MATHEMATICAL MODELING OF ENERGY CONSUMPTION OF A TERTIARY BUILDING

Capstone Report

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ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to all those who provided me the possibility to complete this project. A special gratitude I give to my two supervisors: Dr. Hassan Darhmaoui and Dr. Naeem Nisar Sheikh who invested their time, efforts and resources in guiding me in achieving my goal. I would like to thank Mr. Yassine Alj for providing me with the opportunity of working on this project and for his continuous assistance.

I would also like to acknowledge Dr. Abdelmounaim Lahrech for his precious suggestions and advice. Finally, to Selma Baaki -my teammate- thank you for your much appreciated help and good luck with your final presentation and your future plans.
ABSTRACT

The objective of this capstone is to develop a mathematical model to verify and measure the energy consumption in a tertiary building by developing a baseline energy consumption.

To come up with this mathematical model, we are going to refer to the International Performance Measurement and Verification Protocol (IPMVP). This international protocol contains the exact guidelines and principles to successfully measure and verify the savings after the implementation of an energy conservation measure. We will need to develop an adjusted baseline energy use using the mathematical model which correlates the actual baseline energy data (historical energy) with the independent variables (occupancy, weather, etc.) during the pre-retrofit period. Then, each independent variable is inserted into the baseline mathematical model to produce the adjusted baseline energy consumption. Finally, the difference between the modeled energy and the actual energy usage is the savings (Avoided Energy Use).

In order to find the correlation between the baseline energy data and the independent variables we need to use statistical methods specifically Least Squares Method.
INTRODUCTION

Morocco depends on imports for 91% of energy supply\(^1\). This import dependency is particularly serious calls for actions to be taken. Energy management projects should be promoted and encouraged. In the case of entities and facilities that have already taken part of such projects and invested in energy efficiency projects, we need to quantify their contribution.

In this context, the International Performance Measurement and Verification Protocol (IPMVP) proves useful. IPMVP is created by the Efficiency Valuation Organization (EVO). The protocol has as a purpose to standardize the quantitative methods to measure and manage the energy efficiency\(^2\). Hence, to know how much an Energy Conservation Measure (ECM) has saved, the protocol provides guidelines to decide on a specific M&V plan and measure savings from the implementation of an ECM.

Since we are supposed to work on a tertiary building, we have a university administrative building in Agadir as our sample building that we will use its energy data. ECO TAQA Company will provide us with the electricity consumption of this facility. Using this data, we will develop the mathematical model that will help us measure and verify the energy savings of the university campus on their investment in specific energy conservation measurements.

Throughout this report, we will depict the mathematical model and the process through which we developed it following this outline:

- Literature Review
- Methodology
- Analysis
- Energy Modeling
- Recommendations
LITERATURE REVIEW

STEEPLE Analysis

1. Societal

The M&V ensures public approval of energy management projects. This will encourage people invest in energy saving projects. It will also shed the light on the benefits of M&V such us the reduction of environmental degradation.

2. Technical

The technical scope of this project is to follow a process of identifying and metering energy conservation measures. It requires operational activities to take place at certain points along the process such as visual inspection where we are supposed to view and verify the installation of the ECM. Also, we will analyze the data gathered in order to develop the baseline energy consumption. Thus, the mathematical model will be useful for savings measurement. It can be used by anyone who would like to assess their saving after the installation of an ECM.

3. Environmental

The international protocol offers guidelines to calculate energy savings before and after the implementation of an ECM. Thus, it can help realize decrease of greenhouse gases emissions. Also, it helps documenting the reduction and recognizing the ECMs as an energy management strategy.$^2$

Thus, we might broaden the scope of the project and include the guidelines dictated by the 3\textsuperscript{rd} volume of the international protocol, we will be able to account for the reductions of emissions too.
4. Ethical

The M&V plan obeys to accuracy, repeatability and transparency\(^2\). The final reports should specify the details of how the calculations were made. Also, they should contain information about metering conditions and how the data was gathered and how it will be used. So, all the stakeholders get access to a report where the option chosen is clearly stated, the calculations are shown and the variables are defined. All of this to ensure the transparency of the measurement and verification plan and to apply the 7 principles of M&V plan which are: general, accurate, complete, conservative, consistent, relevant and transparent\(^2\).

5. Political

In Morocco, energy sources are few and energy is expensive. Hence, these kind of energy management projects promote efficient use and deployment of energy sources. The goal is to slow down and stop the slide of the country towards energy poverty. Even more, it gives the government a chance to prepare for alternative sources of energy.

6. Legal

No legal aspects of the project have been identified.

7. Economic

The stakeholders in any energy project want to know the value of the savings and the payback period of the project. Hence, the measurement and verification protocol provides the investors with the accurate energy savings. IPMVP also promotes investments in energy and water projects by offering: the documentation of techniques to evaluate the efficiency of the project for the stakeholders\(^2\). It also contains different methods to determine savings for an
individual ECM or for the whole facility. Finally, it is applicable to different types of facilities such as commercial, residential, industrial, etc.

