# TECHNO-ECONOMIC ANALYSIS OF GAS AND ELECTRICITY TECHNOLOGIES TO SUPPLY ENERGY SERVICES TO COMMERCIAL CONSUMERS

*'Máster Habilitante en Ingeniería Industrial'*

**FINAL PROJECT**

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August 2019, Madrid

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**TECHNO-ECONOMIC ANALYSIS OF GAS AND ELECTRICITY TECHNOLOGIES TO SUPPLY ENERGY SERVICES TO COMMERCIAL CONSUMERS**

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José Pablo Chaves Ávila.

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# TECHNO-ECONOMIC ANALYSIS OF GAS AND ELECTRICITY TECHNOLOGIES TO SUPPLY ENERGY SERVICES TO COMMERCIAL CONSUMERS

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*‘Máster Habilitante en Ingeniería Industrial’*

## Final Project

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August 2019, Madrid

# Executive Summary

The present document seeks for the commercial and business supply optimization to reducing the total costs of the system, mainly for gas and electricity. Next, it is explained, in a briefly and concise way, the steps and procedures followed in each chapter in the project's report.

**Chapter 1** introduces the energy sector in Europe, a breakdown of the most widely used technologies and the ones expected to burst in the sector in the next years.

**Chapters 2**, **3** and **4** explain the State-of-the-Art of the processes and current technologies that are used in the electricity, heat and cooling generation. It should be noted the split of themselves in two main groups: CHP and HVAC technologies. Each of them is briefly explained regarding their operation, main features, emissions and O&M costs, as well as investment costs. Table 5 tidily details the main parameters of the technologies. Such parameters will be introduced in the model as inputs.

***Table 1.*** *Main parameters of CHP machines*

| | ICE | MGT | FC | Stirling |
|---|---|---|---|---|
| **Overall Efficiency [%]** | 70-92 | 60-85 | 85-90 | 65-85 |
| **Electrical Efficiency [%]** | 25-43 | 13-30 | 37-60 | 40 |
| **Power-to-Heat Ratio** | 0.5-0.7 | 1.2-1.7 | 0.8-1.1 | 1.2-1.7 |
| **Life Cycle (yrs]** | 20 | 10 | 10-20 | 10 |
| **CAPEX [$/kW]** | 800-1,600[1] | 1,290[2] | $7,000-$10,000 | 1,300-2,000 |
| **O&M [$/kWh]** | 0.0045-0.0105 | 0.015-0.025 | $36-$45 | N/A[3] |

**Chapter 5** develops the work methodology that has been followed. For this project, it has been used an optimization model called DER-CAM. This model computes with GAMS language.

The most relevant input parameters – besides the technology parameters – considered by the author of this project are as follows:

- Load profile
- Temperatures
- Fuel prices
- Solar insolation where the building to be optimized locates

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[1] With a heat exchanger, there is an increase in the CAPEX.

[2] Same as in footnote 5.

[3] There is not enough data up-to-date to draw a reliable cost for operation and maintenance.

- Spot market prices
- CO2 emissions

Since the building are into contracted power capacities above 15 kW and are connected to the low voltage grid (<1 kV), it is compulsory, by law, register under the tariff 3.0A. This tariff is regulated and is distributed along three periods: on-peak, mid-peak and off-peak. Table 6 shows the capacity and energy costs, fixed term and variable term respectively. This fact allows the consumers to adapt the consumption and elaborate a strategy that makes pay less for the energy consumption, so cheapen costs.

*Table 2. 3.0A access tariff breakdown*

| 3.0A | Period 1 | Period 2 | Period 3 |
|---|---|---|---|
| **Capacity Term [€/kW/year]** | 40.728885 | 24.437330 | 16.291555 |
| **Variable Term [€/kWh]** | 0.018762 | 0.012575 | 0.004670 |

**Chapter 6** is the case study itself, the different scenarios that have been planned prior to launch the model and assumptions made during the development of the project. Firstly, a set of parameters have been selected in order to be able to modify the conditions of the simulations and coming up with different outputs. Table 7 corresponds to the control panel of the model. It consists of 10 binary input variables.

*Table 3. Binary input variables*

| | |
|---|---|
| **DiscreteInvest** | '0-Do nothing, 1-Invest in fuel-fired DG technologies' |
| **ContinuousInvest** | '0-Do nothing, 1-Invest continuous variable techs like PV, solar thermal, storage, and abs chillers' |
| **NGChillInvest** | '0-Do nothing, 1-Invest in fuel-fired direct compression chiller technologies' |
| **PVSales** | '0-No PV Sales, 1-Allow PV Sales. If Sales is set to zero PV Sales will be disabled' |
| **CHP** | '0-with CHP, 1-without CHP' |
| **CO2Tax** | '0-without $CO_2$ Emissions, 1-with $CO_2$ Emissions' |
| **MinimizeCO2** | '0-minimize Energy Costs, 1-minimize $CO_2$ Emissions' |
| **MultiObjective** | '0-no multi-objective function, 1-multi-objective function, which is a weighted combination of costs and $CO_2$' |
| **CentralChiller** | 0 means that no central chiller can be used for cooling. |
| **NetMetering** | '0-unrestricted electric sales to the macrogrid, 1-electricity sales < purchases electricity on an annual basis' |

Six scenarios have been elaborated and planned, which are presented as follows:

- Scenario with exclusive CHP investments
- Scenario with exclusive CHP investment and minimization of $CO_2$ emissions
- Scenario with exclusive continuous investments
- Scenario with exclusive continuous investments and electricity sales
- Scenario with both continuous and discrete investments
- Scenario with continuous and discrete investments and electricity sales

The output the model comes up with dictates that the optimal investment decision is the combination of continuous and discrete investments. The last case cited is the one attains larger savings in energy costs. In order to be able to state it, it was necessary to execute a base case scenario that lays out the system costs if no investments are done.

Table 8 compared the different scenarios with the necessary parameters to be capable of determining and comparing the different proposals to optimizing the current energy model. Within this chapter, there is a section devoted to the discussion of the proposals, highlighting their pros and flaws in each case.

*Table 4. Output summary*

| | BC | D1 | D2 | C1 | DC2 |
|---|---|---|---|---|---|
| **Energy Costs** | $501,392.806 | $150,408.241 | $246,157.121 | $ 495,500.860 | $190,680.564 |
| **System Efficiency** | 0.479 | 0.4999 | 1.137 | 0.597 | 1.254 |
| **Annual Emissions [kgCO$_2$]** | 2,100,623.150 | 3,176,420.626 | 1,394,613.993 | 1,679,901.453 | 1,266,842.368 |
| **PV [kW]** | - | - | - | 210 | 210 |
| **GSHP [kW]** | - | - | - | 70 | 30 |
| **Absorption [kW]** | - | - | - | - | 119 |
| **ICE [kW]** | - | 540 | 1,300 | - | - |
| **MGT [kW]** | - | 120 | 120 | - | 660 |
| **CAPEX** | - | $906,000 | $1,800,000 | $180,044.880 | $937,594.408 |
| **Electric Cost** | $496,217.867 | $276.839 | $1,890.628 | $430,674.373 | $220.621 |
| **Natural Gas Cost** | $5,174.938 | $20,168.201 | $49,326.778 | $22,654.157 | $44,928.008 |
| **Sales [kWh]** | - | - | - | - | 139,260.427 |

Finally, **Chapter 7** gives an assessment of the results and quote a set of conclusions, which have been drawn up very briefly, but they gather in a clear and explicit way the output and they verify the objectives this project had from its beginning. It can be therefore concluded that is not only important the energy costs reduction of the system, but also at what cost it is achieved. It is likely to happen that big initial capitals are needed to make decrease the gas or electricity bill, or the CO$_2$ emissions thrown to the environment as well. Having said that, there are multiple existing alternatives to face the problem, depending on the objectives willing to attain and the available capital investment, one energy model will be chosen or the other.

# Resumen Ejecutivo

El presente documento busca la optimización del abastecimiento de comercios y oficinas para la reducción de costes totales del sistema, principalmente gas y electricidad. A continuación, se explica, de forma breve y concisa, los pasos y procedimientos que se han seguido en cada capítulo de la memoria del proyecto.

El **Capítulo 1** introduce el sector energético en Europa, un desglose de las tecnologías más predominantes y las que se esperan que irrumpan en el sector en los próximos años.

Los **Capítulos 2**, **3** y **4** explican el Estado-del-Arte de los procesos y tecnologías actuales que se emplean en la generación de electricidad, calor y frío. Cabe destacar la separación de las mismas en dos grandes grupos: cogeneración (CHP) y HVAC ("Heating, Ventilation and Air Conditioning" por sus siglas en inglés). De cada tecnología se explica de forma resumida su funcionamiento y operación, principales características, tipo de emisiones y cantidades por unidad de energía producida, costes asociados a su operación y costes de inversión. La Table 5 detalla de forma ordenada los parámetros principales de dichas tecnologías. Dichos parámetros serán introducidos en el modelo como parámetros de entrada.

*__Table 5.__ Principales características de las tecnologías CHP*

| | ICE | MGT | FC | Stirling |
|---|---|---|---|---|
| **Eficiencia Global [%]** | 70-92 | 60-85 | 85-90 | 65-85 |
| **Eficiencia Eléctrica [%]** | 25-43 | 13-30 | 37-60 | 40 |
| **Power-to-Heat Ratio** | 0.5-0.7 | 1.2-1.7 | 0.8-1.1 | 1.2-1.7 |
| **Ciclo (yrs]** | 20 | 10 | 10-20 | 10 |
| **CAPEX [$/kW]** | 800-1,600[4] | 1,290[5] | $7,000-$10,000 | 1,300-2,000 |
| **O&M [$/kWh]** | 0.0045-0.0105 | 0.015-0.025 | $36-$45 | N/A[6] |

El **Capítulo 5** desarrolla la metodología del trabajo que se ha seguido. Para este proyecto se ha usado un modelo de optimización algebraico llamado DER-CAM ("Distributed Energy Resources Customer Adoption Model" por sus siglas en inglés). El modelo está escrito en GAMS.

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[4] With a heat exchanger, there is an increase in the CAPEX.

[5] Same as in footnote 5.

[6] There is not enough data up-to-date to draw a reliable cost for operation and maintenance.

Los parámetros de entrada más relevantes – además de los parámetros de cada tecnología – considerados por el autor de este proyecto han sido los siguientes:

- Perfil de carga
- Temperaturas
- Precio de los combustibles
- Radiación solar del emplazamiento donde se localiza el edificio a optimizar
- Precios del mercado spot
- Emisiones de dióxido de carbono

Al tratarse de edificios con potencias contratadas superiores a 15 kW y conectados a baja tensión (<1 kV), es obligatorio, por ley, acogerse a la tarifa 3.0A. Dicha tarifa está regulada y distribuida en tres períodos: punta, valle y baja carga. La Table 6 detalla los costes por capacidad y por consumo de electricidad, término de potencia y término de energía respectivamente. Este hecho permite a los consumidores dentro de esta tarifa elaborar una estrategia que les permita pagar menos por su consumo de energía y, de esta forma, abaratar sus costes.

***Table 6.*** *Tarifa 3.0A desglosada en períodos*

| **3.0A** | **Period 1** | **Period 2** | **Period 3** |
|---|---|---|---|
| **Término de Capacidad [€/kW/año]** | 40.728885 | 24.437330 | 16.291555 |
| **Término Variable [€/kWh]** | 0.018762 | 0.012575 | 0.004670 |

El **Capítulo 6** recoge el caso de estudio, los diferentes escenarios que se han elaborado previo a lanzar el modelo y suposiciones que se han tomado durante el desarrollo del proyecto. Primeramente, se han tomado una serie de parámetros para ir variando las condiciones de los escenarios y que éstos arrojen diferentes resultados para poder comprarlos después. La Table 7 corresponde al panel de mando que se va a modificar en el proceso. Consta de 10 parámetros binarios de entrada.

***Table** 7. Cuadro de mando del modelo DER-CAM*

| | |
|---|---|
| **DiscreteInvest** | '0-Do nothing, 1-Invest in fuel-fired DG technologies' |
| **ContinuousInvest** | '0-Do nothing, 1-Invest continuous variable techs like PV, solar thermal, storage, and abs chillers' |
| **NGChillInvest** | '0-Do nothing, 1-Invest in fuel-fired direct compression chiller technologies' |
| **PVSales** | '0-No PV Sales, 1-Allow PV Sales. If Sales is set to zero PV Sales will be disabled' |
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| **CO2Tax** | '0-without $CO_2$ Emissions, 1-with $CO_2$ Emissions' |
| **MinimizeCO2** | '0-minimize Energy Costs, 1-minimize $CO_2$ Emissions' |
| **MultiObjective** | '0-no multi-objective function, 1-multi-objective function, which is a weighted combination of costs and $CO_2$' |
| **CentralChiller** | 0 means that no central chiller can be used for cooling. |
| **NetMetering** | '0-unrestricted electric sales to the macrogrid, 1-electricity sales < purchases electricity on an annual basis' |

Se han elaborado 6 escenarios, los cuales se enumeran a continuación:

- Escenario con opción de inversión exclusiva en CHP
- Escenario con opción de inversión exclusiva en CHP y minimizando las emisiones de $CO_2$
- Escenario con opción de inversión exclusiva en "Continuous Technologies"
- Escenario con opción de inversión exclusiva en "Continuous Technologies" y venta de energía en el mercado
- Escenario con inversión discreta y continua
- Escenario con inversión discreta y continua y con ventas de excedentes de energía

Los resultados que arrojados por el modelo dictan que la opción de inversión óptima es la combinación de inversiones discretas y continuas. El último caso enumerado es el que mayores ahorros en costos de energía alcanza. Para poder afirmar esto, ha sido necesario correr un primer caso denominado caso base, que consiste en calcular los costes del sistema si ninguna inversión hubiese sido acometida.

La Table 8 muestra una comparación de los diferentes escenarios elaborados, con los parámetros de salida necesarios para poder determinar y comparar las diferentes estrategias que se proponen para optimizar el modelo energético actual. Dentro del mismo capítulo, hay un apartado donde se discute en favor de una estrategia y de otra, argumentando sus ventajas y desventajas en cada caso.

***Table 8.*** *Resumen de los resultados obtenidos*

| | BC | D1 | D2 | C1 | DC2 |
|---|---|---|---|---|---|
| **Costes de Energía** | $501,392.806 | $150,408.241 | $246,157.121 | $ 495,500.860 | $190,680.564 |
| **Eficiencia del Sistema** | 0.479 | 0.4999 | 1.137 | 0.597 | 1.254 |
| **Emisiones Anuales [kgCO$_2$]** | 2,100,623.150 | 3,176,420.626 | 1,394,613.993 | 1,679,901.453 | 1,266,842.368 |
| **PV [kW]** | - | - | - | 210 | 210 |
| **GSHP [kW]** | - | - | - | 70 | 30 |
| **Absorción [kW]** | - | - | - | - | 119 |
| **ICE [kW]** | - | 540 | 1,300 | - | - |
| **MGT [kW]** | - | 120 | 120 | - | 660 |
| **CAPEX** | - | $906,000 | $1,800,000 | $180,044.880 | $937,594.408 |
| **Electric Cost** | $496,217.867 | $276.839 | $1,890.628 | $430,674.373 | $220.621 |
| **Coste Gas Natural** | $5,174.938 | $20,168.201 | $49,326.778 | $22,654.157 | $44,928.008 |
| **Ventas [kWh]** | - | - | - | - | 139,260.427 |

Por último, el **Capítulo 7** recoge una valoración de los resultados y cita una serie de conclusiones, las cuales han sido redactadas con suma brevedad, pero que recogen de forma clara y explícita los resultados obtenidos y verifica los objetivos que este proyecto tuvo en sus comicios. Se concluye que no solamente es importante la reducción de costes de la energía dentro del sistema, sino también a qué costo se consiguen dichas reducciones. Es posible que se necesite mucho capital inicial para hacer decrecer el gasto en gas o electricidad, o también en reducir las emisiones de dióxido de carbono a la atmósfera. Es por ello que hay que existen múltiples soluciones y formas de abordar un problema, y que dependiendo de los objetivos que se deseen alcanzar y el capital disponible, se optará por un modelo energético diferente.

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August 2019, Madrid

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# Nomenclature

| | |
|---|---|
| **COP** | Coefficient Of Performance |
| **HP** | Heat Pump |
| **ASHP** | Air Source Heat Pump |
| **GSHP** | Ground Source Heat Pump |
| **CHP** | Combined Heat and Power |
| **HVAC** | Heating, Ventilation and Air Conditioning |
| **ICE** | Internal Combustion Engine |
| **MGT** | Micro Gas Turbine |
| **NG** | Natural Gas |
| **DG** | Distributed Generation |
| **RES** | Renewable Energy Sources |
| **KPI** | Key Performance Indicator |
| **PV** | Photovoltaic |
| **O&M** | Operation and Maintenance |
| **TOU** | Time-Of-Use |
| **CAPEX** | Capital Expenditure |

# 1 Introduction

Nowadays, heating and cooling take half of the total energy consumed in the EU, and most of it is wasted [1]. Current developments are intending to achieve a better utilization of this type of energy; cutting-edge technologies are being implemented to substitute the old ones, but still there is a great dependency on imports (especially for natural gas).

The aim of this thesis is to integrate and exploit the synergies of heating, cooling and electricity, so that, the decarbonization process of the energy sector becomes a reality and the dependency on primary energy from other countries decrease such in a notorious manner by means of RES.

Heating and cooling represent the biggest EU's energy sector, and it is expected to remain so [1]. As is depicted in Figure 1, it can be seen the small penetration of low carbon technologies in the heating and cooling installations, being fossil fuels the major supplier with 75% of the total demand.

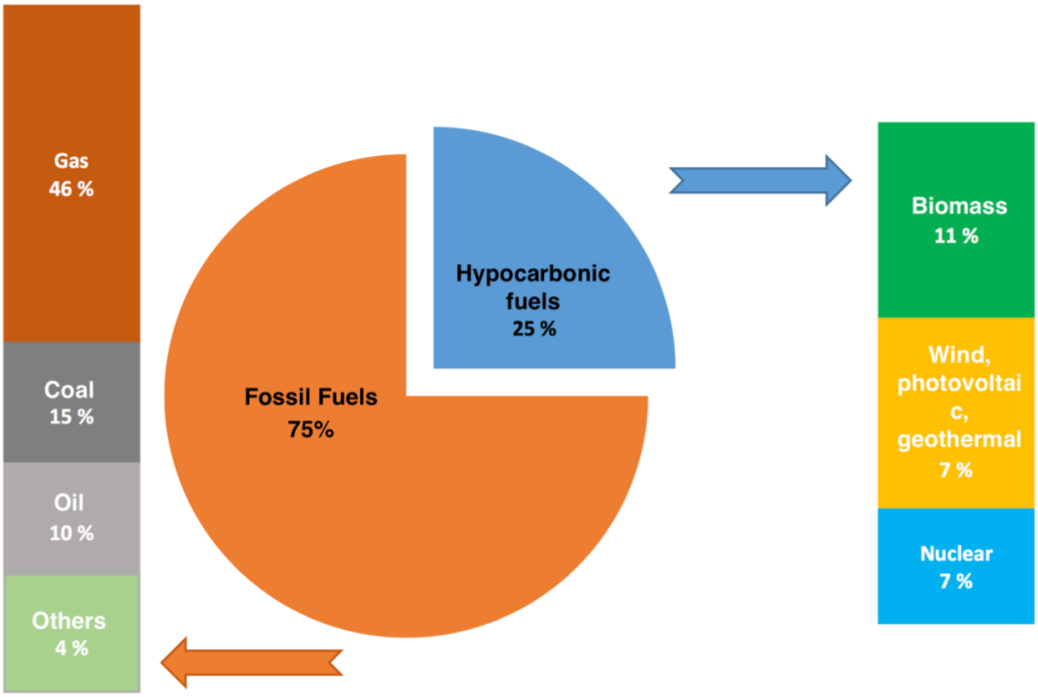

*Figure 1. Primary energy for heating and cooling, 2012 [1]*

Renewables accounted for 18% of the EU's primary energy used in heating and cooling, and it is still growing year by year. The objective of the Member States is to meet the EU targets for 2020, under which 20% of the current GHG emissions must be cut, 20% of electricity generation must come from renewable sources and the gain in efficiency must reach an extra 20% compared to today's efficiency. Likewise, there are new objectives facing the 2030 horizon; 32% of RES share in the energy is desired by the European Commission each SM has by that year.

In order do so, Member States have adopted different measures to achieve those targets. The utmost renewable resource in heating and cooling is biomass. Roughly it represents 90% of renewable heating, and declares itself as the most widely used source among other renewable technologies.

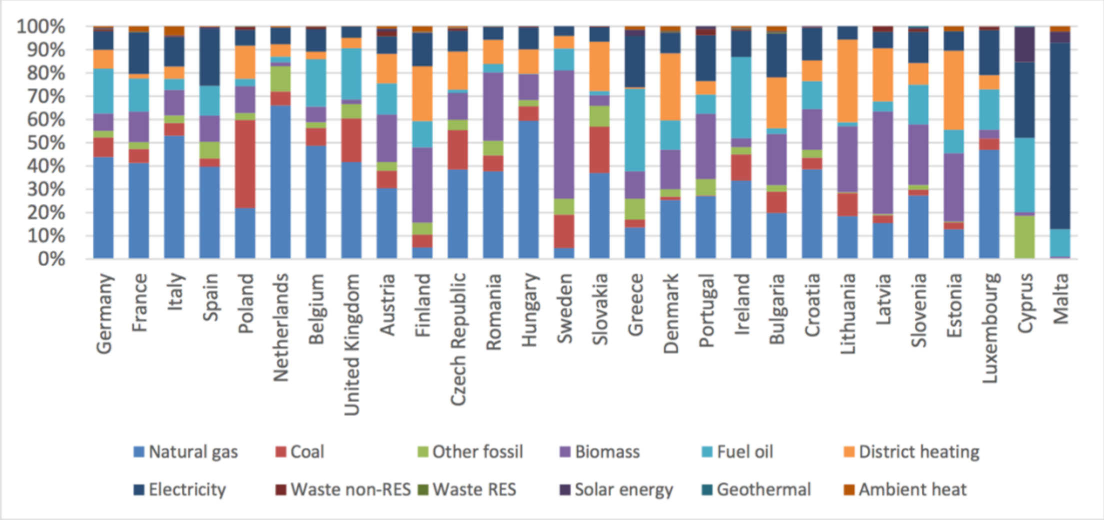

***Figure 2.*** *Final energy consumption for heating and cooling, 2012 [1]*

A 45% of energy used for heating accounts for the residential sector, 37% corresponds to industry and the leftover 17% represents the service sector (commercial buildings, hotels, offices, etc.) [1]. Focusing on services, there is potential to enhance the efficiency and make improvements in the system to better off the current heating system in commercial buildings, which is the purpose of this project.

Improvements on efficiency has to do with better utilization of the energy, both space conditioning and electricity. Since they are related to one another, i.e., some heaters and chillers make use of electricity to work, an increasing of efficiency will come up with less use of electricity for the same amount of heating or cooling demanded. Moreover, the use of micro- and mini-generators would be an optimal solution, yet to be proved, but with high expectations because the more decentralized the energy generation, the larger the potential for reduction of energy losses and better use of heating and cooling procurement. Furthermore, it is important to bear in mind the economies of scale of technologies, which usually are more expensive at small scale. Furthermore, distributed generation is very complex and must be analyzed depending on the country and the consumer characteristics.

As a result, it can be seen there are synergies among electricity, heating and cooling, that can be exploited in order to gain overall efficiency in heating and cooling systems and contribute to sparing money in the billing.

# 2 State-of-the-Art

At the present time, there is not real change in society when talking about heating technologies. The traditional method to heat up and keep houses and buildings warm has to do with the thermal generation. It has been quite long time since our society started burning coal and oil in boilers to warm their places, and so remained for the time being. Those boilers are very inefficient and very pollutant. There is technology available to replace them by new machines and machinery with better performance and low-carbon emissions.

As a way of efficiency gaining, district heating has been widely used in the industrial areas exploiting the residual heat derived from power generation to heat up their installations and use the heat for own processing. The fact is it is quite complicated to bring that heat from the outskirts to the buildings located in the city center. It is very costly to carry heat in long distances up to final consumers, so that this only works on areas in the nearby of an industry or any power plant that produces huge amounts of heat.

Concerning the city centers, it seems there is a need to find another solution, and it exists actually. The idea of these new technologies is to provide cogeneration in areas where district heating cannot operate, i.e., decentralized heat and power generation. Through this, the overall grid efficiency will increase, and everyone will benefit from it. The main reason lies on the fact that the nearer final consumer and generation are, the better quality of service and the less losses in the system.

After this framing, there are some cutting-edge technologies entering the market very strongly and displacing those which used to be the original ones. Roughly speaking, it can be said they are four major technologies, but there is only one that is being very well accepted by customers: the heat pumps.

Heat pumps [2] are characterized by its revolutionary functioning and cleanliness. There are different types of heat pumps depending what transfer medium is used: aerothermal, hydrothermal, ground-water and ground-air heat pumps. Each type simultaneously has different variations according to its functioning principle. Aerothermal and hydrothermal heat pumps are the most commonly used, as they were first commercialized due to its competitive price.

Lately, there have entered new ones which make use of the soil and the ground water: the geothermal heat pumps. The good point of this kind of heating and cooling lies on its stability during operation, and also, they are not much affected by climate conditions as the heat source and energy sink is underground. Its main feature has to do with this, which means no matter what happens the yield and efficiency will remain constant on a regular basis [3]. Hence, it would be easier to predict electricity consumption, which would allow to make predictions on billing and, eventually, would help design in a more accurate way the capacity needs of the installation. In addition, these energy systems do not need fossil fuels to deliver heat and cold, but renewable and electricity as main sources.

Micro gas turbines [4], Stirling engines and fuel cells complete the list of technologies that are gaining market share in the heating and refrigeration industry in recent years [5].

Each of them has its pros and cons. It is therefore required to analyze the building to be conditioned and set up an ad-hoc strategy which best fits the building, a combination of many technologies may occur if this proves beneficial.

In this section, the current development of the several technologies applied in the electricity and heat sectors will be explained in detail. Operational functioning, fuel required to operate, associated costs, emissions and main characteristics of each are now presented, among others.

Two main fields are distinguished when talking about heat and electricity: CHP and HVAC.

# 3 CHP Technologies

Beginning with the CHP (Combined Heat and Power), this kind of machines use fuel to produce both heat and electricity. They admit two different configurations depending on the user's necessities regarding heat or electricity. If the user needs heat, then the machine will be set to produce heat as its main priority, and the other way around, when electricity is demanded the CHP will perform to produce electricity mainly and heat as a secondary energy flow.

For the CHP technologies, they can be classified into: ICE, micro-gas turbine, fuel cell and Stirling engine.

## 3.1 Internal combustion engine

A reciprocating internal combustion engine, better known as ICE or as a piston engine, is a thermal engine which converts the pressure into rotary motion by means of pistons. There are two existing ICE types, i.e., on the one hand there are spark ignition reciprocating engines fed by natural gas as their preferred fuel, but that can also burn propane, gasoline or landfill gas, whereas on the other hand there are compress ignition ICEs which operate on diesel or heavy oil [5]. The range of the ICE can vary from several kW, i.e., 5 kW up to 20 MW at maximum.

***Table 9.*** *Characteristics and parameters of IC engines*

| | **Compressed engines** | **Spark ignition engines** |
|---|---|---|
| **Capacity range** | 5 kW–20 MW | 3 kW–6 MW |
| **Overall efficiency [%]** | 65-90 | 70-92 |
| **Electrical efficiency [%]** | 35-45 | 25-43 |
| **Power-to-heat ratio** | 0.8-2.4 | 0.5-0.7 |
| **Life cycle (years)** | 20 | 20 |

### 3.1.1 Operational functioning of ICE

The two different types of ICEs perform under the same functioning principle. Considering both engines take four strokes of movements of the piston to complete one cycle, these two are commonly known as the Otto cycle and Diesel cycle. Otto cycle belongs to the type of spark ignition while the Diesel one is linked to compress ignition. Next figure represents how they carry out one complete cycle and the events occur in each step of the process.

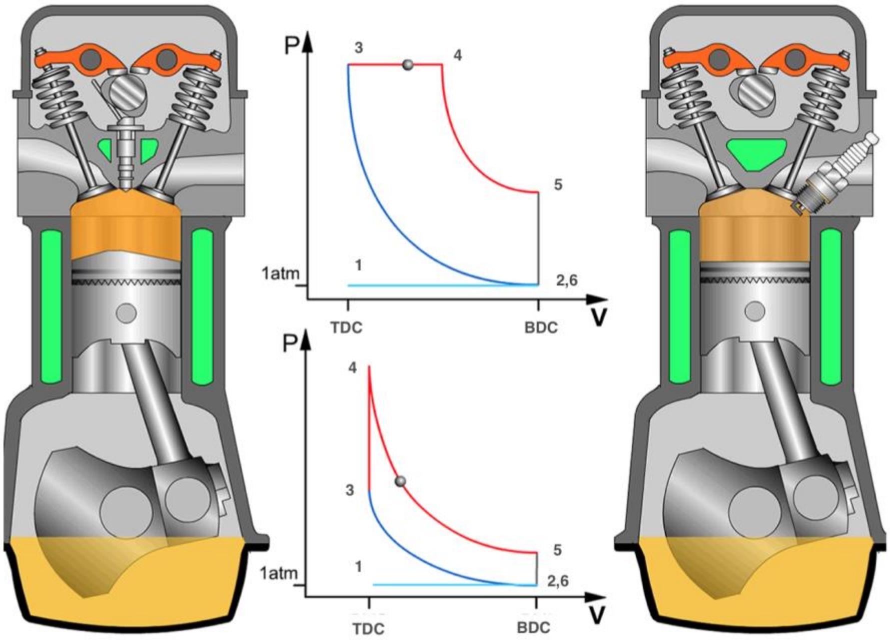

***Figure 3.*** *Diesel cycle and Diesel p-v diagram (left and up). Otto cycle and Otto p-v diagram (right and down) [6]*

As depicted in Figure 3, both cycles are seemingly the same, which indeed is true, but there are some slight differences that are out of the scope of this project and not described here. Following the order by numbering the steps:

Intake stroke. This step (1-2) consists of an isobaric thermal process in which the piston moves from the TDC (Top Dead Center) to the BDC (Bottom Dead Center). At the BDC the inlet valve (right valve) opens and let the air in the combustion chamber.

Compression stroke. Once the air is in, the valve closes and the piston moves up compressing the air and increasing the temperature, so do pressure as well (2-3).

Power stroke. Here comes the main difference between Otto and Diesel (3-4 isochoric process). At the TDC the spark instantaneously ignites the combustion of the mixture of fuel-air and the piston by the force produced by the explosion is displaced virulently and rapidly to the BDC. The Otto injects the fuel just right before the expansion, the mixture reacts by the spark originated by the spark plug, reaching a peak that makes the displacement of the piston downwards. Whereas the Diesel engine reaches by means of compression a very high-pressure rate, then the fuel is injected and the high temperature reached inside the chamber makes possible the auto-ignition.

The mixture is expanded and the piston moves.

Exhaust stroke. As the piston moves to BDC the exhaust valve opens and pressure drops (4-5 isochoric). Eventually the mixture already burned comes out the combustion chamber through the left valve (exhaust valve) and the process starts all over.

The motion of the piston is transmitted by rotary motion through the crankshaft, which is connected to the propeller shaft and finally to the wheels.

### 3.1.2 Emissions of ICE

As already mentioned, there are two main existing technologies which are in use nowadays in CHP. First, the spark ignition engines. They make use of light fuels to work, i.e., gasolines and gas (biogas included). The second group refers to the diesel engines or compressed engines which mainly burn diesel and heavy oils to run, but can also operate with gas and gasolines although its yield would be drastically reduced when burning these light fuels.

***Table 10.*** *Emissions comparative between technologies [7]*

| | **Compressed engines** | **Spark ignition engines** |
|---|---|---|
| **$CO_2$ (kg/MWh)** | 650 | 500-620 |
| **$NO_x$ (kg/MWh)** | 10 | 0.2-1 |

Table 10 shows the noticeable differences between the two existing engines. A priori, it seems the spark ignition is the best option regarding emissions, but this could lead to a misleading. In terms of overall efficiency both are quite similar. Breaking down the electrical efficiency and the heat output ratio (see Table 9) spark engines present a better efficiency concerning heat production, whereas diesel is better at electricity generation. Coming back to emissions, those numbers might vary depending on the kind of energy demanded at a time. If electricity is needed, then the diesel engines would fit better than the spark ones, so that gasoline consumption would increase, so do the CO2 emissions.

Regarding the NOx emissions is indisputable that Diesel engines emits larger amounts of this toxic by-product due to the high compression rates taken place during the combustion. Thanks to the research and development of the current technologies, this NOx rate has drastically decreased through the years by catalytic converters that enables to diminish the temperature at which the combustion shall take place. But it is still at a high level compared to other power technologies.

### 3.1.3 Associated costs of ICE

Costs related to this technology are very dependent on the installed capacity of the engine. This means, the cost would vary in a great manner at different ranges of the machine. The more power the engine has, the larger the investment is required. Table 11 gives an overall idea on how much money is needed in order to make an investment in this CHP machines.

***Table 11.*** *Comparison between ICE technologies according to their costs [7]*

| | Compressed engines | Spark ignition engines |
|---|---|---|
| **Average cost of investment ($/kW)** | 340-1,000 | 800-1,600 |
| **O&M costs ($/kWh)** | 0.0075-0.015 | 0.0045-0.0105 |

## 3.2 Micro-gas turbine

Micro gas turbines, also called micro-turbines, relate to a branch of the combustion turbines but of smaller scale. It is mainly powered by natural gas, although it allows to burn other type of fuels such as diesel, gasoline or high-energy fuels. They are extremely reliable, as they only have one moving part; they use air bearing so that no lubricating oil is needed [7].

As it will be discussed later on, there are no only advantages. For instance, initial costs are higher compared with reciprocating engines, and also, track records on this technology are short [7], but it is further research ongoing and more analysis regarding its operation and how to implement them in an optimal way within the industry and commercial sector, as well as enhancements on their operation.

Concerning some features, their power capacity ranges from several kilo-Watts up to hundreds of kilo-Watts. With this size, they are very suitable for distributed generation and CHP and CCHP[7] systems [5]. Exhaust gases can be used to provide hot-water supply or steam to the adjacent buildings. One of the greatest advantages of micro-turbines is its adaptability and flexibility to different conditions of operation. Another key characteristic is their flexibility that small-scale individual units can be combined easily into large systems of multiple units, making time response very quick compared with other technologies [7].

***Table 12.*** *Main characteristics and parameters of gas turbines [7]*

| | Combustion turbine | Micro-turbine |
|---|---|---|
| **Capacity range** | 250 kW – 50 MW | 15 kW – 300 kW |
| **Electrical efficiency [%]** | 25-42 | 13-30 |
| **Overall efficiency [%]** | 65-87 | 60-85 |
| **Power-to-heat ratio** | 0.2-0.8 | 1.2-1.7 |
| **Life cycle (years)** | 20 | 10 |

---

[7] Combined Cooling Heat and Power.

Detached in Table 12 can be noticed the relation between electric and thermal efficiency: the smaller the installation, the higher the latter, whereas larger installations provide better electric output. Also, the life cycle of the micro-turbines is half of the larger ones, which is quite remarkable and is discussed later on in the chapter.

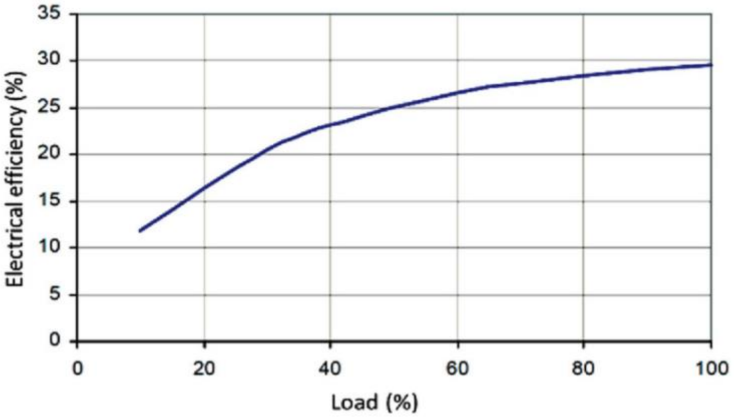

***Figure 4.*** *Partial load efficiency of micro-turbines*

### 3.2.1 Operational functioning of micro-gas turbine

Micro gas turbines operate under the so-called Brayton cycle. This cycle is depicted in Figure 5.

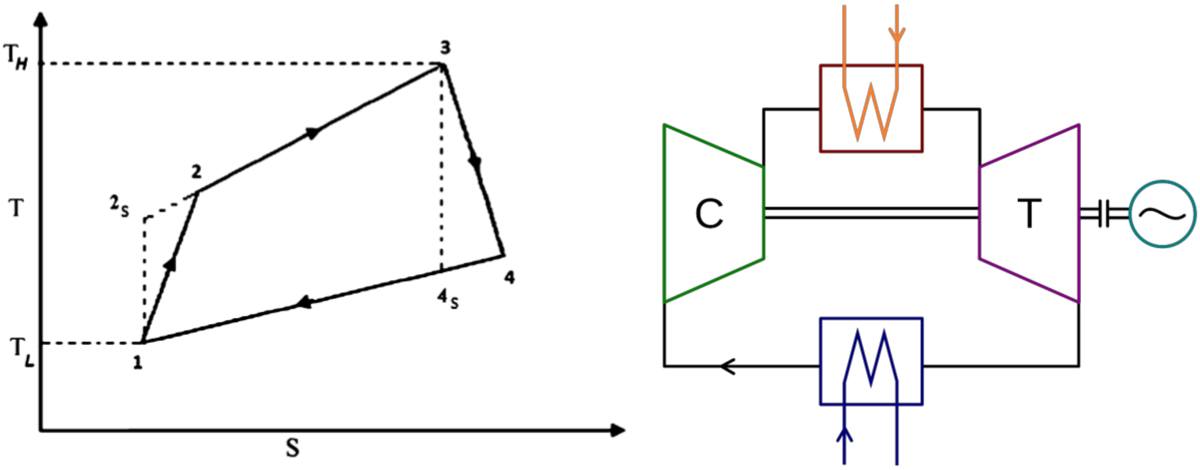

***Figure 5.*** *Diagram T-S of an irreversible closed Brayton cycle (left) and micro gas turbine scheme (right) [8]*

Its functioning consists of four steps:

1) Air inlet. In this first stage the outside air enters the compressor to increase its pressure, and in consequence, the temperature does too. As this process is not ideal, some irreversibilities may happen; that is the reason the entropy increases as temperature rises.
2) Combustion. Once the air is pressurized, it is mixed with the fuel, typically, natural gas. This step takes place in the combustion chamber, in which temperature increases from 2 to 3 (see Figure 5), and entropy moves rightwards.

3) Expansion in the turbine. The mixture ignites itself and produces the rotation of the shaft, which, at the time, moves the generator connected to the turbine. Once again, the irreversibility of the process makes the temperature not decrease as much as if it were an ideal process (4 and 4s).

4) Heat recovery. The exhaust gases stemmed from the combustion and expansion remain at a very high temperature. In order to gain overall efficiency, this residual heat may be used to heat up some other flow, i.e., water or air, avoiding the energy spilling.

The process described above is merely a simplistic description of what in reality is happening; a lot of improvements have come into force to enhance its performance.

MGTs can operate in two modes [9]: non-cogeneration, say, electricity production only; and cogeneration, that is the CHP topic discussed in this chapter (thermal and electric output at the same time).

a. Electrical priority operating mode. The micro turbine operates in open loop, as the only demanded energy flow is electricity; downstream the turbine does no matter. As a result, the exhaust heat from the combustion gases will be spilled.

b. Thermal priority operating mode. Now, the cycle is closed and HR (Heat Recovery) is effective. In other words, the exhaust gases transfer their heat to cold flow in order to heat it up and make use of it in further processing (industrial activities for example). This mode enables the MGT to acquire a high efficiency rate.

The overall efficiency depends on the opening degrees of the BPV (By-Pass Valve).

