AL AKHAWAYN UNIVERSITY IN IFRANE
SCHOOL OF SCIENCE AND ENGINEERING

MODELING ENERGY CONSUMPTION IN RESIDENTIAL BUILDINGS

Capstone Design
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 Supervisor’s approval:  

[Signature]
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In the context of developing renewable energies and improving the energetic efficiency in Morocco, Al Akhawayn University is trying to develop its energy systems in the way of reducing the consumption of energy. Hence, the main objective of this capstone project is to study the impact of changing the electrical system in the residential buildings that aims to reduce the energy consumption on campus, and to develop a mathematical model to calculate the electrical energy consumption in a residency. Before designing and implementing the mathematical model, I performed a literature review to study the need of reducing the energy consumption through the International Performance Measurement and Verification Protocol (IPMVP) by choosing the appropriate option for the data collected from the Ground and Maintenance (Building 12). By evaluating the statistical results of the measurement and verification phases, I was able to determine the electric energy savings on campus during two comparative periods. The results of the energy savings were then plotted for a better analysis. Consequently, the design of the mathematical model was based on the types of the appliances found in a residency, the wattage of the appliances, and the hours of usage of the electric devices. Using these parameters, the model calculates the annual energy consumption and its cost.
6 INTRODUCTION

6.1 GENERAL CONTEXT

The increasing economic and social development of Morocco brought about a significant progress of energy demand. To answer the growing energy needs, Morocco defined a new energy strategy aiming to secure the energy supply while protecting the environment. Hence, renewable energies are the main component of this new strategy. In fact, Morocco has an important renewable energy potential whose exploitation will cover a great part of its growing needs and participate in the protection of environment by substituting the fossil fuels [2].

When energy security and climate change are considered as global challenges for the environment because of the greenhouse effect, it is important to reduce the consumption of energy and emissions. All over the world, the residential and commercial buildings consume about 33% of the final energy and produce the same proportion of greenhouse gas [3]. In Morocco, the annual energy consumption is 0.5 tons that is equivalent to oil per capita, and it increases each year by 4.3%. Concerning electricity, a Moroccan consumes 781 kWh annually that increases each year by 7.8% [8]. The energetic efficiency policy aiming to reducing the energy consumption by 12% by 2020 including the buildings sector, industry and transportation, has been realized by adopting the law 47-09 in 2009 [8].

In the same approach and in order to establish a regulatory framework governing the energy efficiency in the building sector, designing a mathematical model based on the International Performance Measurement and Verification Protocol is a solution to overcome this issue. In fact, the Protocol was introduced in Morocco in November 2015 through a training session offered by the Efficiency Valuation Organization (EVO) [5]. The targeted audience was owners of buildings who wish to measure energy economies generated by their project. Hence,
the implementation of the IPMVP on Al Akhawayn University would be a great opportunity to improve the energy economies especially for the residential life of the students.

By taking sustainable initiatives, Al Akhawayn University will be able to reduce the environmental and economic challenges that include the heating and electric systems. Lately, the university introduced a new lightening system that consumes less electric energy. Yet, when focusing on the residential buildings, the consumption of energy is still somehow high. Thus, using the statistical results of the measurement and verification processes of the international protocol, the mathematical model will be the solution to calculate the savings of the energy consumption.

6.2 PROJECT OBJECTIVES

This capstone project mainly aims to develop a mathematical model of energy consumption in residential buildings regarding the energy savings calculated using the International Performance Measurement and Verification Protocol (IPMVP). During the study, this main objective is detailed to:

- Analyzing the energy data gathered from the Ground and Maintenance Department
- Determining the energy consumption during the baseline and the post-installation periods
- Evaluating the energy consumption before the replacement of light lamps
- Evaluating the energy consumption after the installation of LED lamps
- Analyzing the difference between the two periods of change
- Analyzing the calculations of the energy savings
- Designing a mathematical model for the calculation of energy consumption and its cost
6.3 STEEPLE ANALYSIS

Social

By considering the residential buildings of Al Akhawayn University, the aim of my project is to reduce the energy consumption by residential students to help AUI community to save money and live in a sustainable environment. The awareness of saving energy will then increase as the whole community will take into consideration the importance of improving the economy of Al Akhawayn.

Technical

The main aim of this project is to design a mathematical model that uses the statistical results of the IPMVP for reducing the consumption of energy and determine the energy savings of the residential buildings. Afterwards, Morocco can use the designed model as a simulation to be used for the Moroccan cities.

Economic

My project contributes in the economic development of the country since it aims essentially to reduce the energy savings of consuming electrical energy. Using the IPMVP and the designed mathematical model, Al Akhawayn University will be able to reduce its electricity bills so that it will give the example to all other organizations or universities to implement the mathematical model for the purpose of reducing Moroccan’s dependency on fossil fuels including coal.

Environmental

My project introduces an eco-economic strategy in the context of protecting the environment through applying the methodology of the project that enhances the energetic efficiency and contributes in the sustainable development of residential communities. Hence,
one of the main steps to protect the environment is to save energy that is an abundant, natural and free source.

**Political & Legal**

The Ministry of Energy, Mines, Water, and Environment introduced the Law 47-09 related to the energetic efficiency that supports any action acting positively to the energy consumption regardless of the activity of the sector. My project obeys then by the Law 47-09 as it contributes to increase the energetic efficiency of residential buildings in AUI community.

**Ethical**

Willing to contribute in the protection of the environment, I tried to focus on the idea of giving a value to the ethical fundamentals of environment through introducing a mathematical model that will help us, as human beings, to face the environmental issues by saving energy.

