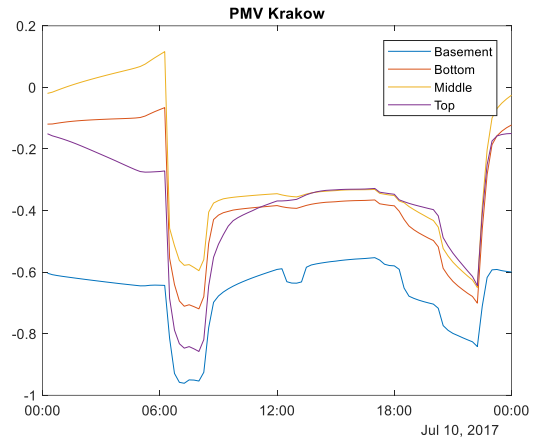
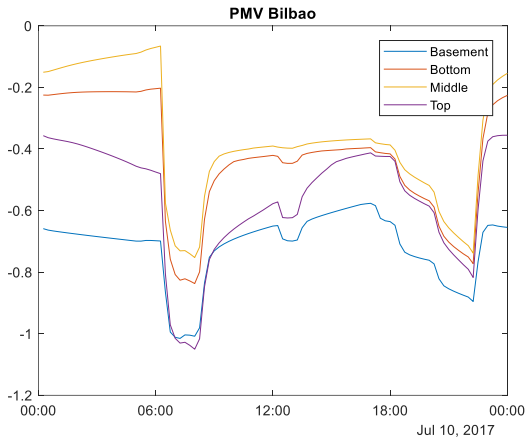


### B.3. ANEX 2. PMV FOR ALL THE LOCATIONS.



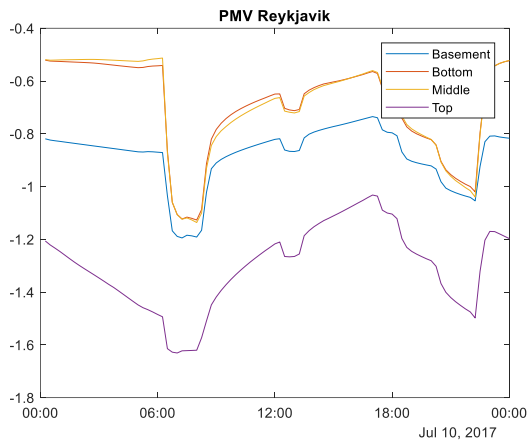
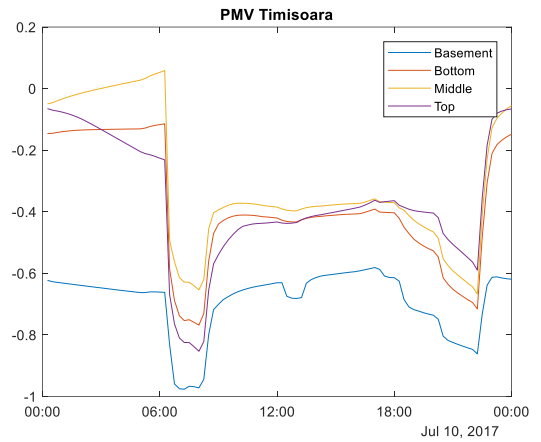
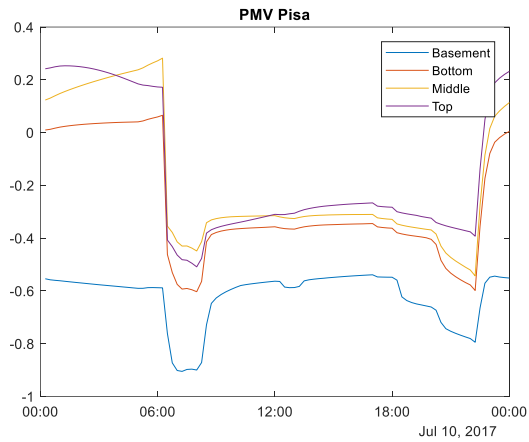
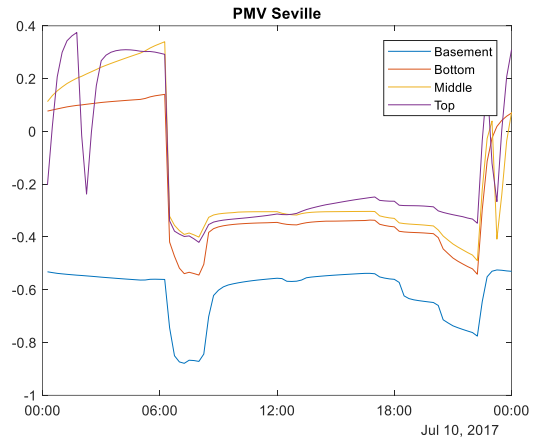
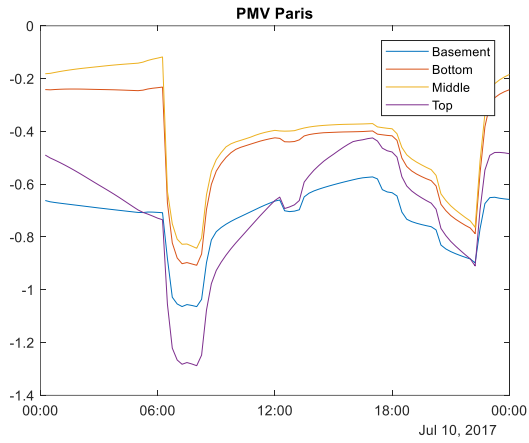