So in this project, the mathematical model will help the investors to check the savings generated after the investment in an energy project.

Background

Terms:
These terms are defined in the IPMVP literature review

- **Adjusted baseline energy**: The energy use of the baseline period adjusted to include the influence of different operating conditions.
- **Baseline energy**: The energy consumption during the baseline period without adjustments.
- **Baseline period**: the period chosen to represent operation of the facility before the implementation of an ECM
- **Energy Conservation Measure (ECM)**: an action taken to increase the energy efficiency of a facility or equipment.
- **Degree days**: the measure of the heating or the cooling load on a facility created by outdoor temperature. A reference temperature is chosen to reflect the temperature at which heating or cooling are no longer need. The difference between the outdoor temperature and the reference temperature is the value of heating or the cooling degree days.
- **Routine adjustments**: any factor that is affecting energy on a routinely basis during the reporting period such as weather and production units
▪ **Non-routine adjustments**: factors which aren’t expected to change like the operation of equipment.

1. **Options of the M&V Plan:**

   IPMVP provides four options to calculate savings: options A, B, C and D². The choice of the option depends on the nature of the project and the availability of the data.

   ✓ **Option A**: key parameter measurement (estimate some and measure some) For instance, measure the efficiency of the newly installed appliance and estimate operating hours.

   ✓ **Option B**: Total measurement of the applicable system energy use separately from the rest of the facility. Both options A and B are for the measurement of energy use (metering) of systems newly implemented.

   ✓ **Option C**: measure energy use of the whole facility

   ✓ **Option D**: calibrated simulation of components or the whole facility. It is used in the absence of the baseline data. It is expensive to use and requires deep knowledge in the field of calibrated simulation.

2. **Avoided Energy Use vs. Normalized Savings:**

   The following equation is illustrated by graph 1:

   \[
   \text{Energy Savings} = \text{Baseline Energy Use} - \text{Post-Retrofit Energy Use} \pm \text{Adjustments} \quad (1)
   \]
**Figure 1**: Adjusted Baseline Energy & Measured Energy (Monitoring and Verification: Verifying your Energy Savings, by Ian Wilms, 2016, retrieved from http://www.energyadvantage.com/blog/2010/02/monitoring-verification-verifying-energy-savings/)

In the adjusted savings model, the baseline energy use is adjusted to reflect “normal” operating conditions. The reporting period energy use is adjusted to reflect what would have occurred if the facility had been equipped and operated as it was in the baseline period under the same “normal” set of conditions.
METHODOLOGY

Energy savings are calculated by comparing the energy use before and after the implementation of an energy conservation measure (ECM).

1. **Choosing the option:**

Since we have energy data of a university campus as a whole, we will use Option C of the protocol to proceed with the determination of savings.

2. **Overview of The Process:**

![Figure 2: Process of Measurement & Verification Plan](image)

2.1. **Baseline data gathering:**

The protocol for Measurement and Verification is applicable in facilities that have already implemented an ECM. Thus, we need to find a tertiary building that meets the previous condition and willing to provide us with their electrical bills before and after the retrofit. They should also be willing to provide us with data about the number and power usage of their appliances along with the operating hours of each. Besides, we will need information about the occupancy of the facility.
2.2. Baseline data analysis:

We can then move to the baseline data analysis. We will need to use linear regression as a statistical method. Its objective will be to evaluate the quality of the available data and the correlation between specific sets of data (e.g. relationship between electrical consumption and the occupancy of the building). These variables might have a direct impact on energy use. The consumption rate in a specific unit period will then differ than the other. For instance, these independent variables might be taken into account in the adjustment:

- Weather adjustment: degree days or hourly dry-bulb are two independent variables that might be affecting the energy consumption².

- Occupancy adjustments: the energy use differs from the peak periods of the day where the consumption is at its maximum to the rest of the day when the energy usage is normal or low⁴.

- Day-type adjustments: weekdays and weekends are also modeled to check the correlation between the type of days and the increase or the decrease of energy use².

2.3. Modeling of baseline energy

Least squares regression is used to describe the correlation between the energy consumption per unit of period and the independent variables⁴. After doing the regression and calculating the variables linking the energy consumption with the variables during the pre-retrofit period, we can finally calculate the adjustments that are the difference between the energy consumption before the implementation of ECM and the modeled energy use. These adjustments are either routine or non-routine ones (you can refer to the background part for more details). The adjustments can finally be used to calculate the exact value of savings.
2.4. Calculation and reporting of energy savings

Using equation (1), we can determine the savings by comparing the actual energy use and the baseline energy use. The savings can be expressed in energy units and pricing units taking into consideration the price rates of energy depending on time of the day. For reporting the results, all the data used in the generation of baseline energy and the savings is presented through graphs and detailed reports to reflect the transparency and accessibility of the M&V process. The report should contain the savings report and the baseline fit report.
ANALYSIS

Introduction

To develop the mathematical model that would describe the energy consumption of a certain facility, we need to use a statistical tool. In our case, we will be using least squares linear regression.