6.4 **LITERATURE REVIEW**

Africa is nowadays living a period of economic growth and transformation on the sustainable development; its population is rapidly increasing, and its savings are amazingly developing and diversifying. Yet, this continuous growth needs a massive investment in the energy field. In fact, Africa has the potential and the ability to make renewable energies the main driver of its growth. As a result, Africa would be considered as a great economic competitor regarding other solutions for energy savings as this can bring about significant advantages in terms of fair development, value creation, energy security, and environmental sustainability [1]. This transformation would happen only if policy makers concert their efforts to implement strategies and mechanisms allowing them to stimulate the investment and to facilitate the development of the sector through relevant policies.
With a population of 83 million today which will reach the 110 million in 2030, and located in the north of Africa and open to the gates of Europe, with a coastline on the Mediterranean and another one on the Atlantic, North Africa (Morocco, Algeria, and Tunisia) occupies a privileged geostrategic location that facilitates the opening to America, Europe, the Middle-East, and Asia. It is endowed with natural varied wealth, solid infrastructure, and especially human quality resources with remarkable intellectual potential. The composition of the Maghreb energy mix is heavily influenced by the total production energy that exceeds far beyond the needs [10]. By country, the situation of fossil fuels is more diverse since Morocco dominates in oil consumption with 74% of the total energy, while the contribution of natural gas is predominant in Algeria with 59% and 45% in Tunisia. However, the consumption of coal in Morocco is limited where it is represents only 18% of the total primary energy consumption. It is the only country in the North African region to operate and still build power plants using coal. At the level of the Maghreb, in 2011, renewable energy accounted for only over 3% of the primary energy consumption including 0.3% for hydropower, 2.7% for biofuels and 0.1% for solar/wind power [13].

With more than 3500 km of coastline, Morocco has significant wind resources. Wind can also be used to decentralized rural electrification as the two projects installed in Moulay Bouzerktoune and Sidi Kaouzi near Essaouira. Moreover, numerous photovoltaic projects were realized in Morocco in the domain of water pumping, telecommunication, decentralized electrification or diverse collective or individual applications in the private and public sectors [3]. For instance, in 2002, a contract relative to the zero rural electrification per solar kits of 16 000 rural households in the provinces of Khemisset, Khouribga, Settat, and Kenitra was signed between the ONE and TEMASOL. Hence, the objective of the strategic plan of development is to increase the energetic dependence to 80% in 2020 which is translated to a reduction of 2.7 billion dirhams of the State budget [11].
Today, the possibilities promoted by the renewable energies are largely unexploited in the MENA region. In fact, the MENA region holds a great part of the renewable energies in the international electrical production, by representing 1% of the hydraulic generation, 0.5% of the electrical production generated from the wind and the sun. In return, the region contributes with up to 6.9% in the international electrical production based on conventional energies that occupies 96.8% of the electrical production.

Hence, Morocco has substantially strengthened the contribution of the renewable energies in the production of electricity since 2009 thanks to the consolidation of the part of the hydraulic in association with the rainfall during the years of 2009 and 2010 [1]. The Moroccan hydroelectric production remains highly variable and unstable from one year to another, but its contribution should increase in the following years with the consumption of the large dams. The largest dams are the dam of Abdelmoumen with a capacity of 350 MW and the dam of M’dez El Menzel with 170 MW [3].

Morocco has also developed the electrical production from wind with a contribution of 2.8% in 2011 compared to 1% in 2005. In this regard, Morocco owns the most developed wind power in the MENA region after Egypt, with a total installed capacity at the end of the year of 2012 of 291 MW³. In parallel, the parts of petroleum and gas are not strengthened to reach 26%
and 16% of the electrical production respectively in 2011 against 17% and 10% only in 2005 [13].

Figure 5.4.2: Graph of evolution of the electrical production in Morocco [1]

The main objective of the energetic efficiency, in the context of a strategic investment and public policy, is the constant need to quantify by a standardized method the results of energetic projects. Hence, the international organization EVO introduced the International Performance Measurement and Verification Protocol (IPMVP) dedicated to developing tools allowing to quantify energetic results. The IPMVP presents a structure and four options of measurement and verification to evaluate the energy savings of a project in a transparent, reliable, and coherent way. It specifies a measurement and verification plan that matches with the fundamental principles of measurement and verification and produces monitoring reports of verifiable savings [6]. The IPVMP is applied to a great variety of facilities including the new buildings, the existing buildings and the industrial processes. The international usage of the IPMVP brings about advantages following the activities of projects that match the recommendations of the protocol. In fact, it improves the reduction of costs of transactions in an eco-energy performance contract because the specifications of the protocol as a basis to conceive the measurement and verification plan of a project can simplify the negotiations of a contract [6]. Also, it gives an international credibility for the monitoring reports of energy savings allowing to increase the value of the project for a buyer. Last but not least, the IPMVP aims to help the national organizations and the industry to promote and realize the effective
management of resources and the environmental objectives in order to increase the credibility of the reported results.

The mathematical model will be implemented for the need of calculating the savings of energy consumption of residential buildings. It will gather the necessary data concerning the electrical power wattage, the number of appliances, the cost of electrical energy, that is monthly paid based on the block tariffs of the National Office of Electricity, and the results of the annual energy consumption with its annual cost. All of these data are used so that the excel solver can present the estimated cost energy savings.

7 METHODOLOGY

My project was done following three main steps. First, when I gathered the data collected from the Ground and Maintenance department, I tried to do a comparative analysis between the data concerning the electrical energy consumed when using the fluorescent lamps in the residential buildings and the electrical energy consumption after replacing the fluorescent lamps with the LED lamps. The second step is to implement the international protocol (IPMVP) using option B since I am studying the modifications done on a specific residential building. By performing a Measurement and Verification Plan, I studied the results using a statistical approach of the factors affecting the energy consumption. Consequently, these results helped me design a mathematical model using Excel that can be used to determine the energy consumption for a residential area. Moreover, the parameters included in the designed model allowed to determine the cost of the energy consumed during a whole year.
8 INTERNATIONAL PERFORMANCE MEASUREMENT AND VERIFICATION

PROTOCOL

8.1 PROCEDURE
The International Performance Measurement and Verification Protocol presents the common practices in measurement, in calculation, and in monitoring the savings realized by projects of energy efficiency or water. It introduces a structure of four options of measurement and verification in order to evaluate the savings of a project in a transparent, coherent and reliable way. The activities of measurement and verification includes the studies concerning the area or the site, the measurement of energy flow or water, the monitoring of independent variables, the calculations and the reports. These activities of measurement and verification can allow to produce reliable and verifiable reports about the generated savings. This protocol requires the preparation of a specific project with and a plan of measurement and verification that is consistent with the terminology of the protocol. The project has to name the option of the IPMVP, the type of monitoring of measurement, the method of analysis used, and the user responsible for the measurement and verification.