# Available energy flexibility: sensitivity study for different climatic conditions





# Available energy flexibility: sensitivity study for different climatic conditions

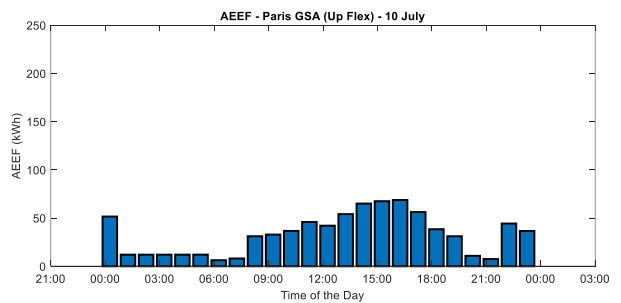
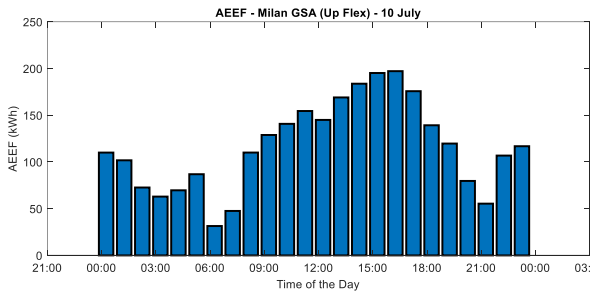
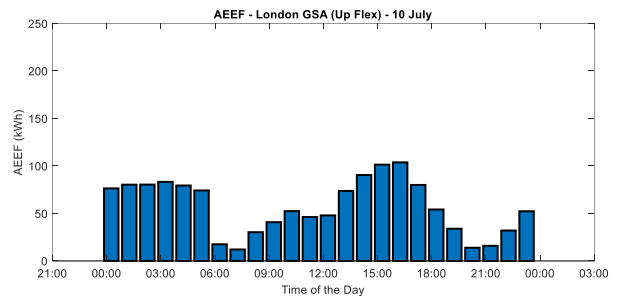
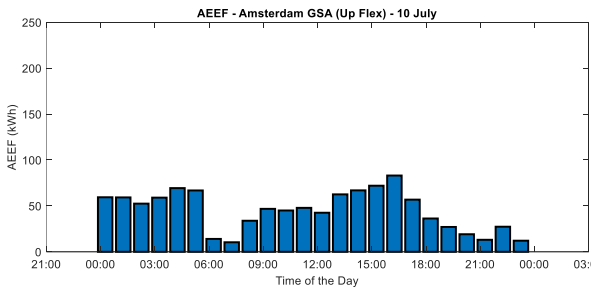
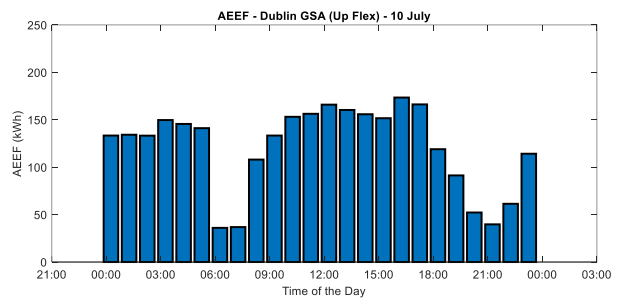
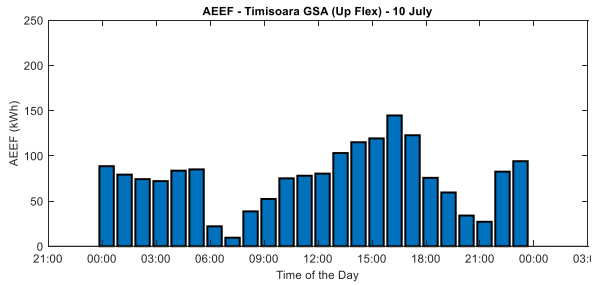
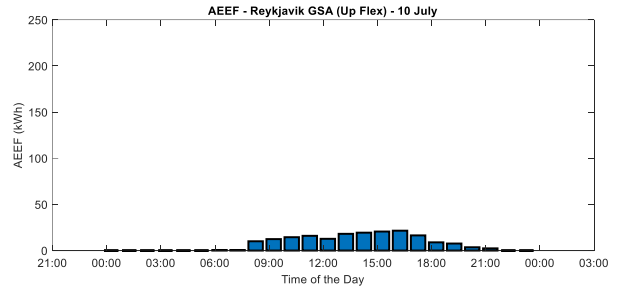
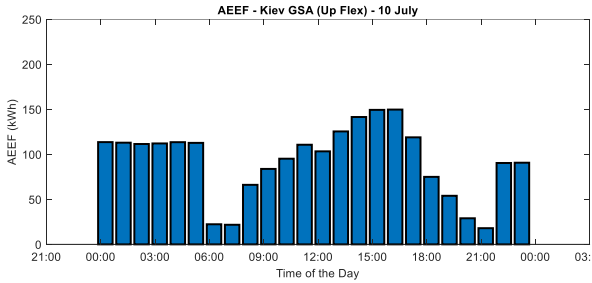