Regression analysis describes the relationship between independent and dependent variables. It presents these relationships as mathematical models. In our case, the independent variable is the energy use; specifically, electrical consumption. For the independent variables, they are factors that might be affecting the energy use. These factors are weather related like the outdoor temperature, or degree days. The independent variables might also be the size, area or occupancy of the facility. Thus, the regression analysis is used to measure and verify energy savings after the implementation of an energy conservation measure.

Building the Model

The energy use can be adequately described by mathematical models that relate the consumption to any factors that affect it. The model of linear regression is of the following form:

\[ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + e \quad (2) \]

where \( Y \) is the dependent variable

\( x_n \) (n=1,2,\ldots): independent variables

\( \beta_n \) (n=1,2,\ldots): regression coefficients
$\beta_0$ regression intercept

e: residual error

The Least Squares Method is used to develop values $b_n$ estimates of the model parameters $\beta_n$ which gives us the estimated regression model:

$$y = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n$$  \hspace{1cm} (3)

This model can be used to estimate the value of $y$. We only need a set of $x$ values. In our case, the model will help us to estimate the future energy use or the energy consumption after the retrofit.

- An Example

\textbf{Figure 3:} Energy Consumption Vs. Average Monthly Outside Temperature


$(\text{Base load})\beta_0 + (\text{coefficient of } T \text{ sensitivity}) \beta_1 \ast (\text{Outside } T(T_{oa}) - \text{Cooling } T(\beta_2))$

This model depicts the energy consumption by including the base load $\beta_0$ that is independent of the outside temperature (independent variable $x$). When the temperature exceeds $\beta_2$, the
consumption becomes dependent on the independent variable and varies linearly with it. The coefficient that describes this correlation is $\beta_1$.

Using regression correlates energy use to other variables. The regression coefficients represent the physical relationship existing between the electrical consumption for instance and could be used to evaluate the energy saving opportunities.$^7$

In our case, we are going to model the energy consumption of a university administration building. We have the data of their electrical bill.
ENERGY MODELING

Baseline Data Gathering

For the baseline energy, we need to have the historical metering data over a specific period. This period should be long enough to allow us to drive an adequate regression analysis. For instance if the meter gives hourly data, a minimum of one month will be sufficient and would allow you to have a sample of 30 measurements. On the other hand, utility bills can be used as historical data, the only constraint would be getting bills of previous years to gather the minimum number of required measurements.

We are working with ECO TAQA Company. It’s a company specialized in energy efficiency and renewable energies. They provided us with the data of energy consumption of an administrative building in Ibn Zohr University (IZU) in Agadir.

Baseline Data Analysis

In our case, we are working on a university administrative building. The contact information working with ECO TAQA Company provided us with the utility bills for 2014 and 2015 (quarterly data). He also gave us data about their appliances, area and occupancy. Since the electricity bill could only provide us with a sample of 8, we tried to model the energy consumption using the data given about lighting and appliances.

We used the following formula to estimate the energy use for the facility:

\[
\text{Energy (kWh)} = \text{Average Use (hours)} \times \text{Power (kW)} \quad (4)
\]

Assuming that the normal occupancy profile is 8 working hours a day, it was estimated that the average use of appliances and lighting is 7 hours a day. Also, the number of working days and
days off for each month were calculated based on the national calendar of national and religious holidays.

- Total Yearly Electricity Consumption:
  - YEAR 2014
    a- Lighting:

In the facility, they have different types of light bulbs with different power usage. They have both fluorescent tubes and compact fluorescent light bulbs (CFL).

The power usage varies between 14W and 23W for CFL and from 13W to 36W for fluorescent tubes. We have assumed that the average use is 6 hours/day from 30 March to 30 October and 7 hours/day for the rest of the year.

<table>
<thead>
<tr>
<th>Type of Light Bulb</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorescent Tubes type 1</td>
<td>36</td>
</tr>
<tr>
<td>Fluorescent Tubes type 2</td>
<td>18</td>
</tr>
<tr>
<td>CFL type 1</td>
<td>14</td>
</tr>
<tr>
<td>CFL type 2</td>
<td>23</td>
</tr>
</tbody>
</table>

*Table 1:* Type of light bulbs and their respective powers in the administrative building IZU (Provided by ECO TAQA Company)

The estimation of the lighting energy consumption is presented in the table below:

<table>
<thead>
<tr>
<th>Lighting (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarter 1</td>
</tr>
<tr>
<td>3990</td>
</tr>
</tbody>
</table>

*Table 2:* Quarterly estimation of lighting consumption in 2014
b- Heating and Air Conditioning:

For the heater and the air conditioner, we made the assumption that in a city like Agadir the heater and the air conditioner aren’t used throughout the whole year.

