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Theme

STUDY OF A POLYGENERATION ENERGY SYSTEM TO PRODUCE POWER HEAT AND COOL IN ALGERIA

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Abstract

The polygeneration system shows higher performance compared to the reference system, which is based on the separate generation of heat and power. It reduces fuel consumption, CO2 emissions and annualized total cost. The avoided fuel and electricity purchase of the polygeneration system has a positive impact on the economy. This together with the environmental and energetic benefits. Due to the relatively high share of energy utilization, there is a significant potential for fossil fuel consumption reduction. This, accordingly, can mitigate the negative environmental and societal impacts of fossil fuel consumption. One of the alternative solutions to reduce energy consumption is the implementation of polygeneration energy systems. Simultaneous production of heating, cooling and power in a combined cooling heating and power system (CCHP), also called polygeneration, results in higher overall efficiency in comparison with the separate heat and power production. Furthermore, having the energy supply system close to end users offers several other advantages such as lower distribution and transmission cost, less power loss through the transmission and distribution line, alleviated environmental impacts, and enhanced resilience of the utility grid.
Keywords: Algeria, polygeneration system, combined cooling, heating, and power generation (CCHP), Feasibility.

Le système de polygénération présente des performances supérieures par rapport au système de référence, qui est basé sur la production séparée de chaleur et d'électricité. Il réduit la consommation de carburant, les émissions de CO2 et le coût total annualisé. L'achat évité de carburant et d'électricité du système de polygénération a un impact positif sur l'économie. Cela s'ajoute aux avantages environnementaux et énergétiques. En raison de la part relativement élevée de l'utilisation de l'énergie, il existe un potentiel important de réduction de la consommation de combustibles fossiles. Cela peut donc atténuer les impacts environnementaux et sociétaux négatifs de la consommation de combustibles fossiles. L'une des solutions alternatives pour réduire la consommation d'énergie est la mise en place de systèmes énergétiques de polygénération. La production simultanée de chauffage, de refroidissement et d'électricité dans un système combiné de refroidissement, de chauffage et d'électricité (CCHP), également appelé polygénération, se traduit par une efficacité globale plus élevée par rapport à la production séparée de chaleur et d'électricité. De plus, avoir le système d'approvisionnement en énergie à proximité des utilisateurs finaux offre plusieurs autres avantages tels que des coûts de distribution et de transmission inférieurs, moins de perte de puissance à travers la ligne de transmission et de distribution, des impacts environnementaux atténués et une résilience accrue du réseau électrique.
Mots-clés : Algérie, système de polygénération, production combinée de froid, de chauffage et d'électricité (CCHP), faisabilité.

يُظهر نظام تعدد الأجيال أداءً أعلى مقارنة بالنظام المرجعي ، الذي يعتمد على توليد منفصل للحرارة والطاقة. يقلل من استهلاك الوقود وانبعاثات ثاني أكسيد الكربون والتكلفة الإجمالية السنوية. إن تجنب شراء الوقود والكهرباء لنظام متعدد الأجيال له تأثير إيجابي على الاقتصاد. هذا جنبًا إلى جنب مع الفوائد البيئية والحيوية. بسبب الحصة العالية نسبيًا لاستخدام الطاقة ، هناك إمكانية كبيرة لخفض استهلاك الوقود الأحفوري. هذا ، وفقًا لذلك ، يمكن أن يخفف من الآثار البيئية والمجتمعية السلبية لاستهلاك الوقود الأحفوري. أحد الحلول البديلة لتقليل استهلاك الطاقة هو تنفيذ أنظمة طاقة متعددة الأجيال. ينتج عن الإنتاج المتزامن للتدفئة والتبريد والطاقة في نظام التبريد والتدفئة المشترك (CCHP) ، والذي يُطلق عليه أيضًا التوليد متعدد الأجيال ، كفاءة إجمالية أعلى مقارنةً بإنتاج الطاقة والحرارة المنفصلين. علاوة على ذلك ، فإن وجود نظام إمداد الطاقة بالقرب من المستخدمين النهائيين يوفر العديد من المزايا الأخرى مثل انخفاض تكلفة التوزيع والنقل ، وتقليل فقد الطاقة من خلال خط النقل والتوزيع ، وتخفيف الآثار البيئية ، وتعزيز مرونة شبكة المرافق.
الكلمات المفتاحية: الجزائر ، نظام متعدد الأجيال ، تبريد مشترك ، تدفئة وتوليد طاقة (CCHP) ، جدوى.

Dedication

we dedicate this work to

our parents,our brothers

and sisters,

our professors,and

ourfriends,

Acknowledgment

We would like to express our sincere gratitude to our advisor **Dr. Recioui Bakhta** for the continuous support of our study in all those years, for her patience, motivation, enthusiasm, and immense knowledge. She guided us through our studies.

We also would like to thank our thesis examiners: **Dr.Cherrad Noureddine** and **Dr.Gouareh abderrahman** for their insightful comments and corrections. Also, we thank our friends and our parents for all the supports all the prayers that help us to reach the level who we are now, Thank you.

Contents

Nomenclature

AOC	Annual Operating Cost
AS	Annual Savings
CHP	Combined Heating and Power
CCHP	Combined Cooling, Heating and Power
CS	Cogeneration System
CCGT	Combined-Cycle Gas Turbine
C_{NG}	Naturel gaz cost
C_{ELEC}	Electric cost
C_{PM}	Prime mover cost
CD	Carbon dioxide
CDD	Cooling Degree Day
COP	Coefficient Of Performance of cooling
CSP	Concentrated Solar Power
CC	Combined Cycle
°C	Degree Celsius
CM	Centimeter
DHW	Domestic Hot Water
$EF_{NG\ ,CD}$	Electric CO_2 emission
$EF_{ELEC\ ,NX}$	Electric NO_X emission
$EF_{NG\ ,M}$	Electric CH_4 emission
$EF_{ELEC,M}$	Natural gaz CH_4 emeission
EUAS	Equivalent Uniform Annual Savings
EUAC	Equivalent Uniform Annual Cost
E_{GRID}	Electric from grid
EMS,G	Emission gases
E_h	yearly Heating energy consumption
E_c	yearly Cooling energy consumption
ESCos	Energy Service Companies
F	Fuel
GHG	Green House Gaz
GW	Giga Watt
HRSG	Heat Recovery Steam Generator
hi	Combined Heat transfer coefficients at the Interior
h0	Combined Heat transfer coefficients at the Exterior
HDD	Heating Degree Day
ICE	Internel Combustion Engine

IRR	Internal Rate of Return
IC	Initial Cost
IEA	International Energy Agency
J	Joule
kW	Kilo Watt
K	Kelvin
kWh	Kilo Watt Hour
Kg	Kilo Gram
L_{PM}	Life time of the primary
LHV	Lower Heating Value of fuel
MW	Mega watt
Mtoe	Million Ton
m^2	Square metre
m^3	Cubic metre
M	Methane
NX	Nitrogen oxides
NHR	Net Heating Requirement
NCR	Net Cooling Requirement
NPRE	National Recover Energy Program
ORC	Organic Rankine Cycle
PV	solar Photovoltaic
PEC	Primary Energy Consumption
PF_{ELEC}	Electric PFC factor
PF_{NG}	Natural gaz PFC factor
PM	Primary Mover
PEMFCs	Proton exchange
PEFCs	Polymer Electrolyte Fuel Cells
$Q_{heating}$	Heating transmission loads
$Q_{cooling}$	Cooling transmission loads
SOFCs	Solid Oxide Fuel Cells
SPP	Simple Payback Period
SEC	Site Energy Consumption
TWh	Tira Watt Hour
Tb	the base temperature
T0	the daily average outdoor air temperature
T_{ES}	Thermal energy storage
U	Overall heat transfer coefficient
y	Year

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General Introduction

Global energy demands are increasing on a daily basis and these demands are still being met with conventional methods of power generation such as burning coal and gasoline these resources are not only limited but also are detrimental to our environment. They Lack of asset with outdated network infrastructure, climate change, rising fuel costs, has resulted inefficient and increasingly unstable electric system. Currently, one of the alternative solutions to reduce energy consumption is the implementation of cogeneration energy systems. Furthermore, having the energy supply system close to end users offers several other advantages.

The cogeneration or CHP system is higher performance compared to the reference system, which is based on the separate generation of heat and power. It reduces fuel consumption, CO_2 emissions and annualized total cost. The cogeneration took the first legislation in the United States in 1978, and in the European Community and in the United Kingdom in 1983. [Roman, K.K., Hasan, M. 2018]

In 2015, Algeria announced the adoption of updated development program for renewable energies (NPRE) in order to diversifying Algeria's power production by increasing generation from sustainable sources and preserving fossil fuel resources. The national plan aims to add 22 GW of renewable over the 2015-2030 period, with the first 4,500 MW commissioned by 2020. The bulk of this new capacity should come from solar PV (13,575 MW), followed by wind power (5,010 MW), solar CSP (2,000 MW), biomass (1,000 MW), CHP (400 MW) and geothermal (15 MW) [Recioui, 2017]. One of the applications of cogeneration in Algeria the new DjamaâelDjazaïr mosque, the Great Mosque of Algiers, to supply four of gas engines for a trigeneration plant that will provide the mosque with reliable, efficient and lower-carbon power, heating and cooling. The natural gas-fueled trigeneration plant will supply 4.25 megawatts (MW) of electricity, 4.3 MW of heat in the winter and 3.5 MW to produce 6 MW of chilled water in the summer at the planned mosque [Clarke, Energy Algérie, 2008].

In Algeria, buildings are major energy consumer of energy among economic sectors, with 39% of total final energy and 3.77% of CO_2 emissions in 2020. Thus, the increasing demand for sustainable buildings with the constant need of cooling and heating power in buildings calls for improving traditional energy production and optimum use. One method to produce sustainable energy is to adopt the combined cooling, heating, and power (CCHP) technology, which is also known as Polygeneration [Trabelsi, M. &Meissa, C.2018]

The objective of dissertation is study of a polygeneration energy system to produce power heat and cool in Algeria. We talk about the polygeneration system and all of the technologies usable in this system and the way it functions and have an application on three different climatic zones with the aid of the polygen.calc program.

The dissertation is distributed as follows:

Chapter1: In this chapter we introduced general definitions of combined cooling and heating, power and we talked about the most technologies of these systems, the Areas of Application and general benefits.

Chapter2: We made this chapter a full modeling of Polygeneration system part by part, we mode also how this system is applied and where do and where we put all of thermal energy and electric energy.

Chapter3: This work presents a method for predicting and forecasting the energy consumption of residential buildings in Algeria uses the degree-day method to determine the annual heating and cooling needs of buildings in different regions 3 stations (TOUGGOURT, ORAN, and DJELFA).

Chapter 4: The modeling of this system and the numerical approach utilized will be the topic of this chapter. We use the POLYGEN.calc tool to pick the kind and size of our Polygeneration system based on our energy consumption.

Chapter 1: The Co and Polygeneration

1.1 Introduction

Cogeneration, i.e. the combined production of useful heat and power (CHP), and the Polygeneration is the combined production the cool, heat and power (CCHP). This system They are usually located close to users as lower distribution and transmission cost, [Wickart, M. 2007] and less power loss through the transmission and distribution line, and to generate electricity improves the overall efficiency of the plant and can displace higher emitting coal generated electricity, alleviated environmental impacts, and enhanced resilience of the utility grid, In this chapter, we first evoke a reminder of the generalities on cogeneration: definition, classification. Then, we will present the different cogeneration technologies and we present the combined cooling, heat and power (CCHP).

1.2 Definition of cogeneration:

Cogeneration, in general, is the simultaneous production of heat and power from a single primary energy source figure 1.1 in the typical cogeneration system, mechanical power is produced from a thermal generation unit, such as a gas turbine. Then the mechanical energy generated by a turbine or an engine is transformed into electrical energy. [Alberta Environment and Sustainable Resource Development, 2012]

Figure 1.1: plant of Cogeneration[Cogeneration, D.F.I.C., 2016]

The generation unit produces waste heat, including exhaust gases that is recovered to meet heating demands of the building or industrial unit.

1.2.1 The Principle of Cogeneration

Cogeneration is a technology that has the dual advantage of limiting line losses and investment in very high voltage lines. So the cogeneration principle encompasses a wide range of proven technologies and that aim for an overall efficiency increased by the priority use of thermal energy, either in an industrial process or in a boiler room. [Cogeneration, D.F.I.C., 2016]

Cogeneration can be divided into small scale applications like the mechanical energy generated by a turbine or an engine is transformed into electrical energy, therefore into independent production of electricity the mechanical / electrical conversion efficiency is around 98%.

In research applications, electricity production can also come from a fuel cell. [RIGHI, S. & SAHLI, I.2020]

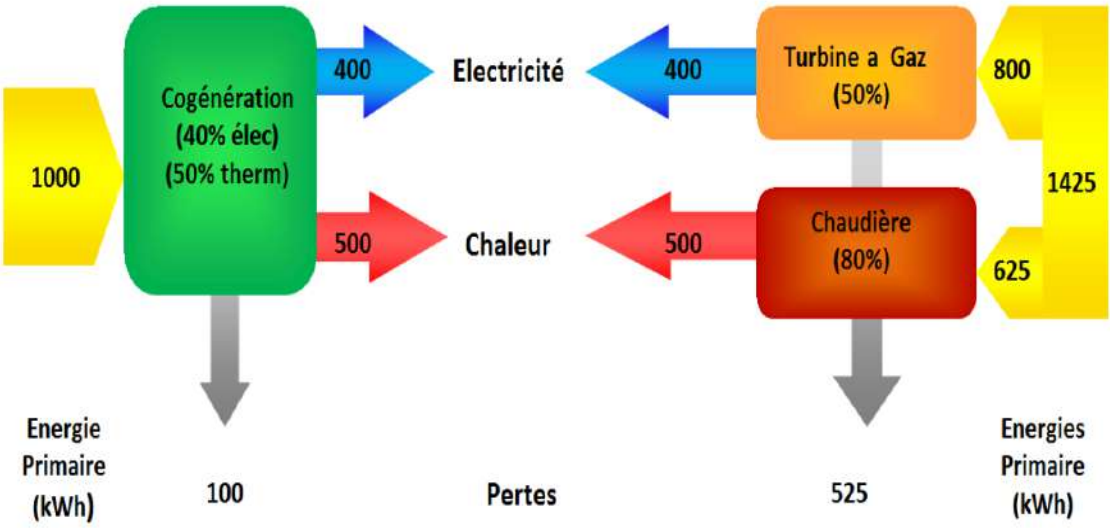


Figure1.2: Cogeneration System working principle [RECIOUI, B., 2017]

Cogeneration also is a way of generating both thermal energy to be used for heating buildings and / or for producing domestic hot water or for industrial processes and stations outlet steam.

1.2.2 Cogeneration technologies

These types of cogeneration plants can be differentiated by technology and feasible capacity, starting from some 1 kW engines that are usually focused on thermal energy supply as illustrated in figure1.3.

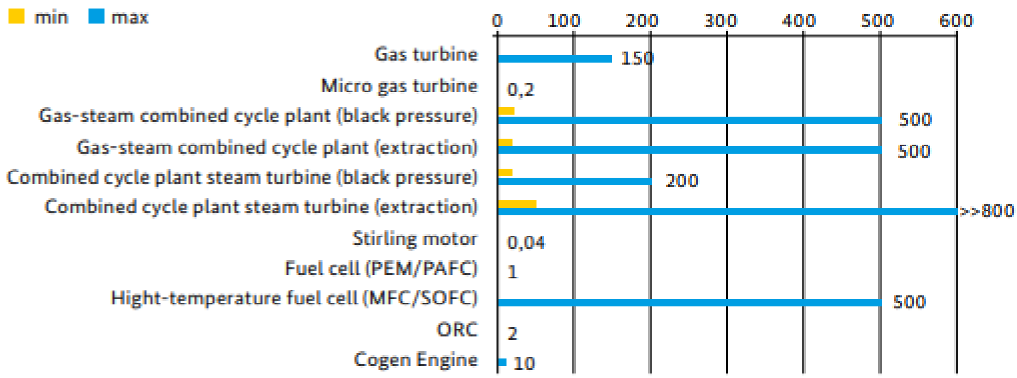


Figure1.3 : Cogeneration Capacity Range per Technology (MW) [Cogeneration, D.F.I.C., 2016]

1.2.2.1 Gas engines-based cogeneration system

One of the first widely used engine technologies in cogeneration it's a gasoline engine. Based on car engines (and technology from the automotive industry).series production, these motors are further optimized and equipped with heat recovery Components tailored to the individual needs of customers.

Figure 1.4: Principle of Cogen with Gas Engines [Cogeneration, D.F.I.C., 2016]

CHP engines range in power from tens of kilowatts to about 10 megawatts. Therefore, it is mainly domestic, tertiary, industrial facilities and applications that are affected by such technologies. Their electrical efficiency is typically between 30% and 40%. [RIGHI, S. & SAHLI, I.2020]

1.2.2.2 Gas turbine-based cogeneration system

A gas turbine cogeneration system can generate all or part of a site's energy needs. The energy released at high temperatures in the stack can be recovered for various heating and cooling applications.

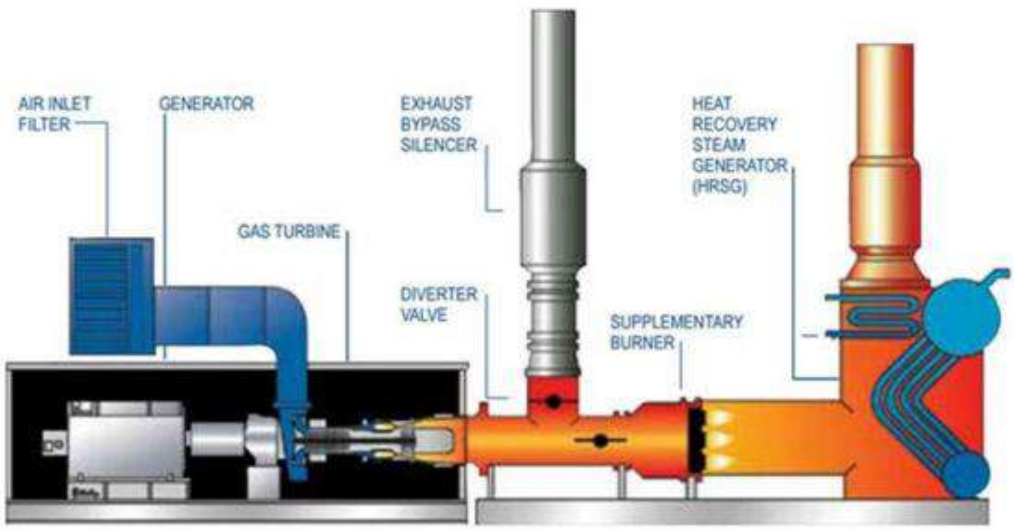


Figure I.5: Gas Turbine Configuration with Heat Recovery [Cogeneration, D.F.I.C., 2016]

While natural gas is the most commonly used, other fuels such as light heating can use oil or diesel. The typical range for gas turbines is from a fraction of a megawatt to about 100 megawatts. [RIGHI, S. & SAHLI, I.2020]

1.3 Definition of Polygeneration (CCHP)

As the name suggests, Polygeneration provides a third form of energy: cooling energy in addition to heat and power. Polygeneration Systems also called Combined Cooling Heating and Power (CCHP) systems are typically a combination of cogeneration plants and chillers to produce electricity, heat and cooling energy in one process. [Roman, K.K., Hasan, M.2018]

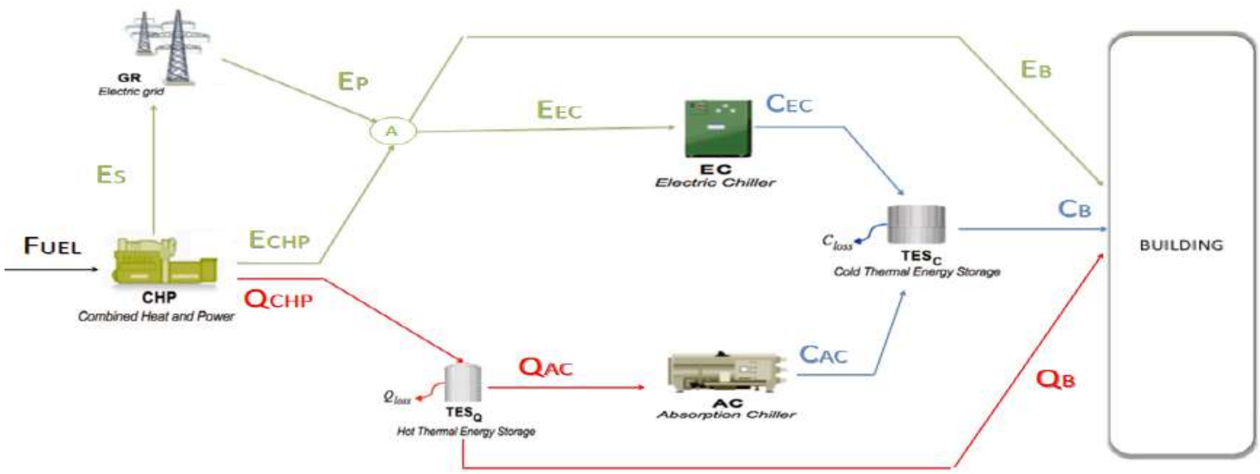


Figure1.6: CCHP system

Waste heat is thereby converted to chilled water, either by absorption or adsorption chiller technology.

