



# Energy efficiency improvement of a building in Tunisia

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The Higher School of Technology and Management is not responsible for the opinions expressed in this report

# Dedication

Dear Father Lassad and my dear Mother Mounira, for their love, sacrifices and support in the most difficult moments, which are at the origin of my success, may God keep and protect them.

To my Brother Dhia, for his continuous encouragement and support since my birth, I wish you a life full of happiness and success.

To all the people who, actively or not, participated and helped in the accomplishment of this work. It is with great pleasure, I dedicate this modest work to you

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# Resumo

Para definir as medidas mais aceitáveis, considerando o edifício interior, recomenda-se a utilização de alguma metodologia para melhorar e garantir o desempenho energético e ambiental do espaço da estrutura.

Esta tese apresenta uma análise energética da empresa de telecomunicações OOREDOO na Tunísia, que consiste num rés-do-chão e 3 andares. Com base numa análise interna das infra-estruturas e dos diferentes elementos que influenciam os gastos energéticos, uma análise de os dados fundamentais do edifício são apresentados a fim de encontrar soluções para o consumo actual e de avaliar possíveis medidas de eficiência energética.

Esta tese visa completar um balanço energético detalhado de um edifício institucional e elaborar propostas para melhorar a sua eficiência energética. A renovação energética apenas melhora os hábitos de vida dos ocupantes, bem como a capacidade do edifício para ser autónomo em termos de gestão energética.

# Abstract

Considering a building, it is recommended to use some methodology to ameliorate and guarantee the energy and environmental performance of the structure space.

This thesis presents an energy analysis of the telecommunication company OOREDOO in Tunisia which consists of a ground floor and 3 floors. Based on an internal analysis of the infrastructure and the different elements influencing the energy expenses, an analysis of the fundamental data of the building is presented in order to find solutions to the current excessive consumption and to evaluate possible energy efficiency measures. This thesis aims to complete a detailed energy balance of an institutional building and to elaborate proposals for improving its energy efficiency. Energy renovation only improves the living habits of the occupants, as well as the ability of the building to consume less in terms of energy.

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# Chapter 1

## INTRODUCTION

The evolution of humanity has been accompanied by a significant increase in the use of energy resources. Energy reserves and the technologies of energy conversion and use are strategic for each country and ensure their development. Several times in recent history, these resources have been, and still are, the object of geopolitical maneuvers and international conflicts [1].

Lower costs have led to a dramatic increase in demand and usage. For example, the average UK resident in 2000 consumed 75 times more artificial light than his or her ancestor did in 1900 and more than 6,000 times more than in 1800... Much of this increase was in the form of outdoor street and building lighting. So we are in the midst of Jevons' paradox: large increases in efficiency have led to large reductions in cost and large increases in lighting demand and energy consumption[2].

During the last 50 years the world energy consumption has grown significantly. In 1965, the world energy consumption reached 3,800 million toe (tons of oil equivalent) while in 2004 it crossed the 10,000 million toe mark. In 2018, it reached 12,800 million toe. By resident, the consumption range lowered in the early 1970s when the price of oil increased rapidly, which led to solutions to save fuel consumption [3].

Since the year 2000, the consumption has decreased due to the systematic application of energy efficiency tools [3]. But any time one reduce the cost of consuming a valued resource, people will respond by consuming more of it: that is the foundation principle of

economics of Jevons Paradox [2].

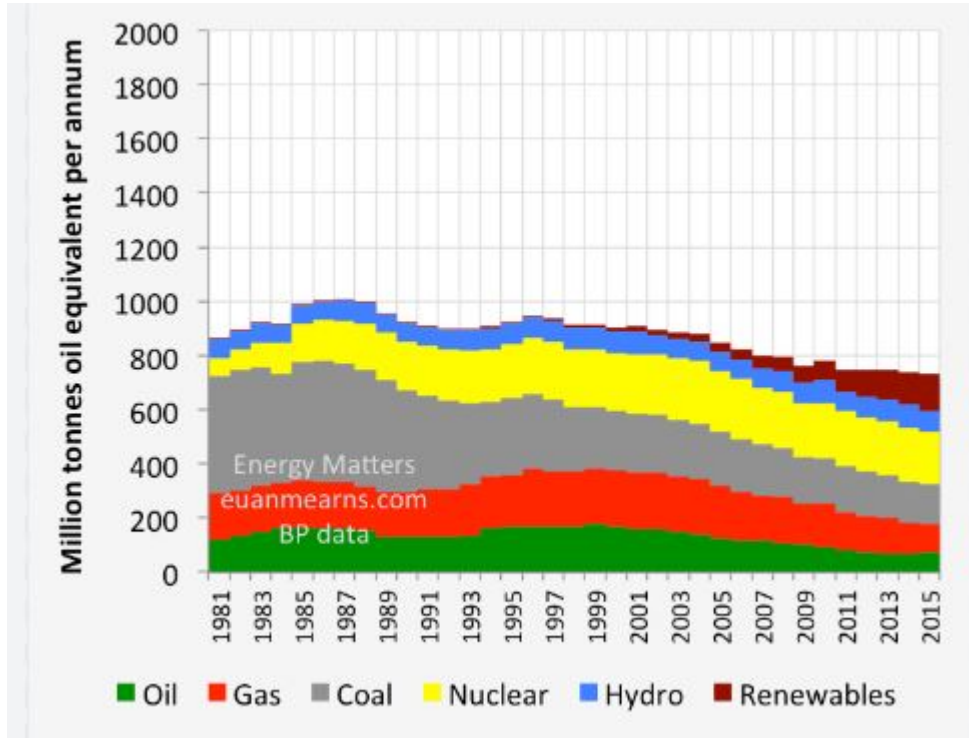


Figure 1.1: World energy Consumption [3]

## 1.1 Objectives

The objective of this thesis is to conduct a detailed analysis of the sources of energy savings in a telecommunication company and to suggest optimal solutions to energy expenses in order to reduce consumption and ensure an optimal return on investment.

Our study is applied to the building of OOREDOO located in Tunisia, which consists of a ground floor and 3 floors. We will identify opportunities to improve the energy efficiency of the entire building to present an improved model of consumption so that the infrastructure is both profitable and less energy intensive.

## 1.2 Introduction of the subject

The improvement of the living conditions of the population is made possible by an increase in the use of energy [4]. This use has led to the depletion of non-renewable energy resources and to massive emissions of greenhouse gases (GHG). Due to the increase in energy consumption, the state of energy reserves seems to be deteriorating. These circumstances seem to be worrying for the energy situation of future generations. Measures are needed to globalize our understanding of the value of energy and how best to use it [5].

In the past, in most buildings people give less importance to the consumption of the different energy components (lighting, heating, cooling, etc.) due to sufficiently abundant and inexpensive energy resources and a smaller population.

Major efforts are being made worldwide to use energy wisely and to replace polluting energy sources with renewable. Improving energy efficiency helps to maintain quality of life through new technological solutions and efficient energy use strategies and as the building sector is the largest consumer of energy in the world, it naturally has a key role to play in this strategy for greater energy efficiency [5].

Planning for a more sustainable world with minimal use of fossil fuels is a concern of humanity to conserve energy [1]. For a long time, investors have considered the cost of energy consumption to be fixed due to the lack of strategies to consume energy efficiently. Today, improving the energy efficiency of buildings has become a way to reduce expenses and protect our energy reserves [5]. Retrofit plans aim to incorporate energy efficiency by reducing fossil fuel and electrical energy consumption to make the infrastructure more advantageous to operate [6]. The increase in energy use has prompted the optimization of energy consumption by implementing a green discipline. This led to the signing of the United Nations Convention on Climate Change by 150 countries, which implies making reductions in energy consumption and in the amount of greenhouse gas emissions. Strategies have been established to make a detailed analysis of the different sources of energy saving in order to study each component for an improvement of the studied building. The

implementation of energy efficiency measures in the energy components of the infrastructure has a significant influence on the billing of energy consumption and can be done by several approaches depending on the type of the component. It can be done by changing the equipment or appliances of the building by other more profitable and less energy consuming ones, improving the thermal quality of the building, installation of automated equipment to minimize energy losses, integration of renewable energy such as photovoltaic panels, etc. All these steps are taken with the aim of obtaining an energy efficient system with an optimal return on investment. It is in this context that this research aims to analyze the sources of energy savings to achieve a reduction in energy consumption.

Specifically, one will focus on solutions to improve the energy efficiency of a telecommunication building, Ooredoo. All energy components will be analyzed, including lighting, HVAC system, operation of electrical appliances and equipment, etc., with the aim of identifying solutions to reduce energy consumption. For this, we will present the different approaches that can be applied for each component leading to an improvement in the functioning of the system.

### **1.3 Methodology**

In order to achieve the objective, an energy audit of the building was carried out, one made an analysis of the components in order to find practical solutions to the problems of high energy consumption. The methodology of the research goes through 3 phases:

#### **1st Phase: Collection and analysis of databases**

Due to the distance, it was difficult to make visits to a building. The data was communicated to us by the fluid engineer of the company Mr. Kais Boumaaza and the manager of the design office "BIM Experts" who collected all the data related to the infrastructure in advance. Lighting, heating, air conditioning and refrigeration (HVAC) have high costs in the bills and their improvement aims at decreasing the energy consumption and the associated bills.

## **2nd phase:Analysis of the data**

Analyzing the data of the building, based on the data itself and proposing scenarios of use when the exact information is not available, methods have been sought to reduce the costs of energy consumption.

## **3rd phase:Improvements**

From the analyses, one defined the most remarkable elements of the different components of energy consumption: lighting equipment, ventilation equipment, etc. This allowed us to propose appropriate solutions to minimize the energy cost of the infrastructure to make the investments required for the improvements to be profitable. The solutions chosen to reduce costs will be interpreted to calculate the energetic gain.

# **1.4 Structure of the report**

This report consists of 4 chapters:

- The first chapter provides a basic description of the project, beginning with an introduction that sets the context. The state of the art and the objective of the study are then presented, as well as the methodology.
- The second chapter presents the current state of world energy consumption as well as statistics and projections on the state of future energy consumption. Next, we define energy efficiency as a solution and explain its fundamental importance and the benefits it can offer to the environment, health and the economy.

We present also some energetic methods that can be used to reduce the consumption of buildings to improve their energy performance.

- The third chapter, included the analyses of different energy measures of the building, we present all our proposals for improving energy efficiency, they include the different solutions to improve the energy performance of each component of the building and their performance.

- The chapter 4, chapter is a conclusion, which provides an overall summary of the energy audit and the proposed solutions for improving the energy efficiency of the building.

# Chapter 2

## THEORETICAL PART

Understanding where and when energy is being consumed is an important first step to understanding where it can be saved. The end use profile, which breaks down the total consumption into the different end users, helps to define where money is being spent and to focus efforts where the highest net financial gain can be obtained.