We used an online tool\(^9\) to generate heating and cooling degree days. The base temperature for heating degree days was 15°C and 26°C for cooling degree days. The data generated by the online tool showed the following:

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD</td>
<td>88</td>
<td>69</td>
<td>40</td>
<td>10</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>13</td>
<td>87</td>
</tr>
<tr>
<td>CDD</td>
<td>2</td>
<td>0</td>
<td>7</td>
<td>7</td>
<td>13</td>
<td>11</td>
<td>14</td>
<td>24</td>
<td>20</td>
<td>37</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

*Table 3:* Monthly heating and cooling degree days for 2014 in Agadir, Morocco.

As you can see, the months with the heating degree days value above 25 are the months during which the heater was operating. The same logic applies for the cooling degree days and the air conditioner. Based on this data, we estimated the energy use of both the heater and the AC throughout the year;

<table>
<thead>
<tr>
<th></th>
<th>Heater +AC (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>quarter 1</td>
<td>quarter 2</td>
</tr>
<tr>
<td>762</td>
<td>0</td>
</tr>
</tbody>
</table>

*Table 4:* Quarterly estimation of heaters and air conditioner consumption in 2014
c- Rest of Appliances:

For the rest of appliances, we have the conventional type of appliances that an administrative facility has. They have desktop computers, printers, scanners, display screens, fridge, etc. We estimated the appliances power usage. 

So, the estimated energy consumption related to the mentioned appliances is shown in the table below:

<table>
<thead>
<tr>
<th>Quarter 1</th>
<th>Quarter 2</th>
<th>Quarter 3</th>
<th>Quarter 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>7712</td>
<td>7863</td>
<td>6204</td>
<td>7713</td>
</tr>
</tbody>
</table>

*Table 5:* Quarterly estimation of rest of appliances consumption in 2014

The total estimated electricity consumption is shown in the table below:

<table>
<thead>
<tr>
<th>Quarter 1</th>
<th>Quarter 2</th>
<th>Quarter 3</th>
<th>Quarter 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>12465.87</td>
<td>11213.04</td>
<td>7879.38</td>
<td>11733.75</td>
</tr>
</tbody>
</table>

*Table 6:* Quarterly estimation of the overall facility consumption in 2014

<table>
<thead>
<tr>
<th>Quarter 1</th>
<th>Quarter 2</th>
<th>Quarter 3</th>
<th>Quarter 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>12161</td>
<td>8996</td>
<td>6010</td>
<td>13205</td>
</tr>
</tbody>
</table>

*Table 7:* Quarterly data from electricity bill of the overall facility consumption in 2014
This table represents the actual data available in the quarterly electricity bill of 2014.

Error difference between the estimated and the actual energy consumption: **14.52%**

- **YEAR 2015:**
  a- Lighting:

  The lighting energy consumption was calculated the same way as the previous year using the same average use.

<table>
<thead>
<tr>
<th>Lighting (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarter 1</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>4056.04</td>
</tr>
</tbody>
</table>

  *Table 8: Quarterly estimation of lighting consumption in 2015*

b- Heating and Air Conditioning:

The summary of the heating and cooling degree days generated by the online tool is shown in the following table:

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDD</td>
<td>113</td>
<td>97</td>
<td>55</td>
<td>21</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>38</td>
<td>63</td>
</tr>
<tr>
<td>CDD</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>25</td>
<td>3</td>
<td><strong>52</strong></td>
<td>21</td>
<td>8</td>
<td>17</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

  *Table 9: Monthly heating and cooling degree days for 2015 in Agadir, Morocco.*

The base temperatures chosen are as follow:

The base temperature for heating degree days: **15°C**

The base temperature for cooling degree days: **26°C**

The total heating and air conditioning for 2015 is shown in the table below:
Table 10: Quarterly estimation of heater and air conditioner consumption in 2015

<table>
<thead>
<tr>
<th>Quarter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heater and AC (kWh)</td>
<td>775</td>
<td>0</td>
<td>231</td>
<td>500</td>
</tr>
</tbody>
</table>

c- Other appliances:

Table 11: Quarterly estimation of other appliances consumption in 2015

<table>
<thead>
<tr>
<th>Quarter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other appliances (kWh)</td>
<td>7611</td>
<td>7813</td>
<td>6958</td>
<td>7712</td>
</tr>
</tbody>
</table>

So the estimated energy consumption for 2015 by quarter is:

Table 12: Quarterly estimation of the overall facility consumption in 2015

<table>
<thead>
<tr>
<th>Quarter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESTIMATED TOTAL (kWh)</td>
<td>12442</td>
<td>11162</td>
<td>9597</td>
<td>11928</td>
</tr>
</tbody>
</table>

Table 13: Quarterly data from electricity bill of the overall facility consumption in 2015

<table>
<thead>
<tr>
<th>Quarter</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTUAL TOTAL 2015 (kWh)</td>
<td>16443</td>
<td>8963</td>
<td>8296</td>
<td>13363</td>
</tr>
</tbody>
</table>

The error difference between the real energy consumption and the estimated one is **18.90%**
### BASELINE ENERGY USE BY SECTION OF THE BUILDING