1.3.1 Principle working of Polygeneration

Polygeneration systems produce heat and electricity which in turn can be used for heating, cooling and hot water heating systems in a building. Electricity produced can also be supplied to the grid if not needed on the site.

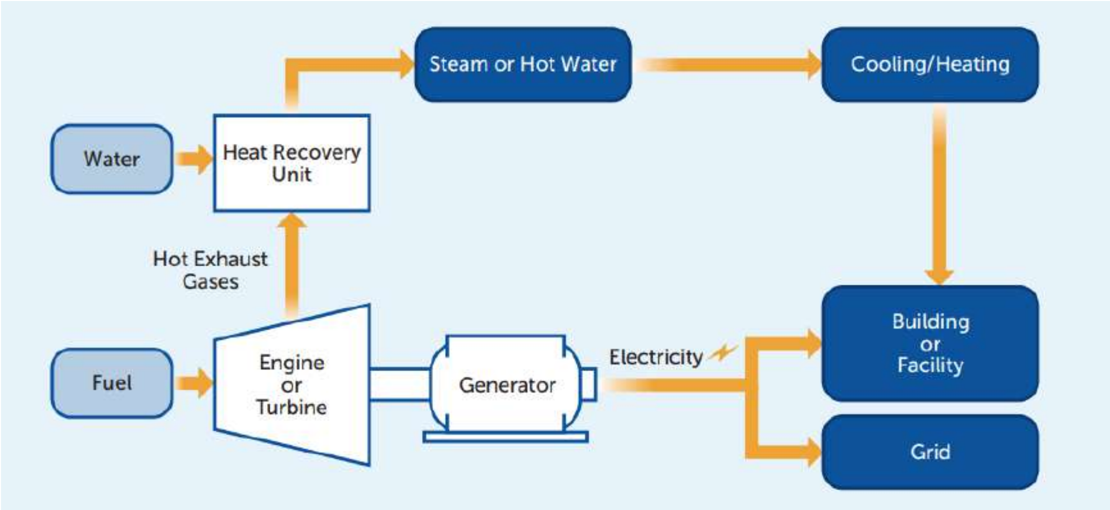


Figure1.7: Working principle of Polygeneration system [U.S. EPA. 2013a]

Polygeneration systems are more commonly used in buildings with readily available waste heat and intense 24 hours operations. [U.S. EPA. 2013a]

1.3.2 Polygeneration technologies

1.3.2.1 Micro-turbines

Micro turbines are small gas turbines. Their principle of operation is based on combustion. A mixture of compressed air and fuel is ignited in an internal combustion engine which drives a turbine. [Onovwiona, H.I. 2006] Currently, commercial micro turbines are sized above 25-30 kW, but research on micro turbines below 25 kW is ongoing. [Sonar, D., Soni, S.L.2014]

The most recognized advantages of micro turbines are their compact size, light weight, low noise, fast response and low maintenance requirements. These advantages are mainly related to the reduction in the number of moving parts. Another advantage of micro turbines is their low NOx emission. This is achieved by low intake air temperature and high fuel to air ratio. [Liu, M., Shi, Y.2014]

Fuel flexibility is also an advantage of micro turbines. There are micro turbines on the market that use natural gas, propane, biogas, LPG, diesel and kerosene as fuels. However, it is important to clarify that the fuel affects the performance of micro turbines via electricity and overall efficiency. [Onovwiona, H.I. 2006]

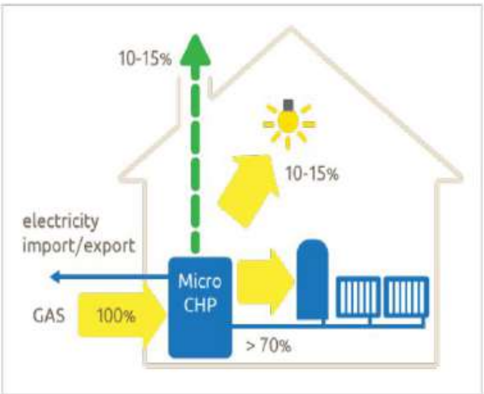


Figure 1.8: micro-turbine system integrated in house [RIGHI, S. & SAHLI, I.2020]

The main disadvantages of micro turbines compared to internal combustion engines are high investment costs and low electrical efficiency. However, for residential applications, the low electrical efficiency is not a major drawback due to the lower load curve compared to medium and large applications. [Liu, M., Shi, Y.2014] Therefore, despite the high investment costs, micro turbines remain good candidates for residential applications. [Sizmaz, S. 2016]

1.3.2.2 Stirling engines

Stirling engines are external combustion engines, which affects some of their advantages. They have a more efficient combustion process and good fuel flexibility than internal combustion engines. [Onovwiona, H.I. 2006] The combustion process outside the combustion chamber allows the use of solid fuels such as wood [Entchev, E., Tzscheutschler, P., Darcovich, K., Sasso, M.2014]. They can also be combined with renewable energy sources such as solar energy. [Murugan, S. and Horák, B. 2016] Since the combustion process is continuous and controlled, the emissions from power generation are low, which helps reduce pollution. [Liu, M., Shi, Y.2014]

Stirling engines are considered to be one of the most promising prime movers for small-scale applications due to their high overall efficiency, fuel flexibility, and reliability. [Renzi, M. 2014]

Figure 1.9: Stirling engine based micro CHP systems available in the market [Sizmaz, S. 2016]

Additionally, their low noise and good part load performance make them more suitable for small CCHP applications. Furthermore, since Stirling engine-based combined heat and power (CHP) [Maraver, D., Sin, A., Royo, J.2013] are already on the market, it is practical to integrate them into combined heat, electricity, and cooling. Micro CHP Stirling systems are sized below 10 kW. [Maghanki, M.M., Ghobadian, B., Najafi, G.2013]

1.4 Areas of Application for CHP and CCHP Technologies

Co/Polygeneration technologies and applications vary by country and region. This is partly due to differences in climatic conditions and economic frameworks as well as local cogeneration market conditions.

The application of Co/Polygeneration technology is not limited to industrial applications, but is also increasingly used in the tertiary sector and the residential sector. The residential sector and buildings in particular offer great potential for CHP and CCHP applications; they are characterized by a high demand for heat and/or cooling, and rising incomes lead to a growing need for thermal comfort.

The International Energy Agency (IEA) describes and differentiates typical CCHP applications as follows:

Table1.1: Overview of Cogeneration Features per Application Segment [Cogeneration, D.F.I.C. 2016]

Application Segment/ Co-gen Feature	Industry (Power Utilities)	Service / Institutional	Space Heating and Cooling
Typical customers	Chemical, pulp and paper, metallurgy, heavy processing (food, textile, timber, minerals), brewing, coke ovens, glass furnaces, (palm) oil refining, agro-sector, incl,dairies, sugar industry	Light manufacturing, hotels, hospitals, large urban office buildings, agricultural operations	All buildings within reach of heat network, including office buildings, hotels, individual houses, campuses, airports, industry
Ease of integration with renewable and waste energy	Moderate – high (particularly industrial energy waste streams)	Low – moderate	High
Temperature level	High	Low to medium	Low to medium
Typical system size	300 kW el – 50 MW el	1 kW el – 10 MW el	Depending on conditions and size of building/cluster to be supplied
Typical prime mover	Steam turbine, gas turbine, reciprocating engine (compression ignition), combined cycle (larger systems)	Reciprocating engine (spark ignition), Stirling engines, fuel cells, micro-turbines	Small and medium-sized gas engines Networks: steam turbine, gas turbine, waste incineration, combined-cycle gas turbine (CCGT)
Energy/fuel source	Any liquid, gaseous or solid fuels; industrial process waste gases (e.g. blast furnace gases, coke oven waste	Liquid or gaseous fuels	Any fuel

	gases)		
Main payers	Industry (power utilities)	End users and utilities	Include local community energy service companies (ESCos), local and national utilities, industry
Ownership	Joint ventures/ third party	Joint ventures/ third party	From full private to full public and partly public/ private, including utilities, industry and municipalities
Heat/electricity load patterns	User- and processspecific	User-specific	Standardized, daily and seasonal fluctuations mitigated by load management and heat storage

It is clear that cogeneration and Polygeneration are versatile in terms of applications, plant scale and fuels that can be used, this is why the study of CHP and CCHP systems is complex and the planning must take into account different parameters. [Cogeneration, D.F.I.C., 2016]

1.5 Benefits of district CHP and CCHP

In general, benefits from Co/Polygeneration are:

- Increased energy efficiency providing useful energy services to facilities with less primary energy input.
- Economic development value allowing businesses to be more economically competitive on a global market thereby maintaining local employment and economic health.
- Reduction in emissions that contribute to global warming increased efficiency of energy use allows facilities to achieve the same levels of output or business activity with lower levels of fossil fuel combustion and reduced emissions of carbon dioxide. [RIGHI, S. & SAHLI, I.2020]

1.6 Cogeneration situation

1.6.1 Global situation

Many governments have concentrated their efforts on this kind of energy, with some stunning outcomes. Cogeneration is an essential aspect of the national energy balance in nations like Denmark and Finland. Cogeneration provides them about 30% of the electrical energy they use. Because of the economic performance of these cogeneration facilities, these nations may obtain a large increase in energy efficiency. Electrical energy generated by cogeneration facilities accounts for a significant portion of overall power production in nations such as Germany and China (about 13% of total electricity production). Cogeneration is often minimal or perhaps non-existent in countries like Italy, Spain, the United States, France, and Japan.

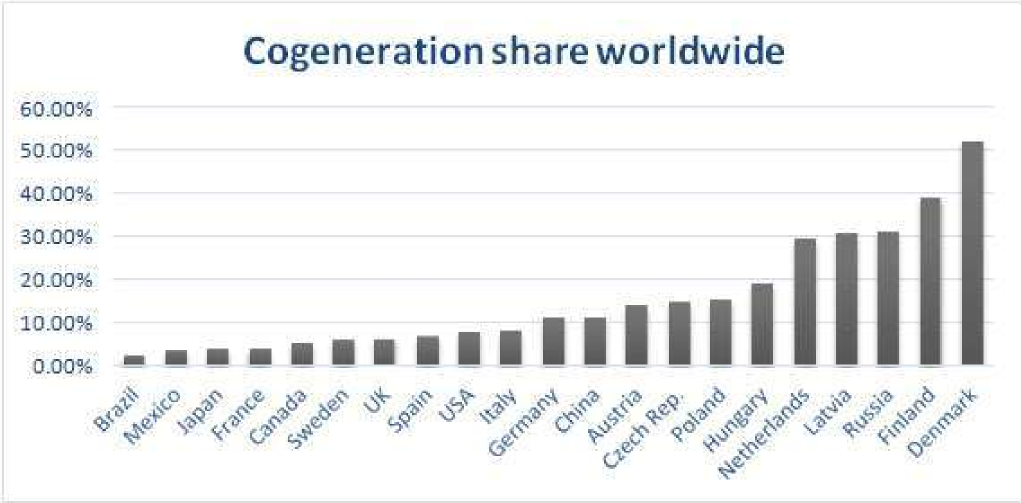


Figure 1.10: Share of cogeneration in the international energy production [RECIOUI, B., 2017]

Cogeneration is one of the energy production methods that contributes to guaranteeing sustainable development in the existing energy mix. Indeed, it is compatible with a wide range of energy sources, including fossil (gas, coal...) and renewable (biomass, solar, geothermal...) sources [RECIOUI, B., 2017]

1.6.2 National situation

The primary energy is kind of a energy found in nature that has not been converted or transformed in any way. It is the energy contained in raw fuels as well as the energy received as a system input.

From 2017 to 2018, commercial primary energy output fell marginally (-0.4%) to 165.2 Mtoe (Million- ton of oil equivalent). The drop in liquid product output (petroleum, condensate, and LPG) was somewhat offset by a rise in natural gas production. [Ministere de l'énergie 2, 2019]

Figure 1.11: Repartition of the primary energy production by products [Ministere de l'énergie 2, 2019]

Natural gas continues to dominate commercial primary energy production, accounting for 56 percent of total output, as shown in fig1.11.

The national output of electrical energy increased by 0.8 percent to 76.9 TWh in 2018, up from 76.0 TWh in 2017. This growth in electrical production is due to the development of new projects. [Ministere de l'énergie 2, 2019]

This type of power plant is utilized in Algeria, as well as other nations, to meet the basic and intermediate electrical load. CC technology has also reached maturity. This technique has grown in popularity in recent years, particularly in emerging nations where power consumption is fast increasing. The combined cycle (CC) is increasing each year, as seen in Fig. 1.12.

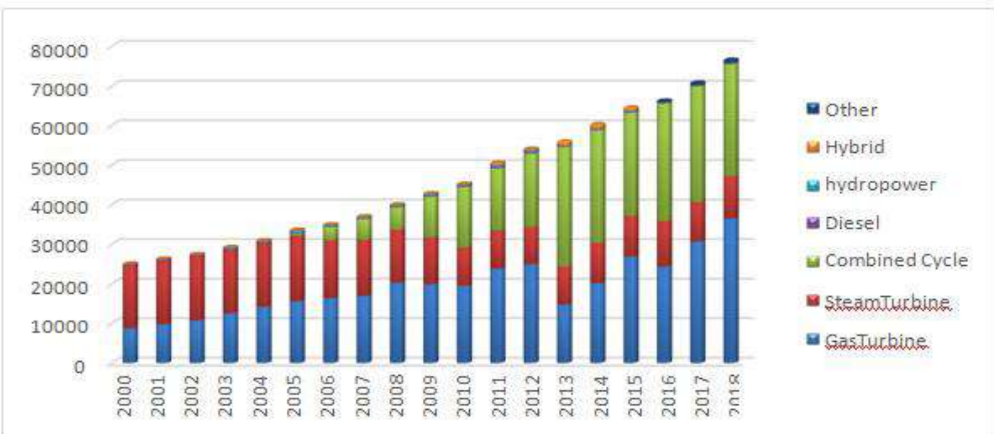


Figure 1.12: Electricity production share by technologies in Algeria [Ministere de L'énergie, 2019]

According to the graph, Algerian energy generation is moving toward combined cycle (CC) technology with each passing year. Currently, the installed capacity is 76.7 TWh, although further capacity is being planned for the next years. [Ministere de L'énergie, 2019].

1.6.2.1 Development projects of cogeneration in Algeria

The production of electricity in Algeria has not been confined to gas turbine power plants in recent years, since Sonelgaz has built several combined cycle power plant projects, which are mentioned below [Ministere de L'énergie, 2019]. In 2018, a total of 1,909 MW of electricity was installed, which was devided as follows:

Table 1.2: Electric centrals realized by SPE. [Ministere de L'énergie, 2019]

Production	site	Wilaya	Power (MW)
Gas Turbines	Ain Djasser III	Batna	139
Combined cycle	Ras Djinet	Boumerdes	754
	Ain Arnat	Sétif	1,016
Total	-	-	1,909

The Djamaâ el Djazar Mosque, also known as the Mohammadia Mosque, will also be powered by a trigeneration system based on four GE Jenbacher gas engines supplied by Clarke Energy.

Figure 1.13: The Djamaâ el Djazaïr Mosque trigeneration project [Stratégie, 2018]

The developers of the new Djamaâ el Djazar (Great Mosque of Algiers) mosque have chosen Clarke Energy, the authorized distribution partner of Jenbacher gas engines in Algeria, to provide four engines, according to GE's Distributed Power business. Jenbacher Gas Fired GE J320 This is a three-generation facility. The facility will provide the mosque with electricity, heating, and conditioning that is dependable, efficient, and low-carbon. The mosque, also known as Mohammadia Mega Mosque, will get 4.25 MW of power, 4.3 MW of heat in the winter, and 3.5 MW to create 6 MW of chilled water in the summer from the natural gas-fired trigeneration plant. Mohammadia is located near Algiers, Algeria's capital [Stratégie, 2018].

In the next years, a total of 4,506MW of power is projected. The following are the projects:

Table 1.3: Under construction electricity production centers for the next years [Ministere de L'énergie, 2019]

Type of production	Site	Wilaya	Power (MW)	Progress (%)
Gas Turbines	Boutlelis	Oran	446	**70**
	Tilghemt	Laghouat	368	**22**
Combined cycle	IIRas Djinet	Boumerdes	1 131	**94**
	Naâma	Naâma	1 163	**64**
	Bellara	Jijel	1 398	**59**
Total	-	-	4506	**-**

1.7 Conclusion

The uses of cogeneration CHP and polygeneration CCHP systems have been thoroughly explained as well as its enormous advantages. This chapter defined those systems and presented the various technologies that use the cogeneration or polygeneration principle with details. CHP (or CCHP) and their role in the world were presented as the new dawn of electricity generation with regard to primary energy conservation. In fact, these systems are obviously the future main factor of the energy sector in Algeria. Thus, we can deduce that cogeneration is the future in everyone, especially since in Algeria it has demonstrated significant economic and environmental efficiency by integrating the CC system in several electric production stations the past and in the future projects, according to this achievement it’s only a matter of time before the other application of cogeneration will take part in the residential and the other sections in Algeria.

But our main concern is the integration of the CCHP system in several sectors like residential which we’ll be detailed in the third chapter.

CHAPTER 2: STUDY OF POLYGENERATION SYSTEM

2.1 Introduction

In order to achieve the first goal of this chapter, we have to do full modeling of the various parts used in Polygeneration system, which is a modeling of the used power supply and cooling and heating from the Polygeneration. Also, this thermal energy and electric energy produced from this system we where store.

2.2 General operation of Polygeneration

A Polygeneration system can meet the heating and cooling needs of a single building while generating electricity. The simplified diagram presented in Figure 2.1 can better illustrate the Polygeneration system.

Natural gas (F) is used to run engines, which drive generators to produce electricity. The heat from exhaust gases is collected. Internal heat exchanger and transported in the hot water flow.

This hot water is used to heat the water in the thermal storage tank. This water is then sent to the domestic hot water tanks (DHW). And the absorption machines to get col water after then send all of this water (hot/cold) to the building.

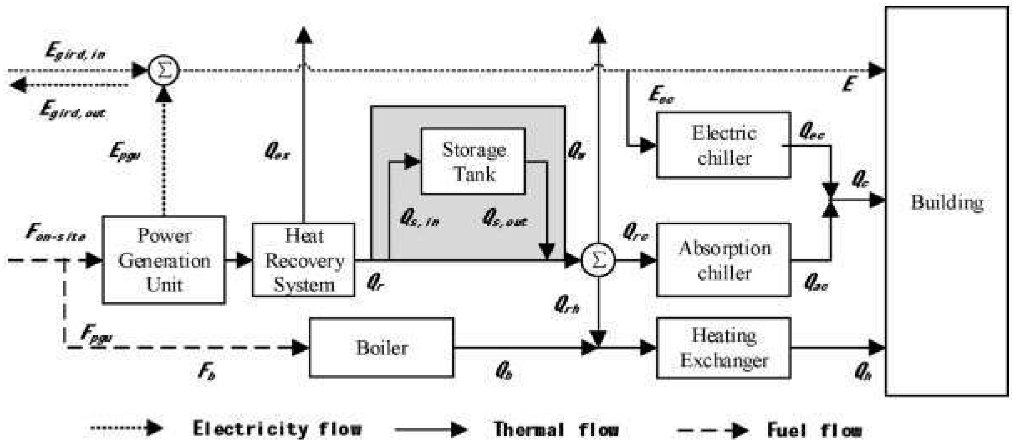


Figure2.1: Simplified diagram of a Polygeneration system [Yang, G., Zheng, C.Y.2017]

The wastewater is then returned to the hot storage tank. The conditioned water leaving the absorber evaporator first passes through a refrigerated tank before being directed to the building. [Tanguay, D.A., SUNYÉ, R., SORIN, M.2011]

2.3 Performance parameters of CCHP

Because of its potential for long-term economic benefits with a quick payback on initial capital expenditure, the CCHP system has sparked a lot of attention. Economic benefit, on the other hand, is a complex calculation that is influenced by factors such as equipment cost, efficiency, electricity and fuel costs, building electric demand, heating and cooling load, and so on.