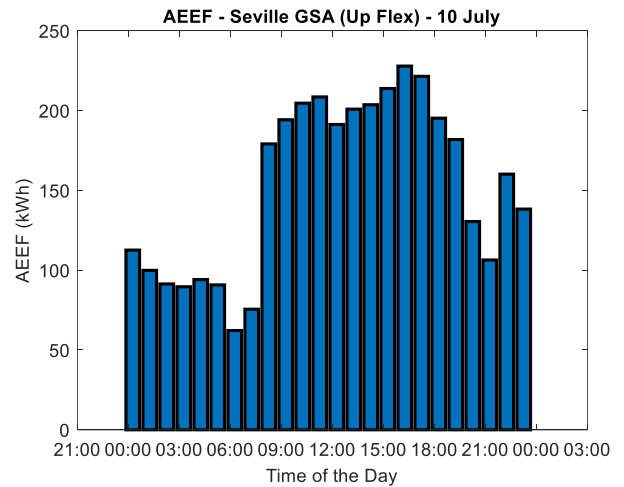
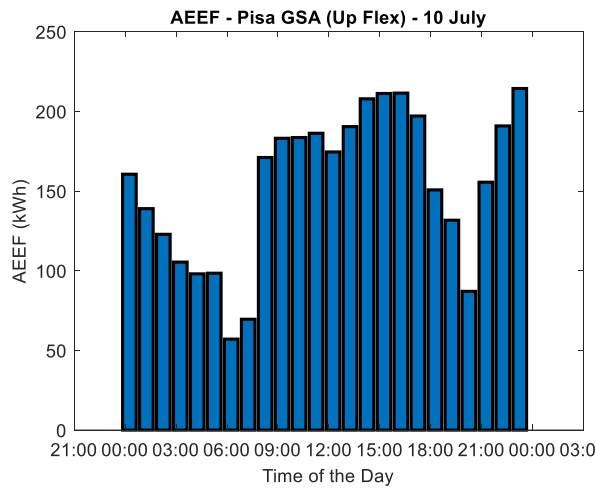
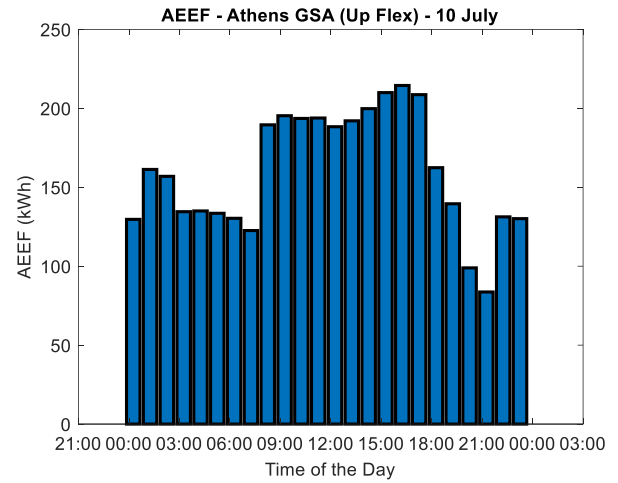
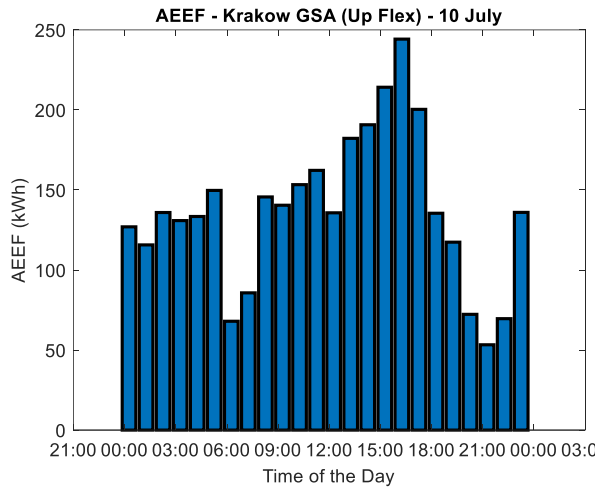
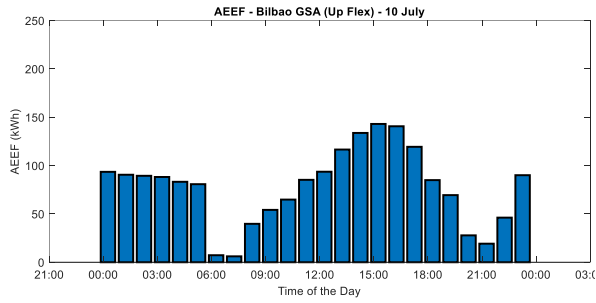
### C. DECREASE SET POINT RESULTS