<table>
<thead>
<tr>
<th>Floor</th>
<th>Section</th>
<th>Energy Use (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground</strong></td>
<td>Left wing</td>
<td>20016</td>
</tr>
<tr>
<td></td>
<td>Hall</td>
<td>1405</td>
</tr>
<tr>
<td></td>
<td>Right wing</td>
<td>3722</td>
</tr>
<tr>
<td><strong>1st floor</strong></td>
<td>Right wing</td>
<td>4109</td>
</tr>
<tr>
<td></td>
<td>Hall</td>
<td>713</td>
</tr>
<tr>
<td></td>
<td>Left wing</td>
<td>4821</td>
</tr>
<tr>
<td><strong>2nd floor</strong></td>
<td>Right wing</td>
<td>20962</td>
</tr>
<tr>
<td></td>
<td>Left wing</td>
<td>1577</td>
</tr>
</tbody>
</table>

*Table 14: Estimation of the overall energy consumption by facility sections 2014-2015*

### BASELINE ENERGY USE BY TYPE OF DAYS

<table>
<thead>
<tr>
<th>Type of Days</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working Days</strong></td>
<td>2326</td>
<td>3147</td>
<td>2874</td>
<td>3010</td>
<td>2874</td>
<td>2874</td>
<td>2874</td>
<td>547</td>
<td>3010</td>
<td>2600</td>
<td>2189</td>
<td>3147</td>
</tr>
<tr>
<td><strong>Days Off</strong></td>
<td>537</td>
<td>168</td>
<td>336</td>
<td>268</td>
<td>369</td>
<td>302</td>
<td>268</td>
<td>873</td>
<td>268</td>
<td>436</td>
<td>537</td>
<td>268</td>
</tr>
</tbody>
</table>

*Table 15: Estimation of the overall energy consumption by type of days 2014*

<table>
<thead>
<tr>
<th>Type of Days</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working Days</strong></td>
<td>2874</td>
<td>2737</td>
<td>2874</td>
<td>3010</td>
<td>2737</td>
<td>3010</td>
<td>2874</td>
<td>684</td>
<td>2737</td>
<td>2874</td>
<td>2600</td>
<td>2874</td>
</tr>
<tr>
<td><strong>Days Off</strong></td>
<td>302</td>
<td>268</td>
<td>336</td>
<td>268</td>
<td>369</td>
<td>268</td>
<td>336</td>
<td>873</td>
<td>336</td>
<td>336</td>
<td>369</td>
<td>336</td>
</tr>
</tbody>
</table>

*Table 16: Estimation of the overall energy consumption by type of days 2015*
**Discussion:**

The difference between the actual energy consumption and the estimated one is due to the following factors:

- Insufficient data about the average usage of each appliance
- The non-routine changes that weren’t taken into consideration. For example, a strike date during which the employees had a day off.
- Insufficient information about specifications of appliances which had led to an estimation of the power of each appliance.

The independent variables that we have chosen are:

- HDD: Heating Degree Days
- CDD: Cooling Degree Days
- WD: Working Days
- DO: Days Off
- \( F_g \): Ground Floor
- \( F_1 \): First Floor
- \( F_2 \): Second Floor

The energy model might look like this one:

\[ y(\text{kWh}) = b_0 + b_1 \times \text{HDD} + b_2 \times \text{CDD} + b_3 \times WD + b_4 \times DO + b_5 \times F_g + b_6 \times F_1 + b_7 \times F_2 \]

Finally, ECO TAQA Company should gather data in the following way:

- They should gather at least 30 Energy use Observations; if they will use the quarterly electricity bills, they will need at least 7 utility bills.
- When they develop the model by following the methodology described in the report, they can recommend to the university to implement specific ECMs. These ECMs might be:
  - Changing the light bulbs to new LED ones
Generalize a strict profile use of their appliances: their appliances should be only on during working hours

- They should plan a reporting period after the implementation of the ECMs to account for the routine and non-routine adjustments

**Modeling of Baseline Energy**

Since we don’t have enough data to use the least squares method for the administrative building in Agadir, we will demonstrate how we can use this statistical method to model the energy use. We will use the data of electricity use of the heating system of buildings 31 and 32 at Al-Akhawayn University. These two buildings are student dormitories and have a single meter that provides hourly energy consumption.

1.1. Define the variables

Regression is believed to be one of the statistical methods that helps you define the relationship between two or more variables. The variable to be predicted is the dependent variable and will be denoted by “y” throughout this part of the report. The variables that will help predict y are called the independent variables.

This statistical tool proves to be useful when the variables are well defined. A wrong definition of the variables will bias your findings and provide an inaccurate model.