The savings of energy, water or demand cannot be directly measured because the savings represent the lack of demand or consumption of energy or water. The savings are rather determined by comparing the consumption measured or the demand before and after the establishment of a project, by configuring the appropriate adjustments for the whole change of condition. The following figure exemplifies the process of evaluating the savings of the energetic history of an industrial boiler before and after the establishment of a measurement of energy conservation in order to recover heat from exhaust fumes. Before the establishment of the project of measurement of energy conservation, the modeling of the reference energy was
studied in order to determine the relationship between the energy consumption and the production. After the installation of the project, this relationship of baseline was used to estimate the quantity of energy that the industry would use each month in the case of the absence of the energy conservation measurement. Consequently, the savings can be determined by calculating the difference between the baseline energy adjusted and the energy that was really measured between the interval readings.

![Energy history of an industrial boiler during the baseline and the post-installation periods](image)

**Figure 7.1.1: Energy history of an industrial boiler during the baseline and the post-installation periods** [4]

### 8.2 THE IPMVP OPTIONS

The IPMVP provides four options to determine the energy savings. The choice among these options involves many considerations including the area of the measurement boundary. This choice depends on whether the savings are to be determined at the level of the site or at the level of a specific change on the site. The four options introduced by the IPMVP are:

#### 8.2.1 Option A: Partially Energy Conservation Measured Isolation:
The savings are determined by the measurement on the site of the essential performance parameters that define the energy consumption of the systems affected by the energy conservation measurement and the success of a project. The frequency of the measurement is extended on a short continuous term according to the measured parameter and the length of the monitoring period. The parameters that are not selected for the measurement on the site are estimated. The evaluations can be based on the historical data or the characteristics of the manufacturer or the judgment of the construction. However, the documentation of the sources or the justification of the estimated parameter is mandatory. The error of the possible savings generated from the evaluations rather than the measurement is also evaluated. This option requires two main steps for the calculations of the savings. First, the calculations of the energy consumption during the baseline and during the monitoring period are done based on the continuous measurements or the short-term parameters of functioning or the estimated values. Second, the calculations should include the periodic and non-periodic adjustments.

8.2.2 Option B: Energy Conservation Measurement Isolation

The savings are determined through the measurement on the site of the energy consumption of the affected systems by the energy conservation measurement. The frequency of measurement is extended on the short continuous term of the parameter measured and the length of the monitoring period. The calculations of the energy savings are based on the measurement of the short or continuous terms of the energy consumption during the baseline and the monitoring period, or on the calculations based to measure the energy consumption including the period and non-periodic adjustments.

8.2.3 Option C: Whole Building Measurement
The savings are determined by measuring the energy consumption at the level of the entire site or a small part of the site. The continuous measurement of the energy consumption or the entire site are done during the monitoring period. The calculations of the energy consumption are done by analyzing the data of the whole building during monitoring period and the baseline. The periodic and non-periodic adjustments are optional to include when using techniques such as simple comparison or regression analysis.

8.2.4 Option D: Calibrated Simulation of Whole Building

The savings are determined by simulating the energy consumption of the whole building. The simulation routines are demonstrated to properly model the energetic performance measure in the building. This option requires normally considerable skills for the calibrated simulation. The calculation of the savings are based on the calibrated simulation of the energy consumption with the hourly and monthly data and the billing or the energy supplier.
The following table gives an overview about the four options by presenting some typical applications for each one.

<table>
<thead>
<tr>
<th><strong>M&amp;V Option</strong></th>
<th><strong>How Baseline is Determined</strong></th>
<th><strong>Typical Applications</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Partially Measured Retrofit Isolation</td>
<td>Projected baseline energy use is determined by calculating the hypothetical energy performance of the baseline system under post-construction operating conditions.</td>
<td>Lighting system where power draw is periodically measured on site. Operating hours are stipulated.</td>
</tr>
<tr>
<td>E. Retrofit Isolation</td>
<td>Projected baseline energy use is determined by calculating the hypothetical energy performance of the baseline system under measured post-construction operating conditions.</td>
<td>Variable speed control of a fan motor. Electricity needed by the motor is measured on a continuous basis throughout the M&amp;V period.</td>
</tr>
<tr>
<td>C. Whole Facility</td>
<td>Projected baseline energy use determined by measuring the whole-building energy use of similar buildings without the ECMs.</td>
<td>New buildings with energy-efficient features are added to a commercial park consisting of buildings of similar type and occupancy.</td>
</tr>
<tr>
<td>D. Calibrated Simulation</td>
<td>Projected baseline energy use is determined by energy simulation of the Baseline under the operating conditions of the M&amp;V period.</td>
<td>Savings determination for the purposes of a new building Performance Contract, with the local energy code defining the baseline.</td>
</tr>
</tbody>
</table>

Table 8.4.1: Overview of the measurement and verification options [4]

### 8.3 Period of Measurement

The periods of measurement are to be chosen based on significant strategies.

- The baseline period is chosen to represent the modes of functioning in the building.

  This period should cover the complete cycle of functioning that includes the maximum and the minimum periods of energy consumption. There should be a clear representation of all conditions of functioning especially in case of employing the same missing data between the baseline period and the monitoring period. The baseline
period should include the periods of time for which the fixed elements and variables are known for the building.