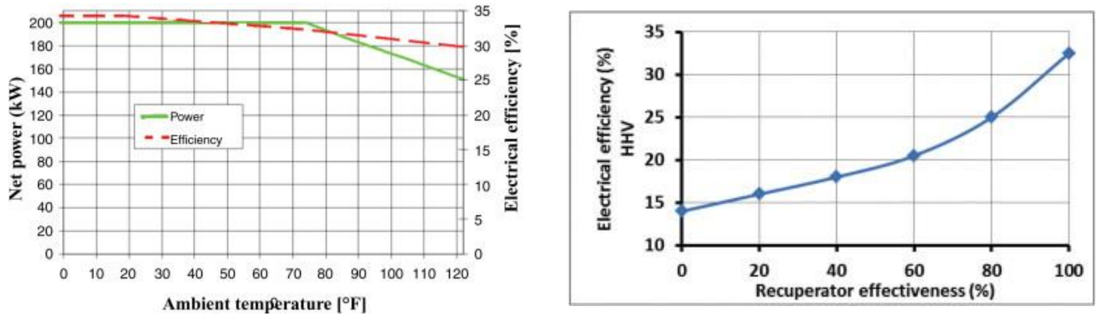

***Figure 6.*** *Electric efficiency against ambient temperature and opening degree of BPV*

### 3.2.2 Emissions of micro-gas turbine

Talking about emissions, MGTs are seemingly in a strong position, thanks to the gaseous fuels, the low inlet temperature and the high fuel-to-air ratios which contribute to decrease the NOx ppm thrown through the flue.

***Table 13.*** *Emissions of GTs and MGTs [7], [10]*

| | **Combustion turbines** | **Micro-turbines** |
|---|---|---|
| **$CO_2$ (kg/MWh)** | 580-680 | 620-790 |
| **$NO_x$ (kg/MWh)** | 0,3-0,5 | 0,1 |

As the electricity capacity becomes larger, the overall emissions tend to decrease. Hence, it would be optimal to install a large MGT which would cope with the equivalent demand of several consumers in order to optimize the GHG and NOx emissions to the ambient.

***Table 14.*** *Emissions of MGTs for a range of electric power capacity* [10]

| **Electricity capacity [kW]** | **100** | **300** | **800** |
|---|---|---|---|
| **NOx** | 0.25 | 0.1 | 0.13 |
| **CO2** | 790 | 720 | 620 |
| **CO** | 0.66 | 0.14 | 0.06 |
| **THC** | 8 | 0.04 | 0.05 |

### 3.2.3 Associated costs of micro-gas turbine

Economies of scale play an important when considering cost of capital per kW of installed capacity. Thus, bigger installation will have a lower cost per unit of power, but also, they will have better electric efficiency lower unitary emissions (kg/MWh).

The point is to what extent the turbine is suitable for the space available to set the machinery. Moreover, it is needed to estimate the demand this MGT will cover; error in estimations will derive in oversizing the installations. Consequently, operating the MGT, as depicted in Figure 4, the lower the load referred to the maximum will result in worse electric efficiency. It is important therefore to adequate the size of the system to the demand to optimize the consumption of fuel, beyond the reduction of emissions.

***Table 15.*** *Average cost of capital for MGTs* [10]

| **Capacity [kW]** | **30** | **65** | **250** |
|---|---|---|---|
| **MGT package [$/kW]** | 1,290 | 1,280 | 1,410 |
| **Heat recovery and other equipment [$/kW]** | 430 | 340 | 190 |
| **Total IC [$/kW]** | 1,730 | 1,620 | 1,600 |

***Table 16.*** *Average cost of operation and maintenance for MGTs* [10]

| **Capacity [kW]** | **30** | **65** | **250** |
|---|---|---|---|
| **O&M [$/kWh]** | 0.015-0.025 | 0.013-0.022 | 0.012-0.02 |

Even though with the drawbacks of higher capital costs than reciprocating engines, low electrical efficiency, and sensitivity of efficiency to changes in ambient conditions, the compact size and low-weight per unit power, a smaller number of moving parts, multi-fuel capability and low GHG emissions still make the micro-turbine an arisen prime mover in distributed energy systems [10].

## 3.3 Fuel cell

Fuel cells is another prime mover gaining market in the CHP and CCHP systems [5]. However, this technology seems far to be fully implemented in the coming years, because it is still a long way until it becomes competitive when compared with other prime movers (micro-turbines for instance, which have been developed during a larger period of time).

In recent years, a lot of work has been carried out to investigate fuel cell technology [5]. Mostly, it can be differentiated six types of fuel cells in the actual market [11]:

i. Alkaline (AFC)
ii. Direct Methanol (DMFC)
iii. Phosphoric acid (PAFC)
iv. Proton Exchange Membrane (PEMFC)
v. Molten Carbonate (MCFC)
vi. Solid Oxide (SOFC)

Each technology has its pros and cons, but there are some common features in all of them. They convert chemical energy from hydrogen into electricity by means of a reaction [5] [11]. As by-products, it is produced heat and water, that can be used in other applications.

The fuel employed in this technology is hydrogen; it derives mainly from a hydrocarbon, e.g., natural gas or biogas [11]. The performance characteristics are showed next. The data are an average among the five main types of fuel cells currently available in the market.

*Table 17. Main characteristics and parameters of fuel cells [7]*

| | |
|---|---|
| **Capacity range** | 5 kW–2 MW |
| **Overall efficiency [%]** | 85-90 |
| **Electrical efficiency [%]** | 37-60 |
| **Power-to-heat ratio** | 0.8-1.1 |
| **Life cycle (years)** | 10-20 |

### 3.3.1 Operational functioning of fuel cell

Fuel cells are composed mainly by three subsystems [11]:

1) Fuel cell stack. It generates the direct current electricity.
2) Fuel processor. In charge of convert natural gas into a hydrogen flow.
3) Power conditioner. It converts the electric energy into alternating current, or just regulate and adapts the direct current to certain output operating conditions.

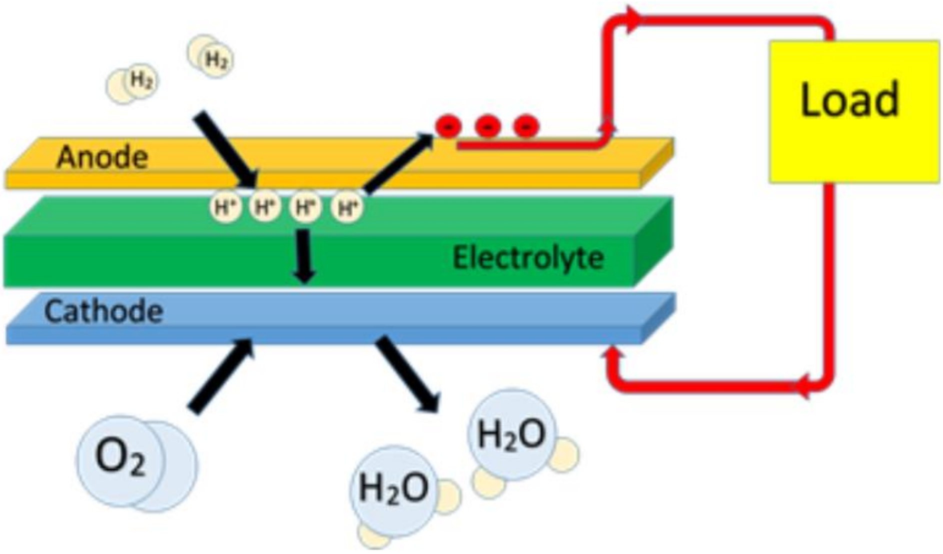

*Figure 7. Fuel cell detached scheme (PAFC type) [11]*

The fuel cell consists of a cathode and an anode, positively and negatively charged respectively, an electrolyte that makes possible the reaction, and an external load. The anode works as an interface between the hydrogen and the electrolyte (catalyzes the reaction, which means electrons tear apart from the $H_2$ molecule). Those electrons conduct to the load through an external circuit but, there is necessary to close the loop; so that the role of the cathode is to separate the oxygen from the electrolyte; it catalyzes the oxygen reaction by mixing $O_2$ with the H+ stemmed from the anode. Also, the H+ mixes up the $O_2$ and the electron from the external circuit of the load forming water and heat. The electrolyte is a non-electrically charged element which prevents the mixing of hydrogen and water; the link between the two electrodes that closes the loop.

$$\text{Anode reaction: } 2H_2 \rightarrow 4H^+ + 4e^-$$

$$\text{Cathode reaction: } O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$$

$$\text{Net fuel cell reaction: } 2H_2 + O_2 \rightarrow 2H_2O(vapor) + Energy$$

The heat produced during the whole process stems from the natural resistances the cell has, in other words, the trespassing of electrons and molecules from one interface to another comes off energy in form of heat. This heat can be either thrown to the environment with no use, or can be conducted to a heat recovery exchanger in order to heat up some other liquid (water for instance).

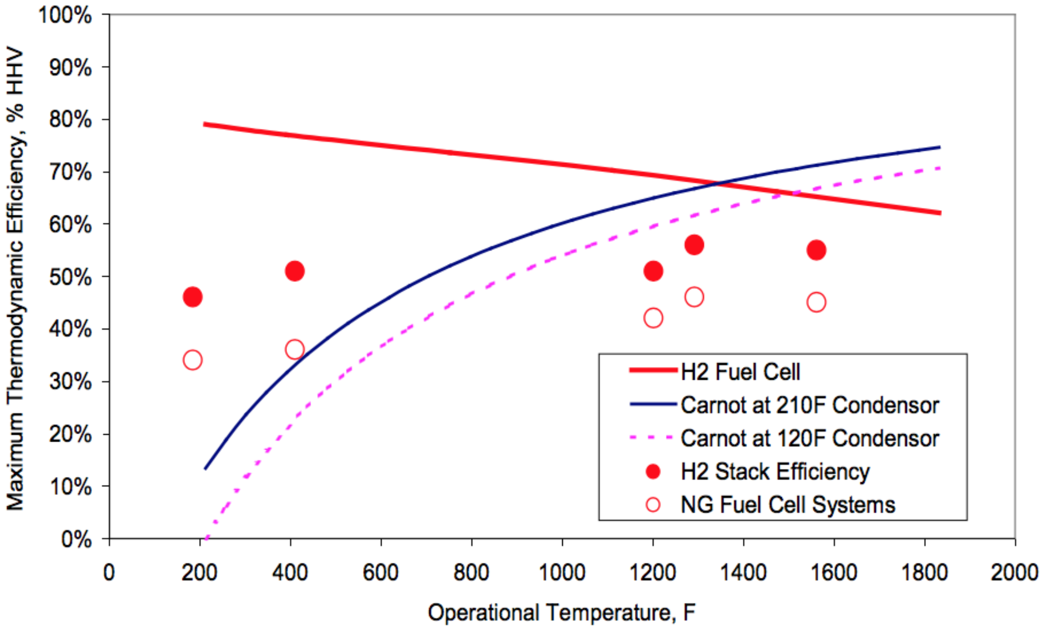

***Figure 8.*** *Effect of operating temperature on fuel cell efficiency [11]*

The overall electrical efficiency of the cell is the ratio of the power generated and the heating value of the hydrogen consumed [11]. As depicted in Figure 8, the electrical efficiency decreases as the by-product temperature increases; the water by-product carries the heat due to high temperatures and, unless the addition of other thermal energy convertors, there is no possibility to exploit and enhance the fuel cell yield.

### 3.3.2 Emissions of fuel cell

The primary fuel source of this kind of systems is hydrogen that stemmed from hydrocarbon fuel, such as oil and gas. Depending on the fuel consumed to operate, the emissions are subject to a range of values. Those fuels are mainly:

- Liquefied Petroleum Gas (LPG). Mostly propane and butane.
- Biogas or any by-product derived from organic waste and bio-degradation.
- Industrial waste gases from refineries, chemical plants and steel mills.
- Pipeline-methane natural gas.
- Manufactured gases derived from pyrolysis and gasification processes.

Since the power generation in fuel cells does not imply combustion, the rate of emissions is very low. Actually, the emissions are indirectly produced in the processing of the fuel, i.e., the fuel processing that turns gas and oil into hydrogen.

The hydrogen formation process takes places at temperatures below 1,000ºC [11], which prevents the formation of $NO_x$ emissions. This low-temperature combustion does not impede the formation of other pollutants such as CO and VOC (Volatile Organic Compounds), being the latter unburned hydrocarbons. Another kind of emission is the $SO_x$, but this can be eliminated before reaching the atmosphere by means of absorbing processes.

As the primary power generation process in fuel cell systems does not involve combustion, very few emissions are generated. In fact, the fuel processing subsystem is the only source of emissions. The anode-off gas that typically consists of 8 to 15 percent hydrogen is combusted in a catalytic or surface burner element to provide heat to the reforming process. The temperature of this very lean combustion can be maintained at less than 1,800° F, which also prevents the formation of oxides of nitrogen ($NO_x$) but is sufficiently high to ensure oxidation of carbon monoxide (CO) and volatile organic compounds (VOCs – unburned, non-methane hydrocarbons). Other pollutants such as oxides of sulfur ($SO_x$) are eliminated because they are typically removed in an absorbed bed before the fuel is processed [11].

***Table 18.*** Estimated fuel cell emissions by type of pollutant [11]

| **Fuel Cell Type** | **PEMFC** | **SOFC** | **MCFC** | **PAFC** | **MCFC** |
|---|---|---|---|---|---|
| **Nominal Electricity Capacity [kW]** | 0.7 | 1.5 | 300 | 400 | 1,400 |
| **$NO_x$ [kg/MWh]** | Negligible | Negligible | 0.01 | 0.01 | 0.01 |
| **$SO_x$ [kg/MWh]** | Negligible | Negligible | 0.0001 | Negligible | 0.0001 |
| **CO [kg/MWh]** | Negligible | Negligible | Negligible | 0.02 | Negligible |
| **VOC [kg/MWh]** | Negligible | Negligible | Negligible | 0.02 | Negligible |
| **$CO_2$ [kg/MWh]** | 1,131 | 734 | 980 | 1,049 | 980 |
| **$CO_2$ with heat recovery [kg/MWh]** | 415 | 555 | 520-680 | 495 | 520 |

### 3.3.3 Associated costs of fuel cell

Concerning the capital and maintenance and operation costs, these are labelled to a wide range that depends on the scope of the plant and equipment, the geographical area, markets conditions, whether is a new installation or a refurbishment of an old machine, among others [11].

Table 19 resumes the capital cost and O&M costs of the fuel cell, depending on the type and nominal capacity of each system. S1 and S2 belong to residential utilization, whereas from S3 to S5 correspond to industrial uses.

*Table 19. Estimated capital and O&M costs for typical fuel cell systems in grid interconnected CHP applications (2014) [11]*

| Installed Cost Components | S1 Residential | S2 Residential | S3 C&I | S4 C&I[8] | S5 C&I |
|---|---|---|---|---|---|
| **Fuel Cell Type** | PEMFC | SOFC | MCFC | PAFC | MCFC |
| **Nominal Electricity capacity [kW]** | 0.7 | 1.5 | 300 | 400 | 1,400 |
| **Total Package Cost [$/kW]** | $22,000 | $23,000 | $10,000 | $7,000 | $4,600 |
| **O&M Costs [$/MWh]** | $60 | $55 | $45 | $36 | $40 |

## 3.4 Stirling engine

The Stirling engine is similar to an IC engine, but, in contrast to the latter, it is an external combustion engine in which the same working fluid alternatively expands and compresses in a closed-loop volume performance [5]. There are two existing types of Stirling engines, i.e., kinematic Stirling engines and free-piston Stirling engine Each of them can operate in three different modes (alpha, beta and gamma) [5].

It can operate on many fuels, e.g., gasoline (and derivatives), natural gas and solar energy [5]. The possibility to operate with renewable sources, the sun; which is a free fuel, allows the Stirling engine to become a promising technology, since the progressive tax carbon increase and the energy policies the countries are adopting in order to protect and guarantee a sustainable environment.

*Table 20. Main characteristics and parameters of Stirling engines [7]*

| | |
|---|---|
| **Capacity range** | 1 kW–1.5 MW |
| **Overall efficiency [%]** | 65-85 |
| **Electrical efficiency [%]** | 40 |
| **Power-to-heat ratio** | 1.2-1.7 |
| **Life cycle (years)** | 10 |

---

[8] Commercial and Industrial.

Another key factor of this kind of engine is its vulnerability to external conditions, say, the outside temperature really affects in great manner to the power output and yield of the Stirling engine [7]. The higher the temperature on the outside, the lower the efficiency the engine develops, since the cold side will be affected by high temperatures, increasing the cold side temperature and reducing the thermal gap between the hot area and cold area in the engine.

### 3.4.1 Operational functioning of Stirling engine

Its principle is exactly the same as the IC engines present. Thermodynamically speaking there are four steps that every engine follows (same as ICE):

1) Heating and expansion. The heat source might be natural gas, gasoline or solar power, increases the gas temperature inside the cylinder, so does pressure as well, and the force is transmitted to the piston, which moves up until reaching the bottom dead center providing work.
2) Flow, cooling. Once the piston expands, the work is carried to the crankshaft which, at the same time, connects to the electricity generator or whatsoever machine responsible to produce electricity. The hot gas flows through a conduct to another cylinder, where the cold source lays. This gas starts cooling down.
3) Compression. As the gas is cooled the heat is removed and the gas is compressed.
4) Reverse flow and heating. The gas moves back to the first cylinder throughput the regenerator, since the pressure is lower than in its actual cylinder, and the cycle repeats.

An important remark is needed. As mentioned, there are three different types of operation with the Stirling engine. In this description of the thermodynamic Stirling engine's cycle, the mode alpha is the described one. Next, schemes of the variants are exposed.

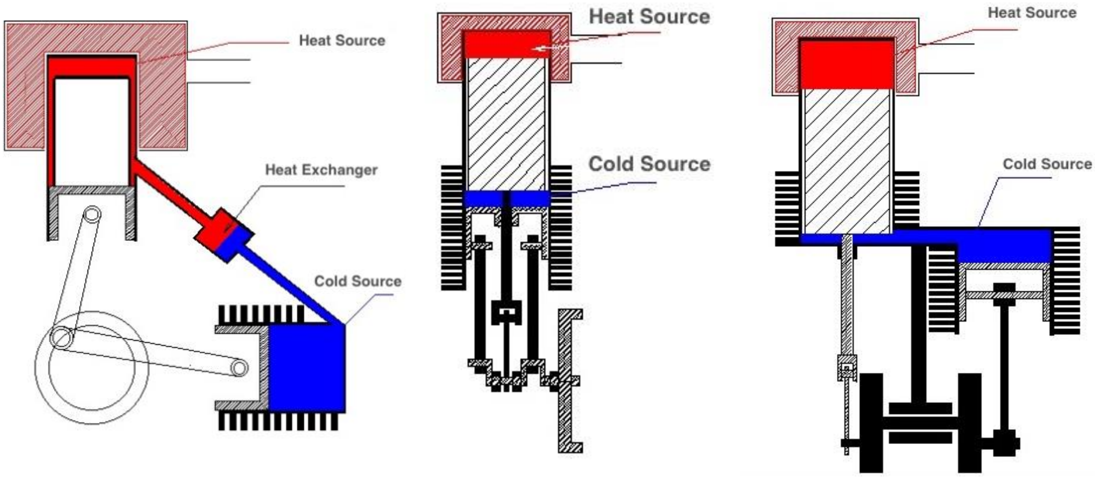

***Figure 9.*** *Alpha, beta and gamma modes of a Stirling engine*

As illustrated above, there are several kinds of Stirling engines, but there are many more. Each with its pros and cons, one with less moving mechanical parts that enhances the efficiency, but the flip side comes with a more complex design, or, simpler design with less efficiency.

### 3.4.2 Emissions of Stirling engine

The thermodynamic process is the same as an IC engine, but the technology differs. This difference makes possible to reduce the GHG emissions compared to the emissions stemmed from an internal combustion engine. Of course, the emissions will be determined by the type of fuel used to operate the engine. As an example of efficiency, the same capacity, 25 MW, for an ICE and a Stirling engine produces a reduction in 34% of GHG pollutants [5].

***Table 21**. Emissions of Stirling engines [7]*

| | |
|---|---|
| **$CO_2$ (kg/MWh)** | 430-490 |
| **$NO_x$ (kg/MWh)** | 0.005-0.01 |

In case the engine is a solar dish Stirling, emissions drop to zero, since the fuel is the sun.

### 3.4.3 Associated costs of Stirling engine

Although this technology is very promising in the coming years due to its low-rate on carbon emissions, the reality is that nowadays this type of engines is still expensive. Also, the lower power output makes them not very useful when considering the installation of hundreds of Kilowatts as the space required is larger than other technologies, e.g., IC engines or micro-gas turbines.

***Table 22.** Cost of capital and O&M for Stirling engines [7]*

| | |
|---|---|
| **Average cost of investment ($/kW)** | 1,300-2,000 |
| **O&M costs ($/kWh)** | N/A[9] |

---

[9] There is not enough data up-to-date to draw a reliable cost for operation and maintenance.

# 4 HVAC technologies

The heat, ventilation and air conditioning technologies are those designed devices to work indoors, offering comfort to the occupants. Currently, in the market, there are two predominant technologies, although there are many others making some noise, but still in the very background.

Those two dominant technologies are the heat pumps and the absorption chillers. Heat pumps are very interesting regarding the energy transition and efficiency due to their good use of the energy. They are powered by electricity, and normally, their COP[10] is not lower than three, which means, with one unit of electricity, a heat pump is capable of producing 3 units of heat. In addition, they are reversible, i.e., they can either heat up or cool down when needed.

Absorption chillers may not have COPs as high as the heat pumps, but they have other advantages. One of them is their ease to combining with other technologies. This way allows to create a multidisciplinary system that gives heat, electricity and cold. They can operate with natural gas or diesel.

## 4.1 Heat Pump

A heat pump is a machine, or device, that is devoted to supply heating, cooling and hot water, at the same time, to residential, commercial and industrial processes. It is known, also, under different name, depending which energy type is predominant at each time. Therefore, a heat pump is called when the energy transfer occurs from the heat source to the cold sink, say, heating is being demanded. Air conditioning unit is the other way around, when cooling is demanded [2].

In accordance with the nature of the sinks, heat pumps may be labelled into three big groups [2]:

- Air source heat pumps;
- water source heat pumps and;
- ground source heat pumps

The classification depends on the energy source the heat pumps employs as sink. The air source heat pumps use outside, indoors or exhaust gas as energy sources [2]. The ground source, or geothermal heat pumps make use of the soil as energy source. The way to use the ground is via horizontal or vertical closed loops; where the loop is filled with refrigerant and transports the energy between the energy source (ground) and the heat pump. Finally, the water heat pumps, as its name denotes, use water as the transfer medium. They are very similar to ground heat pumps, but, instead of using a closed loop, they use an open loop.

An advantage that arises from the heap pump technology is its ease to be combined with other devices, A good example is the combination of heat pumps with solar collectors, or air heat pumps with small gas boilers.

### 4.1.1 Operational functioning of heat pump

Heat pumps make use of the thermodynamic principles to operate. The refrigeration cycle is the cycle use by this sort of devices. It consists of four main components following cited [12]:

---

[10] Coefficient of performance. It measures the units of energy produced per energy unit consumed

1) Compression. The refrigerant fluid, or coolant, is compressed. This is the only step in the whole process that requires energy provided from the outside. It is, normally, electric energy utilized by the compressor. The compressor raises the coolant temperature by means of increasing the pressure.
2) Condensation. Now the fluid is hot, it undergoes through the condenser. This heat exchanger allows the transfer of heat from the fluid to the condenser, lowering the fluid temperature and liquefying it.
3) Expansion valve. Once the coolant is cold down, putting back the fluid at low pressure is needed. For this reason, the expansion valve is used to carry out such task. This device is merely a valve that, ideally, do not create any disturbance in any other parameter, it just creates large pressures drops.
4) Evaporation. Closing up the cycle, the evaporator develops the opposite work as the condenser does. It takes heat from the ambient to heat up the fluid and turn it to vapor, so that it can go through the compressor.
5)

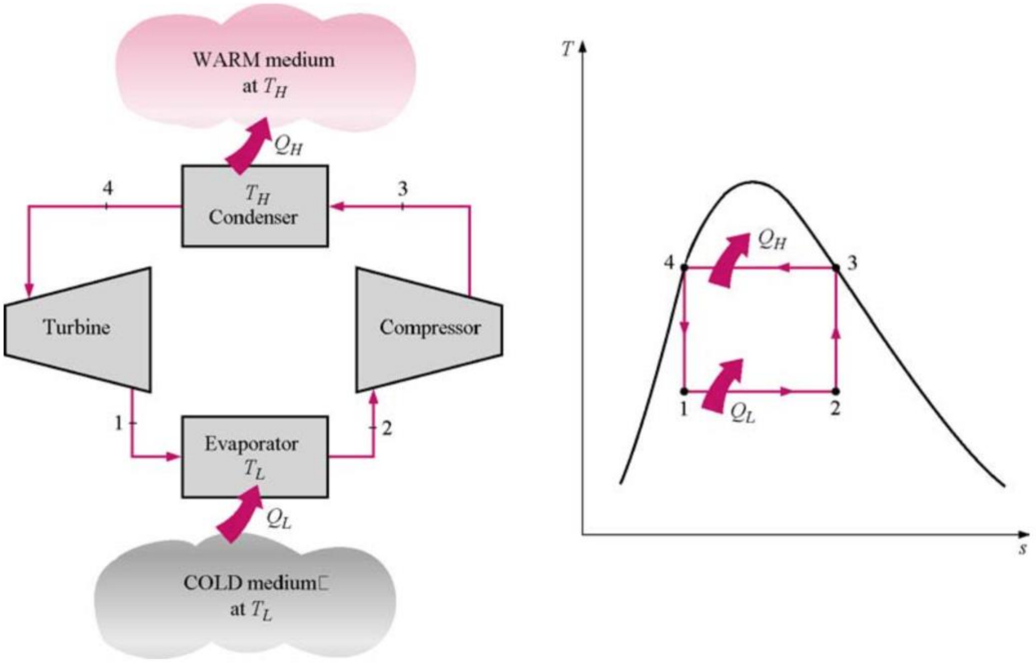

***Figure 10.*** *Standard refrigeration cycle [13]*

The evacuation of the energy within the closed loop in the heat pump is done by means of water- or air-based medium, e.g., hot water or air conditioning, respectively.

### 4.1.2 Emissions and efficiency of heat pump

Previously mentioned, it was stated heat pumps are normally powered by electricity. Commonly, most of the electricity comes from large generators that are connected to the grid, and, at the same time, consumers are connected to the grid and are provided with the electricity generated upstream.

In this regard, heat pumps do not emit any sort of emissions, since electricity is a clean energy. However, indirectly, the emissions are related to the mix of non-renewable energies that are producing electricity and, therefore, that electricity heat pumps are using contains emissions.

Although the indirect emissions heat pumps are producing during their functioning, their carbon footprint is much lesser than any other technology. This fact has to do with their good performance and efficiency they have.

The efficiency is measured by a KPI[11] called COP. Generally, heat pumps need one unit of electricity to generate approximately 3-5 units of useful heat [2]. This is possible thanks to the ambient source that gives the leftover energy needed to keep up the process.

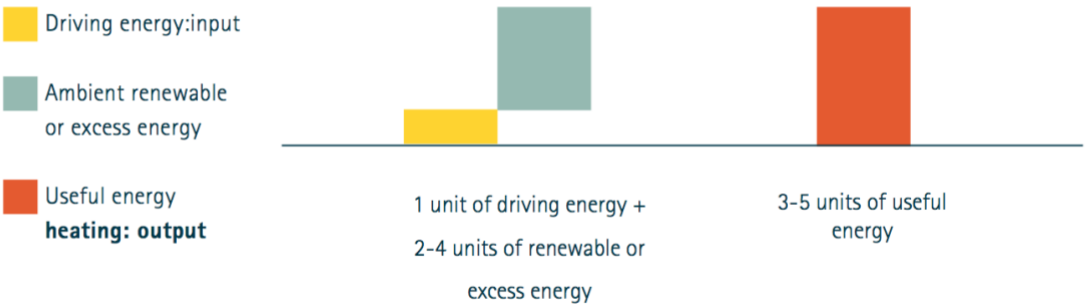

***Figure 11.*** *How energy is generated by an electric heat pump system [2]*

Most of the energy generated comes from the environment, thus, a significant reduction in non-renewable energy sources is made, so does the emissions ratio too. Table 23 illustrates the efficiency of each system per unit of electricity.

*Table 23. COP table for GSHP and ASHP*

| **Type of HP** | **COP (Heating)** | **COP (Cooling)** |
|---|---|---|
| **Ground Source Heat Pump** | 4-5 | 3-4 |
| **Air Source Heat Pump** | 5-6 | 4-5 |

### 4.1.3 Associated costs of heat pump

The investment capital to put upfront may vary depending on many parameters. Some of those parameters are the location (i.e., climate conditions, temperature profile on a yearly basis, etc.), the capacity willing to install, the type of heat pump, among others.

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[11] Key Performance Indicator. It is a parameter that defines and measures some value within a process, for instance, and gives at a glance if something is under control or not. KPIs must be easily to calculate and measure.

In this specific project, only ground source heat pumps and air source heat pumps are considered. Table 24 shows a comparison between GSHP and ASHP in terms of capital costs (initial investment).

***Table 24.*** *Cost comparison between GSHP and ASHP [14]*

| Type of HP | Capital Cost (initial investment) |
|---|---|
| **Ground Source Heat Pump** | $9,000 |
| **Air Source Heat Pump** | $4,900 |

It is important to add that the capital cost may be lower if the installation of the heat pump system is going to replace and old system, since the piping system and many other components could be used. In addition, the O&M costs depend very much on the usage of the system, the location and the capacity of the machine.

Compared to other heating technologies, heat pump systems may seem very expensive due to their capital cost, but, analyzing the annual savings in fuel and less consumption of electricity they could be deemed very competitive in the long term.

## 4.2 Absorption chiller

Same as heat pump systems, absorption chiller are thermal driven machines designed to provide refrigeration. They are widely used due to their high efficiency rate under standard operation.

The difference between heat pumps and this machine lies in the phase where, in the case of a heat pump, the coolant is compressed and carried to the condenser. Absorption chiller do not have a compressor, but an absorber instead, thus they take the name out of this feature.

### 4.2.1 Operational functioning of absorption chiller

Because the operation is the same as any other cooling or heating machine, this section is focused on explaining the absorber, and how it works; what makes different this machine from the others.

The condenser, throttle and evaporator remain the same either in heat pumps or absorption chillers. In this latter, the compressor is divided into two main components: a generator, or desorber, and an absorber. In Figure 12, it can be seen a schematic representation on how this machine looks like.

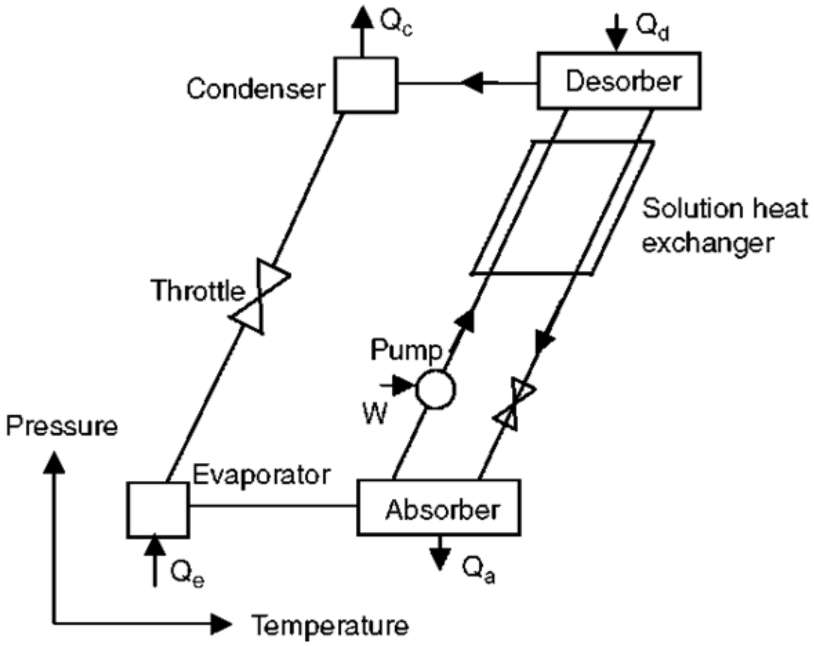

***Figure 12.** Absorption chiller scheme [15]*

The compression of the vapor does not happen in an absorption chiller, but separating and recombining two fluids (the refrigerant and the absorbent) by means of heating up the mixture. Usually, there are two main pairs of fluids widely used: the ammonia-water cycle and the lithium bromide cycle. While in the former the water acts as absorbent and the ammonia as refrigerant, the latter employs water as refrigerant and the lithium bromide as absorbent.

In the generator (or desorber), the heat separates water from ammonia, and this latter directs to the condenser, while the water is flowed through a heat exchanger. The hot and pressurized ammonia enters the condenser cooling down and go through the expansion valve to reduce its pressure to evaporator pressure level. Once in the evaporator, it absorbs the heat from the environment and comes out being an ammonia saturated vapor. Last step before starting the cycle over again is the absorber stage. In this stage, the saturated ammonia is sprayed with an ammonia-water solution and is pumped through a heat exchanger (the hot water from the generator transfers heat to the ammonia-water mixture heating it up and increasing its pressure) [16].

### 4.2.2 Emissions of absorption chiller

Parallel to heat pumps, the only consumption that absorption chiller has is the external heat source this machine uses to separate the two fluids.

Considering the multiple nature, the emissions that could come from the energy source may vary a lot. In case it makes use of solar energy or the chiller is integrated in a CHP system, then, residual heat can be used and no incremental $CO_2$ emissions will occur.

Their COP is not as high as a heat pump, but still, it reaches COPs in the range of three to four, depending on the energy sources used to heating.

### 4.2.3 Associated costs of absorption chiller

Regarding associated costs, they are included in a broad range. This range is dependent on many factors; citing some of them, the installed capacity, the application, the location and the fuel are important parameters to take into account.

Capacity is determinant to set the cost per kW of installed capacity. In addition, the application of the machine influences the final price, especially the fixed cost or upfront capital cost; it is not the same devote the absorption machine just for cooling than for cooling, heating and hot water supplying. Finally, location because there might be some countries specialized in this technology and could give important discounts to local partners, and fuel due to the price in the commodity markets.

Table 25 presents a possible breakdown of costs a user may incurs in by acquiring a machine of such characteristics.

***Table 25.*** *Absorption chiller's costs breakdown [17]*

| | |
|---|---|
| **Investment Cost** | 600 – 700 $/kW |
| **Fixed Cost** | $0 |
| **Operation Maintenance Cost*[12]** | 0.022 $/kWh |

### 4.2.4 Solar panels. PV technology

Even-though the photovoltaic technology does not belong to the HVAC, nor to CHP technologies, the PV devices are increasingly gaining importance in the market, and consumers are now more confident about its benefits.

The volatility of the market and the drop in solar cells have stirred up the awareness, and people are now beating very hard on this sort of technologies. The on-site PV installations not only provide benefits for the user himself, but promotes the green economy and helps to reach the decarbonization of the world, shifting the generation and consumption to a greener panorama with renewable energies leading the process, followed by low-carbon technologies.

The operation principle of such technology is the exploitation of the energy contained in the sun. By means of chemical components, the cells are capable of turning that solar radiation to direct current. This electricity does not need to undergo through any sort of process to increase or lower the voltage, because it is ready to be consumed. That is the good point of PV panels, that it cheapens the costs of transport and distribution, as well as the transforming process.

As later on will be explained in the model, continuous investment in RES may facilitate to reach an optimal solution for the building to be optimized in consumption and distributed energies low carbon emissions. The limitation of this technologies lies in its performance yield, which is

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[12] Affected by the cost of fuel, it it exists.

quite low for the time being when comparing to other technologies; and the space available to deploy these installations, which can at maximum occupied the roof of the building.

# 5 Methodology

Next step consists in defining the procedure to be followed. This chapter will explain the work methodology, as well as the model that has been used to compute and obtain the results. Once this latter is done, a case study will be presented in order to demonstrate how the model works and the potential it does have to solve optimization problems.

## 5.1 DER-CAM

The software's name stands for Distributed Energy Resources Customer Adoption Model. DER-CAM is a software tool developed at the Berkeley Lab in which the economically optimal CHP DER system is determined for a site, given the site's energy usage, utility tariffs, and DER equipment options. Equipment options include natural gas-fired generators such as reciprocating engines, micro-turbines, and fuel cells; heat recovery and utilization equipment such as heat exchangers and absorption chillers; and photovoltaics.

The last update of this tool has enabled new features to consider. Some of them are cited following:

- Opportunity to consider trends in building loads and utility tariffs (electricity rates, fuel prices, utility services...),
- Opportunity to consider optimal reinvestments through a dedicated option,
- Linear model for stationary battery degradation.

DER-CAM is written as mixed integer linear program, written in the optimization platform GAMS. Key inputs DER-CAM's code include are:

- End-use load profiles. Electricity only: loads that can only be met by electricity, cooling, space heating, water heating and natural gas only (such as cooking and distributed heating).
- Electricity tariff. Volumetric ($/kWh) prices, demand ($/kW) prices, varying by time of use and by month and fixed ($) monthly fees.
- Natural gas tariff. Volumetric ($/kWh) prices, varying by type of use (DG, cooling, or other) and month fixed ($) monthly fees.
- Distributed generation costs. Amortized capital costs for equipment, system design, and installation, fixed ($/kW capacity) annual maintenance costs and variable ($/kWh) maintenance costs
- Distributed generation performance. Electrical efficiency, heat to electricity ratio for combined heat and power systems and minimum and maximum load
- Energy Conversion Efficiency. Recovered heat used for heating and absorption cooling, natural gas used for heating and absorption cooling and electricity used for cooling.

The model is also subject to some constraints that limits the model to give an output that might be out of range, or simply, that is technically impossible. The maximum payback period, the maximum of operating hours each technology has throughout a year and the minimum CHP efficiency are some of these constraints the model considers when running cases, among others.

Regarding the outputs, CHP optimal investment, the operating schedule, energy costs, fuel consumption and $CO_2$ emissions are key parameters to measure and analyze the feasibility of the results given by the optimization tool.

## 5.2 Key input parameters

There are many inputs to consider when optimizing, but only several of them are deemed to be more important than others. For this current case study, the chosen parameters that have been chosen as the main drivers will be following explained in detail, how they have been calculated, the importance of them and so forth.

### 5.2.1 Load

This first input, the load, is the most important one. The reason lies in the fact that with no consumption data is not possible to estimate the power and energy needed at each time of the day, on a yearly basis, and therefore, impossible to determine the amount of CHP technologies to be deployed within the building under study.

Due to the complexity of defining day by day, hour by hour, the consumption profile of a commercial building, instead, what it has been done is set a representative day for each month of the year, on an hourly basis. Hence, there are 24 consumption data for each of the twelve months. Moreover, and trying to be as much accurate as possible in the computation, the representative day making is done for a weekday, a weekend day and a peak day. This way the model, alongside other parameters incorporated in its inner code, can choose among a broader range of load curves and make iterations based on different profiles to finally compare all of them.

The data source used to acquire the consumption data is the U.S. Department of Energy Within this database, profiles similar to medium-large commercial consumers have been selected to be part of the model. Such consumers are supermarkets, hotels, offices, etc. The dataset gathers hourly load profile consumption for 16 commercial building types, based on the DOE commercial reference building models) [18].

Consumption is not merely a general concept, but instead, there are different types of consumption. Electricity consumption may be the first that come in mind when talking about this concept, but there are many others. According to the Department of Energy of the United States, the consumption can be classified into several groups, but only five are taken into the model. Those are the use of electricity, cooling, refrigeration, water heating and use of natural gas.

An important issue that will be later on commented is that although these data belong to the US, and the study must be carried out for Spain, it is very needed to find a common reference between both countries. For that reason, and searching carefully locations with similarities, the city of Los Angeles has finally been pointed to be the common point between the two territories. Spain is, on average, a country with Mediterranean climate conditions. At the same time, the Californian State gathers similar weather conditions, and specifically Los Angeles.

The reference location in Spain that keeps more in common with Los Angeles seems to be island of Menorca, due to its humidity and medium temperatures during winter time.