1.1.1. Dependent Variable

In our case, we defined y to be the daily energy consumption of the heating system in both buildings 31 and 32 in Al Akhawayn University in Ifrane. We will study the energy use from mid-October to the end of February.
y: the daily energy consumption of the electrical heaters in buildings 31 and 32

1.1.2. Independent Variable

a. Weather:

In the case of a heating system, the factors that affect the energy consumption are normally, the weather or the occupancy. For a city like Ifrane, the weather has an important impact on the heating system usage. Thus, the independent variable related to the weather will be the outside air temperature. The temperature associated variables are denoted as follow:

\( T_{\text{min}} \): The minimum outside air temperature of the day

\( T_{\text{max}} \): The maximum outside air temperature of the day

We got the historical weather data from an online tool\(^{10}\). It was the only accessible online tool that provides the data for the city of Ifrane for the years 2014 and 2015.

b. Operating System

i. Temperature related

For the operating hours, the following heating planning was provided by Ground and Maintenance Department in Al Akhawayn University.

\[ \text{Figure 4: Heating schedule for buildings 31 and 32 in AUI} \]
As shown in the heating planning, if the outside air temperature is below 7°C from midnight to 8 am or from 7 pm to midnight, the heaters should be working. During the day, the outside temperature should be below 14°C for the maintenance department to turn the heaters of the buildings on.

We have the maximum and minimum daily outside air temperature data. We also have the daily heating energy consumption. However, we have the hourly operating system of the heaters.

Taking an approximation of the value of daily operating hours based on the maximum and minimum outside air temperature will bias our energy model. Also, regression analysis treats the independent variables as numerical. However, the operating hours are non-numerical attributes that affect the energy consumption and consequently should be included in the regression model.

For this purpose, we will define 2 dummy variables to account for the operating hours. We assume that during the early morning or during night, we measure the minimum outside air temperature occurs. Also, the maximum outside air temperature could occur during the day; specifically from 9 am to 7 pm. The dummy variables are defined as follow:

\[ D_1: \text{first dummy variable linked to the minimum outside air temperature. } D_1 = 1 \text{ if } T_{\text{min}} \text{ is below 7°C; otherwise it’s 0.} \]

\[ D_2: \text{second dummy variable linked to maximum outside air temperature.} \]

The following tables represent the conditions defining the dummy variables.
### Tables 17 & 18: Dummy variables definition for outside air temperature.

#### ii. Occupancy related

Since the energy use is related to the occupancy of the buildings too, we will define occupancy variables too. The university has a strict holidays’ calendar that we will take into account.

D₃: third dummy variable related to holidays during the academic year. It takes 1 during holidays and takes 0 when it is a normal day of the semester.

1.2. **Scatter Diagram**

The scatter diagram enables us to observe the data graphically and to draw preliminary conclusions about the possible relationship between the variables.¹⁰

So before running regression, we need to do a scatter plot of the dependent versus each independent variable we defined.

These are the scatter diagrams of Y (energy consumption of the heating system) with each independent variable:

<table>
<thead>
<tr>
<th>D1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tₘᵢₙ &lt; 7</td>
<td>1</td>
</tr>
<tr>
<td>Tₘᵢₙ &gt; 7</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>D2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Tₘᵃₓ &lt; 14</td>
<td>1</td>
</tr>
<tr>
<td>Tₘᵃₓ &gt; 14</td>
<td>0</td>
</tr>
</tbody>
</table>
1.2.1. **Minimum Outside temperature** $T_{\text{min}}$

*Figure 5:* Scatter diagram of energy use vs. minimum temperature

1.2.2. **Maximum Outside Temperature** $T_{\text{max}}$

*Figure 6:* Scatter diagram of energy use vs. maximum temperature

The preliminary conclusion that we can draw from this scatter diagram, the relationship between the daily heater energy use and the minimum outside temperature could only approximated by a
straight line (i.e. positive linear relationship). Thus, we choose the multiple linear regression model because there is some remaining variability in the dependent variable (i.e. we need to add at least one more variable to the model).

From the scatter diagram of the energy use versus the maximum outside temperature. We can assume that the relationships between these two variables is linear. Also for this case, we need to run multiple linear regression to account for the variability in the energy use.

1.3. Model Assumptions Testing

With our model, we need to present the significance laying between the dependent variable \( y \) and the independent variables. This significance is presented by the estimated regression model (equation 2). But first we need to check for the appropriateness of the assumed model (equation 3) To do so, we need to check if the assumptions about the error term hold.

We need to check these assumptions in order to make sure that the estimated model is predicting the response \( y \) and that any randomness unrelated to the deterministic part of the model is left to the error part.\(^5\). The assumptions to be tested are: Independence, equal variances, normality and randomness.

1.3.1. Independence:

We need to check the independence of the error on the time variables and factors of the model. For time variables we have the daily energy use of the heating system. For the factors, we have the maximum and minimum outside air temperatures.
a. Time variable

**Figure 7**: Scatter diagram of residuals vs. energy use

b. Factors:

The pattern present in the plots of the residuals versus the time variable and the factors show a random pattern of the distribution of the error. As a result, the independency assumption holds. Hence, there are no time variables that could conceivably influence results.

**Figure 8**: Scatter diagram of residuals vs. minimum temperature
1.3.2. **Equal Variances**

**Figure 9:** Scatter diagram of residuals vs. maximum temperature

**Figure 10:** Scatter diagram of residuals vs. estimated energy use

As we can see in the diagram below, for each value on the x-axis the residuals are approximately of the same distance from 0.
1.3.3. Normality

From the plot of observation values (energy use) against the expected values, we can see a positive linear relationship between the two variables. This shows that the heater energy use is normally distributed and the normality assumption holds.

