KTH Industrial Engineering
and Management

Energy Management in Buildings

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Abstract

This report is the result of a minor field study (MFS) performed in the Dominican Republic. The country strongly relies on energy sources from adjacent countries, currently the nation depends on fossil fuel for 86 % of its electricity generation and in 2011, 8.6 % of its GDP was spent on fossil fuel imports. Since the country has a growing middle-class the demand for energy is increasing intensively and makes the necessity of a transition to a more sustainable energy system crucial for future growth. This project mainly focuses on the energy use in buildings and to analyze the situation, Emilio Rodríguez Demorizi library at Instituto Tecnológico de Santo Domingo was taken as case study.

In order to evaluate the current situation an energy audit was performed, for simulations RETScreen was used, an energy management tool that enables modeling of a buildings energy use. The program allows the user to inspect the current consumption and demands and later propose a solution in order to make the investigated object more efficient. Components such as, lighting, electric equipment, ventilation and climate system are taken into account. Also the behavioral needs of the occupants in the building have been analyzed. However, no technical solution will actually be implemented and the study will be restricted to the area of Santo Domingo.

The result of the study showed that more electricity was used in the afternoon compared to mornings and evenings. The biggest factor for this increase is due to the use of climate systems which accounts for 71% of the yearly electricity consumption. An improved case was suggested, where upgrades were made in climate systems and electrical equipment and simulations in RETScreen show that electricity use can be decreased by 56 % if the proposed case was to be implemented. An investigation has been made on a proposed solar project, it would only cover 4% of the buildings annual electricity need in the current state and 10 % of the annual need in the proposed case, a conclusion has been made that at the moment the solar project would not be financially viable, considering the size of the investments that would be needed. However, in the future when more advanced technology is affordable and available it might be worth bearing in mind. Furthermore, the behavioral needs of the occupants in the building substantially contribute to the energy utilization in the building, major reductions can be made if cooling which is the main factor for electricity consumption, was used only when and where needed.

Keywords: Dominican Republic, INTEC library, RETScreen, Energy management, Climate control systems

Sammanfattning

Detta kandidatexamensarbete är resultatet av en MFS-studie utförd i Dominikanska Republiken. Landet är starkt beroende av energikällor från angränsande länder, för närvarande är 86 % av elektricitet producerad från fossila bränslen, 2011 spenderade landet 8,6 % av dess BNP på bränsle import. Då landet har en växande medelklass ökar efterfrågan på energi och gör behovet av en övergång till hållbar energiteknik avgörande för framtida tillväxt. Denna rapport fokuserar huvudsakligen på energianvändning i byggnader. Som fallstudie har biblioteket Emilio Rodríguez Demorizi på Instituto Tecnológico de Santo Domingo använts.

För att utvärdera situationen har en energikartläggning genomförts på byggnaden, för att analysera resultatet har energihanteringsverktyget RETScreen använts, ett verktyg som möjliggör modellering av byggnaders energianvändning. Programmet ger användaren möjligheten att inspektera nuvarande användning och krav och senare även föreslå förbättringar inom energieffektivisering, minskningar av växthusgaser och även finansiella förbättringar. Komponenter såsom belysning, elektrisk utrustning, ventilation och klimatsystem beaktas. Även beteendet hos de som använder byggnaden är en viktig faktor att ta hänsyn till. Ingen faktiskt lösning kommer att föreslås och studien kommer att begränsas till Santo Domingo-området.

Resultatet visar att elanvändningen är högre på eftermiddagen jämfört med på kvällen. Den största faktorn till denna ökning är klimatsystemet som står för 71 % av den årliga elektricitetsförbrukningen. Ett förbättrat fall har föreslagits där uppgraderingar i klimatsystem och elektronisk utrustning införts. Simuleringar i RETScreen visar att förbrukningen kan minskas med 56 % om det förbättrade fallet implementeras. En utredning har genomförts på ett förslaget solpanelsprojekt, i byggnadens nuvarande tillstånd så skulle det täcka 4 % av den årliga elanvändningen, för det föreslagna fallet skulle det täcka ca 10 %. Slutsatsen har dragits att projektet inte är ekonomiskt hållbart, med tanke på de enorma investeringar som krävs. Däremot så är det något man bör se över när mer effektiv utrustning finns tillgänglig. Vidare så är beteendet av de som använder byggnaden en stor orsak till den höga energianvändningen. Betydande besparingar kan göras om klimatanläggningen, vilket är det största bidraget till den höga elanvändning, används endast var och när det är i behov.

Resumen

Esta tesis de licenciatura es el resultado de un estudio MFS realizado en la República Dominicana. Este país es extremadamente dependiente de fuentes de energía de países cercanos, en este momento el 86 % de la electricidad es producida por medio de combustibles fósiles y en el año 2011 el país gastó el 8,6 % de su GDP en el importe de combustible. El país está conformado por una creciente clase media, lo que hace que la demanda de energía haya aumentado y la necesidad de cambiar a energías sostenibles es crucial para el futuro crecimiento. Se ha hecho un estudio de campo en la República Dominicana, en donde la situación energética actual se ha analizado. Con este fin se ha trabajado como punto de referencia en la biblioteca Emilio Rodríguez Demorizi en el Instituto Tecnológico de Santo Domingo.

Para analizar la situación, se efectuó una auditoría energética del edificio y por medio de la herramienta de manejo de energía RETscreen se evaluaron los resultados. Esta herramienta posibilita hacer un modelo del uso de energía del edificio y dar la posibilidad al usuario de inspeccionar el uso y la demanda actual, así como la posibilidad de proponer mejoras. Componentes como iluminación, equipos eléctricos, ventilación, y equipos de climatización son tomados en cuenta. Pero también el comportamiento de los ocupantes del edificio es un factor importante. En este trabajo no se presentará ninguna solución específica y el estudio se limitará a la zona de Santo Domingo.

Los Resultados muestran que el uso de electricidad es más alto en horas de la tarde comparado con las noches. El factor más importante que afecta este aumento son los sistemas de climatización, que suponen el 71 % del consumo anual de electricidad. De acuerdo a simulaciones hechas en RETScreen, el alto consumo puede ser disminuido de una forma significante, aproximadamente 54 %, por medio de inversiones en mejores tecnologías, y debido al alto precio de la electricidad, el estudio muestra que las inversiones serían económicamente viables a corto y a largo plazo. Además, el comportamiento de los ocupantes puede contribuir a una disminución importante en el consumo, por ejemplo, en el mejor manejo de los sistemas de climatización. Se probó también una propuesta de paneles solares en el techo de la edificación, en el estado actual del edificio los paneles generarían el 4 % del consumo total, y el 10 % en el caso propuesto. Por motivo de los altos consumos de energía en el edificio, el proyecto no es económicamente viable en este momento. Sin embargo, este tipo de proyectos puede ser evaluado otra vez en el futuro cuando sea posible adquirir tecnologías más eficientes o en caso de una reducción drástica del consumo de la edificación.

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This study has been carried out within the framework of the Minor Field Studies Scholarship Programme, MFS, which is funded by the Swedish International Development Cooperation Agency, Sida.

The MFS Scholarship Programme offers Swedish university students an opportunity to carry out two months' field work, usually the student's final degree project, in a country in Africa, Asia or Latin America. The results of the work are presented in an MFS report which is also the student's Bachelor or Master of Science Thesis. Minor Field Studies are primarily conducted within subject areas of importance from a development perspective and in a country where Swedish international cooperation is ongoing.

The main purpose of the MFS Programme is to enhance Swedish university students' knowledge and understanding of these countries and their problems and opportunities. MFS should provide the student with initial experience of conditions in such a country. The overall goals are to widen the Swedish human resources cadre for engagement in international development cooperation as well as to promote scientific exchange between unversities, research institutes and similar authorities as well as NGOs in developing countries and in Sweden.

The International Relations Office at KTH the Royal Institute of Technology, Stockholm, Sweden, administers the MFS Programme within engineering and applied natural sciences.

Erika Svensson
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MFS Programme, KTH International Relations Office

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Victor and Paulo from a sunny Santo Domingo. *2016-05-23*

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Acronyms and abbreviations

AC	Air Conditioning
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
CFL	Compact florescent light bulbs
CNE	National Energy Commission
COP	Coefficient of performance
CPU	Central Processing Unit
DR	Dominican Republic
ERV	Energy Recovery System
GDP	Gross domestic product
GHG	Green house gases
GHI	Global Horizontal Irradiance
ICT	Information and Communication Technology
INTEC	Instituto Tecnológico de Santo Domingo
ISO	The International Organization for Standardization
kWh	Kilowatt Hour
MWh	Megawatt Hour
HFO	Heavy fuel oils
HVAC	Heating, ventilation, and air conditioning
LED	Light-emitting diodes
MDG	Millennium Development Goals
PV	Photovoltaic
Q_c	Heat Gains or Heat Losses by Conduction
Q_e	Evaporation Heat Losses
Q_i	Internal Heat Gains
Q_m	Heat Gains and Heat Losses Due to Mechanical Climate Systems
Q_s	Solar Heat Gains
Q_v	Heat Gains or Heat Losses by Ventilation - Convection
RETScreen	Renewable Energy Project Analysis Software
SEER	Seasonal Energy Efficiency Ratio
SIDA	The Swedish International Development Cooperation Agency
tCO_2	Tonnes of Carbon Dioxide Equivalents

UN	United Nations
USD	U.S. Dollars

1 Introduction

One main issue in many developing countries is the lack of energy resources, this could be due to the slow developing infrastructure and the nonexistence of development policies.

The area that has been addressed in this project is the accelerated energy use in commercial buildings. Emilio Rodríguez Demorizi library at Instituto Tecnológico de Santo Domingo (INTEC), has been taken as case study.

1.1 Country overview

The Dominican Republic (DR) is located in the Caribbean, West Indies (Figure 1.1). Christopher Columbus explored and claimed the island on his first voyage in 1492 and it became a springboard for Spanish conquest of the Caribbean and the American mainland. The country has a total area of 48 422 km^2 and covers two thirds of the island of Hispaniola; the other part belongs to Haiti. The official language is Spanish. The country has a population of 10,2 million (2013) and the capital is Santo Domingo. (World Atlas, 2015)

Figure 1.1 Map over the Dominican Republic and other Caribbean countries. (WorldAtlas, 2015)

Over the last two decades, the Dominican Republic has been standing out as one of the fastest growing economies in the Caribbean with an average real Gross domestic product (GDP) growth of 5.4 % between 1992 and 2014 (World Bank, 2016). This can be explained by the growing tourism, between 2003 and 2013 the amount of tourists per year increased by 30 % compared to the previous decade (Knoema, 2016a).

1.2 Climate in the Dominican Republic

The Caribbean climate is tropical throughout the year and individual climate conditions are strongly dependent on elevation. In the Dominican Republic the average temperature hovers around 25°C and some call the country's climate 'the endless summer' (Ariza, 2016). Even though the temperature average is the same all year round the humidity and precipitation affects the feeling of the actual heat. Figure 1.2 shows the average yearly precipitation, the winter season is from November to April and those are the driest months of the year, rain season is from May until late October. In Figure 1.3 the temperature average from January to December is shown, the temperature increases between the months of April and September, the average high is approximately 26 °C (Worldbank, 2016a).

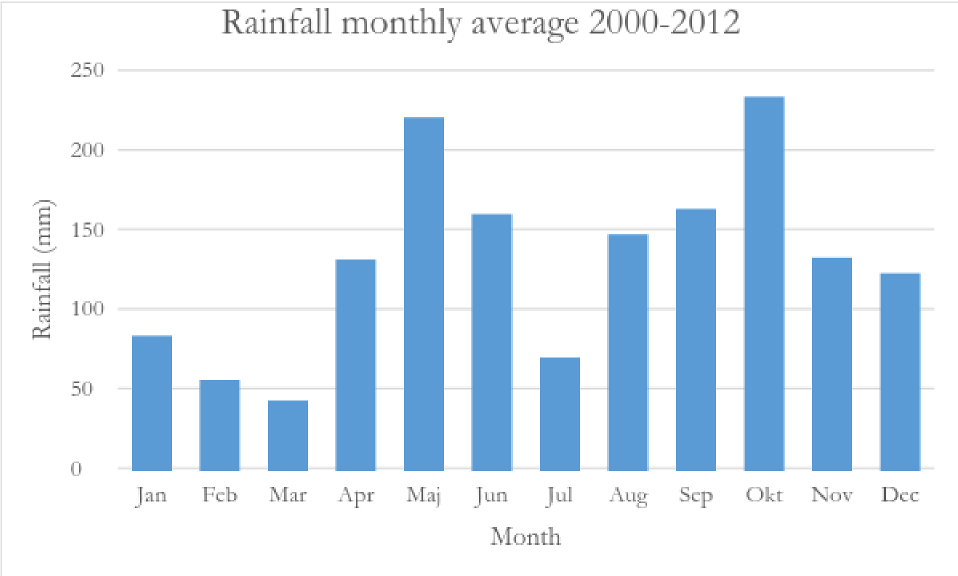

Figure 1.2 Monthly precipitation average between 2000 – 2012 (WorldBank, 2016a).

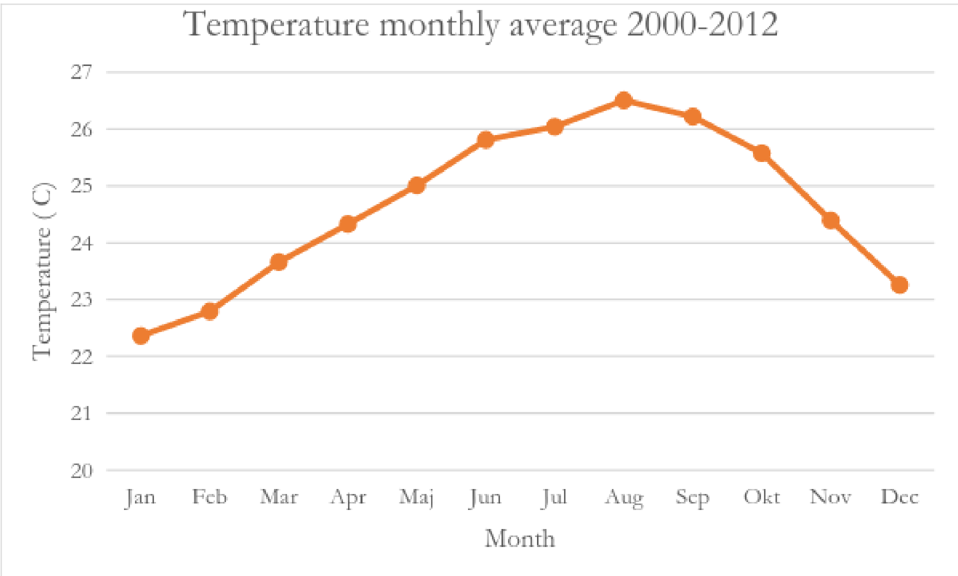

Figure 1.3 Monthly temperature average between 2000 – 2012 (WorldBank, 2016a).