Several equations were used to establish the best performance settings and increase the performance of the CCHP system. Equations for calculating GHG emissions [e.g., carbon dioxide (CD)] have also been established. Furthermore, equations can be used to illustrate methodologies for calculating annual cost savings and primary energy consumption (PEC).[Roman, K.K., Hasan, M.2018]

2.3.1 Energy consumption

Generally, the energy conservation parameter for the design is the primary energy consumption (PEC). Another parameter, referred to as site energy consumption (SEC) always increases when the CCHP is used. In contrast, the PEC is a better indicator of energy feasibility because of its potential to decrease when the CCHP is operational. [Roman, K.K., Hasan, M.2018]

Savings in primary energy consumption can be calculated by

$$PEC_s = \sum_{i=1}^{8760} \frac{(F_{m\,ref} PF_{NG} + E_{grid\,ref} PF_{elec}) - (F_{mi} PF_{NG} + E_{grid} PF_{elec})}{F_{m\,ref} PF_{NG} + E_{grid} PF_{elec}} \quad (1)$$

Where PF_{elec} and PF_{NG} are the primary energy conversion factors for electricity and natural gas.

2.3.2 Emission characteristics

When compared to traditional heating and cooling systems, emissions savings might be a major factor in deciding whether or not to install a CCHP system. Even if the savings are not significant, government agencies or the environmental protection industry will always choose to construct energy systems with superior emission characteristics (i.e. CCHP). Carbon credits have been issued as emissions incentives by various federal, state, and municipal government agencies in recent years to promote energy efficient technology such as CCHP systems to industrial and residential consumers. Even when the economic returns of CCHP systems are negative when compared to standard building air conditioning units by SPP, IRR, and EUAS, CCHP systems are economically viable in terms of carbon credits.

The equations for the reduction in emissions for all three gases considered in this study, relative to the reference system [Roman, K.K., Hasan, M.2018]

$$\mathrm{Em}_{s,g} = \sum_{i=1}^{8760} \frac{\mathrm{Em}_{ref} - \mathrm{Em}_{CCHP}}{\mathrm{Em}_{ref}} \tag{2}$$

Here, g in the subscripts represents the gas for which the savings are being calculated, i.e., represents the emission savings for carbon dioxide (g = CD), nitrogen oxides (g = NX), and methane (g=M) are the emissions from the reference case and are the emissions obtained when the CCHP system is operated and can be calculated by

$$\mathrm{Em}_{CCHP} = \mathrm{F}_{m}\mathrm{EF}_{NG,g} + \mathrm{E}_{grid}\,\mathrm{EF}_{elec,g} \tag{3}$$

$$\mathrm{Em}_{ref} = \mathrm{Fm}_{ref}\,\mathrm{EF}_{NG,g} + \mathrm{E}_{grid.ref}\,\mathrm{EF}_{elec,g} \tag{4}$$

2.3.3 Economic analysis

Equation (5) can be used to calculate the total annual operating cost (AOC) of the CCHP system together with the reference system.

$$AOC_{PM} = \sum_{i=1}^{8760} FmiCNG + Egrid_iCelec + PPMi\ CPM \quad (5)$$

Parameters C_{NG} and C_{elec} used in Equation (5) and (6) are the cost of natural gas and electricity, respectively.

The operational (excluding fuel) and maintenance cost per unit of energy produced by the PM is desginated as COM.

$$AOC_{ref} = \sum_{i=1}^{8760} FmiCNG + Egrid_iCelec \quad (6)$$

The value represents the energy produced during the itch interval. The annual savings can be calculated by deducting AOC_{PM} from the AOC_{ref} as shown in Equation (7).

$$AS = AOC_{ref} - AOC_{PM} \quad (7)$$

As shown in Equation (8), the calculation of the simple payback period (SPP) depends on the AS calculation

$$SPP = \frac{IC}{AS} \quad (8)$$

Where, IC is the initial cost. A discounted cash flow method, such as internal rate of return (IRR), is also used to evaluate these CCHP systems. CCHP is attractive for building operations when IRR is greater than the minimum attractive rate of return (MARR). IRR can be calculated from the Equation (9).

$$IC = AS\frac{(1+IRR)^{Lpm}-1}{IRR(1+IRR)^{Lpm}} \quad (9)$$

Where, LPM is the lifetime of the PM. Another discounted cash flow method is the net present value (NPV) for CCHP systems. NPV can be calculated as shown in Equation (10).

$$NPV = \sum_{n=0}^{N}\frac{AS}{(1+i)^n} - IC \quad (10)$$

Where, i is the discount rate, n is the time of cash flow (period), and N is the total number of periods. A third analysis that uses discounted cash flow is the equivalent uniform annual savings. First, the equivalent uniform annual cost is determined according to:

$$EUAC = IC\frac{\xi(1+\xi)^{Lpm}}{(1+\xi)^{Lpm}-1} \tag{11}$$

Where, ξ is the interest rate, chosen as a representative value for bank offered rates. Equivalent uniform annual saving can then be calculated from: [Roman, K.K., Hasan, M.2018]

$$EUAS=EUAC-AS \tag{12}$$

2.4 Power process in CCHP

Fuel cells create energy by an electrochemical reaction including hydrogen, oxygen, and water as a by-product [Kuhn, V., Klemeš, J.2008]. A fuel cell and fuel reformer with a cathode, anode, and electrolyte, as well as a power converter that converts direct current to alternating current, make up a conventional fuel cell. Different types of fuel cells, such as solid oxide fuel cells (SOFCs), polymer electrolyte fuel cells (PEFCs), and proton exchange membrane fuel cells, can be utilized depending on the application (PEMFCs).

PEFC is distinguished by its small size and inexpensive cost when compared to other types of fuel cells. PEFC, on the other hand, has a low electrical efficiency. SOFCs are noted for their high operating temperatures, which can reach 1000 degrees Celsius. Natural gas can be used to power micro-CHPs, which eliminate the problem of obtaining pure hydrogen and provide electrical efficiency of up to 55%. PEMFCs, on the other hand, can run at low temperatures of roughly 80°C [Maghanki, M.M., Ghobadian, B., Najafi, G.2013] and have operational flexibility, such as the ability to swiftly adjust to variations in electrical demand [Jradi, M.2014], as well as effective partial load control. [Onovwiona, H.I.2006]

Fuel cells, in general, have fewer moving parts than internal combustion engines and turbines, which minimizes the need for frequent maintenance and enhances reliability. Another advantage of fuel cells is that they are environmentally benign, as they only create water as a by-product of power generation. [Liu, M., Shi, Y.2014]

While the electricity production process produces no emissions, the fuel reforming process, such as the reforming of natural gas to acquire the hydrogen needed to power fuel cells, produces some pollutants. Wind or photovoltaic electrolysis, on the other hand, might be employed to make the fuel cell system renewable and carbon-free. [Becker, W.L., Braun, R.J., Penev, M.2012]

Another advantage of fuel cells is their low noise, as well as their small size, which makes them suitable for residential use [Wu, D.2006]. Fuel cells, on the other hand, have significant drawbacks. The most significant disadvantage is their complicated design and hefty investment cost. Furthermore, because fuel cells are still in the R&D stage, there are few fuel cell cogeneration devices on the market. [Jradi, M.2014]

2.5 Heating process in CCHP

Because not all of the heat produced by the gas turbine combustion process can be transmitted to the water or steam in the steam boiler, a considerable quantity of heat is lost through the flue gases. As a result, collecting heat from exhaust fumes can assist enhance the CHP system's overall efficiency, By sending flue gases through a heat exchanger or utilizing an Organic Rankine Cycle (ORC) engine to generate electricity from low-quality waste heat, heat may be recovered.

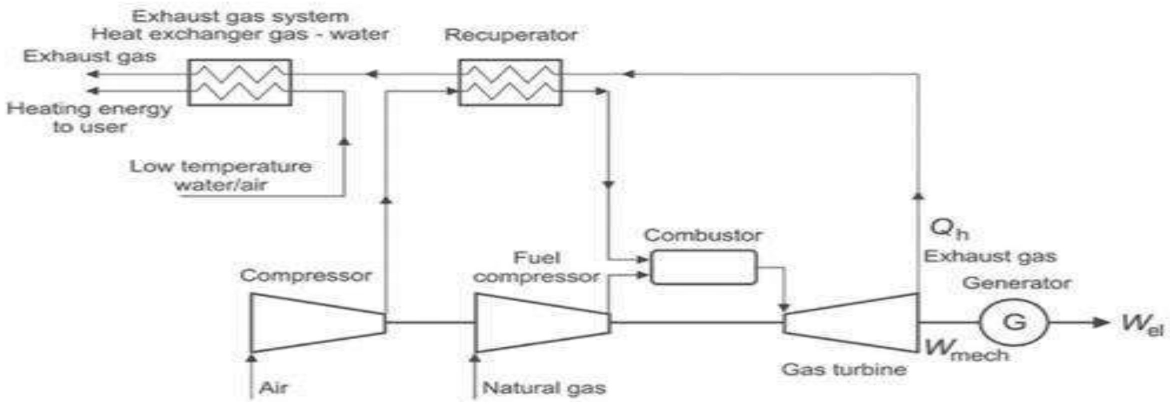


Figure2.2: CCHP system design with a micro turbine as a basic aggregate [Roman, K.K., Hasan, M.2018]

The effective utilization of the thermal energy contained in the exhaust gases is critical to the economics of gas turbines as CHP in process applications. A gas turbine generator with exhaust heat recovery transmitting power to a heat recovery steam generator (HRSG) that can supply steam for the process or drive a steam turbine generator is seen in Figure 2.2 Thermal energy accounts for 60 to 70 percent of the total energy utilized by the fuel. The creation of steam in non-stretched or supplemental combustion heat recovery steam generators is the most prevalent application of this energy.

Gas turbine exhaust, on the other hand, can be utilized as a direct power source for unheated or burned process fluid warmers, or as warmed combustion air for electric boilers. The simplest steam cogeneration design is a recycled heat generator, which can create steam up to 83 bars. [Munikwa, R.2019]

2.6 Cooling process in CCHP

A Polygeneration system further optimizes the efficiency of cogeneration by using the generated (waste) heat for heating and/or cooling purposes. In addition, CCHP increases the flexibility of using waste heat as the process adapts to seasonal changes in heating and cooling energy demands. [Cogeneration, D.F.I.C. 2016]

3.5.1 Absorption

Absorption chillers have four main components: an absorber, a generator, a condenser and an evaporator. An absorbent and a refrigerator form a working fluid which is passing over the components of the device. The most preferred working pairs are lithium bromide-water and water-ammonia. [Jradi, M.2014] The choice of the working fluid pair depends on the evaporation temperatures required by an application. Lithium bromide water is mainly used for air cooling applications where the evaporation temperatures vary between 5-10 °C whereas the water-ammonia pair is preferred in application with evaporation temperatures lower than 0 °C which are typically small size air conditioning and large size industrial applications [Sizmaz, S. 2016]

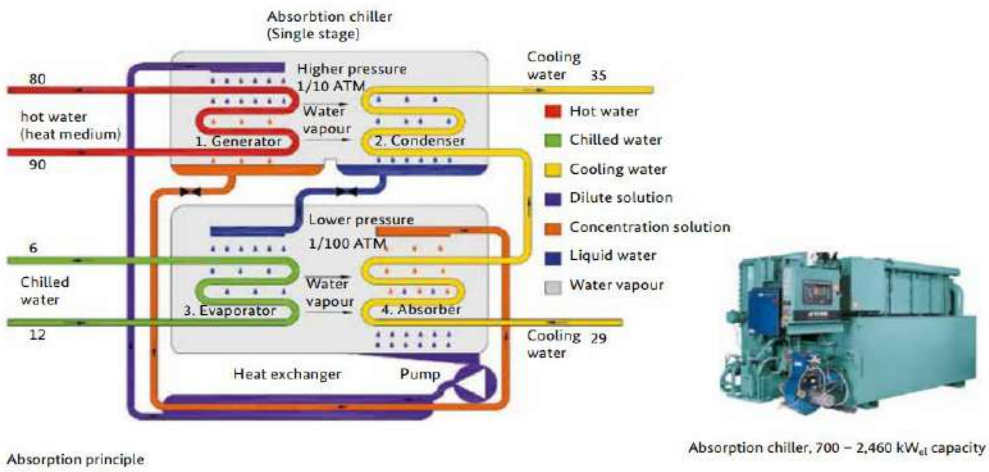
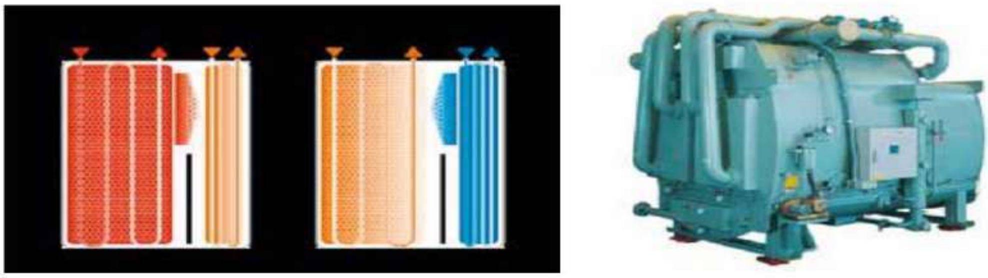


Figure2.3: Absorption Process [Cogeneration, D.F.I.C. 2016]

The working fluid selection has influence on the overall system performance since it affects the energy utilization factor. The advantages of absorption chillers compared to traditional vapor compression chillers include no emissions since they do not need electricity for their operation and less noise and vibration as they have few moving parts. However, they have lower coefficient of performance and higher costs compared to electrical chillers. [Sonar, D., Soni, S.L.2014]

3.5.2 Adsorption

Adsorption refrigerators operate on the principle of adsorption rather than absorption, i.e. molecules adhere to the surface of the adsorbent instead of dissolving. The adsorption chamber of the chiller is filled with solid materials (such as zeolite, silica gel, alumina, activated carbon and some types of metallic salts) which adsorb the refrigerant in a neutral state (in most water cases). When heated, the solid desorbs (releases) the refrigerant vapor, which cools and liquefies. This liquid refrigerant then provides a cooling effect at the evaporator absorbs external heat and becomes vapor again. In the last step, the refrigerant vapor is (re)adsorbed into the solids.



Adsorption principle

Adsorption chiller, 50 kW_{el} capacity

Figure2.4: Adsorption Process [Cogeneration, D.F.I.C. 2016]

Once the material is saturated, adding heat to the power source will cause it to regenerate again. This process results in intermittent cooling. [Cogeneration, D.F.I.C. 2016]

2.6.3 Electric chiller

Traditional vapor compression refrigeration equipment, such as electric chillers, are still used in Polygeneration systems in addition to thermally powered cooling devices.

Despite the fact that the goal of utilizing thermally activated cooling devices is to reduce the system's power usage by removing the need for electric chillers, some Polygeneration systems incorporate both thermally activated cooling devices and electric chillers [Liu, M., Shi, Y.2014]. Because of their age and dependability, electric chillers are still popular. Despite these benefits, satisfying cooling demand solely using an electric vapor compression chiller powered by the prime mover may not be feasible in small-scale Polygeneration applications due to lower electrical efficiency of small-scale prime movers.

As a result, electric vapor compression chillers are only advised when they are used in conjunction with a thermally actuated cooling device to increase the CCHP system's dependability and economics. [Wu, D.2006]

2.7 Thermal energy storage (cold/hot)

Heat accumulators are used when there is excess heat input in Polygeneration systems. The preference for including a heat accumulator in the system depends on the operating strategy determined. For example, if the system follows electrical load, i.e. prioritizes meeting electrical demand, the use of thermal stores is advantageous because the system generates more demand or waste of energy.

Thermal energy Storing excess heat and using it when needed can increase the thermal efficiency of the system. [Wang, J., Zhai, Z.J., Jing, Y.2010]

Table 2.1: Thermal storage examples [Sizmaz, S. 2016]

Sensible heat	Latent heat	Thermochemical
Underground thermal energy storage	Ice storage	Chemical reactions
Pit storage	Phase change material storage	
Molten salts		
Solid media storage		
Hot and cold water storage		

Additionally, the required chiller size, and hence the cost of the system, can be reduced by including thermal storage in the system. [Al-Sulaiman, F.A., Hamdullahpur, F.2011] Thermal storage can be divided into three main groups: sensible, latent and thermochemical [IEA, 2014.] Table 2.1 shows some examples of thermal storage systems within these main categories. [Sizmaz, S. 2016]

2.8 Electricity storages

In Polygeneration systems, while excess heat can be stored in thermal accumulators, excess electricity can also be stored in electrical storage devices such as batteries or capacitors [Onovwiona, H.I.2006]. Energy storage devices are devices that increase the efficiency of Polygeneration systems through appropriate device size and appropriate operating strategies [Kuhn, V., Klemeš, J.2008]. Electricity storage can be divided into several categories: mechanical, electrochemical, chemical and electrical

Table 2.2: Electricity storage examples [Sizmaz, S. 2016]

Mechanical	Electrical	Electrochemical	Chemical
Pumped hydropower	Super capacitors	Lithium based batteries	Electricity to hydrogen
Flywheels	Superconducting magnetic energy storage	Sodium-sulphur batteries	
Compressed air storage		Lead-acid batteries	

Mechanical storage converts electrical energy into mechanical energy or potential energy for storage, and is the most advanced way of storing electricity today. 99% of installed energy storage capacity is pumped hydro generation using potential energy. On the other hand, electrical storage is based on static electricity or magnetic fields. Research is still ongoing, so the cost of such storage is high. Electrochemical storage is another type of storage based on the flow of electrons caused by the chemical reaction of two or more electrochemical cells. [IEA, 2014]

They are generally used for smaller applications due to their limited capacity. Lead-acid batteries are an electrochemical storage that is known to be commonly used in backup power applications, including off-grid systems. [Kalinci, Y., Hepbasli, A.2015]

2.9 Conclusion

The world's energy profile is moving toward a cleaner, more sustainable energy system, and polygeneration systems play a key part in this transition. Because household consumption accounts for such a high percentage of total consumption, this study concentrated on small-scale polygeneration systems, which include a CHP unit, thermal energy storage, an auxiliary boiler, and a vapor compression chiller. trigeneration systems, in particular, are widely employed. For these systems, system setup, component sizes, and operating strategy are critical. Decision-making criteria for selecting the prime mover, which is the most important component of a CHP or CCHP unit, were established in order to give direction for persons who wish to invest in CHP or CCHP units. Internal combustion engines, Stirling engines, micro turbines and fuel cells were evaluated by these criteria. However, apart from these criteria, the importance of market conditions and weather conditions, thus energy demand profile are emphasized.

Chapter 3: Integration of Polygeneration in the Building

3.1 Introduction

In order to compute energy use, residential energy models rely on input data. This chapter proposes a method for calculating residential building energy consumption in Algeria. The usable energy demand of various end consumers in the base year is the starting point for constructing future energy consumption predictions (2021). We choose three different zones from The Algerian territory is divided into climatic zones. To estimate annual energy consumption. The annual heating and cooling consumption of buildings are calculated using the degree-day approach.

This method is the easiest and most intuitive way to estimate the annual heating and cooling energy consumption of a building. Calculate energy consumption for heating, cooling. [Ghedamsi, R.2016]

The energy used in residential buildings is provided by the following different uses of energy:

- Natural gas is used for space heating.
- Electricity is used to power air conditioners, fans, lighting, and office equipment.

3.2 Heating and cooling degree days

The degree-day approach is one of the ways for predicting a building's heating and cooling energy requirements. The method posits that the difference between the base temperature and the average outside air temperature is related to the energy demand of a building.

We calculated the HDD and CDD by

$$\mathrm{HDD} = \sum_{\mathrm{days}} (\mathrm{T_b} - \mathrm{T_0})^{+} \quad (13)$$

$$\mathrm{CDD} = \sum\nolimits_{\mathrm{days}} (\mathrm{T_0} - \mathrm{T_b})^{+} \tag{14}$$

Where Tb is the base temperature and T0 is the daily average outdoor air temperature, the total days of heating and cooling degrees (HDD and CDD) per year is determined. Only positive values are counted, as indicated by the + sign above the parenthesis. The fundamental temperature chosen from the standpoint of thermal comfort changes with the numerical value in this study, assuming that the heating period is 18 °C and the cooling period is 26 °C. [Ghedamsi, R.2016]

Table3.1: airports and weather stations

REGIONS	STATION
TOUGGOURT	Sidi Mahdi Air Port
ORAN	Es Senia Air Port
DJELFA	Tsletsi Air Port

The following three Algerian airports and weather stations are represented in Table3.1.