- The monitoring period should cover at least one cycle of normal functioning of the equipment in the building in order to entirely characterize the economic efficiency in all the modes of normal functioning. This period evaluates the energy savings according to the procedure introduced by the IPMVP. However, if the savings match to the IPMVP, they can be used as a background to predict the future savings.

For these reasons, and in order to apply the requirements of the International Performance Measurement and Verification Protocol, the periods chosen for the project were of the same duration and the same months. In fact, the two periods show no missing data concerning the energy measurement and include the same variables and fixed elements of the same buildings studied.

9 MEASUREMENT AND VERIFICATION PLAN

When implementing the International Performance of Measurement and Verification Protocol, the Measurement and Verification Plan of studying the electrical energy consumption of the buildings 28 and 33 was set by determining the data of the energy consumption, the measurement periods, the IPMVP option, and the energy savings of the post-installation period. Therefore, for the residential buildings of Al Akhawayn University the baseline period is chosen to be from 1st November to 31st December 2014, and the post-installation modeling (monitoring) period is set to start from 1st November 2015 to 31st December 2015, as I will consider a period of 61 days each. The data gathered from the Ground and Maintenance department (Building 12) shows the energy consumption during these periods, and they allowed
to calculate the energy savings after the installation of the LED lamps in the residential buildings 28 and 33.

9.1 **Electricity Measurement**

The transportation and distribution network of the national electricity in Morocco is characterized by electrical substations that transport, distribute, and generate electrical power through the infrastructure installed. An electrical substation is an element of the electrical network that transforms and distributes electricity. It raises the voltage of the electrical transmission and brings it down for so that it can be consumed by the users. The electricity that comes to a particular goes first by a transformer station that is known as the electrical station source. Hence, Al Akhawayn University has six electrical substations as shown in the figure. The electrical substantial in Building 12 is the electrical station source that receives two electrical lines from the National Office of Electricity of 22 kV each. The electrical substantial that follows it is the one in Building 3 that transforms the voltage received from 22 kV to 400 V. The cycle continues as the electric power flows through the other substations of Building 38, Building 36, Building 13, and Building 9. The buildings 28 and 33, that we are studying, receive electricity from the electrical substation in Building 3 or known as Station A.
To measure the electricity consumption with accuracy, the voltage, the amperage, and the power factor are measured with one instrument. However, measurement of amperage and voltage is the only one that can adequately define the power in the resistive charges as for the incandescent lamps. By measuring the power, it is important to make sure that the electric wave of the resistive charge is not changed by other devices on the building.

The methods of energy measurement varies from one energy supplier to another. The method of measuring the electric demand on a sub-meter should reproduced the method that the company of electricity uses for billing the meter. For instance, if the company of electricity calculates the maximum demand at 15 minutes intervals, then the meter should be installed to save the data for the same 15 minutes intervals. Nevertheless, if the company uses a mobile range for saving the data of the electric demand, the recording device should have the similar capacities. After processing the data based on the intervals of the electric company, they should be converted to time data for further analysis. For Al Akhawayn Univeristy, the metering
measurement is done by hour and recorded from the electrical bridge of each substation. The recorded data shows the apparent energy in kVAh, the active energy in kWh, and the reactive energy in kVARh with the estimated errors of measurement and the time difference between each measurement. The data considered for this capstone project was the active energy in kWh. In order to determine the energy consumed during each hour, a simple calculation was done. In fact, the energy consumed during an hour $T$ is equal to the difference between the energy measured at the previous hour and the energy measurement during the concerned hour $T$.

### 9.2 Energy Data

The data used in the capstone project was collected from the Ground and Maintenance department. It shows the energy consumption of electricity system in the buildings 28 and 33. The building 28 has an area of 300 m² and is composed of 13 rooms with 10 occupants, and the building 33 has an area of 400 m² and is composed of 53 rooms with 100 occupants. The two buildings have a common power meter, so the activation energy was measured by hour during the whole functioning periods. Thus, the calculations of the activation energy were done to determine the energy consumption per day. The data selected for the capstone project depends on the baseline and the post-installation periods. The maintenance department of the university changes the lighting system by replacing the fluorescent lamps of 20W by the LED lamps of 10W. This change was done in November 2015. Therefore, the selection of the baseline and post-installation periods were done based on this change. The baseline period is then the two months of November and December 2014; whereas, the post-installation period is the two months of November and December 2015. The following table shows the calculated electrical energy consumed per day during the 61 days of the baseline period.
<table>
<thead>
<tr>
<th>Days</th>
<th>Energy Consumed (kWh)</th>
<th>Days</th>
<th>Energy Consumed (kWh)</th>
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<tbody>
<tr>
<td>1</td>
<td>385,398</td>
<td>31</td>
<td>684,261</td>
</tr>
<tr>
<td>2</td>
<td>401,409</td>
<td>32</td>
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<td>54</td>
<td>455,515</td>
</tr>
<tr>
<td>25</td>
<td>483,691</td>
<td>55</td>
<td>472,743</td>
</tr>
<tr>
<td>26</td>
<td>479,508</td>
<td>56</td>
<td>417,171</td>
</tr>
<tr>
<td>27</td>
<td>554,375</td>
<td>57</td>
<td>372,477</td>
</tr>
<tr>
<td>28</td>
<td>639,289</td>
<td>58</td>
<td>330,324</td>
</tr>
<tr>
<td>29</td>
<td>600,379</td>
<td>59</td>
<td>400,387</td>
</tr>
<tr>
<td>30</td>
<td>625,848</td>
<td>60</td>
<td>374,695</td>
</tr>
<tr>
<td></td>
<td></td>
<td>61</td>
<td>394,285</td>
</tr>
</tbody>
</table>