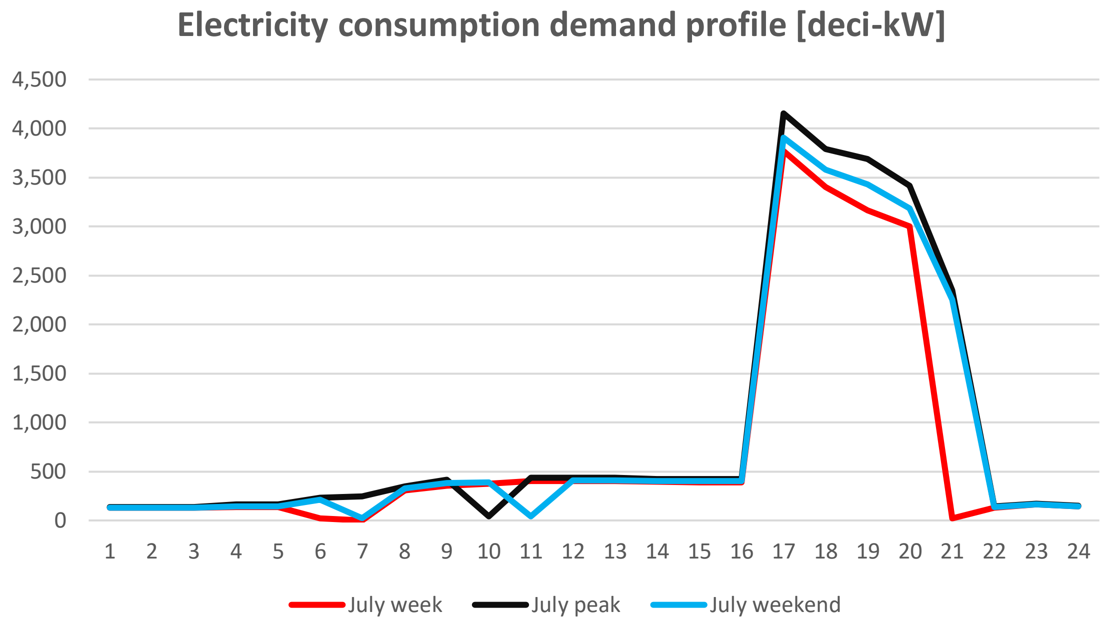

***Figure 13.*** *Electricity consumption for week, peak and weekend electricity-only use in a reference supermarket*

### 5.2.2 Temperature

As mentioned before, the island of Menorca is the reference location that keeps similarities to Los Angeles city in the United States. Likewise, the temperature must be broken down in an hourly basis.

Making use of the tool released by AEMET[13], it is possible to make such temperature spreadsheet. Likewise, a representative day for each month of the year. The temperature input is very relevant due to its implications with the use of air conditioners, heaters; and, combined with the solar radiation it permits the calculation of the power generated by PV panels and any other electric device powered by the solar energy.

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[13] *Asociación Española de Meteorología.*

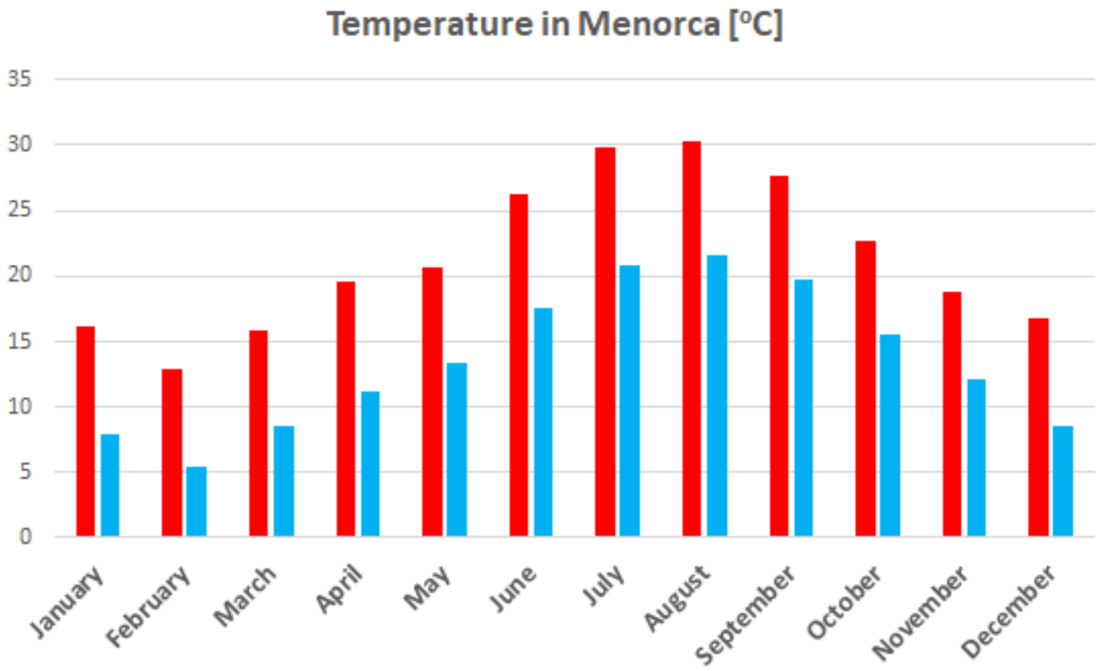

***Figure 14.*** *Average maximum and minimum temperature in Menorca*

In red, the maximum temperatures, while colored in blue stand the average minimum temperatures registered in Menorca from 1981 until 2010 [19].

### 5.2.3 Solar insolation

Solar insolation determines the theoretical potential solar installations can reach while operating. The higher the insolation the higher the power production, and, in case of on-site PV panels, the less energy purchased in the market will be needed. Spain is in a good location to take advantage of time with sunlight, decreasing the independence from the network and allowing making effective a reduction in the electricity bill.

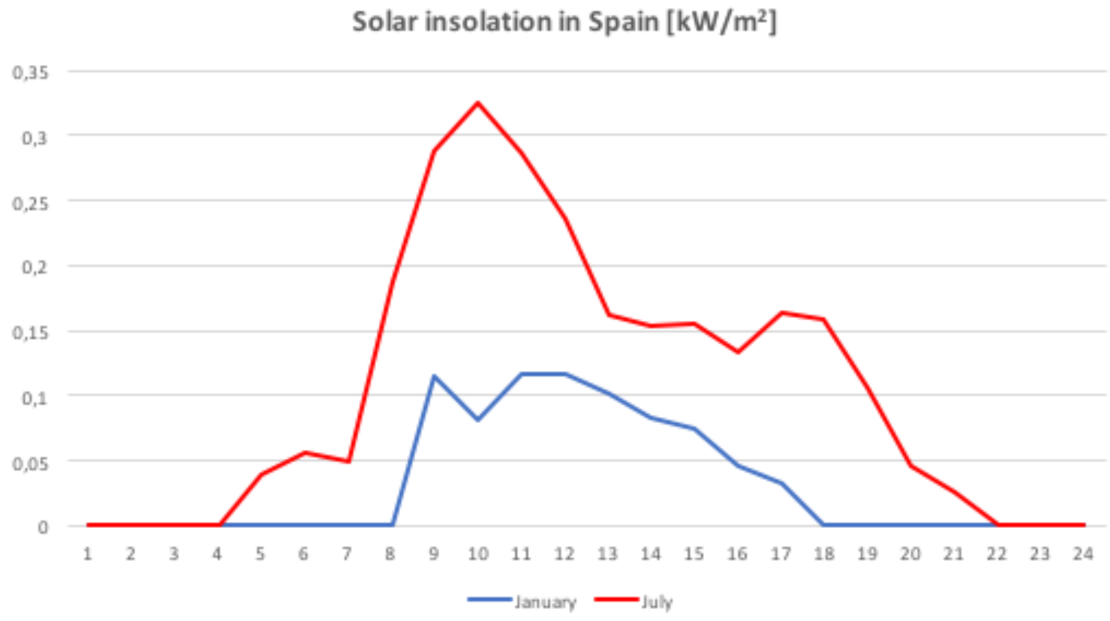

*Figure 15. Average solar insolation in Spain*

Summer presents higher rates of solar radiation, as expected, whereas in winter it reaches minimum values. Thus, it is reasonable to say that during summer time, the use of electricity supplied by the network will be diminished in exchange of larger utilization of PV panels.

### 5.2.4 Electricity rates

The electricity rates term has to do with the prices cleared in the wholesale market. Spanish electricity market is cleared by OMIE[14]. Lately in 2019, the Spanish government has made a change in the paradigm concerning self-generation. This been said, now it is possible in the Spanish market to inject into the grid the energy surpluses produced by facilities and installation under particular ownership.

There are slight differences when considering either purchasing or selling electricity in the wholesale market. Purchasing electricity consists in be supplied by the national grid with energy that enables coping the current demand at any time of the day. There are several agents in the process that must be remunerated for their services, as well as the cost of the grid has to be recovered. The way to socialize and collect the money that pays back the infrastructure is by means the implementation of the so-called access tariff.

The access tariff allows the cost recovery of the grid and the remuneration to the agents that facilitates the market activity. Depending on the type of consumer, a different tariff shall apply. This project studies the commercial businesses, so that a tariff 3.0A is the one which has been chosen to carry on onto the analysis. Table 26 shows the features of the access tariff 3.0A.

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[14] *Operador del Mercado Ibérico de Electricidad*.

*Table 26. 3.0A Spanish access tariff breakdown in 2019*

| 3.0A | Period 1 | Period 2 | Period 3 |
|---|---|---|---|
| **Capacity Term [€/kW/year]** | 40.728885 | 24.437330 | 16.291555 |
| **Variable Term [€/kWh]** | 0.018762 | 0.012575 | 0.004670 |

This Time-Of-Use tariff (TOU tariff) is divided into three periods, which means depending on the time consumers are switching on appliances they will pay one rate or another. This tariff suits to those customers connected to the grid in low voltage (<1kV) and with a contracted capacity higher than 15 kW. The hourly discrimination is convenient to those electric intensive businesses, that can modulate the load to consume when price decreases.

The capacity term of the tariff relates to the cost of the grid and the power contracted; it is expressed in €/kW. On the other hand, the variable term that changes depending on the load profile, and, in consequence, so does it with the consumption and is expressed in €/kWh.

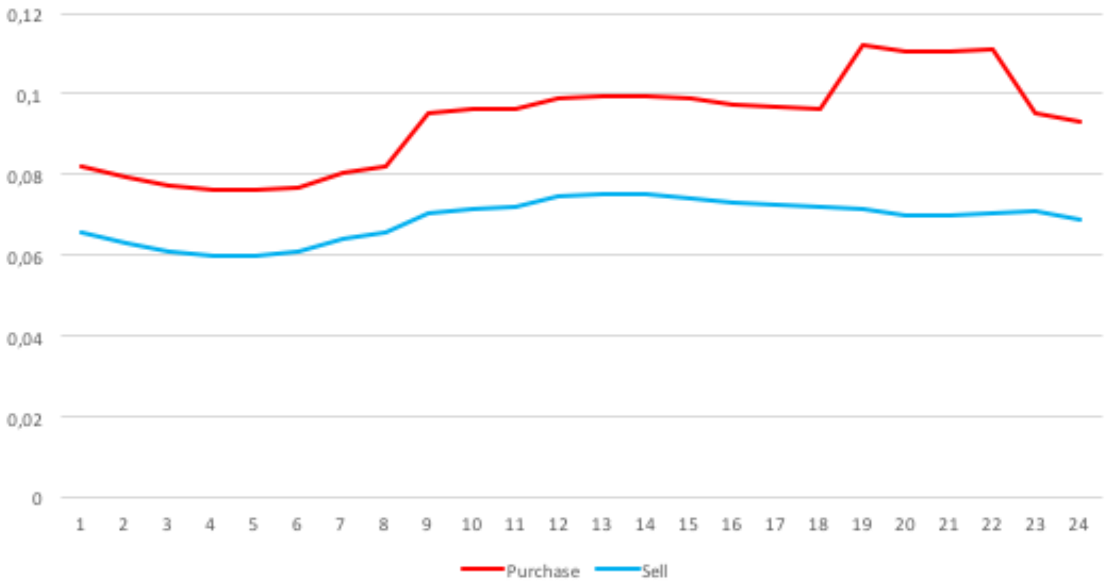

*Figure 16. Comparison between purchasing electricity and selling electricity in the Iberian Market*

The revenues gain by selling surpluses electricity are lower than the retail price. The good point is that now it is permitted to inject electricity into the grid and be paid for it, there might be some technologies attracting investors, as the exceeded energy can be sold.

### 5.2.5 Fuel prices

Natural gas is the key driver to decarbonize the economy in the short and medium term, in detriment of the use of coal. Hence, gas prices are deemed to be an important factor to consider when designing the optimal technologies to deploy in a building.

***Figure 17.*** *2018 HH prices for the natural gas in Dollars [20]*

Figure 17 illustrates the evolution of the natural gas price throughout a natural year. 2018 is the year chosen to compute the fuel prices in the DER-CAM model. Following, a table with the average monthly prices for 2018.

***Table 27.*** *Average monthly Henry Hub price in 2018 in $/MMBTU [20]*

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $3.46 | $2.74 | $2.89 | $2.82 | $3.00 | $3.01 | $2.87 | $3.03 | $3.06 | $3.36 | $4.69 | $3.32 |

Considering the price of diesel, commonly used in CHP technologies such as cogeneration, the reference index in Europe is the Brent quotation. This index is the one considered when compiling the price of the diesel due its well-known criteria to calculate it and, more importantly, because it is widely used.

***Figure 18.*** *Brent quotation in $/barrel [20]*

Table 28 shows the average prices, on a monthly basis, for the year 2018.

***Table 28.*** *Average monthly Brent Price in 2018 [21]*

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $69.05 | $65.78 | $70.27 | $75.17 | $77.59 | $79.44 | $74.25 | $77.42 | $82.72 | $75.47 | $58.71 | $53.80 |

As a comparison, an in order to demonstrate how important is the fuel price in the coming years, here lies a chart that depicts both natural gas and Brent historical prices. It can be seen how the natural gas price has drastically decreased in the recent years, making it more attractive to large producers and consumers planning on changing their actual boilers, generators, etc.

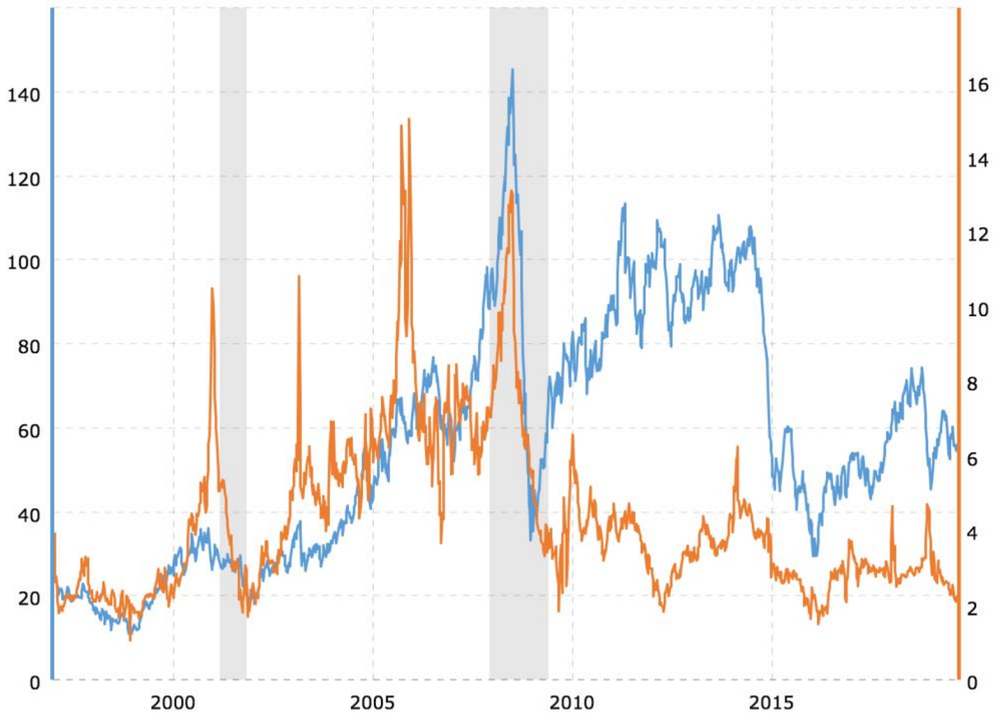

***Figure 19.*** *Comparison between oil prices and natural gas prices*

In orange, the gas price, and blue belong to Brent price. The grey parts correspond to those recession periods the global economy suffered. After the last recession, in 2008, NG started declining, especially thanks to a new way of extracting this fuel: the fracking process. This fact places the US nowadays as the world's first LNG exporter, and it is the main reason the NG is so cheap in the market.

### 5.2.6 Emission allowances

The European Union $CO_2$ emissions trading system is currently the largest carbon market in the world. It is devoted to mitigating and struggle against the climate change. To do so, the aim of this system is gradually reducing the greenhouse gas emissions in the European region [22].

The success of the mechanism lies in the existence of a cap that regulates the total amount of emissions allowed. It limits the greenhouse gas emissions emitted by over more than 11,000 installations in the European Union. Therefore, if an installation is short in emissions, it must go to the market and buy allowances that give the right to emit such amount of $CO_2$. As the cap is reduced over time, so does the total amount. This measure pushes the companies and installations to invest in low-carbon processes and take action in efficiency matters. Otherwise, the allowance price will very high and unaffordable for most of them, since the number of rights is less but the emissions remain the same.

Since 2017 the price has dramatically increased, as Figure 20 shows. The reason is the recent amendment the European Commission has made effective, retiring a great number of allowances (cutting the emissions cap), rising the prices and giving signals to the heavy industries that accounts for 45% of the total $CO_2$ emissions in the European territory.

***Figure 20.*** *EU ETS quotation in 2018. €/ton$_{CO2}$ [23]*

$CO_2$ emissions pricing is relevant when computing the CHP technologies to install in the building. If the emission allowance is extremely high, it may happen PV panels are better to put in place, since the cost of diesel and natural gas will be more expensive. A price of 30 $/MWh was set in concept of the emissions tax in the model.

# 6 Case study

This sixth chapter is devoted to the explanation and computation of the inputs and parameters that have been previously commented, in order to come up with optimal solutions for those commercial businesses that are interested in optimizing their operational and energy costs.

Based on the Department of Energy of the United States database for commercial reference buildings, a large hotel has been selected as the reference building for this project. There are other reference buildings such as offices, hospitals, restaurants and supermarkets, but a hotel fits pretty good with the object of this thesis, since the demand of a hotel is seasonal and it exists demand for almost any kind of energy: heating, refrigeration, electricity and gas.

## 6.1 Model parameters

Before starting running and discussing the scenarios, an explanation of the parameters that are changeable within the model is necessary.

A set of variables, binary variables, allows the model to follow one path or another. Some of the binary variables that are going to be managed are shown in Table 29.

*Table 29. Set of binary variables in DER-CAM*

| | |
|---|---|
| **DiscreteInvest** | '0-Do nothing, 1-Invest in fuel-fired DG technologies' |
| **ContinuousInvest** | '0-Do nothing, 1-Invest continuous variable techs like PV, solar thermal, storage, and abs chillers' |
| **NGChillInvest** | '0-Do nothing, 1-Invest in fuel-fired direct compression chiller technologies' |
| **PVSales** | '0-No PV Sales, 1-Allow PV Sales. If Sales is set to zero PV Sales will be disabled' |
| **CHP** | '0-with CHP, 1-without CHP' |
| **CO2Tax** | '0-without $CO_2$ Emissions, 1-with $CO_2$ Emissions' |
| **MinimizeCO2** | '0-minimize Energy Costs, 1-minimize $CO_2$ Emissions' |
| **MultiObjective** | '0-no multi-objective function, 1-multi-objective function, which is a weighted combination of costs and $CO_2$' |
| **CentralChiller** | 0 means that no central chiller can be used for cooling. |
| **NetMetering** | '0-unrestricted electric sales to the macrogrid, 1-electricity sales < purchases electricity on an annual basis' |

The dimensions of the building are changed in the model accordingly. These parameters, the area of the building measured as the surface of its roof, is relevant for the PV panels installation. The hotel has an estimated total rooftop surface of 1000 $m^2$.

Load, temperature, spot purchase and sell prices, access tariffs, solar radiation, $CO_2$ hourly marginal emissions and fuel prices are gathered and already treated separate in a database. This database is called from the model as inputs when it runs.

## 6.2 Base case scenario

To calibrate the model and give it a set point to start with the optimization, it is necessary to run first the model with no parameters online. In other words, it is going to be calculated the energy costs of the hotel as if everything was purchased from the network. In this case, there must be central chiller that cools down and heats up the entire building, thus, CentralChiller variable is set by default to 1.

***Table 30.*** *Binary variables set for the base case*

| | |
|---|---|
| **DiscreteInvest** | 0 |
| **ContinuousInvest** | 0 |
| **NGChillInvest** | 0 |
| **PVSales** | 0 |
| **CHP** | 0 |
| **CO2Tax** | 0 |
| **MinimizeCO2** | 0 |
| **MultiObjective** | 0 |
| **CentralChiller** | 1 |
| **NetMetering** | 0 |

Following, some figures plotting the daily consumption, weekday consumption, in summertime and wintertime, for gas and electricity, as depicted in Figure 21.

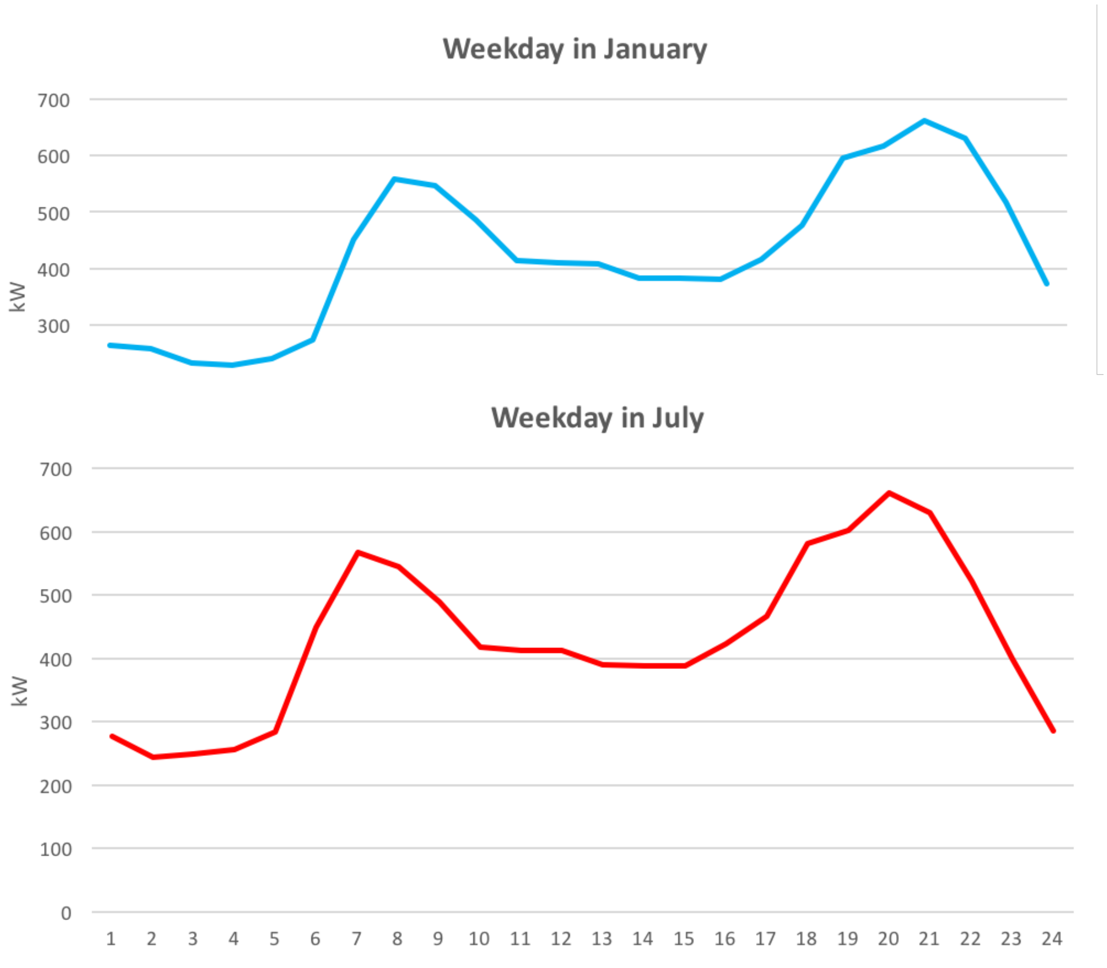

***Figure 21.*** *Electricity load profile in a large hotel*

Both profiles are very similar. This may have to do with hotel lighting and other services that are full day in operation and rarely stop their performance. Cooling also follows the same trend, being constant throughout the year, with no big leaps between summer and winter.

Since water heating is needed no matter what season of the year is, so does the water heating load profile, being almost similar in every month of the year. The hot water is used for showering, cooking, indoors swimming pools; facilities and utilizations that are almost constant.

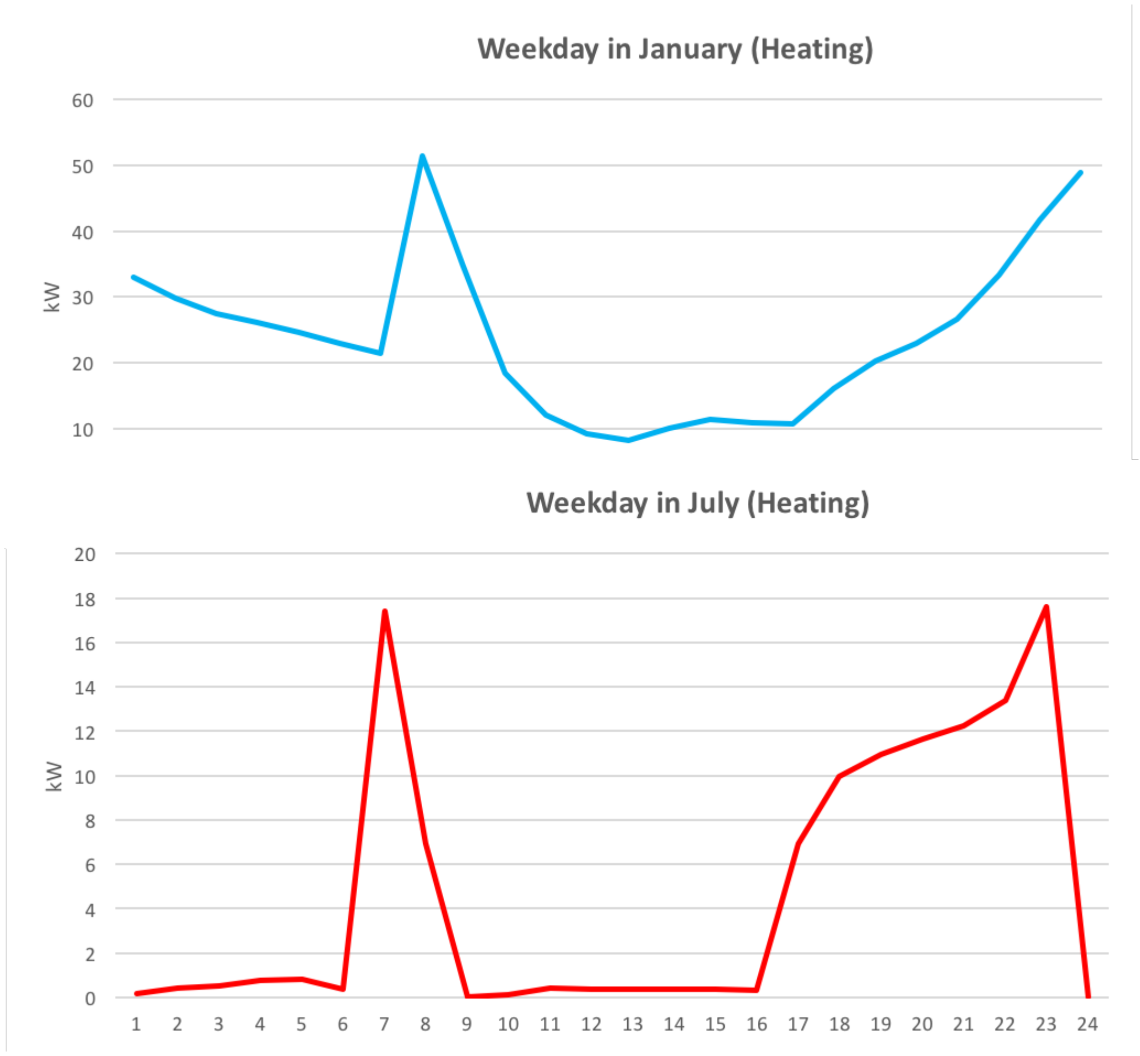

***Figure 22.*** *Heating load profile in a large hotel*

By contrast, as Figure 22 plots, even-though the seasonal profiles could be similar, they are not equal in terms of energy demand. In the case of heating, it is reasonable to think that during summertime that demand tends to zero. Due to the fact most of the times natural gas is used in heating and processes that require hot sources, the natural gas demand in winter is higher than of summer.

Before running the model, the drivers of each CHP and HVAC technologies must be registered. Table 31 and Table 32 shows the parameters introduced in the DER-CAM in order to be ready to run the model on its base case.

*Table 31. Drivers of CHP machines*

| | ICE | MGT | FC | Stirling |
|---|---|---|---|---|
| **Overall Efficiency [%]** | 70-92 | 60-85 | 85-90 | 65-85 |
| **Electrical Efficiency [%]** | 25-43 | 13-30 | 37-60 | 40 |
| **Power-to-Heat Ratio** | 0.5-0.7 | 1.2-1.7 | 0.8-1.1 | 1.2-1.7 |
| **Life Cycle (yrs]** | 20 | 10 | 10-20 | 10 |
| **CAPEX [$/kW]** | 800-1,600[15] | 1,290[16] | $7,000-$10,000 | 1,300-2,000 |
| **O&M [$/kWh]** | 0.0045-0.0105 | 0.015-0.025 | $36-$45 | N/A[17] |

*Table 32. Drivers of HVAC machines*

| | GSHP | ASHP | Absorption Chiller |
|---|---|---|---|
| **COP (Heating)** | 5-6 | 4-5 | 3-4 |
| **COP (Cooling)** | 4-5 | 3-4 | 2-3 |
| **Life Cycle (yrs]** | 15 | 15 | 10-20 |
| **CAPEX [$/kW]** | $50,000[18] | $30,000[19] | $600 -$700 |
| **O&M [$/kWh]** | $0 | $0 | $0.022 |

### 6.2.1 Results of the base case scenario

The first case, used to calibrate the model and set the starting point of the optimization, is plotted in Figure 23. Comparing a typical day in January and July, there are slight differences. First, the natural gas burned in the chillers is relatively higher during summertime, due to the air conditioning units; and the other way around, the natural gas mostly used in heating is higher during the cold wave in winter.

---

[15] With a heat exchanger, there is an increase in the CAPEX.

[16] Same as in footnote 5.

[17] There is not enough data up-to-date to draw a reliable cost for operation and maintenance.

[18] Total investment regardless the size of the system.

[19] Same as footnote 6.

Electricity consumption remains constant in both seasons. Kitchen, electrical devices, lighting are permanent in operation, since the guests are coming constantly. Alike, because there are disabled any option of investments in self-generation is disabled, all the energy is purchased in the market at the market price.

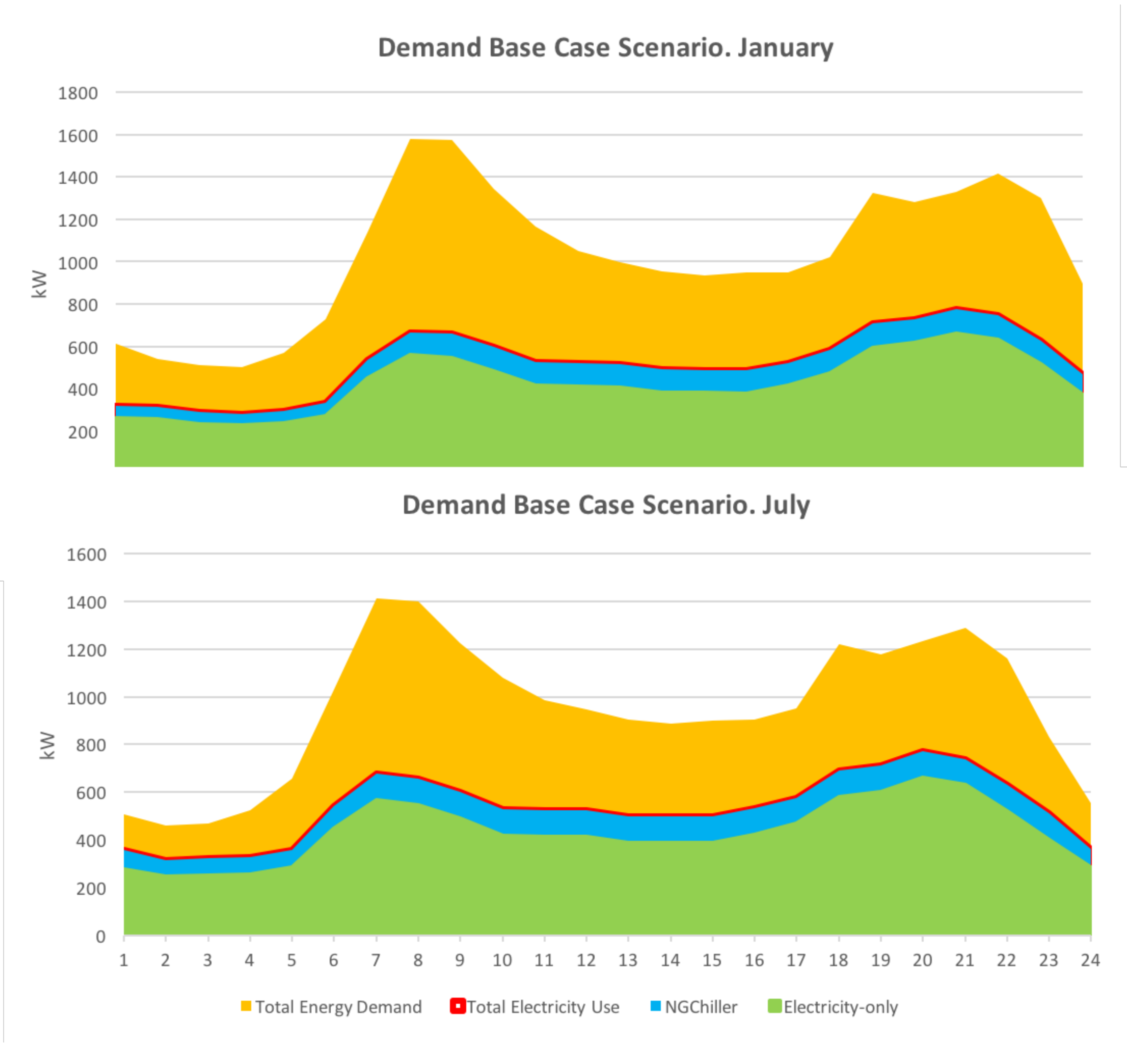

***Figure 23.*** *Demand load profile in the base case scenario*

This scenario with conditions of no-investments and fully supplied by the network and market comes up with an annual cost of \$501,392.8055. Table 33 illustrates a summary after running the model in the first attempt. The part colored in yellow is energy demand provided by other energy sources such as natural gas.

*Table 33. Base case scenario output*

| | |
|---|---|
| **Total Energy Costs – Electricity Sales** | \$501,392.806 |
| **System Efficiency** | 0.479 |
| **Annual $CO_2$ Emissions [$kgCO_2$]** | 2,100,623.150 |

## 6.3 Discrete investments

This section focuses on the optimization of the system just installing discrete technologies, in other words, CHP machines such as ICE, MGT and so forth.

In total, two different cases will be analyzed, each with different options and conditions. Those case studies are:

- Discrete investment option and investments in natural gas chillers
- Discrete investment activated with $CO_2$ tax and its minimization

### 6.3.1 Case D1

In this case, as already explained, just discrete investment option will be activated on DER-CAM's control panel. Table 34 shows the control panel before running the model.

*Table 34. Binary variables set for Case D1*

| | |
|---|---|
| **DiscreteInvest** | 1 |
| **ContinuousInvest** | 0 |
| **NGChillInvest** | 1 |
| **PVSales** | 0 |
| **CHP** | 0 |
| **CO2Tax** | 0 |
| **MinimizeCO2** | 0 |
| **MultiObjective** | 0 |
| **CentralChiller** | 1 |
| **NetMetering** | 0 |

Enabling CentralChiller and NGChiller variable allows the model deciding which option is less costly. Table 35 summarizes the final outputs after model running completion.

*Table 35. Case D1 output summary*

| | |
|---|---|
| **Total Energy Costs** | $150,408.241 |
| **System Efficiency** | 0.4999 |
| **Annual $CO_2$ Emissions [$kgCO_2$]** | 3,176,420.626 |
| **ICE Installed Capacity [kW]** | 540 |
| **MGT Installed Capacity [kW]** | 120 |
| **CAPEX** | $906,000 |
| **Microgrid-Benefit per Year** | $87,352.924 |
| **Electric Cost** | $276.839 |
| **Natural Gas Total Cost** | $20,168.201 |

The energy costs have dropped drastically after allowing discrete CHP technologies acquisition. They have diminished more than three times compared with the base case. This reduction in costs comes, as expected, along an increase in $CO_2$ emissions if, as it happens in this case D1, no $CO_2$ allowances fees are in force.

Economically, the benefits that stem from the microsystem amount to approximately $87,500 per year, with an initial capital investment of nearly 1 M$, included discrete technologies and chillers for refrigeration. A in the base case, Figure 24 plots the final output of the total energy demand and the electricity-only use. The same as in the base case scenario, natural gas, space heating, cooling and water heating complete the yellow part corresponding to the total energy demand.

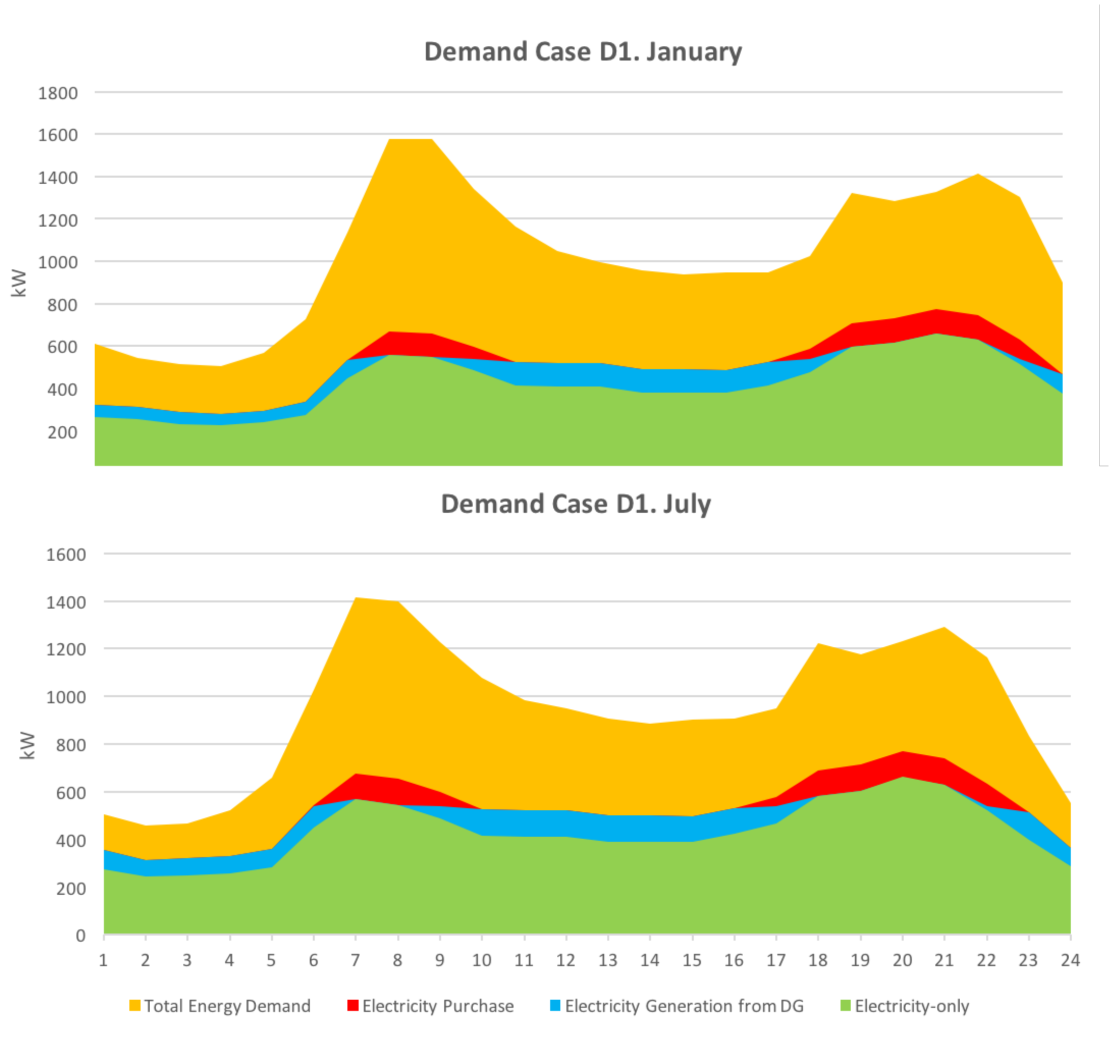

*Figure 24. Demand load profile in case D1*

The electricity supply is mostly covered with the ICEs and MGTs, but there are some peaks where they are not sufficient, thus electricity from the spot market is needed. That electricity purchased in the spot market is colored in red. The use of electricity for electric devices is covered by the CHP machines, and there is some time that it exceeds. That surplus is used in other appliances that are electrically driven to produce other source of energy, e.g., chillers' compressors.