Caribbean countries are extremely vulnerable to climate change. Hotter temperature, sea-level rise and increased hurricane intensity threaten property and livelihood throughout the Caribbean. The devastating impacts will occur regardless of the fact that Caribbean nations have contributed little to the release of the greenhouse gases that drive climate change. (Bueno et al, 2008)

1.3 Energy use

Most Caribbean countries are faced with several challenges associated with the generation, distribution and use of energy. Economic-, market- and policy-research is needed to advance the adaption to new energy technology. The Dominican Republic is the third largest energy consumer in the Caribbean, after Cuba and Puerto Rico. Approximately 92 % of the country's towns and villages are connected to the grid and 96 % of the population has access to electricity. Fossil fuels dominate the electricity generation in all Caribbean countries. In the Dominican Republic 85 % of all electricity generation comes from fossil fuels, approximately 36 % is heavy fuel oil (HFO), 25% natural gas and 14 % coal (see Figure 1.4). The reliance on fossil fuels has great impact on the levels of harmful emissions and since the country is dependent on imported fuels it is also extremely vulnerable to geostrategic and geopolitical change. (Worldwatch, 2015)

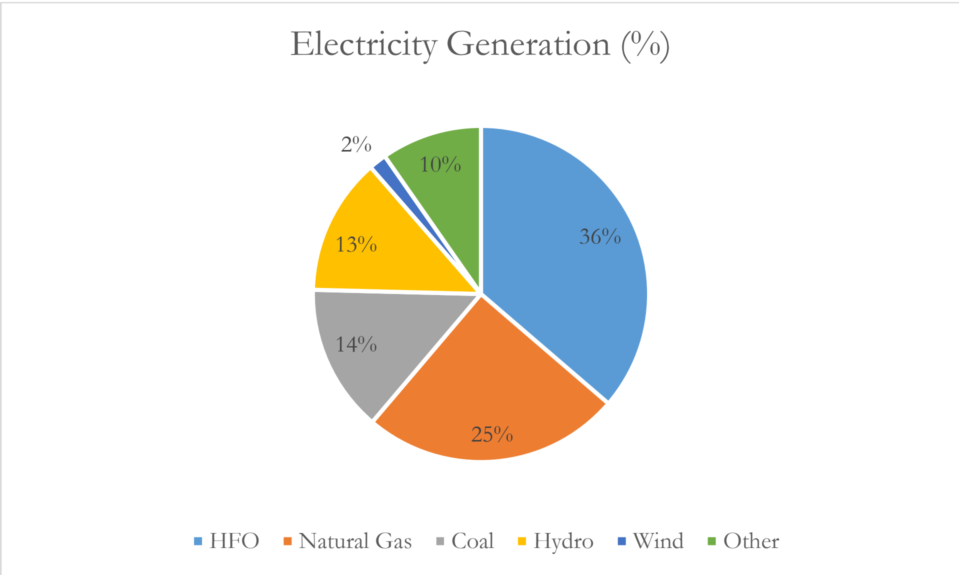

Figure 1.4 Annual electricity generation in the Dominican Republic, by fuel type 2013 (Worldwatch, 2015).

Like many other Caribbean countries, the Dominican Republic relies on the Petrocaribe preferential oil import agreement with Venezuela. In 2003 the DR bought almost 110,000 barrels of crude oil per day from Venezuela and when the country could not pay for all the oil they financed it by trading black beans and selling bonds. At some points the country has been forced to import and then export beans to pay back the debt to Venezuela (Fiezer, 2013). Not only does the country lack sources for energy, the Dominican electricity grid also experiences high levels of transmission and distribution loss, in 2014 the losses were as high as 32 %, this could be compared to the United States whom had an average loss of only 7 % annually. 12 % of the electricity loss is due to technical inefficiencies at generation plants, substations and transmission lines. The remaining 20 % of system loss is mainly attributed by electricity theft, which is considered to be the largest obstacle that electricity sectors must overcome (Worldwatch, 2015). The growing tourism in the Dominican Republic has also resulted in increased energy use and data shows that the country has the quickest growing energy demand of all Caribbean countries. (Edwards et al, 2011) In Figure 1.5 the electricity consumption between 2007 and 2013 is shown, in 2013 the consumption per capita was estimated to be 1517 kWh/person/year. This can be compared to the neighboring country Haiti whom had a consumption per capita at thirty times less the amount (WorldBank, 2016b).

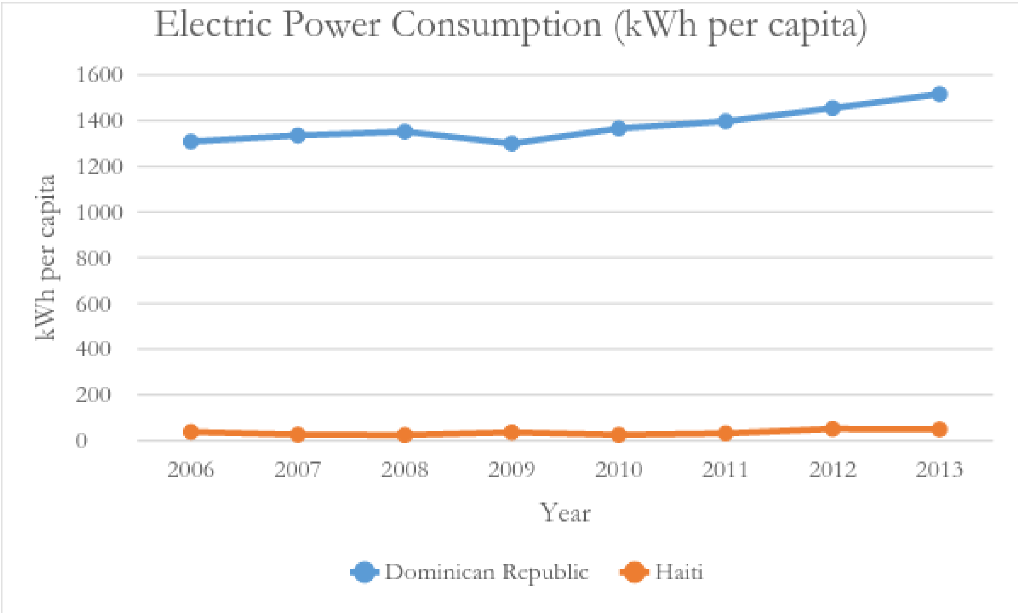

Figure 1.5 Electricity Power Consumption increase per capita. The Dominican Republic compared to Haiti (Worldbank, 2016b).

1.4 Millennium Development goals

The Millennium Development Goals (MDG) were established during the Millennium Summit of the United Nations (UN) in 2000. All 189 member states (among these the Dominican Republic) committed to help achieve the goals. During the event an explicit link between access to energy and poverty reduction was found and the UN confirmed that the available energy services worldwide fail to meet the needs of the poor. For the energy sector in the Dominican Republic, five key recommendations need to be prioritized in order to achieve the goals (UN-Development, 2015). They should:

1. *Adopt legal and regulatory frameworks that will provide incentives for effective partnerships among government institutions (including local governments), private-sector utilities and other operators, and community organizations.*

2. *Adopt strategic, institutional, and financial measures to ensure wider access for households and small businesses in urban and peri-urban settings to services such as illumination and power, information and communication technology (ICT), refrigeration, and other beneficial uses.*

3. *Adopt measures to ensure reliable electricity supply to households, businesses, public institutions, commercial establishments, and industry.*

4. *Provide access to mechanical power (for water lifting/delivery systems and agro processing) and electricity for public facilities (health clinics/centers, schools, government offices, and community centers) in all rural communities.*

5. *Take a flexible approach to selecting from a wide range of technologies as well as a wide range of institutional structures for the delivery of energy services.*

(UN-Development, 2005)

As of today the country has no regulations or policies in the energy sectors. All buildings and households are constructed within the framework of what the constructor or investor consider to be "appropriate". This approach has slowed down the development of the infrastructure and measures at this front have to be taken in order to reach the MDGs. (Jauregi, pers.comm.,2016)

With lacking resources of fossil fuel, the country has been forced to look for alternative ways for improvement. There are several energy projects underway, but the one that sticks out might be the solar power plant in the region of Monte Plata. The plant is the largest of its kind in Latin America and the project is set to be used as an alternative to fossil fuel. The plant will be connected directly to the public electricity grid and it is expected that it will provide up to 45 GWh of electricity per year. It will also lead to CO_2 emission reductions up to 232,000 tons. (MyClimate, n.d.) This can be seen as a big step forward, since the country has as a goal to reduce greenhouse gas emissions with 25 % by 2030. (Worldwatch, 2013)

2 Problem Description

To maintain an efficient and sustainable energy supply is a crucial matter in all nations. The welfare and development of infrastructure and living standards is dependent on the availability of energy. High electricity price in the country pose a big burden for Dominican households and as of today electricity costs are roughly 0.19 U.S. cents per kWh (NREL, 2015).

Most of the buildings in the Dominican Republic are old and have outdated equipment, and with the increasing living standard in the country the demand on buildings are higher than ever. The countries commercial sector is currently one of the biggest utilizers of energy, and at the moment there are no measures taken for energy management and energy savings. One of the main factors for high energy use in the commercial sector is the increased use of air-conditioning, occupants' unawareness of the impact of overconsumption is leading to technical and financial instability in the country. Also many buildings are old and in need of renovation, high infiltration in the envelope lead to high energy loss that in many cases can be avoided with minor investments in reparations.

2.1 Objectives

The primary objective for the project is to investigate the energy use in a building and to focus on potential improvements. This includes the possibility of making buildings self-sufficient, mapping data over current energy use and also revenue of investments in new technology. A case study will be conducted at the library at Instituto Tecnológico de Santo Domingo.

Specific objectives that have been set to simplify the process:

- Map data over energy use in the building and look into areas such as Heating, Ventilation and Air-Conditioning systems (HVAC), lighting, electrical equipment and climate, also find ways to reduce current energy use.
- Identify areas with high-energy consumption and locate spaces with overconsumption in order to minimize usage.
- Access the possibilities of making the building self-sufficient and make a cost analysis to see if an investment is profitable.
- Investigate the behavioral needs of students at INTEC.

2.2 Delimitations

To be able to approach the problem without going to vast, several limitations are set to concentrate the study. These can be shown below:

- The study focuses on energy management restricted to the library at the INTEC campus in Santo Domingo.
- No examples of systems will be constructed on site, only an analysis over possible technical, economic and environmental improvements will be suggested.
- Only available data will be taken into account and if assumptions are made they will be based on facilities or technology with similar character.

3 Method

The thesis will be planned according to prevalent standards for case studies which includes the following stages (Gustavsson, 2003):

- Planning and structuring
- Collection of data
- Analysis and interpretation
- Securing and evaluation of the quality
- Writing of report

3.1 Process of study

To achieve an energy management analysis on the INTEC Library in Santo Domingo a study was made through the perspective of energy minimization and sustainable development. The current energy situation as well as the projected long term progress had to be taken into account.

The steps of the study are shown in Figure 3.1. During the field study information was gathered through observations, measurements and advisory with responsible personal. Specific information of the energy use in the building was gathered through an energy audit conducted on the building. Among the information collected includes the exact amount of equipment such as computers and TVs etc., type of lighting used, specifications about the cooling and ventilation system and also the total amount of electricity used within a year. The data was later processed through Microsoft Excel and the energy management tool RETScreen. With the tools three types of simulations were made:

1. Technical – to conclude which solution is most efficient in regards of energy usage.
2. Environmental – to conclude which solution has the least impact on the environment.
3. Financial – to conclude which solution is the most profitable.

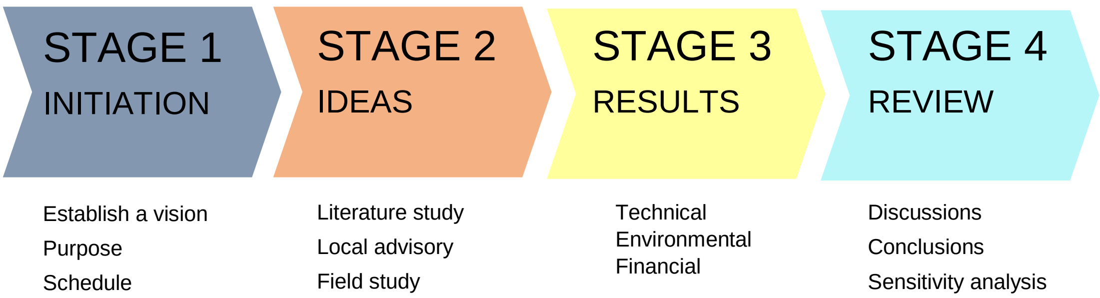

Figure 3.1 Methodology of project, step by step.

3.2 Modelling

RETScreen Energy Management is a clean energy software package developed by the Government of Canada. The software can help reduce energy costs by identifying and assessing potential energy improvements. First the software makes an analysis over the current energy use according to gathered data and later it allows users to determine whether or not a proposed improved case in terms of renewable energy, energy efficiency, makes financial sense. If a project is viable – or not. (NRCAN, 2016)

3.3 Energy Audit

The purpose of an energy audit is to determine where, why and how energy is used in a facility and to identify opportunities for improvement. The audit usually begins with a review of historical and current energy data.