![Normal Probability Plot](image)

*Figure 11: Normal Probability Plot*

1.3.4. Randomness

![Residuals](image)

*Figure 12: Scatter diagram of the error*
From the graph, we can clearly see that the error terms represented by its approximate residuals are randomly distributed.

1.4. Regression

Now that we have defined the dependent and independent variables and checked the appropriateness of the model by checking that the assumptions hold, we can finally run the regression tool. With a 95% Confidence Interval and $R^2=0.72$ the estimated energy model is as follows:

$$y(MWh) = 501.10 + 20.42 \times T_{min} - 17.69 \times T_{max} + 69.25 \times D_1 - 109.70 \times D_2 - 162.08 \times D_3$$

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_0$</td>
<td>501.10</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>20.42</td>
</tr>
<tr>
<td>$\beta_2$</td>
<td>-17.69</td>
</tr>
<tr>
<td>$\beta_3$</td>
<td>69.25</td>
</tr>
<tr>
<td>$\beta_4$</td>
<td>-109.70</td>
</tr>
<tr>
<td>$\beta_5$</td>
<td>-262.08</td>
</tr>
</tbody>
</table>

1.4.1. Overall Significance:

We need to test if there is a statistical significance between the dependent variable and the set of all independent variables. The test that is used for the overall significance is the F-test and it is used to test the hypotheses

$$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$$

$$H_1: \text{One or more of the parameters is not equal to 0}$$
Rejection rule:

1- reject $H_0$ if $F \geq F_\alpha$
2- reject $H_0$ if $p$-value $\leq \alpha$

We have $F_{0.05}=2.29$ and $F=41.36$. We also have $\alpha = 0.05$ and $p$-value=$7.9\times10^{-26}$. So, we reject $H_0$ and accept that there are one or more of the coefficients different than 0

1.4.2. Individual Significance:

$$H_0: \beta_n = 0 \quad \text{Such that } n=1,2,3,4 \text{ or } 5$$

$$H_1: \beta_n \neq 0$$

Rejection rule:

1- reject $H_0$ if $t \leq -t_{\alpha/2}$ or $t \geq t_{\alpha/2}$
2- reject $H_0$ if $p$-value $\leq \alpha$

a. Coefficient of $T_{\text{min}}$:

We have $t=3.32$ and $t_{0.025}=1.98$. We also have $p$-value=0.0012 and $\alpha =0.05$. So $\beta_1 \neq 0$

b. Coefficient of $T_{\text{max}}$:

We have $t=-3.24$ and $-t_{0.025}=-1.98$. We also have $p$-value=0.0015 and $\alpha =0.05$. So $\beta_2 \neq 0$

c. Coefficient of $D_1$:

We have $t=3.04$ and $t_{0.025}=1.98$. We also have $p$-value=0.0029 and $\alpha =0.05$. So $\beta_3 \neq 0$

d. Coefficient of $D_2$:

We have $t=-3.20$ and $-t_{0.025}=-1.98$. We also have $p$-value=0.0017 and $\alpha =0.05$. So $\beta_3 \neq 0$
e. Coefficient of D₃:

We have \( t = \text{13.65} \) and \( -t_{0.025} = \text{1.98} \). We also have \( p\text{-value}=1.83 \times 10^{-26} \) and \( \alpha = 0.05 \). So \( \beta_4 \neq 0 \)

1.5. Coefficient of Variation of the Root Mean Squared Error

Coefficient of Variation of the Root Mean Squared Error \( CV \text{ (RMSE)} \) is a measure of how much variation there is between the actual and modeled energy. It is calculated using this formula:\(^8\):

\[
CV \text{ (RMSE)} = \frac{1}{\bar{y}} \left[ \frac{\sum (y_i - \hat{y})^2}{n - p} \right]^{1/2}
\]

\( n \): number of observations

\( p \): number of variables

\( y_i \): actual value

\( \hat{y} \): estimated value

In our case, we calculated \( CV \text{ (RMSE)} \) and found it to be 14.73\%. It represents how accurate the model is in estimating the electricity consumption due to the heaters in both buildings. So, for each 10,000 kWh a variation of 1473 kWh between the modeled energy and the real energy consumption.

**Calculation and Reporting of Energy Savings**

To calculate the savings, we need to use this equation as mentioned in the International Protocol We use Equation (1)
1.6. Baseline energy use:

In our case, we have the baseline energy use to be the metering data of the heaters in both buildings.