Figure 25 depicts the distributed generation operation, being the ICE the technology that copes with the baseload. The microturbines are switched on just during peak hours (dark grey colored).

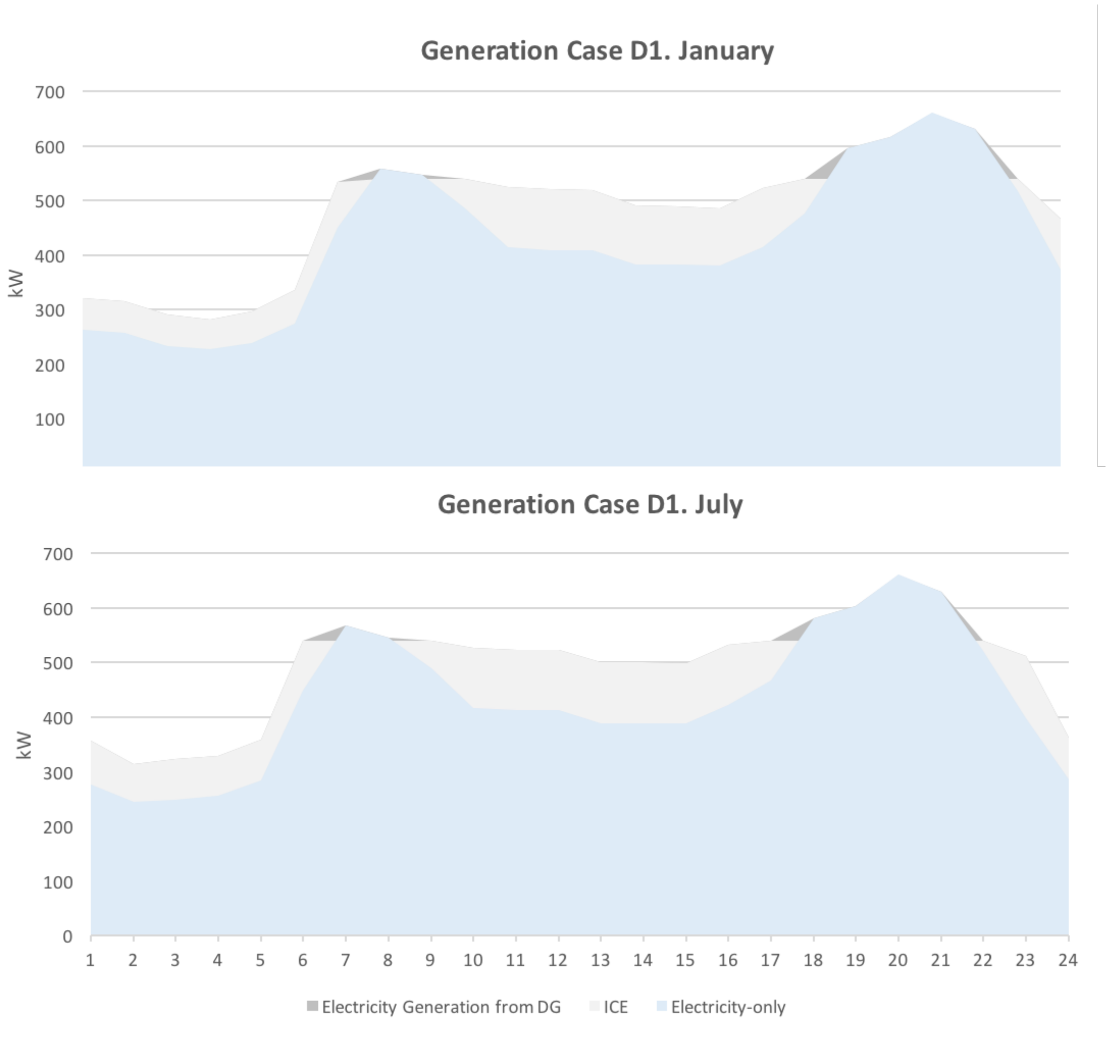

***Figure 25.*** *Electricity generation profile in case D1*

With a secondary axis, Figure 26 compares the discrete generation with the NG chiller generation. It is curious to see that when central chiller is operating, the CHP machines can cope with that consumption, among others, pretty well. The periods where central chiller is switched off and the natural gas chiller starts up, it is when peak hours take place. The reason is that a natural gas chiller is more efficient and less costly than the central chiller. Central chiller disposes electricity, great amount of it, during operation; and, peak hours in the hotel are coincident with peak hours in the spot market. For that reason, it is convenient to stop operation and start up chiller that burn natural gas, since the fuel price is low and there is a noticeable gain in performance ratio.

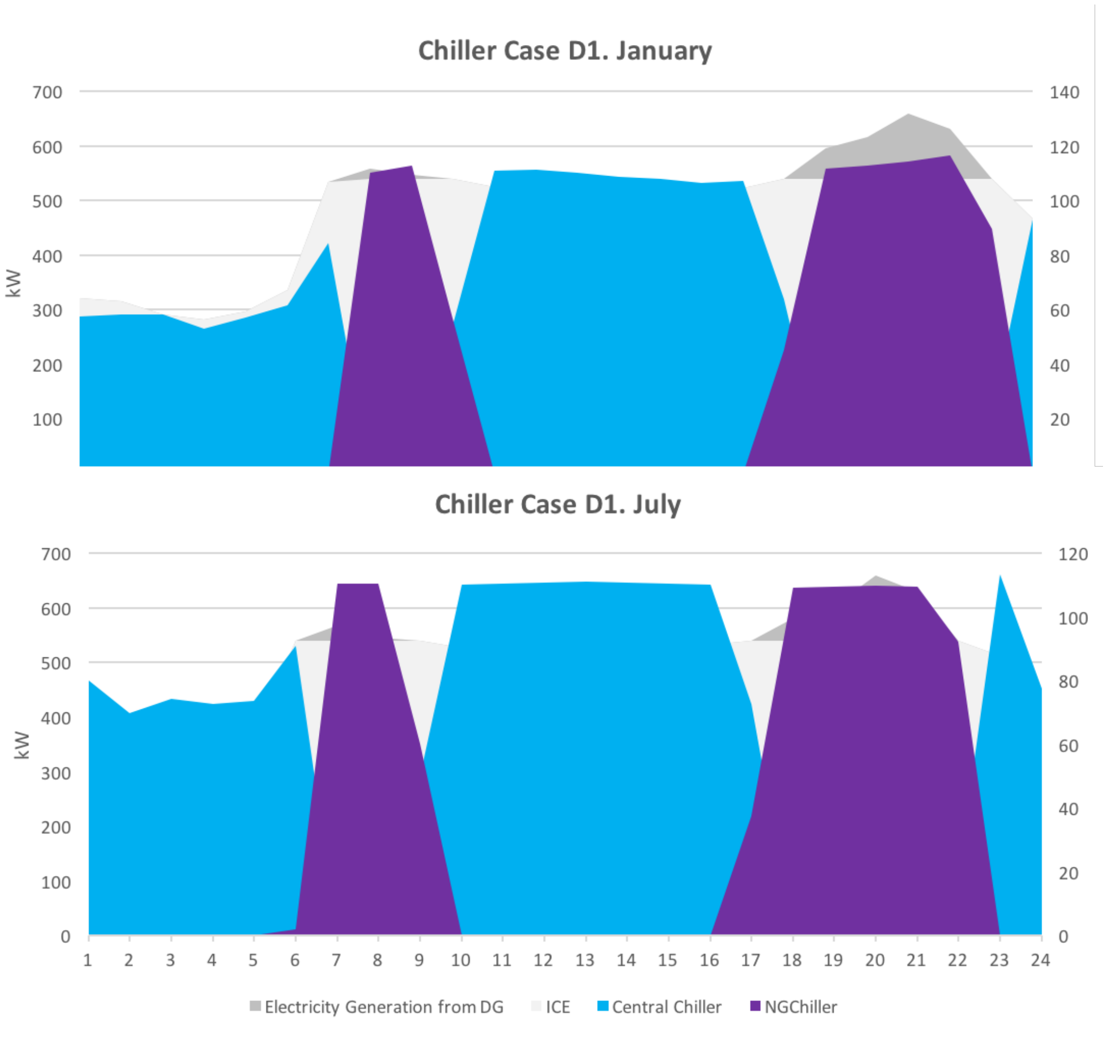

*Figure 26. Electricity consumption by NG chillers in case D1*

The use of CHP and natural gas boilers have enormously increased the natural gas consumption and made total electricity costs below $300 on a yearly basis.

### 6.3.2 Case D2

It is true that installation of CHP and HVAC technologies implies a notorious energy cost reduction, but this occurs in exchange of emitting more $CO_2$ to the environment. For that reason, this D2 case study is focusing on attaining a cost reduction at the same time it tries to minimize the $CO_2$ emissions by applying a $CO_2$ tax on the technologies.

Three possibilities arise from the task of decrease carbon emissions. Those are:

- Just activation of the CO2Tax option. Called Option1
- CO2Tax and MinimizeCO2 options activated. Called Option2
- CO2Tax and MultiObjective options activated. Option3

First option just calculates the energy costs without taking into account the carbon emissions, but just the cost of them. The second alternative focuses on just minimizing the $CO_2$ emissions, not optimizing the total energy costs. Last but not least, the option that weighs a combination between energy costs and emissions.

***Table 36.*** *Comparison of options in case D2*

| | **Option1** | **Option2** | **Option3** |
|---|---|---|---|
| **Total Energy Costs** | $236,884.582 | $611,572.185 | $246,157.121 |
| **$CO_2$ Emissions [$kg_{CO2}$]** | 1,815,832.932 | 1,373,331.093 | 1,394,613.993 |

Seeing the three outputs, it can be stated that Option2 is out of range, mainly because the total costs is by $100k above the base case scenario. On the contrary, Option1 and Option2 are quite similar; one with lower costs and the other with less annual emissions.

However, Option1 just takes advantage when talking about costs incurred by $10,000, whereas, by contrast, Option1 roughly produces 400 CO2 tons more than the former. Consequently, Option3 was selected as the optimal solution for this scenario. Hence, Table 37 shows how the control panels must be before running the model.

***Table 37.*** *Binary variables set for Case D2*

| | |
|---|---|
| **DiscreteInvest** | 1 |
| **ContinuousInvest** | 0 |
| **NGChillInvest** | 1 |
| **PVSales** | 0 |
| **CHP** | 0 |
| **CO2Tax** | 1 |
| **MinimizeCO2** | 0 |
| **MultiObjective** | 1 |
| **CentralChiller** | 1 |
| **NetMetering** | 0 |

After running the model, the results are shown in Table 38. The heat exchanger of the CHP technologies allows the system to gain an overall efficiency of 113.7%. For such purpose, the installed capacity required is large, accounting, in total, for 1,420 kW between ICEs and MGTs. Being the capacity very high, so is the capital expenditure, which amounts to 1.8M$.

The cogeneration implies very high efficiencies, but, this means more fuel is burnt in the combustion chambers of the CHPs. That is the reason of doubling the quantity of gas purchased.

*Table 38. Case D2 output summary*

| | |
|---|---|
| **Total Energy Costs** | $246,157.121 |
| **System Efficiency** | 1.137 |
| **Annual $CO_2$ Emissions [$kgCO_2$]** | 1,394,613.993 |
| **ICE Installed Capacity [kW]** | 1,300 |
| **MGT Installed Capacity [kW]** | 120 |
| **CAPEX** | $1,800,000 |
| **Electric Cost** | $1,890.628 |
| **Natural Gas Total Cost** | $49,326.778 |

Figure 27 illustrates the load profile that has been explained in Case D1. Seasonality is not relevant, as the tendency stays constant. The total energy demand accounts for natural gas, cooling, heat and electricity. Having a look at the peak period, first peak period, it can be seen the demand in winter is 200 kW higher than in summer. This has to do with the natural gas demand for space heating and water heating houses make use of very early in the morning; probably before heading work.

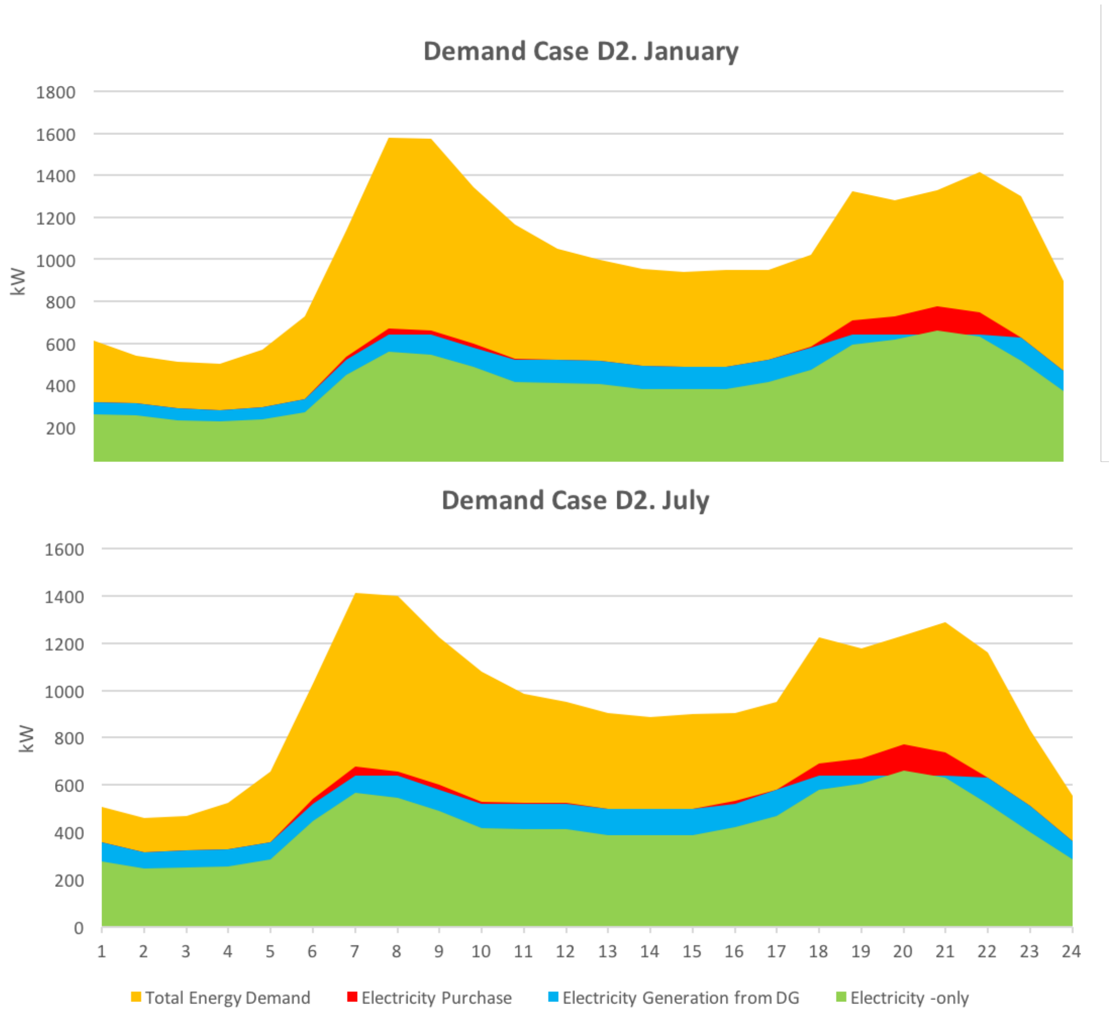

*Figure 27. Demand load profile in case D2*

In Figure 28, nothing else to add than commenting what it was already done in Case D1. ICE and MGT, both equipped with heat exchangers produce the major share of the electricity. Those peaks where the electricity-only surface is greater than the others it is when electricity is purchased directly in the market.

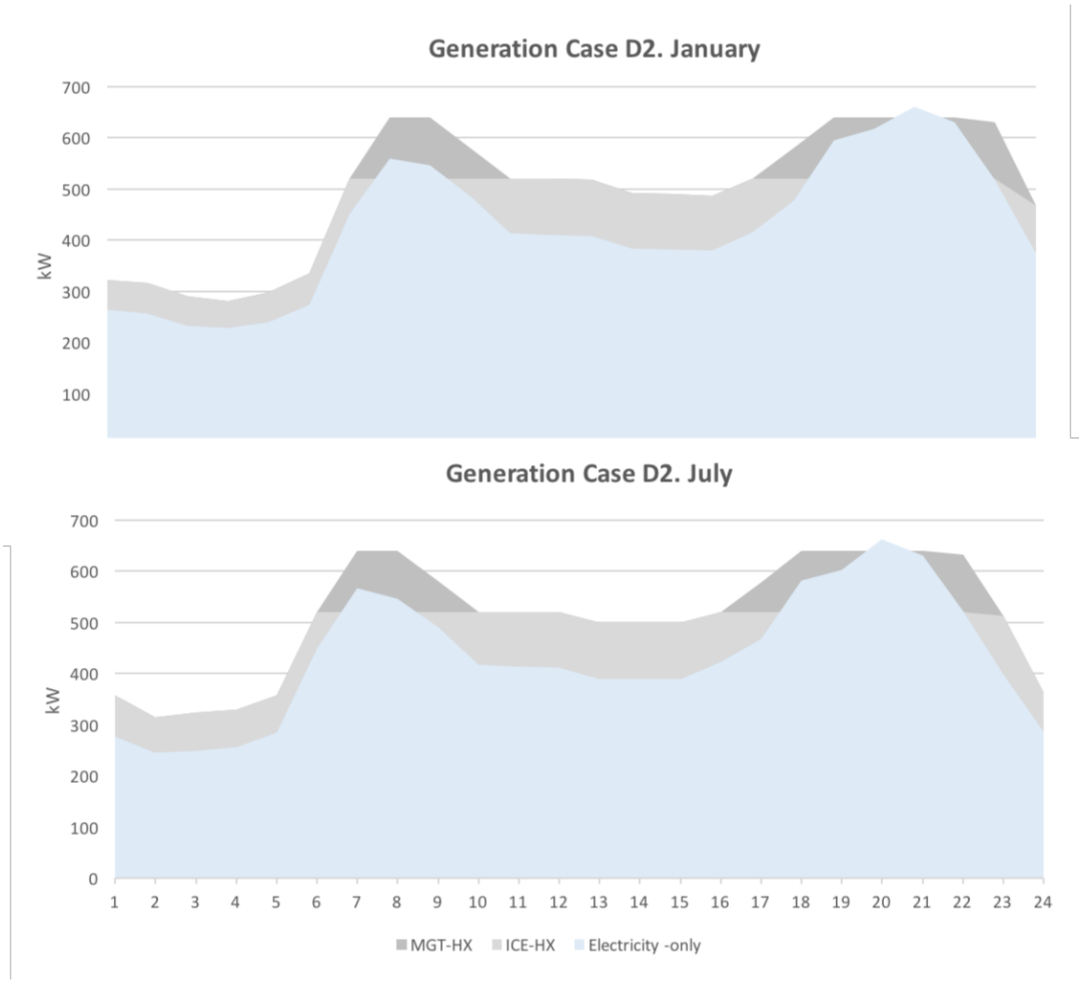

***Figure 28.*** *Electricity generation profile in case D2*

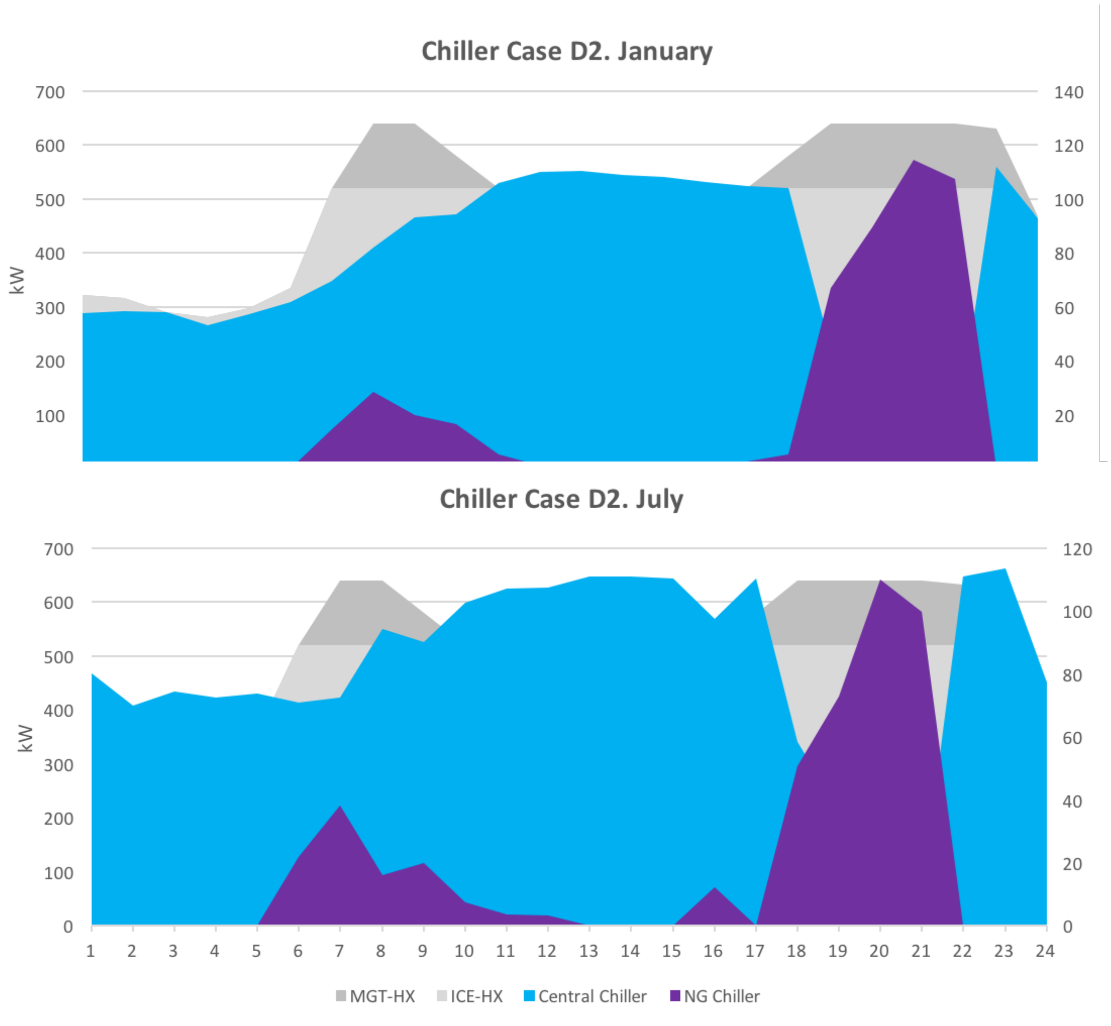

***Figure 29.*** *Electricity consumption by NG chillers in case D2*

Talking about the central and natural gas chillers (see Figure 29) the NG chillers start up during peak hours, but in this Case D2 the operation is not as steep as it was in Case D1. Central chiller is operative most of the time; just in the second peak period, it seems the natural gas chillers copes with the total cooling demand, but rapidly stops and central chiller takes on back again.

Finally, there is a new chart to explain. Figure 30 is of relevant importance since the CHP technologies operate with a heat exchanger. The heat exchangers are in charge of supplying their residual heat, or not residual but produced it on purpose, to provide with energy those appliances and devices demanding such heat. It is the case of space heating and water heating. Most of the heat directs to the water heating, probably because the temperature is lower and the CHP is enough to provide that service. Space heating may need more than just CHP residual heat, it takes some of it, but the rest comes from natural gas furnaces. In addition, the keeping warm a hotel, especially in winter, is extremely energy intensive, thus, the optimal solution is to utilize gas for such task.

The leftover part to cope with the total energy demand accounts for the natural gas, which is mainly use for heating purposes.

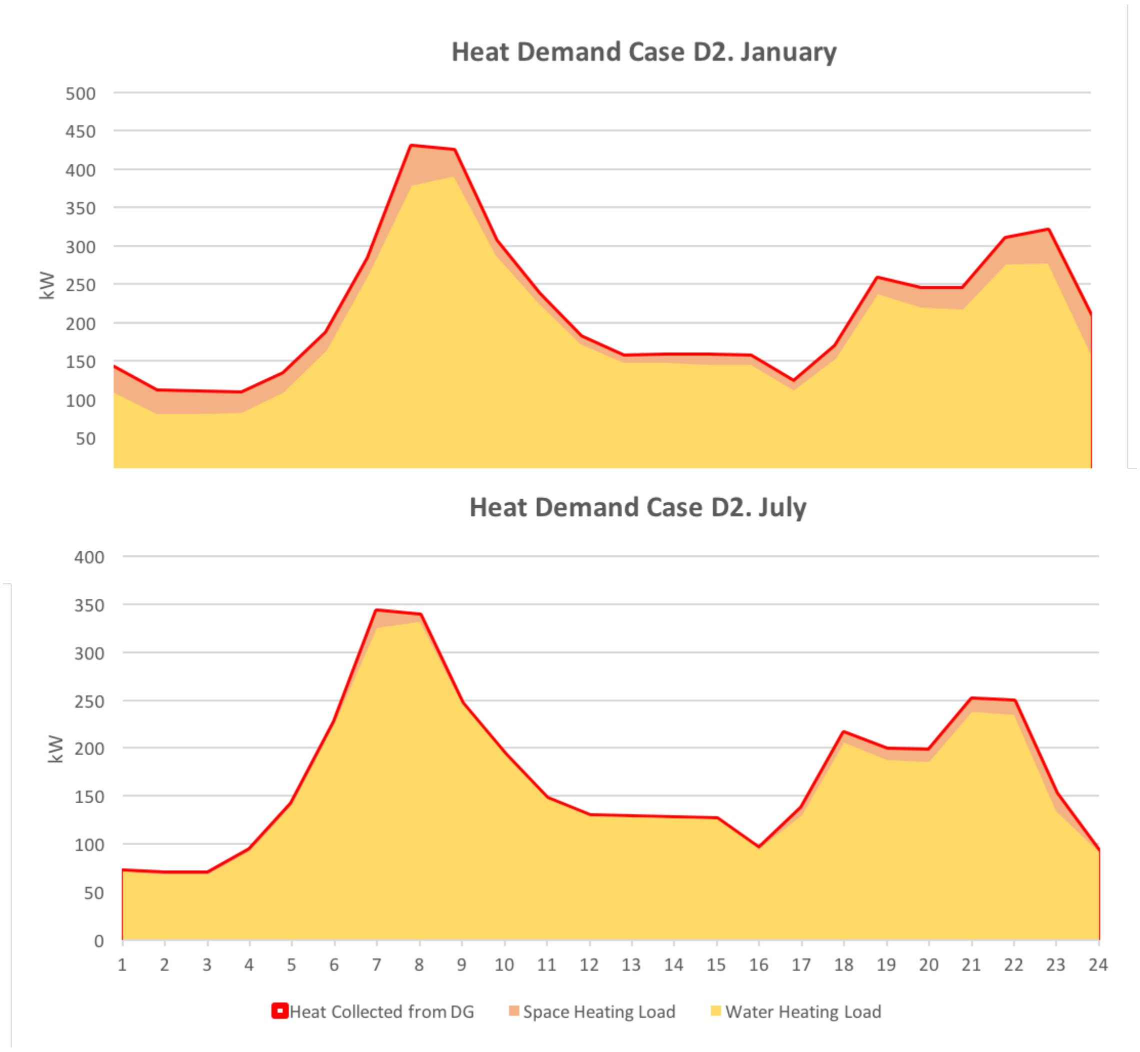

*Figure 30. Heat demand profile in case D2*

## 6.4 Continuous investments

Moving on another direction, this section follows the path of continuous installations investments.

Continuous investments refer to any technology that its capacity is not fixed by units, but gives some flexibility to the consumers to adopt his consumption to their capacity needs. PV solar panels, heat pumps, absorption chillers, solar thermal, among others, are examples of technologies deemed as continuous.

As in discrete investments, two cases arise, considering that $CO_2$ optimization is going to be included in all cases from now:

- Continuous investments with PV sales enabled
- Continuous investments with PV sales and NG chillers

### 6.4.1 Case C1

The DER-CAM panel changes from discrete to continuous investments. Just putting a zero in the DiscreteInvest and typing a one in ContinuousInvest option like in Table 39.

***Table 39.*** *Binary variables set for Case C1*

| | |
|---|---|
| **DiscreteInvest** | 0 |
| **ContinuousInvest** | 1 |
| **NGChillInvest** | 1 |
| **PVSales** | 0 |
| **CHP** | 0 |
| **CO2Tax** | 1 |
| **MinimizeCO2** | 0 |
| **MultiObjective** | 1 |
| **CentralChiller** | 1 |
| **NetMetering** | 0 |

After the model has been successfully executed, a summary is presented in Table 40.

*Table 40. Case C1 output summary*

| | |
|---|---|
| **Total Energy Costs** | $ 495,500.860 |
| **System Efficiency** | 0.597 |
| **Annual $CO_2$ Emissions [$kgCO_2$]** | 1,679,901.453 |
| **PV Installed Capacity [kW]** | 210 |
| **GSHP Installed Capacity [kW]** | 70 |
| **CAPEX** | $180,044.880 |
| **Electric Cost** | $430,674.373 |
| **Natural Gas Total Cost** | $22,654.157 |

The output is very flaw, since the results are not as expected. Capital investment is relatively high; and excesses the base case total cost-function, the system efficiency is low if considering the installation of more than 300 kW of renewable capacity. The reason of this low efficiency is the poor use given to the facilities, substituting them by natural gas in most of the cases. An example is the solar PV, with maximum peak generation of 39.548 kW on July at 13 p.m.

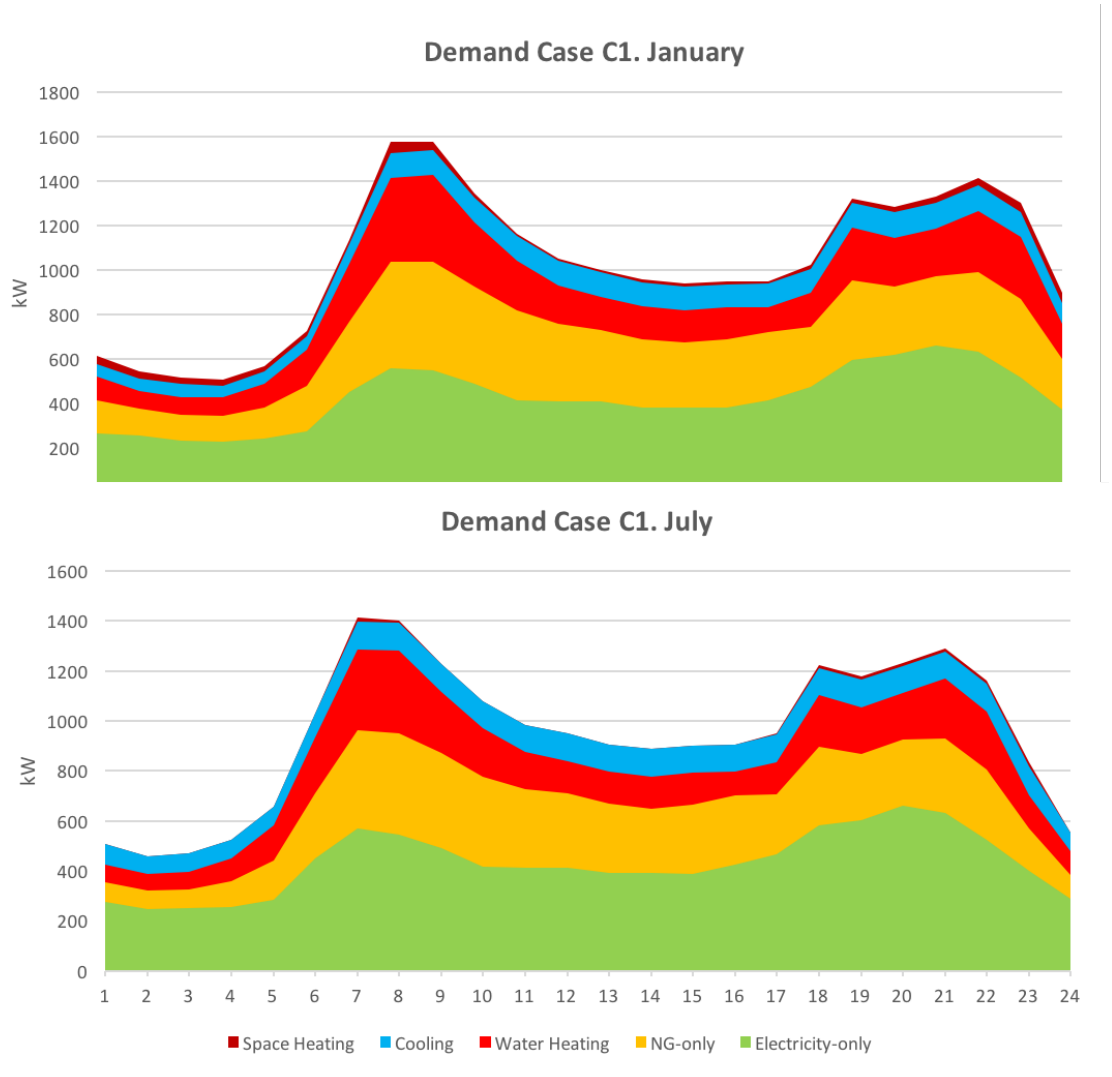

*Figure 31. Energy breakdown in case C1*

Electricity is still, by large, the most demanded type of energy. Since the PV capacity has a very poor performance, more than 95% of the total electricity consumed comes from the grid, in other words, electricity supply is provided by the spot market through a commercial retailer. Absolute peak demand is reached in wintertime; specifically, in January, it is reached at 8 a.m. with 1,600 kW.

Moving forward, there is a steep change when talking about renewables in heating demand. Figure 32 plots the contribution of each technology in supplying heating and water heating.

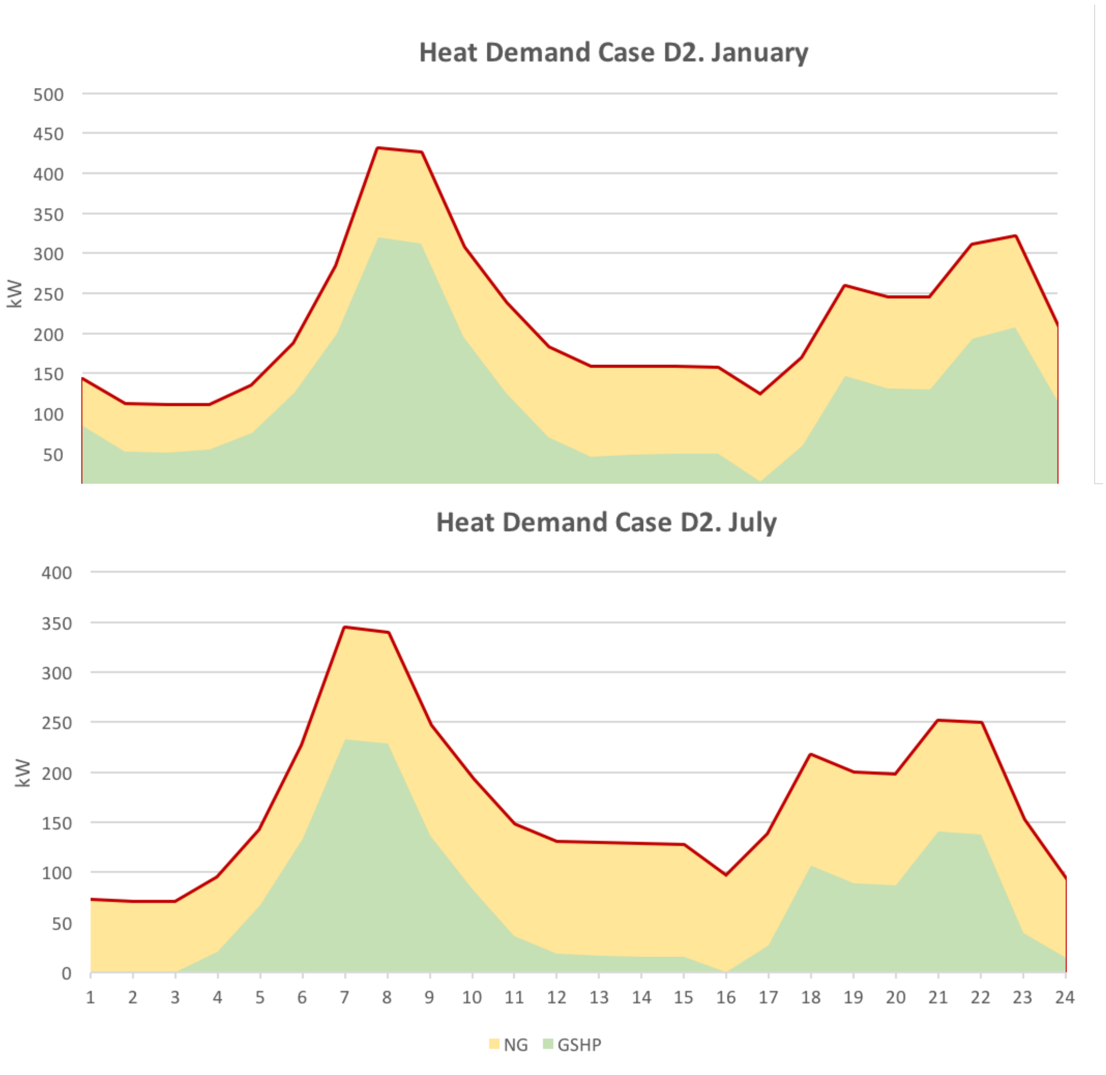

*Figure 32. Heat demand profile in case C1*

It is remarkable to say that the ground source heat pump facility is capable of covering half of the heat demand just with a maximum installed capacity of 70 kW. The fact is its good performance yield, the so-called COP. GSHPs can operate with COPs between five and six in heating mode, which means that with one unit of electric energy, it generates five or six units of useful heat. This outstanding performance makes a lot of savings in the natural gas procurement.

Going to the opposite side in the energy field, from heat to refrigeration, Figure 33 plots the distribution of the cooling generation by type of technology. As it is depicted, most of the cooling generation lies in the NG chillers, leaving small room for other technologies such as the GSHP (operating in cooling mode) at specific times during the day.

Differing from the discrete investment cases, central chiller is not optimal anymore. Although it is not illustrated, central chiller starts up only during peak hours, when NG and GSHP cannot meet the demand.

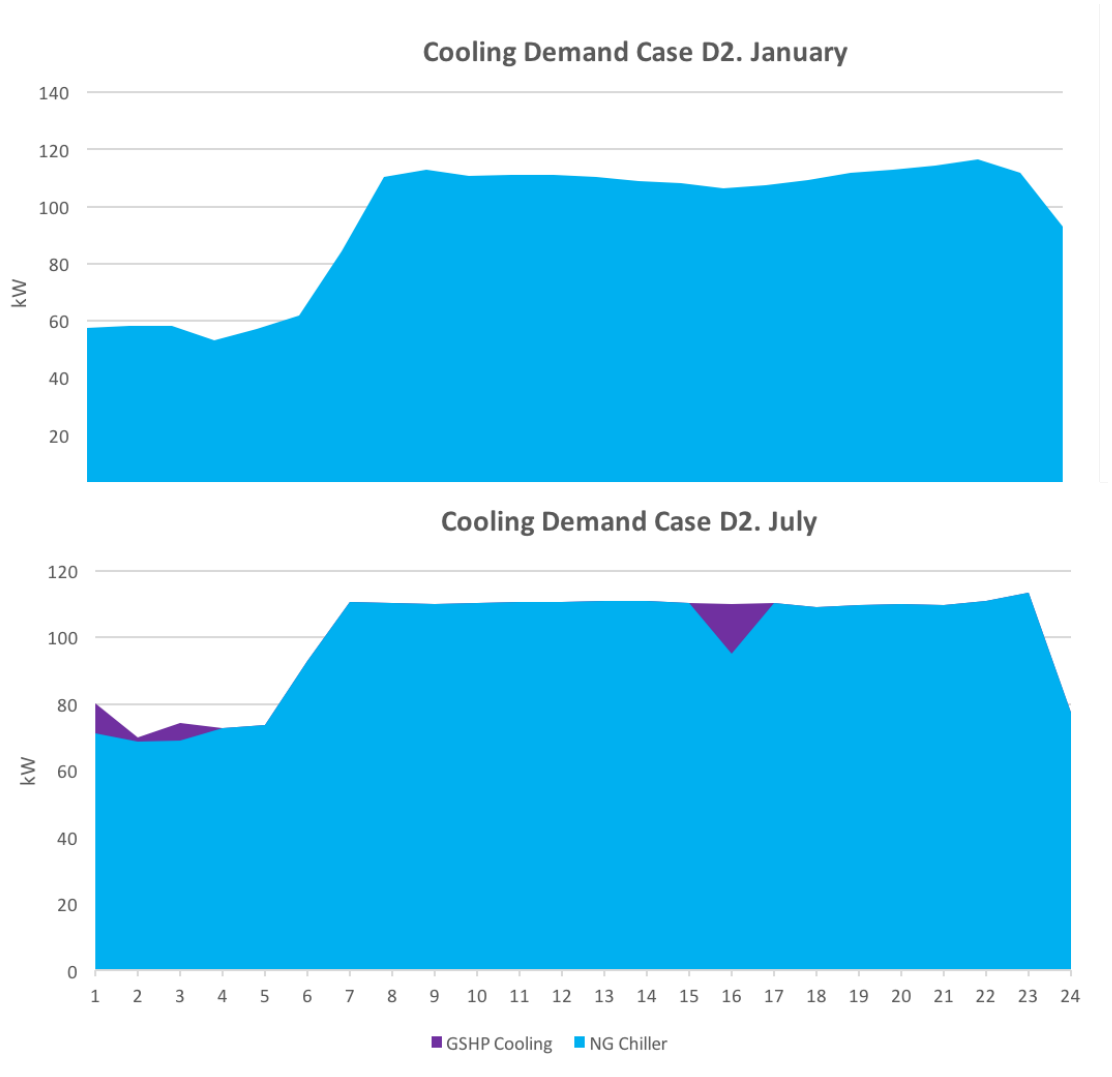

*Figure 33. Cooling demand profile in case C1*

### 6.4.2 Case C2

The output of this running after execution is very similar to the Case C1. This second case within the continuous investment routine added up the PVSales Option, but, as shown in Table 41, the savings are still below the baseline cost-function.