3.3 Annual heating and cooling loads

External walls, ceilings, windows, and basements, as well as infiltration, are the primary sources of heat loss in buildings. Only heat loss through external walls is addressed in this study. The heating and cooling transmission loads per unit area of exterior wall are calculated using the degree-days technique.

$$Q_{heating} = 86400 \times HDD \times U \tag{15}$$

$$\mathrm{Q_{cooling}} = 86400 \times \mathrm{CDD} \times \mathrm{U} \tag{16}$$

The total heat transfer coefficient for a typical wall (U) is determined as follows:

$$U = \frac{1}{\frac{1}{h_i} + \sum_{j=1}^{N} \frac{ej}{kj} + \frac{1}{h_0}} \tag{17}$$

Where hi and h0 are the combined heat transfer coefficients at the interior and exterior wall surfaces, respectively , these coefficients are considered to be 10 and 20W/m2 K. The thickness and thermal conductivity of the jth layer are represented by ej and kj, respectively.[Ghedamsi, R.2016]

The following equation may be used to determine the yearly energy usage for heating.

$$E_h = \frac{86400 \times HDD \times U}{LHV \times \eta_s} \tag{18}$$

Where LHV is the lower heating value of the fuel, which is commonly expressed in J/kg, J/m3, or J/kWh depending on the fuel type and S, is the heating system's efficiency. Similarly, yearly cooling energy consumption may be calculated using the same formula.

$$E_c = \frac{86400 \times CDD \times U}{COP} \tag{19}$$

The COP is coefficient of performance of cooling system. [Ghedamsi, R.2016]

3.4 Characteristics of the housing type studied

Building energy consumption accounts for a significant portion of the world's total end-use energy, accounting for around 40% of global energy consumption and the largest part of greenhouse gas emissions. The building sector utilizes the most energy in Algeria, accounting for 43 %, followed by transportation (36%), and industry (21%). Significant increases in population and housing, low prices of conventional energy, increased number of electrical equipment in each house, use of non-economic electrical equipment such as incandescent lamps and cheap air conditioners, lack of awareness and culture on energy efficiency, and people's growing desire for comfort are all factors that contribute to an increase in energy demand[Ghedamsi, R.2016].

To undertake thermal simulations, a single family dwelling type was chosen (Fig3.1); total area of 80 m2, total useable space of 40 m², with 3 m of wall height, and the involved wall area became 54 m2. 2 cm exterior cement layers, 10 cm brick block, 5 cm air gap, 15 cm brick block, and 1.5 cm interior plaster make up the wall construction (Fig3.2).

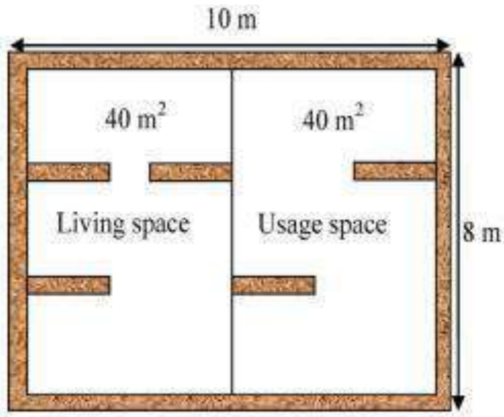


Figure3.1: Plan of the single family house.[Ghedamsi, R.2016]

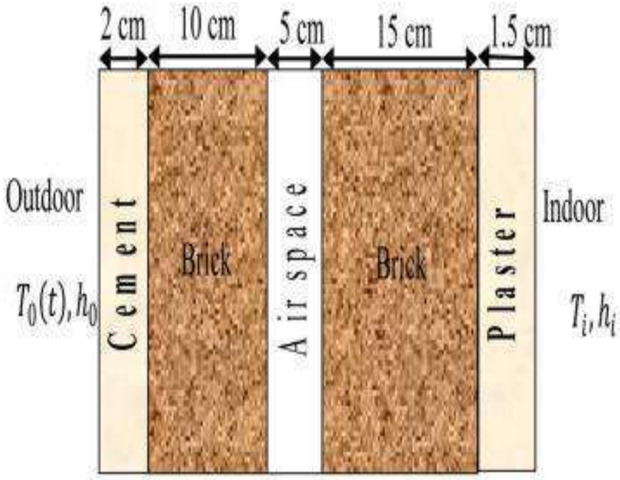


Figure3.2: Typical wall [Ghedamsi, R.2016]

For all cities analyzed, this structure is employed in the computations (Touggourt, Oran, Djelfa)

3.5 Results and discussion

3.5.1 Net Heating and Cooling Requirement

The unit is scaled based on heating and cooling demands to achieve a so-called quality Polygeneration capable of making the most of the energy generated. The power generated is supposed to be utilized solely within the company. Let's look at three stations in the month of December, which has the highest heating usage, and the month of August, which has the highest cooling consumption.

Table 3.2: Net heating and cooling requirement (NHR/NCR)

Station	**NHR (kWh /y)**	**NCR (kWh/y)**
TOUGGOURT	**67500**	**756000**
ORAN	**54000**	**378000**
DJELFA	**135000**	**297000**

3.5.2 Cooling and heating consumption

In all climatic zones, the cooling and heating consumption in one square meter of the home outer wall is calculated using the degree-days approach. We calculate the energy necessary for cooling and heating one dwelling in each zone by multiplying these values by the living wall envelope surface. The graph depicts the cooling and heating requirements for only first zones as example.

ZONES 1: TOUGGOURT (STATION SIDI MAHDI AIR PORT)

Cooling consumption :

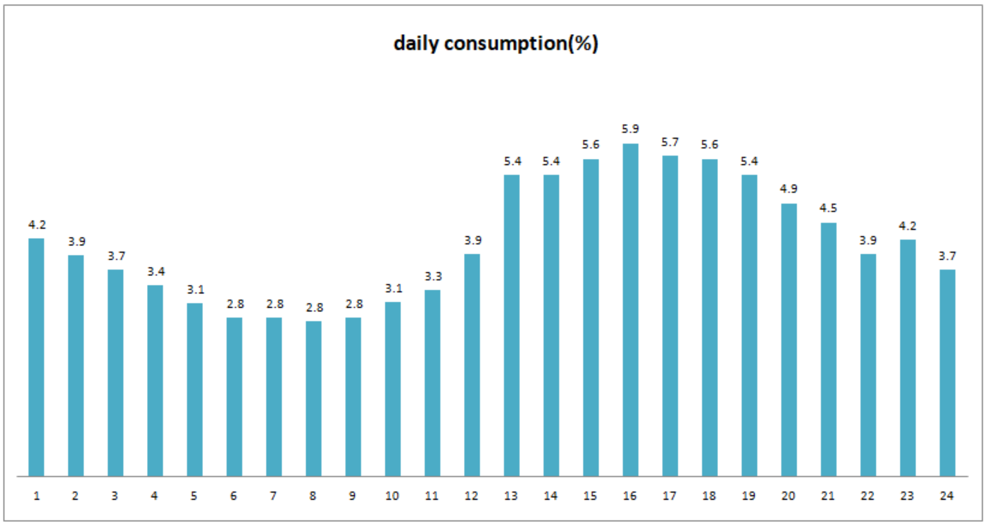


Figure3.3: daily consumption of cooling in Touggourt

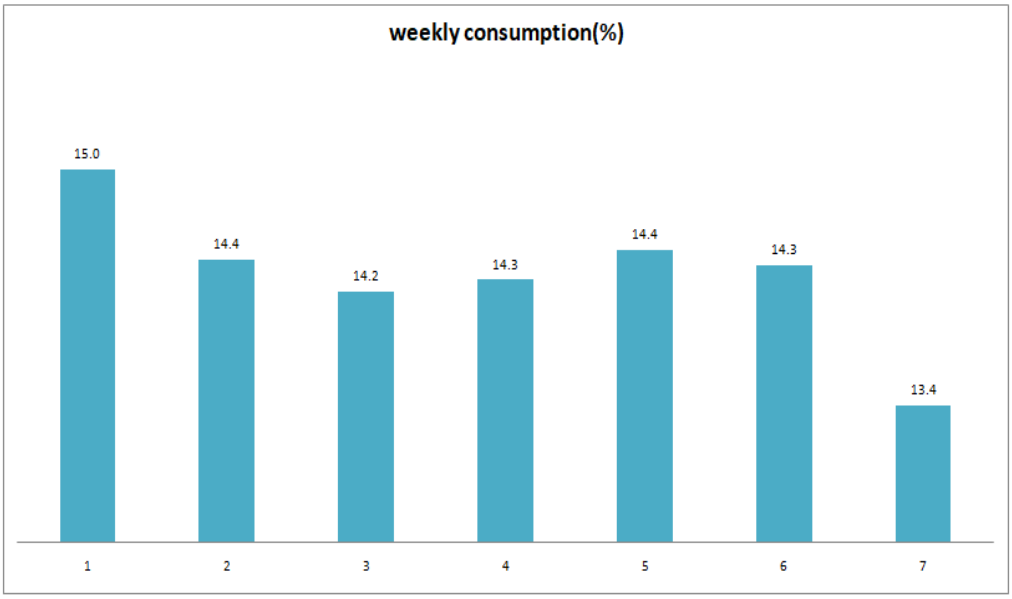


Figure3.4: weekly consumption of cooling in Touggourt

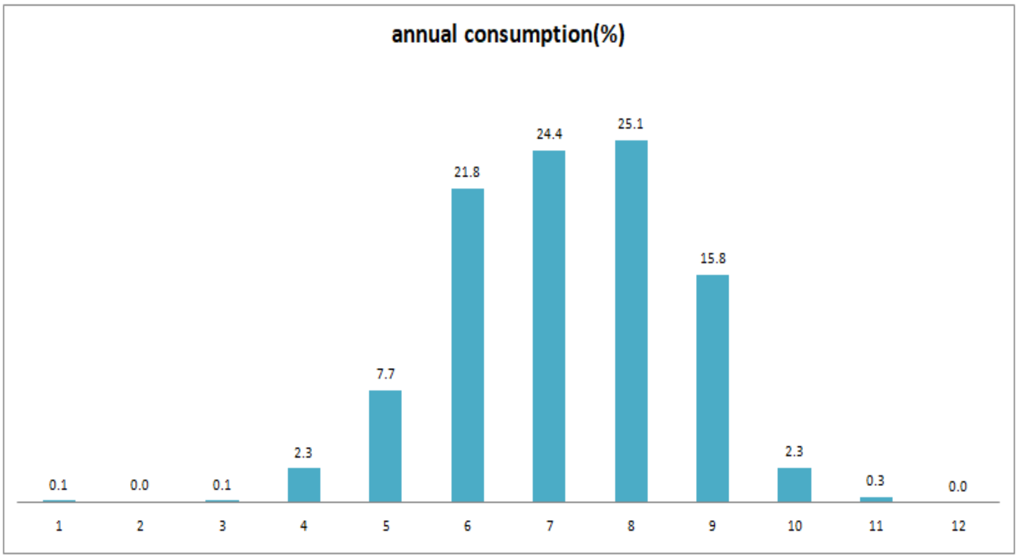


Figure3.5: annual consumption of cooling in Touggourt

Heating consumption:

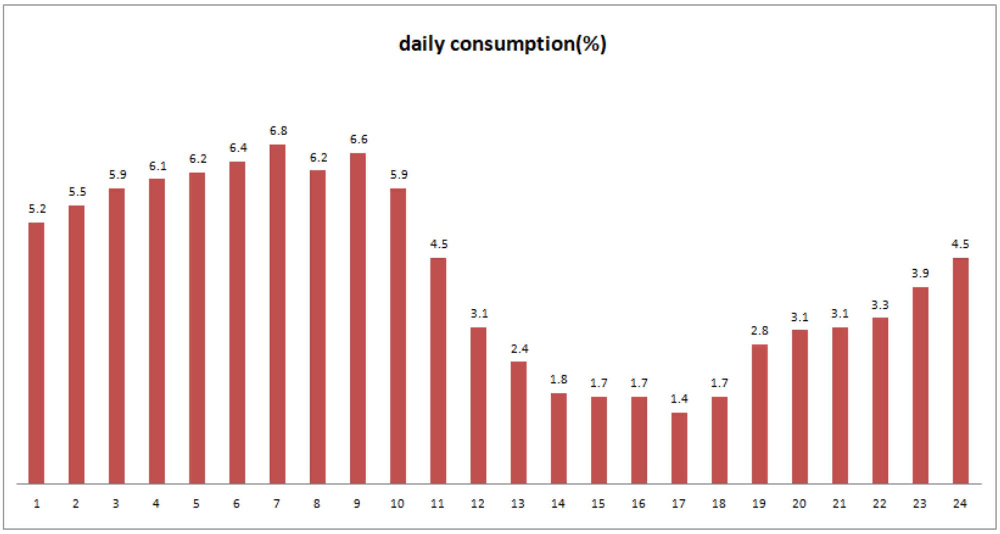


Figure3.6: daily consumption of heating in Touggourt

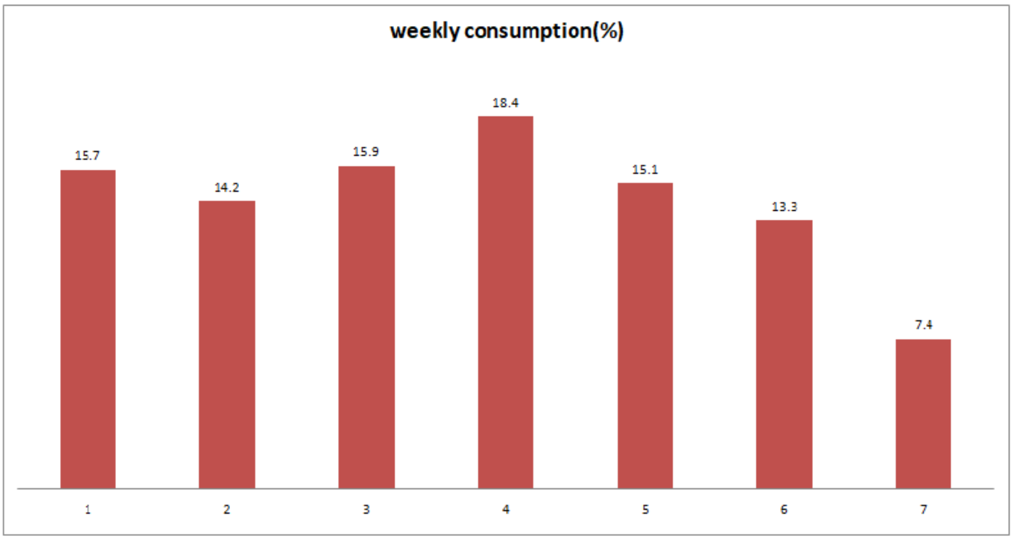


Figure3.7: weekly consumption of heating in Touggourt

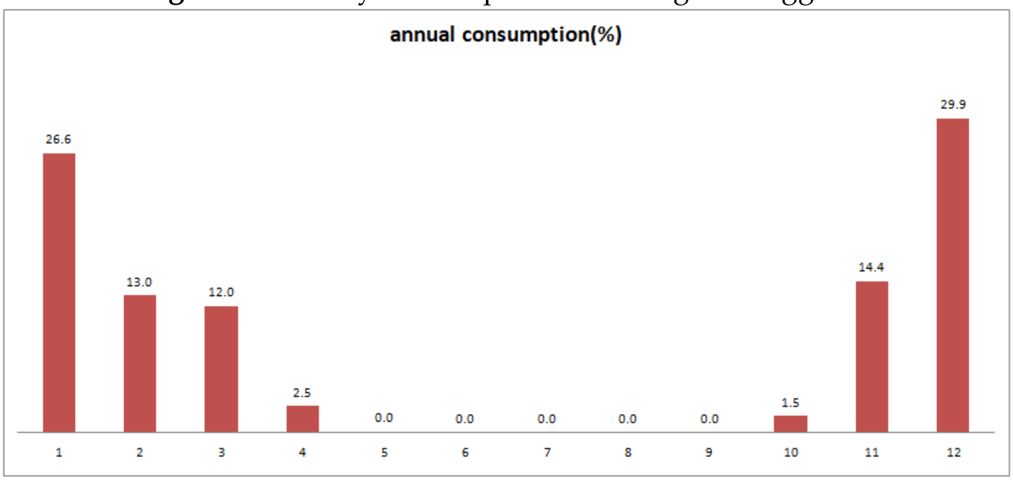


Figure3.8: annual consumption of heating in Touggourt

3.5.3 Total production heating and cooling from CCHP

Monthly results of heat and cold needs and productions by Polygeneration system

Cold production:

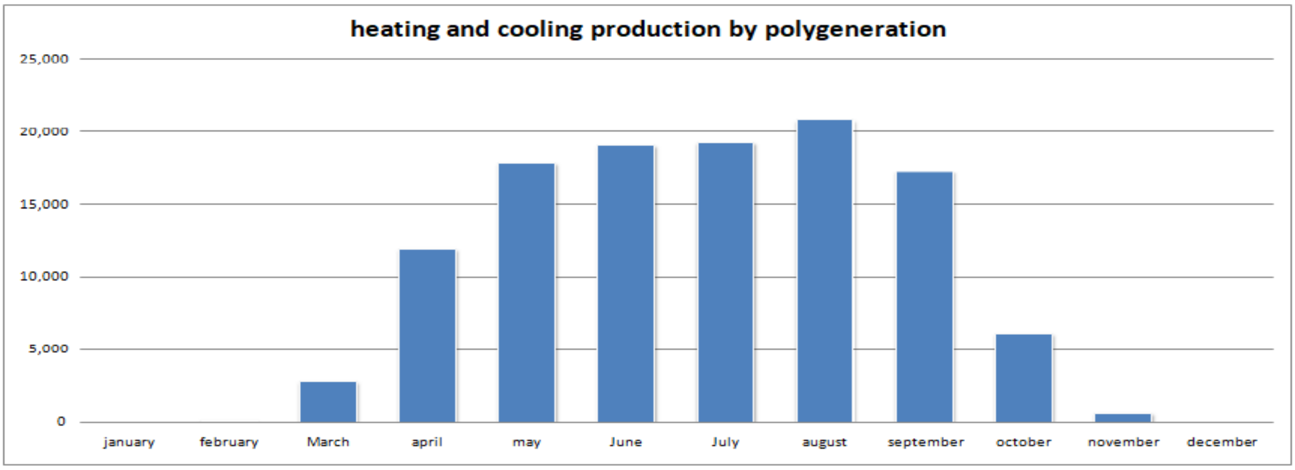


Figure3.9: Annual production of cooling in Touggourt

Heat production:

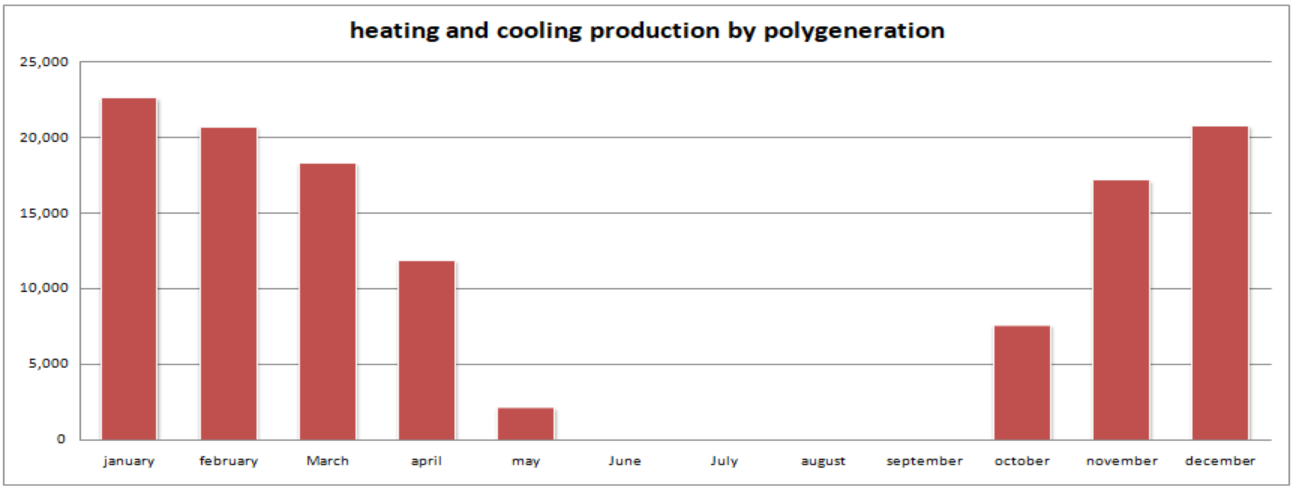


Figure3.10: Annual production of heating in Touggourt

3.6 Conclusion

This chapter outlines a method for predicting and calculating energy usage in residential structures in the year 2021. The usable energy demand for various end-uses is determined as the beginning point for making forecasts for future energy consumption. The goal of this research is to find the net heat and cool requirement in deferent climatic zone in Algeria and the total production this energy from CCHP.