### 2.1 Concept of energy efficiency

Energy efficiency is the judicious use of energy without affecting the comfort of users, the functionality of industrial, commercial and institutional facilities. The improvement of energy efficiency is the result of a study of the different energy consumption items in the whole building including installations, equipment and appliances. These studies highlight possible solutions to reduce energy consumption, the costs associated with their implementation and the effects on future operations. The implementation of these solutions allows, in many cases, to reduce operating costs, improve competitiveness and reduce GHG emissions. We aim to optimize the use of resources while maintaining the required functionality[7].

## 2.2 Benefits of energy efficiency

Energy efficiency has many benefits in different areas of human life as explained in the next sections.

### 2.2.1 Protects energy reserves

Due to their massive use in people's daily life, energy reserves are gradually decreasing. Non-efficient energy consumption is increasingly affecting the energy reserves. In the face of this increase, energy efficiency is the best choice for people to live better, preserve their resources and spend less. A study was conducted on energy consumption from 1990 to 2016 and the results showed the impact of energy efficiency measures on the number of recorded energy consumption. Significant energy savings were recorded in just 26 years, resulting in a reduction of 2 Petajoules (PJ) of energy worth \$45 billion [6].

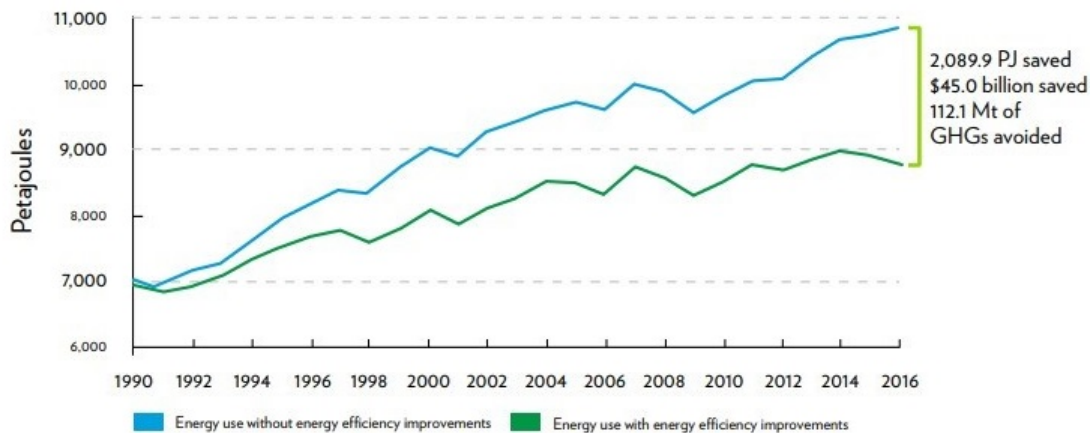


Figure 2.1: Evolution of energy efficiency[6]

### 2.2.2 Supports competitiveness and investment

Reducing a company's energy consumption costs means improving its energy profitability. In the business world, companies with lower energy consumption have a competitive advantage. Companies that implement energy efficiency policies have reduced their energy

expenses, restoring investor confidence in creating new opportunities. These saved costs can be used to increase different aspects related to the internal operation of the company such as the acquisition of production equipment [6].

### **2.2.3 Preserves the environment**

Oil, coal and gas are fossil fuels that emit heat and greenhouse gases, they have a huge impact on the environment of our planet. Energy efficiency helps to reduce energy consumption and avoid GHG emissions that harm our environment[6].

### **2.2.4 Reduces the need for new production capacity**

The transition of countries to non-GHG emitting energy sources will increase the demand for new capacity. Energy conservation now reduces the need to build additional generation facilities in the future. This will reduce long-term energy production costs and the social and environmental impacts associated with some generation projects. Energy efficiency also eases the burden on existing infrastructure by reducing recurring maintenance costs [6].

The first reflex that conduct an energy efficiency study, the engineer must have a thorough understanding of the energy components and types of equipment in an infrastructure to find savings opportunities.

## **2.3 Sources of energy savings to develop energy efficiency**

### **2.3.1 Building envelope**

The building envelope is the set of walls that are in direct contact with the outside environment. The thermal quality of the interior spaces depends on the design of the walls,

the construction materials and can increase or decrease the need for HVAC systems. This is where the important role of wall insulation appears [8]. The best use of wall insulation will strengthen our structure and reduce heat transfer within the building. It increases the thermal resistance of the wall and therefore the thermal quality of the interior areas. All this reduces the need to use HVAC systems[8]. The greater the thermal resistance, the more insulating the material. The thermal resistance (R) of a wall depends on the coefficient of thermal conductivity ( $\lambda$ ) of the materials used and the thickness (e) of the layers of each material. It is expressed in  $m^2 \cdot ^\circ C/W$  and is calculated by the following equation:

$$R = \frac{e}{\lambda} \quad (2.1)$$

The table 2.1 shows some examples of the values of the thermal conductivity coefficient depending on the type of building materials used.

Table 2.1: Thermal conductivity of different types of material [8]

<b>Materials</b>	<b>Thermal conductivity(<math>W/^\circ C.m</math>)</b>
Reed	0.05
Sawdust	0.06-0.07
Natural silk	0.052
Cement asbestos	0.4
Natural pozzolanic concrete	0.25-0.61
Geoconcrete	0.7-0.8
Reinforced concrete	1.5-2.04
Bitumen	0.16
Plywood	0.14
Smoothed lime or plaster coating	0.87
Cement plaster	0.87
Wood chips	0.081
Concrete	0.9-1.7
Limestone	1.05-2.2
Terracotta	1.15
Solid brick wall	0.85
Hollow brick wall	0.4
Natural wood	0.12-0.044

The equivalent thermal resistance of a wall depends on whether the wall is horizontal or vertical.

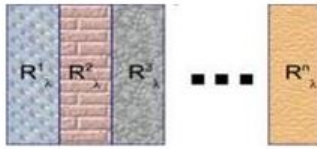


Figure 2.2: Horizontal wall

For the horizontal wall (series) like in the figure 2.2, the equivalent thermal resistance is:

$$R_{eq} = \sum R^n \quad (2.2)$$

The insulation of infrastructure walls is an effective way to increase the thermal quality of interior areas. given their direct exposure to solar radiation, the walls of the infrastructure are among the important elements of an infrastructure that can generate thermal transfers from the outside, which can influence the thermal quality of the interior spaces[9].

### 2.3.2 Roof insulation

There are 4 types of insulation materials suitable for flat roofs.

#### Warm roof

The insulation for this roof is placed between the ballast, the waterproofing membrane (which provides good protection), the substrate and a vapour barrier as shown in figure 2.3 This type of insulation is very common and is characterized by its simple installation [10].

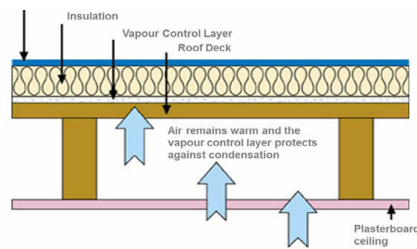


Figure 2.3: Warm roof [10]

## Inverted roof

What characterizes the inverted roof in terms of execution is that its insulation is put on a waterproofing directly on the support. To execute this type of roof, the slope of this system must be at least greater than or equal to 3mm/m. the installation is very expensive and rainwater can affect the insulation and negatively influence its performance [11].

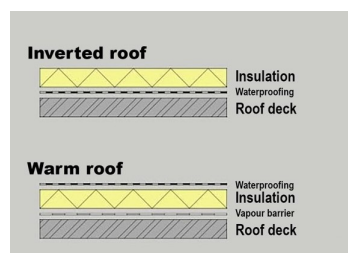


Figure 2.4: Inverted roof [11]

## Combination roof

This type of roof encompasses the two previous techniques and is characterized by the use of two internal insulations resulting in a better quality of insulation [9].

## Insulating Flat Roofs from the Inside

Insulating roofs from the inside is an optimal choice when exterior insulation is complex to install. For this type of insulation, the insulation is installed over a vapour barrier and

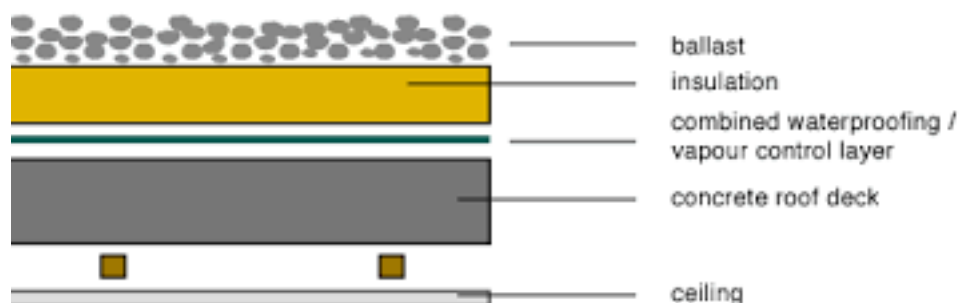


Figure 2.5: Combination roof[9]

possibly a false ceiling [9].

### **2.3.3 Insulation of walls**

The walls are directly exposed to the external environment. the execution of thermal insulation of the external walls will have a positive impact on the thermal quality of the internal area.

#### **Insulation from the inside**

The insulation of walls from the inside is done by plates or by masonry walls [9].

-Insulation with plaster: The plaster is located after the masonry and consists of elements such as laths or sometimes being glued, insulation, possible vapour barrier, and finishing panels. It is a homogeneous system that will allow an optimal thermal insulation[9].

-Bulkhead Insulation: This type of interior insulation is accomplished by adding two elements. The first is an internal insulation in polystyrene or glass wool. The second is a wall in the form of plaster tiles[9].

#### **Wall insulation from the outside**

For an efficient and optimal insulation of an infrastructure, the system of thermal insulation from the outside is among the most recommended actions[9].

-Insulating plaster for this type of insulation, a bonding layer is required to properly place and fix the insulation. The overall structure consists of a granular mortar (e.g. perlite), a binder (cement) and an insulating plaster. Knowing that compared with conventional insulation is less efficient and to improve the effectiveness of the insulation, we must increase the thickness of the layer performed [9].

-Insulating panels Insulation is done with insulating panels either under plaster or with a support system.

Under plaster: The installation of coated panels under plaster is the most frequent structure and is divided into a system under hydraulic plaster and a system under thin plaster.

They consist of an insulation panel made of wood fiber or polystyrene, placed and glued to the wall and coated with a finishing plaster[9].

With a support system: A homogeneous structure is fixed to the wall and the insulation is among the components that play in this type the role of a support to the plaster especially to the internal reinforcements[9].