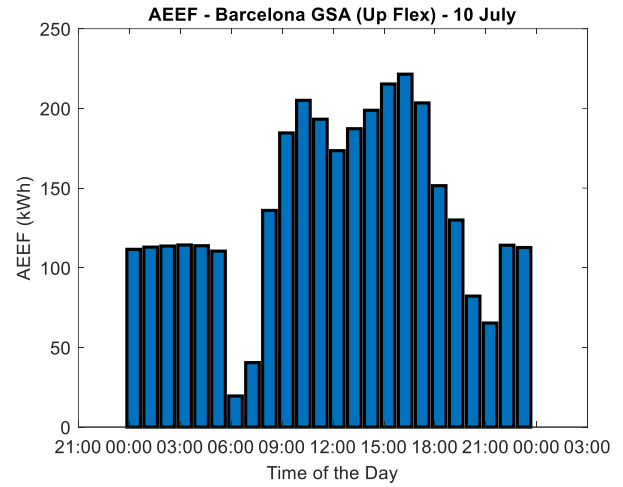
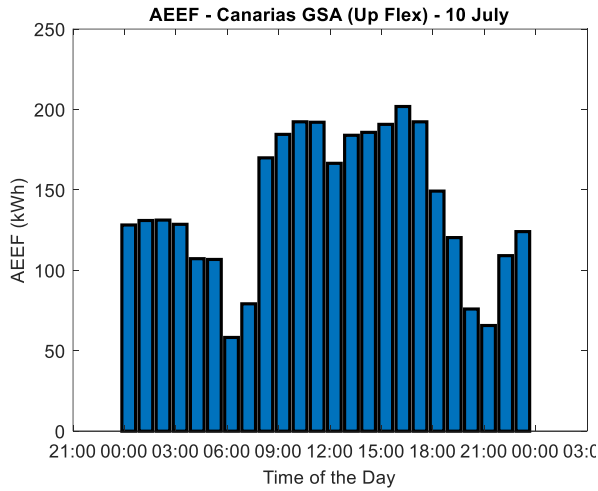
#### C.1. AEEF RESULTS DECREASE SET POINT



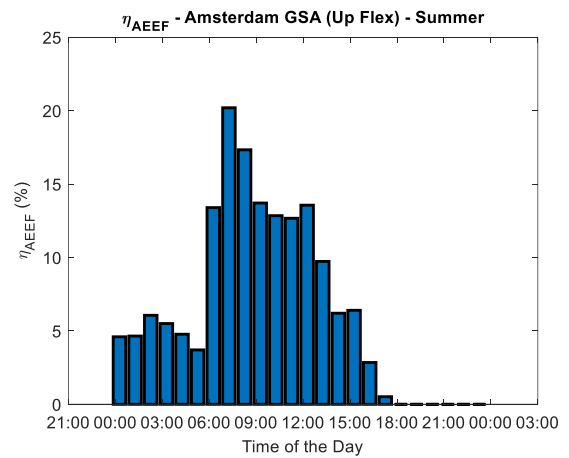
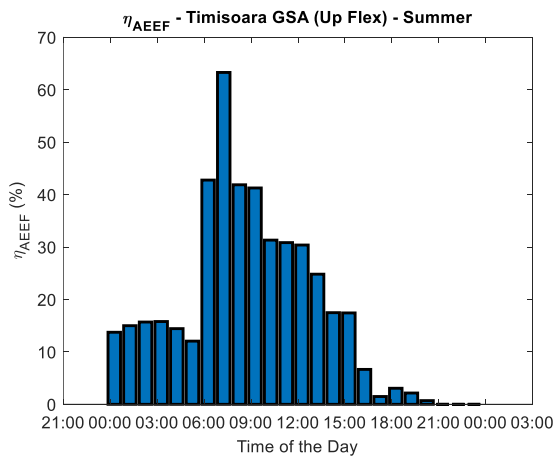
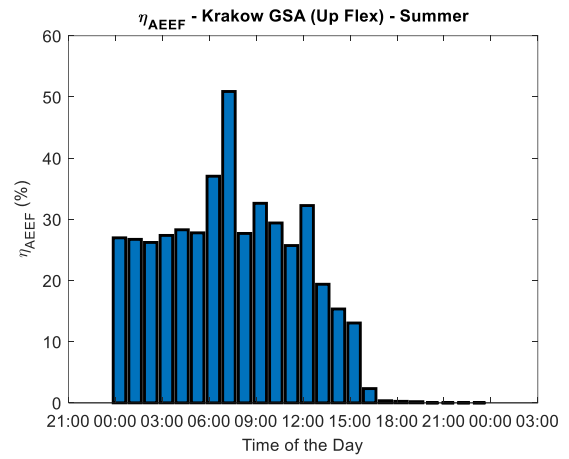
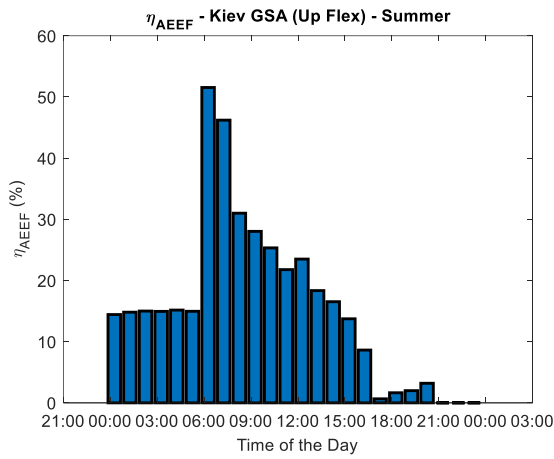