Energy systems as a whole are often complex, involving many different components, flows, temperatures, etc. Large buildings are not an exception and almost all feature unique installations designed for specific purposes (Pacific Northwest, 2011).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines three levels of audits. Each audit level builds on the previous level. As audit complexity increases, so does thoroughness of the site assessment. (ASHRAE, 2011)

- **Level 1:** Site Assessment or Preliminary Audits is alternatively called a "simple audit" and is the starting point for a buildings energy optimization. It involves brief interviews with personnel and reviews of the facility's utility bills and operating hours. The ASHRAE level 1 can be defined as understanding the general building configuration and defining the type of activity the specific building is intended for. (Microgrid, 2010)

- **Level 2:** Energy Survey and Engineering Analysis Audits starts with the findings of the Level 1 audit and evaluates the building energy system in detail to define a variety of potential energy improvements. This includes the buildings lighting, heating, ventilation and cooling. The audit should result in a clear and concise report of modifications that can be made and also general costs. (Microgrid, 2010)

- **Level 3:** Detailed Analysis of Capital-Intensive Modification Audits focuses on a "whole-building computer simulation", where a computer program is used to accurately model the way the building would respond to changes in the energy system. It can be architectural modifications to walls, windows and roofs, but also financial aspects such as changes in electricity price. (Microgrid, 2010)

3.4 Energy Management

Energy efficiency means using less energy while fulfilling the requirements and needs of in this case a building, an energy management program is a strategy used to accomplish this. It is recognized as one of the most important and cost-effective solutions for reducing greenhouse gas emissions (GHG). Importantly, energy efficiency not only reduces GHG emissions, but it can also improve a sectors economic situation and productivity (OECD, 2015).

The methods to accomplish energy savings are:

- Examine the acceptance of the program at considered sector.
- Establish a checklist and a methodology for the implementation.
- Analyze the costs of the energy conservation method.

4 Literature study

To justify the needs for the building an extended literature review has been performed, this serves several purposes. First it enables the reader to understand more fully the underlying theory and research that has been made within the subject. Secondly, it enables the opportunity to identify needs for improvements. Thirdly, the review allows the reader to have a contextual background, to later understand the results in a bigger context.

4.1 Heat Balance in building and rooms

Thermal conditions in buildings depend on the magnitude of heat gains and losses. In warmer countries like the Dominican Republic temperature differences indoors versus outdoors usually differ. Buildings will tend to heat up when heat gains outweigh the losses, and to cool off in the opposite situation. Conditions of discomfort can easily be sensed when indoors, which, in extreme situations, require artificial cooling systems (cooling and/or heating). (Havtun et al, 2015)

Thermal balance in a building occurs when the sum of the heat losses and heat gains is zero, reaching a neutral point. (Havtun et al, 2015)

The main sources of gains and/or heat losses of a building are divided into six categories (Havtun et al, 2015):

- **Internal gains (Q_i):** Internal gains represent heat sources inside the building, including people, heaters, lights, and practically all energy consuming devices. A person performing light activities can add 180W of heat energy, a TV can add more than 300W, depending on its size. (Havtun et al, 2015)
  To estimate the internal heat gains it is recommendable to calculate the contributions at a given time. This means that it should not be assumed that all devices are turned on at the same time, it is necessary to establish a reasonable average. Some electronic manuals provide standard rates of internal heat gains in watts per square meter of floor space (W / m^2). In this case the rate will be multiplied by the total floor area to estimate total gains. (ASHRAE, 2013).

- **Solar gains (Q_s):** Solar radiation striking the building can generate significant heat gains. When it occurs through opaque surfaces (walls and roofs) it is called indirect gains, and when it occurs through transparent surfaces such as glass, it is called direct gains. (Designing buildings, 2016).

- **Gains or losses by Conduction (Q_c):** Gains and losses by conduction occur when there are heat flows through the building envelope (walls, roofs, windows and floors). The amount of heat gained or lost depends on the thermal characteristics of the materials, the difference between the indoor and outdoor temperature and the total area exposed. (Sol-arq, 2016). A great deal of the heat gains is emitted from windows. The U-value which is the overall heat transfer coefficient determines the thermal qualities of a material, and in windows, walls and doors, it is a crucial factor to have in mind since it measures the rate of heat loss through a material (Mayo Energy Agency, 2007).

- **Gains or losses on ventilation - convection (Q_v):** Gains and losses by ventilation occur when the outside air enters and circulates through the building, which also means that indoor air is expelled out. Ventilation can happen intentionally, through vents, windows and doors, or involuntarily, by infiltration through the building envelope. When the outside air temperature is higher than indoors, there will be heat gains and vice versa when the temperature outside is cooler than indoors. (Sol-arq, 2016).

- **Evaporation losses (Q_e):** Heat losses by evaporation occur when water evaporates and enters the air of the interior space. (CLEAR, 2016).

- **Heat and cooling requirement (Q_m):** This factor is generally considered as an independent variable that can be adjusted according to the other factors in the balance. This means that this factor can be controlled in order to achieve a balance. (Sol-arq, 2016). The heat balance in a building is defined by equation 1 below (Sol-arq, 2016):

$$Q_m = Q_i + Q_s \pm Q_c \pm Q_v - Q_e \qquad [1]$$

  If the Q_m value is greater than zero, cooling will be needed. On the other hand, if the Q_m value is less than zero, there will be the need for heating.

HVAC systems are expensive and lead to additional energy consumption in buildings, which can reach excessive levels. In that sense the designer should always try to reduce cooling requirements to a minimum by applying passive strategies, using better materials and construction systems, and taking advantage of available natural resources. (Havtun et al, 2015)

4.2 Thermal Comfort

In a building comfortable thermal environment is important. According to ASHRAE and ISO 7730 standards thermal comfort is defined as "that condition of mind that expresses satisfaction with the thermal environment" (ASHRAE, 2013).

Thermal comfort is then a subjective concept that expresses the physical and psychological wellbeing of a person when the conditions of temperature, humidity and air movement are favorable to our activities.

Based on experience in designing air conditioning systems, it has been determined that most people feel comfortable when the temperature is between 21 ° C and 26 ° C and relative humidity between 30% and 70% (Randall, 2005). These values apply when people are dressed in light clothing, shaded and fairly inactive. ASHRAE has conducted research over many years involving hundreds of people in an attempt to relate the factors of temperature, humidity and air movement to human comfort. The results of these tests show that different people react in different ways to atmospheric conditions that surround them (ASHRAE, 2013).

Evaluating the thermal comfort is a complex task, since sensation always involves an important subjective burden; however, there are some variables that influence the thermal exchanges between the individual and the environment and contribute to the feeling of comfort. Below is a summary of these factors. (Havtun et al, 2015)

Atmospheric Conditions:

- **Temperature:** The difference between the indoors temperature and the skin temperature determines the heat exchange between the body and the air, this exchange is called "convective heat exchange". There is also the radiative heat exchange between some environmental surfaces (skin, machinery, glass, walls, ceilings, etc.), which means that, for example, it can be comfortable to be in a house where the air temperature is 15 ° C, but its walls are 22 °C. If the skin temperature is greater than the mean radiant temperature, the body loses heat by radiation to the environment; if reversed, the body absorbs heat from the surrounding. (Havtun et al, 2015)

- **Humidity:** Humidity is the moisture content of water vapour in the air. The mechanism by which heat is removed from the body is transpiration. The more moisture there is, the lower the transpiration; that is why it is more pleasant to have dry heat than humid heat. An important value connected with the humidity is the relative humidity, which is the percentage of moisture in the air with respect to the maximum admitted. (Havtun et al, 2015)

- **Air Velocity:** The air velocity is directly involved in the thermal balance and thermal sensation, since, depending on the speed, the air layer that isolates the body varies and leads to an increase in the evaporation of sweat. (Havtun et al, 2015)

Labor Activity:
Regardless of environmental conditions, intense activities give us a greater sense of warmth. Our body converts less than 10 % of energy consumed into useful work; the rest is transformed into heat which must be removed to prevent the body temperature to rise to dangerous levels. (Sahta et al, 2014)

Clothing:
The type of clothing is an important variable that influences the sense of comfort; the greater the thermal resistance of the clothes, the more difficult it is for the body to transfer the heat generated to the surrounding. Thermal comfort is achieved when there is a balance between the heat generated by the body, and the capability of transmitting or absorbing heat. (Sahta et al, 2014)

4.3 Ventilation

Ventilation is crucial to maintain optimum air quality and thermal comfort in buildings. It is needed to dilute and remove pollutants emitted from the surrounding such as metabolism and activity from occupants (Havtun et al, 2015). Figure 4.1 shows common pollutants that can penetrate in and out of a building. Improving ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building.

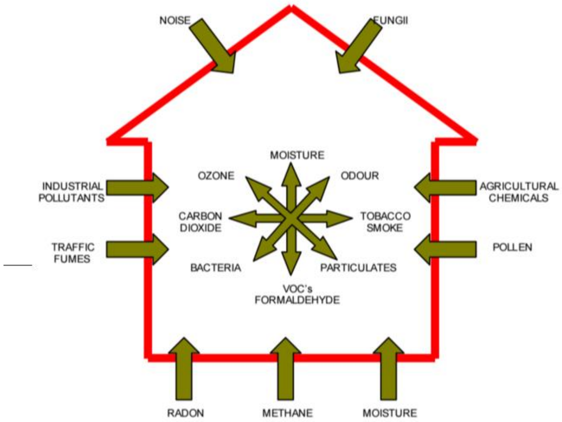

Figure 4.1 Possible pollutants in a building (Havtun et al, 2015).

The requirement of visitors and employees comfort is critical to consider when constructing a building and an important thing to have in mind is that every type of room has to be designed according to its intended activity. In most situations, air needs to be supplied and distributed mechanically using fans and ducts. Supply air provides a replacement for the air exhausted by the fans and helps to create a steady flow throughout the building. If the building consists of big spaces and few rooms it is often sufficient enough with one inflow and exhaust, but if the building consists of many smaller rooms it may require multiple ventilation units. Recirculation is also a good tool for ventilation, in this case filters remove pollutants and odors and then reintroduces the air back into the building (Maheshwari, 2012). Especially in commercial buildings with high cooling or heating load it is often beneficial to install an energy recovery system (ERV), these types of systems are used to reduce the exhaust of indoor heat in cool climates. However, they can be used for the same purpose in air-conditioned spaces. The ERV system will cool the incoming fresh air, by recycling the already refrigerated air from the climate systems (Cleanaire, n.d.). The system will not only cool the incoming air, it will also enhance the indoor air quality by regulating the humidity (HPR, 2015). Figure 4.2 illustrates how the ERV system functions during summer.

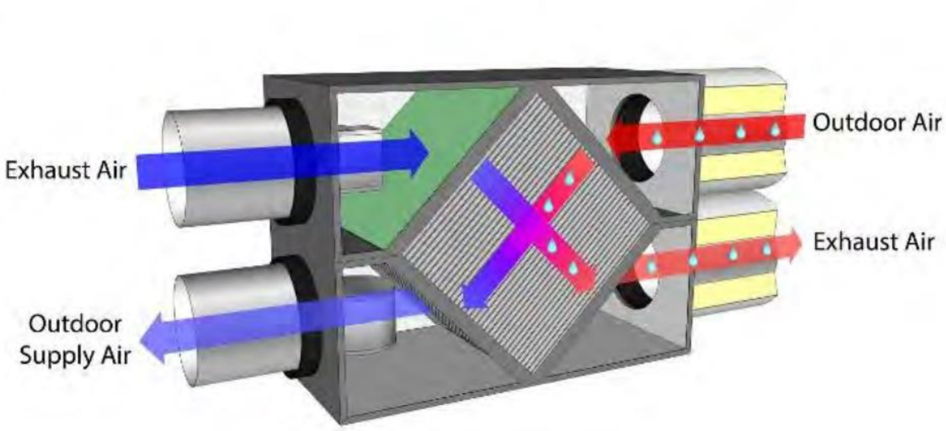

Figure 4.2 Illustration of an ERV systems function during summer. (Cleanaire, n.d.)

4.4 Heating

The average monthly temperature in Santo Domingo is almost never less than 25 °C (Worldbank, 2016). Certain days and night during the months of December to February the temperature can be lower but given the relatively short time heating might be needed, it is hard to justify the investment of a heating system.

4.5 Cooling

The purpose of cooling is to reduce and maintain the temperature of a body or substance below the outdoor temperature. (ASHRAE, 2013).
Air conditioning systems are used to monitor temperature, moisture content, flow and purity of air within a space and regulate the conditions in order to achieve desired thermal comfort for the occupants. During the last decades, the relative deficiency of conventional energy sources and costs have resulted in an evaluation of the design and application of air conditioning systems. The development of new technologies and processes to achieve comfort in buildings by natural means is prioritized, since globally, buildings are responsible for approximately 40% of annual energy consumption (C2ES, 2006).
Most rooms and areas do not need cooling 24 hours a day since they are not occupied during for example night and weekends. Although there are exceptions, for example server halls. These spaces need 24 hours a day cooling, since computers and screens in some cases cannot be completely switched off which leads to heat gains that have to be reduced.

4.5.1 The Vapour Compression Refrigeration cycle

The vapour compression refrigeration cycle has five essential components to cool and the cycle is illustrated in Figure 4.3 below (Refrigerating Engineering, 2015):

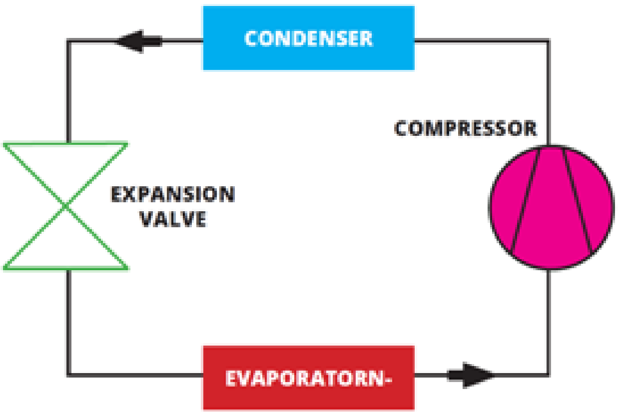

Figure 4.3 The vapour compression refrigeration cycle.

- **The refrigerant:** The refrigerant is a substance or mixture which circulate through the cycle, it undergoes state changes which allow heat transfer to happen between the surrounding and the refrigerant.
- **The compressor:** The function of the compressor in the refrigeration cycle is to compress the refrigerant from the evaporator in gaseous state to the condenser. This work is achieved by providing electricity.