Filling a hollow wall:

this technique can be carried out by injection or blowing, when the wall that we want to insulate is a hollow wall. It consists in filling the empty spaces with insulating material:

By injection: insulation by injection is done by a spray gun expandable foam allows a targeting of the empty spaces of the wall on the outside.

By insufflation: this technique consists of putting the insulation under pressure on a wall and is done with a single material. One of its advantages is that it requires less maintenance and work for its installation[9].

## **Insulation of windows and openings**

-Added protection against solar radiation: The addition of solar radiation protection, glazing changes and protective films are among the techniques that can improve the value of the conductivity coefficient and thus the thermal quality. For an effective and less expensive solar protection, shading systems are an optimal solution. Shading systems can be divided into two types:

Internal shading systems such as curtains and blinds.

External shading systems such as overhangs, vegetation and shutters[9].

-Change of glazing: In order to reduce heat gain (by conduction and radiation), changing the glazing can be a good solution.

These involve the application of materials with lower thermal conductivity (U) and the use of double or triple glazing, which allows a significant amount of visible light to enter.[9]

Table 2.2: Value of conductivity(U) for each type of glazing

<b>Type of glazing</b>	<b>Indicative value</b> <b>U(W/m<sup>2</sup>.K)</b>	<b>Indicative value</b> <b>U(W/m<sup>2</sup>.K)</b>	<b>Indicative value</b> <b>U(W/m<sup>2</sup>.K)</b>
thickness	6mm	12mm	16mm
Single glazing	4.8	-	-
Double glazing (air filling)	3.1	2.8	2.7
Emissivity=0.2	2.7	2.3	2.1
Emissivity=0.5	2.6	2.0	1.8
Double glazing (argon filling)	2.9	2.7	2.6
Emissivity = 0.2	2.5	2.1	2.0
Emissivity = 0.5	2.3	1.8	1.7
Triple glazing (air filling)	2.4	2.1	2.0
Emissivity = 0.2	2.1	1.7	1.6
Emissivity = 0.5	1.9	1.5	1.4
Triple glazing (argon filling)	2.2	2.0	1.9
Emissivity = 0.2	1.9	1.6	1.5
Emissivity = 0.5	1.7	1.4	1.3

## 2.4 Energy-consuming components

To conduct an energy efficiency study, the engineer must have a thorough understanding of the energy components and types of equipment in an infrastructure to find savings opportunities.

### 2.4.1 Lighting

Lighting is one of the sources of energy savings that an engineer must consider when conducting an energy efficiency study. Its importance in our study can be clearly seen from the high expenses that appear in the balance sheets and invoices[12].

#### Incandescent Lamps

These lamps are "classic" because of their old use and their low cost. Their operation is based on the transformation of electrical energy into heat and light with a lower luminous

efficiency and a low energy efficiency. Their power varies from 5 to 500W and have a life span of up to 1500 hours[13].

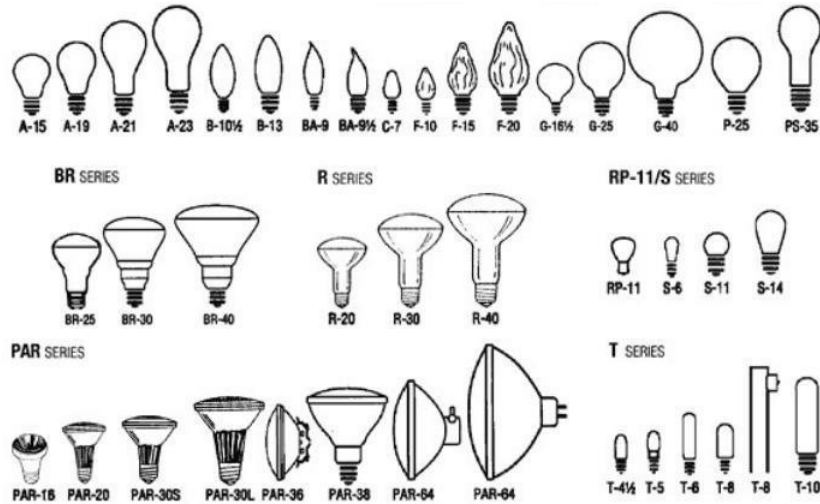
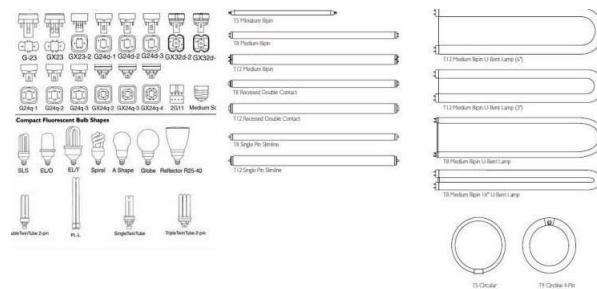


Figure 2.6: Incandescent lamps[13]

## Fluorescent Lamps

The compact fluorescent lamps or tubes are discharge lamps that have a minimum consumption and have a high energy efficiency. Compared to incandescent lamps, fluorescent lamps are 5 times more economical and their life is 12 times longer; their efficiency is incomparable to that of incandescent lamps. For decades, these lamps have undergone a remarkable development in terms of light quality; they generate a high quality lighting atmosphere [14].



## Metallic halogen Lamps

Metallic halogen lamps can work at a temperature of  $2900^{\circ}\text{C}$  which allows them to give off more ultraviolet radiation.[15]

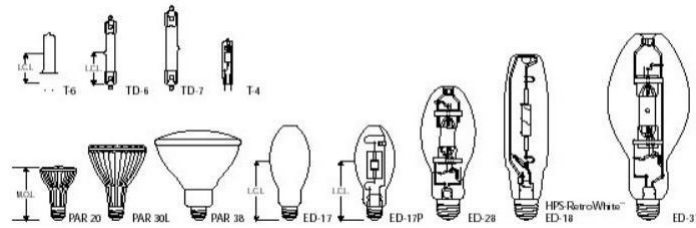


Figure 2.8: Metal iodide lamps[15]

## LED lamps

LED lighting is very different from other lighting types such as incandescent and CFL. Key differences include:

**Light Source:** LED are the size of a fleck of pepper, and can emit light in a range of colors. A mix of red, green, and blue LED is sometimes used to make white light.

**Direction:** LED emit light in a specific direction, reducing the need for reflectors and diffusers that can trap light. This feature makes LED more efficient for many uses such as recessed downlights and task lighting. With other types of lighting, the light must be reflected to the desired direction and more than half of the light may never leave the fixture.

**Heat:** LED emit very little heat. In comparison, incandescent bulbs release 90% of their energy as heat and CFL release about 80% of their energy as heat.

**Lifetime:** LED lighting products typically last much longer than other lighting types. a good quality LED bulb can last 3 to 5 times longer than a CFL and 30 times longer than an incandescent bulb.

## Presence detectors

One of the most effective systems in the management of light is the presence detector. With the help of an infrared detector of the movement of the occupants, these spaces will

be lit only if there are occupants in the area concerned. We will benefit from an effective and safe use of energy. Their use can cover any type of area. The infrared detector can be installed in walls or ceilings [16].



Figure 2.9: Presence detectors[16]

## 2.4.2 Heating, Cooling and Mechanical ventilation

In the early 1970s, there was less concern about the electrical consumption of heating, air conditioning, and mechanical ventilation. After this period, energy prices began to rise and the energy needs of HVAC increased significantly. These needs now represent twice the total consumption of African countries and 30% of the energy expenditures for other countries. This evolution has led to a particular interest in the energy efficiency of the HVAC system. To do this, we will explore the different systems found in a building, their fundamental characteristics as well as the approaches allowing their optimization [17].

### Centralized systems

Heating, cooling and controlled mechanical ventilation are the functions performed by centralized systems. These are composed of elements that produce quantities of heat and cold of the concerned spaces of the building (heat pumps, boilers, etc.), divide the quantities of heat and cold to distribute them to the concerned spaces of the building (pumps, piping, air handling units, air ducts, etc.) and evacuate out of the building quantities of heat or cold of the concerned spaces of the building (fan coil units, radiators, etc.). The centralized systems are divided into centralized all-air and water/ air-water systems.[17]

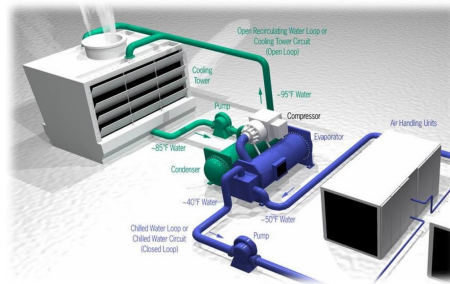


Figure 2.10: Centralized system

### Controlled mechanical ventilation (CMV)

Mechanical ventilation of premises involves changing the air in the area concerned to improve air quality. This process is done by introducing outside air to the interior spaces of the building with the aim of minimizing stale air to a reasonable level. There are two types of centralized mechanical ventilation (CMV) either with or without an air handling unit.



Figure 2.11: CMV system [18]

### Centralized mechanical ventilation with air handling unit

The centralized mechanical ventilation with air handling unit is joined to the installations that assure functions of blowing or inclusion as presented below: The air handling system ensures both the introduction of fresh air and the extraction of stale air through the air handling unit (AHU) equipped with economizer. The air handling system ensures the introduction of fresh air by the AHU and the extraction of stale air is ensured by one or several extraction fans controlled by the AHU. The air handling unit introduces fresh air

through the AHU and the exhaust air is extracted by ex-filtration from the rooms with specific pollution (kitchen, toilets, etc.) which may or may not be equipped with exhaust fans.[17]

### **Mechanical ventilation without air handling unit**

Centralized mechanical ventilation in spaces without a central air handling system is carried out by equipment such as exhaust fans, regulation, air inlets, air ducts and extract units. The spaces concerned with ventilation are equipped with air extractors connected to duct work to remove poor quality air.[17]



Figure 2.12: Types of extractors[17]

### **Install a programmable or smart thermostat**

A programmable thermostat can be set to automatically turn off or reduce heating and cooling during the times when you are asleep or away. When you install a programmable thermostat, you eliminate wasteful energy use from heating and cooling without upgrading your HVAC system.[19]

On average, a programmable thermostat can save you \$180 per year. Programmable thermostats come in different models that can be set to fit your weekly schedule. Additional features of programmable thermostats can include indicators for when to replace air filters or HVAC system problems, which also improve the efficiency of your heating and cooling system.[19]

Consumption has been growing overall for the past 40 years, at an average rate of 0.2% per year in Europe and Russia, and 0.5% per year in the United States and Canada. Growth has been much stronger in Africa, at +3.1% per year.