***Table 41.*** *Results comparison for cases C1 and C2*

| | **C1** | **C2** |
|---|---|---|
| **Total Energy Costs** | $ 495,500.860 | $489,883.596 |
| **System Efficiency** | 0.597 | 0.574 |
| **Annual $CO_2$ Emissions [$kgCO_2$]** | 1,679,901.453 | 1,823,894.260 |
| **PV Installed Capacity [kW]** | 210 | 210 |
| **GSHP Installed Capacity [kW]** | 70 | 0 |
| **Absorption Chiller Installed Capacity [kW]** | | 2 |
| **CAPEX** | $180,044.880 | $220,000.047 |
| **Electric Cost** | $ 430,674.373 | $415,165.142 |
| **Natural Gas Total Cost** | $ 22,654.157 | $29,124.334 |

The savings are narrowly below the baseline, but they are a bit lower than in Case C1; the overall efficiency diminishes, part of it is due to the nonexistence of GSHP capacity procuring heating to the building. An important issue that varied a lot is the $CO_2$ annual emissions; 200 tones more are emitted, and the reason lies in the use of more natural gas in exchange of renewable energies.

Linking to the emissions and non-investments in RES, NG expenditures sky-rocked, in turn of decreasing the electric costs derived from the purchasing activities.

Summing up, continuous-alone investments have proved not have been the best alternative as an optimal solution for the commercial businesses. Next step starts with the combination of both discrete and continuous investment.

## 6.5 Discrete and continuous investments

Last but not least, executions considering both types of investments are made. Two branches derived from this process:

- Investments without sales
- Investments with sales in the market

Both cases are under the CO2 minimization process, but concerning, also, the optimization of energy costs.

### 6.5.1 Case DC1

A priori, the results should better off the previous ones, as the model combines and take advantages of the synergies derived from the discrete and continuous investments. Table 42 presents the command panel prior to the execution.

***Table 42.*** *Binary variables set for Case DC1*

| | |
|---|---|
| **DiscreteInvest** | 1 |
| **ContinuousInvest** | 1 |
| **NGChillInvest** | 1 |
| **PVSales** | 0 |
| **CHP** | 0 |
| **CO2Tax** | 1 |
| **MinimizeCO2** | 0 |
| **MultiObjective** | 1 |
| **CentralChiller** | 1 |
| **NetMetering** | 0 |

Results have better off, as expected, and the cost-function is below the cost baseline. Furthermore, revising just the real cases, say, those optimizations where the $CO_2$ constraint is included, it comes up to be the lowest cost up-to-date (see Table 43). Likewise, the annual carbon emissions result to be the lowest among all the scenarios run already.

Regarding the capacity installed, 210 kW of solar PV are in place deployed over the 1,000 $m^2$ of available rooftop surface; 119 kW were invested in absorption chillers, amounting a total CAPEX of nearly 1M$. Since most of the electricity is produced with 210 kW of PV solar panels and 660 kW of CHP microturbines, all these latter equipped with heat exchangers; reason to verify the low emissions of carbon, as the residual heat from the machines is used instead of burning gas in the combustion chambers.

Providing heating and cooling energy services are found 119 kW of absorption machines and 36 kW of renewable ground source heat pumps.

*Table 43. Case DC1 output summary*

| | |
|---|---|
| **Total Energy Costs** | $214,052.159 |
| **System Efficiency** | 1.278 |
| **Annual $CO_2$ Emissions [kg$CO_2$]** | 1,242,697.162 |
| **MGT Installed Capacity [kW]** | 660 |
| **PV Installed Capacity [kW]** | 210 |
| **Absorption chiller Installed Capacity [kW]** | 119 |
| **GSHP Installed Capacity [kW]** | 36 |
| **CAPEX** | $937,615.289 |
| **Electric Cost** | $220.621 |
| **Natural Gas Total Cost** | $44,075.158 |

Part of the electricity produced does not find its destination in electric driven appliances, as shown in Figure 34; colored in purple and yellow appears the electricity surpluses that may be used as secondary energy, for instance, in the compressors or pumps of the chillers and absorption machines. It is remarkable that PV production is peaking when load is off-peak.

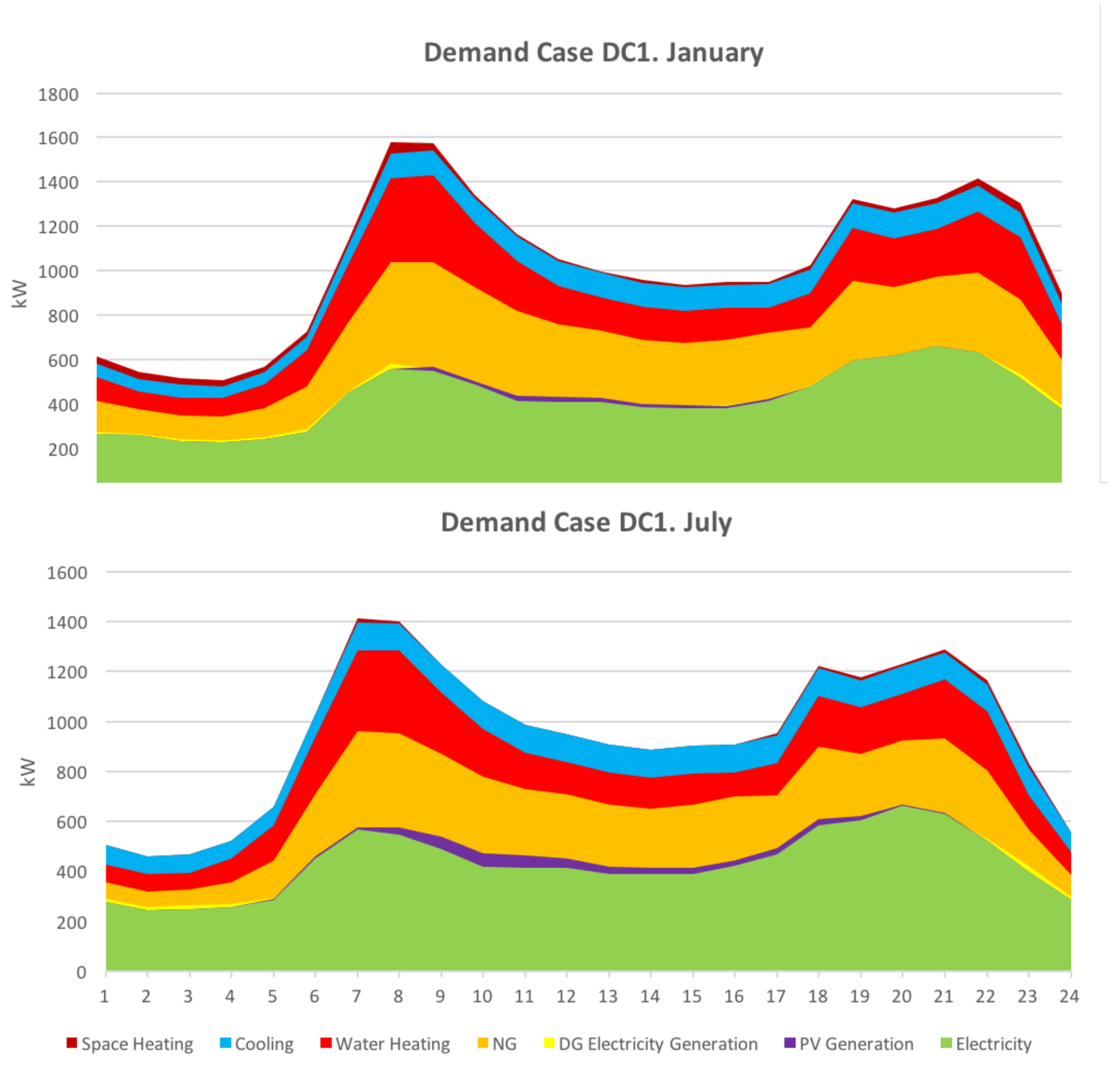

*Figure 34. Energy breakdown in case DC1*

Figure 35 zooms in what has been explained already, that PV generations reaches a maximum during off-peak hours. It is very likely that due to this fact the PV production remains very low if compare with its total installed capacity which accounts for 210 kW. The problem might be sorted out if sales were enabled and that electricity could be sold and injected into the grid, being paid for that activity as well.

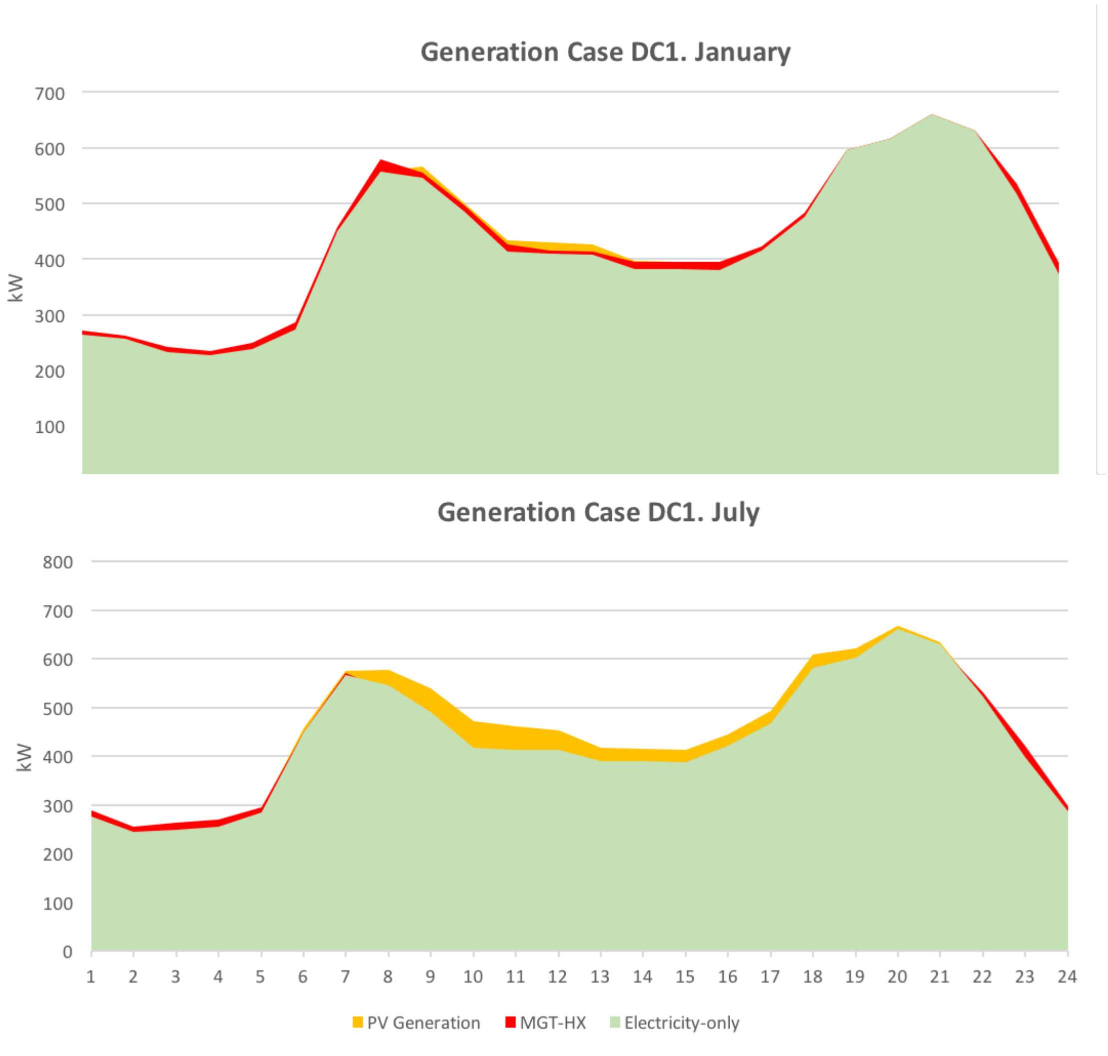

*Figure 35. Electricity generation profile in case DC1*

This case DC1 does not contemplate the possibility of a central chiller, or at least, the operation of a central machine if demand is not very high or it does not ramp up very quickly. Hence, absorption chillers and a GSHP are the technologies selected to fully cover the hotel's cooling demand. Largely, the former copes with more than 70% of the total cooling demand, being periods providing it completely.

The GSHP system serves as a support for the absorption machine, helping it in the ramp-ups and ramp-downs. Once again, the COP of the heat pump allows to produce large amounts of usable heat with less than 40 kW. The drawback, and the reason, why there are not big investments in this technology is the initial investment and the building work effort to deploy ne of this type of systems.

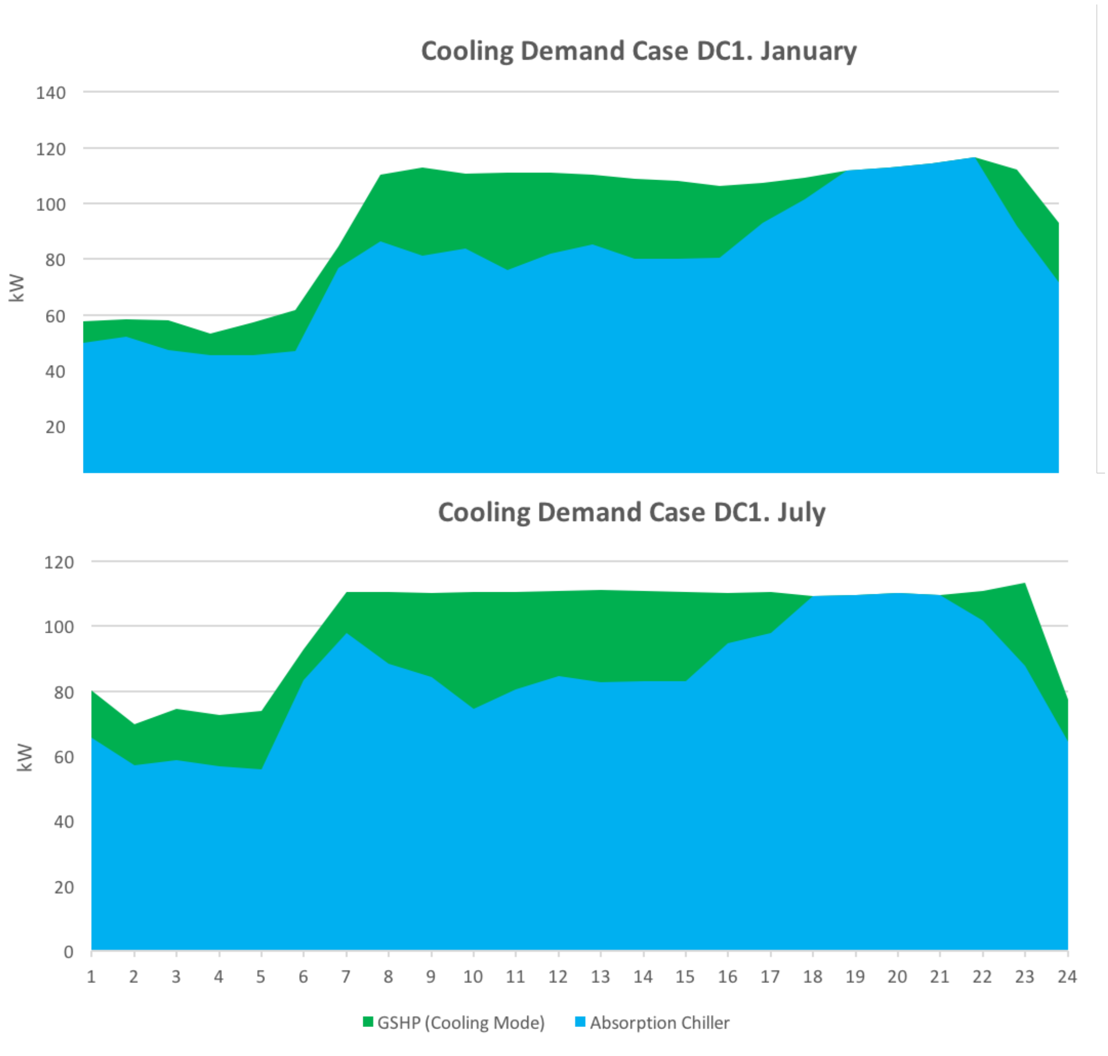

***Figure 36.*** *Cooling demand profile in case DC1*

Pointing out that absorption chillers do not emit any kind of carbon-dioxide, if the heat source necessary for the operation of the generator within the machine comes from a renewable source. In this case, that heat stems from the residual heat of the CHP engines that by means of heat exchangers transfer the heat to a secondary fluid that directs the points where heat is needed through a piping system. The fluid can be either air or water.

The heat demand is distributed into three main demands:

- Absorption machines
- Space heating
- Water heating

Absorption machines requires great amounts of heat to make their system work, space heating accounts for a tiny piece, probably because the direct heating is not the efficient way to heating up the hotel, or the proper way to make the heat flow all over the place.

Instead, there are more efficient systems and way to do it. Water heating could be used by heaters by means of a water piping system that carries the hot water through the tubes that, at the same time, are placed in every room and in every hall.

Another way to do it is by burning gas to heating up water or air, and throughout tubes and pipes conduct the energy carrier to the places desired. The good point of not using residual heating directly offer the possibility to control the temperature and the flow of heat. Otherwise, the heat will be very difficult to manage and part of it will be wasted as energy spillages.

In the Case DC1 the natural gas is not used for heat collection, just for operating the MGTs.

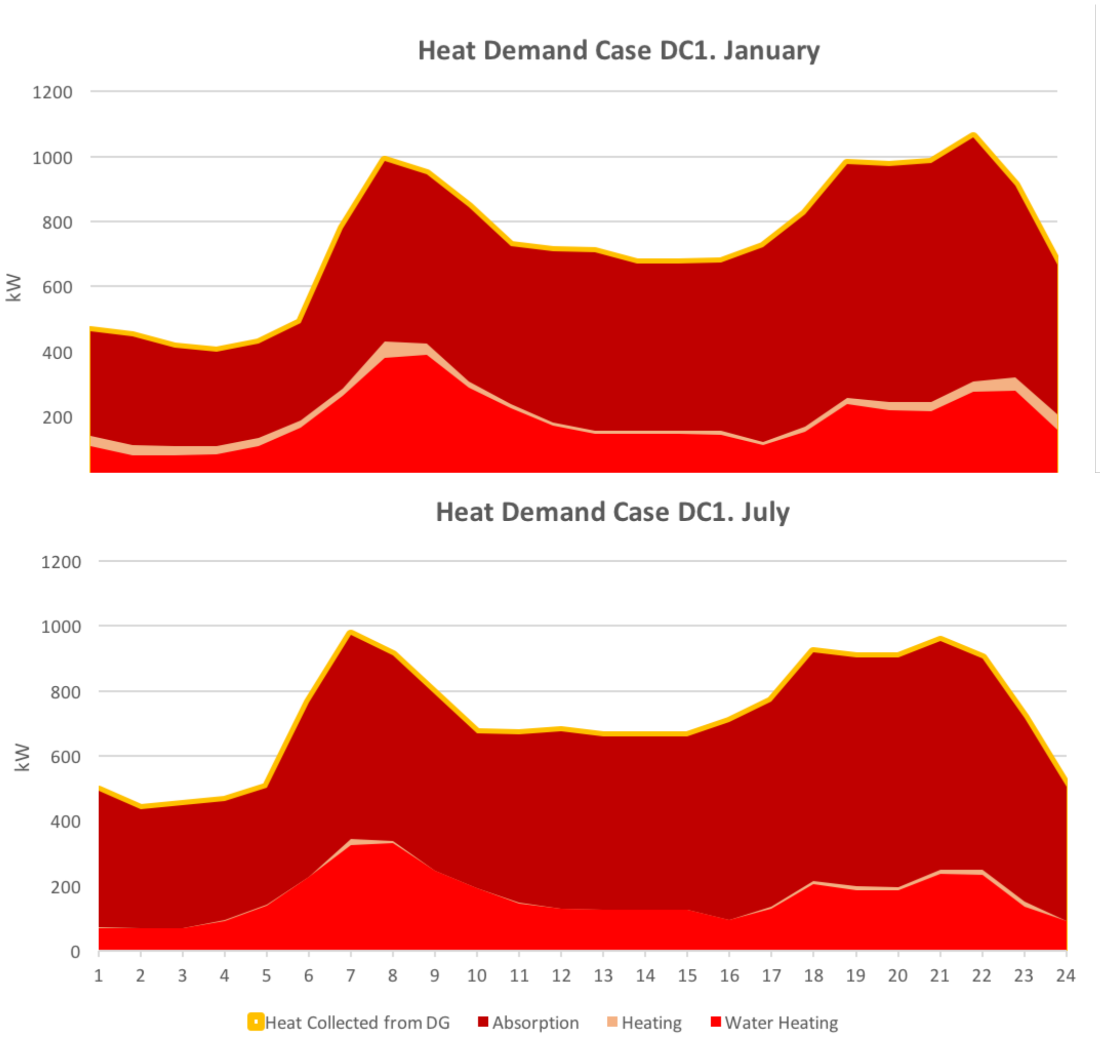

*Figure 37. Heat demand profile in case DC1*

### 6.5.2 Case DC2

In this last execution, all modes of investments are enabled, as well as the possibility to sell the energy surpluses in the market. Table 44 shows the control panel of the DER-CAM model.

***Table 44.*** *Binary variables set for Case DC2*

| | |
|---|---|
| **DiscreteInvest** | 1 |
| **ContinuousInvest** | 1 |
| **NGChillInvest** | 1 |
| **PVSales** | 1 |
| **CHP** | 0 |
| **CO2Tax** | 1 |
| **MinimizeCO2** | 0 |
| **MultiObjective** | 1 |
| **CentralChiller** | 1 |
| **NetMetering** | 0 |

The model's output speaks itself; the total costs and carbon emissions are the lowest values out of the six simulations. In exchange of that, some other parameters have slightly increased, or decreased in the case of the system's overall efficiency.

*Table 45. Case DC2 output summary*

| | |
|---|---|
| **Total Energy Costs** | $190,680.564 |
| **System Efficiency** | 1.254 |
| **Annual $CO_2$ Emissions [kg$CO_2$]** | 1,266,842.368 |
| **MGT Installed Capacity [kW]** | 660 |
| **PV Installed Capacity [kW]** | 210 |
| **Absorption chiller Installed Capacity [kW]** | 119 |
| **GSHP Installed Capacity [kW]** | 30 |
| **CAPEX** | $937,594.408 |
| **Electric Cost** | $220.621 |
| **Natural Gas Total Cost** | $44,928.008 |
| **Electricity Sales [kWh]** | 139,260.427 |
| **Annual Sales [$]** | $26,080.198 |

Based on the Figure 38, it charts the energy consumptions by type of energy, and there is a breakdown in the electricity generation, in order to assess the origin of the energy produced.

As expected, distributed generation, DG, copes with most of the total electricity produced, supported by the 200 kW-PV installation, whereof is sold in the spot market. Those parts in the Figure 38 where there is not any yellow or purple strip means that electricity was purchased in the market, but, that value amounts to $220.6 in year. Therefore, it can be stated the electricity is produced independently from the network and large generators.

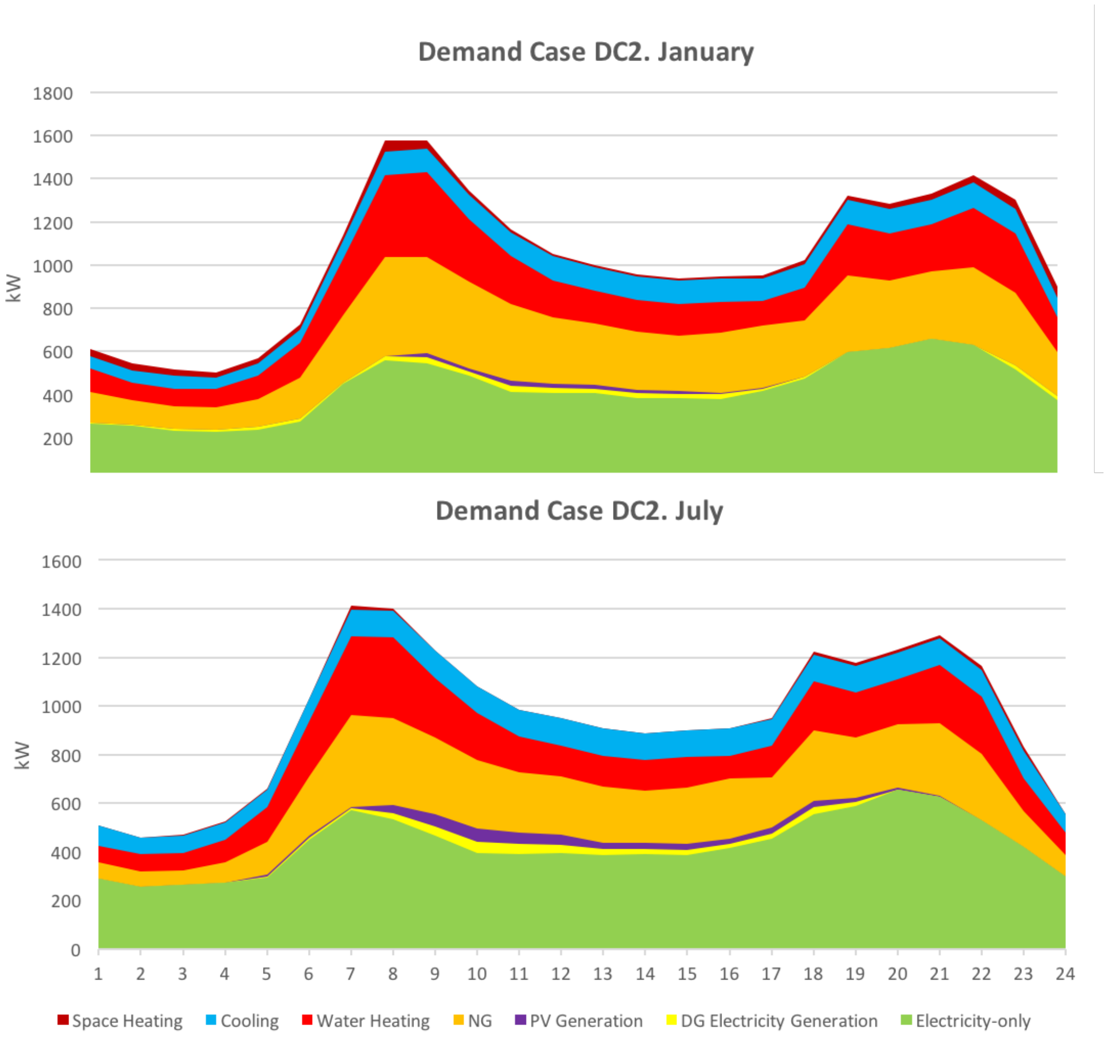

*Figure 38. Energy breakdown in case DC2*

Because the PVSales Option was activated, the optimal PV production has increased, and all of it is spilled in the market being remunerated for that. Figure 39 charts, and especially in July where the solar radiation is stronger, the solar production is maximum. The rest is generated with the MGTs.

Regarding the heating and cooling demand; first, the heating is supplied in the same way it is done in Case DC1, with the residual heat of the CHP technologies through the heat exchanger located in the exhaust chamber, transferring heat to water or air. Absorption chiller still demand large amounts of heat to operate themselves and produce cooling energy in combination with a ground source heat pump.

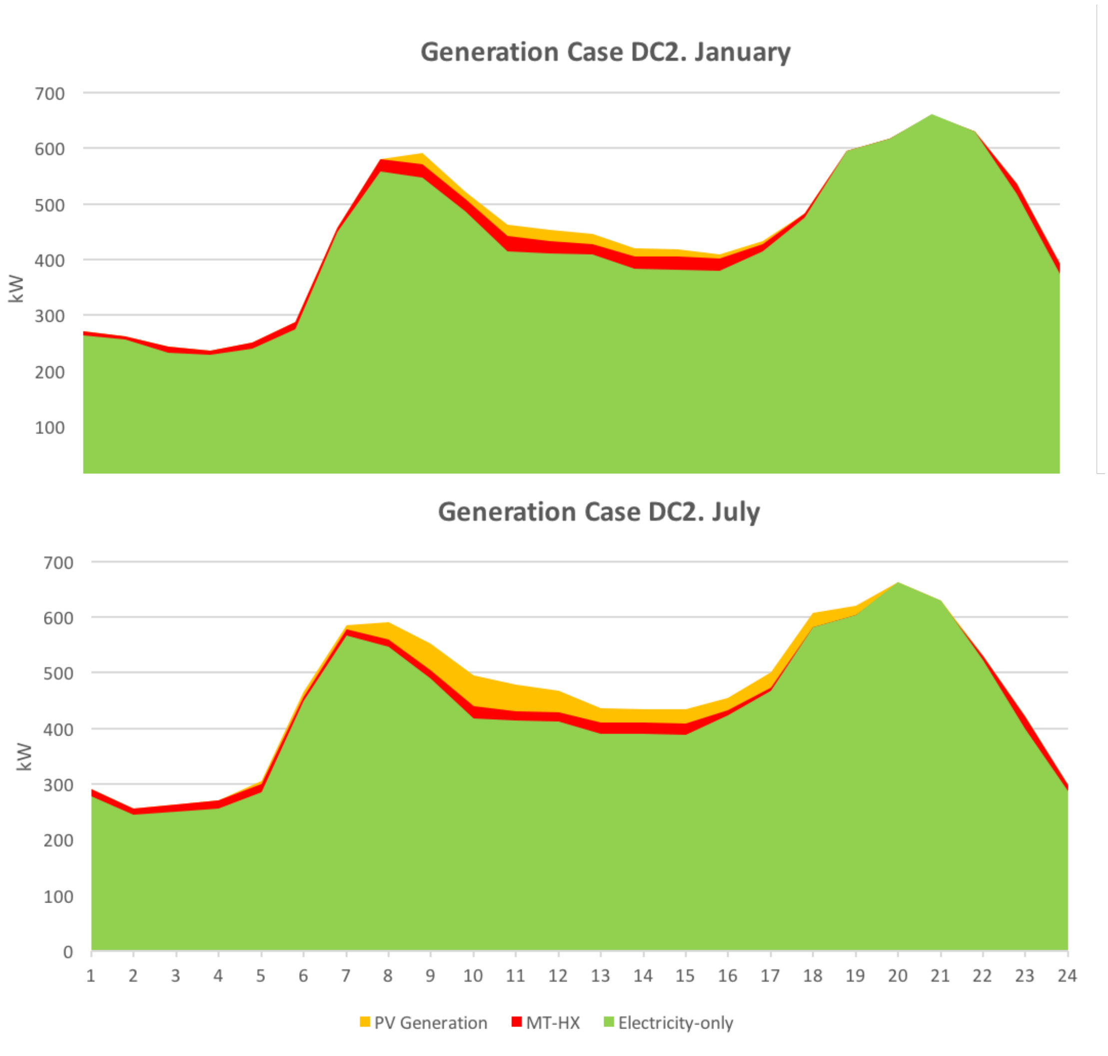

***Figure 39.*** *Electricity generation profile in case DC2*

The electricity sales are due every time PV panels generates electricity. In the case of July, being vacation time in Spain, the peaks are not very steep, but still, it can be appreciated looking the electricity load profile, where the high prices may be. Solar peak occurs right when the market price starts climbing, so do benefits out of it can be achieved.

The Case DC2 is the only that finds optimal the electricity sales from the PV generation. This has to do with the advantage of producing at ‘zero cost’ and be paid for selling costless energy produced. This is relative, because, in order to do such activity, it is necessary to invest in solar PV facilities, pay the annual O&M and other charges associated to the operation of the installation.

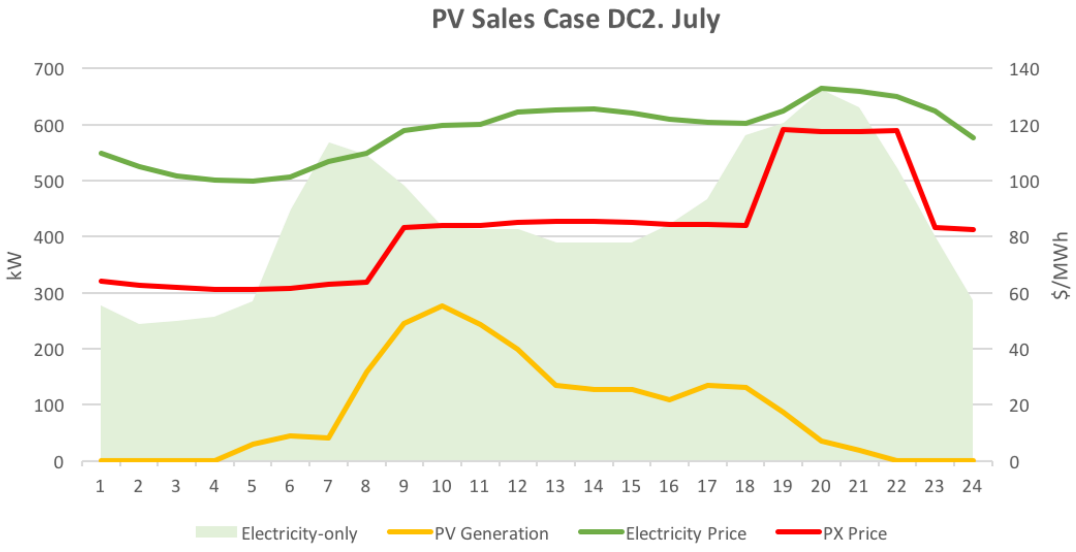

***Figure 40.*** *PV generation compared with the spot price in the Iberian electricity market*

## 6.6 Discussion of the results

This chapter is dedicated to discussing and comparing the six simulations and to addressing the main pros and flaws each business model have. Since there have been proved some simulations to be worthless and not realistic, only four of them are presented in Table 46.

***Table 46.*** *Output after-math simulation summary*

| | **BC** | **D1** | **D2** | **C1** | **DC2** |
|---|---|---|---|---|---|
| **Energy Costs** | $501,392.806 | $150,408.241 | $246,157.121 | $ 495,500.860 | $190,680.564 |
| **System Efficiency** | 0.479 | 0.4999 | 1.137 | 0.597 | 1.254 |
| **Annual Emissions [kgCO$_2$]** | 2,100,623.150 | 3,176,420.626 | 1,394,613.993 | 1,679,901.453 | 1,266,842.368 |
| **PV [kW]** | - | - | - | 210 | 210 |
| **GSHP [kW]** | - | - | - | 70 | 30 |
| **Absorption [kW]** | - | - | - | - | 119 |
| **ICE [kW]** | - | 540 | 1,300 | - | - |
| **MGT [kW]** | - | 120 | 120 | - | 660 |
| **CAPEX** | - | $906,000 | $1,800,000 | $180,044.880 | $937,594.408 |
| **Electric Cost** | $496,217.867 | $276.839 | $1,890.628 | $430,674.373 | $220.621 |
| **Natural Gas Cost** | $5,174.938 | $20,168.201 | $49,326.778 | $22,654.157 | $44,928.008 |
| **Sales [kWh]** | - | - | - | - | 139,260.427 |

The best scenario is relative, it depends on many factors. Giving some of them, relevant parameters to consider are as follows:

- Capital investment budget
- Size of the emplacement
- Location of the building
- Purpose of the renewal work

Although the energy costs are lower in all cases, it is not being taken into account the initial outlay in technologies. That assumption is gathered in Figure 41, which sums the energy costs (natural gas and electricity costs in one year) plus the initial expenditure.

The chart does not look as it did when presented the results of the simulation. Indeed, the base case is the optimal one. Despite this fact, the investments are planned in the long-term, thus, a forecasting on how the costs will evolve is needed.

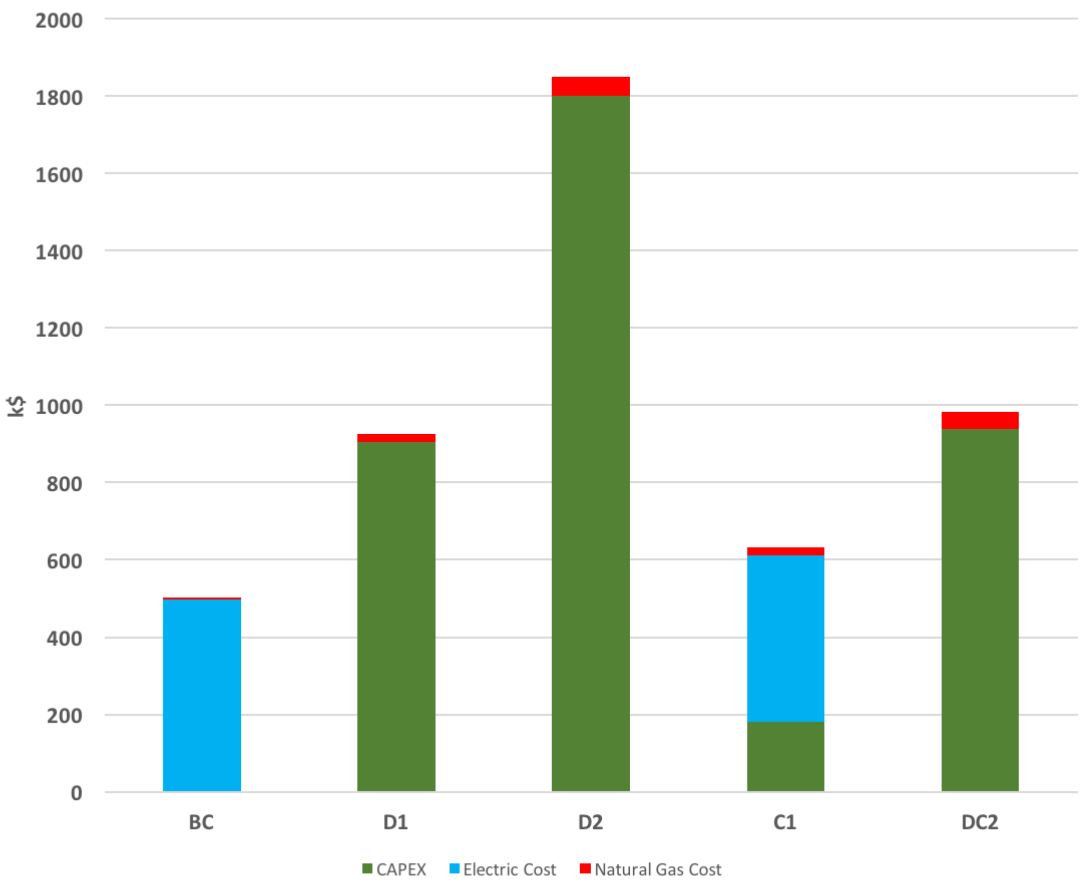

***Figure 41.*** *Comparison of the simulation results for year 1 (2019)*

Every year, to a greater or lesser extent, investments attain some savings with respect to the base case. Doing so, what it is happening is the collection of money that pays back the expenditure invested in new technologies. Some of them make the cost recovery very fast, giving real cost reductions by the end of the fifth year after the startup of the installations.

D1 is the project that first recover and make real savings, but this project is not realistic since $CO_2$ emissions and fee on them are not been under consideration. The second fastest project is DC2; expected result bearing in mind that it was the case with the highest potential savings on the paper; and the only that injects electricity into the national network.