- **The condenser:** The condenser is a heat exchanger, it removes heat from the high pressure refrigerant and reject it to the environment. This heat, in principle, is the sum of the heat absorbed by the evaporator and produced by the compression work.
- **The expansion valve**: The central function of the expansion valve in the refrigeration cycle is to provide the pressure difference established between the sides of high and low pressure of the refrigeration circuit.
- **The evaporator:** The evaporator is a heat exchanger, where the refrigerant absorbs heat from the environment in which it is located and evaporates. In the cycle heat is absorbed from indoors and transferred outdoors, resulting in the refrigeration of a space.

4.5.2 Central vs. split system

Central, "all air" conditioning systems (or package systems) are used in large buildings, hotels, theaters, airports, shopping centers, etc. Large compressors, condensers, expansion valves and evaporators are placed outdoors or in a machine room. The cold air from the system passes through ducts to all rooms, the amount of cold air needed for each room can be controlled by the vent openings depending on the total heat load in the room (Havtun et al, 2015).
An alternative to central systems is the use of splits systems, which are more suitable for individual or small office spaces. These systems use separate indoor and outdoor coils where the refrigerant travels throw a pipe instead of the cold air from the outdoor unit. The benefit of these units is the possibility of cooling spaces only when occupied (Mitsubishi, n.d.).

4.6 Lighting

One of the contributions to the load in a refrigerated space is lighting. It is especially important to have efficient lighting, since the cost of the operating energy must be paid for twice; first the user must pay for the electricity for the lights, and secondly for the operation of the refrigerating machinery to remove the heat from the lights.
There are several types of light bulbs with varying levels of efficiency, however this project will primarily look into Incandescent light bulbs and Light-emitting diodes.

Incandescent light bulbs: Incandescent lights produce light by heating filament wire until it starts to glow. These types of light bulbs are widely used, but are increasingly replaced in favor of more energy-efficient equivalents. They can be considered to be extremely inefficient since 90 % of the energy consumed is lost through waste heat and only small amounts is actually harnessed to produce light. (U.S Energy, n.d.)

Light-emitting diodes (LEDs): LEDs are gaining in popularity and availability; they work by moving electrons in order to release energy in the form of photons. It is proved that LEDs use at least 75 % less energy than incandescent bulbs, emit basically no heat, and lasts 25 times longer. However, they are significantly more expensive. (U.S Energy, n.d.)

In the Dominican Republic one of the largest consumers of electricity is lighting. CNE conducted a study and robust energy efficiency measures for lighting could save the country an estimated 848 MWh of electricity and 540 000 tons of CO_2 emissions per year (CNE, n.d.). Using natural daylight as a source of lighting is another good way to increase lighting efficiency, however increasing direct sunshine can lead to heat gains. By installing louvers, blinds or light shelves, direct sunlight can be avoided and in the meantime distribute daylight evenly across a surface (Erwine et al, 2001).

4.7 Equipment

In order to estimate the cooling load in a building, the heat gains from all appliances (electrical, gas, or steam) need to be taken in account. This can be very subjective for the reason that there is a large diversity of appliances, applications, schedules, uses, installations and that usually the only information available about the heat gain is on its specifications, which rarely reflect the actual power consumption. The real power consumption is assumed to be equal to the total heat gains (radiant plus convective).
Not only does electric equipment lead to heat gains, older models of computers and screens etc. are often more electricity consuming. Investments in more efficient units can reduce energy use. For instance laptops typically use 85 % less over a year compared to a CPU, and tablets can use up to 70 % less than a laptop (EST, n.d.).

4.8 Possibilities for Self-Sufficiency

Self-sufficient buildings generate energy by renewable energy sources, these kind of buildings as the name suggests do not need external energy, water supplies, waste management services and wastewater drainage and simultaneously offer the same quality as a non-self-sufficient building. The environmental aspect is also beneficial since the climate impact from a self-sufficient building is zero. However, in this project, self-sufficiency in the manner of electricity from photovoltaic solar panels will only be evaluated. (Self-Sustaining Building, 2016).

In order to accomplish self-sufficient buildings in terms of electricity from the sun, major investments have to be made in technology, however the average global horizontal irradiance (GHI), which evaluates solar energy potential in a region shows that investments can be profitable in the Santo Domingo area (Solargis, 2016). Table 4.1 shows the average monthly GHI for Santo Domingo, it ranges from five to seven kilowatt-hours per square meter per day (NASA, 2016).

Monthly Averages Insolation Incident On A Horizontal Surface													
Santo Domingo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average ($kWh/m^2/day$)	5.43	6.39	7.18	7.47	7.43	5.77	5.17	5.29	5.86	5.99	5.47	5.11	6.04

Table 4.1 Monthly Average GHI over Santo Domingo (NASA, 2016))

The power and the size of a PV system is determined by the available area and the investment capacity. In order to produce electricity for own use, it is very important to take in account the consumption of the building.

5 Field Study

An analysis of Energy Efficiency involves an extended energy audit, in order to quantify in which way buildings consumes energy resources.

This activity was performed in cooperation with INTEC, which have made qualified personnel available to facilitate the knowledge of the particular activities practiced and the equipment used in the library.

5.1 INTEC Library

INTEC is an institution of private higher education, the school was founded in 1972. It characterized by their academic offerings in engineering, business, medicine, environmental science and also social science. Today INTEC is a community of 5200 university students. The campus has six different buildings and over 60 classrooms. The building that will be studied during this thesis is the library and is located in the center of the INTEC campus. (INTEC, 2016a)

Biblioteca Emilio Rodríguez Demorizi is the library at the INTEC Campus and was completed in 1986. The total area of the building is 3197 m^2. An extended building envelope overview is presented in Appendix IV. Since its opening the facilities have undergone several minor renovations, although no alterations have been made to the windows and facades. (INTEC, 2016b)

The building consists of three floors, the first floor contains a large assembly hall, office spaces and also a lending desk for audio tapes. The floor is home of the school's radio station and a part of the space serves as a studio. The main entrance leads to the second floor, there is a large lobby, a lending desk, a large reading room and also an area for books. The top floor functions mainly as a study space for the students, the floor is divided into reading rooms but also individual study rooms. The remaining part of the books are also on the third floor.

5.2 Temperature measurements in the INTEC library

Measurements were made for temperature and humidity both indoors and outdoors on the 2nd of May 2016. Figure 5.1 shows how the indoor temperature and humidity is relative outdoors. The average temperature indoors hovers around 25 °C throughout the day, however outdoors the temperature increases as the sun rises. The indoor temperature is within the boundaries for what can be considered to be "good". Due to insulation and climate control systems indoor humidity is lower than outdoors throughout the day and during operating hours humidity levels indoor can be considered to be acceptable.

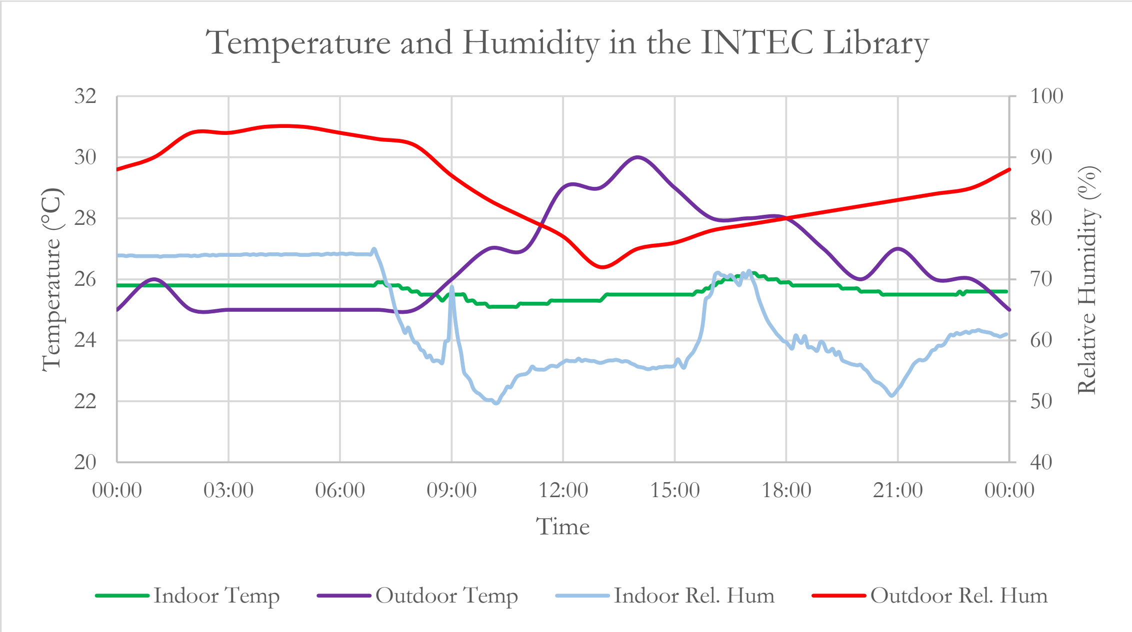

Figure 5.1 Measured temperature and humidity indoors and outdoors on May 2nd 2016.

5.3 Energy Use at INTEC Library

The INTEC library is constantly in use, computers, lighting, climate systems are operated 7.00 – 21.00. Although some units like servers and lights in the lobby are continuously powered on. The electricity was measured for a section of the INTEC library in April 2013. Figure 5.2 shows the hourly electricity use for a section of the INTEC Campus that includes the library, most electricity is consumed during the hours 9.00 – 17.00. These times are the office hours for employees but also the school hours. The monthly energy consumptions for the same section can be seen in Figure 5.3, the electricity use follows the pattern of the outdoor temperature; the hottest months between June and August are also the months when most electricity is consumed. This is due to the climate systems that are running on a higher load.

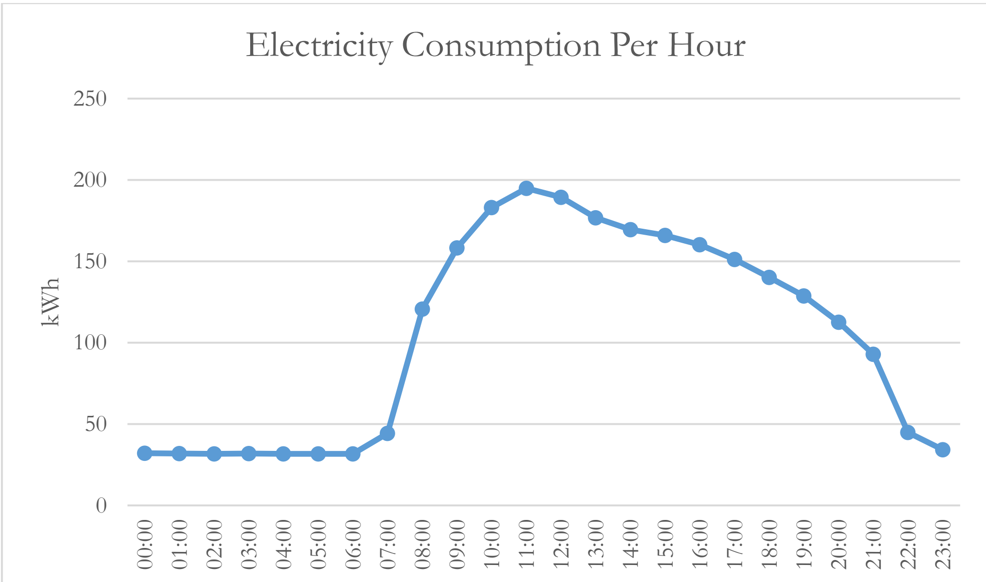

Figure 5.2 Average energy Consumption by hour for a section of the INTEC Campus for a five day interval. Measurement apply to the dates of 19-26th April 2013.

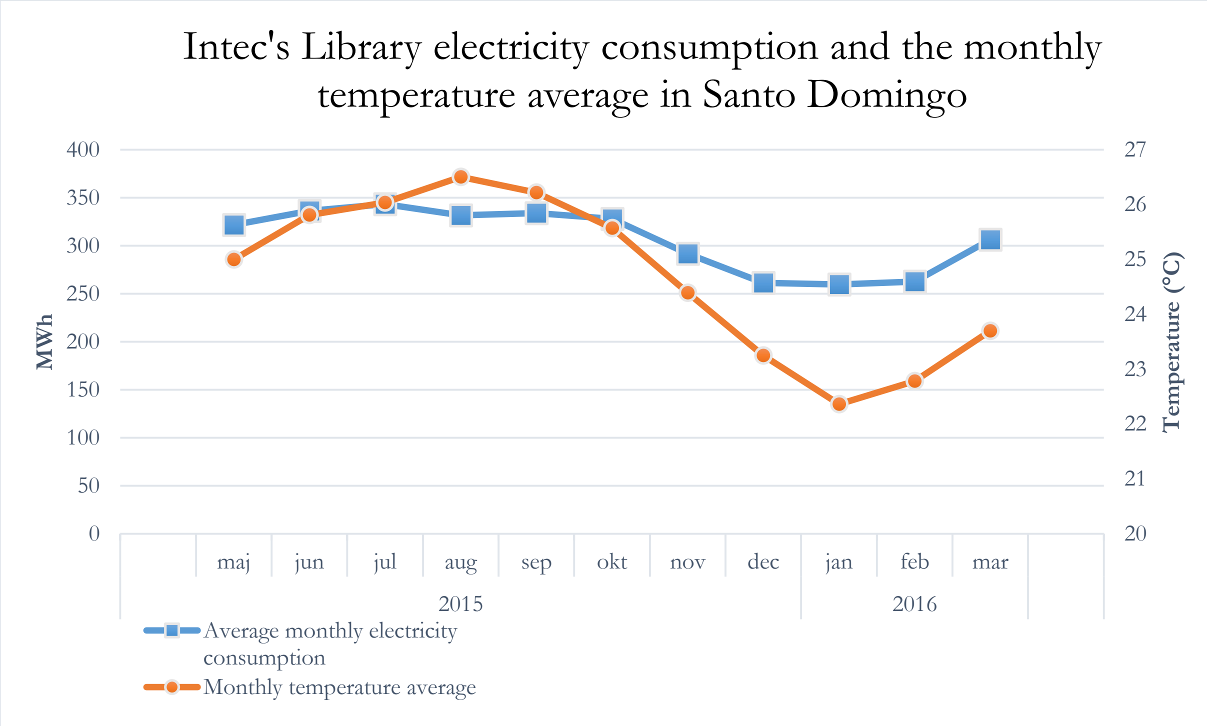

Figure 5.3 Electricity Consumption by month for several buildings at the INTEC. Month of April excluded. Measurements apply to the dates of 21st March 2015 to 19th March 2016.