Energy efficiency and its valuable benefits for the economy, environment and health, gives

added value to buildings and improves their energy performance to generate a more energy efficient system.

Energy efficiency is a cost-effective solution adopted by countries around the world to reduce the energy costs of infrastructure. The most energy consuming components of an infrastructure are the lighting and HVAC systems approximately 60%. and are characterized by specific properties to their operation. To provide comfort to the occupants in the buildings, these functional components use various equipment and facilities.



# Chapter 3

## CASE STUDY: DATA, RESULTS AND DISCUSSION

After presenting the various components associated with infrastructure energy expenditures and the available energy efficiency measures, this chapter is specifically devoted to the presentation of our case study data, the overall project simulation, and discussions of the results obtained.

### 3.1 Description of the case study

#### 3.1.1 Overview of the studied infrastructure

Ooredoo, formerly Tunisiana, is a private telecommunications operator in Tunisia.// On May 11, 2002, Tunisiana signed a license agreement with the Tunisian government for the installation and operation of a second mobile telephony network in the country, valid for fifteen years and renewable for another five years. In fact, Tunisiana was the first private operator to obtain a cell phone license in the country. With a capital of 359.172 million dinars, Tunisiana made its commercial launch on December 27 of the same year. Six months later, its network covers 60% of the Tunisian population. The coverage of the network extends to 99% of the population during the year 2005.[20]



Figure 3.1: Company "OOREDOO"

Table 3.1: OOREDOO company address

Company name	Address of the head office	Phone number
OOREDOO	Zenith Building 1053 Berge Du Lac Tunis, Tunisia	+21622111111

### 3.1.2 Building profile

The table 3.2 shows the type of building and its area.

Table 3.2: Building information

Building Type	Occupancy: Number of people	Coefficient of occupation of the premises	Surface area ( $m^2$ )
Offices	650 Persons	70%	10200

The table 3.3 shows the occupation schedule in the company.

Table 3.3: Profile company

<b>Weekly operating profile</b>	<b>Daily operating profile</b>	<b>Electricity distributors</b>
5 days /7 (working days: 251 days / year)	Start of occupation [hh:mm] : 06:00 End of occupancy [hh:mm] : 20:00	STEG

The table 3.4 enclosed shows the equipment which will intervene in the calculation of the consumptions.

Table 3.4: Electrical equipments

<b>ELECTRICAL EQUIPMENTS</b>
MV/LV transformers
Elevators
Lighting
Office automation
Mechanical ventilation
Cooling by fan coil units
Cafeteria equipment
Various floor equipment (fridge)

## 3.2 Lighting results

We present in the following tables the data obtained on the consumption of different equipment and facilities at the company OOREDOO.

### 3.2.1 Data lighting office

#### Problem

Table 3.5: Offices data lighting before improvement

<b>Type of room</b>	<b>Type of lighth</b>	<b>Num-ber</b>	<b>Unit power (W)</b>	<b>Area (<math>m^2</math>)</b>	<b>Specific lighting power (<math>W/m^2</math>)</b>	<b>Installed power (<math>kW</math>)</b>
offices (500lux)	low luminance (16mm)	2131	38	6630	12	79.6

Remembering that the operating range is from 06h to 20h that is mean 14 hours per day and 251 days per year: so the total consumption equal to:

$$C_{total} = 79.6 * 14 * 251 = 279714.4kWh/year \quad (3.1)$$

### Solution

It was proposed to replace the types of lighting installed by LED bulb type and we calculate the new consumption.

so the new total consumption equal to:

Table 3.6: Offices data lighting after improvement

Type of room	Type of lighth	Num-ber	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
offices (500lux)	LED lamps	2131	18	6630	5.78	38.32

$$C_{total} = 38.32 * 14 * 251 = 134\ 656.5 \text{ kWh/year}$$

$$\text{we can deduce the lighting gain: } G = (279\ 714.4 - 134\ 656.5) / 279\ 714.4 * 100 = 51.8\%$$

### 3.2.2 Corridor lighting

#### Problem

Table 3.7: Data lighting of corridor before improvement

Type of room	Type of lighth	Num-ber	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
corridor (200lux)	compact fluorescent lamps	236	32	1020	9	9.18

we considerate the same operating range (14 hours) so the total consumption equal to:

$$C_{total} = 9.18 * 14 * 251 = 32\ 258.52 \text{ kWh/year}$$

## Solution

If we change the types installed by LED lamps we find:

Table 3.8: Data lighting of corridor after improvement

Type of room	Type of lighth	Num-ber	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (KW)
corridor (200lux)	LED lamps	286	22	1020	6.17	6.3

so total consumption will be equal to:

$$C \text{ total} = 6.3 * 14 * 251 = 22 \text{ 138.2 kWh/year}$$

$$\text{lighting gain: } G = (32 \text{ 258.52} - 22 \text{ 138.2}) / 32 \text{ 258.52} * 100 = 31.37\%$$

### 3.2.3 Staircase lighting

#### Problem

Table 3.9: Data lighting of staircase before improvement

Type of room	Type of lighth	Num-ber	unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
staircase (200 lux)	fluorescent (16mm)T5 shape very high efficiency	65	14	153	6	0.92

we considerate the same operating range (14 hours) we find total consumption equal to:

$$C \text{ total} = 0.92 * 14 * 251 = 3 \text{ 232.88 kWh/year}$$

#### Solution

We propose to change the types installed by the LED lamps and we calculate the new consumption.

Table 3.10: Data lighting of staircase after improvement

Type of room	Type of lighth	Number	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
staircase (200lux)	LED fluorescent light	65	9	153	3.82	0.6

$$C \text{ total} = 0.6 * 14 * 251 = 2108.4 \text{ kWh/year}$$

$$\text{Gain } G = (3232.88 - 2108.4) / 3232.88 * 100 = 35\%$$

### 3.2.4 Lighting of sanitary

#### Problem

Table 3.11: Data lighting of sanitary before improvement

Type of room	Type of lighth	Number	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
sanitary (200lux)	compact fluorescent lamps	67	34	255	9	2.3

If we considerate the same operating range (14 hours); we considerate that the lamps works without interruption during the operating time of building we find total consumption equal to:

$$C \text{ total} = 2.3 * 14 * 251 = 8082 \text{ kWh/year}$$

#### Solution

Concerning the lighting of the sanitary we propose Modern LED technology enables glare-free lighting in sanitary facilities, while creating a pleasant atmosphere by selecting individual color temperatures. Since the sanitary facilities are usually only used occasionally, an intelligent lighting management system with a presence detector can significantly reduce the energy costs of lighting. With lighting regulated by means of a presence detector,

the energy consumption of the lighting can be reduced by 15-30% [16].

If we consider the minimum gain(15%) the annual consumption will be equal to:

$$C_{\text{total}} = 8\,082 - (8\,082 * 0.15) = 6\,869,7 \text{ kWh/year}$$

### 3.2.5 Cafeteria lighting

Table 3.12: Data lighting of cafeteria

Type of room	Type of light	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
cafeteria (500lux)	compact fluorescent lamps	240	8	1.92

The cafeteria is open 12 hours a day (from 7am to 7pm)

Annual consumption is equal to:

$$C_{\text{total}} = 1.92 * 12 * 251 = 5738 \text{ kWh/year}$$

### 3.2.6 Parking lights

#### Problem

Table 3.13: Data lighting of parking before improvement

Type of room	Type of light	Number	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	In- stalled power (kW)
parking (500lux)	Fluorescent (hermetic tube)	145	56	3264	2.5	8.2

The parking is used 13 hours a day (from 7am to 8pm)

Annual consumption is equal to:

$$C \text{ total} = 8.2 * 13 * 251 = 26\,756,6 \text{ kWh/year}$$

## Solution

Parking lots and walkways should always be well lit for obvious safety reasons. In traffic areas shared by vehicles and pedestrians, the need for effective lighting is greater than in parking areas. Good lighting not only reduces the risk of accidents, but also ensures that employees, customers and guests feel safe. Recommended solutions are LED floodlights and wide-angle lighting poles such as LED SOX bulbs, discharge lamps, and ceramic outdoor lamps.

we have chosen the type ceramic outdoor lamps model CELA.

Table 3.14: Data lighting of parking after improvement

Type of room	Type of lighth	Number	Unit power (W)	Area ( $m^2$ )	Specific lighting power ( $W/m^2$ )	Installed power (kW)
parking (500lux)	Ceramic outdoor lamps	145	15	3264	0.7	2.28

Annual consumption will be equal to:

$$C \text{ total} = 2.28 * 13 * 251 = 7\,439.6 \text{ kWh/year}$$

### 3.2.7 Exterior lighting

ooreedoo building exterior lighting system is a twilight switch: lights up when it gets dark and goes out when natural light appears.

we estimate that the hours of working equal to : 4085 hours/year.

Table 3.15: Exterior lighting

Type of room	Type of lighth	Lighting power (kW)	Annual consumption (kWh/year)
exterior lighting	twilight switch	1.2	4902

## Summary

Table 3.16: Summary of lighting consumption before and after improvements

Space	Real consumption (kWh/year)	Consumption percentage (%)	Consumption after improvement (kWh/year)
Offices	279 714.40	77.55	134 656.5
Corridor	32 258.52	8.94	22 138.2
staircase	3 232.88	0.9	2 108.4
Sanitary	8 082.00	2.24	6 869.7
Cafeteria	5 738.00	1.59	5 738.0
Parking	26 756.60	7.42	7 439.6
Exterior	4 902.00	1.36	4 902.0
Total	360 684.4	100	183 852

Changing to less consuming appliances can reduce energy consumption from 360 684 kWh/year to 183 852 kWh/year.

## 3.3 Results of HVAC consumption

This part aims at estimating the electrical consumption related to the transport of fresh air or ventilation air.

The ventilation system was configured according to 5 groups of typical rooms: sanitary, work rooms, conference rooms, the restaurant and the parking.

### 3.3.1 Sanitary Extraction

Rate of ventilation depends on the type of space and the area,

The calculation of the power of our CMV is quite specific, since it takes into account various parameters such as the volume of the rooms and the frequency of the air renewal (approximately 8 to 12 times in WC).

Table 3.17: Ventilation data

Ventilation rate ( $m^3/h$ )	Flow rate per unit ( $m^3/h/unit$ )	Number of units	Flow rate of system ( $m^3/h$ )
3600	60	48	2880

we will estimate that it functions 10 times per hour.

the system of CMV consumes between 30 and 50 W.

The power absorbed by the air transfer it is equal to:

$$P = \text{consumption of CMV} * \text{air change frequency} / \text{flow rate} \quad (3.2)$$

Table 3.18: Power consumption

Electrical consumption (W)	Power absorbed by the air transfer ( $W/(m^3/h)$ )	Total consumption ( $KWh/year$ )
30	0.1	3154
50	0.18	5676

system operation is 24/24h without interruption that is mean 8760 hours/years.