Table 9.2.a: Table of daily energy consumed during the baseline period

Similarly, the table below shows the energy consumption measured per day during the post-installation period that were calculated using the measurement data collected from the Ground and Maintenance Department of Building 12.
Table 9.2.b: Table of daily energy consumed during the post-installation period

<table>
<thead>
<tr>
<th>Days</th>
<th>Energy Consumed (kWh)</th>
<th>Days</th>
<th>Energy Consumed (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>476,625</td>
<td>31</td>
<td>558,469</td>
</tr>
<tr>
<td>2</td>
<td>527,782</td>
<td>32</td>
<td>546,312</td>
</tr>
<tr>
<td>3</td>
<td>543,437</td>
<td>33</td>
<td>577,906</td>
</tr>
<tr>
<td>4</td>
<td>524,438</td>
<td>34</td>
<td>592,579</td>
</tr>
<tr>
<td>5</td>
<td>494,172</td>
<td>35</td>
<td>565,203</td>
</tr>
<tr>
<td>6</td>
<td>423,14</td>
<td>36</td>
<td>548,781</td>
</tr>
<tr>
<td>7</td>
<td>419,156</td>
<td>37</td>
<td>574,906</td>
</tr>
<tr>
<td>8</td>
<td>425,657</td>
<td>38</td>
<td>625,438</td>
</tr>
<tr>
<td>9</td>
<td>484,109</td>
<td>39</td>
<td>597,218</td>
</tr>
<tr>
<td>10</td>
<td>513,766</td>
<td>40</td>
<td>574,75</td>
</tr>
<tr>
<td>11</td>
<td>505</td>
<td>41</td>
<td>603,157</td>
</tr>
<tr>
<td>12</td>
<td>494,343</td>
<td>42</td>
<td>578,593</td>
</tr>
<tr>
<td>13</td>
<td>484,719</td>
<td>43</td>
<td>542,844</td>
</tr>
<tr>
<td>14</td>
<td>441,672</td>
<td>44</td>
<td>559,594</td>
</tr>
<tr>
<td>15</td>
<td>455,328</td>
<td>45</td>
<td>651,312</td>
</tr>
<tr>
<td>16</td>
<td>480,25</td>
<td>46</td>
<td>602,782</td>
</tr>
<tr>
<td>17</td>
<td>484,625</td>
<td>47</td>
<td>543,937</td>
</tr>
<tr>
<td>18</td>
<td>475,844</td>
<td>48</td>
<td>515,985</td>
</tr>
<tr>
<td>19</td>
<td>505,562</td>
<td>49</td>
<td>400,5</td>
</tr>
<tr>
<td>20</td>
<td>515,063</td>
<td>50</td>
<td>345,39</td>
</tr>
<tr>
<td>21</td>
<td>456,781</td>
<td>51</td>
<td>360,141</td>
</tr>
<tr>
<td>22</td>
<td>464,328</td>
<td>52</td>
<td>370,437</td>
</tr>
<tr>
<td>23</td>
<td>574,703</td>
<td>53</td>
<td>384,844</td>
</tr>
<tr>
<td>24</td>
<td>602,907</td>
<td>54</td>
<td>327,391</td>
</tr>
<tr>
<td>25</td>
<td>579,437</td>
<td>55</td>
<td>335,937</td>
</tr>
<tr>
<td>26</td>
<td>649,266</td>
<td>56</td>
<td>347,813</td>
</tr>
<tr>
<td>27</td>
<td>601,922</td>
<td>57</td>
<td>353,843</td>
</tr>
<tr>
<td>28</td>
<td>528,703</td>
<td>58</td>
<td>378,657</td>
</tr>
<tr>
<td>29</td>
<td>522,172</td>
<td>59</td>
<td>365,656</td>
</tr>
<tr>
<td>30</td>
<td>576,031</td>
<td>60</td>
<td>384,219</td>
</tr>
</tbody>
</table>

9.2.1 Baseline Energy Data

From the hourly energy data gathered, I could calculate the daily energy consumed of the lighting in the two buildings 28 and 33. During the baseline period, the highest energy consumption noticed was 779.72 kW, and the lowest energy consumption noticed was 330.32
kW. Thus, the average energy consumed is 543.18 kW. The following figure shows the results of the energy calculations during the baseline period of November and December 2014.

![Baseline Energy Consumption](image)

**Figure 9.2.1: Graph of baseline energy consumption**

### 9.2.2 Post-Installation Energy Data

Performing the same daily energy calculations for the post-installation period of November and December 2015, the results showed that the highest energy consumed was 651.31 kW, and the lowest energy consumed was 327.39 kW. Hence, the average energy consumption during this period is 496.64 kW. The following figure shows the results of the energy consumption during the post-installation period.
9.2.3 Results Analysis

From the two graphs, we can notice the difference in the lighting energy consumption during the two periods. After the replacement of the fluorescent lamps by the LED lamps, the consumption of energy decreased which means that the project increased the profitability of the residential campus at Al Akhawayn University. In fact, the change of the lighting system was performed for economic and saving energy purposes. In fact, the fluorescent lamps are used for a stable power of electricity, but they resent the low temperatures which makes a poor performance in winter conditions. In this case the light bulbs should be replaced by another type of lamps. Moreover, their electronic system does not support certain environmental outdoor conditions such as humidity and exposure to sunlight. In the tube of the fluorescent lamps, there are fluorescent powders and a mercury-based gas that are considered as hazardous waste for the environment. For these reasons, Al Akhawayn University replaced the fluorescent lamps by the LED lamps that have many advantages for the residential campus. The LED lamps
have the greatest lifetime compared the other technologies, so the purchase or replacement of a LED lamp would be less frequent, which improves the profitability of the investment. Also, they have a much higher energy efficiency than conventional lamps; thus, the majority of lamps for home lighting today offers a satisfactory quality of light as they consume up to 12 Watts. The LED bulbs reach a maximum level of brightness from the ignition. In fact, they instantly emit the desired light output, without warming up, which may be advantageous for specific applications such as corridors. They operate at very low voltage and even under low temperatures, which can be an advantage for electrical safety in residential buildings. With a warming of only 32°C, the LEDs contain no mercury and are largely recycled as non-hazardous waste. Also, they do not heat up as much as fluorescent lamps (70 °C). Last but not least, they are insensitive to shock, making them more robust than other lighting sources.