5.3.1 Cooling

Centralized climate systems, or a standalone air conditioner are used in nearly all areas of the INTEC library and are crucial for the thermal comfort of the students and personnel occupying the facilities. ASHRAE defines comfort air conditioning as "the process of treating air to control simultaneously its temperature, humidity, cleanliness and distribution to meet comfort requirements". The climate systems in the library works according to the vapour compression refrigeration cycle where heat is removed from indoors trough radiation, convection or conduction. The Air conditioning in the INTEC library is accomplished by the use of a central system with 7 outdoor units and 10 smaller split systems. The Table 5.1 below shows the amount of air conditioning units, the cooling capacity in tons of refrigeration and the year when the units were installed. The energy audit revealed that an area of 1054 m^2 is climate controlled, the rest is ventilated and cooled by natural means. In the INTEC library the ventilation system is integrated into the central climate system, areas that are not climate controlled are ventilated with windows and ducts.

Model	Quantity	Cooling Capacity (RT)	Cooling Capacity (kW)	Year of purchase
Carrier, direct expansion	7	15	53	1986
TGM and Comfort Master, direct expansion	5	5	18	2006
Comfort Master	3	4	14	2010
Comfort Master	2	1	3,5	2010
AMICO AC Server Room	1	2	7	2000-2016
Total	18	27	95,5	-

Table 5.1 AC-units currently used in the INTEC library.

5.3.2 Lighting

The INTEC library changed all their CFLs to LEDs in 2014. The initial investment cost was 50 470 USD and the project is projected to be profitable within 2,5 years. It has also lead to an annual GHG emission reduction of 107 tons $CO_{2.}$ (Airis, 2013)

Since the country is situated near the equator, the suns path over Santo Domingo is directly from west to east (Figure 5.4), and because most of the windows at the INTEC library are not exposed to direct sunlight. Also since the lighting in the library is recently upgraded, there is no need to use the sun as effective lighting.

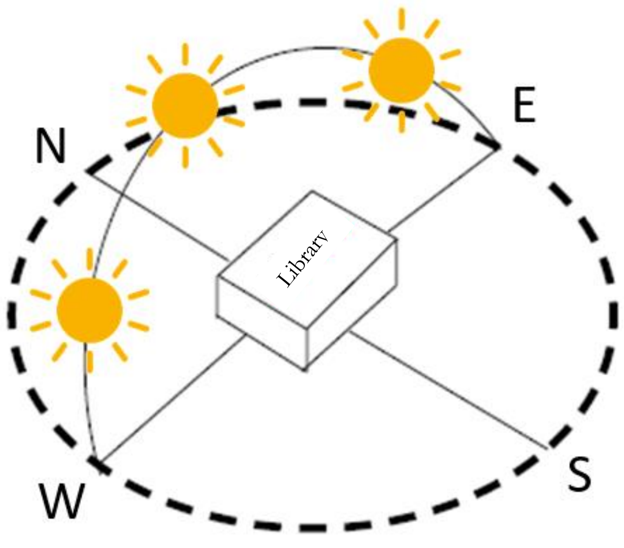

Figure 5.4 Sun's path over the library. North and south side of the building is not exposed to direct sunlight (Appendix IV).

In the book halls in the INTEC library, infrared sensors are used as an accessible tool to improve the energy savings of lighting. The system turns off the lights when the building space is unoccupied. However, there are still several areas like stairwells and corridors where the use of infrared sensors could be beneficial. Not only does the avoided lighting save electricity, it also reduces the need for cooling, for every 3W of lighting there is an increased cooling need of 1W. (Worldwatch, 2015).

5.3.3 Equipment

To meet the demands of student and employees the library has an extended amount of electrical equipment. An inventory is listed in Table 5.2. Operating hours of electric equipment are estimated from the opening hours of the library. Servers and radio station equipment need uninterruptable power supply.

Description	Quantity	Operating hours
CPU	51	13
Monitors	81	13
NAS	30	13
Printers	10	13
Copy Machines	1	13
Servers	1	24
Radio station	1	24
Television screens	2	13

Table 5.2 Inventory list and operating hours of electrical equipment in the library.

5.3.4 Generators

Electricity loss is a major problem, aging grid and electricity theft contribute greatly to grid inefficiencies. Because of the inefficiencies power shutdowns occur every day and the need for backup generators is essential.

There are two generators with a total capacity of 608 kW installed at the INTEC library, however there are no output meters installed at any generator at the whole campus. This makes it impossible to know how often they are in use and how much they consume. Lack of measurement points is a consistent problem at INTEC, and the only data the school has for the generators is the diesel bill that includes the fuel consumption from all the generators of the campus. However, since power outages occur every day, it can be concluded that the generators are frequently in use.

5.4 Photovoltaic project proposal

In 2009 a preliminary PV investigation was presented for the INTEC library, an installation with a nominal output of 28 kW was proposed. Six PV panels that would cover 201,2 m^2 were to be placed on the roof of the library. Specifications for the equipment is listed in Appendix V. Annually the project was estimated to generate 45,5 MWh, the initial investment cost was calculated to be 174 274 USD. (Guillermo, 2009) At the moment the proposal has not yet been realized and it is not known if it is to be.

6 Results from simulations in RETScreen

Following chapters shows the results from simulations in RETScreen, and the assumptions and the uncertainties that had to be evaluated.

6.1 Assumptions and Uncertainties

All simulations and models have been made in RETScreen, the program is used for energy modeling in different types of buildings. However, since the program is a freeware, meaning available free of charge some functions are slightly simplified compared to other energy management programs. What could be questioned is that the program does not take all heat gains into consideration, there is for instance no way of simulating the occupancy flow or additional wear on the building. These factors affect the cooling load on the building.

There is no way of acquiring accurate statistics for electricity use since several buildings are linked to the same measurement point, hence it is impossible to assure that the calculated total electricity use is truthful. Due to lack of data for electrical components and HVAC systems, assumptions had to be drawn, data for similar equipment has been used. Assumptions were also made for the average daily usage of computers, printers and lights etc. The assumed values for the duty cycles for electrical components and coefficient of performance (COP) for cooling systems are listen in Table 6.1 and Table 6.2. Typical heat gain values for office appliances are taken from Appendix I.

Description	Electricity load (kW)	Duty Cycle (%)
CPU	0,69	50
Monitors	0,24	50
NAS (Network-attached storage)	0,04	100
Printers	0,48	17
Copy Machines	1,75	17
Servers	14,4	100
Radio station	1,5	100
Television screens	0,2	100

Table 6.1 Assumptions made for duty cycle regarding the electrical equipment in the INTEC library.

All electrical devices are used regularly, though components like printers, copy machines and monitors are only used occasionally. Devices like laptops and phone chargers are excluded from the modelling since there is no way of calculating when they are in use.

Unit	COP (Reference)	Duty Cycle (%)
Air Conditioning 15 ton	2,5 (CTW, 2016)	50
Air Conditioning 5 ton	2,7 (Appendix II)	50
Air Conditioning 4 ton	2,7 (Estimated)	50
Air Conditioning 1 ton	2,7 (Estimated)	50
AMICO AC Server Room	4,2 (Appendix II)	50

Table 6.2 Assumed duty cycle for AC-units in the library

Since there was no way of calculating the power input or output for the climate control systems no exact COP was retrieved, however for the 5 ton unit and the AMICO unit in the server room, specifications were found and are listed in Appendix II. An estimation was made that the 1 and 4 ton unit had similar COP as the 5 ton since they were of similar model. No specifications for the 15 ton units purchased in 1986 was found, when comparing to similar systems a conclusion was made that an appropriate approximation of COP is somewhere from 2,2-3,8 (CTW, 2016).

To prevent AC from icing it is preferable to run the units at less than half the time, therefore a rule of thumb for the duty cycle is approximately 50 % (Carlyle, 2012).

U-values and infiltration losses are impossible to accurately determine without having advanced measurement instruments. Hence, the U-values and infiltration losses are estimated only from observations. Windows and doors are made of single paned glass and most walls are of solid concrete. There are also infiltration losses in the ventilation system since there is no recirculation installed. Appendix VII shows the windows and doors in the INTEC library. U-values for windows and doors are estimated to 6,63, for the concrete walls 0,87 is chosen (Yunus et al, 2015). It can also be seen in the Appendix VII that all windows cannot be completely closed which lead to infiltration losses.

Since there is no way of knowing the exact usage, the electricity production from the generators are excluded from all simulation.

6.2 Total Energy Use

All gathered data has been simulated in RETScreen Figure 6.1 shows how the electricity use is distributed in the INTEC library. The total annual electricity use is 1250 MWh. The majority of the electricity is consumed by the climate system, the second largest consumer is equipment which stands for 22 %. After changing to LEDs the lighting accounts 7 % of the total electricity consumption.

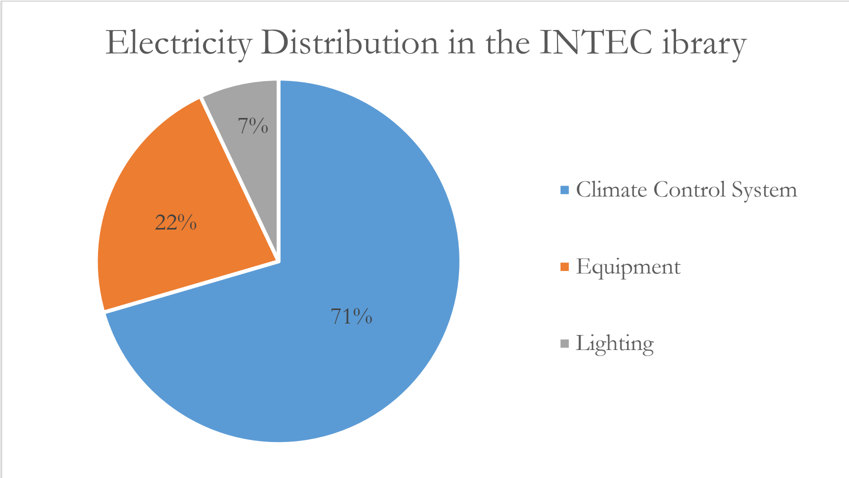

Figure 6.1 Breakdown of total electricity distribution.

6.3 Electricity for lighting

Figure 6.2 shows the amount of electricity saved after all lights were changed. According to simulations in RETScreen and quotation from the installation company, changing from lightbulbs to LEDs has led to annual electricity savings of 60 % it has also decreased the cooling load on the building (Airis, 2013). Furthermore, after simulating the change in RETScreen, it is shown that the savings in electricity for lighting will lead to annual GHG reductions of 107 tons CO_2.

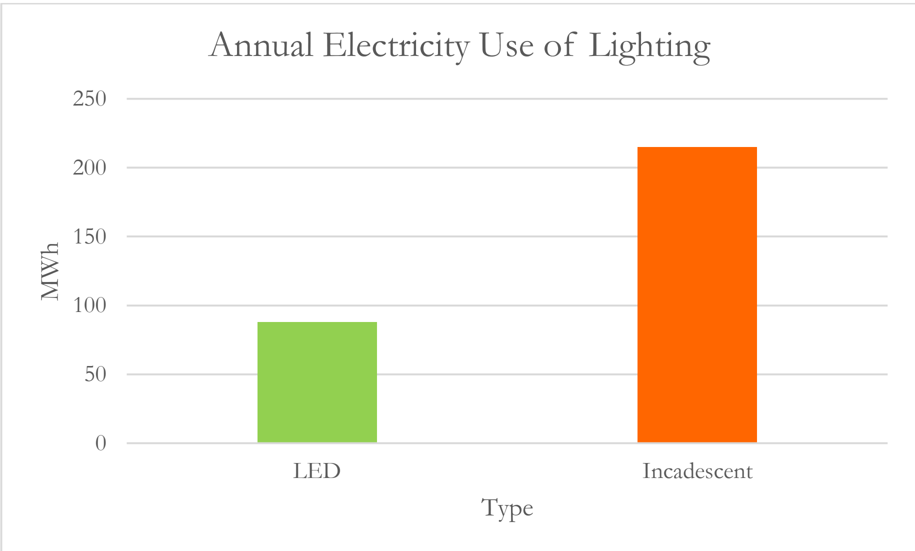

Figure 6.2 Comparison of electricity use before and after changing to LED-lights.

7 Improvements simulated in RETScreen

In this chapter improvements for the INTEC library are suggested, among these is the transition to a more efficient climate system and also improvements on the electrical equipment.

7.1 Improved Climate systems

Since seven of the central air-conditioners are thirty years old there are more efficient alternatives on the market, an investment in newer units can reduce energy usage substantially. Another easy solution for reducing energy use is to install thermostats in areas that are infrequently occupied, this allows occupants to turn on and off cooling. Changing or cleaning filters regularly will improve the airflow and decrease the load on the system, clean filters will also prevent dust and dirt from building up in the system (EPA, 2009). To better evaluate the energy consumed for cooling it is important to install temperature, flow and energy meters. At the moment there is no way of knowing how much energy is consumed for cooling, and if no record is kept it is difficult to evaluate when there is need for improvement.

In the proposed case the air-conditioning system Carrier 30HXC-271 is chosen (3 units), the units have a COP of 4,9 and a cooling capacity of 15 RT (Carrier, 2016). When the design temperature for the proposed case is set as 30° C which is the highest expected outdoor temperature (Worldbank, 2009), simulations show that the building needs 265 MWh electricity annually for cooling. When simulating the current energy use in RETScreen, the building has an electricity consumption of 881 MWh for cooling, see Figure 7.1. If the suggested installation was installed, annual electricity use for cooling would be reduced by 70 %. In this case, RETScreen makes an energy balance calculation and take into account all the heat gains (electrical equipment, infiltration, radiation and convection) in order give a result of the total cooling used in the building (RETScreen, 2016).