To simplify the calculation we consider that the extraction rate =  $3600 m^3/h$

In mechanical ventilation systems (single or double flow), the electrical consumption of the ventilator is estimated by:

$$\text{cons}_{el} = \frac{Q_v}{3600} * \Delta p * \frac{t}{\eta_{vent}} \quad (3.3)$$

With:

$\text{cons}_{el}$ : Energy consumption of air transport (Wh/year).

$Q_v$ : fresh air flow rate ( $m^3/h$ )

3600 : 3600 Seconds per hour (s/h)

$\Delta p$ : Pressure drop (supply + exhaust) (pa)

t : operating time (h/year)

$\eta_{vent}$ : Total efficiency of the ventilation system (average between supply and exhaust).

Pressure losses of the extraction = 250 Pa

Estimated overall efficiency of ventilators = 50%

So we find :  $cons_{el} = 4380kWh/year$

### 3.3.2 Work spaces (offices, meeting rooms)

Table 3.19: Data ventilation of offices

Ventilation rate ( $m^3/h$ )	Flow per person ( $m^3/h/person$ )	Number of person	Working time (hours/year)
19500	30	650	8760

The existing type of air supply is a mechanical impulse, the power absorbed by the air transfer will ranges from [0.3 to 0.5]

So we find an air transfer consumption between (51246 and 90535 kWh/year).

Pilsion pressure losses equal to:800 Pa

Estimated ventilators efficiency is : 65%

Power consumption of ventilators is equal:

$$cons_{el} = 58400kWh/year \quad (3.4)$$

### 3.3.3 Double flow ventilation

conference room, lecture hall

Table 3.20: Data ventilation of conference room

Ventilation rate ( $m^3/h$ )	Flow per person ( $m^3/h/person$ )	Number of person	Working time (hours/year)
3000	30	100	8760

The power absorbed by the air transfer will ranges from [0.4 to 0.7W/( $m^3/h$ )]

So we find an air transfer consumption between (10512 and 18396 kWh/year).

we have the same losses (pilsion pressure losses equal to:800 Pa and pressure losses of the extraction equal to: 250 Pa)

Estimated ventilators efficiency is : 65%

$$cons_{el} = 8985kWh/year \quad (3.5)$$

power consumption of extraction equal:

$$cons_{el} = 2808kWh/year \quad (3.6)$$

**restaurant**

Table 3.21: Data ventilation of cafeteria

Ventilation rate ( $m^3/h$ )	Flow per person ( $m^3/h/person$ )	Number of person	Working time (hours/year)
3000	30	100	3012

The power absorbed by the air transfer will ranges also from [0.4 to 0.7 ( $W/(m^3/h)$ )]  
 So we find an air transfer consumption between (3614.4 and 6324.2 KWh/year).  
 Considerate the same values of losses (pilsion pressure and extraction losses (800 and 250 Pa), and we have the same ventilators efficiency (65%)  
 we find:

power consumption of ventilators equal:

$$cons_{el} = 3090kWh/year \quad (3.7)$$

power consumption of extraction equal:

$$cons_{el} = 965.4kWh/year \quad (3.8)$$

Table 3.22: Data ventilation

Type of ventilation	Consumption (kWh/year)	Efficiency (%)	Annual consumption (kWh/year)	Power (kW)
Extraction	4380.00	81%	5407.00	0.65
Impulse	58400.00	70%	83428.00	9.52
Double flow ventilation(impulse)	11793.00	81%	14560.00	1.66
Double flow ventilation(extraction)	3717.00	81%	4646.00	1.54

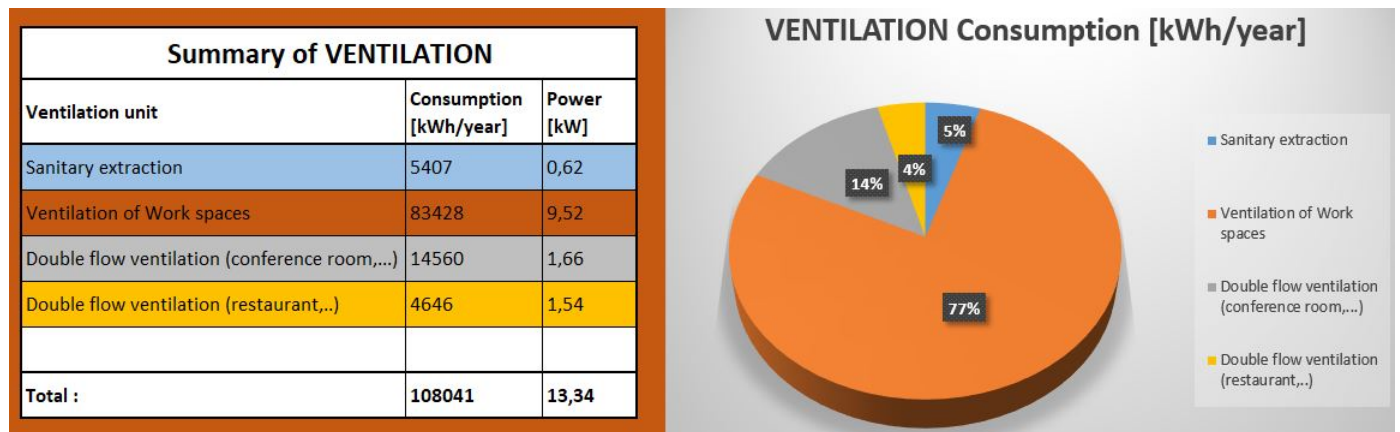


Figure 3.2: Summary ventilation

## Improvement

We can see that the total consumption of ventilation is around 108 MWh/year so we can propose a solution to minimize the cost of the consumption.

One propose to install Thermodynamic double flow CMV: The principle is the combination of a double flow CMV and a heat pump. Instead of capturing the calories of the outside air, the heat pump will capture the energy contained in the extracted air. It will then transmit it to the new air which will be blown.

The thermodynamic double flow CMV is particularly recommended in well insulated buildings with optimal air tightness. This is an essential condition to cover all the heating needs of the building. Depending on the quality of the insulation and the climate. The consumption it can can be reduced by 30 to 60%.

If we considerate that the total consumption will be reduced by 30%; we can find:

$$C_{el} = 108041 - (108041 * 0.3) = 108041 - 32412.3 = 75628.7kWh/year$$

### **3.3.4 Evaluate the consumption of auxiliary equipment for space cooling Fan coil units (cooling and heating)**

In this section we estimate the electrical consumption related to the cooling of the premises and to the humidification of the hygienic air or ventilation air, this means the consumption of the refrigeration machine, the pumps on the chilled water circuit, the fan coils and the humidifier if it is electric.

The fan coil system works in heating and cooling from 7am to 8pm 5 days a week.

The power of fan coils equal to 20 KW with 90% efficiency, so we have:

$$\text{consumption} = 20 * 0.9 * 13 * 251 = 58\,734 \text{ kWh/year}$$

#### **Cooling power to be provided in the premises**

The estimation of the building loads is very important to estimate the cooling power to be supplied.

The thermal loads of the building are divided into external and internal loads:

The external thermal load of a building consists of :

- Solar heat: on and through the window glazing, on the exterior walls and roofs
- The temperature of the outside air
- Outside air infiltration (when a building is not well insulated and air can enter the building)
- Ventilated air: where warm outside air is blown into the building without being cooled to the desired temperature.

The internal heat load of a building consists of :

- The heat released by the people present. The amount of heat depends on the number of people and their activity level
- Electrical lighting

-Heat radiated by machines, equipment and the production process (ovens, generators, mechanical milling (process), etc.)

-Heat transfer from the environment (such as heat exchange between unconditioned and conditioned areas).

To simplify the calculations, the cooling power can be estimated by the usual ratio method, that's mean the power required per square meter.

Table 3.23: Data cooling system

<b>Max power per square meter (<math>W/m^2</math>)</b>	<b>Air conditioned area (<math>m^2</math>)</b>	<b>Power consumption of the cooling machine (kW)</b>	<b>Average COP of the cooling machine</b>	<b>Number of operating hours (hours/year)</b>	<b>Cooling power consumption (kW)</b>	<b>Total consumption (KWh/year)</b>
120	7200	864	3	800	288	230 400

### Pumps for chilled water circulation in fan coils

To circulate the chilled water in the fan coils we need circulating pumps.

Table 3.24: Data circulating pumps

<b>Power indicated on the nameplates (W)</b>	<b>Efficiency of pumps</b>	<b>Power consumption of the circulators (hours/year)</b>	<b>Working time (hours/year)</b>	<b>total electrical consumption (<math>kWh/year</math>)</b>
32000	90%	28.8	4056	116813

In addition we estimate that we need 11kW throughout the year for the cooling of private premises

$$\text{consumption} = 11 * 365 * 24 = 96\ 360 \text{ kWh/year}$$

### Summary of Air-conditioning

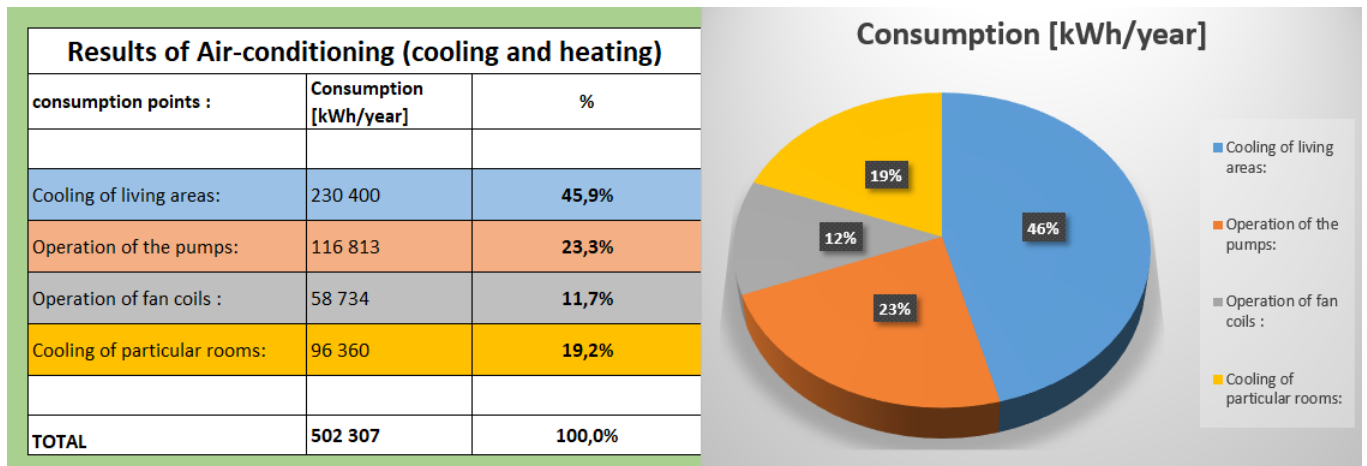


Figure 3.3: Summary of Air-conditioning

### 3.4 Consumption of transformer

The transformer allows the transfer of energy (in alternative form) from a source to a load, while changing the value of the voltage. The voltage can be either raised or lowered according to the desired use.