# Study of available electrical energy in a commercial building in different locations



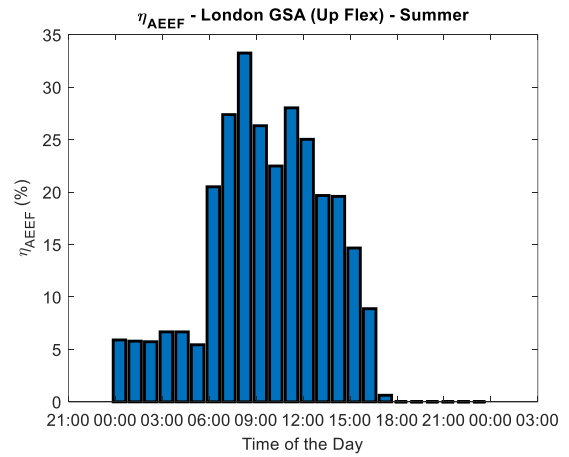
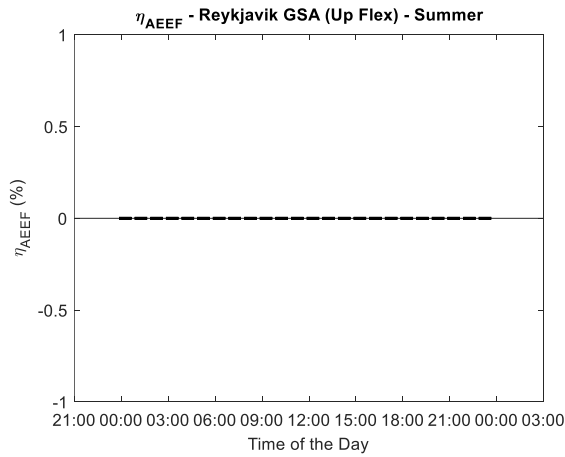
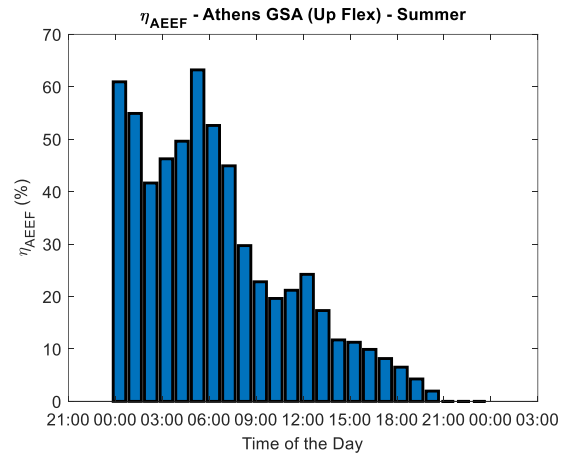
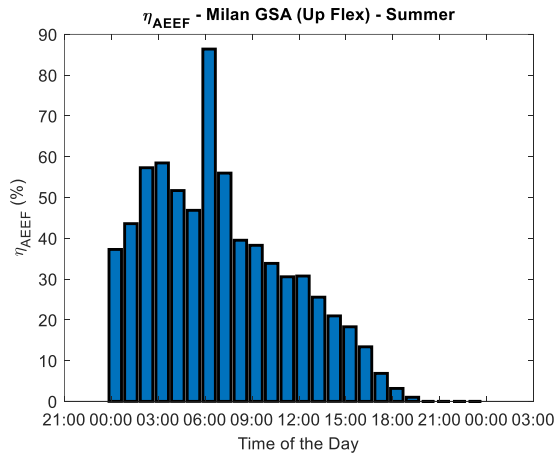
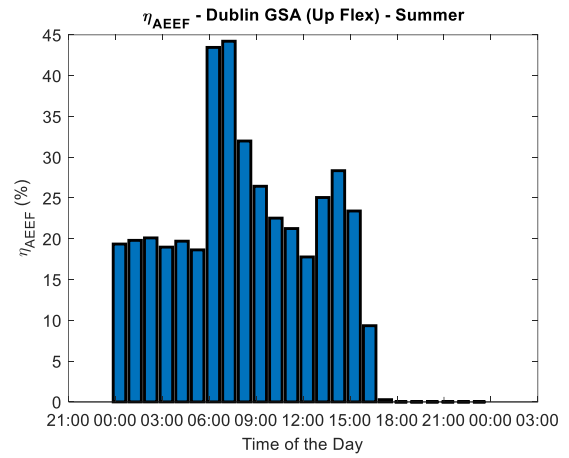
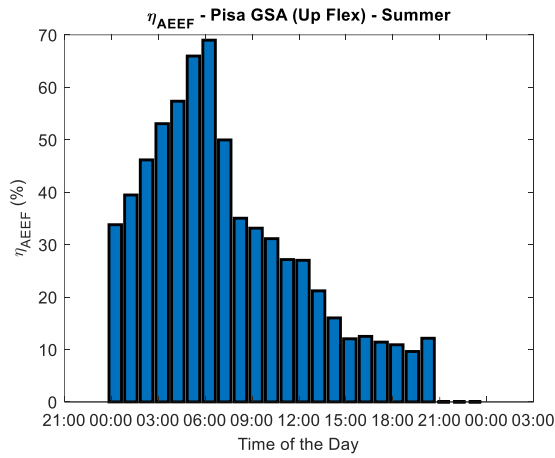