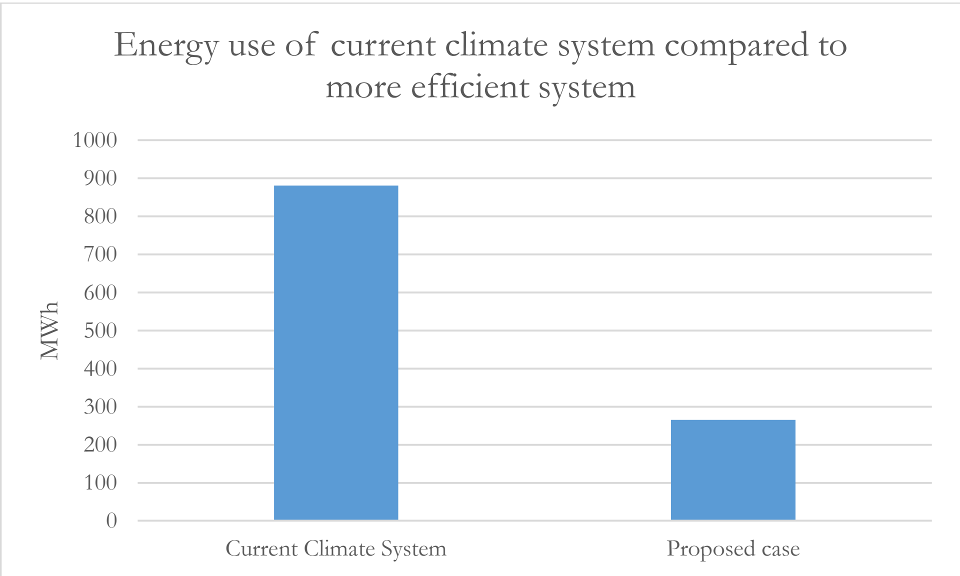

Figure 7.1 Electricity use for current and proposed climate system.

7.2 Decrease infiltration in windows and doors

Infiltration loss is a big issue in the INTEC library. Windows and doors are not insulated properly. Often doors between cooled and uncooled areas are kept open and that leads to major energy losses. To ventilate study rooms windows are often opened which lead to losses in cooling but also heat gains from outdoors. Another option could be to install revolving doors to the main entrance that would reduce infiltration when doors are opened.

RETScreen also show that if infiltration in the library was reduced by 50 %, the cooling load could be decreased by 9 %. This could be achieved by repairing cracks, insulating frames or simply by closing doors and windows.

7.3 Improved electrical equipment

There are improvements that can be made for the electrical equipment in the library. Since the computers are not used for high performance work, it is not necessary to use separate CPU units. CPU units do not only have a higher electricity load they also emit more heat, by connecting all 81 monitors to the servers lead to reductions in electricity use for equipment, furthermore it reduces the cooling load on the building were savings also can be made. Copy machines and television screens are only used partially during the day and it is not seen feasible to change these units. Figure 7.2 shows how the electricity use would decrease from more effective equipment and how the cooling load would reduce by avoided heat gains.

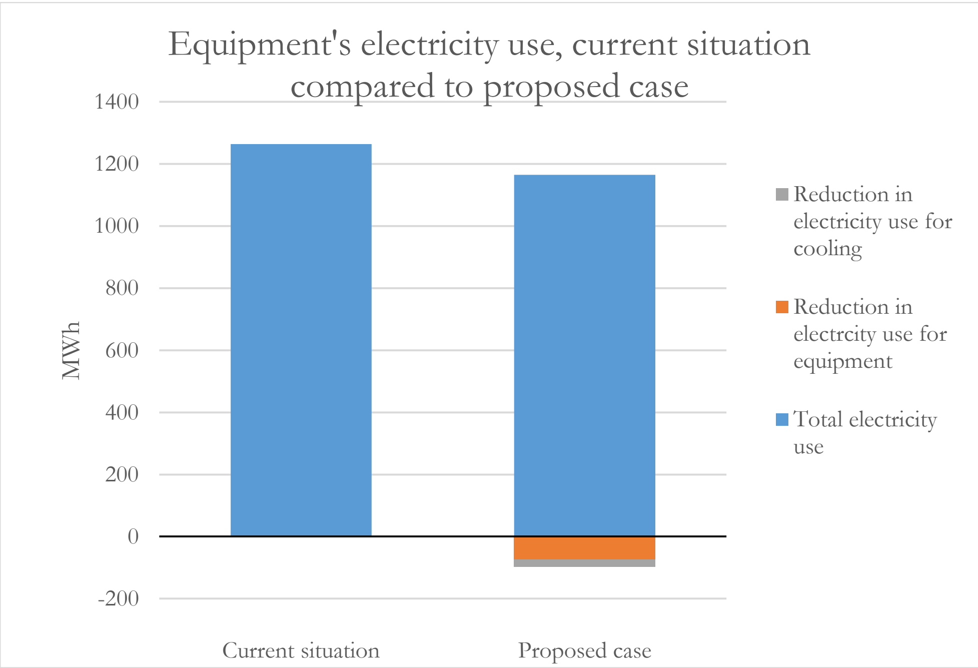

Figure 7.2 Reductions in electricity consumption if investments were made in new technology.

7.4 Conclusion of improvements

After applying the proposed case the electricity use will be distributed as can be seen in Figure 7.3. Instead of 74 % the electricity distribution for climate systems will land at 47 %.

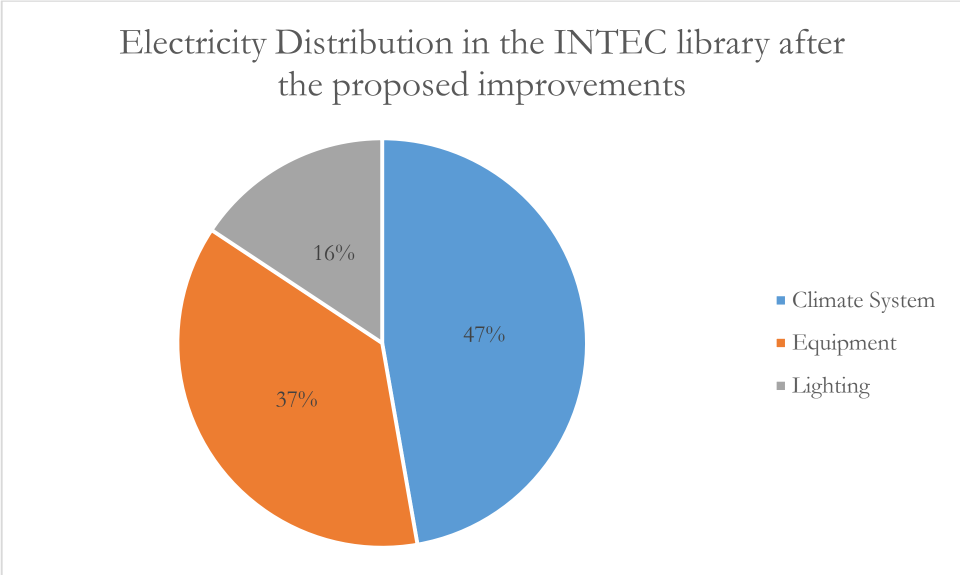

Figure 7.3 Electricity breakdown after proposed case is implemented.

Figure 7.4 shows the amount of electricity that can be saved with the proposed case that includes, improved HVAC system and equipment. By installing a new climate system as much as 616 MWh annually can be saved on cooling, by improving electrical equipment 74 MWh can be saved. In total 690 MWh in electricity per year can be avoided by implementing the proposed case. Which is a 56% decrease compared to the current situation.

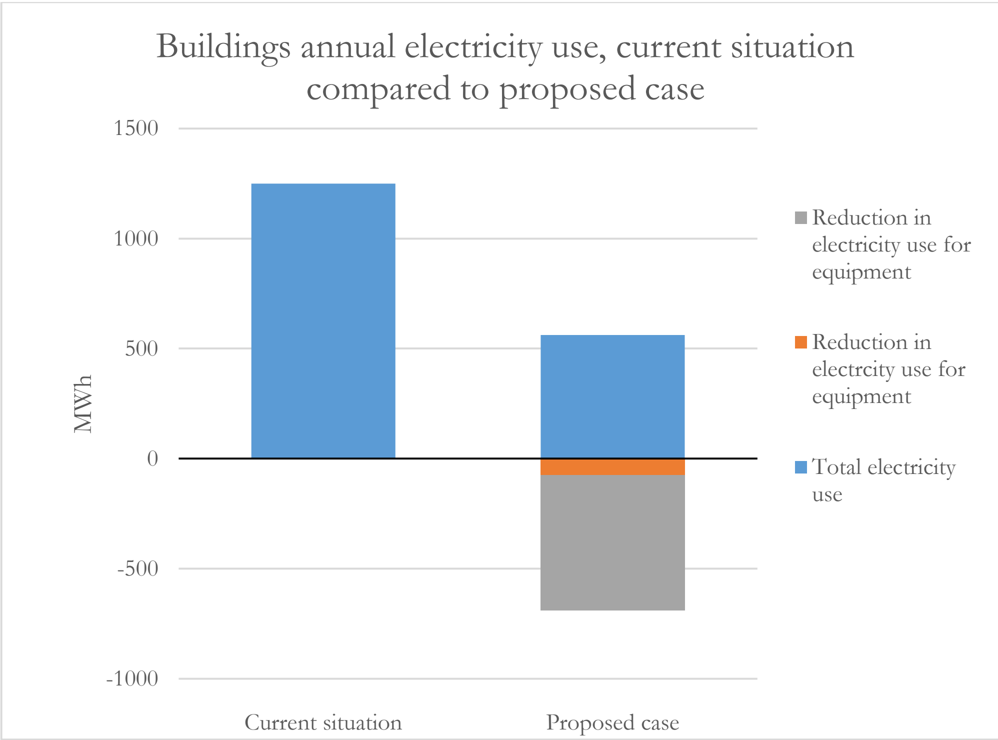

Figure 7.4 Illustration over electricity reductions that can be with the proposed case, compared to the current situation.

By realizing the proposed solar panel project, the library will partially become self-sufficient. It will reduce electricity costs but it will also lead to reductions of greenhouse gases. According to simulations in RETScreen, it is estimated that the solar project can produce up to 55 MWh electricity per year, and a decrease of GHG by 32 tons CO_2. This calculation was for 201,2 m^2 of solar panels. In the current situation the solar-project would only cover 4 % of the total electricity use, for the proposed case it would cover 10 % (Figure 7.5).

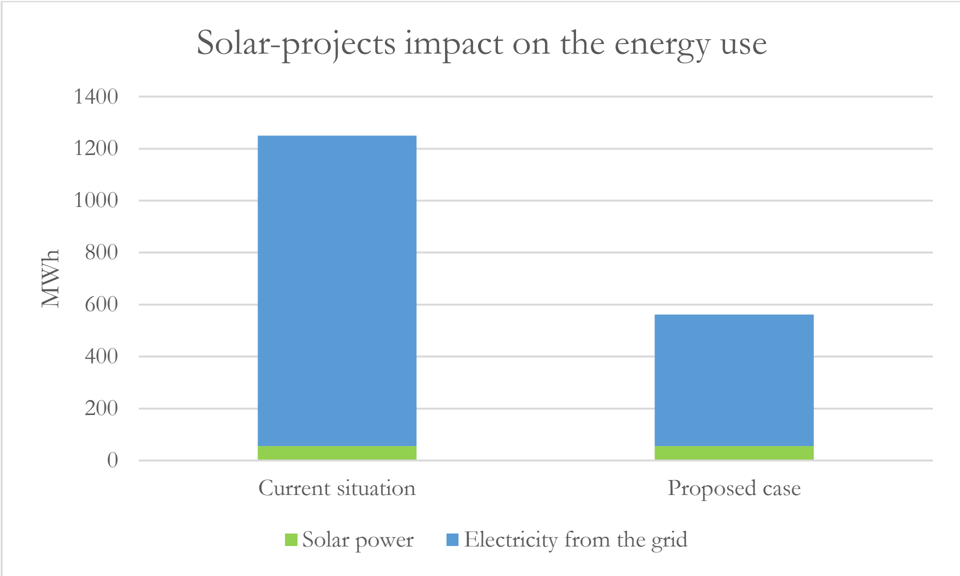

Figure 7.5 Proportion of what solar electricity would cover if solar project would be realized.

Figure 7.6 shows greenhouse gas emissions for the current situation and for the proposed case. Not only could electricity use be decreased, but GHG emissions annually could be reduced by 53 %.

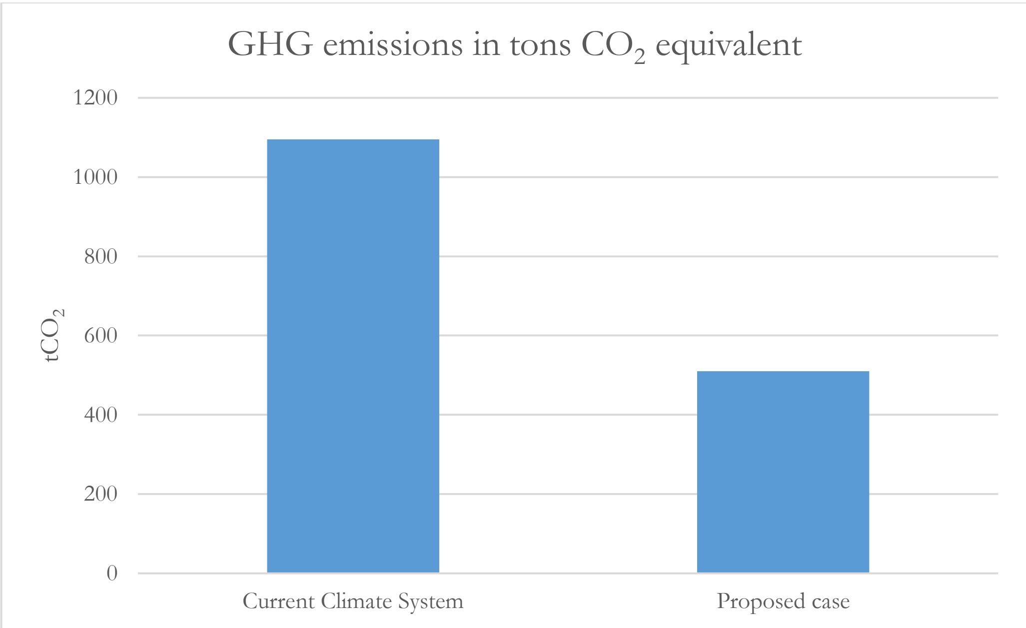

Figure 7.6 Current greenhouse gas emissions and for proposed case.

7.5 Financial results

The results show that the costs for the electricity is massive in the current situation, INTEC pays $212 554 annually to power up the library. However, the improvements implemented in the proposed case lead to savings of $117 238 annually. For instance, RETScreen simulations show that a hypothetical investment in improved climate systems and electrical equipment of $1 000 000 could have a payback period of 8,5 years, when factors such as inflation rate, project life, debt ratio, debt interest rate and debt term are taken in account (Appendix III). Another simulation was made for an investment to improve the building envelope and is also included in Appendix III.