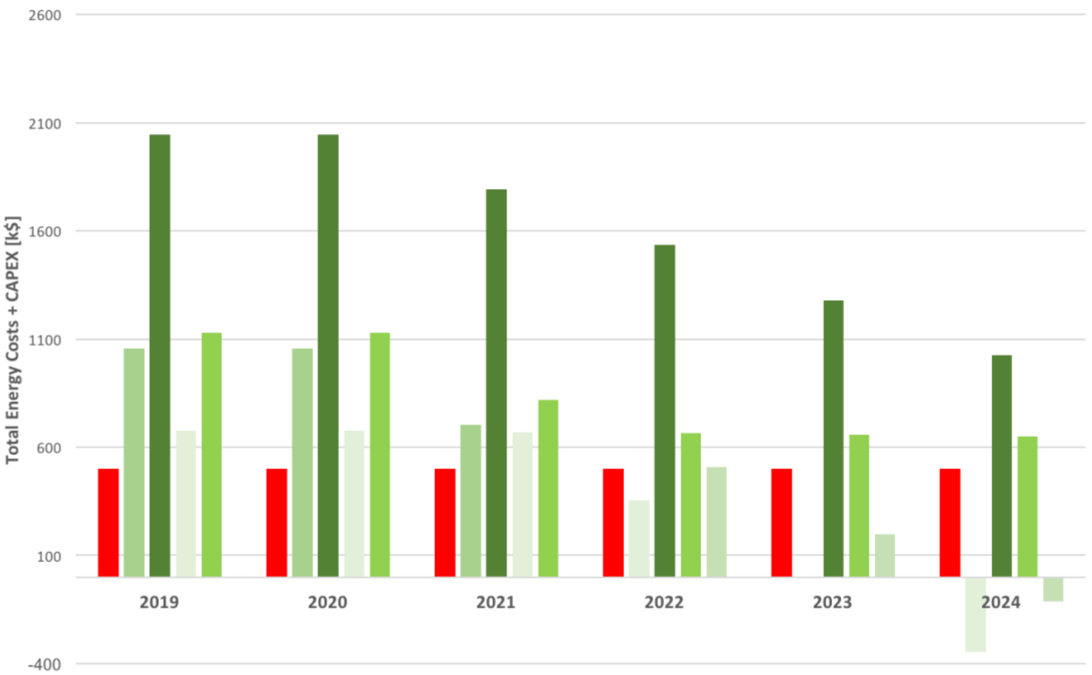

***Figure 42.*** *5-year forecasting on total costs*

Having said that, on a 10-year forecasting (see Figure 43) there are some projects that go ahead one on other. It is the case of D2, that, by year 2024 D2 is the project with more money to collect, basically because it was the most capital-intensive project out of the six scenarios; and by the end of 2029 it places in third position, if not considering D1 project it goes to the second position just right after DC2 project.

**Figure 42** and Figure 43 have no legend in the graph, because the colors are for classification purposes. Red color belongs to the cost baseline, and it remains constant for every year in the forecast. There are five columns each year; in this order they are BC, D1, D2, C1 and DC2 (for more information about the acronyms, address to Table 46). The darker the color, the more cost recovery is needed to attain savings. Therefore, the column with the lightest color means it is the best option for that year, because it beats all the others and has made more savings. The cost recovery is cumulative.

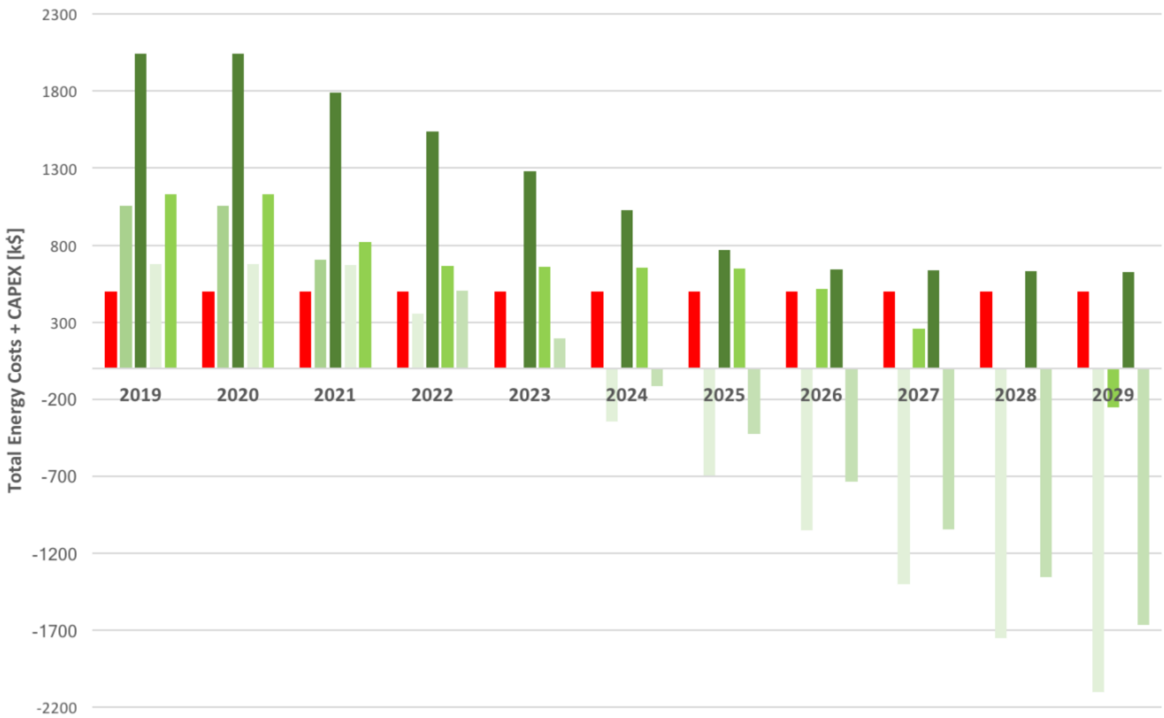

*Figure 43. 10-year forecasting on total costs*

The $CO_2$ tax applies to any facility that emits a proportion of carbon particles to the environment. In the power industry, this tax is implicitly in the purchase price, added by the generating companies to recovery their variable costs. In other industries, this may change, and could happen some facilities do not pay for it.

This fact makes sense in considering models with or without $CO_2$ allowances. In any case, DC2 was executed with CO2Tax Option activated, and attained better results than of D1 with $CO_2$ emissions deactivated. Hence, D2 with no CO2Tax will be even better option.

# 7 Conclusions

There is a renewable-like lack of awareness about the benefits new technologies can give. Benefits not only in terms of personal benefits, but also for the rest of the society and the environment.

This project intended to optimize the performance of a commercial – or business – reference building in order to minimize energy costs in the long-term run. The completion of the project has brought some results and conclusions along.

First, there is room for the entry of new technologies that displace the traditional ones, making some benefits in the community and gaining economic incentives to keep investing. The utilization of a single technology, or the straight-use of the electric grid to provide services is not economically and technically efficient anymore. The network was very useful in the old days, but there are existing technologies that procures the same service, but in a cheaper and more efficient way. Talking about efficient ways, combined heat and power technologies are a good option when both energies are demanded; so do solar PV panels in electricity generation as well.

Second, the project has proved that the best investment decision is the deployment of hybrids systems consisting of CHP machines (internal combustion engines and micro-gas turbines) and other sort of miscellaneous technologies whereof a handful of them must be named. Those technologies – or the so-called continuous technologies – are solar PV panels, absorption chillers and heat pumps (HP). The CHP and HVAC machines provide the baseload and stability to the system, whereas PV generates and decide whether or not to use the electricity or sell it to the grid. This option is valid only in countries with third-party permissions that allows small and medium consumers carried out the activity of selling and purchasing at any time.

Third, the optimization does not implicitly mean reduction in all aspects at the same time, but it does in the long-term. Achieving significant cost reduction carries the decision-making in spending large lumps of money, which are not affordable for everybody. Based on the project, a hotel chain could do it, due to its financial muscle. The big consumption happening in hotels might be sufficient reason to face such outlays; and also, those hotelier's firms have some certainty whether or not the investment is worthy.

Last but not least, the payback period depends on the difference between the cost baseline stemmed from the cost if no new investments happen; and the cost after investing in new technologies. The $CO_2$ allowances plays an important role in this regard, because it is ultimately the factor that determines one investment path or another. In this specific project, carbon emissions were considered and included in the analysis.

Summing up, there is still a long way to go in the development of local technologies, proven to be economically under certain circumstances and for certain consumers. The technology and knowledge is there, but new regulations and aggressive energy policies would be very helpful to give a momentum to the investors.

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# 9 Annex

This section is devoted to chart the input tables and graphs used in the development of the project.

Data consumptions of a large hotel broken down into five types of demand: electricity, cooling, space heating, water heating and natural gas demand.

*Source: [18].*

| **WEEK (Electricity)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 264.227511 | 257.10368 | 232.70782 | 228.203817 | 239.490236 | 273.86339 | 450.25878 | 558.214092 | 546.875204 | 485.898293 | 414.232106 | 409.953703 | 408.676137 | 382.940785 | 382.128916 | 380.178157 | 415.317939 | 475.999761 | 595.347765 | 616.54387 | 660.897064 | 630.668093 | 517.644691 | 373.950034 |
| February | 266.731165 | 258.919484 | 236.389753 | 233.471908 | 244.33749 | 278.547783 | 449.912472 | 561.972809 | 548.356744 | 491.751353 | 419.75486 | 415.483078 | 413.801722 | 388.506973 | 388.899914 | 389.215383 | 421.436414 | 473.236535 | 597.327009 | 619.334375 | 663.06183 | 631.446446 | 522.180735 | 385.310352 |
| March | 254.076252 | 242.779184 | 236.272599 | 240.68481 | 268.42302 | 395.377389 | 529.321322 | 551.23003 | 511.152507 | 447.5567 | 418.789287 | 416.706085 | 401.476059 | 393.134639 | 392.205499 | 413.68894 | 455.077519 | 546.45662 | 615.835193 | 651.702587 | 645.68351 | 563.775055 | 437.742375 | 312.157132 |
| April | 257.192776 | 244.275107 | 238.846294 | 249.337639 | 280.752838 | 451.879006 | 564.291946 | 551.897668 | 495.018941 | 423.325078 | 418.806114 | 418.081894 | 394.209024 | 394.010468 | 393.631471 | 427.761376 | 470.872282 | 587.251657 | 618.116475 | 664.487754 | 633.397995 | 525.585615 | 397.356457 | 277.481811 |
| May | 262.022982 | 244.729737 | 243.300535 | 252.538448 | 282.417615 | 453.757883 | 569.676222 | 548.024121 | 493.102145 | 421.079821 | 417.294791 | 416.826023 | 393.575021 | 393.469147 | 393.111578 | 427.023813 | 471.275007 | 586.038205 | 612.069395 | 665.260473 | 633.522444 | 524.859773 | 400.476923 | 279.933818 |
| June | 268.542446 | 242.122377 | 245.163962 | 254.63493 | 282.034269 | 451.875359 | 571.837578 | 544.421852 | 490.61399 | 418.060843 | 414.346019 | 413.896774 | 390.930822 | 390.612208 | 390.026713 | 423.631614 | 468.716805 | 582.402895 | 604.39048 | 663.3025 | 631.411362 | 521.906509 | 399.168936 | 282.954998 |
| July | 276.833365 | 244.788842 | 249.262353 | 256.382586 | 284.644613 | 449.15958 | 567.542293 | 545.728695 | 490.027761 | 417.28909 | 413.01578 | 412.589449 | 389.404491 | 389.175917 | 388.654695 | 422.374109 | 467.172638 | 581.666803 | 603.205865 | 661.697576 | 630.1314 | 521.550643 | 398.73353 | 285.970461 |
| August | 283.645177 | 256.25105 | 255.042421 | 261.100324 | 293.839217 | 458.272375 | 567.721388 | 542.676571 | 487.671606 | 414.979521 | 410.933807 | 410.611937 | 387.975612 | 387.666525 | 387.065619 | 421.093155 | 466.851932 | 581.46581 | 610.194081 | 661.449108 | 629.266202 | 520.050315 | 397.164408 | 292.753185 |
| September | 282.189984 | 252.264087 | 252.086666 | 259.666352 | 291.633409 | 457.683002 | 564.15068 | 544.644962 | 487.458428 | 414.598882 | 409.982508 | 409.508615 | 386.372198 | 386.256811 | 385.94396 | 420.259766 | 465.753303 | 583.019049 | 613.767098 | 660.165381 | 628.25738 | 520.004538 | 397.129839 | 290.629156 |
| October | 268.099964 | 241.825573 | 243.028511 | 256.313626 | 286.94084 | 461.104154 | 564.472146 | 550.456286 | 491.607725 | 419.876773 | 414.979251 | 413.794258 | 388.885315 | 388.657236 | 388.822041 | 423.361732 | 467.93043 | 597.215726 | 619.885823 | 662.237614 | 629.415217 | 522.355446 | 400.44647 | 283.773787 |
| November | 268.539322 | 255.449607 | 244.728801 | 239.808 | 255.042492 | 317.692385 | 476.906139 | 566.574349 | 537.698372 | 477.877593 | 419.503436 | 416.670574 | 411.439201 | 391.050552 | 391.050663 | 398.066963 | 438.336835 | 507.719817 | 604.987883 | 629.805438 | 659.843549 | 611.494027 | 499.225631 | 370.663928 |
| December | 260.569113 | 257.552675 | 232.854528 | 233.207317 | 239.195573 | 274.488397 | 450.705677 | 559.522324 | 551.753736 | 492.734375 | 421.711763 | 416.798259 | 416.148378 | 392.084003 | 392.08299 | 392.815045 | 433.736801 | 487.723812 | 604.322954 | 623.055205 | 664.421409 | 632.85961 | 521.934786 | 381.761095 |

| **PEAK (Electricity)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 297.78263 | 308.913368 | 259.559418 | 247.787842 | 258.009032 | 302.48017 | 506.287194 | 603.823373 | 594.193128 | 518.507542 | 437.105499 | 429.640588 | 429.533655 | 400.32468 | 400.48332 | 400.275424 | 434.995348 | 495.347211 | 620.353346 | 627.12706 | 677.219278 | 641.472517 | 541.009895 | 401.625702 |
| February | 301.784699 | 321.257475 | 250.99175 | 260.510504 | 274.375742 | 307.518845 | 492.860782 | 603.21382 | 594.353851 | 519.618377 | 438.213383 | 431.075026 | 431.322501 | 401.69116 | 401.912995 | 402.03908 | 438.807769 | 489.97039 | 621.482842 | 627.121185 | 676.362405 | 641.498098 | 543.109348 | 409.840164 |
| March | 296.315439 | 300.411018 | 258.107358 | 258.742855 | 301.112357 | 498.058561 | 605.120996 | 602.514668 | 593.712953 | 520.155935 | 439.756232 | 431.75564 | 432.324733 | 401.907899 | 401.487265 | 435.004692 | 476.496267 | 605.967493 | 626.551355 | 677.469701 | 677.070144 | 641.342348 | 541.03031 | 408.952609 |
| April | 311.887305 | 265.721033 | 266.674054 | 282.692937 | 303.623803 | 499.71531 | 603.474429 | 593.353596 | 520.204847 | 439.819608 | 431.11033 | 430.672306 | 403.018852 | 401.580901 | 401.549522 | 435.680578 | 477.210792 | 603.290589 | 624.550619 | 677.291495 | 641.966036 | 540.539904 | 407.576045 | 311.91157 |
| May | 311.445924 | 268.303306 | 277.022433 | 284.058545 | 305.636994 | 488.076045 | 603.384941 | 593.765095 | 519.601829 | 438.352392 | 430.773604 | 430.442233 | 402.036843 | 402.101803 | 402.026244 | 435.760921 | 476.409749 | 602.678927 | 618.683701 | 677.396547 | 641.474063 | 541.013467 | 407.745125 | 300.093121 |
| June | 307.886656 | 277.361057 | 271.420574 | 275.830809 | 306.118001 | 487.152127 | 603.387145 | 593.765095 | 519.229448 | 438.278085 | 430.533901 | 430.38238 | 402.082472 | 401.652317 | 401.276964 | 434.716259 | 476.227023 | 602.578857 | 614.839975 | 676.414791 | 640.308456 | 540.674147 | 407.745125 | 306.297042 |
| July | 312.480858 | 268.979136 | 276.240053 | 286.928515 | 319.22997 | 484.999072 | 601.995911 | 591.506413 | 518.347567 | 436.344297 | 426.348414 | 426.703403 | 399.853503 | 399.197859 | 397.737133 | 431.255217 | 474.251947 | 598.580209 | 607.761823 | 674.448873 | 638.204179 | 537.616657 | 405.508405 | 316.091848 |
| August | 321.359786 | 295.624789 | 285.184561 | 289.896303 | 315.257662 | 490.103196 | 601.985874 | 593.007644 | 514.254752 | 434.825908 | 426.076986 | 426.584335 | 395.565176 | 395.384304 | 394.803478 | 428.377072 | 475.647842 | 597.302596 | 616.021142 | 673.651196 | 637.552114 | 536.722564 | 403.7571 | 320.263283 |
| September | 311.939791 | 277.751576 | 279.312852 | 285.468756 | 313.28493 | 497.961777 | 599.825997 | 590.439237 | 516.574817 | 435.286494 | 428.061086 | 427.4176 | 399.590092 | 399.462702 | 399.229743 | 433.521347 | 473.511059 | 607.071157 | 623.674295 | 673.54829 | 637.152574 | 540.060896 | 407.237785 | 305.989731 |
| October | 313.340879 | 269.628824 | 257.483346 | 280.038156 | 312.125309 | 504.973243 | 605.453762 | 593.810204 | 519.587217 | 438.336453 | 429.348861 | 427.543528 | 400.410844 | 399.79759 | 400.555946 | 435.185423 | 477.712767 | 619.144162 | 626.021963 | 676.596575 | 641.112495 | 540.539246 | 406.691954 | 317.441255 |
| November | 310.133224 | 320.213089 | 267.304759 | 277.715747 | 307.80957 | 508.250408 | 606.412011 | 603.285793 | 593.091002 | 518.046631 | 436.176534 | 430.388933 | 428.486852 | 400.090073 | 400.476969 | 433.502832 | 478.187122 | 617.923799 | 625.803302 | 676.17447 | 677.360483 | 641.878332 | 543.097725 | 408.020998 |
| December | 288.375004 | 294.003738 | 262.603596 | 252.816673 | 258.06747 | 300.753305 | 501.796605 | 603.331191 | 593.851988 | 519.94724 | 438.702586 | 429.819778 | 429.202203 | 401.550653 | 401.176778 | 401.772019 | 443.485271 | 494.350934 | 620.818376 | 627.062042 | 677.091874 | 642.131022 | 541.563373 | 406.042267 |

| **WEEKEND (Electricity)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 259.625635 | 243.66028 | 224.568636 | 232.080708 | 235.557701 | 287.774216 | 492.282314 | 601.269104 | 514.484212 | 480.675409 | 409.135432 | 411.259439 | 410.776126 | 390.919273 | 391.288088 | 391.555857 | 427.066371 | 486.502596 | 593.393902 | 621.789372 | 676.20524 | 640.988147 | 517.441048 | 375.537481 |
| February | 253.697011 | 240.213371 | 227.660281 | 231.774931 | 232.488369 | 284.9515 | 488.49489 | 600.855199 | 514.574696 | 479.7031 | 409.005781 | 410.463661 | 409.567166 | 390.020213 | 390.155412 | 390.487375 | 423.044478 | 482.765165 | 596.347488 | 622.399522 | 673.918932 | 640.400883 | 518.504487 | 374.626221 |
| March | 237.221892 | 230.822575 | 227.13988 | 231.436836 | 266.114505 | 423.194451 | 561.475014 | 538.631165 | 486.986161 | 431.02623 | 404.171095 | 404.013543 | 392.116575 | 387.117966 | 387.14055 | 407.503728 | 454.389489 | 547.452714 | 614.466252 | 658.437739 | 652.670333 | 556.85369 | 421.585704 | 303.602466 |
| April | 235.68404 | 241.943714 | 230.830981 | 242.834555 | 294.693011 | 491.961151 | 602.129051 | 518.591037 | 478.680989 | 407.718825 | 410.639548 | 410.42858 | 390.116348 | 390.136773 | 389.827139 | 422.191933 | 473.220645 | 582.361634 | 622.463769 | 676.671259 | 639.857906 | 520.177537 | 390.591063 | 266.64995 |
| May | 244.090271 | 239.689747 | 243.027612 | 249.54938 | 296.660171 | 481.48866 | 602.037231 | 519.165278 | 482.789496 | 410.940176 | 412.714478 | 412.241261 | 392.61652 | 392.452771 | 392.049473 | 425.775451 | 475.303636 | 581.551185 | 615.000025 | 675.920371 | 639.776803 | 521.160141 | 396.525374 | 265.513817 |
| June | 257.396873 | 239.625601 | 241.092501 | 249.181444 | 294.201842 | 479.520674 | 600.639295 | 517.686559 | 480.773287 | 409.014129 | 410.379939 | 409.818856 | 390.264509 | 389.870196 | 389.30451 | 422.999072 | 472.785356 | 579.038447 | 608.637787 | 673.653737 | 637.647312 | 519.153126 | 397.190345 | 273.505053 |
| July | 274.723291 | 242.91086 | 246.947259 | 254.799577 | 297.456013 | 466.120636 | 589.989439 | 525.093497 | 480.90014 | 409.643868 | 409.526715 | 409.117618 | 387.9451 | 387.976956 | 387.344085 | 420.880574 | 469.486795 | 577.663833 | 605.067058 | 669.950154 | 633.26028 | 517.92095 | 396.684896 | 284.388789 |
| August | 276.269214 | 250.153169 | 250.408642 | 255.703899 | 298.582859 | 480.964584 | 598.242713 | 514.893893 | 477.167965 | 404.950798 | 406.074139 | 405.503767 | 385.758995 | 385.461074 | 385.089431 | 419.017256 | 470.014939 | 576.120978 | 611.614605 | 671.516748 | 635.436994 | 516.799411 | 394.564078 | 286.095502 |
| September | 271.817641 | 247.558063 | 246.749755 | 255.7327 | 307.119022 | 485.570864 | 596.647002 | 513.399231 | 474.662377 | 401.648755 | 402.346694 | 401.429999 | 382.086 | 382.222959 | 382.067839 | 416.564205 | 468.385891 | 577.948238 | 619.258594 | 670.115221 | 634.184199 | 515.640471 | 393.713464 | 281.414002 |
| October | 238.074738 | 242.535619 | 248.31927 | 246.224155 | 298.92693 | 493.239949 | 601.85388 | 517.886898 | 480.705689 | 408.336655 | 408.58819 | 406.614025 | 386.413734 | 386.411925 | 386.613249 | 421.385401 | 472.757796 | 592.136022 | 622.676156 | 672.92487 | 637.181026 | 518.696856 | 396.820059 | 275.521931 |
| November | 258.862167 | 246.793647 | 235.596093 | 237.414693 | 245.130321 | 309.053195 | 500.443283 | 591.021594 | 512.047415 | 471.383102 | 407.413401 | 408.167511 | 405.271316 | 387.770707 | 387.661387 | 392.185233 | 433.837344 | 503.095491 | 600.568865 | 629.899736 | 669.579569 | 625.621478 | 504.593655 | 371.831312 |
| December | 252.592643 | 244.724212 | 229.223818 | 232.483317 | 232.650456 | 287.907479 | 491.733796 | 601.928514 | 514.991302 | 478.918035 | 407.188669 | 409.625134 | 410.572894 | 391.097952 | 391.278308 | 391.690048 | 429.972697 | 490.798487 | 598.522495 | 626.308361 | 676.521378 | 641.185607 | 514.503177 | 364.305873 |

| **WEEK (Cooling)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 57.6317701 | 58.2663668 | 58.0880578 | 53.1443807 | 57.2076853 | 61.8030409 | 84.4607423 | 110.205793 | 113.005769 | 110.695546 | 111.098389 | 111.184273 | 110.245111 | 108.857607 | 108.030768 | 106.399144 | 107.344223 | 109.32829 | 111.770531 | 112.933435 | 114.430735 | 116.560671 | 111.970844 | 92.8691382 |
| February | 60.1397562 | 60.5027189 | 61.6848185 | 58.3128805 | 61.2533596 | 66.6612675 | 88.8418677 | 113.864468 | 114.439004 | 115.923693 | 116.578455 | 116.900098 | 115.636255 | 114.556809 | 115.112551 | 115.478421 | 114.185132 | 113.069138 | 113.168806 | 115.475915 | 116.569496 | 116.429135 | 115.621979 | 103.757349 |
| March | 55.3257165 | 61.1613914 | 61.1968887 | 62.0338388 | 65.7889085 | 81.899994 | 108.273291 | 114.971011 | 117.949942 | 119.504938 | 119.726971 | 119.412432 | 119.380662 | 119.035202 | 118.238356 | 118.459616 | 118.816413 | 118.757763 | 118.350401 | 118.938942 | 118.322812 | 117.619702 | 111.018079 | 78.8882294 |
| April | 58.4451465 | 68.3285994 | 63.1127971 | 66.0138198 | 68.6170463 | 95.5746908 | 116.370714 | 116.910387 | 117.805136 | 119.058475 | 119.681697 | 119.573721 | 119.322787 | 119.089764 | 118.743145 | 119.353623 | 118.661986 | 118.393466 | 117.870294 | 118.025251 | 117.480679 | 118.017952 | 115.299498 | 68.890086 |
| May | 62.5089 | 67.6151997 | 66.3669033 | 68.4375983 | 69.9251961 | 98.8913326 | 116.649222 | 116.46318 | 116.911328 | 117.891842 | 118.466695 | 118.541901 | 118.472972 | 118.230356 | 117.864756 | 118.149379 | 117.879672 | 117.107863 | 117.140404 | 116.807727 | 116.153772 | 117.259081 | 118.268122 | 69.8546666 |
| June | 68.7812321 | 67.0527667 | 67.0906082 | 69.7671884 | 72.8828057 | 95.3028298 | 115.375838 | 115.165687 | 115.206606 | 115.670899 | 115.893165 | 115.928523 | 115.880102 | 115.507346 | 114.986143 | 114.837564 | 114.6939 | 113.57506 | 113.69074 | 113.56274 | 113.12476 | 114.362524 | 116.840651 | 72.9314807 |
| July | 80.145999 | 69.8850237 | 74.4055369 | 72.6529831 | 73.7778611 | 92.8348615 | 110.624998 | 110.414595 | 110.106205 | 110.351114 | 110.591404 | 110.779042 | 111.007996 | 110.863608 | 110.362861 | 110.07828 | 110.344734 | 109.099564 | 109.584504 | 110.021722 | 109.577544 | 110.842629 | 113.378135 | 77.4579297 |
| August | 82.3267441 | 78.1241987 | 77.0435983 | 76.0396806 | 77.37808 | 96.1503934 | 110.332059 | 110.044098 | 109.82852 | 110.238264 | 110.500513 | 110.811931 | 111.303396 | 110.969633 | 110.342408 | 110.338199 | 111.070391 | 110.213803 | 110.221204 | 109.651196 | 108.746619 | 109.784097 | 112.062499 | 81.6492201 |
| September | 77.9248305 | 70.9471187 | 71.1317768 | 72.7536944 | 74.9541532 | 94.3874981 | 109.618675 | 108.404172 | 107.3115 | 107.540825 | 107.670644 | 107.644208 | 107.829906 | 107.881406 | 107.783369 | 108.385804 | 109.666428 | 109.570394 | 109.841419 | 109.097833 | 107.961148 | 109.004352 | 111.568043 | 77.1055761 |
| October | 66.9994219 | 64.9773272 | 65.739464 | 71.034577 | 72.6554168 | 94.0303403 | 113.805867 | 114.276844 | 113.909296 | 114.188843 | 113.94892 | 113.174908 | 112.708763 | 112.436679 | 112.703378 | 113.703859 | 114.676001 | 114.161928 | 113.537982 | 112.954409 | 112.324645 | 113.731985 | 116.539349 | 72.7132977 |
| November | 61.8177257 | 61.1133565 | 67.966446 | 62.3016793 | 66.093765 | 74.4200092 | 99.8197185 | 116.262523 | 115.778322 | 116.229098 | 116.447511 | 116.597001 | 116.351341 | 116.269885 | 116.497311 | 117.291135 | 117.835416 | 116.865857 | 117.330867 | 116.740289 | 116.556226 | 116.355455 | 116.790604 | 102.651906 |
| December | 54.4004592 | 58.7264441 | 58.9531123 | 57.1548474 | 57.7263154 | 63.4654863 | 88.2560397 | 113.974018 | 115.889587 | 115.785954 | 117.167828 | 117.125102 | 116.718534 | 117.095538 | 117.353297 | 118.289475 | 120.233181 | 120.206188 | 119.666019 | 119.232916 | 118.595149 | 118.377339 | 115.274927 | 100.307449 |

| **PEAK (Cooling)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 82.3148168 | 82.1312059 | 85.9366221 | 74.0066067 | 77.2966663 | 78.8264372 | 109.640798 | 119.995951 | 119.80164 | 121.003611 | 121.1762 | 121.430698 | 121.610316 | 121.317165 | 122.796913 | 122.752658 | 123.250977 | 123.119854 | 122.107305 | 121.110195 | 120.295205 | 119.954782 | 120.508319 | 121.322032 |
| February | 80.3937541 | 93.4840988 | 76.678741 | 80.5213145 | 81.5834808 | 84.3955999 | 102.37718 | 120.029327 | 120.40563 | 120.673169 | 121.768182 | 121.418192 | 121.708848 | 122.285838 | 122.412819 | 122.193688 | 122.668439 | 122.505686 | 120.966379 | 120.766096 | 120.158155 | 120.229452 | 120.481739 | 121.083905 |
| March | 83.1563377 | 84.9555596 | 84.6419929 | 80.958631 | 83.1841232 | 107.500789 | 120.074873 | 119.868096 | 120.571141 | 121.449403 | 121.944844 | 121.740583 | 121.861968 | 122.205062 | 122.335053 | 122.127643 | 122.733237 | 122.316978 | 120.879861 | 120.657669 | 119.979234 | 120.409919 | 121.279503 | 121.462783 |
| April | 86.0484673 | 82.4358942 | 81.8596036 | 83.0671566 | 81.9909189 | 110.739502 | 120.430651 | 119.722024 | 120.858588 | 121.314254 | 121.968642 | 121.930945 | 121.514545 | 121.11642 | 121.15618 | 121.539342 | 121.136638 | 120.329393 | 120.558106 | 120.142254 | 119.861817 | 120.109741 | 121.137815 | 84.9606939 |
| May | 83.9658695 | 83.5347311 | 84.7485846 | 85.3546427 | 83.308028 | 107.240691 | 119.966731 | 118.98649 | 120.148054 | 120.907968 | 121.426378 | 121.801243 | 122.08628 | 121.902496 | 121.941243 | 122.33209 | 119.905935 | 119.656151 | 120.091444 | 120.399308 | 119.311613 | 120.434665 | 121.439557 | 77.2387036 |
| June | 83.5231854 | 85.0445372 | 80.3991867 | 82.597729 | 86.4664443 | 106.469496 | 119.988143 | 119.105925 | 119.606649 | 120.072798 | 120.318501 | 120.504897 | 120.540194 | 120.320168 | 119.39873 | 119.860019 | 119.905935 | 118.85807 | 118.09042 | 118.292033 | 117.690613 | 119.086537 | 121.473656 | 81.8228673 |
| July | 89.9723815 | 91.3847203 | 88.9310211 | 86.0480834 | 91.6374489 | 101.297845 | 116.308324 | 117.336019 | 116.529748 | 117.572003 | 118.62674 | 117.808295 | 117.387499 | 116.564433 | 115.538794 | 115.247479 | 114.945491 | 113.360129 | 114.410856 | 114.252284 | 113.734362 | 115.486431 | 117.785587 | 93.1852032 |
| August | 93.5760013 | 101.217257 | 95.3790186 | 91.1644914 | 92.2933648 | 101.91578 | 115.955451 | 116.762557 | 116.800444 | 114.683281 | 114.555088 | 115.155771 | 115.500933 | 115.909798 | 115.768488 | 115.953524 | 116.336839 | 114.34897 | 113.909783 | 112.797076 | 111.769661 | 113.1745 | 114.670196 | 96.5236326 |
| September | 96.386276 | 88.7289215 | 89.4368666 | 93.424519 | 87.4924956 | 106.639203 | 117.423923 | 113.4834 | 113.206538 | 113.804673 | 114.634842 | 114.437638 | 115.801934 | 115.795903 | 115.344566 | 115.637278 | 116.884983 | 117.746286 | 117.258529 | 115.761456 | 115.666909 | 116.30509 | 119.328493 | 99.453745 |
| October | 90.1916417 | 95.8677139 | 79.9122125 | 86.240865 | 86.8088224 | 109.012522 | 118.116783 | 118.131358 | 117.776007 | 118.826235 | 119.469929 | 118.635795 | 117.193136 | 117.256687 | 118.355664 | 119.864832 | 120.355007 | 119.091584 | 118.319616 | 117.576084 | 117.671511 | 118.652299 | 121.591097 | 90.1772987 |
| November | 85.9784641 | 91.7494586 | 86.0291939 | 87.707096 | 82.6529434 | 110.417936 | 118.831842 | 118.349234 | 118.957288 | 120.936241 | 121.20013 | 121.897483 | 122.387286 | 122.213864 | 122.642873 | 122.974134 | 123.424636 | 121.264766 | 120.424395 | 120.779517 | 120.244245 | 120.395109 | 121.214377 | 121.092237 |
| December | 73.3734783 | 81.201357 | 89.21595 | 79.3008654 | 78.1385438 | 78.835081 | 108.270517 | 120.881581 | 119.025517 | 119.464629 | 121.292207 | 121.879389 | 121.011885 | 121.195392 | 121.050774 | 121.281442 | 122.463549 | 122.244596 | 121.350064 | 120.477017 | 119.938359 | 120.355021 | 120.211222 | 121.826667 |

| **WEEKEND (Cooling)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 59.9583021 | 58.7606803 | 55.8813113 | 60.5841288 | 57.8442586 | 66.3197463 | 96.8487744 | 116.730149 | 114.710183 | 117.668146 | 118.118545 | 118.797112 | 118.729632 | 117.935084 | 118.131443 | 118.652163 | 119.584857 | 114.35684 | 112.918524 | 114.708846 | 118.669287 | 118.468124 | 115.338891 | 98.081258 |
| February | 53.9704494 | 55.065013 | 57.4149624 | 59.5564743 | 54.6307978 | 63.623909 | 98.1621053 | 116.129106 | 114.337572 | 115.902679 | 117.202912 | 117.701962 | 117.454698 | 117.455677 | 117.629204 | 118.07183 | 117.29282 | 117.383412 | 116.249159 | 115.70902 | 116.679822 | 118.123496 | 116.516949 | 97.3254285 |
| March | 47.9894016 | 54.7640657 | 55.9725575 | 55.2139153 | 58.7340913 | 86.1977115 | 110.731724 | 110.751284 | 111.975273 | 116.571881 | 112.9819 | 112.810047 | 114.017554 | 115.515505 | 115.524064 | 113.507631 | 115.706485 | 118.084377 | 116.928998 | 118.261188 | 118.895394 | 114.714015 | 102.525295 | 77.291049 |
| April | 50.5617761 | 69.0340308 | 59.3868127 | 63.7664555 | 71.9477264 | 105.011188 | 117.368798 | 118.478362 | 115.426885 | 116.61773 | 118.391075 | 118.560564 | 117.552765 | 117.582167 | 117.320401 | 115.978825 | 116.554408 | 118.20088 | 119.132661 | 118.585049 | 116.693902 | 117.518499 | 112.507024 | 64.5772796 |
| May | 58.0161594 | 67.2500482 | 70.2008182 | 69.8121296 | 75.9118469 | 101.241 | 116.345785 | 118.167515 | 118.892542 | 119.374876 | 120.045828 | 120.092076 | 119.978572 | 119.764417 | 119.404279 | 119.384846 | 118.193401 | 116.769493 | 117.733358 | 117.697188 | 116.355514 | 117.975318 | 117.984106 | 63.0721483 |
| June | 68.7058422 | 66.392673 | 67.5959268 | 68.6774894 | 75.1456448 | 98.216782 | 113.835159 | 115.611186 | 115.770884 | 116.351452 | 116.629378 | 116.556139 | 116.49685 | 115.963758 | 115.341786 | 115.145445 | 114.265694 | 112.865243 | 113.973112 | 114.085035 | 112.907598 | 114.668146 | 117.352324 | 69.3459309 |
| July | 79.5614886 | 67.1996585 | 70.4127094 | 71.1767976 | 76.2634577 | 92.6571427 | 110.835155 | 112.340825 | 112.396769 | 112.533334 | 112.45338 | 112.523119 | 113.196963 | 113.189151 | 112.540547 | 111.944608 | 111.833455 | 110.449502 | 110.713073 | 111.030422 | 110.326456 | 111.966553 | 114.47391 | 76.3631759 |
| August | 85.1918457 | 75.2610379 | 75.28515 | 73.7540857 | 73.8836438 | 95.2002972 | 109.645237 | 110.963274 | 110.56367 | 110.837503 | 111.099001 | 111.126458 | 110.987227 | 110.639768 | 110.214972 | 109.93716 | 110.350761 | 108.752445 | 109.493081 | 110.373232 | 109.067519 | 110.572421 | 112.911249 | 80.2196609 |
| September | 81.6342198 | 73.0829823 | 72.2099713 | 73.7232375 | 81.1771351 | 93.6756601 | 107.976372 | 109.555263 | 107.981851 | 107.564452 | 107.394205 | 107.074312 | 107.310623 | 107.39445 | 107.192802 | 107.650643 | 108.852235 | 108.695628 | 109.299655 | 108.853921 | 107.787148 | 109.42973 | 112.158686 | 76.4906502 |
| October | 52.8172724 | 68.9126709 | 74.1568501 | 66.127587 | 75.0753598 | 97.1485076 | 115.109857 | 116.217952 | 115.413904 | 115.019312 | 114.202773 | 112.941106 | 112.205021 | 112.200506 | 112.55433 | 113.712283 | 114.467458 | 113.473015 | 113.41083 | 113.144215 | 112.368054 | 114.12751 | 116.888331 | 71.4829433 |
| November | 60.1492069 | 62.3030141 | 64.4181168 | 64.4463096 | 61.6760325 | 67.9027782 | 101.442584 | 115.437353 | 115.313809 | 115.211581 | 115.213282 | 114.810856 | 114.476471 | 114.516292 | 114.483157 | 115.59388 | 117.305834 | 117.80923 | 116.701195 | 116.626944 | 115.169526 | 115.736284 | 115.592476 | 102.134652 |
| December | 53.5209181 | 59.7215221 | 59.8823472 | 60.2253271 | 55.1001734 | 65.8028957 | 98.6148337 | 117.633019 | 115.409497 | 116.029503 | 116.548362 | 117.778962 | 119.102617 | 118.966557 | 119.300206 | 119.878369 | 118.803784 | 118.655047 | 118.641237 | 119.881697 | 119.463655 | 119.058963 | 112.669324 | 87.1985813 |