9.3 Calculations Adjustments

The measurement of the residential buildings in Al Akhawayn University campus is done on the short term period as it will be based on the monthly data. The energy consumption of both the referential (baseline) and the monitoring (post-installation) period was calculated using the following equation:

\[
\text{Energy Savings} = \text{Baseline Energy Use} - \text{Post-Installation Energy Use} +/\text{- Adjustments}
\]

The adjustments are calculated from the physical identifiable facts concerning the elements reacting to the energetic needs of the equipment in the measurement boundaries. There are two possible types of adjustments. The periodic adjustments include the factors reacting on the energy that are presumed to sometimes change during the monitoring period as the external temperature or the volume of production. The non-periodic adjustments include the factors reacting on the energy that habitually do not change such as the size of the building, the
functioning of the equipment installed, and the number or type of occupants. However, for the option B of the IPMVP, and regarding the placement of the measurement boundary and the length of the monitoring period or the period between the measurement during the referential and the monitoring periods, there is a possibility of not taking into account the adjustments either periodic or non-periodic. Hence, the equation becomes:

\[
\text{Energy Savings} = \text{Baseline Energy Use} - \text{Post-Installation Energy Use}
\]

In fact, for studying the residential buildings 28 and 33, adjustments that may affect the energy savings equation are the outside temperature that is related to the sunny days, the area of the two buildings, and the residential occupancy. However, due to the impossibility to determine the outside temperature during the baseline period of November and December 2014 and the exact number of residents in the buildings during the same period, and due to the length of the periods that are of two months only, the adjustments were not considered. Moreover, the study of the buildings is done as if they were only one building because the metering measurement is done for both of the two buildings 28 and 33. Thus, the area to take into account is the total sum area of the two buildings. But, the two buildings differ in the area as the rooms are not of the same size and characteristics from one building to another. In fact, Building 28 is a residence containing apartments only; whereas, Building 33 is a residence composed of single rooms, double rooms, and studios. Hence, each of these residential buildings has its own area aspect for the specific room. This is why, the factor of area is also not included as one the non-period adjustments in the calculation of the energy savings.
9.4 Measurement and Verification Plan: Building 28 and Building 33

9.5 M&V Option

The option B approach will be used since the energy savings are determined by measuring the whole residential buildings of the energy consumption of the affected systems by the measurement of the energy conservation. The frequency of measurement is extended on the short to the continuous terms according to the planned variations and the length of the monitoring period.

9.5.1 Baseline Period

The measurement of the lightening in the buildings of 28 and 33 was recorded in the Ground and Maintenance Department during the baseline period of the two months of November and December 2014 before the installation of the LED bulbs.

<table>
<thead>
<tr>
<th>Meter</th>
<th>Start Date</th>
<th>End date</th>
<th>Interval</th>
<th>Points</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED Bulbs</td>
<td>Nov 1, 2014</td>
<td>Dec 31, 2014</td>
<td>Days</td>
<td>61</td>
<td>kWh</td>
</tr>
</tbody>
</table>

Table 9.5.1: Specifications of the baseline period

9.5.2 Post-Installation Modeling Period

The measurement of the lightening in the buildings of 28 and 33 was recorded in the Ground and Maintenance Department during the post-installation period during the two months of November and December 2015 after replacing the fluorescent lamp by the LED bulbs.

<table>
<thead>
<tr>
<th>Meter</th>
<th>Start Date</th>
<th>End date</th>
<th>Interval</th>
<th>Points</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED Bulbs</td>
<td>Nov 1, 2015</td>
<td>Dec 31, 2015</td>
<td>Days</td>
<td>61</td>
<td>kWh</td>
</tr>
</tbody>
</table>

Table 9.5.2: Specifications of the post-installation period
9.5.3 Calculating the Savings

By adjusting the baseline and the post-installation energy use, the savings are estimated for each source of energy. By selecting the right weather conditions of the climate zone for the residential buildings, the hourly data was gathered for each day. The weekends and the holidays were recognized and marked with as a workday variable. Hence, for each source of energy, both the monthly baseline energy use and the post-installation energy use were deliberated through the following calculation:

\[
\text{Energy Savings} = \text{Baseline Energy Use} - \text{Post-Installation Energy Use}
\]

\[
\text{Energy Savings} = 33\,134.113 - 30\,295.094
\]

\[
\text{Energy Savings} = 2\,839.019 \text{ kWh}
\]

<table>
<thead>
<tr>
<th>Meter</th>
<th>Monthly Baseline Use</th>
<th>Monthly Post-Installation Use</th>
<th>Savings</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED lamps</td>
<td>33,134.113</td>
<td>30,295.094</td>
<td>2,839.019</td>
<td>kWh</td>
</tr>
</tbody>
</table>

Table 9.5.3: Energy savings results

9.5.4 Graph Analysis

By gathering the results of both the baseline and the post-installation periods, the historical energy graph was drawn to emphasize on the significant difference of the energy consumption during the two periods. In fact, the graph shows the two curves of the baseline and post-installation periods. The blue curve refers to the baseline energy consumption; whereas, the red curve represents the post-installation energy consumption. Hence we can notice a decrease in energy consumption after the installation of the LED lamps over the same period of time and season.
The variations of the energy consumption on the graph are explained by different factors in the residential buildings. In fact, the residents of the buildings consume the electrical energy according to their personal usage that is related to their presence in their rooms in the buildings, to the sunny days of the winter season during the two months of November and December, and to the location of the rooms regarding the position of the sun. All to say, that the occupancy and the climate change plays an important role in the fluctuations of the electric energy consumption. It is without a doubt that the important factor affecting the consumption of energy is the occupancy of the residents in the buildings. In fact, there is a clear correlation between the electricity consumption and the occupancy. For example, during the weekends and the holidays, the energy consumption is noticed to be less than the normal days when the students are on campus. For instance, the 6th of November is a day off since Morocco celebrates the Green March. In 2015, the 6th of November was a Friday, and the energy consumption is noticed to be 423.14 kWh which is the lowest value during the month of November. Moreover, as we
can see on the graph below, it can be noticed that the energy consumption decreases during the last days of December. This is due to the fact that the Fall semester ends before the 10 last days of December; thus, the occupancy decreases as well as the lighting usage as seen in the figure below of the monitoring period.