7.6 Sensitivity analysis

Depending on the countries development in the energy sector, electricity prices will most certainly change over time. A sensitivity analysis for the scenario where electricity price increases and decreases with 50 % has been performed. The changes for the annual electricity spent is practically linear with the change in electricity price for both the current and proposed case, see Figure 7.7. However, the current case has a steeper incline than the proposed case. This once again proves that the proposed case will long term be more profitable.

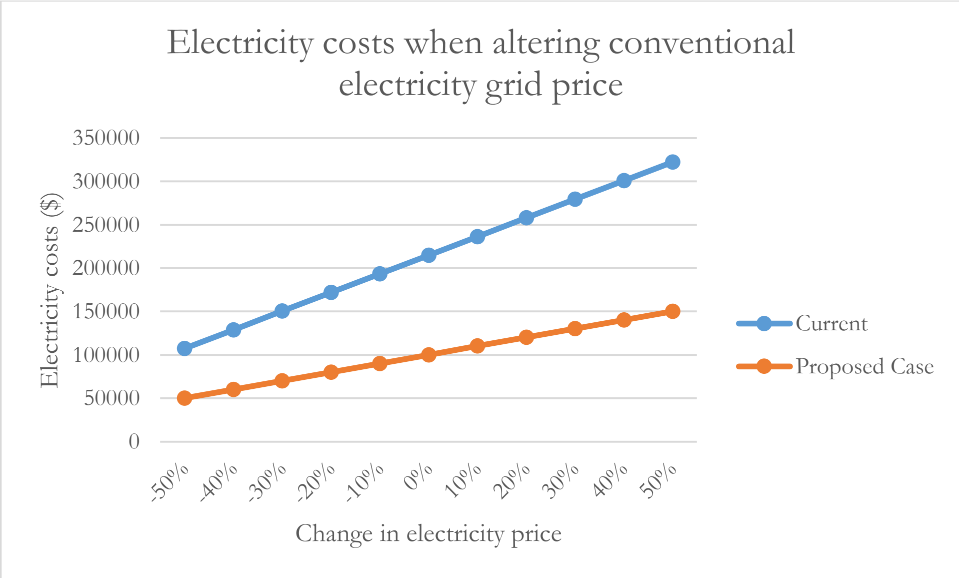

Figure 7.7 Sensitivity analysis of the buildings yearly electricity cost, when altering the electricity price.

One of the parameters estimated are the duty cycles for the air-conditioners, since the duty cycle varies with the outdoor temperature the electricity use will change with it. In Figure 7.8, it can be seen that the increase-rate in electricity is higher for the current system compared to the proposed. This could be explained by the fact that the proposed system consists of more efficient AC-units, the current installation has several units with varied efficiency.

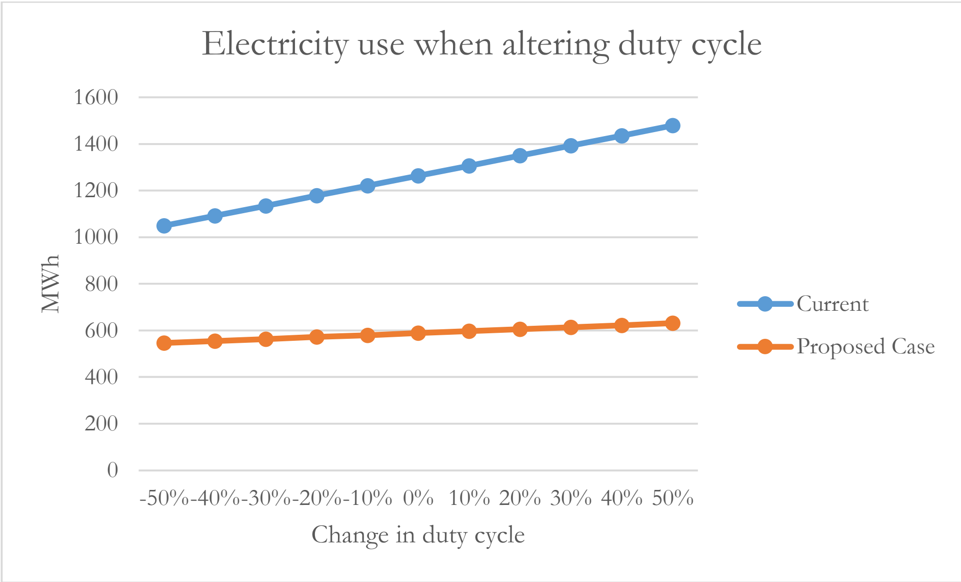

Figure 7.8 Sensitivity analysis of buildings electricity use when altering the duty cycle.

8 Discussion

For a building of such size the electricity use can be considered to be extremely high. This can mostly be blamed on the inefficient AC-units that are in use and the fact that the building has an installed cooling load of 509 kW which is 340 kW more than what is actually needed. Another explanation for high electricity use for cooling is that infiltration losses are high, windows and doors are not energy efficient and are often left open. An option could be to replace them, however in many cases it is sufficient enough to properly insulate and seal openings. The LED project shows that the school is taking measurements to reduce electricity use and significant results has been achieved, although it is not enough to improve the overall energy use. The electronic equipment that is being used, could be improved, but is in line with what can be considered normal for a building of such purpose. Savings can be made by investing in electrical equipment and improving insulation, however if an investment was made in new climate systems major energy reductions could be accomplished.

Changing climate systems will lead to savings, but if overall attitude from occupants towards electricity use and sustainability is kept the same, no investments will lead to long term improvement. Policies and rules has to be introduced for the future development of the building sector. Since there are no agencies regulating and forcing the sector towards sustainability there is no motivation or obligation to further develop. In commercial buildings air-conditioning is often overconsumed, in areas that are unoccupied AC-units are often left running. Another major issue is that many buildings like the INTEC library have no way of measuring the electricity use, often several buildings are connected to the same electricity meter, hence makes it impossible to make accurate energy audits. Inventory lists are in many cases not updated, equipment like compressors and filters can be replaced without being recorded and all these factors makes it more difficult to monitor the actual electricity consumption.

The proposed solar panel is a good intention, and PV systems offer environmental superiority over electricity generation from conventional resources, but taken in account the current electricity consumption it will not lead to a considerable change and investment in the project is not financially viable. However, since the proposed project is from 2009 it might be time to look over the possibilities for partial self-sufficiency since more efficient technology is available.

Not only do improvements lead to energy savings, but it will also lead to reductions in greenhouse gases. On the whole, if energy management projects would be conducted and fulfilled it will help the country to achieve the MDGs that have been set.

The reliance on imported fuels has led to high cost of generation and significant increase in foreign debt, and it is clear that a transition to a sustainable electricity sector based on the use of renewables is technically feasible in the Dominican Republic. However, rising energy demand will require further capacity additions. Significant investments have to be made, but since the country has high potential for renewables, long term it will prove to be profitable.

Not all factors are taken in account in RETScreen, which may have affected the results. For instance, there is no way to measure the exact amount of infiltration in the building, no way of knowing the circulation of people at every moment and if occupants use laptops or change phones. Also the simulation is made for 365 days, holidays and weekends which have slightly different conditions are not taken into consideration. However, on the whole, the results do reflect the actual energy breakdown.

9 Conclusion and Future work

What can be concluded from the discussion and overall from this report, is that there are possibilities for reductions in energy use. HVAC systems are inefficient and consume more electricity than what is considered to be reasonable, improved building envelope could help reduce energy for climatization and help save significant amounts of money. However, since there is no way of measuring the electricity consumption it is hard to conduct an energy management project. If the current energy use is not known, there is no way of knowing how much energy is saved when applying an improvement. Computer simulations will give an overall overview but there are many factors that cannot be replicated, this makes it hard to say if results are completely accurate. Therefore, for future projects it is suggested that proper measurements of exact energy use are taken.

What also can be concluded is that policies and regulations within the building sector has to be implemented if change is going to take place. At the moment the majority of the population are not environmental aware, and as a social project it may be appropriate to educate the population in energy management and how the current situation effect on global level. This could be achieved by handing out surveys to students and employees and investigate their perception of the situation.

What can be said is that if other buildings on the INTEC Campus have the same conditions as the library, the reductions in energy use that can be made are immense.

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Appendix I. Heat gain values for electrical equipment

Equipment	Description	Nameplate Power, W	Average Power, W	Radiant Fraction
Desktop computer	Manufacturer A (model A); 2.8 GHz processor, 1 GB RAM	480	73	0,10
	Manufacturer A (model B); 2.6 GHz processor, 2 GB RAM	480	49	0,10
	Manufacturer B (model A); 3.0 GHz processor, 2 GB RAM	690	77	0,10
	Manufacturer B (model B); 3.0 GHz processor, 2 GB RAM	690	48	0,10
	Manufacturer A (model C); 2.3 GHz processor, 3 GB RAM	1200	97	0,10
Laptop computer	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 430 mm screen	130	36	0,25
	Manufacturer 1; 1.8 GHz processor, 1 GB RAM, 430 mm screen	90	23	0,25
	Manufacturer 1; 2.0 GHz processor, 2 GB RAM, 355 mm screen	90	31	0,25
	Manufacturer 2; 2.13 GHz processor, 1 GB RAM, 355 mm screen, tablet PC	90	29	0,25
	Manufacturer 2; 366 MHz processor, 130 MB RAM (355 mm screen)	70	22	0,25
	Manufacturer 3; 900 MHz processor, 256 MB RAM (265 mm screen)	50	12	0,25
Flat-panel monitor	Manufacturer X (model A); 760 mm screen	383	90	0,40
	Manufacturer X (model B); 560 mm screen	360	36	0,40
	Manufacturer Y (model A); 480 mm screen	288	28	0,40
	Manufacturer Y (model B); 430 mm screen	240	27	0,40
	Manufacturer Z (model A); 30 mm screen	240	29	0,40
	Manufacturer Z (model C); 380 mm screen	240	19	0,40

Table I.1 Recommended Heat Gain from Typical Computer Equipment (2013 ASHRAE Handbook-Fundamentals (SI))

Equipment	Description	Nameplate Power, W	Average Power, W	Radiant Fraction
Laser printer, typical desktop, small-office type	Printing speed up to 10 pages per minute	430	137	0,30
	Printing speed up to 35 pages per minute	890	74	0,30
	Printing speed up to 19 pages per minute	508	88	0,30
	Printing speed up to 17 pages per minute	508	98	0,30
	Printing speed up to 19 pages per minute	635	110	0,30
	Printing speed up to 24 page per minute	1344	13	0,30
Multifunction (copy, print, scan)	Small, desktop type	600	30	
		40	15	
	Medium, desktop type	700	135	
Scanner	Small, desktop type	19	16	
Copy machine	Large, multiuser, office type	1750	800 (idle 260 W)	
		1440	550 (idle 135 W)	
		1850	1060 (idle 305 W)	
Fax machine	Medium	936	90	
	Small	40	20	
Plotter	Manufacturer A	400	250	
	Manufacturer B	456	140	

Table I.2 Recommended Heat Gain from Typical Laser Printers and Copiers (2013 ASHRAE Handbook-Fundamentals (SI))

Appendix II. Specifications AC-units

Specifications for 5 ton AC-unit.

Commercial A/C

TCV3_B

Three Phase Vertical Discharge Condensing Units / Unidades Condensadoras de Descarga Vertical Trifásicas

Features and Benefits

- Copper tube aluminum fin coils / Serpentín de tubería de cobre internamente estriado con aletas de aluminio tipo acordeón
- Plastic-coated grille and plastic mesh for protection / Rejilla acabada con plástico anti-corrosión
- Pedestal base with drain holes / Base tipo pedestal (2 ½ pulgadas sobre el suelo) con agujeros y ranuras de drenaje
- Permanently lubricated motor / Motor lubricado permanentemente
- Easy access service panels to controls and compressor / Paneles de acceso facil para servicio y mantenimiento
- Full Service valves with brazed connections / Válvulas de servicio con conexiones soldadas
- 5 minute delay control to extend compressor life / Protección del compresor con retardador de tiempo de 5 minutos
- Powder coated paint finish tested to 950 salt spray hours / Pintura tipo polvo electrostático que sobrepasa prueba de spray de agua salada de 950 horas (standard de industria solo 450 horas)

Technical Specifications / Especificaciones Técnicas

Model/Modelo TCV3		036B	048B	060B
Capacity/Capacidad	Btu/hour - Btu/hora	36,000	48,000	60,000
Voltage/Hertz/Phase - Voltaje/Ciclos/Fases			208-230V / 3PH / 60Hz	
Electrical Data/Data Electrónica	Amps	12.1	15	19
	Delay fuse Max.	25	30	40
	Min. circuit ampacity	14.8	18.4	23.4
SEER		10	10	10
Coil/Serpentín	Area	10	15.3	15.3
	Rows-FPI	1 - 16	1 - 16	1 - 16
	Tube Dia.	3/8	3/8	3/8
Fan Motor/Ventilador Moto	Type	PSC	PSC	PSC
	Amps	1.25	1.4	1.5
	Watts	160	245	245
	HP	1/8	1/4	1/8
Fan Blade/Aspa de ventilador	Dia. In.	18	24	24
	No. blades	3	2	3
	SCFM	2500	3300	3300
Compressor/compresor	RLA	10.8	13.6	17.6
	LRA	65	90	105
Refrigeration/Refrigeración Connections/Conexiones	liquid/liquido	3/8	3/8	3/8
	suction/succión-15ft.	3/4	7/8	7/8
	25ft.	3/4	7/8	1 1/8
Net Dimensions/Dimensiones Netas Inches/Pulgadas	Height	26.5	26.5	26.5
	Width	22.5	30.5	30.5
	Depth	22.5	30.5	30.5
Net Weight/Peso Neto	Pounds/Libras	145	178	216

13 | TGM Air Conditioning Systems

Specifications for COP value when design temperature is set as 30°C. From graph it can be estimated to 3,7.