**C.2. EFFICIENCY RESULTS DECREASE SET POINT**



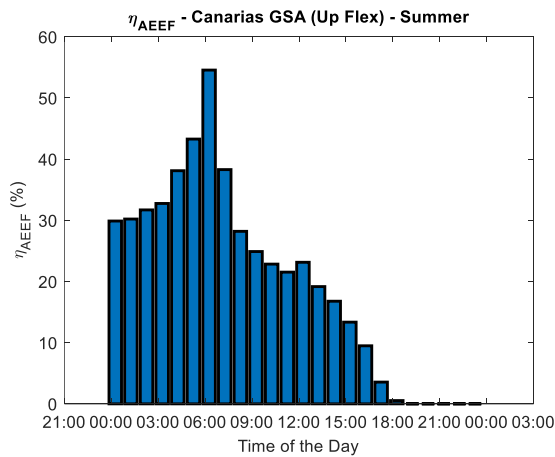
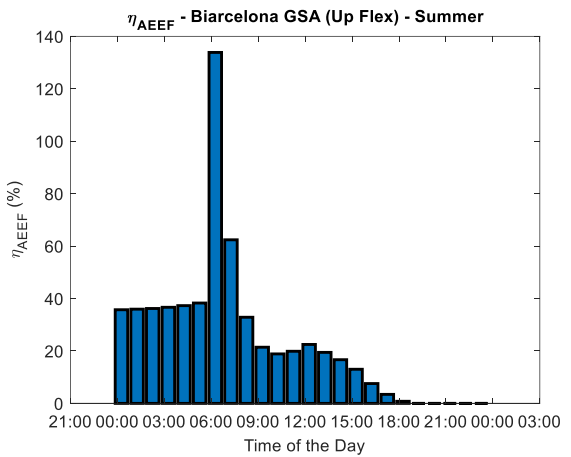
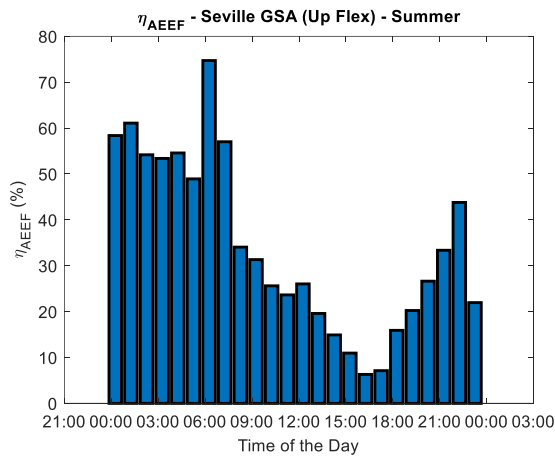
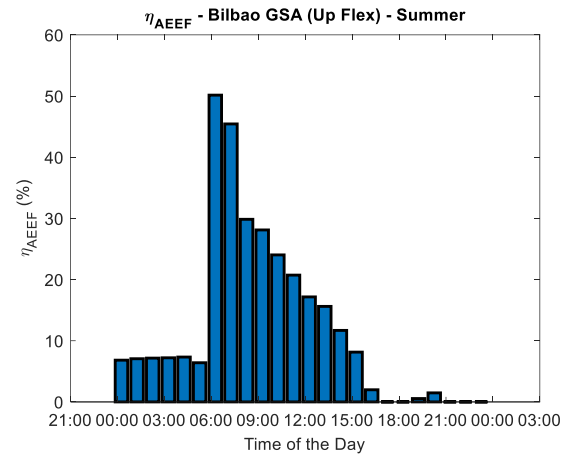
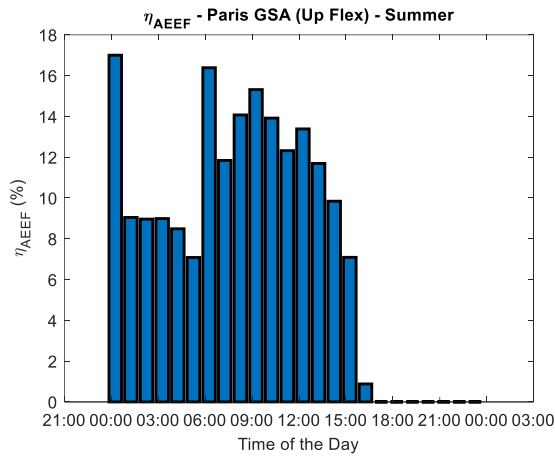