The transformer was used 24 hours a day all year round with a power equal to 630kva. A dielectric fluid (mineral oil) is used in the cooling circuit to dissipate heat from the magnetic circuit and the windings.

Table 3.25: Characteristics of the transformer

No-load losses ( <i>W</i> )	Load losses ( <i>W</i> )	Hours of use per month ( <i>hours</i> )	No-load consumption ( <i>kWh/year</i> )	Load consumption ( <i>kWh/year</i> )
860	5400	200	7534	12 960

So we find total consumption equal to:

$$\text{cons} = \text{no-load consumption} + \text{load consumption} = 20\,494 \text{ kWh/year}$$

### 3.5 Evaluation of elevator consumption

In this section we estimate the electrical consumption related to the elevators. This is due to the cabins and their interior lighting.

The calculation of the car drive consumption is based on the number of trips made the duration of an average run and the characteristics of the drive motor.

This calculation is independent of the number of cabins in the building, because all the elevators in the building are identical.

#### Consumption of cabins during races

As we have 3 floors served by the elevator we assume that the ground floor is occupied in a similar way to the other floors, The proposed number of trips is based on the following assumptions:

- all floor occupants use the elevator in pairs in the morning, midday and evening
- during off-peak hours, visitors and staff use the elevator at the rate of one trip per two occupants.

Table 3.26: Data of elevator

Morning	Midday	Evening	Complementary trips	Number (trips/day)	Number (trips/year)
163	163	163	163	652	163 652

#### Characteristics of elevators

To know the consumption of elevators we need some informations like (load, speed, duration of trip,...)

Table 3.27: Information of elevator

Nominal current (A)	Power factor(cos phi)	Speed (m/s)	Duration of trip (seconds)	Payload per elevator (kg)	Electric power absorbed by a trip (kW)
21	0.9	1	5	1000	1.732 * $I_{nom} * V * \cos\phi =$ $1.732 * 21 * 380 * 0.9 = 12.4$

So to know the total electrical consumption we need to multiply the consumption of one trip by the number of trips in the year:

$$Cons_{trip} = \text{Duration of trip} * \text{electrical power absorbed by a trip} = \frac{5}{3600} * 12.4 = 17.2Wh$$

$$cons_{elev} = Cons_{trip} * \text{number of trip in the year} = 17.2 * 163\ 652 = 2\ 815\ kWh/year$$

## Problem

### Cabin lighting

In the cabins of the elevators there is a need of lighting

Table 3.28: Data lighting of elevator

Type of lamps	Management type	Number of lamps in a cabin	Power of a lamp (W)	Number of cabins in the building	Total power of lamps (W)
fluorescent lamp	permanent lighting	2	18	4	144

So the annual consumption related to elevator lighting:

$$cons = 365 * 24 * 144 = 1261\ kWh/year$$

Therefore the total electrical consumption of elevators equal to:

$$con_{tot} = 1261 + 2815 = 4076kWh/year$$

## Solution

When an elevator will be equipped with a halogen lamp and a presence detector and will be illuminated only if there is someone on board, it can be a solution to minimize the consumption.

we propose a halogen lamp of 40 [W] with a luminous efficiency of 20 [lm/W] it works according to the occupation of the cabin (by presence detection)

remembering that we estimate that we have 163 652 trips/year and each trip take 5 seconds, so the occupation time of elevator is equal to: 227.3 hours/year

the lighting consumption will be equal to :

$$cons = powerofalamp * numberoflamps * numberofcabins * operatingtime \quad (3.9)$$

$$cons = 40 * 2 * 4 * 227.3 = 73 \text{ kWh/year}$$

So the total consumption will be equal to:

$$\text{Total consumption} = 73 + 2815 = 2888 \text{ kWh/year}$$

### 3.6 Evaluation of the consumption of office machines

For this item the following building data was used:

The number of devices:

- computers
- printers (laser and inkjet)
- fax machines (thermal, laser or inkjet)
- photocopiers (and their speed in copies/minutes)

For each of these types of devices, their operating hours and whether they are put on standby when not in use.

The average number of copies :

- per person with a computer for the different types of printers
- per person for fax machines
- per person for the different types of photocopiers.

Also the consumption of any floor refrigerators,

## Computers

We assumed that 95% of the workers use computers and we considered the maximum possible power consumption of a desktop computer

Table 3.29: Consumption of computers

Number of computers	Power per unit (kWh)	Operating period	Total consumption (kWh/year)
618	730	24hours(70% in real operation and 30% in standby)	315798

## Printers

the operating range of the printers is from 8am to 6pm and 251 days in the year

Table 3.30: Consumption of printers

Power of a printer in printing (W)	Hours of working (hours)	Number of days in the year (days/year)	Total consumption (kWh/year)
840	10	251	2108

## Server

Collaborative work in the company requires a server: collaborative software offers different functions for project management and to centralize on a single platform.

The installed power of the server is equal to 20000W and it is in operation 24h throughout the year

so the consumption of server is equal to:

$$cons = \frac{20000}{1000} * 24 * 365 = 175200kWh/year$$

## **Faxes**

The average power consumption of the fax machine is equal to 1080 W at 25C

Assuming the same period of operation of the printers (10 hours per day and 251 days per year), we found total consumption equal to:

$$cons = \frac{1080}{1000} * 10 * 251 = 2710.8kWh/year$$

## **Photocopiers**

In addition to printers there are also photocopiers, the average consumption of a photocopier is equal to 177 W.

taking the same period of operation(10hours per day and 251 days per year), we find total consumption equal to:

$$cons = \frac{177}{1000} * 10 * 251 = 444.27kWh/year$$

## **Various equipment**

Other special equipment must be taken into account. For example: a stamp machine, a printing press, a bookbinder, etc.

It is assumed that this equipment operates continuously on working days, during the hours of occupancy of the building, i.e. 10 hours per day and 251 days per year.

The average power of these equipments is equal to 5000W, so the consumption will be equal to:

$$cons = \frac{5000}{1000} * 10 * 251 = 12550kWh/year$$

## Summary of office equipment

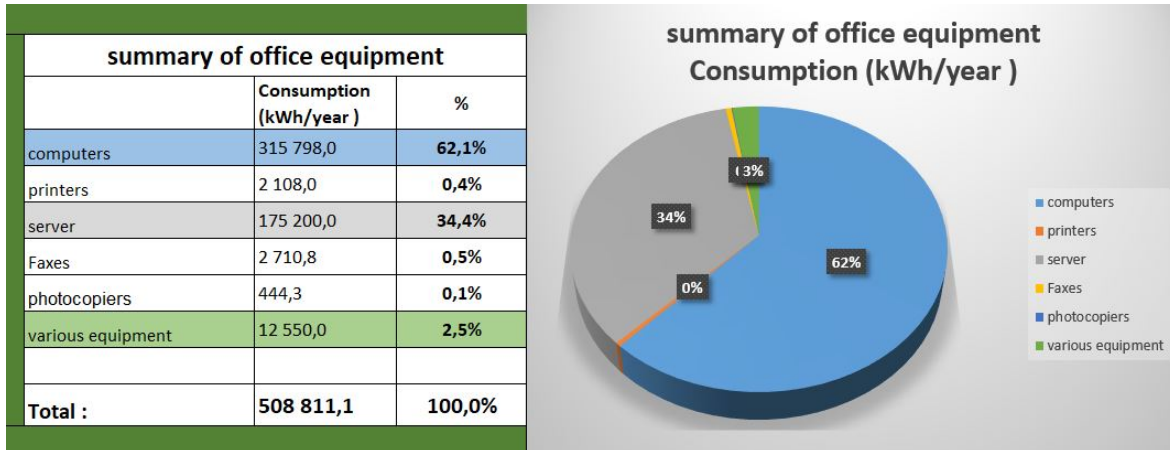


Figure 3.4: Summary office equipment

## 3.7 Various power supplies

In addition to the mentioned equipment there are other machines installed in the building which consume energy such as fridges, coffee machines...

### Fridges

Volume of fridge (liters)	Number of fridges	Annual consumption per unit (kWh/day)	Total consumption (KWh/year)
125	30	0.67	7336.5

Table 3.31: Consumption of fridges

### Water heater

The heat of water: this is the amount of energy needed to raise the temperature of one liter of water by one degree Celsius. Its value is 1.162 Wh/liter or  $1.162kWh/m^3$ .

so the consumption will be equal to:

$$cons = 1.162 * (55 - 12) * \frac{200}{1000} * 251 = 2508.3kWh/year$$

Volume of heater (liters)	City water temperature ( $^{\circ}C$ )	Temperature to be reached ( $^{\circ}C$ )	Period of operation (days/year)
200	$12^{\circ}C$	$55^{\circ}C$	251

Table 3.32: Consumption of water heater

### Coffee machine

In the building cafeteria there is a percolator and a coffee machine they consume 2200 W per hour, It is assumed also that this equipment operates continuously on working days, during the hours of occupancy of the building, i.e. 10 hours per day and 251 days per year.

so the annual consumption will be equal to:

$$cons = \frac{2200}{1000} * 10 * 251 = 5522kWh/year$$

## 3.8 Assessment of thermal insulation

After the modifications of the lighting types and ventilation system we think about the insulation of the building.

To improve the energy performance of a building, it is also necessary to carry out insulation work. Roof, walls, openings: find out what to insulate in priority.

Wall insulation

The walls of a building allow up to 25% of heat to escape.[21] After the roof, this is the largest heat loss in any building. There are two ways to improve the energy performance of your building: interior insulation and exterior insulation.

Insulation from the inside; we did not work on this technique because it causes a loss of living space.

Insulation from the outside; is a technique particularly adapted in renovation, this type of insulation is extremely powerful on the energy plan.[21]

### 3.8.1 Facade walls

A wall is usually composed of several layers of materials of varying thickness and thermal conductivity, and it is necessary to know its composition to determine the thermal resistance in order to calculate the contributions by transmission.