According to the findings, customers in Touggourt use more energy for cooling than they do for heating. Associated with the climate of the southern hemisphere, this is marked by high temperatures for several months of the year.

CHAPTER 4: POLYGEN.CALC

MODE EXCEL

4.1 Introduction

Polygeneration will ideally provide "the foundation" of your heating and cooling requirements in order to run as consistently as possible, which is generally associated with profitability. There is, however, no automated procedure for calculating this "basis." Polygeneration of various sizes is therefore conceivable for the same structure. There is, however, an optimum, the pursuit of which comprises the design office's added value through a feasibility design. The preliminary and free stage of the relevance research assumes that the size of Polygeneration that generates the most heat, cold, and electricity is optimal. A strategy based on prior experience that must be backed up by a feasibility design tailored to your building.

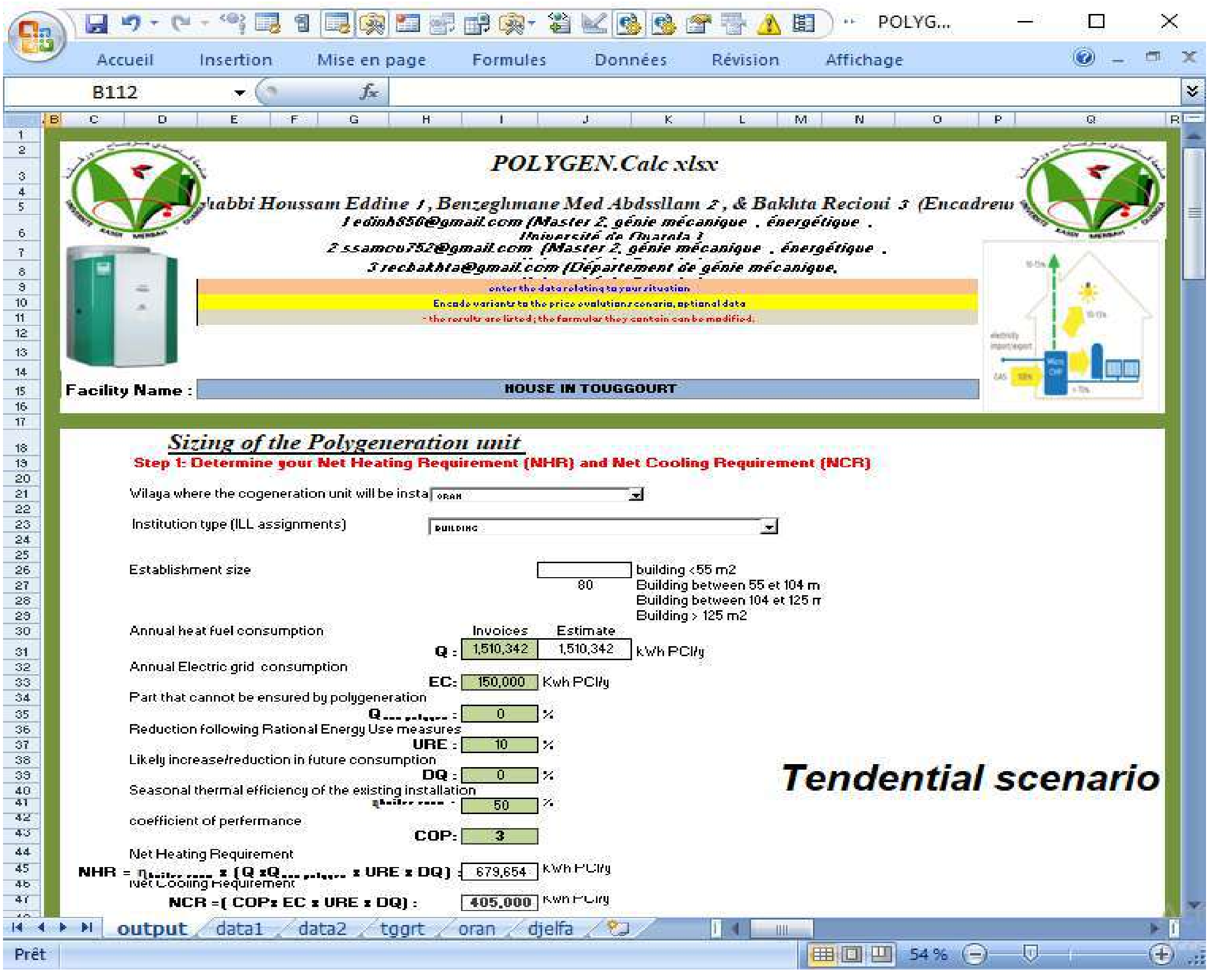


Figure4.1: Polygeneration excel calculating tool

The objective of the chapter is to calculate the feasibility and profitability and return on investment using POLYGEN.calc

POLYGEN.calc is an Excel calculating tool for predicting or estimating the feasibility of a Polygeneration installation for various structures based on their existing energy consumption and energy efficiency. POLYGEN.calc used the same technique of computation as Cogen.calc from Belgium to boost cooling, and the method of calculation was the same. [GUIDE COGÉNÉRATION. 2009]

It also allows you to calculate the Polygeneration project's profitability and return on investment by comparing the cost of building and operating the system to the current cost of gas and electricity bills.[GUIDE COGÉNÉRATION. 2009]

4.2 Sizing of the Polygeneration unit

The pre-dimensioning of the Polygeneration unit entails calculating the heating, cooling, and electrical powers, as well as the running hours required to recover all of the heat, cold, and electricity generated.

The recommended technique is based on your establishment's heating and cooling requirements, and it walks you through the four steps:

- Calculate your total heating and cooling requirements.
- Choose a "typical" heating and cooling use profile.
- Calculate the Polygeneration unit's heating and cooling power
- Select a Polygeneration unit [GUIDE COGÉNÉRATION. 2009]

4.2.1 Step 1 : determine your net heat and cool requirements

The unit is often scaled according to the cooling and heating demands to achieve so-called quality Polygeneration, which allows for the most efficient use of the energy generated. The generated power can always be used domestically or sold to the grid. The relevance research assumes that all of the power generated is utilized totally inside.

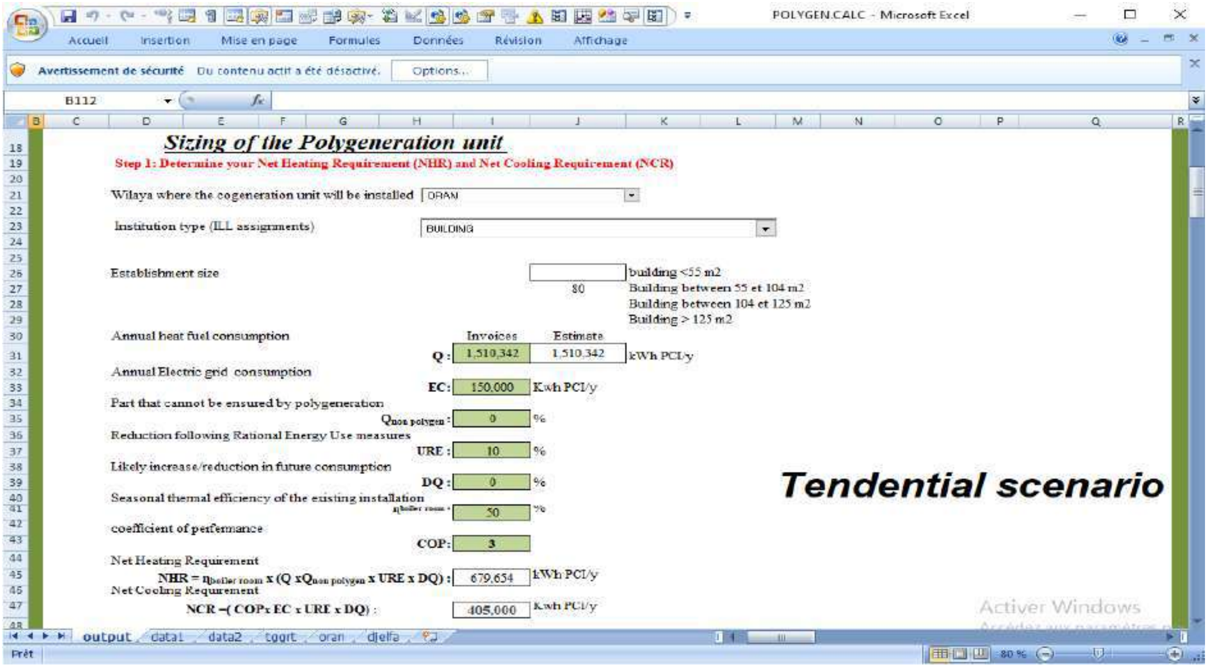


Figure4.2: Step 1 from sizing of the polygeneration unite

A net heat requirement (NHR (kWh PCI/y)) throughout the year is:

$$\text{NHR} = \eta_{\text{boiler room}} \text{ x } (\text{Q} - \text{Qnon polygen} - \text{URE x } \Delta\text{Q}) \qquad (20)$$

- Q annual fuel consumption (natural gas) of our establishment
- Q n_polygen the energy that is not used to produce hot water or steam (cooking and other specific applications), estimated at around 0%.
- ***η***boiler room boiler efficiency which characterizes the losses at the level of the boiler room (90% for a recent boiler and 50 to 85% for an old boiler. An estimate of 50% is attributed.
- URE energy savings before installing the CCHP unit to avoid costly oversizing. Losses are easily reduced with good insulation, better regulation, etc. In our case, we propose 10% since our buildings suffer from a serious problem in thermal insulation.
- ΔQ evolution of consumption in the future (reduction or increase; for example for an extension) of the initial consumption mentioned. There are new architecture buildings under construction that will require an

increase of about 0% of the current consumption[GUIDE COGÉNÉRATION. 2009]

A net cool requirement (NCR (kWh PCI/y)) throughout the year is:

$$\text{NCR} = (\text{COP} \times \text{EC} \times \text{URE} \times \Delta Q) \qquad (21)$$

- EC annual electric grid consumption
- COP coefficient of performance de air conditioning system

Tabel4.1: Presentation of the values to calculate NHR and NCR

zones	Q	EC	URE	ΔQ	ηboiler	COP	NHR	NCR
TGGRT	150000	250000	10%	0%	50%	3	67500	675000
ORAN	120000	140000	10%	0%	50%	3	54000	378000
DJELFA	300000	110000	10%	0%	50%	3	135000	297000

4.2.2 Step 2: select a "typical profile" heat and cold consumption

The evolution of your establishment's heat demand is critical for Polygeneration unit pre-sizing. We might assume that your hot and cold intake follows a normal profile indicative of an activity cycle. Choose the optimal zone type from the three options below. [GUIDE COGÉNÉRATION. 2009]

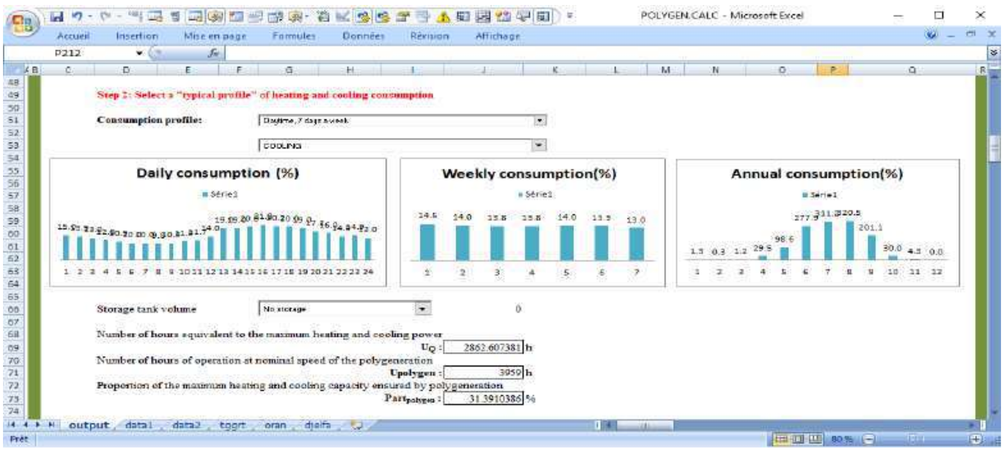


Figure4.3: Step 2 from sizing of the polygeneration unite

ZONES 1: TOUGGOURT (STATION SIDI MAHDI AIR PORT)

Cooling consumption :

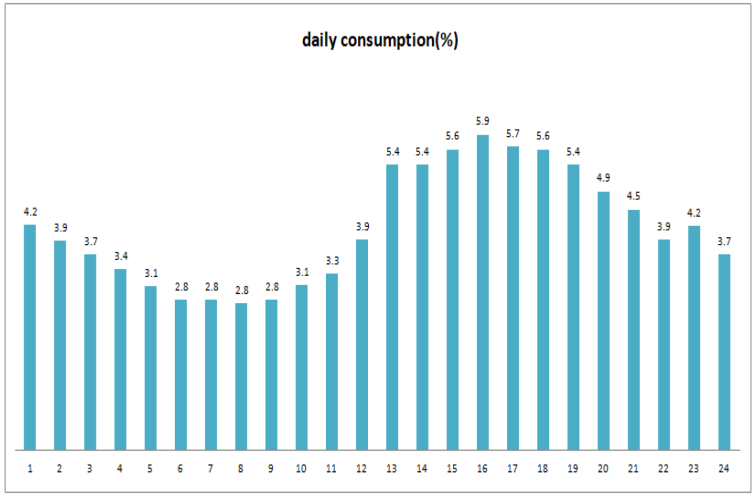


Figure4.4: daily consumption of cooling in Touggourt

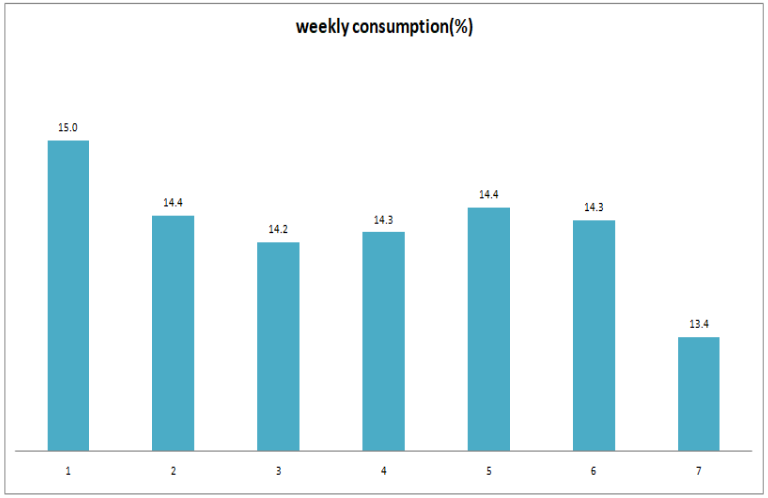


Figure4.5: weekly consumption of cooling in Touggourt

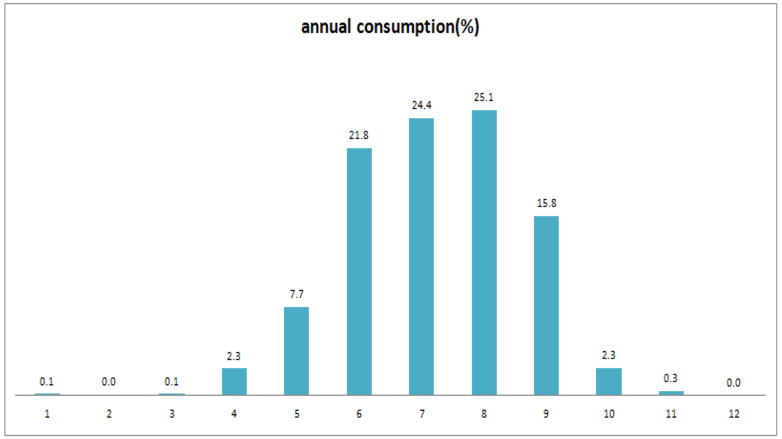


Figure4.6: annual consumption of cooling in Touggourt

Heating consumption:

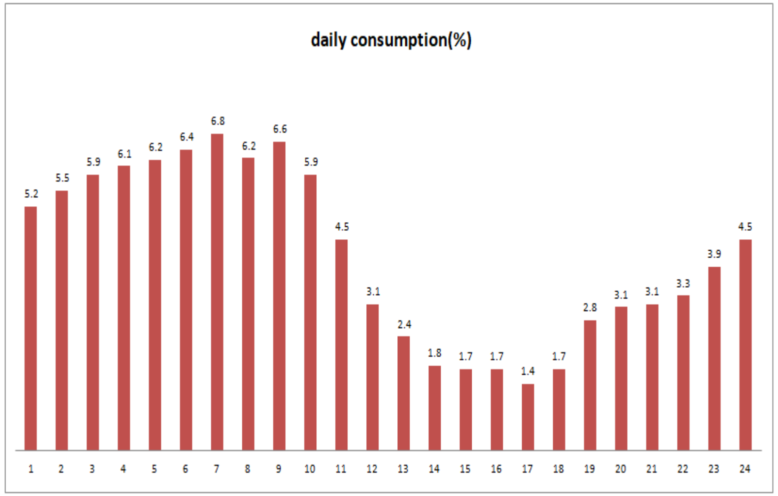


Figure4.7: daily consumption of heating in Touggourt

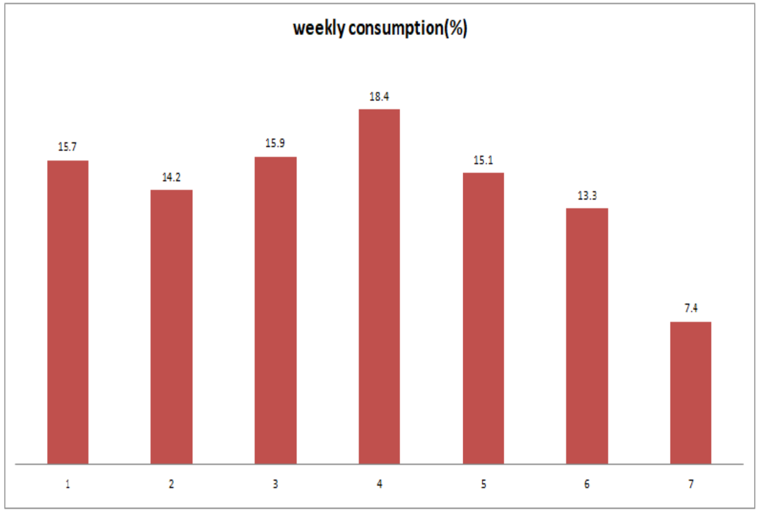


Figure4.8: weekly consumption of heating in Touggourt

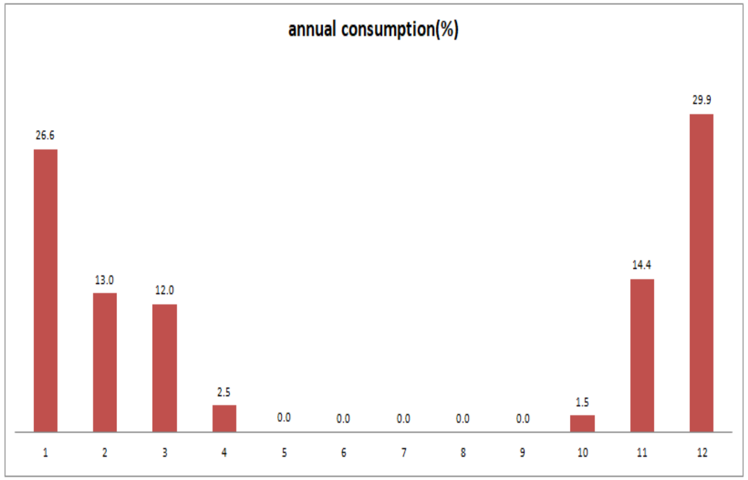


Figure4.9: annual consumption of heating in Touggourt

ZONES 2: ORAN (STATION ES SENIA AIR PORT)

Cooling consumption :