<table>
<thead>
<tr>
<th>Date</th>
<th>Baseline Energy Consumption of the Heating System 2015-2016 (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-Oct-15</td>
<td>5044.71</td>
</tr>
<tr>
<td>30-Nov-15</td>
<td>11036.76</td>
</tr>
<tr>
<td>31-Dec-15</td>
<td>9676.31</td>
</tr>
<tr>
<td>31-Jan-16</td>
<td>9672.69</td>
</tr>
<tr>
<td>21-Feb-16</td>
<td>7232.41</td>
</tr>
</tbody>
</table>

Table 19: Estimation of energy consumption of the heating system buildings 31-32, AUI(15-16)

We have the energy modeled by the following equation:

\[ y(kWh) = 501.10 + 20.42 \times T_{\text{min}} - 17.69 \times T_{\text{max}} + 69.25 \times D_1 - 109.70 \times D_2 - 162.08 \times D_3 \]

So with this energy model, we can calculate the savings. We have the factors affecting the heating system energy use that are the independent variables: \( T_{\text{min}} \), \( T_{\text{max}} \), \( D_1 \), \( D_2 \) and \( D_3 \)

Using the estimated energy model we developed, we can predict the future energy use of the heating system. We will calculate the future energy consumption from 15\(^{th}\) October 2016 to 21\(^{th}\) February 2017.

We used the prediction of the online tool AccuWeather to get the data about the daily outside air temperatures. Also, we used the same operating plan that the Maintenance Department in Al Akhawayn follow. Thus, the results of our calculations are as follow:

<table>
<thead>
<tr>
<th>Date</th>
<th>Estimated Energy Consumption of the Heating System 2016-2017 (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-Oct-16</td>
<td>5645.51</td>
</tr>
<tr>
<td>30-Nov-16</td>
<td>8891.75</td>
</tr>
<tr>
<td>31-Dec-16</td>
<td>11840.49</td>
</tr>
<tr>
<td>31-Jan-17</td>
<td>10971.92</td>
</tr>
<tr>
<td>21-Feb-17</td>
<td>7890.28</td>
</tr>
</tbody>
</table>

Table 20: Estimation of energy consumption of the heating system buildings 31-32, AUI(16-17)
The estimated energy consumption of the heaters in both buildings 31 and 32 from mid-October 2016 until the end of February 2017

1.7. Post Retrofit Energy Use:

Possible ECM: Change in the Operating Plan (Turn off the heaters from 9 am to 6 pm)

This change will be related to the second dummy variable $D_2$. The heaters will be turned off during the day (from 9am until 6pm) regardless of the outside of the air temperature.

| Post-Retrofit Energy Consumption of the Heating System 2016-2017 (kWh) |
|-----------------|-----------------|----------------|----------------|----------------|----------------|
| 31-Oct-16       | 31-Nov-16       | 31-Dec-16      | 31-Jan-17      | 21-Feb-17      |
| 3531.65         | 4899.02         | 7479.37        | 6528.54        | 4924.58        |

*Table 21:* Estimation of post-retrofit energy consumption of the heating system buildings 31-32, AUI

1.8. Adjustments:

There are no specific routine or non-routine adjustments that need to be taken into consideration when calculating the savings on energy consumption.

1.9. Savings:

If we implement this energy conservation measure, the expected savings on the heating system for both buildings for the end of 2016 and the beginning of 2017 are presented in the following table
### Savings on Energy Consumption of the Heating System

<table>
<thead>
<tr>
<th></th>
<th>31-Oct-16</th>
<th>30-Nov-16</th>
<th>31-Dec-16</th>
<th>31-Jan-17</th>
<th>21-Feb-17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kWh)</td>
<td>1513.06</td>
<td>6137.74</td>
<td>2196.94</td>
<td>3144.14</td>
<td>2307.83</td>
</tr>
<tr>
<td>Percentage</td>
<td>30%</td>
<td>56%</td>
<td>23%</td>
<td>33%</td>
<td>32%</td>
</tr>
<tr>
<td>Financial (MAD)</td>
<td>1520.97</td>
<td>6169.61</td>
<td>2208.36</td>
<td>3152.00</td>
<td>2313.60</td>
</tr>
</tbody>
</table>

*Table 22*: Estimation of energy consumption savings of the heating system buildings 31-32, AUI
CONCLUSION & FUTURE WORK

Throughout this project, we had a university administrative building in Agadir as our sample tertiary building. We did an energy audit for their electricity consumption for 2014 and 2015. We planned to mathematically model their energy consumption but there wasn’t enough data presented. So as to demonstrate the process of modeling the energy use of a certain facility or system, we made use of the electricity powered heating system data provided by maintenance department in Al Akhawayn University. Using this data, we developed the mathematical model that helped us estimated the energy savings of the university campus.

Finally, we were able to provide the company with some recommendations concerning data gathering and the reporting period if they are planning to model their energy following the guidelines of the international protocol and using the statistical methods demonstrated throughout the report. This will allow us to be one of pioneers in implementing the IPMVP in an energy efficiency project in Morocco and help make one step forward in the energy field.

An implementation of a user guide interface (GUI) would be an interesting step to take in order to expand this project. This interface might be built using Matlab to allow the user to provide their energy consumption data. Accordingly, the user will be given a M&V report including the mathematical model and savings measurements. This report might also propose the implementation of some ECMs to be considered by the user.
REFERENCES