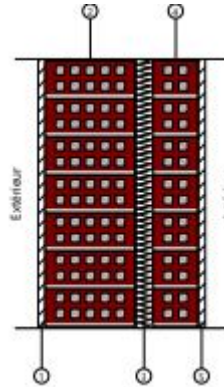


Figure 3.5: Vertical exterior wall

Table 3.33: Characteristics of the layers

Layers	Thick- ness (cm)	Conductivity $\lambda(W/m.K)$
(1):G01 - 16 mm gyp board	1.59	0.16
(2):Red brick 12 holes (0.207 W/(m.K))	20.00	0.27
(3):Plates cut from molded blocks and conforming to the standard NF EN 13163 (EPS) (Nominal density 8)	4.00	0.06
(4):Red brick 8 holes (0.190 W/(m.K))	10.00	0.27
(5):G01 - 16 mm gyp board	1.59	0.16

The thermal transmittance:

$$U_{walls} = \frac{1}{R_t} \quad (3.10)$$

With:

$$R_t = \sum \frac{e}{\lambda} + \frac{1}{h_i} + \frac{1}{h_e} = 2.189m^2.K/W \quad (3.11)$$

So  $U_{walls} = 0.46W/m^2.K$

The total surface of the exterior walls is equal to  $615.2m^2$

The outdoor temperature is taken from the ANME document (see appendix) (in average

35°C in the summer) and (in average 7°C in the winter), however the interior temperature was set in a way to ensure the thermal comfort of the building( 20°C in winter and 25°C in summer).

So the thermal losses of the external walls:

$$Q_{walls} = U_{walls} * S_w * \Delta T \quad (3.12)$$

In summer:  $Q_{walls} = 2\,829.92\text{ W}$

In winter:  $Q_{walls} = 3\,678.896\text{ W}$

## Improvement

It was proposed to add exterior thermal insulation(ITE): mechanical or glued fixing. The insulation, in the form of panels, is fixed to the wall by gluing or mechanically using pegs or profiles. It is then used as a support for a fiberglass reinforcement, covered with a decorative finishing coat.

Glue-down installation

This is the simplest and fastest solution to install. The insulation is glued directly to the wall. Polystyrene offers a performance of external insulation essential to improve the performance of the house. The white polystyrene will generally be sold under a thickness of 14 cm. For graphite polystyrene, a thickness of 12 cm will be sufficient. The difference between these two materials lies in the integration of graphite particles in the second, it is very effective to insulate.

Table 3.34: Characteristics of the new layer

Layer	Thickness (cm)	Conductivity $\lambda(W/m.K)$	resistance <b>R</b> ( $m^2.K/W$ )
graphite polystyrene	12	0.031	$R = \frac{e}{\lambda}=3.87$

The new resistance of walls:

$$R_{new} = R_t + \frac{e_{pg}}{\lambda_{pg}} = 6.059m^2.K/W \quad (3.13)$$

And the new thermal transmission:  $U = 0.16W/m^2.K$

In summer  $Q_{walls} = 1\ 168.88\ W$

In winter  $Q_{walls} = 1\ 279.616\ W$

### 3.8.2 Covers

As the largest wall in direct contact with the outside, the roof is the primary source of heat loss in a building. Insulating it is therefore essential to enjoy a building with a good energy performance.

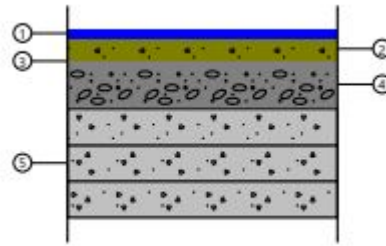


Figure 3.6: Sharp floor

Table 3.35: Characteristics of the sharp floor layers

Layers	Thickness (cm)	Conductivity $\lambda(W/m.K)$
(1):Baked clay tile	2.00	1
(2):Sand and gravel	5.00	2
(3):Pure asphalt	0.40	0.7
(4):Mortar (Dry Density 2300)	10.00	1.8
(5):One-way floor 20+5 cm (Concrete joist)	25.00	1.32

The thermal transmittance:

$$U_{cover} = \frac{1}{R_t} \quad (3.14)$$

With:

$$R_t = \sum \frac{e}{\lambda} + \frac{1}{h_i} + \frac{1}{h_e} = 0.437 m^2.K/W \quad (3.15)$$

so:  $U = 2.29 W/(m^2.K)$

The total area of the sharp floor is equal to  $661.7 m^2$

So the thermal contributions of the cover:

$$Q_{cover} = U_{cover} * S_{cover} * \Delta T \quad (3.16)$$

In summer:  $Q_{cover} = 13\ 637.637\ W$

In winter:  $Q_{cover} = 28\ 790.567\ W$

## Improvement

We propose to install bubble insulation because it is flexible and easy to install, it is cost-effective and less expensive than other options. Also it keeps external heat out in summer and protects indoor heat during winter.

Table 3.36: Characteristics of bubble insulation

Layer	Thickness (cm)	Conductivity $\lambda(W/m.K)$	resistance <b>R</b> ( $m^2.K/W$ )
Bubble insulation	2.5	0.032	$R = \frac{e}{\lambda} = 0.781$

The new resistance of the cover:

$$R_{new} = R_t + \frac{e_{bi}}{\lambda_{bi}} = 1.218 m^2.K/W \quad (3.17)$$

And the new thermal transmission:  $U = 0.82 W/m^2.K$

In summer:  $Q_{cover} = 4\ 883.34\ W$

In winter:  $Q_{cover} = 10\ 309.28\ W$

## 3.9 Discussion

### 3.9.1 STEG

The Tunisian Company of Electricity and Gas "STEG" is a Contractor operating in the energy sector: Production, Transport and Distribution of Electricity and Gas.

### 3.9.2 Bills

The Tunisian Company of Electricity and Gas (STEG) always announces new rates.

The rates are as follows:

If consumption is less than 2,400 (kilowatt hour/year): The price remains unchanged at 0.181 dinars.

If the consumption is between 2401 and 3600 (kilowatt-hour/year): The consumption will be charged at the rate of 0.223 dinars per kilowatt.

If the consumption is between 3601 and 6000 (kilowatt-hour/year) : Consumption will be charged at 0.338 dinars per kilowatt.

If the consumption exceeds 6000 (kilowatt hour/year): an invoice will be issued for the total consumption at the price of 0.419 dinars per kilowatt.[22]

So if we considerate the first consumption of the building as equal to: 1 519 410 kWh/year, therefore the bill will be equal to:

$$Bills = consumption/year * priceofakilowatthour \quad (3.18)$$

Table 3.37: Comparison of consumption before and after improvements

<b>Equipement</b>	<b>Real consumption (kWh/year)</b>	<b>Consumption after improvement (kWh/year)</b>
Transformer	20 494	20 494
Elevators	3 705	2 888
Lighting	360 684	183 852
Office equipment	508 811	508 811
Pumps	116 813	116 813
Ventilation	108 041	75 629
Air-conditioning	385 494	385 494
Equipment cafeteria	8 030	8 030
Fridges	7 337	7 337
<b>Total</b>	<b>1 519 410</b>	<b>1 309 348</b>

$$\text{Bill} = 1\,519\,410 \cdot 419 = 636\,632,8 \text{ TND} = 199\,000 \text{ EUR}$$

After improvements the consumption is decreases; it will be equal to: 1 304 133 kWh/year, consequently the bill will be decrease also.

new bill = 1 309 348 \* 419 = 548 616 TND = 175 000 EUR We can conclude that the total energy gain is equal to:

$$\text{Gain} = 1\,519\,410 - 1\,309\,348 = 210\,062 \text{ kWh/year}$$

The cost of this gain will be equal:

$$\text{money not spent} = 210\,062 \cdot 419 = 88\,015 \text{ TND} = 28\,000 \text{ EUR}$$

### 3.9.3 Investment

Table 3.38: Investment

<b>Equipement</b>	<b>Number</b>	<b>Price per unit (EUR)</b>	<b>Cost</b>
LED bulb for offices	2131	3.59	7 650
LED lamps for corridor	286	6.49	1 856
LED fluorescent light for staircase	65	3.31	215
Ceramic outdoor lamp:CELA	145	33	4 785
Thermodynamic double flow CMV	1	7 000	7 000
Halogen lamp for elevator	8	4.5	36
<b>Total</b>	<b>-</b>	<b>-</b>	<b>21 542</b>

So in the first year the company can invest an amount of 21 542 Euro and decrease the cost of consumption by 28 000 Euro.

So the net value gained is 6 458 Euro equal to 20 665 TND.

Then it can invest in the insulation of the building envelope (exterior walls and cover) to minimize the heating and cooling needs.



# Chapter 4

## CONCLUSION

This report presents an energy efficiency study which aims to study solutions to reduce the electrical consumption of a telecommunications building located in Tunisia. To achieve this objective, several solutions, targeting all energy components of the building, were studied. Lighting management, thermal insulation of the building envelope, optimization of heating, air conditioning and ventilation, etc. are all points that we tried to improve in order to make the establishment less energy consuming. For the lighting, we have installed installations such as presence detectors and we have modified the existing lamps with lamps that consume less electricity and are more efficient. For the thermal insulation, we opted for the installation of insulating carpet for the roof and an insulation by the outside for the walls. This increases the thermal quality of the building and minimizes the need for HVAC systems. To conclude, it should be remembered that the study of energy efficiency of a building is an essential step because not only does it allow energy savings, reduce electricity costs and thus turn a load into a depreciable asset, but also for its ecological impact.