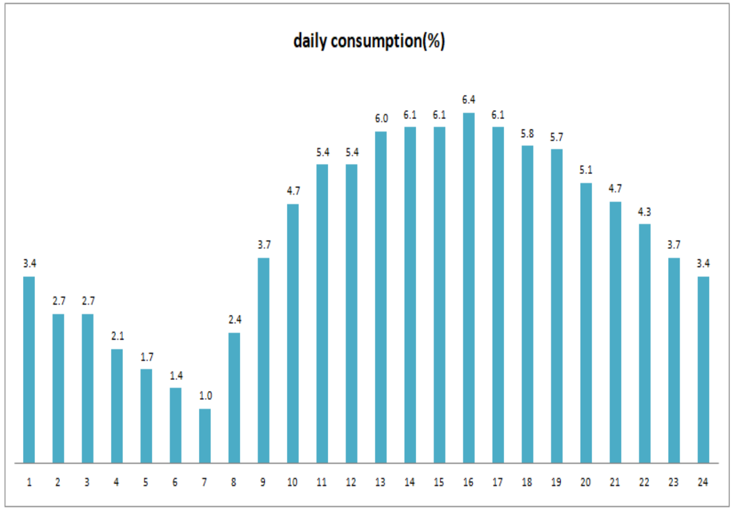


Figure4.10: daily consumption of cooling in Oran

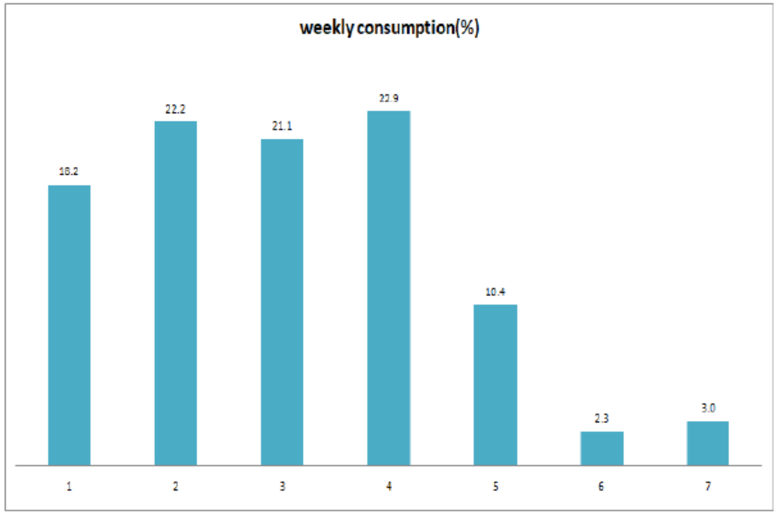


Figure4.11: weekly consumption of cooling in Oran

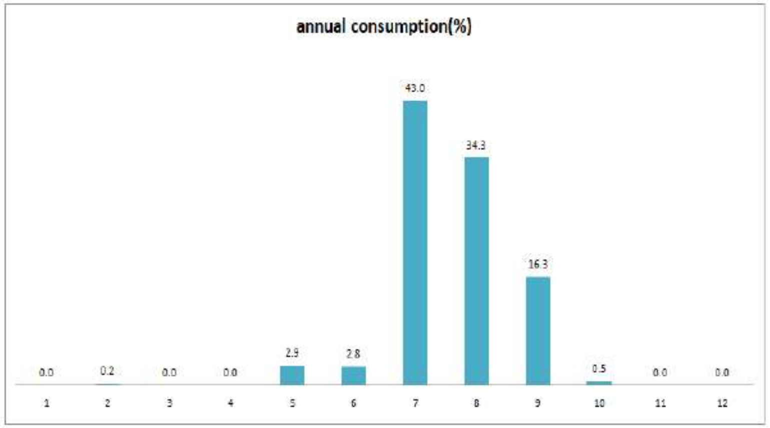


Figure4.12: annual consumption of cooling in Oran

Heating consumption:

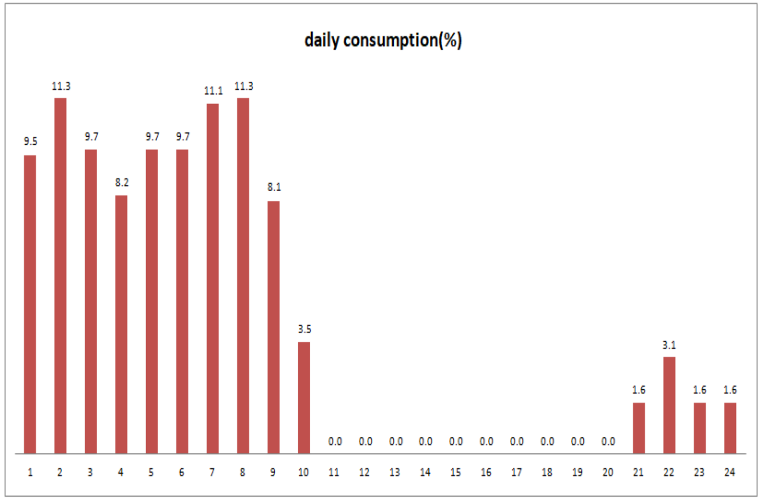


Figure4.13: daily consumption of heating in Oran

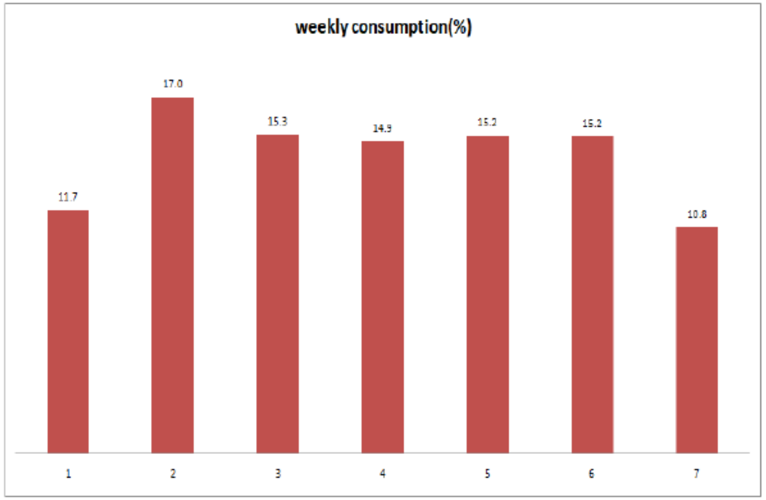


Figure4.14: weekly consumption of heating in Oran

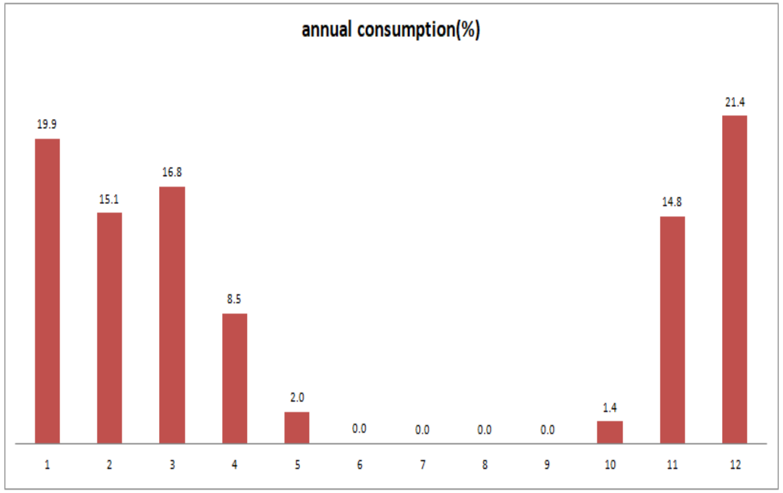


Figure4.15: annual consumption of heating in Oran

ZONES 3: DJELFA (STATION TSLETSI AIR PORT)

Cooling consumption:

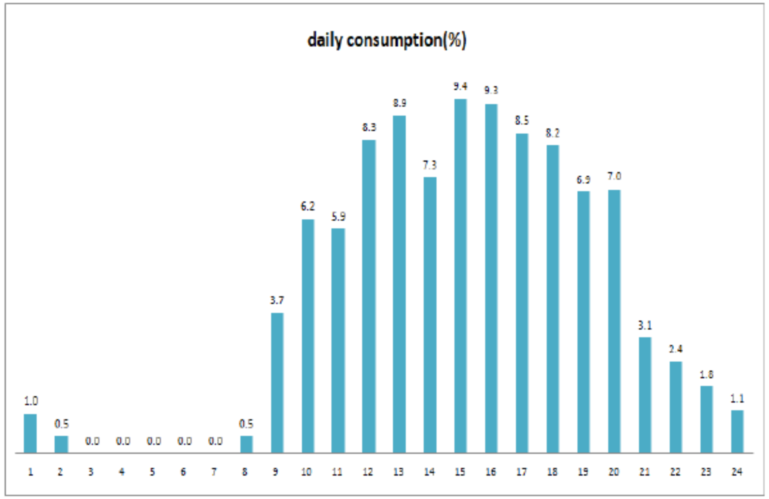


Figure4.16: daily consumption of cooling in Djelfa

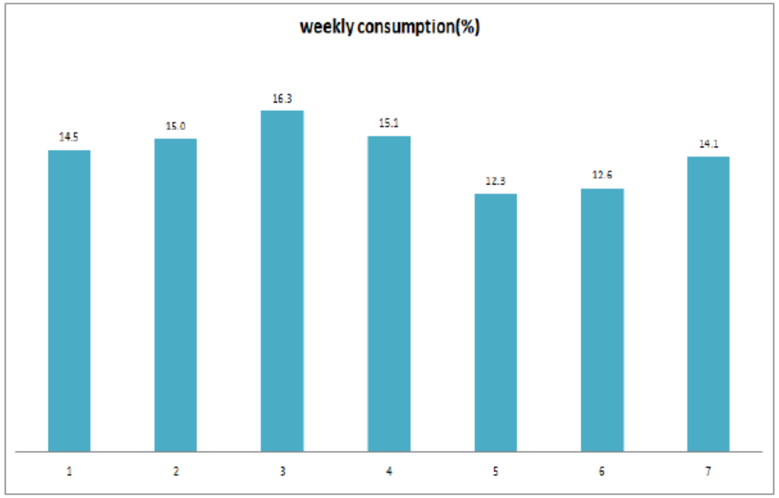


Figure4.17: weekly consumption of cooling in Djelfa

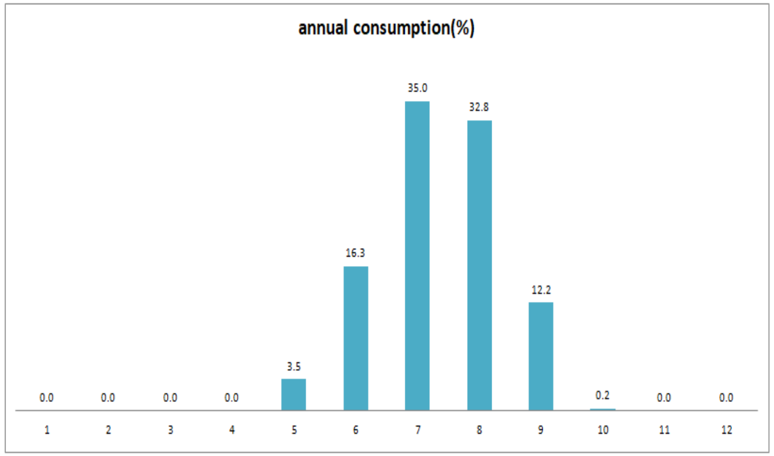


Figure4.18: annual consumption of cooling in Djelfa

Heating consumption:

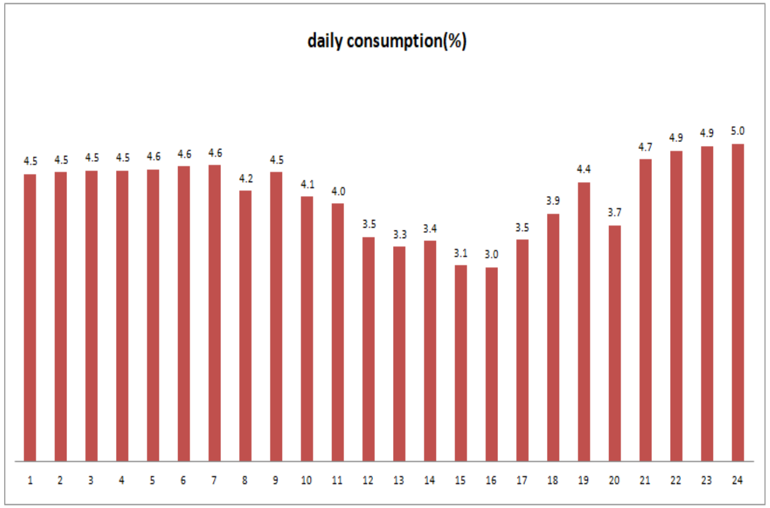


Figure4.19: daily consumption of heating in Djelfa

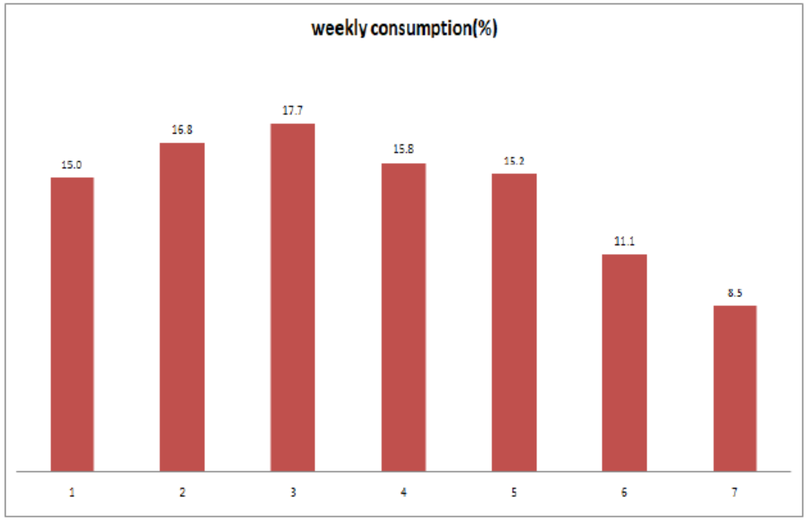


Figure4.20: weekly consumption of heating in Djelfa

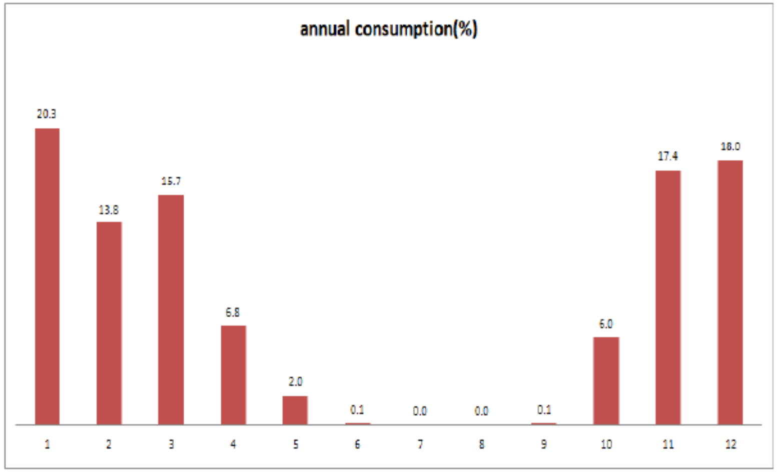


Figure4.21: annual consumption of heating in Djelfa

4.2.3 Step 3 : determine the Polygeneration units heating and cooling capacity

Based on the previously predefined parameters, POLYGEN.calc can directly determine the heating and cooling capacity of the Polygeneration unit as follows:

$\mathbf{P_{Qpolygen}}$ the heating capacity of the Polygeneration unit

$$P_{\ Qpolygen} = \frac{NHR \times Part_{polygen}}{U_Q} \tag{22}$$

$P_{Cpolygen}$ the cooling capacity of the Polygeneration unit

$$P_{\ Cpolygen} = \frac{NCR \times Part_{polygen}}{U_Q} \tag{23}$$

Hpolygen the amount of heat supplied by the CCHP unit per year

$$Hpolygen = P_{Q\ polygen} \text{ x } Upolygen \tag{24}$$

Cpolygen the amount of cool supplied by the CCHP unit per year

$$Cpolygen = P_{C\ polygen} \text{ x } Upolygen \tag{25}$$

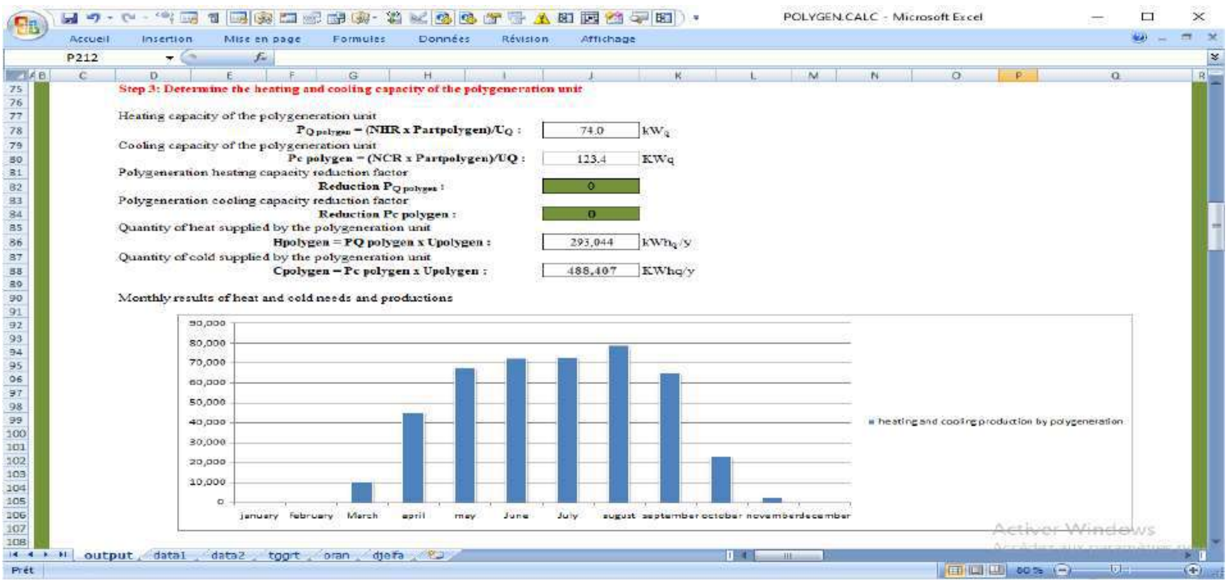


Figure4.22: Step 3 from sizing of the polygeneration unite

Based on the typical profiles of heating and cooling needs, the POLYGEN.calc calculation tool provides:

- UQ: Number of hours equivalent to maximum heating and cooling power.
- Upolygen: Number of hours of operation at rated speed of Polygeneration.
- Partpolygen: Part of the maximum heating and cooling power ensured by the Polygeneration.[GUIDE COGÉNÉRATION. 2009]

Without Storage:

Tabel4.2: Presentation of the values Without Storage obtained with POLYGEN.calc

	$P_{Qpolygen}$ (KWq)	$P_{Cpolygen}$ (KWq)	$H_{polygen}$ (KWq)	$C_{polygen}$ (KWq)	UQ(h)	$U_{polygen}$(h)	$Part_{polygen}$(%)
TGGRT	7.4	82.9	29304	328210	2862.6	3959	31.39
ORAN	5.9	41.5	23444	1644105	2862.6	3959	31.39
DJELFA	14.8	32.6	58609	128939	2862.6	3959	31.39

With Storage: Equivalent storage 1/2 hour

Tabel4.3: Presentation of the values Equivalent storage 1/2 hour obtained with POLYGEN.calc

	$P_{Qpolygen}$ (KWq)	$P_{Cpolygen}$ (KWq)	$H_{polygen}$ (KWq)	$C_{polygen}$ (KWq)	UQ(h)	$U_{polygen}$(h)	$Part_{polygen}$(%)
TGGRT	7.4	82.9	35230	394573	2862.6	4759.5	31.39
ORAN	5.9	41.5	28184	197286	2862.6	4759.5	31.39
DJELFA	14.8	54.3	70459	155011	2862.6	4759.5	31.39

With Storage: Equivalent storage 1 hour

Tabel4.4: Presentation of the values Equivalent storage 1 hour obtained with POLYGEN.calc