| **WEEK (Heating)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 33.0366632 | 29.7434979 | 27.5034692 | 26.1213203 | 24.60256 | 22.963861 | 21.381711 | 51.2947962 | 34.5827444 | 18.4120934 | 12.0664079 | 9.30851469 | 8.17485217 | 9.99977717 | 11.3943633 | 10.8489016 | 10.7312274 | 16.0336979 | 20.1904928 | 23.0161962 | 26.6344544 | 33.3293156 | 41.6159875 | 48.7926334 |
| February | 27.009084 | 25.0192256 | 21.8856051 | 20.2292554 | 19.4555866 | 17.8083778 | 17.5886357 | 33.6126118 | 23.375127 | 11.5957345 | 9.08232785 | 7.11062714 | 6.42977077 | 7.03870012 | 7.45259327 | 8.41138999 | 9.10715311 | 13.8421346 | 18.4183204 | 19.9523376 | 20.8202005 | 22.773843 | 26.8884922 | 32.5646757 |
| March | 23.6944446 | 24.1103809 | 23.2128053 | 20.5478657 | 19.1903783 | 19.0529602 | 26.0897483 | 16.1826446 | 6.81594464 | 3.41863196 | 3.3633404 | 3.26531106 | 3.34277223 | 3.85506387 | 4.55671695 | 4.50029006 | 6.90171486 | 12.0434752 | 17.3932416 | 19.3652863 | 21.392465 | 24.3016566 | 28.0253929 | 27.6277244 |
| April | 17.679348 | 20.0546392 | 22.1006389 | 21.4454545 | 19.1492754 | 15.238657 | 16.6650501 | 9.69801971 | 4.261105 | 4.21043325 | 4.3773271 | 4.19054762 | 4.28236647 | 4.41144992 | 4.73960871 | 4.32880696 | 8.29276931 | 11.2542043 | 16.0722652 | 17.6975114 | 18.3553594 | 20.044341 | 23.557999 | 16.1933821 |
| May | 6.45225788 | 8.04089296 | 9.2726187 | 9.82740964 | 10.6908916 | 7.74347864 | 15.0415864 | 5.90810606 | 1.38930102 | 5.26210835 | 6.5194308 | 6.45993074 | 7.02299424 | 7.17895582 | 7.21237782 | 5.2362337 | 10.6383785 | 10.2064971 | 10.2950044 | 11.4256437 | 12.9046359 | 15.9012789 | 20.2317008 | 5.09569599 |
| June | 1.63081575 | 2.18003037 | 2.45251788 | 2.65412736 | 2.33166667 | 1.37805545 | 16.8026294 | 6.91651482 | 0.54502797 | 4.37307454 | 6.07690583 | 6.10895475 | 6.69894861 | 6.78254026 | 6.66591776 | 4.26491976 | 10.7296499 | 11.0286112 | 10.967368 | 11.7549776 | 13.3468168 | 17.2956205 | 22.3758572 | 2.331672 |
| July | 0.19367936 | 0.39928639 | 0.53982598 | 0.75083052 | 0.81881761 | 0.39493917 | 17.4302407 | 6.91646424 | 0 | 0.104934 | 0.40225288 | 0.37956411 | 0.37428524 | 0.3659715 | 0.36666255 | 0.32825602 | 6.93070951 | 9.94086447 | 10.9496627 | 11.6273218 | 12.2470914 | 13.3693404 | 17.6212568 | 0.03973518 |
| August | 0.25567448 | 0.40032289 | 0.32707524 | 0.28355894 | 0.40362047 | 0.23540817 | 17.6563954 | 6.92717029 | 0 | 0 | 0.00161829 | 0.00366497 | 0.00404579 | 0.00456941 | 0.00123754 | 0.00963084 | 6.34874461 | 9.97824422 | 10.9869564 | 11.6770197 | 12.3006196 | 12.989343 | 15.4814582 | 0.02723296 |
| September | 0.18548695 | 0.74253662 | 1.02523209 | 1.61919663 | 2.75661453 | 3.06606292 | 17.4155568 | 6.690331 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.15232772 | 9.68843697 | 10.6694396 | 11.3407951 | 11.9505301 | 12.5784123 | 15.1471878 | 0.11878797 |
| October | 3.66422894 | 5.97595701 | 7.66451295 | 9.1957887 | 14.3741356 | 13.1433229 | 20.3454296 | 7.24520673 | 0.12687089 | 0.38798425 | 0.71599045 | 0.63199526 | 0.59941578 | 0.51221864 | 0.55280333 | 0.61279878 | 5.8986981 | 7.92513356 | 8.41337755 | 8.98437158 | 9.70754016 | 11.6108203 | 15.6719799 | 2.4248073 |
| November | 14.3232084 | 16.5984233 | 16.690059 | 16.5964337 | 17.0018209 | 16.073616 | 16.0013264 | 14.8394891 | 4.93337898 | 1.50715708 | 1.28045934 | 1.37347004 | 1.54807255 | 1.92545261 | 2.19372734 | 2.43190762 | 3.10115622 | 6.41592286 | 7.36732999 | 7.98287457 | 9.01098103 | 10.9020005 | 15.7144542 | 18.4600807 |
| December | 33.3021746 | 34.0058432 | 31.2934445 | 28.6516681 | 26.2510733 | 22.4637648 | 19.0335649 | 35.1810681 | 15.66208 | 4.48319702 | 1.36356164 | 1.40740604 | 1.43056803 | 1.6846041 | 2.02962106 | 2.39126998 | 2.86633854 | 6.96273195 | 8.77460964 | 9.77042793 | 11.1083286 | 16.0141622 | 24.8178352 | 32.8278159 |

| **PEAK (Heating)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 58.5943638 | 52.7282267 | 53.0500052 | 55.3683921 | 45.6113553 | 38.9155559 | 50.476739 | 109.53916 | 95.9714387 | 81.8364491 | 88.158242 | 59.6687134 | 47.2336376 | 72.9751341 | 98.5153672 | 60.4930558 | 51.798626 | 58.4863431 | 65.2683051 | 72.037337 | 110.096912 | 130.061324 | 128.9849 | 110.668695 |
| February | 47.7851722 | 39.9993572 | 35.8369286 | 30.3003189 | 42.9026497 | 41.6190434 | 35.0433864 | 93.3356354 | 70.7842135 | 38.9376048 | 40.7622857 | 31.5641152 | 25.7968647 | 29.0945404 | 34.1863601 | 38.1709952 | 41.8511049 | 50.273802 | 59.5933467 | 53.8357289 | 53.551494 | 54.7652608 | 57.6438721 | 61.1814879 |
| March | 40.3939906 | 53.1631391 | 45.906753 | 38.5125857 | 32.8508114 | 34.599064 | 79.7672677 | 28.2362216 | 13.7129489 | 8.18809997 | 8.81734239 | 9.71862326 | 10.7101142 | 11.1974222 | 17.8288138 | 19.568756 | 25.323609 | 38.7250282 | 44.4327454 | 43.929404 | 41.2116399 | 43.6370391 | 50.1604981 | 44.3510319 |
| April | 41.5019075 | 43.5134903 | 50.1426165 | 51.7544933 | 51.7316367 | 39.3002736 | 33.2909975 | 30.7331146 | 20.4145068 | 14.1030053 | 11.5334421 | 8.20262465 | 8.24700061 | 8.10652657 | 8.45101111 | 10.5401467 | 16.6410024 | 25.8650068 | 43.4073598 | 39.0801502 | 38.4783315 | 40.1037027 | 44.8409304 | 38.0749697 |
| May | 39.1992425 | 57.526769 | 82.8782187 | 81.4432531 | 66.820185 | 55.0808367 | 35.8254997 | 8.29770787 | 2.35060914 | 8.57807889 | 9.9051718 | 9.89721738 | 11.6053277 | 11.8672315 | 12.3575225 | 12.3167094 | 19.8994043 | 19.3955679 | 26.8229371 | 34.6888762 | 37.2679157 | 36.0360768 | 38.3491979 | 34.9877148 |
| June | 16.8738358 | 13.7681771 | 13.5002039 | 13.7228283 | 12.8533391 | 7.35563231 | 20.2478456 | 8.29770787 | 2.35060914 | 8.57807889 | 9.9051718 | 9.89721738 | 11.6053277 | 11.8672315 | 12.3575225 | 12.3167094 | 19.8994043 | 16.3498107 | 13.5848155 | 20.4000473 | 33.7040919 | 40.2312932 | 44.0319129 | 20.2845894 |
| July | 0.85329401 | 0.97678007 | 6.55078103 | 10.4024419 | 11.6161568 | 3.24930815 | 17.85259 | 7.20820739 | 0 | 1.82635539 | 3.61541363 | 3.62470566 | 3.15419945 | 2.82221612 | 2.61269961 | 2.53124407 | 9.52154109 | 10.2517492 | 11.2625952 | 11.9454772 | 12.5674594 | 15.5503396 | 20.25851 | 0.10352346 |
| August | 0.86108152 | 0.86979873 | 0.84801875 | 0.82196617 | 0.81727231 | 0.33218164 | 18.1092231 | 7.20368395 | 0 | 0 | 0.03398405 | 0.07696439 | 0.08496151 | 0.09595755 | 0.02498912 | 0.2022477 | 8.22498081 | 10.4317256 | 11.3900236 | 12.0603477 | 12.6863104 | 14.8210049 | 19.3950104 | 0.10268615 |
| September | 0.91417779 | 5.31883793 | 11.7861137 | 17.2937386 | 25.5195287 | 28.9920827 | 22.1316299 | 7.20572956 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.86127626 | 10.5198679 | 11.4985451 | 12.1462573 | 12.7713481 | 13.5843131 | 17.9905369 | 0.82524148 |
| October | 31.6777691 | 55.7589474 | 58.4712533 | 51.7117557 | 90.6282208 | 95.2235699 | 63.9811896 | 15.8256728 | 1.30228253 | 2.3981118 | 3.93951703 | 3.96880435 | 3.81247121 | 3.64532341 | 4.17300238 | 4.8755423 | 12.3411531 | 12.8225262 | 11.3213949 | 12.0082545 | 12.6216679 | 18.0335597 | 22.528321 | 21.3010639 |
| November | 40.1864598 | 43.2036094 | 41.9194754 | 35.25803 | 29.904202 | 35.1747993 | 39.0602873 | 41.5411653 | 22.5435104 | 12.6944823 | 3.96330436 | 5.17567701 | 5.95742927 | 9.87741192 | 10.2192561 | 8.13599467 | 14.0094225 | 24.0645387 | 30.4041205 | 37.0053589 | 42.7883275 | 43.4306902 | 43.9559548 | 43.0181792 |
| December | 50.601927 | 52.3736738 | 55.3825375 | 45.7308496 | 38.0955389 | 32.3914079 | 27.927712 | 91.963647 | 28.1899974 | 21.2911773 | 3.39111258 | 3.5190871 | 3.83007521 | 4.29589426 | 4.82515884 | 4.91587172 | 8.78831956 | 18.2550191 | 23.1244136 | 26.3744664 | 25.8137529 | 37.9092194 | 48.0772488 | 52.8768586 |

| **WEEKEND (Heating)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 26.9541381 | 25.7047421 | 24.1070279 | 24.5824461 | 23.7248175 | 20.182546 | 17.9721621 | 42.3115144 | 25.4840506 | 10.0426985 | 4.07707454 | 2.87079653 | 2.51237713 | 2.48048239 | 2.81634913 | 3.16494041 | 3.14216729 | 8.89915617 | 13.7791222 | 14.7317756 | 15.9198297 | 18.471217 | 25.185574 | 38.9165397 |
| February | 31.5051086 | 29.5332361 | 26.990824 | 25.5201526 | 23.2928507 | 20.7507018 | 18.3531201 | 32.2700759 | 17.0036164 | 6.13724306 | 3.86812948 | 3.43038232 | 3.75392217 | 4.45998212 | 5.37510614 | 5.98724743 | 4.79015469 | 9.57471691 | 13.7951405 | 16.5070758 | 18.0562884 | 20.0503006 | 25.635456 | 34.8197224 |
| March | 33.1740091 | 32.6338245 | 30.5358314 | 31.8390533 | 29.063175 | 22.0187924 | 31.1486258 | 31.2906299 | 16.4125499 | 10.0888597 | 8.34720317 | 12.0093493 | 9.32375757 | 8.39231308 | 8.97184675 | 12.5333185 | 12.8254257 | 16.1478509 | 20.524723 | 25.2180751 | 29.0635595 | 28.4580146 | 36.5786601 | 27.4984829 |
| April | 19.1869228 | 18.6879071 | 19.0987119 | 18.8580797 | 18.3747438 | 16.9162808 | 18.3340432 | 10.9620017 | 7.98859985 | 8.63237562 | 6.54614426 | 5.66172392 | 5.68409292 | 5.94262557 | 6.08258542 | 4.32601749 | 8.03570063 | 10.0290377 | 13.9956618 | 17.5405116 | 21.9369543 | 23.6856547 | 24.6650082 | 16.9314315 |
| May | 10.1036317 | 10.8647749 | 12.6295579 | 13.7846851 | 13.9046163 | 8.79485686 | 13.9812846 | 6.33374516 | 1.98781949 | 6.5183283 | 7.34879483 | 7.23346631 | 7.25396315 | 7.3120023 | 7.13998269 | 2.9860793 | 8.24448313 | 10.1923553 | 11.2140071 | 13.8726937 | 13.921972 | 17.9084043 | 22.7836592 | 7.84305952 |
| June | 1.94825096 | 2.21833344 | 4.00621522 | 5.73624394 | 5.35799596 | 2.39580545 | 16.2879036 | 7.03508961 | 0.83499555 | 5.44225636 | 6.94271469 | 7.05500357 | 7.03305291 | 7.07002196 | 6.74182083 | 2.16991408 | 8.48567562 | 10.4714116 | 10.672387 | 11.3789577 | 12.0003332 | 15.4002451 | 20.8475392 | 1.05378835 |
| July | 0.1159313 | 0.50097057 | 0.30186037 | 0.29761012 | 0.54234118 | 0.29299202 | 17.5737791 | 6.98294049 | 0 | 0.03232187 | 0.26271034 | 0.30706765 | 0.23919488 | 0.22231896 | 0.23493652 | 0.05706468 | 6.47791205 | 9.97330514 | 10.9527196 | 11.6223104 | 12.2436933 | 13.0700834 | 16.8236125 | 0.04224799 |
| August | 0.13952327 | 0.44508387 | 0.2549373 | 0.30068757 | 0.32950412 | 0.25551802 | 17.7871833 | 7.0827628 | 0 | 0 | 0 | 0 | 0.0005996 | 0.00179881 | 0 | 0 | 6.29492105 | 10.0111423 | 10.999676 | 11.6780387 | 12.3034332 | 12.9096522 | 14.8799434 | 0.02195793 |
| September | 0.14069926 | 0.42663563 | 0.36328991 | 0.46634412 | 0.70167173 | 0.80049414 | 16.7930352 | 6.76503257 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.16945387 | 9.74585019 | 10.6989054 | 11.3631477 | 11.9690534 | 12.5535503 | 14.029637 | 0.04045946 |
| October | 0.18377834 | 0.97025633 | 3.49153361 | 7.99700117 | 12.6873654 | 14.2836725 | 20.4082949 | 6.31073737 | 0 | 0.26938066 | 0.13974952 | 0.04382507 | 0.03711101 | 0.08866595 | 0.18979201 | 0.00439075 | 5.07941858 | 7.95216055 | 8.74268392 | 9.30939219 | 9.83612618 | 10.6794616 | 14.8470061 | 0.43479744 |
| November | 17.5985197 | 21.4028829 | 26.8780388 | 26.7325234 | 29.4686373 | 27.8381768 | 22.9389273 | 23.8454416 | 7.03659339 | 1.18299851 | 0.76975716 | 0.8126364 | 0.82324727 | 0.84506796 | 0.95339327 | 1.25418984 | 1.51736562 | 4.87501615 | 7.59972655 | 7.85973876 | 9.42704252 | 12.7640957 | 17.6335972 | 21.258321 |
| December | 25.3103554 | 28.6782984 | 28.3658925 | 28.3034387 | 27.2333162 | 24.7203067 | 23.0170944 | 38.7967564 | 22.5376151 | 9.6339259 | 4.49127816 | 3.36242473 | 2.85136483 | 2.68849381 | 2.90044387 | 3.51069334 | 4.67180973 | 9.27712628 | 12.2105699 | 13.7946058 | 14.970275 | 20.4051374 | 29.7546596 | 38.3076179 |

| **WEEK (Water heating)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 108.551499 | 80.5608518 | 80.9400111 | 82.0912923 | 108.322562 | 163.936546 | 262.458778 | 378.552637 | 389.869907 | 287.983286 | 224.383849 | 171.523124 | 147.968757 | 147.140985 | 145.469521 | 144.723082 | 111.120467 | 152.457318 | 237.439402 | 220.162876 | 216.955201 | 275.633556 | 277.608255 | 158.745077 |
| February | 108.396648 | 81.1851026 | 81.1682052 | 82.5051699 | 108.086378 | 163.948942 | 263.227795 | 380.470343 | 388.610292 | 287.690664 | 223.774386 | 172.6866 | 148.602037 | 146.896989 | 145.18762 | 145.786981 | 109.925584 | 152.699627 | 239.472651 | 219.167306 | 217.92295 | 276.663093 | 277.387196 | 158.607792 |
| March | 89.4548299 | 79.582612 | 79.451264 | 97.4298954 | 143.658886 | 232.254187 | 340.081018 | 375.364036 | 311.390973 | 237.570739 | 183.299574 | 152.367092 | 145.028571 | 143.30571 | 143.667526 | 120.986113 | 135.974271 | 211.93652 | 226.268637 | 214.481437 | 256.894801 | 270.445718 | 193.675748 | 123.291587 |
| April | 77.9567619 | 76.8562115 | 77.4190713 | 102.894921 | 155.042469 | 248.66665 | 360.523048 | 369.919092 | 274.902814 | 211.567207 | 164.799002 | 141.571211 | 139.762781 | 139.480677 | 138.513226 | 103.82593 | 144.96771 | 226.201454 | 209.322037 | 206.727343 | 260.302073 | 263.795193 | 151.119291 | 101.93545 |
| May | 74.4257667 | 73.6517787 | 74.4007944 | 97.9962368 | 150.13282 | 241.943692 | 348.370028 | 352.052236 | 260.714126 | 203.378715 | 156.830855 | 135.499652 | 135.040838 | 133.424025 | 134.521973 | 99.3674226 | 140.648105 | 219.486196 | 199.275644 | 199.088814 | 252.497339 | 251.26895 | 142.828248 | 98.7003251 |
| June | 72.1299748 | 71.8101739 | 72.0513925 | 95.1688522 | 146.740624 | 236.818209 | 339.17269 | 340.486995 | 252.09175 | 196.275532 | 151.69168 | 132.379749 | 130.760659 | 130.207982 | 130.51058 | 97.296451 | 135.774239 | 215.18066 | 193.98829 | 192.616123 | 247.195121 | 242.196984 | 137.838109 | 94.9132841 |
| July | 71.0818304 | 68.4339746 | 68.5159957 | 92.8911018 | 140.514224 | 226.202315 | 325.441827 | 331.555566 | 246.083438 | 192.539508 | 146.697169 | 129.014287 | 127.421551 | 126.330688 | 125.60302 | 94.7212932 | 130.103807 | 205.899063 | 187.156322 | 185.072112 | 237.914575 | 235.021754 | 134.63642 | 91.9063393 |
| August | 68.980067 | 69.7190539 | 68.7443345 | 92.4261519 | 142.09859 | 231.401998 | 329.800124 | 325.455738 | 242.361238 | 189.196699 | 145.210586 | 128.214948 | 126.570977 | 126.070944 | 126.380168 | 94.2622805 | 130.464522 | 211.93729 | 186.737151 | 185.119235 | 241.716152 | 231.589896 | 131.322433 | 93.3313154 |
| September | 71.0065746 | 71.3336313 | 70.6183267 | 93.8669474 | 142.352436 | 228.473121 | 329.983688 | 340.662601 | 252.222157 | 195.933996 | 152.187505 | 130.821365 | 129.480292 | 128.196569 | 128.861124 | 95.8327624 | 133.310275 | 206.886405 | 190.943377 | 189.71457 | 239.941937 | 241.277876 | 137.592777 | 94.2945144 |
| October | 74.0237221 | 73.8465671 | 74.1577184 | 96.717206 | 148.822652 | 237.166583 | 343.016106 | 352.949915 | 262.09367 | 203.784259 | 156.733177 | 135.35558 | 133.559331 | 132.747712 | 132.546803 | 100.453587 | 137.955459 | 214.911124 | 198.335247 | 197.847366 | 248.759436 | 250.790532 | 143.467274 | 97.4824906 |
| November | 97.6888109 | 76.7224987 | 77.5972991 | 80.9823514 | 112.383998 | 171.952446 | 271.570746 | 364.877352 | 346.424149 | 258.911063 | 200.54399 | 158.091462 | 140.028874 | 139.644332 | 137.040813 | 132.173755 | 110.807897 | 159.716458 | 225.242206 | 206.662277 | 214.544181 | 265.06295 | 238.267285 | 138.667445 |
| December | 106.701981 | 79.2186255 | 79.7351362 | 80.0711819 | 105.92091 | 158.788122 | 253.337458 | 368.765053 | 385.731416 | 283.567935 | 219.758718 | 170.812465 | 145.094696 | 143.862087 | 142.905337 | 142.834801 | 108.378463 | 148.122893 | 230.542656 | 214.536774 | 212.691807 | 267.089496 | 274.110278 | 155.716579 |

| **PEAK (Water heating)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 113.652147 | 80.6701365 | 86.843792 | 86.8584795 | 109.781528 | 187.710441 | 326.283046 | 430.628295 | 466.731158 | 333.748981 | 255.693792 | 205.01678 | 153.275474 | 152.854267 | 151.253179 | 146.263708 | 115.094987 | 169.324343 | 302.497284 | 224.172349 | 221.7902 | 327.605281 | 321.256489 | 190.491084 |
| February | 109.291913 | 86.8534769 | 86.747956 | 86.835966 | 109.671019 | 187.69334 | 323.204146 | 433.186374 | 463.063096 | 333.379784 | 255.899922 | 205.013372 | 153.283224 | 152.964638 | 146.263659 | 152.743884 | 115.108648 | 169.381195 | 302.585927 | 224.247823 | 223.543331 | 327.875167 | 320.328798 | 187.918783 |
| March | 109.434069 | 81.683594 | 80.5722988 | 108.14394 | 186.608039 | 318.698515 | 418.511523 | 456.840499 | 460.890403 | 332.23643 | 254.122418 | 204.512857 | 152.948557 | 147.477846 | 148.30425 | 148.341713 | 162.093377 | 292.692721 | 296.592344 | 223.691853 | 319.149559 | 320.331984 | 318.696662 | 187.316284 |
| April | 80.4162519 | 80.3948917 | 80.3981322 | 107.900761 | 179.262956 | 312.959989 | 412.583219 | 445.445239 | 321.896721 | 245.008116 | 196.381349 | 145.844803 | 145.666133 | 145.316754 | 142.302084 | 108.240731 | 161.207349 | 289.921139 | 214.520659 | 214.362856 | 308.109747 | 312.125735 | 183.581449 | 106.14666 |
| May | 80.0612117 | 80.0267879 | 80.1095022 | 101.073825 | 177.920022 | 298.76257 | 399.791828 | 420.993228 | 306.436603 | 234.85881 | 187.563673 | 138.312617 | 138.126823 | 137.991479 | 137.982658 | 101.355616 | 153.734686 | 278.175929 | 204.971563 | 205.251203 | 301.386401 | 297.56071 | 173.288062 | 101.149053 |
| June | 76.1960872 | 77.6334281 | 73.7977779 | 100.859803 | 170.25126 | 292.272626 | 388.272409 | 417.748881 | 299.504821 | 232.711246 | 184.246536 | 137.938069 | 137.770563 | 137.332166 | 137.614103 | 101.129606 | 153.111922 | 268.582486 | 202.491471 | 200.710918 | 292.636978 | 291.124276 | 170.356107 | 100.934482 |
| July | 73.4992624 | 73.5683573 | 73.4989389 | 94.0825407 | 161.815714 | 278.53688 | 366.978848 | 397.204522 | 289.63306 | 223.449369 | 177.939979 | 130.520598 | 130.370135 | 130.238314 | 130.240808 | 98.2275217 | 145.104496 | 256.309477 | 191.788441 | 187.812282 | 279.139289 | 276.576893 | 162.03248 | 94.1650293 |
| August | 73.5411333 | 73.5184506 | 73.5319043 | 94.0209489 | 161.781144 | 278.594006 | 367.302356 | 398.549888 | 288.328464 | 221.575621 | 178.027766 | 130.420238 | 130.271245 | 130.068128 | 130.061188 | 96.7653107 | 141.378217 | 256.166302 | 190.768723 | 187.656709 | 278.894279 | 277.616153 | 161.69283 | 94.120181 |
| September | 73.6856895 | 73.6783159 | 73.6717731 | 94.339871 | 166.845099 | 289.40779 | 377.921585 | 407.834906 | 295.62266 | 224.903789 | 182.117129 | 137.091325 | 132.33717 | 133.41166 | 134.502754 | 100.82326 | 145.854138 | 263.805907 | 196.340016 | 195.936406 | 287.093111 | 282.358141 | 163.069668 | 98.1465054 |
| October | 80.0842795 | 77.4443177 | 79.4551516 | 101.029562 | 177.635617 | 294.398602 | 392.120453 | 427.096832 | 306.073537 | 235.073659 | 185.898026 | 138.262333 | 138.097256 | 137.92155 | 137.909888 | 104.156606 | 150.476612 | 277.865233 | 204.616427 | 204.883694 | 297.783794 | 293.184683 | 177.75916 | 101.142883 |
| November | 107.841684 | 80.3427604 | 80.3407591 | 101.140575 | 175.612702 | 297.450402 | 399.491607 | 432.978113 | 441.119072 | 318.588572 | 244.374621 | 195.971372 | 145.422997 | 145.284249 | 142.257889 | 144.938451 | 153.161269 | 278.468519 | 284.533817 | 214.674962 | 303.238381 | 314.439657 | 305.784257 | 179.145522 |
| December | 108.335761 | 86.7433393 | 80.5710405 | 86.7376592 | 108.193205 | 187.187409 | 319.22552 | 423.996522 | 457.785402 | 331.438978 | 254.363594 | 204.484086 | 148.132439 | 149.489913 | 145.995937 | 145.991734 | 114.863877 | 162.196381 | 293.201316 | 216.271987 | 217.208284 | 319.794004 | 318.587682 | 187.436531 |

| **WEEK (Natural gas)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 148.252402 | 116.96859 | 115.10772 | 114.876853 | 139.589362 | 203.561007 | 317.161689 | 479.829233 | 491.095051 | 440.013179 | 403.389256 | 347.770639 | 323.08261 | 307.419163 | 290.481684 | 305.850384 | 305.451294 | 268.454616 | 357.593495 | 309.821472 | 310.232055 | 358.944671 | 352.545443 | 224.198311 |
| February | 142.069972 | 112.868568 | 109.71805 | 109.398665 | 134.206205 | 198.41792 | 314.137631 | 464.064754 | 478.627819 | 432.904199 | 399.795714 | 346.736227 | 321.970808 | 304.214089 | 286.258013 | 304.476771 | 302.632337 | 266.505362 | 357.854571 | 305.762043 | 305.38555 | 349.418736 | 337.596888 | 207.833068 |
| March | 119.813515 | 110.357233 | 109.328309 | 124.642001 | 175.874824 | 278.569947 | 410.094167 | 452.13068 | 427.470026 | 395.81157 | 353.601914 | 322.571403 | 304.708143 | 286.836974 | 292.444243 | 296.969203 | 273.252676 | 323.943596 | 322.421078 | 300.489124 | 334.327466 | 334.126975 | 244.420141 | 161.218591 |
| April | 102.30035 | 103.575091 | 106.18395 | 131.004615 | 190.852345 | 297.226507 | 427.169898 | 446.259511 | 412.781719 | 382.716641 | 336.115329 | 312.700759 | 294.323548 | 277.509927 | 293.531235 | 291.754337 | 253.224079 | 337.419258 | 292.036703 | 291.067254 | 328.639232 | 317.160734 | 191.33789 | 124.793072 |
| May | 87.5422645 | 88.3569116 | 90.3376531 | 114.487886 | 177.484312 | 283.00837 | 413.393415 | 424.602742 | 395.721227 | 375.579824 | 330.289286 | 308.898582 | 292.342232 | 274.220781 | 292.01275 | 288.203256 | 251.250083 | 329.656293 | 276.213048 | 277.156858 | 315.383775 | 300.491429 | 179.720549 | 110.460261 |
| June | 80.4250305 | 80.6544442 | 81.1681503 | 104.48722 | 165.732891 | 271.517464 | 405.957119 | 414.04591 | 386.254578 | 367.587607 | 324.707586 | 305.427704 | 287.738008 | 270.608322 | 287.454898 | 285.160971 | 246.467489 | 326.172871 | 271.598058 | 271.013501 | 310.523738 | 292.813805 | 176.874566 | 103.909196 |
| July | 77.9397497 | 75.497501 | 75.7200617 | 100.306172 | 157.993641 | 259.918454 | 392.853868 | 405.11443 | 379.701238 | 359.583442 | 314.038422 | 296.332851 | 278.074236 | 260.31446 | 276.248082 | 278.649149 | 236.998117 | 315.803528 | 264.748385 | 263.341834 | 300.143467 | 281.712294 | 168.918277 | 98.6103145 |
| August | 75.8999815 | 76.7836168 | 75.7356497 | 99.3739508 | 159.16281 | 264.958606 | 397.438319 | 399.025309 | 375.979038 | 356.135699 | 312.151204 | 295.157613 | 276.853423 | 259.693313 | 276.659806 | 277.871511 | 236.776866 | 321.879134 | 264.366507 | 263.438655 | 303.998572 | 277.900439 | 163.464491 | 100.022788 |
| September | 77.8563016 | 78.740408 | 78.3077988 | 102.150384 | 161.769651 | 264.860384 | 397.381045 | 413.995332 | 385.839957 | 362.872996 | 319.126505 | 297.760365 | 279.758692 | 261.814369 | 279.139524 | 279.432362 | 239.426203 | 316.538442 | 268.255217 | 267.697765 | 301.874267 | 287.177488 | 169.400565 | 101.077542 |
| October | 84.352191 | 86.4867641 | 88.4864714 | 112.577235 | 179.857388 | 283.631106 | 413.343335 | 426.837522 | 395.838341 | 371.111243 | 324.388167 | 302.926575 | 284.437147 | 266.877731 | 283.378007 | 284.665986 | 243.817757 | 322.799858 | 273.391024 | 273.474138 | 308.448776 | 295.722553 | 175.799853 | 106.571538 |
| November | 118.676259 | 99.985162 | 100.951598 | 104.243025 | 137.954127 | 207.860109 | 324.06672 | 432.872089 | 430.757147 | 400.382915 | 368.763449 | 326.403932 | 305.342499 | 288.674737 | 276.025788 | 291.230958 | 281.577987 | 266.095981 | 326.22624 | 281.287552 | 287.024114 | 322.773303 | 284.129492 | 171.884057 |
| December | 146.668396 | 119.888709 | 117.692821 | 115.38709 | 138.836224 | 197.912486 | 305.692223 | 453.927921 | 468.035896 | 421.668932 | 388.06128 | 339.158871 | 313.464264 | 295.825091 | 278.552758 | 295.504471 | 294.844401 | 255.049225 | 339.280866 | 290.949602 | 290.442536 | 333.085459 | 332.249313 | 205.204995 |

| **WEEKEND (Water heating)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 108.239794 | 80.531859 | 80.8188434 | 80.9393482 | 108.302277 | 186.950556 | 321.289036 | 427.79098 | 331.317825 | 252.172343 | 198.841458 | 148.556305 | 146.178873 | 145.996324 | 145.820654 | 145.190873 | 110.449957 | 163.425509 | 297.390783 | 220.330877 | 217.352272 | 324.019172 | 241.473823 | 136.741383 |
| February | 108.053098 | 81.8606107 | 80.5515892 | 80.6059595 | 108.495398 | 187.367701 | 321.926681 | 427.645949 | 332.313901 | 251.849061 | 200.338609 | 146.981026 | 147.601774 | 146.474689 | 144.670483 | 145.329771 | 111.846076 | 163.68342 | 295.770185 | 221.70906 | 217.988001 | 324.111516 | 241.602132 | 135.342376 |
| March | 88.4535317 | 79.5878197 | 79.7201113 | 97.7535411 | 157.875934 | 271.520283 | 384.714989 | 357.810308 | 274.419587 | 212.377 | 163.892189 | 144.924365 | 143.326884 | 144.583307 | 142.394944 | 120.101408 | 144.375885 | 246.693785 | 242.020676 | 214.76787 | 282.540692 | 264.716878 | 168.706749 | 115.297541 |
| April | 77.7014077 | 77.604124 | 77.6411346 | 102.426491 | 178.305226 | 303.759591 | 406.594057 | 315.694795 | 239.988748 | 188.992432 | 142.077741 | 140.441762 | 139.780764 | 139.177014 | 138.811644 | 102.77391 | 157.050062 | 282.299356 | 209.206469 | 208.176654 | 305.548862 | 231.448579 | 127.82599 | 102.430382 |
| May | 74.4050566 | 73.177887 | 74.0375371 | 98.1710126 | 170.285252 | 291.973916 | 388.102602 | 302.04643 | 230.958036 | 181.73447 | 135.763837 | 135.821907 | 133.905063 | 132.986447 | 133.806183 | 100.492024 | 148.651385 | 269.869153 | 200.27484 | 199.024943 | 292.907765 | 221.615844 | 122.028849 | 98.0999312 |
| June | 72.8295946 | 70.6595237 | 71.9883942 | 95.4667602 | 165.224476 | 283.693678 | 376.453632 | 294.142629 | 223.81999 | 177.154847 | 133.071052 | 131.91173 | 130.488474 | 128.450695 | 130.425519 | 97.6397688 | 144.210332 | 262.164465 | 194.550556 | 192.961939 | 284.96708 | 214.550033 | 118.717816 | 96.1633666 |
| July | 68.8722995 | 70.4053413 | 69.6406301 | 92.4364499 | 153.336777 | 260.438569 | 353.202902 | 298.906977 | 225.231653 | 176.530301 | 135.281461 | 128.382338 | 125.210078 | 126.309414 | 126.84519 | 93.7794995 | 137.502504 | 238.512693 | 188.463727 | 185.667321 | 265.126361 | 215.774944 | 120.598537 | 90.8277256 |
| August | 69.1588448 | 69.7743542 | 69.1622514 | 91.6049946 | 159.404594 | 273.356722 | 363.613919 | 283.431291 | 216.330612 | 172.951342 | 126.734242 | 129.920915 | 125.25878 | 126.396061 | 125.064747 | 93.9845334 | 140.219273 | 252.697794 | 187.424324 | 186.346331 | 275.032163 | 208.066694 | 113.67694 | 91.6100228 |
| September | 69.8964314 | 71.2610558 | 69.976658 | 94.4920558 | 162.763284 | 281.305921 | 371.718078 | 289.239234 | 221.32867 | 174.843907 | 131.677655 | 129.201687 | 128.837519 | 129.621852 | 124.981852 | 98.6643353 | 141.840792 | 259.340625 | 191.851281 | 189.515439 | 282.16943 | 209.311497 | 119.265457 | 94.5193373 |
| October | 73.7578538 | 74.4459889 | 73.7570045 | 98.0028504 | 168.100675 | 289.954501 | 385.073857 | 303.418114 | 228.547641 | 181.26675 | 134.720578 | 135.481305 | 133.075098 | 131.775188 | 132.630329 | 100.694093 | 147.782801 | 268.072652 | 199.465814 | 197.186539 | 293.037474 | 218.760953 | 121.918455 | 97.9727998 |
| November | 98.546096 | 77.3845983 | 76.5239547 | 79.0826239 | 109.357373 | 191.02878 | 315.444221 | 392.886213 | 306.530509 | 233.29489 | 183.471569 | 141.641743 | 140.008291 | 138.255964 | 138.200559 | 133.29527 | 110.107217 | 167.980014 | 272.710064 | 208.627597 | 216.856715 | 296.781102 | 217.992257 | 125.273332 |
| December | 107.933857 | 77.8128584 | 79.8952353 | 80.4033706 | 104.853164 | 183.280408 | 315.308219 | 417.033853 | 325.376363 | 246.924996 | 195.864589 | 144.844249 | 143.997177 | 143.618061 | 143.269834 | 141.076339 | 108.84093 | 161.19361 | 289.605167 | 215.573077 | 213.883195 | 316.26728 | 237.120044 | 132.816546 |

| **PEAK (Natural gas)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 173.74352 | 140.041749 | 146.558037 | 142.674199 | 160.606316 | 241.587933 | 410.080985 | 561.942966 | 625.902071 | 498.270633 | 456.769081 | 411.073909 | 360.649094 | 376.107801 | 378.337908 | 356.892816 | 344.021383 | 315.788369 | 451.910663 | 361.49664 | 393.612842 | 500.550307 | 479.789704 | 314.524307 |
| February | 162.781829 | 128.808878 | 127.46341 | 123.792714 | 154.691367 | 242.551118 | 389.418253 | 552.232504 | 594.406836 | 499.804965 | 463.601208 | 403.516487 | 339.79404 | 325.619385 | 313.672891 | 334.330805 | 334.020604 | 295.604298 | 448.65926 | 336.791079 | 335.968205 | 422.113219 | 411.29387 | 263.579126 |
| March | 152.865494 | 137.973309 | 133.020811 | 153.161143 | 225.018435 | 378.519167 | 547.775473 | 543.608998 | 530.212091 | 467.967311 | 423.875041 | 377.407236 | 323.645311 | 307.302936 | 313.449086 | 311.407465 | 302.723529 | 416.031343 | 418.679733 | 325.619626 | 406.081735 | 397.867989 | 372.168773 | 236.625543 |
| April | 128.440374 | 124.326146 | 137.131737 | 159.600682 | 246.504405 | 371.78774 | 495.856017 | 542.086132 | 475.929027 | 423.117661 | 371.943549 | 320.368098 | 298.949065 | 283.00133 | 296.550815 | 302.245019 | 267.169195 | 406.096889 | 324.346686 | 313.605255 | 396.569878 | 385.550637 | 241.952491 | 146.40117 |
| May | 124.124439 | 138.110579 | 167.173911 | 185.429885 | 261.400807 | 383.43335 | 485.599128 | 492.652286 | 440.803519 | 407.063462 | 360.633134 | 314.40248 | 297.038085 | 278.707916 | 296.952428 | 296.356866 | 265.718888 | 392.697935 | 296.895655 | 306.582479 | 388.636116 | 343.619018 | 212.404596 | 142.774359 |
| June | 97.0621905 | 94.0923834 | 93.8239976 | 114.746288 | 195.630243 | 329.715247 | 452.729131 | 490.904841 | 434.667095 | 405.371407 | 360.633134 | 314.40248 | 297.038085 | 278.707916 | 296.952428 | 296.356866 | 261.294244 | 378.121734 | 279.663229 | 283.161097 | 372.121127 | 343.619018 | 212.404596 | 121.326343 |
| July | 80.9542366 | 80.4454668 | 80.910907 | 111.0611 | 189.891058 | 312.185803 | 434.813238 | 470.938275 | 423.25086 | 392.214724 | 345.49891 | 301.084303 | 283.802734 | 266.67833 | 283.131908 | 282.571419 | 251.6002 | 366.175867 | 269.631519 | 266.224722 | 341.160991 | 323.327692 | 198.95159 | 100.895395 |
| August | 80.3717384 | 80.9509048 | 80.3822244 | 101.113234 | 178.885318 | 312.221281 | 435.146446 | 471.87415 | 421.946264 | 388.514621 | 344.966766 | 297.359238 | 280.549645 | 263.685928 | 280.339588 | 280.364911 | 247.522058 | 366.202794 | 268.550791 | 266.173533 | 341.033084 | 323.825055 | 197.443553 | 100.854906 |
| September | 81.0786223 | 83.8182392 | 90.4158694 | 116.546996 | 205.41291 | 333.427112 | 445.065384 | 481.013295 | 429.24046 | 391.842789 | 349.056129 | 304.030325 | 282.61557 | 267.02946 | 284.781154 | 284.42286 | 252.359585 | 373.762785 | 274.059185 | 274.353612 | 348.505335 | 328.687951 | 196.743736 | 104.914985 |
| October | 114.722753 | 139.867505 | 138.982189 | 159.372109 | 277.899116 | 422.038935 | 505.150775 | 504.480374 | 440.299722 | 402.966233 | 353.118599 | 308.676436 | 291.853203 | 271.53935 | 289.028016 | 289.583844 | 254.616057 | 384.33728 | 281.160787 | 276.078873 | 359.367736 | 342.772108 | 209.441518 | 122.640702 |
| November | 148.366084 | 123.856195 | 128.760731 | 130.537039 | 219.831243 | 365.946402 | 482.542216 | 512.880035 | 523.067082 | 455.929501 | 411.620126 | 363.308137 | 313.670846 | 296.053176 | 295.013203 | 299.038162 | 299.385164 | 383.958975 | 403.492833 | 308.437368 | 359.350861 | 378.591265 | 378.51306 | 238.41709 |
| December | 165.531792 | 139.446528 | 136.253722 | 132.788657 | 152.64149 | 226.147825 | 372.119199 | 537.619462 | 552.6178 | 483.116624 | 424.693706 | 372.242529 | 318.296835 | 302.96107 | 282.508724 | 300.332878 | 304.671454 | 271.086657 | 403.166771 | 308.785373 | 307.652053 | 390.792049 | 399.986131 | 250.161774 |

| **WEEKEND (Natural gas)** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 141.858172 | 112.900841 | 111.590111 | 112.186034 | 138.691335 | 223.793702 | 372.582398 | 520.084294 | 423.444275 | 395.832841 | 369.857533 | 318.366102 | 315.63025 | 298.755206 | 282.254803 | 298.634214 | 297.191724 | 272.288265 | 411.133505 | 301.705053 | 299.914502 | 392.472189 | 299.980597 | 192.318523 |
| February | 146.222447 | 118.058087 | 114.206653 | 112.790352 | 138.452489 | 224.779002 | 373.601002 | 509.897825 | 415.959917 | 391.604104 | 371.145739 | 317.350408 | 318.294696 | 301.213071 | 283.663389 | 301.595418 | 300.235831 | 273.221737 | 409.528926 | 304.858536 | 302.686689 | 394.143617 | 300.558788 | 186.822699 |
| March | 128.291781 | 118.885884 | 116.920183 | 136.256834 | 200.267589 | 321.306742 | 460.291881 | 450.189804 | 402.124803 | 378.297793 | 339.178392 | 323.872714 | 308.482575 | 292.146954 | 296.091657 | 305.127259 | 285.043578 | 362.805236 | 340.294866 | 306.628345 | 367.139585 | 332.049625 | 227.499543 | 152.792384 |
| April | 103.552571 | 102.956271 | 103.404087 | 127.948811 | 213.34057 | 353.997072 | 474.909901 | 393.299197 | 381.595147 | 364.563807 | 315.562885 | 313.042486 | 295.743257 | 278.737439 | 295.17263 | 290.699528 | 265.049363 | 392.291994 | 289.84453 | 292.359565 | 377.467616 | 288.455434 | 169.151599 | 126.026053 |
| May | 91.1729283 | 90.7069019 | 93.331335 | 118.619938 | 200.850468 | 334.089973 | 452.065687 | 375.022575 | 366.563656 | 355.191798 | 310.051632 | 309.994373 | 291.437427 | 273.916249 | 291.224566 | 287.077703 | 256.859469 | 380.025109 | 278.131247 | 279.540037 | 356.811537 | 272.845448 | 161.473108 | 112.607231 |
| June | 81.4420855 | 79.5420971 | 82.6588495 | 107.867244 | 187.243072 | 319.410684 | 442.723336 | 367.820118 | 358.272786 | 349.536103 | 306.952767 | 305.905734 | 287.799927 | 269.138517 | 287.44574 | 283.409283 | 252.659608 | 372.599477 | 271.865343 | 270.983297 | 346.949213 | 263.271478 | 156.225955 | 103.881395 |
| July | 75.6524708 | 77.5705519 | 76.6067304 | 99.3983 | 170.539718 | 294.052761 | 420.758481 | 372.532318 | 358.849453 | 343.501623 | 302.483171 | 295.628406 | 275.727673 | 260.149533 | 277.358526 | 277.436164 | 243.944016 | 348.449598 | 266.058847 | 263.932032 | 327.351854 | 262.166228 | 154.08275 | 97.5342136 |
| August | 75.9626081 | 76.883678 | 76.0814287 | 98.5699221 | 176.394699 | 306.93344 | 431.382903 | 357.156454 | 349.948412 | 339.890342 | 293.673242 | 296.859915 | 275.537779 | 260.01566 | 275.343147 | 277.584133 | 246.477794 | 362.672536 | 265.0664 | 264.66677 | 337.317396 | 254.297546 | 145.217483 | 98.2962207 |
| September | 76.7013707 | 78.3519314 | 77.0041879 | 101.62264 | 180.125555 | 315.427615 | 438.492913 | 362.646667 | 354.94647 | 341.782907 | 298.616655 | 296.140687 | 279.115919 | 263.239652 | 275.260252 | 282.263935 | 247.973846 | 369.050076 | 269.192586 | 267.520987 | 344.120284 | 255.186247 | 149.955694 | 101.224037 |
| October | 80.6058721 | 82.0804853 | 83.9127781 | 112.664092 | 197.448641 | 337.559374 | 455.463952 | 376.371251 | 362.165441 | 348.475131 | 301.799328 | 302.46413 | 283.390609 | 265.481654 | 283.098521 | 284.298084 | 252.825819 | 375.988412 | 274.850898 | 273.138332 | 352.8554 | 262.761615 | 153.426061 | 105.071837 |
| November | 122.808856 | 105.451721 | 110.066233 | 112.479387 | 146.600957 | 237.378735 | 373.555527 | 468.564633 | 387.651213 | 371.798044 | 351.180327 | 309.393379 | 305.91936 | 287.528254 | 274.62293 | 288.530216 | 285.931294 | 272.81863 | 376.571035 | 283.129736 | 291.07498 | 357.67582 | 267.095876 | 162.081546 |
| December | 139.908453 | 113.155397 | 114.925368 | 115.371049 | 138.750721 | 224.661314 | 371.646513 | 505.812409 | 414.556378 | 390.176722 | 367.294867 | 315.145673 | 313.787542 | 296.584954 | 279.788078 | 294.865432 | 297.112339 | 270.434336 | 401.779336 | 296.010083 | 295.495871 | 386.654218 | 300.195903 | 187.784764 |

Sale and purchase monthly prices in the Iberian electricity market. Based on type days (on-peak, mid-load and off-peak days).