Figure 9.5.4b: Graph of energy consumption in December 2015

10 Modeling Energy Consumption

10.1 Overview

According to the results of the International Performance Measurement and Verification Protocol applied on the data of the energy consumed in the residential buildings of Al Akhawayn University, I was able to design a model for the calculation of the electrical energy consumption in a residential area. In fact, the user of the model can calculate the quantity of energy consumed and the cost of its consumption for the appliances of the residency. The data needed is the wattage of each appliance with the number of usage hours of the devices.
10.2 Objectives

The purpose of the model is to determine:

- The annual energy consumption of the appliances in a residency
- The annual energy cost during a year in a residency

10.3 Description

The model is designed on Excel. The first sheet of the Excel model contains the user manual that presents the instructions to follow when entering the data. The following sheets concern the calculations done over the 12 months of the year. Then, the final sheet gathers the results of the calculations by presenting a graph of the variations of the electric energy consumption and its cost during the whole year.

10.4 User Manual

The user of the mathematical model is requested to enter three inputs: the hours of usage of the electric appliances, the wattage of each appliance, and the number of items of the appliances. The inputs should be entered in the blue boxes. The model generates the results of the calculations of the energy consumed per day for appliance in order to present the total energy consumed per month. The final sheet of the Excel model presents the graphical results of the annual energy consumption as well as an estimation of the annual cost energy. The model contains 12 sheets for each month. Thus, the user has to enter the inputs for each month in order to complete the calculations of the whole year.

The model divides the residency by the type of rooms according to the different electrical appliances found at home. Among the rooms included in the model, there is the kitchen that gathers the following appliances:
- Oven
- Microwave
- Refrigerator
- Stove
- Washing Machine
- Dishwasher
- Toaster
- Coffee Maker
- Blender
- Deep Fryer
- Kettle
- Mixer
- Exhaust Hood

The following room is the bathroom that mentions the:

- Hair Dryer
- Towel Dryer
- Electric Toothbrush

The living room is then counted in with the following devices:

- TV
- TV Channel Box
- Computer
- Phone Charger

The last room of the model designed is the bedroom that comprises:
The lamps of the residency are included in each room as well as the ones of the corridors in order to facilitate the calculations for each room in the building.

10.5 Model Calculations

The model performs the calculations of the monthly energy consumption and the annual cost energy. The monthly energy consumption is calculated through few steps. The first calculation is the multiplication of the usage hours of the appliance by its wattage and the number of items of the appliance at home, as in the following formula:

\[ \text{Hours used} \times \text{Wattage} \times \text{Quantity} = \text{Energy (Wh) per day} \]

The resulted energy is then converted to the kWh:

\[ \frac{\text{Energy (Wh) per day}}{1000} = \text{Energy (kWh)} \]

The energy model calculates then the energy consumed in a month depending on the number of days for each month.

- For the months of January, March, May, July, August, October, and December, it multiplies the converted energy in kWh by 31 days:

  \[ \text{Monthly Energy} = \text{Energy (kWh)} \times 31 \]

- For the months of April, June, September, and November, it multiplies the converted energy in kWh by 30 days:
Monthly Energy = Energy (kWh) x 30

- For February, it multiplies the converted energy by 28 days:

Monthly Energy = Energy (kWh) x 28

On the other hand, the cost of energy consumption is calculating regarding the pricing of the kWh presented by the National Office of Electricity. In fact, the ONE introduces the pricing in block tariffs that divides the electricity price into six blocks by including the value-added tax that stands at 14%:

<table>
<thead>
<tr>
<th>If the monthly energy consumption is</th>
<th>The price of the kWh is (in MAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 0 and 100 kWh</td>
<td>0.9010</td>
</tr>
<tr>
<td>Between 101 and 150 kWh</td>
<td>1.0370</td>
</tr>
<tr>
<td>Between 151 and 200 kWh</td>
<td>1.0370</td>
</tr>
<tr>
<td>Between 201 and 300 kWh</td>
<td>1.1282</td>
</tr>
<tr>
<td>Between 301 and 500 kWh</td>
<td>1.3351</td>
</tr>
<tr>
<td>Greater than 500 kWh</td>
<td>1.5420</td>
</tr>
</tbody>
</table>

Table 10.5: Table of pricing of the kWh by blocks [14]

Hence, using these block tariffs, the IF function was performed on the Excel model to calculate the energy cost, as the following:

**IF (condition; value if true; value if false)**

For each appliance, the IF function was used with this resulting formula from the above table:

IF (0 ≤ Energy (kWh) per month ≤ 100; Energy (kWh) per month x 0.9010;

IF (101 ≤ Energy (kWh) per month ≤ 150; Energy (kWh) per month x 1.0370;

IF (151 ≤ Energy (kWh) per month ≤ 200; Energy (kWh) per month x 1.0370;
IF (201 ≤ Energy (kWh) per month ≤ 300; Energy (kWh) per month x 1.1282;

IF (301 ≤ Energy (kWh) per month ≤ 500; Energy (kWh) per month x 1.3351;

IF (Energy (kWh) per month ≥ 501; Energy (kWh) per month x 1.5420; “Error”))))

Then, the monthly energy consumption and its monthly cost is summed up with the function SUM to get the total of both amount.