# Available energy flexibility: sensitivity study for different climatic conditions





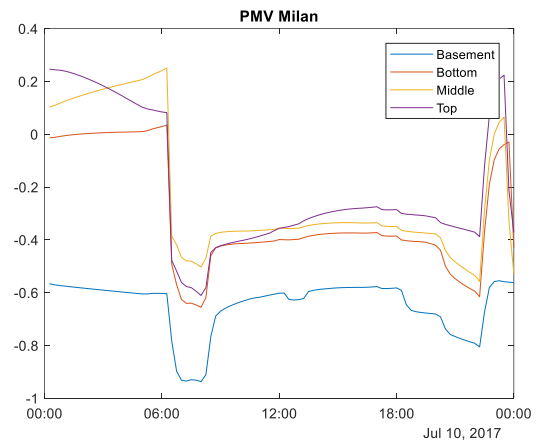
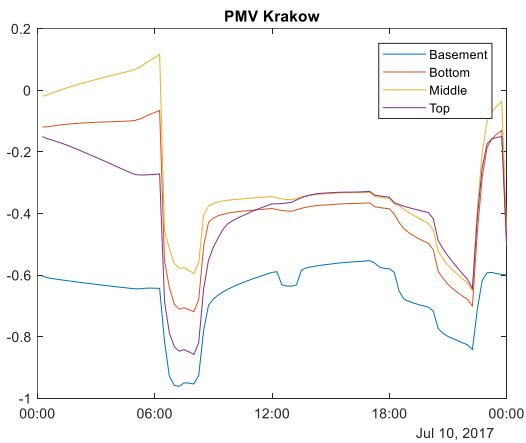
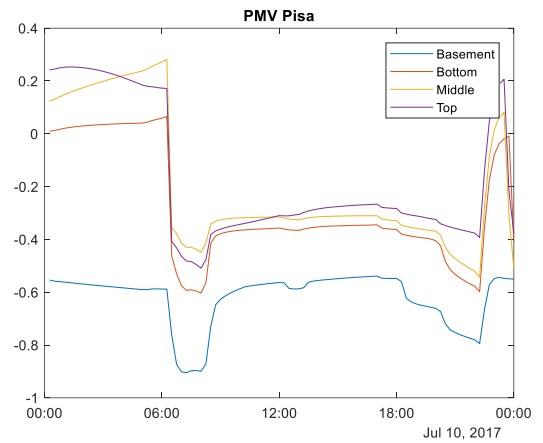
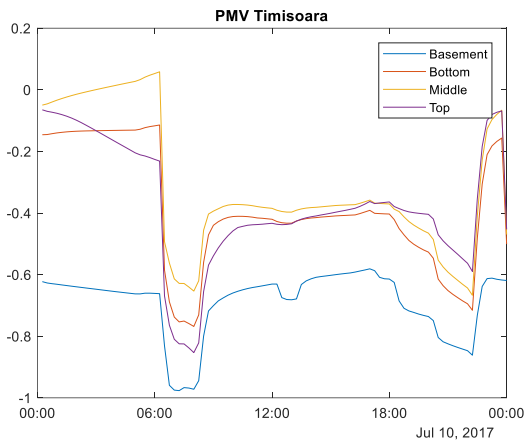
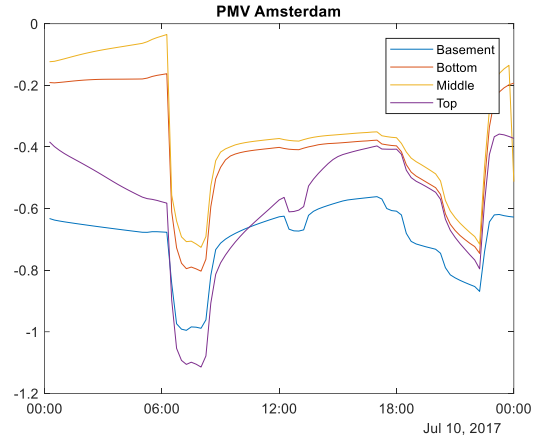
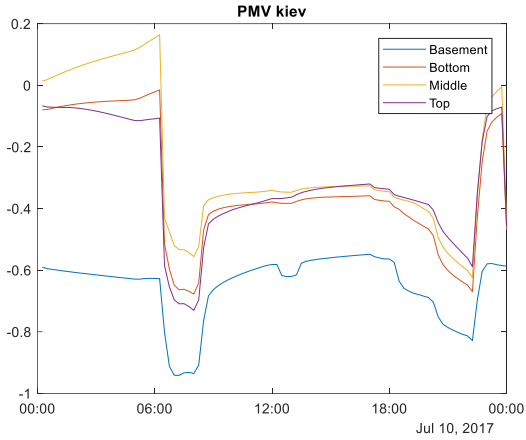
# Available energy flexibility: sensitivity study for different climatic conditions