*Source: Own.*

| | | SALE MARKET PRICE | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| January | Week | 52.927 | 45.746 | 42.064 | 40.734 | 40.354 | 42.157 | 48.829 | 56.388 | 63.195 | 63.877 | 65.028 | 63.404 | 62.231 | 60.231 | 59.591 | 58.713 | 58.075 | 60.039 | 65.748 | 67.099 | 67.943 | 66.016 | 62.320 | 59.006 |
| February | Week | 56.478 | 52.889 | 49.897 | 48.407 | 47.842 | 48.818 | 54.340 | 62.877 | 68.046 | 68.556 | 69.229 | 67.448 | 66.405 | 64.135 | 62.220 | 60.789 | 61.387 | 63.829 | 69.583 | 72.296 | 72.887 | 70.340 | 66.260 | 61.718 |
| March | Week | 45.743 | 41.974 | 39.660 | 38.795 | 38.593 | 40.996 | 46.388 | 53.863 | 60.530 | 60.854 | 58.909 | 57.431 | 55.571 | 53.946 | 51.497 | 49.272 | 48.222 | 49.002 | 52.624 | 60.115 | 63.321 | 60.006 | 53.804 | 47.975 |
| April | Week | 48.457 | 45.842 | 43.319 | 42.372 | 42.394 | 44.648 | 49.953 | 54.059 | 58.810 | 59.275 | 58.020 | 57.064 | 55.973 | 55.017 | 52.628 | 50.499 | 49.710 | 49.761 | 50.247 | 53.867 | 58.345 | 62.163 | 57.265 | 53.741 |
| May | Week | 61.470 | 59.033 | 57.310 | 56.778 | 56.893 | 57.903 | 60.935 | 63.066 | 65.606 | 65.804 | 65.010 | 65.325 | 65.371 | 65.390 | 64.539 | 63.000 | 62.480 | 61.891 | 61.375 | 62.496 | 64.751 | 66.619 | 65.643 | 62.865 |
| June | Week | 62.996 | 62.029 | 60.496 | 59.466 | 59.309 | 59.930 | 62.441 | 63.917 | 67.252 | 67.775 | 67.769 | 69.381 | 69.676 | 69.646 | 68.913 | 66.908 | 66.424 | 66.495 | 66.233 | 66.145 | 66.614 | 67.794 | 67.460 | 64.914 |
| July | Week | 65.665 | 62.928 | 60.827 | 59.848 | 59.667 | 60.676 | 63.963 | 65.636 | 70.579 | 71.715 | 71.850 | 74.478 | 74.968 | 75.133 | 74.306 | 72.958 | 72.329 | 72.031 | 71.506 | 69.898 | 69.895 | 70.427 | 70.698 | 68.870 |
| August | Week | 68.138 | 65.397 | 62.413 | 61.296 | 60.614 | 61.249 | 65.675 | 69.508 | 73.273 | 75.007 | 74.873 | 75.408 | 75.761 | 76.076 | 75.657 | 73.767 | 73.405 | 73.558 | 74.014 | 74.381 | 75.065 | 76.110 | 74.730 | 70.226 |
| September | Week | 72.980 | 71.153 | 68.798 | 67.781 | 67.404 | 68.275 | 74.142 | 79.011 | 82.159 | 82.636 | 82.116 | 81.745 | 81.761 | 82.098 | 81.148 | 79.761 | 79.412 | 79.923 | 80.849 | 82.661 | 84.488 | 83.089 | 79.319 | 78.202 |
| October | Week | 64.790 | 62.046 | 59.572 | 58.168 | 57.763 | 59.589 | 68.175 | 75.708 | 78.888 | 79.333 | 78.797 | 77.981 | 77.191 | 75.624 | 72.606 | 71.063 | 71.436 | 76.024 | 78.113 | 81.091 | 83.175 | 79.955 | 74.267 | 70.194 |
| November | Week | 62.269 | 59.138 | 56.580 | 54.590 | 53.395 | 55.574 | 60.652 | 64.900 | 67.842 | 69.670 | 70.090 | 69.810 | 69.201 | 68.711 | 67.282 | 66.297 | 66.950 | 71.004 | 75.869 | 76.514 | 74.678 | 72.242 | 68.986 | 65.605 |
| December | Week | 64.333 | 60.578 | 57.755 | 56.263 | 55.788 | 57.027 | 62.210 | 67.800 | 71.556 | 72.298 | 73.426 | 73.104 | 72.621 | 71.257 | 70.589 | 70.000 | 70.380 | 73.042 | 76.925 | 76.433 | 75.513 | 73.210 | 70.573 | 68.252 |
| January | Peak | 71.880 | 62.700 | 61.060 | 56.600 | 54.090 | 55.390 | 63.540 | 70.390 | 76.200 | 75.580 | 77.620 | 76.620 | 76.410 | 74.880 | 74.490 | 74.450 | 72.630 | 73.320 | 77.670 | 78.410 | 78.990 | 83.060 | 76.720 | 72.730 |
| February | Peak | 66.190 | 64.680 | 63.190 | 59.320 | 58.360 | 58.190 | 63.310 | 68.750 | 73.120 | 76.770 | 79.160 | 78.890 | 79.620 | 76.970 | 77.130 | 72.450 | 76.170 | 73.960 | 82.420 | 83.100 | 84.730 | 80.910 | 75.160 | 73.240 |
| March | Peak | 57.340 | 56.990 | 56.470 | 53.710 | 52.360 | 54.610 | 58.460 | 66.080 | 70.700 | 72.590 | 72.190 | 71.580 | 70.580 | 68.680 | 64.480 | 61.940 | 61.340 | 62.560 | 71.330 | 78.740 | 80.530 | 77.810 | 64.050 | 59.010 |
| April | Peak | 63.960 | 61.010 | 58.780 | 57.600 | 56.550 | 57.180 | 62.900 | 63.840 | 72.110 | 72.460 | 69.880 | 70.290 | 70.190 | 70.450 | 66.910 | 65.300 | 65.020 | 62.760 | 60.850 | 64.340 | 70.090 | 82.620 | 69.590 | 66.340 |
| May | Peak | 71.230 | 70.920 | 70.170 | 69.710 | 70.170 | 70.050 | 70.970 | 70.900 | 72.730 | 72.500 | 72.230 | 72.810 | 72.870 | 73.010 | 72.170 | 71.100 | 70.660 | 69.850 | 70.250 | 71.110 | 71.590 | 73.310 | 73.000 | 71.400 |
| June | Peak | 70.850 | 70.080 | 68.670 | 68.470 | 68.280 | 67.580 | 70.020 | 70.490 | 71.230 | 71.930 | 71.630 | 74.090 | 74.450 | 74.410 | 73.210 | 71.920 | 71.550 | 71.390 | 71.030 | 70.140 | 70.290 | 71.430 | 71.530 | 70.680 |
| July | Peak | 70.530 | 69.370 | 67.260 | 67.280 | 66.330 | 66.590 | 68.770 | 69.160 | 75.580 | 75.470 | 75.510 | 78.240 | 78.180 | 78.470 | 78.080 | 76.890 | 75.500 | 75.170 | 75.020 | 75.720 | 72.880 | 74.550 | 74.390 | 73.630 |
| August | Peak | 73.970 | 71.470 | 70.380 | 68.560 | 68.210 | 68.390 | 71.760 | 76.050 | 79.490 | 83.010 | 81.250 | 81.700 | 82.380 | 82.820 | 82.200 | 79.460 | 78.450 | 77.550 | 80.790 | 80.630 | 81.160 | 82.980 | 80.370 | 75.800 |
| September | Peak | 78.790 | 77.820 | 76.610 | 76.790 | 76.690 | 76.770 | 78.830 | 82.720 | 86.200 | 86.860 | 86.140 | 85.980 | 84.930 | 85.460 | 84.460 | 82.780 | 82.410 | 82.340 | 83.260 | 86.300 | 88.140 | 87.060 | 83.890 | 81.090 |
| October | Peak | 77.970 | 77.720 | 76.540 | 74.410 | 72.840 | 69.520 | 78.390 | 86.110 | 88.380 | 89.700 | 86.470 | 85.270 | 83.150 | 83.370 | 80.630 | 79.680 | 78.980 | 84.740 | 87.760 | 88.330 | 91.740 | 87.870 | 80.850 | 76.400 |
| November | Peak | 74.230 | 71.880 | 70.220 | 69.530 | 65.550 | 65.470 | 72.950 | 73.760 | 76.130 | 76.660 | 77.320 | 76.630 | 77.150 | 76.960 | 75.790 | 74.910 | 75.000 | 78.260 | 81.200 | 81.440 | 80.250 | 79.580 | 75.330 | 72.880 |
| December | Peak | 72.330 | 70.680 | 67.130 | 64.050 | 63.210 | 65.870 | 69.980 | 72.870 | 76.130 | 76.380 | 77.360 | 77.310 | 77.010 | 75.340 | 74.550 | 74.260 | 74.500 | 77.830 | 84.210 | 84.230 | 79.290 | 77.640 | 73.410 | 73.610 |
| January | Weekend | 55.798 | 46.764 | 43.393 | 42.483 | 40.224 | 40.759 | 41.964 | 44.823 | 48.058 | 53.714 | 58.586 | 59.084 | 57.055 | 58.513 | 56.783 | 52.750 | 51.310 | 54.104 | 62.789 | 66.274 | 67.789 | 68.434 | 64.241 | 61.285 |
| February | Weekend | 60.116 | 56.965 | 53.923 | 51.663 | 50.599 | 50.571 | 50.543 | 52.189 | 52.528 | 57.039 | 61.121 | 59.350 | 57.749 | 58.575 | 57.189 | 54.720 | 53.223 | 54.501 | 61.164 | 66.726 | 67.916 | 67.928 | 64.654 | 62.020 |
| March | Weekend | 41.126 | 38.450 | 34.877 | 33.819 | 33.059 | 33.386 | 33.864 | 34.516 | 37.482 | 40.770 | 41.448 | 40.814 | 40.349 | 39.636 | 38.271 | 35.477 | 33.807 | 36.714 | 41.840 | 50.453 | 55.650 | 54.151 | 51.236 | 45.198 |
| April | Weekend | 51.009 | 47.028 | 44.261 | 44.256 | 44.019 | 43.924 | 44.362 | 44.026 | 44.642 | 46.439 | 47.392 | 47.587 | 46.070 | 44.323 | 42.726 | 37.941 | 36.538 | 37.351 | 39.049 | 42.669 | 49.889 | 57.013 | 55.612 | 51.493 |
| May | Weekend | 61.361 | 60.210 | 58.926 | 58.643 | 58.526 | 58.454 | 58.136 | 57.178 | 59.406 | 60.500 | 59.605 | 59.883 | 59.451 | 59.204 | 58.720 | 54.064 | 50.881 | 50.815 | 52.016 | 54.948 | 57.686 | 62.705 | 62.696 | 61.146 |
| June | Weekend | 62.473 | 61.966 | 60.542 | 60.577 | 59.759 | 59.258 | 58.923 | 58.196 | 60.052 | 61.287 | 62.220 | 63.040 | 63.043 | 63.586 | 63.493 | 60.104 | 58.100 | 57.617 | 57.856 | 59.613 | 61.956 | 65.886 | 66.544 | 64.503 |
| July | Weekend | 66.813 | 65.628 | 64.499 | 63.788 | 63.114 | 63.033 | 62.648 | 61.886 | 63.942 | 64.568 | 65.060 | 66.284 | 66.616 | 67.288 | 66.962 | 64.598 | 62.988 | 62.238 | 61.768 | 63.058 | 64.702 | 67.560 | 69.088 | 67.431 |
| August | Weekend | 68.139 | 66.520 | 64.380 | 63.425 | 63.020 | 62.813 | 62.841 | 62.514 | 63.961 | 66.134 | 66.256 | 67.680 | 69.376 | 70.880 | 71.041 | 68.531 | 67.056 | 66.104 | 66.580 | 69.450 | 71.665 | 73.756 | 74.156 | 71.715 |
| September | Weekend | 74.854 | 72.530 | 70.941 | 70.383 | 69.690 | 69.548 | 70.458 | 71.526 | 72.112 | 75.317 | 75.012 | 75.526 | 75.487 | 76.414 | 76.054 | 73.472 | 71.858 | 71.368 | 72.339 | 77.094 | 81.400 | 82.588 | 79.885 | 76.332 |
| October | Weekend | 66.605 | 62.535 | 60.351 | 58.616 | 57.238 | 55.685 | 56.665 | 59.469 | 61.358 | 66.688 | 66.989 | 66.241 | 64.773 | 65.098 | 63.081 | 59.415 | 59.031 | 61.749 | 67.496 | 75.226 | 79.283 | 75.749 | 72.609 | 69.635 |
| November | Weekend | 63.425 | 58.958 | 56.459 | 53.505 | 51.933 | 53.409 | 53.964 | 56.955 | 60.138 | 63.581 | 65.030 | 65.773 | 65.840 | 65.401 | 63.814 | 61.334 | 61.463 | 67.496 | 74.414 | 74.995 | 72.790 | 70.824 | 67.329 | 64.466 |
| December | Weekend | 65.375 | 60.592 | 57.060 | 55.659 | 54.821 | 55.105 | 56.013 | 57.603 | 59.644 | 64.529 | 66.592 | 66.624 | 66.554 | 67.154 | 66.117 | 63.911 | 63.717 | 67.610 | 71.943 | 72.003 | 71.517 | 71.014 | 69.753 | 67.241 |

| | | PURCHASE MARKET PRICE | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| January | Week | 69.219 | 62.038 | 58.356 | 57.025 | 56.645 | 58.448 | 65.120 | 72.680 | 87.633 | 88.314 | 89.466 | 87.841 | 86.668 | 84.668 | 84.028 | 83.151 | 82.513 | 84.476 | 106.477 | 107.828 | 108.671 | 106.745 | 86.758 | 83.443 |
| February | Week | 72.769 | 69.181 | 66.189 | 64.698 | 64.134 | 65.110 | 70.632 | 79.168 | 92.483 | 92.993 | 93.666 | 91.885 | 90.842 | 88.572 | 86.657 | 85.226 | 85.824 | 88.266 | 110.311 | 113.024 | 113.616 | 111.068 | 90.697 | 86.155 |
| March | Week | 62.035 | 58.266 | 55.951 | 55.086 | 54.884 | 57.287 | 62.680 | 70.155 | 84.967 | 85.291 | 83.346 | 81.868 | 80.009 | 78.383 | 75.934 | 73.710 | 72.660 | 73.440 | 93.353 | 100.844 | 104.050 | 100.735 | 78.241 | 72.412 |
| April | Week | 64.748 | 62.134 | 59.610 | 58.663 | 58.685 | 60.940 | 66.244 | 70.351 | 83.248 | 83.713 | 82.458 | 81.502 | 80.411 | 79.454 | 77.065 | 74.936 | 74.147 | 74.199 | 90.976 | 94.596 | 99.074 | 102.892 | 81.703 | 78.178 |
| May | Week | 77.761 | 75.325 | 73.602 | 73.069 | 73.185 | 74.195 | 77.227 | 79.357 | 90.043 | 90.241 | 89.447 | 89.762 | 89.809 | 89.827 | 88.976 | 87.437 | 86.917 | 86.328 | 102.104 | 103.225 | 105.480 | 107.348 | 90.080 | 87.302 |
| June | Week | 79.288 | 78.320 | 76.788 | 75.758 | 75.601 | 76.222 | 78.733 | 80.208 | 91.689 | 92.212 | 92.206 | 93.819 | 94.113 | 94.084 | 93.350 | 91.345 | 90.862 | 90.933 | 106.962 | 106.874 | 107.343 | 108.523 | 91.898 | 89.351 |
| July | Week | 81.957 | 79.219 | 77.119 | 76.139 | 75.958 | 76.967 | 80.254 | 81.928 | 95.016 | 96.152 | 96.288 | 98.916 | 99.405 | 99.570 | 98.744 | 97.396 | 96.766 | 96.468 | 112.235 | 110.627 | 110.624 | 111.156 | 95.136 | 93.307 |
| August | Week | 84.430 | 81.689 | 78.705 | 77.587 | 76.906 | 77.541 | 81.967 | 85.799 | 97.710 | 99.444 | 99.310 | 99.846 | 100.199 | 100.513 | 100.094 | 98.204 | 97.842 | 97.996 | 114.743 | 115.110 | 115.794 | 116.839 | 99.167 | 94.663 |
| September | Week | 89.272 | 87.445 | 85.090 | 84.072 | 83.695 | 84.566 | 90.433 | 95.303 | 106.596 | 107.073 | 106.553 | 106.182 | 106.198 | 106.535 | 105.585 | 104.198 | 103.849 | 104.360 | 121.577 | 123.389 | 125.217 | 123.818 | 103.756 | 102.639 |
| October | Week | 81.082 | 78.337 | 75.864 | 74.460 | 74.055 | 75.881 | 84.466 | 92.000 | 103.325 | 103.770 | 103.234 | 102.419 | 101.629 | 100.061 | 97.043 | 95.501 | 95.873 | 100.462 | 118.841 | 121.820 | 123.904 | 120.684 | 98.704 | 94.631 |
| November | Week | 78.561 | 75.429 | 72.872 | 70.882 | 69.687 | 71.866 | 76.944 | 81.192 | 92.279 | 94.107 | 94.528 | 94.247 | 93.639 | 93.149 | 91.720 | 90.734 | 91.387 | 95.441 | 116.598 | 117.243 | 115.407 | 112.971 | 93.423 | 90.042 |
| December | Week | 80.625 | 76.869 | 74.046 | 72.555 | 72.079 | 73.318 | 78.502 | 84.091 | 95.994 | 96.735 | 97.863 | 97.542 | 97.058 | 95.694 | 95.026 | 94.437 | 94.817 | 97.479 | 117.654 | 117.162 | 116.242 | 113.939 | 95.010 | 92.689 |
| January | Peak | 88.172 | 78.992 | 77.352 | 72.892 | 70.382 | 71.682 | 79.832 | 86.682 | 100.637 | 100.017 | 102.057 | 101.057 | 100.847 | 99.317 | 98.927 | 98.887 | 97.067 | 97.757 | 118.399 | 119.139 | 119.719 | 123.789 | 101.157 | 97.167 |
| February | Peak | 82.482 | 80.972 | 79.482 | 75.612 | 74.652 | 74.482 | 79.602 | 85.042 | 97.557 | 101.207 | 103.597 | 103.327 | 104.057 | 101.407 | 101.567 | 96.887 | 100.607 | 98.397 | 123.149 | 123.829 | 125.459 | 121.639 | 99.597 | 97.677 |
| March | Peak | 73.632 | 73.282 | 72.762 | 70.002 | 68.652 | 70.902 | 74.752 | 82.372 | 95.137 | 97.027 | 96.627 | 96.017 | 95.017 | 93.117 | 88.917 | 86.377 | 85.777 | 86.997 | 112.059 | 119.469 | 121.259 | 118.539 | 88.487 | 83.447 |
| April | Peak | 80.252 | 77.302 | 75.072 | 73.892 | 72.842 | 73.472 | 79.192 | 80.132 | 96.547 | 96.897 | 94.317 | 94.727 | 94.627 | 94.887 | 91.347 | 89.737 | 89.457 | 87.197 | 101.579 | 105.069 | 110.819 | 123.349 | 94.027 | 90.777 |
| May | Peak | 87.522 | 87.212 | 86.462 | 86.002 | 86.462 | 86.342 | 87.262 | 87.192 | 97.167 | 96.937 | 96.667 | 97.247 | 97.307 | 97.447 | 96.607 | 95.537 | 95.097 | 94.287 | 110.979 | 111.839 | 112.319 | 114.039 | 97.437 | 95.837 |
| June | Peak | 87.142 | 86.372 | 84.962 | 84.762 | 84.572 | 83.872 | 86.312 | 86.782 | 95.667 | 96.367 | 96.067 | 98.527 | 98.887 | 98.847 | 97.647 | 96.357 | 95.987 | 95.827 | 111.759 | 110.869 | 111.019 | 112.159 | 95.967 | 95.117 |
| July | Peak | 86.822 | 85.662 | 83.552 | 83.572 | 82.622 | 82.882 | 85.062 | 85.452 | 100.017 | 99.907 | 99.947 | 102.677 | 102.617 | 102.907 | 102.517 | 101.327 | 99.937 | 99.607 | 115.749 | 116.449 | 113.609 | 115.279 | 98.827 | 98.067 |
| August | Peak | 90.262 | 87.762 | 86.672 | 84.852 | 84.502 | 84.682 | 88.052 | 92.342 | 103.927 | 107.447 | 105.687 | 106.137 | 106.817 | 107.257 | 106.637 | 103.897 | 102.887 | 101.987 | 121.519 | 121.359 | 121.889 | 123.709 | 104.807 | 100.237 |
| September | Peak | 95.082 | 94.112 | 92.902 | 93.082 | 92.982 | 93.062 | 95.122 | 99.012 | 110.637 | 111.297 | 110.577 | 110.417 | 109.367 | 109.897 | 108.897 | 107.217 | 106.847 | 106.777 | 123.989 | 127.029 | 128.869 | 127.789 | 108.327 | 105.527 |
| October | Peak | 94.262 | 94.012 | 92.832 | 90.702 | 89.132 | 85.812 | 94.682 | 102.402 | 112.817 | 114.137 | 110.907 | 109.707 | 107.587 | 107.807 | 105.067 | 104.117 | 103.417 | 109.177 | 128.489 | 129.059 | 132.469 | 128.599 | 105.287 | 100.837 |
| November | Peak | 90.522 | 88.172 | 86.512 | 85.822 | 81.842 | 81.762 | 89.242 | 90.052 | 100.567 | 101.097 | 101.757 | 101.067 | 101.587 | 101.397 | 100.227 | 99.347 | 99.437 | 102.697 | 121.929 | 122.169 | 120.979 | 120.309 | 99.767 | 97.317 |
| December | Peak | 88.622 | 86.972 | 83.422 | 80.342 | 79.502 | 82.162 | 86.272 | 89.162 | 100.567 | 100.817 | 101.797 | 101.747 | 101.447 | 99.777 | 98.987 | 98.697 | 98.937 | 102.267 | 124.939 | 124.959 | 120.019 | 118.369 | 97.847 | 98.047 |
| January | Weekend | 72.089 | 63.055 | 59.684 | 58.774 | 56.515 | 57.050 | 58.255 | 61.114 | 72.495 | 78.151 | 83.024 | 83.521 | 81.492 | 82.950 | 81.220 | 77.187 | 75.747 | 78.541 | 103.518 | 107.003 | 108.518 | 109.163 | 88.679 | 85.722 |
| February | Weekend | 76.408 | 73.257 | 70.214 | 67.954 | 66.890 | 66.863 | 66.834 | 68.480 | 76.965 | 81.476 | 85.559 | 83.787 | 82.186 | 83.012 | 81.626 | 79.157 | 77.660 | 78.939 | 101.893 | 107.455 | 108.645 | 108.656 | 89.091 | 86.457 |
| March | Weekend | 57.417 | 54.742 | 51.168 | 50.110 | 49.350 | 49.677 | 50.156 | 50.807 | 61.920 | 65.207 | 65.885 | 65.252 | 64.786 | 64.073 | 62.708 | 59.914 | 58.244 | 61.152 | 82.569 | 91.182 | 96.379 | 94.880 | 75.673 | 69.635 |
| April | Weekend | 67.300 | 63.319 | 60.553 | 60.547 | 60.310 | 60.216 | 60.654 | 60.317 | 69.080 | 70.876 | 71.830 | 72.024 | 70.507 | 68.761 | 67.163 | 62.378 | 60.975 | 61.788 | 79.778 | 83.398 | 90.618 | 97.742 | 80.050 | 75.931 |
| May | Weekend | 77.653 | 76.502 | 75.218 | 74.934 | 74.818 | 74.745 | 74.428 | 73.469 | 83.844 | 84.937 | 84.042 | 84.320 | 83.889 | 83.641 | 83.157 | 78.501 | 75.319 | 75.252 | 92.745 | 95.676 | 98.415 | 103.434 | 87.134 | 85.584 |
| June | Weekend | 78.765 | 78.257 | 76.834 | 76.868 | 76.050 | 75.549 | 75.215 | 74.487 | 84.490 | 85.724 | 86.657 | 87.477 | 87.481 | 88.023 | 87.931 | 84.542 | 82.537 | 82.054 | 98.584 | 100.342 | 102.684 | 106.614 | 90.982 | 88.941 |
| July | Weekend | 83.105 | 81.919 | 80.790 | 80.079 | 79.406 | 79.325 | 78.939 | 78.177 | 88.380 | 89.005 | 89.497 | 90.722 | 91.053 | 91.725 | 91.400 | 89.035 | 87.425 | 86.675 | 102.497 | 103.787 | 105.431 | 108.289 | 93.525 | 91.868 |
| August | Weekend | 84.430 | 82.812 | 80.672 | 79.717 | 79.312 | 79.104 | 79.133 | 78.805 | 88.399 | 90.571 | 90.694 | 92.117 | 93.814 | 95.317 | 95.479 | 92.969 | 91.494 | 90.541 | 107.309 | 110.179 | 112.394 | 114.485 | 98.594 | 96.152 |
| September | Weekend | 91.146 | 88.822 | 87.233 | 86.675 | 85.982 | 85.840 | 86.750 | 87.818 | 96.549 | 99.754 | 99.449 | 99.963 | 99.924 | 100.851 | 100.491 | 97.909 | 96.295 | 95.805 | 113.068 | 117.823 | 122.129 | 123.317 | 104.322 | 100.769 |
| October | Weekend | 82.897 | 78.827 | 76.643 | 74.908 | 73.529 | 71.977 | 72.957 | 75.760 | 85.795 | 91.125 | 91.426 | 90.679 | 89.210 | 89.535 | 87.519 | 83.852 | 83.469 | 86.186 | 108.225 | 115.955 | 120.011 | 116.478 | 97.046 | 94.072 |
| November | Weekend | 79.717 | 75.249 | 72.750 | 69.797 | 68.224 | 69.700 | 70.255 | 73.247 | 84.575 | 88.019 | 89.467 | 90.210 | 90.277 | 89.839 | 88.251 | 85.771 | 85.900 | 91.934 | 115.143 | 115.724 | 113.519 | 111.553 | 91.766 | 88.904 |
| December | Weekend | 81.667 | 76.884 | 73.352 | 71.951 | 71.113 | 71.397 | 72.305 | 73.895 | 84.081 | 88.966 | 91.029 | 91.061 | 90.991 | 91.591 | 90.554 | 88.348 | 88.154 | 92.047 | 112.672 | 112.732 | 112.246 | 111.743 | 94.190 | 91.678 |

Hourly marginal CO2 emissions.

*Source: Own.*

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 0.26059 | 0.27261 | 0.28837 | 0.29900 | 0.30418 | 0.31047 | 0.28701 | 0.27571 | 0.28056 | 0.28499 | 0.28545 | 0.28533 | 0.29490 | 0.29798 | 0.31055 | 0.31732 | 0.32427 | 0.32649 | 0.31650 | 0.30685 | 0.30607 | 0.30535 | 0.31525 | 0.32959 |
| February | 0.32399 | 0.32760 | 0.33853 | 0.34686 | 0.35340 | 0.35640 | 0.35810 | 0.34733 | 0.32778 | 0.30123 | 0.28319 | 0.28066 | 0.28549 | 0.28554 | 0.29155 | 0.30445 | 0.31132 | 0.31736 | 0.30466 | 0.28826 | 0.27561 | 0.27480 | 0.28488 | 0.29942 |
| March | 0.16469 | 0.15761 | 0.16973 | 0.16790 | 0.17327 | 0.17706 | 0.19084 | 0.19211 | 0.18658 | 0.15041 | 0.17445 | 0.18066 | 0.17353 | 0.17441 | 0.17799 | 0.18711 | 0.19677 | 0.20118 | 0.20870 | 0.20382 | 0.19105 | 0.18700 | 0.18050 | 0.17057 |
| April | 0.17449 | 0.17970 | 0.18435 | 0.19132 | 0.18519 | 0.18737 | 0.19097 | 0.18860 | 0.19911 | 0.17321 | 0.18331 | 0.18633 | 0.18650 | 0.18712 | 0.18151 | 0.17933 | 0.17824 | 0.17847 | 0.18348 | 0.18943 | 0.19646 | 0.19546 | 0.20285 | 0.19599 |
| May | 0.32506 | 0.33803 | 0.34589 | 0.35164 | 0.35955 | 0.35880 | 0.33862 | 0.31129 | 0.28192 | 0.27065 | 0.26714 | 0.26551 | 0.26319 | 0.26401 | 0.27073 | 0.27468 | 0.27716 | 0.27866 | 0.27544 | 0.27306 | 0.27513 | 0.27502 | 0.28782 | 0.31580 |
| June | 0.32914 | 0.33365 | 0.33440 | 0.33931 | 0.33947 | 0.33674 | 0.32264 | 0.30476 | 0.28910 | 0.27731 | 0.26751 | 0.26565 | 0.26016 | 0.25314 | 0.24710 | 0.24839 | 0.24190 | 0.24103 | 0.24102 | 0.23356 | 0.23278 | 0.23774 | 0.26538 | 0.27746 |
| July | 0.26561 | 0.27215 | 0.27562 | 0.27384 | 0.28281 | 0.28476 | 0.28396 | 0.27881 | 0.27358 | 0.26751 | 0.26123 | 0.25440 | 0.25105 | 0.24842 | 0.24990 | 0.24965 | 0.24877 | 0.25053 | 0.25770 | 0.26290 | 0.26133 | 0.26172 | 0.25806 | 0.25909 |
| August | 0.29233 | 0.30199 | 0.29979 | 0.30262 | 0.30911 | 0.31951 | 0.34021 | 0.34420 | 0.33537 | 0.32217 | 0.31255 | 0.30373 | 0.29472 | 0.28880 | 0.28127 | 0.27945 | 0.28096 | 0.28207 | 0.28915 | 0.30297 | 0.31078 | 0.30274 | 0.30415 | 0.29098 |
| September | 0.31317 | 0.32197 | 0.33413 | 0.33729 | 0.33905 | 0.33704 | 0.31497 | 0.30813 | 0.30257 | 0.29478 | 0.28739 | 0.27955 | 0.27227 | 0.26708 | 0.26917 | 0.27380 | 0.27484 | 0.27588 | 0.28623 | 0.30153 | 0.29955 | 0.29439 | 0.32016 | 0.31613 |
| October | 0.23163 | 0.20802 | 0.21023 | 0.21556 | 0.20770 | 0.21265 | 0.22756 | 0.23473 | 0.24743 | 0.25175 | 0.24910 | 0.24517 | 0.24325 | 0.24353 | 0.24376 | 0.24851 | 0.25755 | 0.26424 | 0.28147 | 0.27689 | 0.26171 | 0.26210 | 0.26740 | 0.26558 |
| November | 0.34694 | 0.35807 | 0.35651 | 0.34429 | 0.34431 | 0.37805 | 0.35946 | 0.33456 | 0.33394 | 0.32812 | 0.32566 | 0.32381 | 0.32153 | 0.32670 | 0.34150 | 0.34805 | 0.35715 | 0.35568 | 0.33779 | 0.33149 | 0.33224 | 0.33817 | 0.33750 | 0.34345 |
| December | 0.30590 | 0.30593 | 0.30550 | 0.31632 | 0.29985 | 0.30352 | 0.31913 | 0.29450 | 0.27950 | 0.27404 | 0.27241 | 0.27460 | 0.27779 | 0.27711 | 0.27460 | 0.28952 | 0.29320 | 0.29203 | 0.28003 | 0.27501 | 0.26581 | 0.26589 | 0.28122 | 0.27684 |

Hourly temperatures by month.

*Source: Own*

| | Promedio | Real | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January | 12.0 | 11.9 | 7.9 | 8.5 | 9.5 | 11.2 | 12.5 | 13.2 | 14.7 | 15.5 | 16.1 | 15.6 | 14.9 | 14.1 | 13.7 | 13.3 | 13.0 | 12.7 | 12.4 | 11.9 | 11.1 | 10.3 | 9.4 | 8.8 | 8.3 | 8.1 |
| February | 9.0 | 9.3 | 5.6 | 5.5 | 6.3 | 7.0 | 7.8 | 8.6 | 9.8 | 10.7 | 11.9 | 12.9 | 12.7 | 12.5 | 12.4 | 12.3 | 11.8 | 11.1 | 10.3 | 9.7 | 9.0 | 8.4 | 7.9 | 7.2 | 6.7 | 5.9 |
| March | 12.0 | 12.0 | 8.7 | 8.6 | 8.5 | 9.6 | 10.9 | 12.2 | 12.9 | 13.7 | 14.9 | 15.5 | 15.8 | 15.7 | 15.1 | 14.6 | 13.8 | 13.1 | 12.4 | 11.8 | 11.4 | 10.7 | 10.3 | 9.8 | 9.3 | 8.9 |
| April | 15.0 | 15.3 | 12.6 | 12.1 | 11.5 | 11.2 | 11.7 | 12.5 | 13.1 | 14.7 | 15.8 | 17.8 | 18.7 | 19.6 | 19.3 | 18.9 | 18.6 | 18.2 | 17.3 | 16.8 | 16.1 | 15.2 | 14.8 | 14.5 | 13.9 | 13.4 |
| May | 16.6 | 16.6 | 14.6 | 14.1 | 13.7 | 13.3 | 13.0 | 13.7 | 14.3 | 14.9 | 15.7 | 16.5 | 17.8 | 18.4 | 20.7 | 20.3 | 20.1 | 19.6 | 19.1 | 18.6 | 18.2 | 17.6 | 16.8 | 16.1 | 15.7 | 15.3 |
| June | 21.6 | 21.9 | 19.7 | 18.9 | 18.3 | 17.9 | 17.6 | 17.5 | 18.2 | 20.3 | 21.5 | 22.1 | 22.9 | 23.5 | 24.6 | 26.3 | 26.1 | 25.9 | 25.3 | 24.8 | 24.3 | 23.9 | 22.6 | 21.8 | 21.2 | 20.6 |
| July | 25.5 | 25.8 | 25.1 | 24.4 | 23.7 | 22.6 | 22.3 | 21.6 | 20.9 | 21.7 | 22.9 | 23.9 | 24.7 | 25.8 | 26.9 | 28.7 | 31.0 | 29.8 | 29.2 | 29.1 | 28.9 | 28.7 | 28.2 | 27.5 | 26.8 | 25.9 |
| August | 25.6 | 25.8 | 24.6 | 23.8 | 23.3 | 22.6 | 21.9 | 21.6 | 22.3 | 23.1 | 24.5 | 25.4 | 26.7 | 27.4 | 28.8 | 30.3 | 29.6 | 29.1 | 28.4 | 27.8 | 27.4 | 27.1 | 26.6 | 26.0 | 25.6 | 25.2 |
| September | 23.4 | 23.8 | 22.4 | 21.8 | 21.2 | 20.4 | 19.8 | 20.3 | 21.3 | 22.4 | 22.7 | 23.5 | 24.3 | 25.8 | 27.7 | 27.3 | 26.8 | 26.6 | 26.4 | 26.1 | 25.7 | 25.1 | 24.6 | 23.9 | 23.2 | 22.6 |
| October | 19.1 | 18.9 | 16.3 | 15.9 | 15.7 | 15.6 | 16.1 | 16.7 | 17.6 | 18.3 | 19.8 | 20.9 | 21.6 | 23.0 | 22.7 | 22.1 | 21.8 | 21.4 | 20.5 | 19.4 | 18.9 | 18.4 | 18.1 | 17.7 | 17.2 | 16.7 |
| November | 15.3 | 15.2 | 12.5 | 12.3 | 12.1 | 12.9 | 13.4 | 13.8 | 14.6 | 15.7 | 16.1 | 17.0 | 18.8 | 18.5 | 18.2 | 17.7 | 17.2 | 16.8 | 16.3 | 15.9 | 15.5 | 14.8 | 14.5 | 14.0 | 13.6 | 12.9 |
| December | 12.5 | 12.5 | 8.7 | 8.0 | 8.6 | 9.3 | 10.1 | 11.4 | 12.3 | 13.8 | 15.7 | 17.0 | 16.8 | 16.2 | 15.9 | 15.4 | 14.8 | 14.5 | 13.9 | 13.2 | 12.4 | 11.7 | 11.1 | 10.6 | 9.8 | 9.1 |