	$P_{Qpolygen}$ (KWq)	$P_{Cpolygen}$ (KWq)	$H_{polygen}$ (KWq)	$C_{polygen}$ (KWq)	UQ(h)	$U_{polygen}$(h)	$Part_{polygen}$(%)
TGGRT	7.4	82.9	38335	429350	2862.6	5179	31.39
ORAN	5.9	41.5	30668	214675	2862.6	5179	31.39
DJELFA	14.8	32.6	76670	168673	2862.6	5179	31.39

4.2.4 Step 4: Choice a Polygeneration unit

The final stage in the dimensioning process is to select a Polygeneration< technology. Despite the fact that POLYGEN.calc provides two types of engines (natural gas and diesel), the installation's thermal engine is natural gas. As a result,

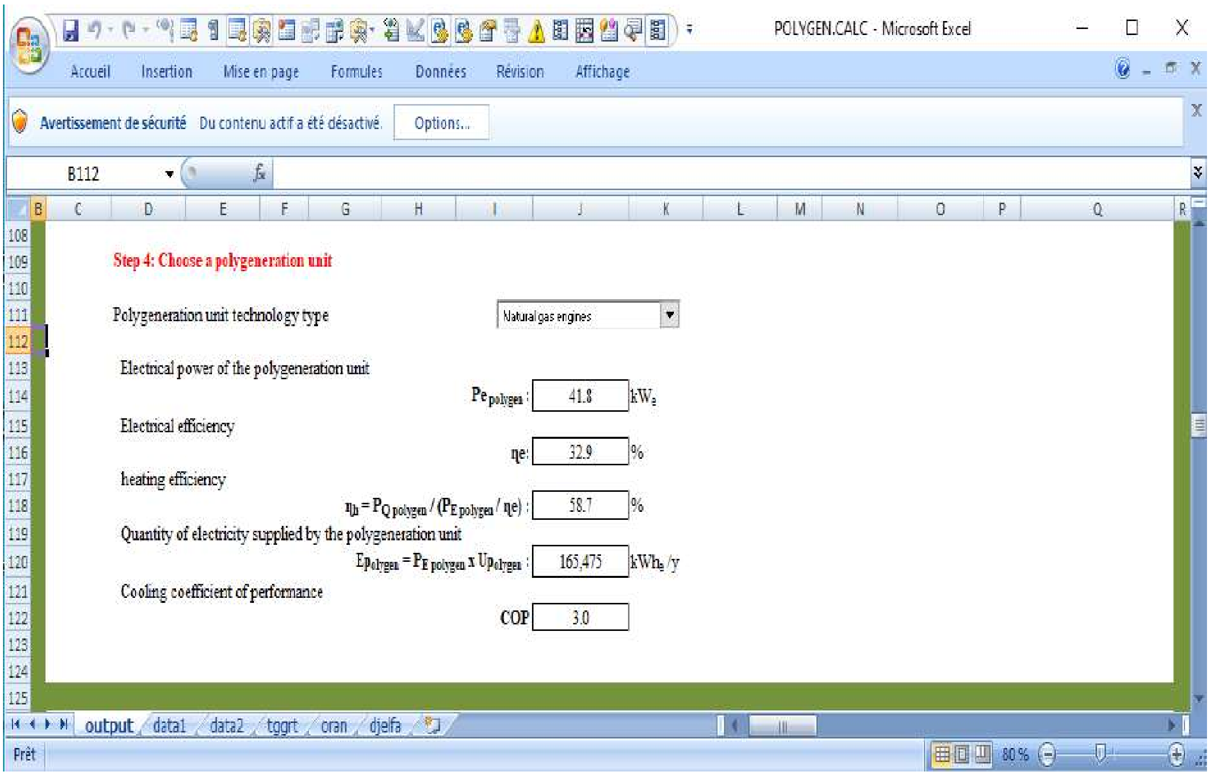


Figure4.23: Step 4 from sizing of the polygeneration unite

- $Pe_{polygen}$: Electrical power of the Polygeneration unit
- η_e: Electrical performance of the selected unit
- η_{th}: Heating efficiency of chosen unit

$$\eta_{th} = \frac{PQ\ polygen}{(PE\ polygen\ /\ \eta e)} \tag{26}$$

- Annual electric power of the chosen unit

$$E_{polygen} = Pe_{polygen}\ x\ Upolygen \tag{27}$$

- COP: Cooling coefficient of performance

Polygeneration unit technology type natural gas engines

Tabel4.5: Presentation of the values whit natural gas engines in POLYGEN.calc

	$Pe_{polygen}$	η_e	η_{th}	$E_{polygen}$	COP
Touggourt	3.1KWe	28.6%	69.1%	12138KWh/y	3
Oran	2.4KWe	28.2%	70.2%	9430KWh/y	3
Djelfa	6.7LWe	29.8%	65.8%	26587KWh/y	3

Polygeneration unit technology type diesel engines

Tabel4.6: Presentation of the values whit diesel engines in POLYGEN.calc

	$Pe_{polygen}$	η_e	η_{th}	$E_{polygen}$	COP
Touggourt	3.8KWe	30.6%	59.3%	15099KWh/y	3
Oran	3KWe	30.2%	60.2%	11757KWh/y	3
Djelfa	8.3KWe	31.9%	56.9%	32845KWh/y	3

4.3 Calculate the profitability of your Polygeneration project

Polygeneration provides several benefits to its owner, both economically and socially and environmentally. However, the economics of a Polygeneration project will frequently determine the final selection.

A Polygeneration unit may fulfill some of your heating and cooling demands while also producing some of the power required by your business. As a result, you will no longer need to buy power from your provider. The net yearly gain is calculated by adding the gain from the sale of green certificates and subtracting the maintenance costs and excessive fuel use. The difference between the annual gains and expenses is the net annual gain.

We are now going to go through the 8 steps of calculating the profitability of a Polygeneration project together.

4.3.1 Step 1: calculate the gain on the electric bill

The entire value of the invoice includes:

- The supply price: this is the single variable that distinguishes each provider. This determines its pricing based on its general costs, commercial policies, and the price formulae it provides you based on the quantity you consume or your profile.
- The transmission and distribution rate, which is determined by the federal regulator, is non-negotiable data. It should be noted, however, that it may vary based on each manager's network operational costs.
- Taxes and surcharges: these are government payments designed to fund the federal regulatory body, the de-nuclearization of Mol-based facilities, social initiatives, and greenhouse gas emission reduction policies. Surcharges at the regional level include a road tax and a levy. [GUIDE COGÉNÉRATION. 2009]

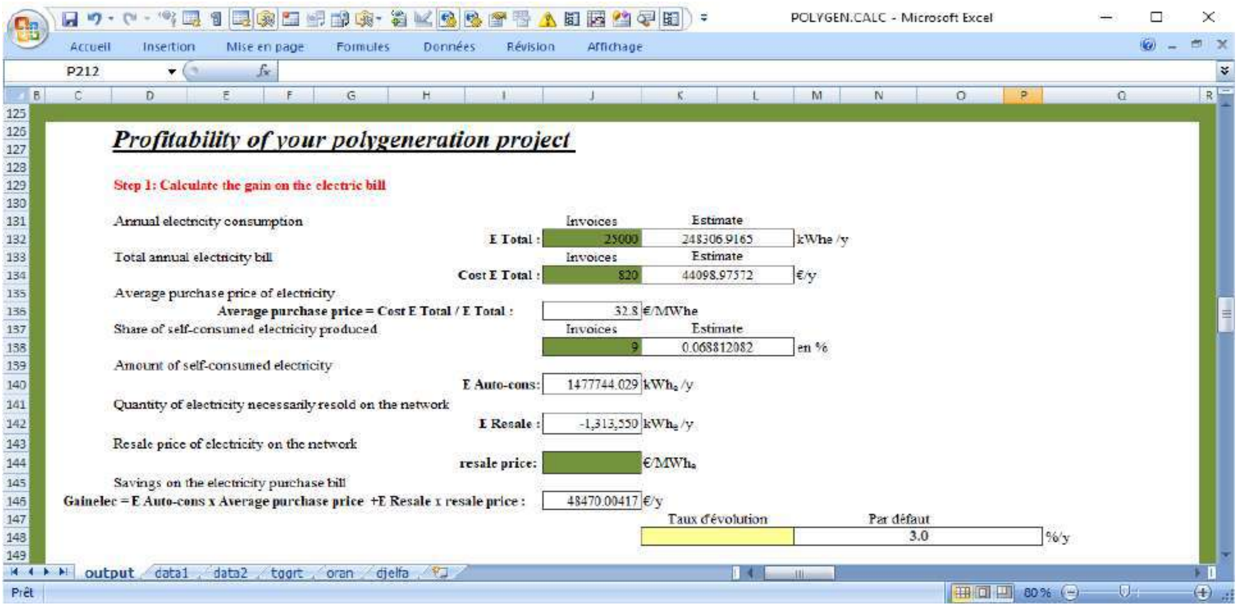


Figure4.24: Step 1 from profitability of your Polygeneration project

With total electricity consumption ***E***-total and total cost E-***C***ost we can calculate the average price of electricity:

$$Average\ purchase\ price\ = \frac{E\ Cost}{E\ Total}\ (\frac{\text{EUR}}{\text{kWh}}) \tag{28}$$

To calculate the gain on the power bill(EUR/y), multiply the average price of electricity by the quantity of electricity produced by the Polygeneration unit as a first approximation. Quantity that will no longer need to be purchased from the power grid.

$$Gain_{elec}\ = E_{Auto-cons}\ x\ Average\ purchase\ price\ \ + E\ _{Resale}\ x\ resale\ price (31)$$

- E auto-cons: Amount of self-consumed electricity
- E resale: Quantity of electricity necessarily resold on the network
- Resale price: Resale price of electricity on the network

4.3.2 Step 2: calculate heat gain

Heat is traditionally generated using fuel oil or natural gas. The average price of the fuel that currently serves your boiler room is obtained by division.

$$Average\ fuel\ price\ = \frac{Cost\ Q}{Q}\ (\frac{\text{EUR}}{\text{kWh}}) \tag{29}$$

Cost Q: Total annual fuel bill

Q: Annual fuel consumption

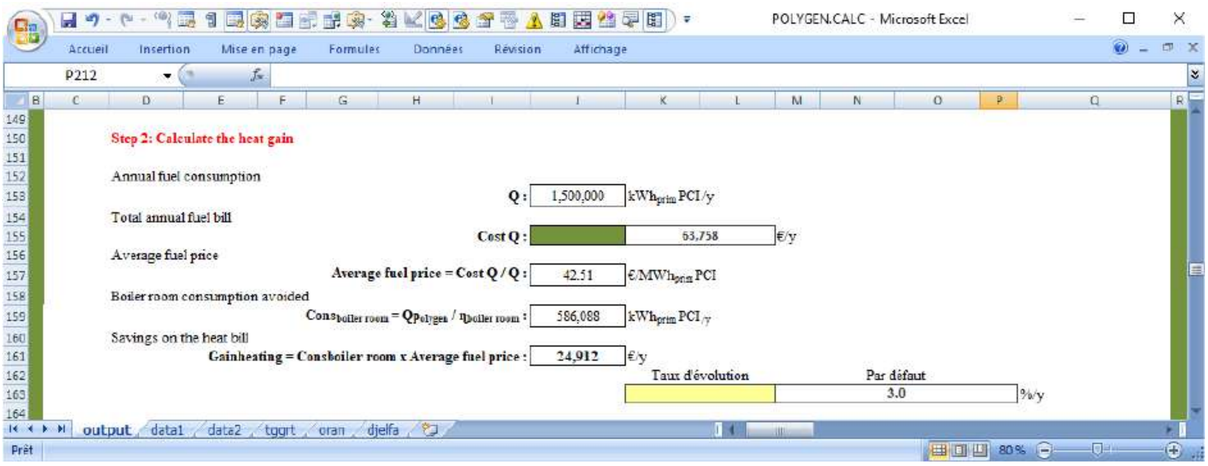


Figure4.25: Step 2 from profitability of your Polygeneration project

Simply divide the quantity of heat produced by the Polygenerator by the boiler room's efficiency to get the amount of fuel that will no longer be used by the present boiler room.

$$Cons_{boiler\ room} = \frac{Hpolygen}{\eta_{boiler\ room}} \tag{30}$$

The corresponding gain is obtained by multiplication with the average fuel price.

$$Gain_{heating} = Cons_{\ boiler\ room} x\ Average\ fuel\ price\ (\frac{EUR}{y}) \tag{31}$$

4.3.3 Step 3: calculate cold gain

Heat is traditionally generated using electricity. The average price of the energy that currently serves your chiller is obtained by division.

$$Average\ energy\ price = \frac{Cost\ EC}{EC}\ (\frac{\text{EUR}}{\text{kWh}}) \tag{32}$$

Cost Q: Total annual energy bill

Q: Annual energy consumption

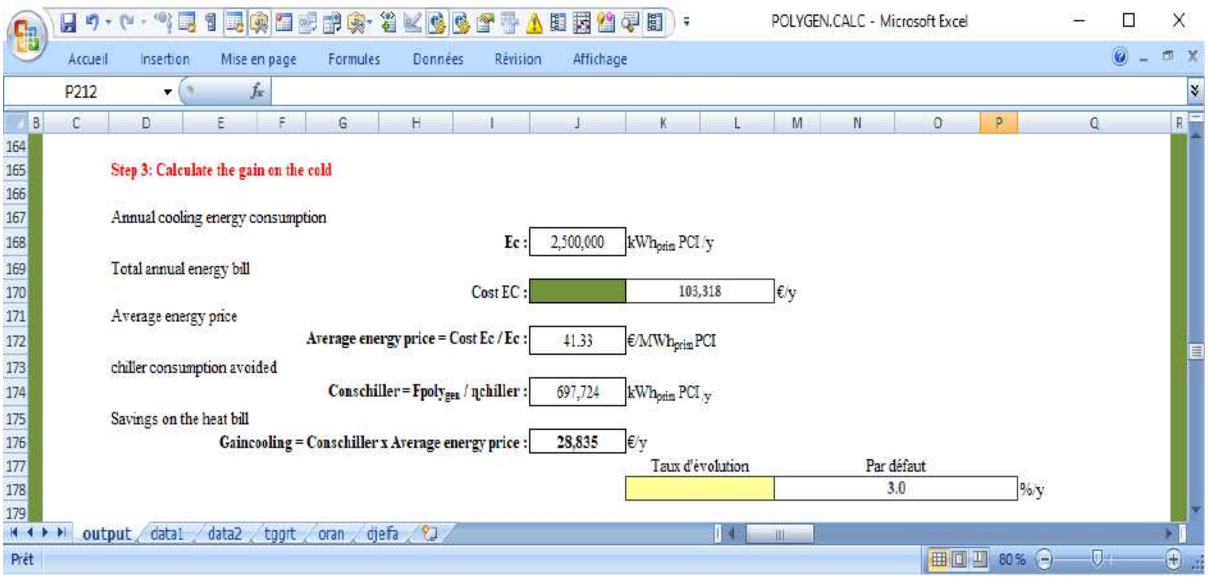


Figure4.26: Step 3 from profitability of your Polygeneration project

Simply divide the quantity of cool produced by the Polygenerator by chiller efficiency to get the amount of energy that will no longer be used by the present chiller.

$$Cons_{chiller} = \frac{Cpolygen}{\eta_{chiller}} \left(\frac{\text{kWhprim}}{\text{y}}\right) \tag{33}$$

The corresponding gain is obtained by multiplication with the average energy price.

$$Gain_{cooling} = Cons_{\ chiller}\ x\ Average\ energy\ price\left(\frac{\text{EUR}}{\text{kWh}}\right) \tag{34}$$

4.3.4 Step 4: calculate gain by green certificates

The owner of a "excellent" Polygeneration might supplement his revenue by selling green certifications. The price of a green certificate, on the other hand, is determined by the law of supply and demand.

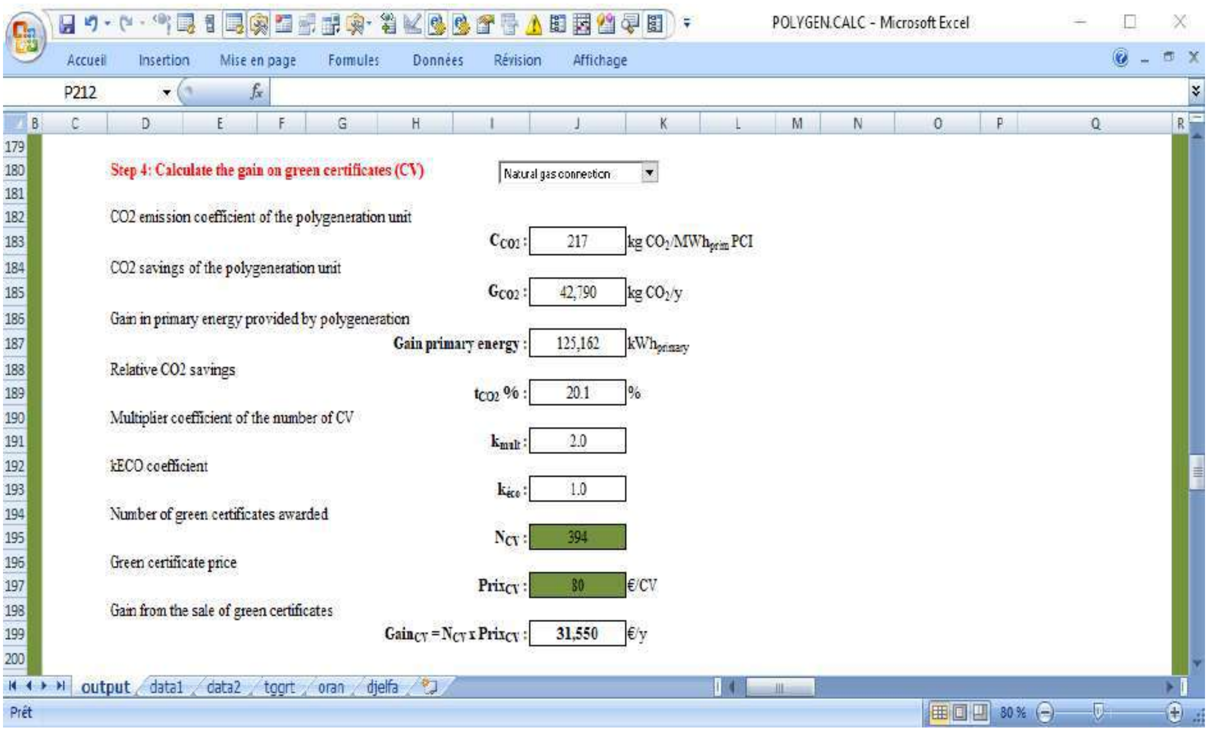


Figure4.27: Step 4 from profitability of your Polygeneration project

The following formula calculates the additional profit generated by the selling of green certificates:

$$Gain_{CV} = N_{CV} \times Price_{CV}(\frac{\text{kWh}}{\text{y}}) \quad (35)$$

Ncv: Number of green certificates awarded

Pricecv: Green certificate price

4.3.5 Step 5: calculate the fuel expenditure

Of course, fuel will be required to power this Polygeneration. Simply divide the quantity of power generated by the cogeneration unit's electrical efficiency to determine the amount of fuel required.