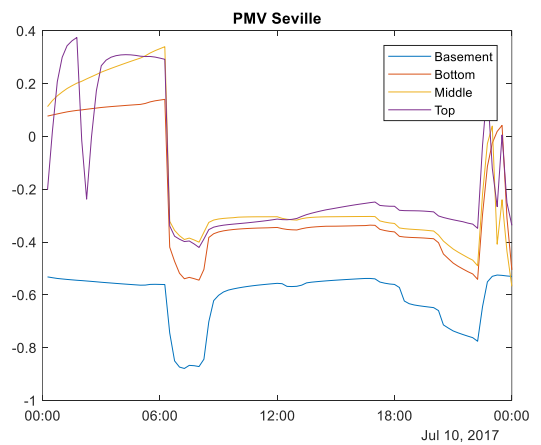
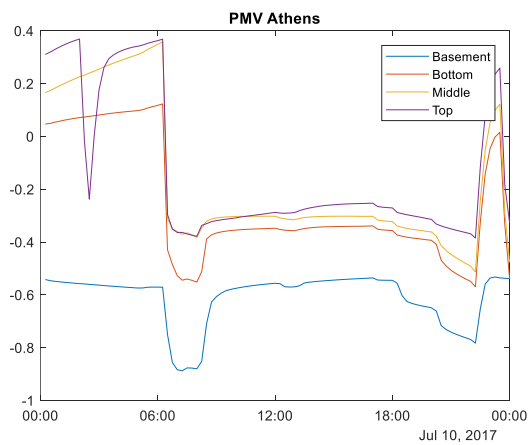
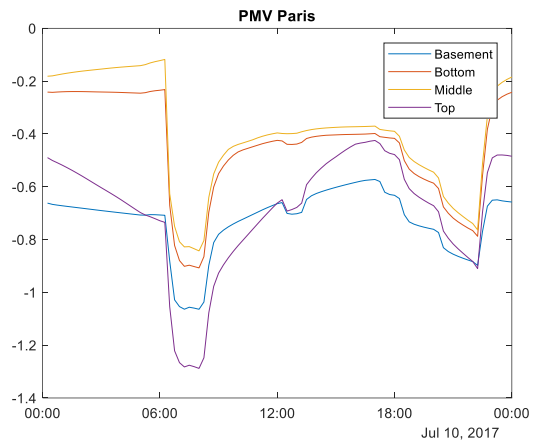
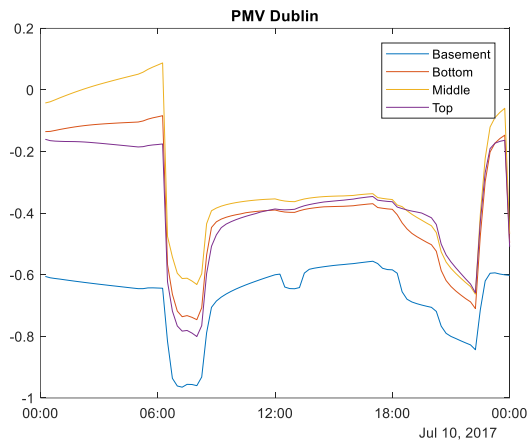
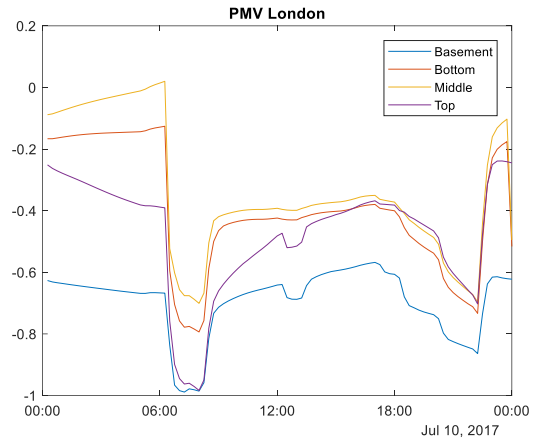
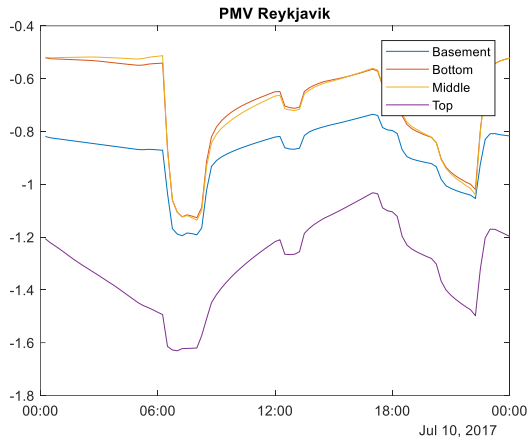
### C.3. PMV RESULTS DECREASE SET POINT

#### PMV analysis for decrease set point DR





# Available energy flexibility: sensitivity study for different climatic conditions





# Available energy flexibility: sensitivity study for different climatic conditions