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# Appendix A

## Annex

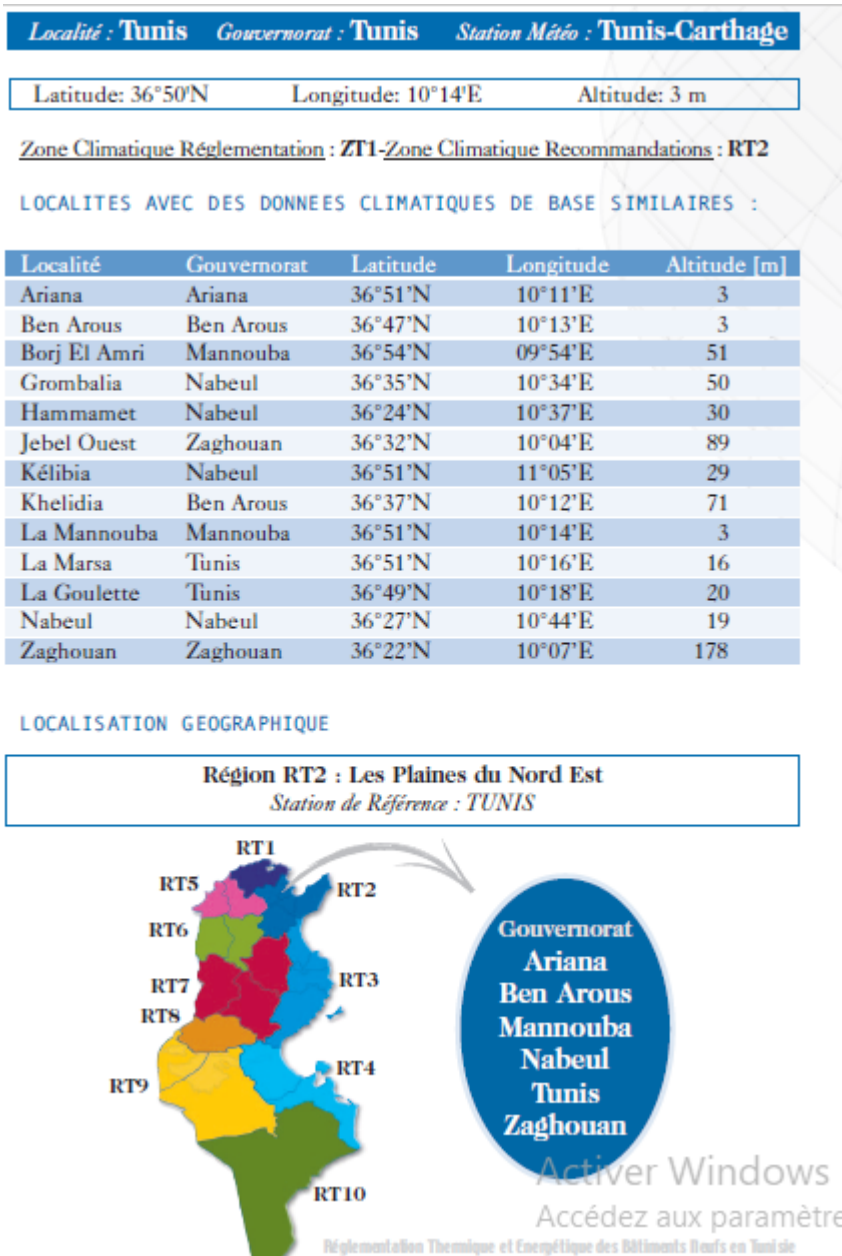


Figure A.1: GPS coordinates"ANME"



Agence Nationale pour la Maîtrise de l'Énergie

**Localité : Tunis    Gouvernorat : Tunis    Station Météo : Tunis-Carthage**

**DONNEES CLIMATIQUES DE BASE POUR LE CALCUL DES PUISSANCES DE CHAUFFAGE DES LOCAUX (Décembre – Février)**

**LOCAUX A USAGE D'HABITATION / LOCAUX OCCUPES LA NUIT**

Moyenne Saisonnière des Amplitudes de température – 9.0 °C	Fréquences Cumulées [%]	Température [°C]	HR Coïncidente
Constructions légères et/ou exigences rigoureuses de chauffage	99,0	4	89%
Constructions avec inertie thermique moyenne	97,5	5	90%
Constructions avec inertie thermique importante	95,0	6	88%

**LOCAUX OCCUPES UNIQUEMENT PENDANT LES HORAIRES ADMINISTRATIFS DE TRAVAIL (7h :00- 18h:00)**

Moyenne Saisonnière des Amplitudes de température – 9.0 °C	Fréquences Cumulées [%]	Température [°C]	HR Coïncidente
Constructions légères et exigences rigoureuses de chauffage	99,0	6	85%
Constructions avec inertie thermique moyenne ou constructions légères & exigences normales de chauffage	97,5	7	85%
Constructions avec inertie thermique importante	95,0	8	84%

Figure A.2: Heating regulations"ANME"

**Localité : Tunis    Gouvernorat : Tunis    Station Météo : Tunis-Carthage**

**DONNEES CLIMATIQUES DE BASE POUR LE CALCUL DES PUISSANCES DE REFROIDISSEMENT DES LOGAUX (Juin – Septembre)**

**LOGAUX AVEC CONTROLE USUEL DE L'HUMIDITE RELATIVE**

Moyenne Saisonnière des Amplitudes de température - 12 °C	Fréquences Cumulées [%]	Température [°C]	HR Coïncidente	
			Intérieur	Littoral
Locaux avec exigences rigoureuses de refroidissement	1,0	37	30%	38%
Locaux refroidis d'une façon discontinue et/ou locaux occupés pendant les horaires administratifs de travail	2,5	35	35%	45%
Locaux refroidis d'une façon continue et/ou locaux à usage d'habitation	5,0	33	41%	52%

**LOGAUX AVEC CONTROLE RIGOREUX DE L'HUMIDITE RELATIVE**

Moyenne Saisonnière des Amplitudes de température - 12 °C	Fréquences Cumulées [%]	Température [°C]	HR Coïncidente	
			Intérieur	Littoral
Locaux avec exigences rigoureuses de refroidissement	1,0	37	42%	50%
Locaux refroidis d'une façon discontinue et/ou locaux occupés pendant les horaires administratifs de travail	2,5	35	51%	61%
Locaux refroidis d'une façon continue	5,0	33	58%	69%

Figure A.3: Cooling regulations"ANME"

## TECHNICAL DATA

### Electrical data

Nominal wattage	18 W
Construction wattage	18.00 W
Nominal voltage	120...277 V
Claimed equiv. conventional lamp power	36 W
Nominal current	77 mA
Type of current	AC
Operating frequency	50...60 Hz
Mains frequency	50...60 Hz
Total harmonic distortion	< 20 %
Power factor $\lambda$	0.92

### Photometrical data

Luminous flux	900 lm
Luminous efficacy	50 lm/W
Lumen main.fact.at end of nom.life time	0.70
Light color (designation)	Cold White
Color temperature	5000 K
Color rendering Index Ra	80
Light color	850

### Light technical data

Beam angle	250 °
Starting time	< 0.5 s
Rated beam angle (half peak value)	250.00 °

### Dimensions & Weight

Overall length	1214.00 mm
Diameter	28.00 mm
Tube diameter	26 mm
Maximum diameter	26 mm
Product weight	191.00 g

Activer W  
Accédez aux

Figure A.4: Data sheet Led lamp 18W

## TECHNICAL DATA

### Electrical data

Nominal wattage	22 W
Construction wattage	22.00 W
Nominal voltage	220...240 V
Claimed equiv. conventional lamp power	80 W
Nominal current	120 mA
Type of current	AC
Inrush current	10 A
Operating frequency	50/60 Hz
Mains frequency	50/60 Hz
Max. lamp no. on circuit break. 10 A (B)	66
Max. lamp no. on circuit break. B10 A - CCG without compensation	55
Max. lamp no. on circuit break. B10 A - CCG with compensation	55
Max. lamp no. on circuit break. 16 A (B)	105
Max. lamp no. on circuit break. B16 A - CCG without compensation	88
Max. lamp no. on circuit break. B16 A - CCG with compensation	88
Total harmonic distortion	< 25 %
Power factor $\lambda$	> 0.90

Figure A.5: Data sheet Led lamp 22W

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## TECHNICAL DATA

### Electrical data

Nominal wattage	9 W
Construction wattage	9.00 W
Nominal voltage	120...277 V
Claimed equiv. conventional lamp power	18 W
Nominal current	77 mA
Type of current	AC
Operating frequency	50...60 Hz
Mains frequency	50...60 Hz
Total harmonic distortion	< 20 %
Power factor $\lambda$	0.92

### Photometrical data

Luminous flux	900 lm
Luminous efficacy	100 lm/W
Lumen main.fact.at end of nom.life time	0.70
Light color (designation)	Cool Daylight
Color temperature	6500 K
Color rendering index Ra	80
Light color	865

Activer Windows  
Accédez aux paramètres po

Figure A.6: Data sheet Led lamp 9W

Couches					
Matériau	e	$\rho$	$\lambda$	RT	Cp
G01 - 16 mm gyp board	1.59	800.90	0.16	0.099	1088.00
Brique rouge 12 trous (0.207 W/(m-K))	20.00	664.00	0.27	0.739	741.00
Plaques découpées dans des blocs moulés et conformes à la norme NF EN 13163 (EPS) (Masse volumique nominale 8)	4.00	8.50	0.06	0.714	1450.00
Brique rouge 8 trous (0.190 W/(m-K))	10.00	918.00	0.27	0.368	741.00
Plâtre "gâché serré" ou "très serré", masse volumique nominale 1300	1.20	1350.00	0.56	0.021	1000.00
Brique rouge 8 trous (0.190 W/(m-K))	10.00	918.00	0.24	0.414	741.00
Plâtre "gâché serré" ou "très serré", masse volumique nominale 1300	2.50	1350.00	0.56	0.045	1000.00
Brique rouge 12 trous (0.207 W/(m-K))	20.00	664.00	0.26	0.778	741.00
M08 - 200 mm LW concrete block (filled)	15.24	512.00	0.26	0.586	880.00
Plâtre "gâché serré" ou "très serré", masse volumique nominale 1300	5.00	1350.00	0.56	0.089	1000.00
Carrelage en argile cuite	2.00	2000.00	1.00	0.020	800.00
Sable et gravier	5.00	1950.00	2.00	0.025	1000.00
Asphalte pur	0.40	1050.00	0.70	0.006	1000.00
Mortier (Masse volumique sèche 2300)	10.00	2500.00	1.80	0.056	1000.00
Plancher unidirectionnel 20+5 cm (Entrevous en béton)	25.00	1327.33	1.32	0.190	1000.00
Carrelage en céramique porcelaine	2.00	2300.00	1.30	0.015	840.00
Sable et gravier	10.00	1950.00	2.00	0.050	1000.00
Mortier (Masse volumique sèche 2300)	5.00	2500.00	1.80	0.028	1000.00
Abréviations utilisées					
e	Épaisseur cm		RT	Résistance thermique (m <sup>2</sup> -K)/W	
$\rho$	Densité kg/m <sup>3</sup>		Cp	Chaleur spécifique J/(kg-K)	
$\lambda$	Conductivité thermique W/(m-K)				

Figure A.7: Layers of the walls and roof

	Pari en contact avec :			Pari en contact avec :		
	1/h <sub>i</sub>	1/h <sub>e</sub>	1/h <sub>i</sub> + 1/h <sub>e</sub>	1/h <sub>i</sub>	1/h' <sub>i</sub>	1/h <sub>i</sub> + 1/h' <sub>i</sub>
- l'extérieur, - un passage ouvert, - un local ouvert.						
- un autre local, chauffé ou non chauffé, - un comble, un vide sanitaire.						
Pari verticale ou faisant avec le plan horizontal un angle supérieur à 60° (FIG)	0,11	0,06	0,17	0,11	0,11	0,22
Pari horizontale ou faisant avec le plan horizontal un angle égal ou inférieur à 60°, flux ascendant (toiture) (FIG)	0,09	0,05	0,14	0,09	0,09	0,18
flux descendant (plancher bas) (FIG)	0,17	0,05	0,22	0,17	0,17	0,34

Figure A.8: Different values of convections