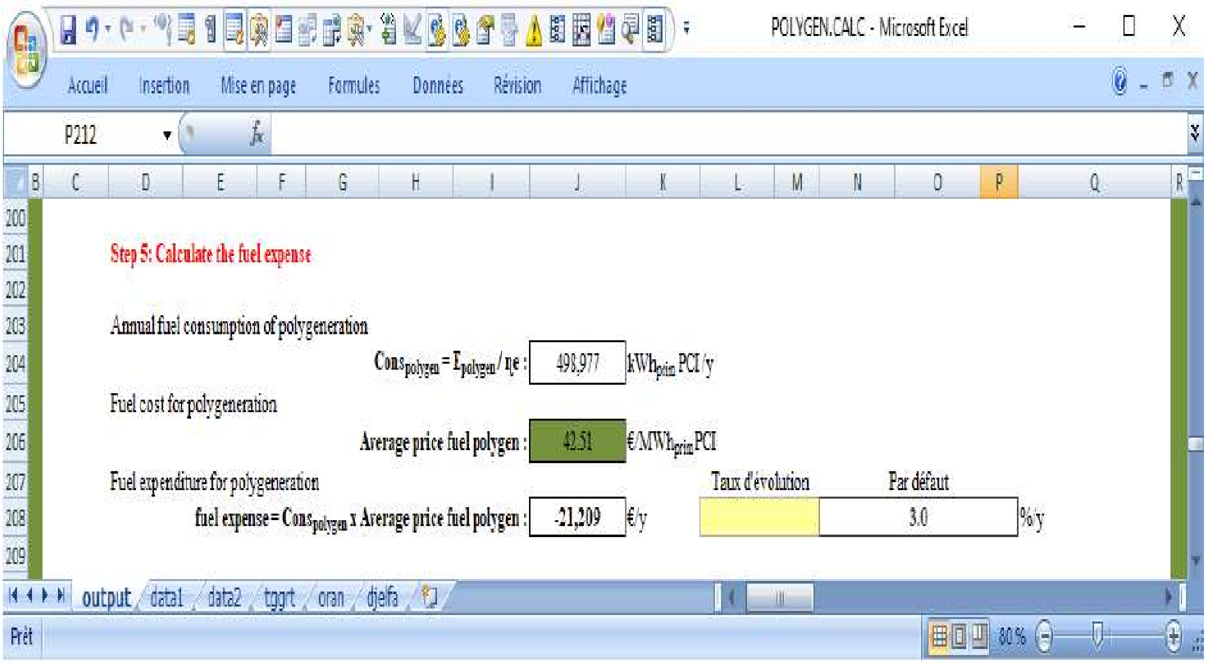


Figure4.28: Step 5 from profitability of your Polygeneration project

$$Cons_{polygen} = \frac{Epolygen}{\eta e}(\frac{\text{kWhprim}}{\text{y}}) \quad (36)$$

The fuel expense is calculated by multiplying this usage by the average cost of the fuel required for Polygeneration.

$$fuel\ expense = Conspolygen\ x\ Average\ price\ fuel\ polygen(\frac{EUR}{y}) \quad (37)$$

4.3.6 Step 6: calculate the maintenance expenditure

The Polygeneration unit must be kept in good working order. Maintenance expenses are calculated based on the technology selected and the unit's size. The yearly maintenance cost is calculated by multiplying this cost by the amount of power produced.

$$Maintenance\ expense\ = Epolygen\ x\ Maintenance\ cost(\frac{EUR}{y}) \quad (38)$$

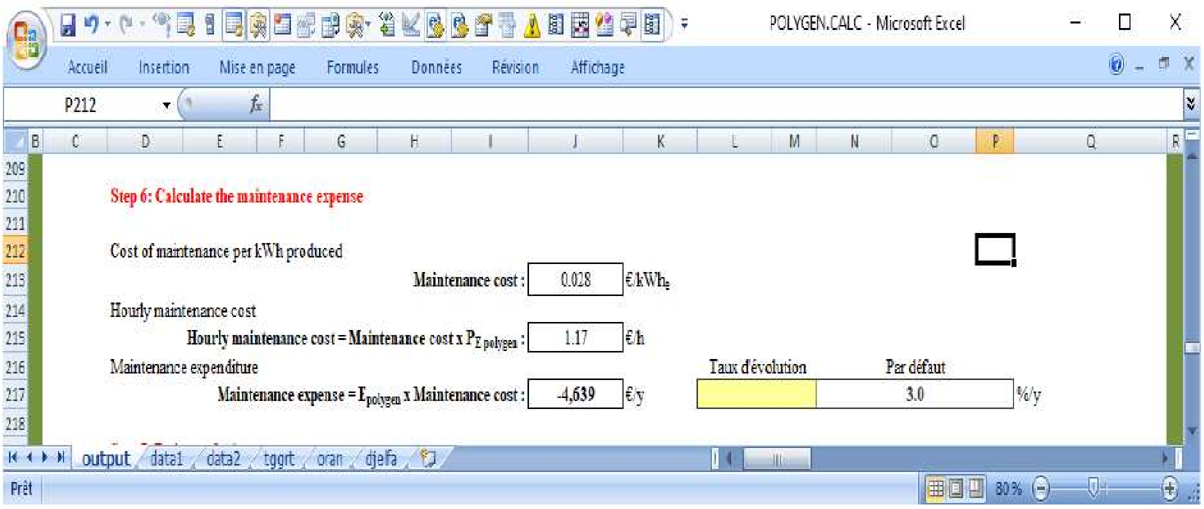


Figure4.29: Step 6 from profitability of your Polygeneration project

4.3.7 Step 7: estimate the investment amount

The amount of investment is calculated by multiplying the cost per kWe installed by the cogeneration's electrical power, after subtracting any subsidies. An overinvestment ratio of 30% is used to account for design expenses (7%), assembly and installation costs (13%), and any contingencies (10%).

$$Invnet\ polygen\ = Invpolygen\ +\ Surinvpolygen - Premiums(\text{EUR HTVA})$$

(39)

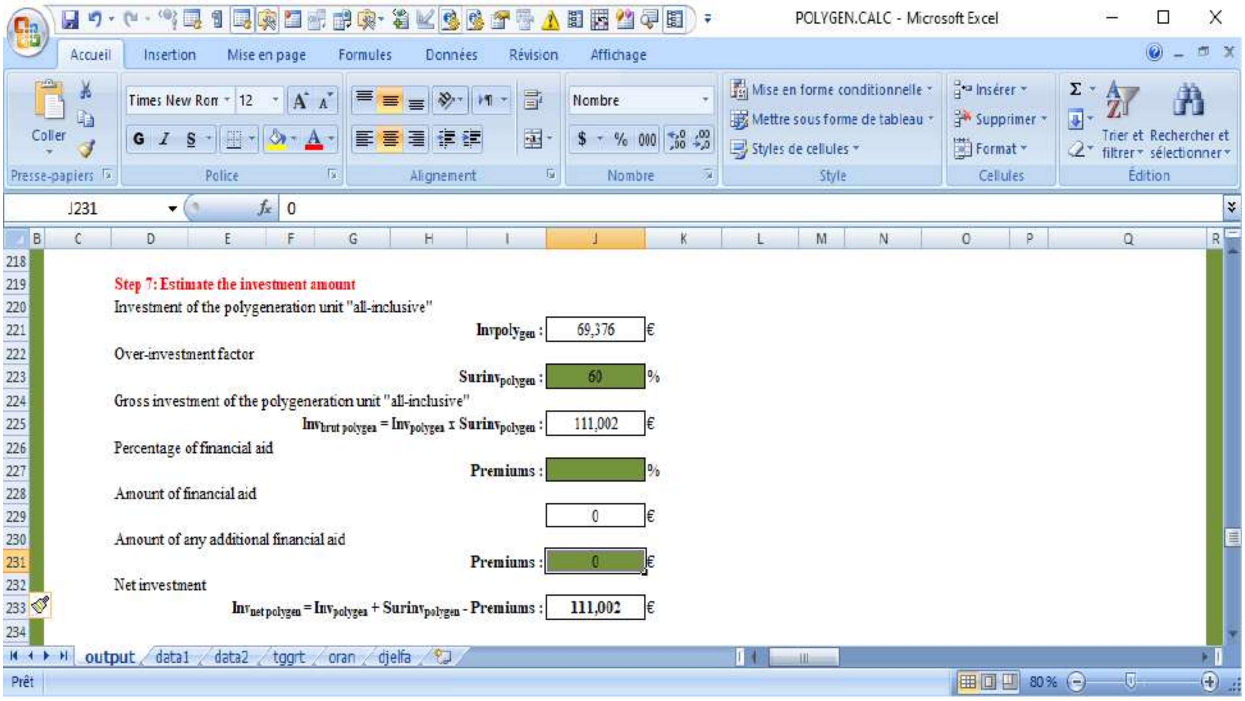


Figure4.30: Step 7 from profitability of your Polygeneration project

4.3.8 Step 8: estimate the profitability of the project

The first condition for profitability is a positive net yearly gain. The difference between the total of all profits and the sum of all costs is the net yearly gain.

$$\mathrm{Gain}_{\mathrm{annuelnet}} = \mathrm{Gain}_{\mathrm{elec}} + \mathrm{Gain}_{\mathrm{heating}} + \mathrm{Gain}_{\mathrm{CV}} + \mathrm{Gain}_{\mathrm{supp}} + \mathrm{Gain}_{\mathrm{cooling}} - \mathrm{fuel}_{\mathrm{expense}} - \mathrm{Maintenance}_{\mathrm{expense}} - \mathrm{Supp}_{\mathrm{expense}} \left(\frac{\mathrm{EUR}}{\mathrm{y}}\right) \quad (40)$$

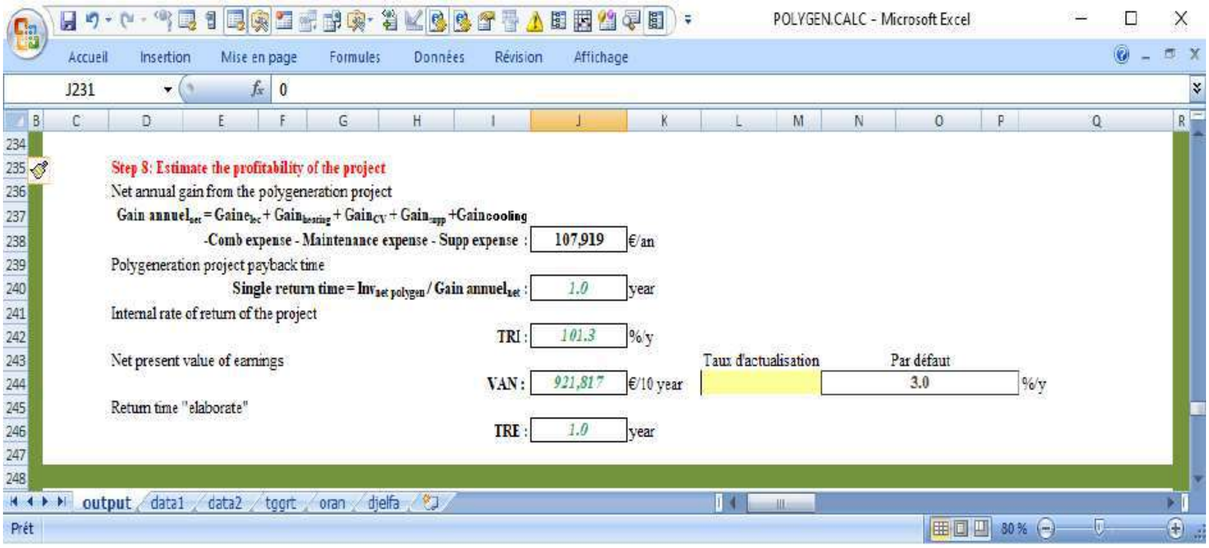


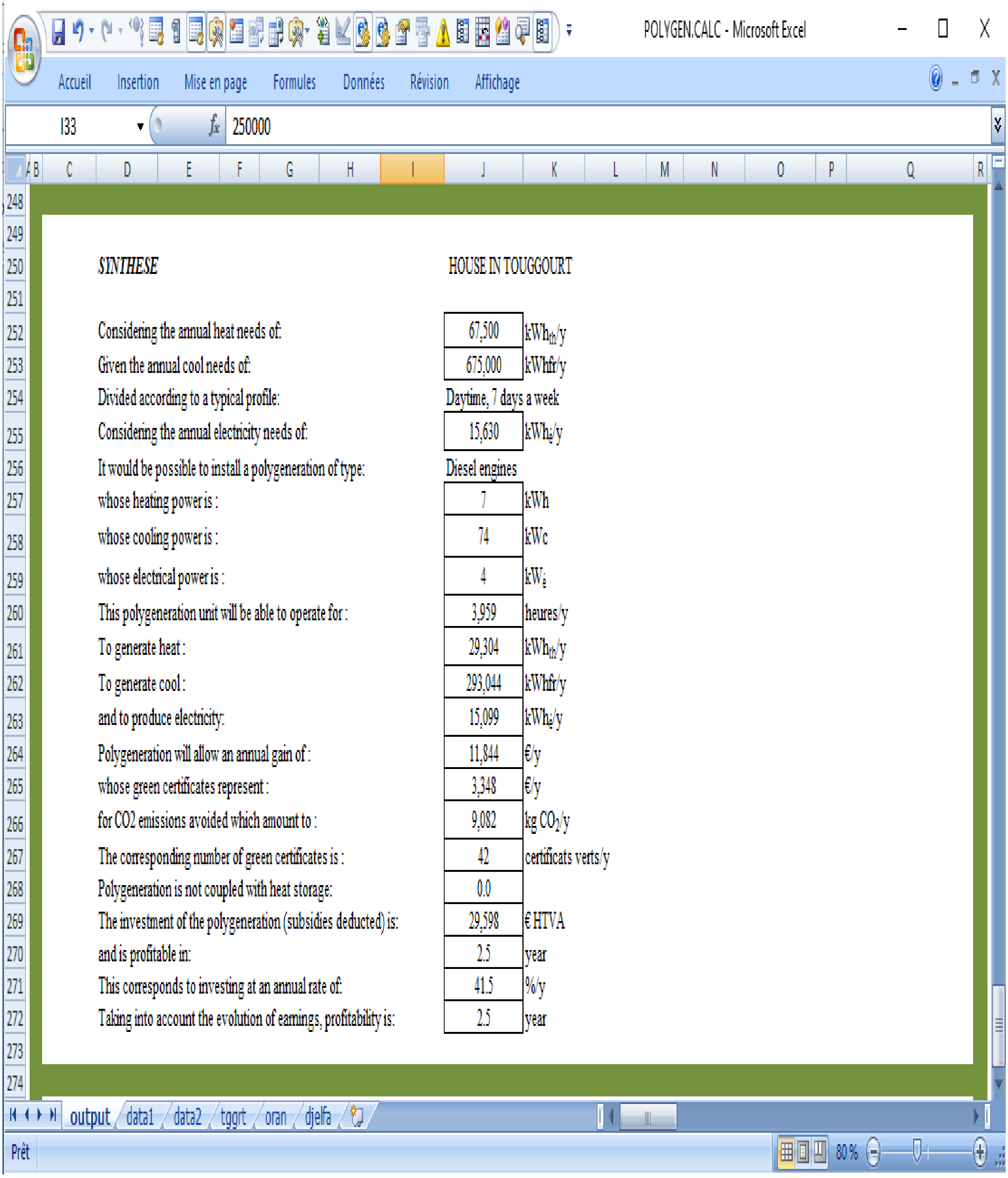
Figure4.31: Step 8 from profitability of your Polygeneration project

The simple return on investment time is a second criterion that has the advantage of swiftly demonstrating a project's financial interest. This is the time span, stated in years, during which all gains have allowed the initial net investment to be repaid. [GUIDE COGÉNÉRATION. 2009]

Simply multiply the net yearly gain by the net investment.

$$Single\ return\ time\ = \frac{Invnet\ polygen}{Gain\ annuelnet}(y) \qquad (41)$$

Example :



SYNTHESE	HOUSE IN TOUGGOURT	
Considering the annual heat needs of:	67,500	kWh_{th}/y
Given the annual cool needs of:	675,000	kWhfr/y
Divided according to a typical profile:	Daytime, 7 days a week	
Considering the annual electricity needs of:	15,630	kWh_e/y
It would be possible to install a polygeneration of type:	Diesel engines	
whose heating power is :	7	kWh
whose cooling power is :	74	kWc
whose electrical power is :	4	kW_e
This polygeneration unit will be able to operate for :	3,959	heures/y
To generate heat :	29,304	kWh_{th}/y
To generate cool :	293,044	kWhfr/y
and to produce electricity:	15,099	kWh_e/y
Polygeneration will allow an annual gain of :	11,844	€/y
whose green certificates represent :	3,348	€/y
for CO2 emissions avoided which amount to :	9,082	kg CO_2/y
The corresponding number of green certificates is :	42	certificats verts/y
Polygeneration is not coupled with heat storage:	0.0	
The investment of the polygeneration (subsidies deducted) is:	29,598	€ HTVA
and is profitable in:	2.5	year
This corresponds to investing at an annual rate of:	41.5	%/y
Taking into account the evolution of earnings, profitability is:	2.5	year

Figure4.32: syntheses of house in touggourt

Tabel4.7: Presentation the values of the profitability of your Polygeneration project

	Touggourt	Oran	Djelfa
Average purchase price	33.72eur/kwh	33.72eur/kwh	33.72eur/kwh
Gain electric	3683.6eur/y	2861.88eur/y	8067.90eur/y
Average fuel price	47.82eur/kwh	48.33eur/kwh	46.22eur/kwh
Cons boiler rom	58602kwh	46887kwh	117218 kwh
Gain heating	2802eur/y	2266 eur/y	5418 eur/y
Average energy price	46.38 eur/kwh	47.98 eur/kwh	48.53 eur/kwh
Cons chiller	109403 kwh	54702 kwh	42980 kwh
Gain cooling	5074 eur/y	2624 eur/y	2086 eur/y
Gain cv	3204 eur/y	332 eur/y	903 eur/y
Cons polygen	42419	33405	89088
Fuel expense	-2028 eur/y	-1615 eur/y	-4117 eur/y
Maintenance expens	-594 eur/y	-487 eur/y	-1103 eur/y
Inves net polygen	26702eur	14537 eur	41004 eur
Gain annual net	12141 eur/y	5983 eur/y	11254 eur/y
Single return time	2.2year	3.9year	3.6year

Using the faculty's yearly energy and gas usage, polygen.calc calculates the size and profitability of the polygeneration system. However, as seen in this chapter, the current yearly energy consumption schedule is divided into three zones. Customers in Touggourt (Zone 1) use significantly more energy for cooling than consumers in other Zones (Oran and Djelfa). This gap is attributable to the frequent use of air conditioning in southern zones, which is characterized by high temperatures for several months of the year. of a consumer who lives in a different Zone This group utilizes gas to heat their houses privately due to the harsh winter weather in Djelfa Zone 3.In comparison to the other zones, zone 1 profitability is the highest.

4.4 Conclusion

For small scale polygeneration system study, system setup, operating strategy, and component sizing are important considerations. This thesis is primarily concerned with identifying the best components for a small-scale polygeneration system and calculating the component sizes that are most appropriate for the system. Techno-economic analyses of various system study and operating strategies are also conducted.

The world's energy profile is shifting toward a cleaner, more sustainable energy system, and polygeneration systems play a key part in this transition. Because household consumption accounts for such a high percentage of total energy consumption, this study concentrated on small-scale polygeneration systems, notably cogeneration and trigeneration systems, which are widely employed. For these systems, system setup, component sizes, and operational strategy are critical. Decision-making criteria for selecting the primary mover, which is the most important component of such systems, were established in order to provide direction for consumers who want to invest in CHP or CCHP units.

GENERAL CONCLUSION

General Conclusion

As the world's population grows, so does its energy need, necessitating the development of alternative energy sources in light of the world's delicate environmental situation. As a result, dispersed energy suppliers have become fashionable. Polygeneration systems include cogeneration and trigeneration systems. Heat is produced in addition to power in cogeneration systems, while cooling and heat are byproducts in trigeneration systems. These systems can both reduce and achieve greenhouse gas (GHG) emission reductions.

The work of dissertations focused on study of a polygeneration energy system to produce cool, heat and power in Algeria. The need for efficient and environmentally friendly power generation led to the creation of distributed generating units, which employ a variety of technologies and are integrated into power systems. Integration of polygeneration units, which are generally used to recover lost heat energy and transform it into electrical power or other thermal energy (hot or cold) to primarily enhance the distribution network.

In fact, these cogenerations and polygeneration systems are obviously the future main factor of the energy sector in Algeria. It has demonstrated significant economic and environmental efficiency by integrating the CC system in several electric production stations the past and in the future projects. But our main concern is the integration of the CCHP systems in several sectors like residential

In this study, a CHP unit was combined with a thermal energy storage system and a compression chiller. An excel model was constructed to describe the appropriate operational strategy and component sizes. The model is used in a case study involving a single-family household in three different Algerian cities (Oran, Djelfa, and Touggourt). We propose this technology that can determine energy usage in the deferent climatic zoning form Algerian buildings. POLYGEN.calc can determine the size and profitability of the polygeneration system.

General Conclusion

In the final chapter, a feasibility assessment performed with the polygen.calc tool resulted in the selection of the polygeneration construct. Where the results of the need for heating in the state of Djelfa were estimated at 135000 kWh/y, which is the largest percentage of the other states of Touggourt and Oran, which the need for them was estimated at 67500 kWh/y and 54000 kWh/y, respectively, similar to the need for cooling was with the largest percentage estimated at 756000 kWh/y In Touggourt, both Djelfa and Oran, the estimated need is 297000kWh/y and 378000kWh/y. The latter allows an estimate of the size and profitability of a polygeneration system based on the total annual use of electricity and gas. We may note that the results of the scale and profitability of the polygeneration system are interesting, as the largest profitability was in Touggourt with a net profit of 12141 eur/y less than in Djelfa 11254 eur/y and it was in Oran 5983 eur/y.

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