10.6 Results

The results sheet presents the annual energy consumption in a table that gathers the monthly consumption during the whole year. Similarly, the annual energy cost is presented in a table that brings together the monthly energy costs. These tables are used as a data for the scatter plot that demonstrates the variations of the annual energy consumption and its cost. Obviously, the two graphs will have the same shape of the curve since the calculation of the cost depends on the energy consumption, yet with different values, as the user can analyze the energy consumption for his residency according to the factors that affect it.

10.7 Simulation

The first sheet of the Excel model represents a manual user that gives a small description of the model and instructions to follow. It explains how the calculations of the energy consumption per day and per month are done; as well as, it presents the pricing of one kWh for the calculations of the cost of the energy consumed per month.
The purpose of this model is to help you determine:
- the consumption of electrical appliances in your home
- the cost of electrical energy consumption
of a residential building (e.g. your home for each month during one year).

The energy consumption for each month is calculated using three inputs from the user:
- The hours used of the appliance
- The wattage of the appliance
- The quantity of the appliances

The energy consumed is then calculated per day with the following formula:

\[ \text{Hours Used} \times \text{Wattage} \times \text{Quantity} = \text{Energy (Wh) per day} \]

Then converted to kWh by dividing the result by 1000.
To calculate the energy consumed in each month,
the converted energy to kWh per day is multiplied by the number of days for each month.

The cost of the energy consumption is calculated according to the pricing consumption brackets
presented by the National Office of Electricity.
The National Office of Electricity classifies the pricing of the monthly consumption by 6 categories:

<table>
<thead>
<tr>
<th>If the monthly energy consumption is</th>
<th>The price of the kWh is</th>
</tr>
</thead>
<tbody>
<tr>
<td>between 0 and 100 kWh</td>
<td>0.901</td>
</tr>
<tr>
<td>between 101 and 150 kWh</td>
<td>1.037</td>
</tr>
<tr>
<td>between 151 and 200 kWh</td>
<td>1.037</td>
</tr>
<tr>
<td>between 201 and 300 kWh</td>
<td>1.1232</td>
</tr>
<tr>
<td>between 301 and 500 kWh</td>
<td>1.3351</td>
</tr>
<tr>
<td>greater than 500 kWh</td>
<td>1.542</td>
</tr>
</tbody>
</table>

The results sheet represents the annual energy consumption and its annual cost by graphs.

Notes:
Enter the values in the blue cells only.

**Figure 10.7a**: Excel sheet of manual user of the model

The following figure is a simulation of the energy model. The user has to enter the inputs of the hours used of the appliances in his home, the wattage power of the appliances, and the number quantity of the items. The blue cells are the cells of inputs. The white cells are computed automatically from the model to get the results in the green and red cells. The green cell is the resulted calculation of the energy consumed in the month of the specific appliance, and the red cell gives the result of the cost energy consumption of the appliance.
Figure 10.7b: Excel sheet of January month energy consumption and its cost

By filling the whole cells of all the months, the results are showed in a graph as below. The energy consumption graph shows the consumption of electricity during one whole year; whereas, the second graph shows its cost.
11 CONCLUSION

In the context of improving the energetic efficiency, I had the opportunity to develop a mathematical model on Excel that calculates the electrical energy consumption for a residential building. To do so, I had first to present an overview about the development of renewable energies and to present the Moroccan situation in the electrical production based on energies. This helped me consider the International Performance Measurement and Verification Protocol.
that is not yet used in the Moroccan companies. This protocol presents a measurement and verification plan that calculates the energy savings of two periods. The procedure of the protocol was followed to determine the baseline period, the post-installation period, the measurement boundaries, and the energy data. All of these parameters were the key to calculate the energy savings of two residential buildings that have common metering measurement at Al Akhawayn University. The analysis of the results allowed to consider the factors that affect the variations of the electrical energy consumption during the two periods. Finally, by taking into account the outcomes of the implementation of the IPMVP on the residential buildings on campus, I was able to design an Excel model that calculates the energy consumption of a residency. The limitations that I have faced during the preparation of my capstone project were the lack of data from the Ground Maintenance of Building 12 concerning the outside temperatures of the baseline and post-installation periods, as they were not saved in the records. Also, the housing department was not able to provide me information about the occupancy during the two periods since they do not record the number of students leaving or entering their rooms during the off days or break periods. Despite this lack of information, I was able to analyze the factors that affect the energy consumption based on the energetic efficiency background and the literature review.
12 References


CHAPITRE PREMIER
DEFINITIONS

Article premier : Au sens de la présente loi, on entend par :

1. Efficacité énergétique : toute action agissant positivement sur la consommation de l’énergie, quelle que soit l’activité du secteur considéré, tendant à :
   - la gestion optimale des ressources énergétiques ;
   - la maîtrise de la demande d’énergie ;
   - l’augmentation de la compétitivité de l’activité économique ;
   - la maîtrise des choix technologiques d’avenir économiquement viable ;
   - l’utilisation rationnelle de l’énergie ;
   et ce, en maintenant à un niveau équivalent les résultats, le service, le produit ou la qualité d’énergie obtenue.

2. Performance énergétique : est la quantité d’énergie effectivement consommée ou estimée dans le cadre d’une utilisation standardisée à partir de valeurs de référence.


4. Entreprises de services énergétiques : toute personne morale qui s’engage vis-à-vis d’un établissement consommateur d’énergie à :
   - Effectuer des études visant à réaliser des économies dans la consommation de l’énergie ;
   - Préparer un projet qui réalise des économies d’énergies et veiller à son exécution, sa gestion, son suivi et éventuellement son financement ;
   - Garantir l’efficacité du projet dans le domaine de l’économie d’énergie.