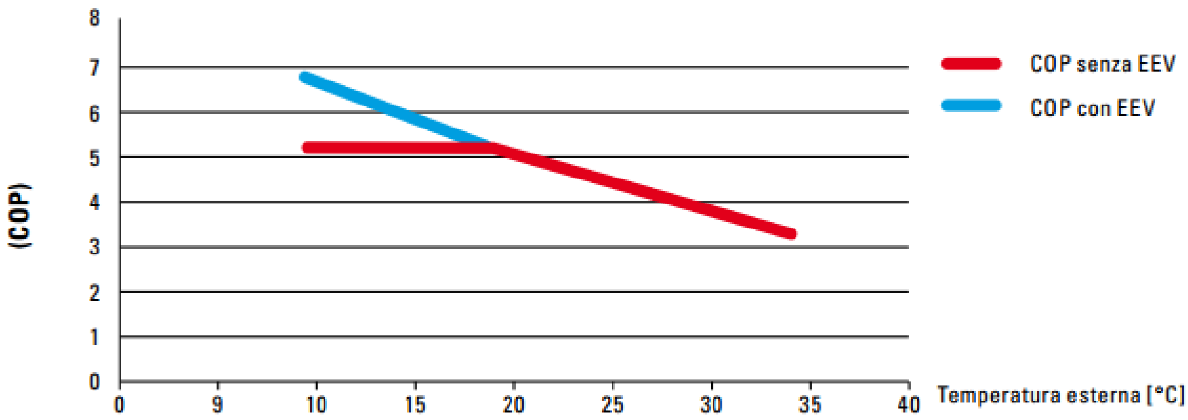

Figure II.1 COP value for ac-unit Amico. (Unflair, 2010)

When Seasonal Energy Efficiency Ratio (SEER) is given the following equation is used to convert into COP (Power Calculations, 2015).

$$COP = \frac{1{,}12 \times SEER - 0{,}02 \times SEER^2}{3{,}41} \qquad [2]$$

Appendix III. Financial Payback Periods

A hypothetical investment $1 000 000 to make improvements in the library would have a payback period of 8,5 years. This calculation includes the following factors:

Inflation rate	4,7%
Project life	20 years
Debt ratio	50%
Debt interest rate	16,00%
Debt term	20 years

Table III.1 Financial Parameters

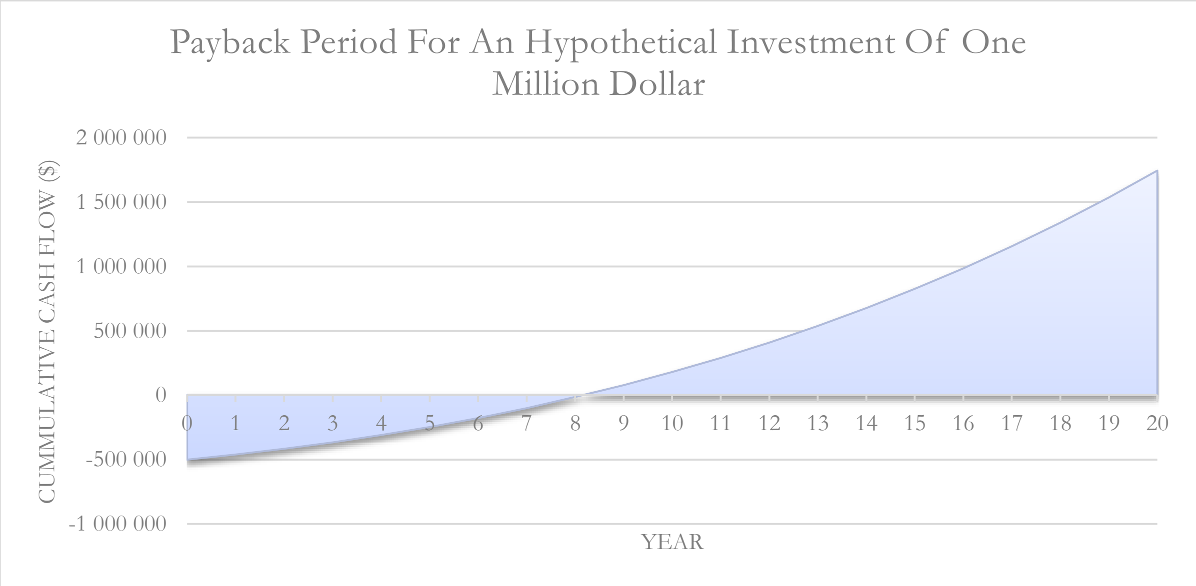

Figure III.1 Payback Period For An Hypothetical Investment Of One Million Dollar

To insulate a window by adding fasteners, vent flow baffles and sealing tapes has an average cost of $35 (HW, 2016). The INTEC library has approximately 120 windows, and if investments of $10 000 were made, electricity for cooling would annually be reduced by 31 MWh which corresponds to $ 5268. The simple payback for the project would be 1,9 years.

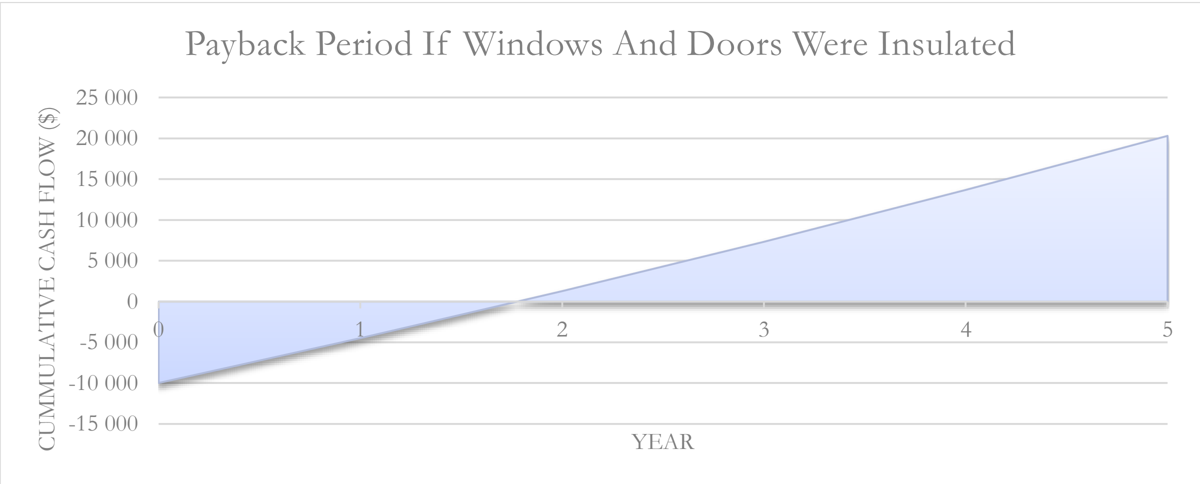

Figure III.2 Payback Period If Windows And Doors Were Insulated

Appendix IV. Building envelope

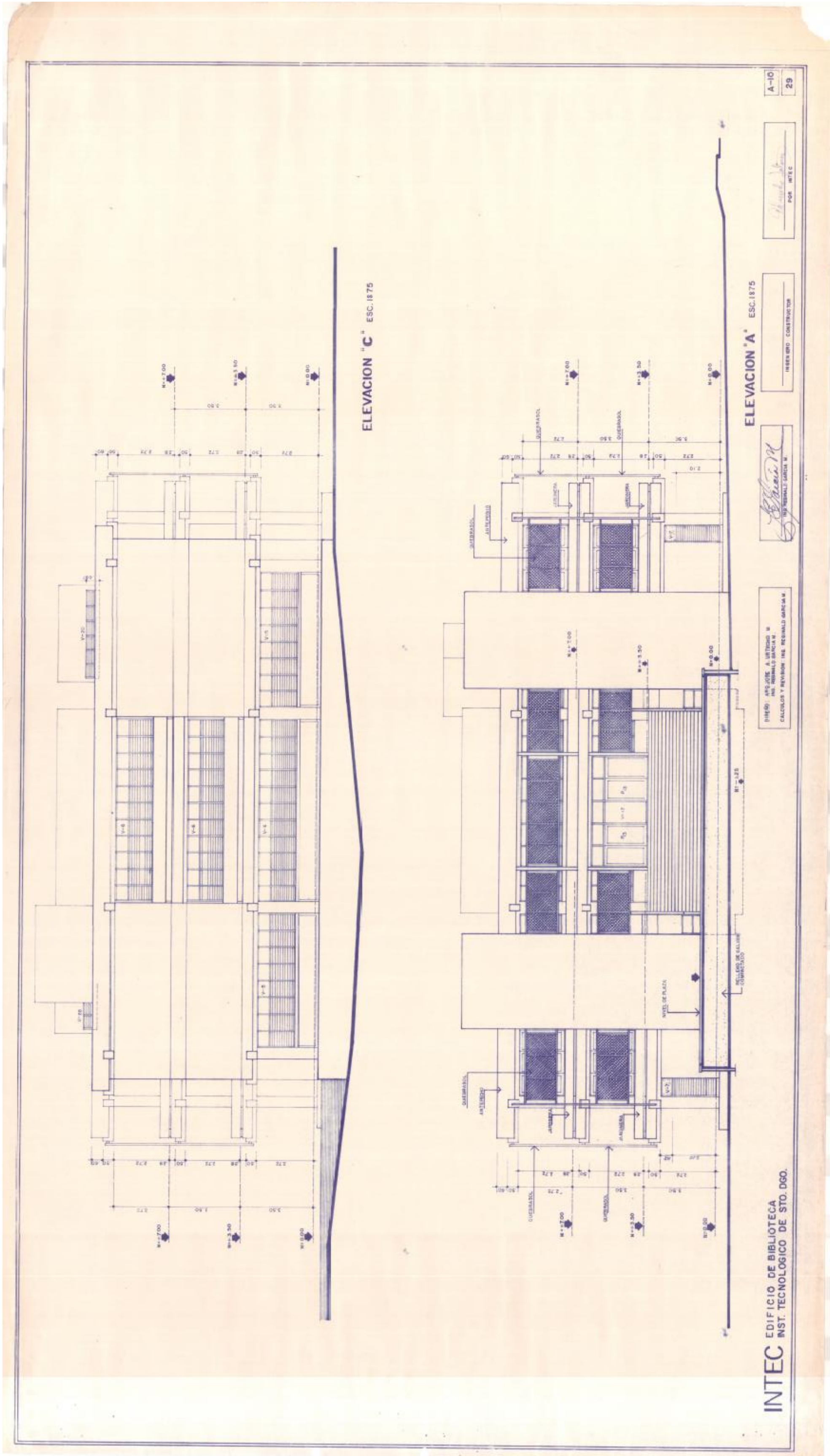

Figure IV.1 West and East side of INTEC library.

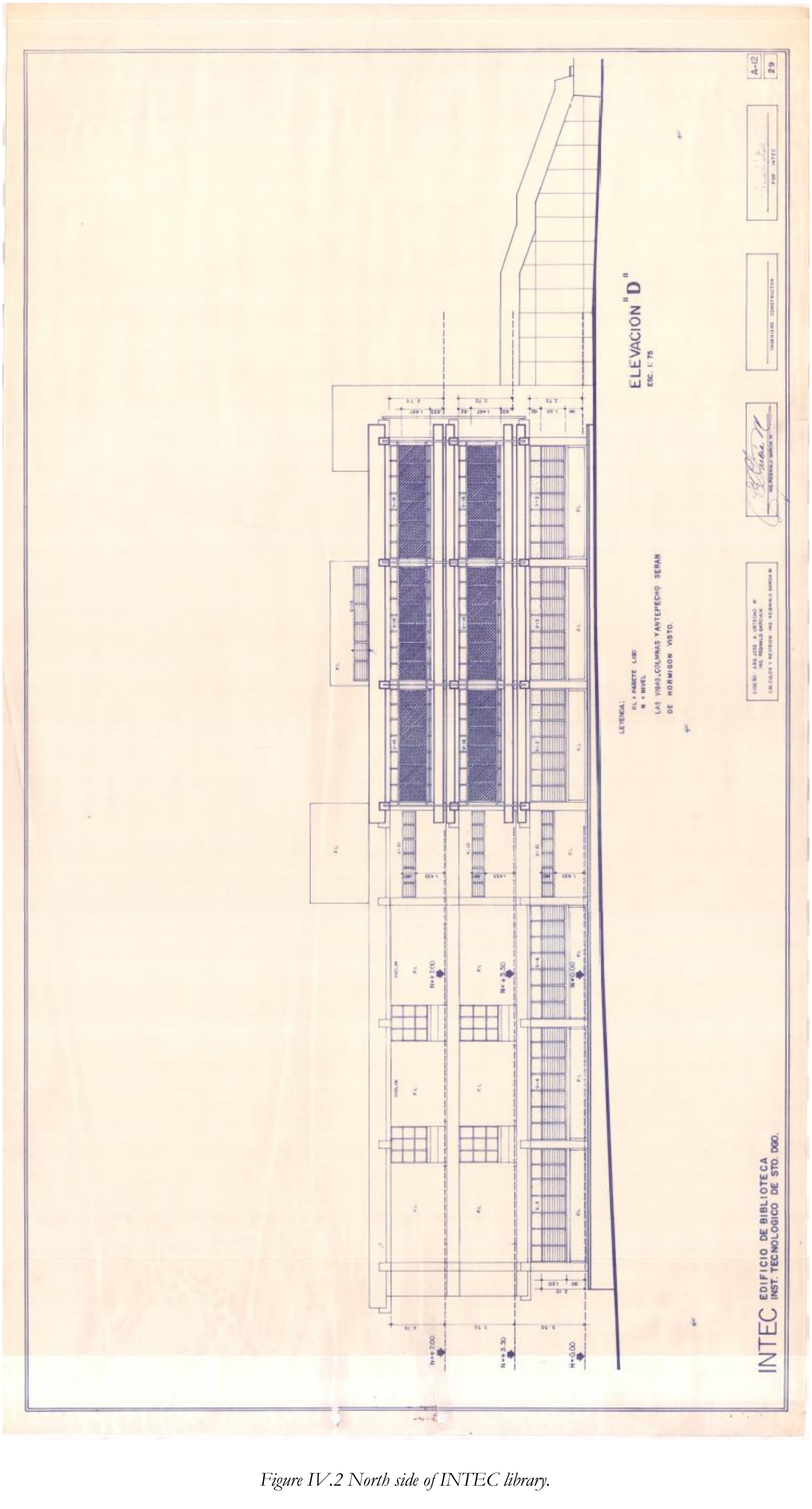

Figure IV.2 North side of INTEC library.

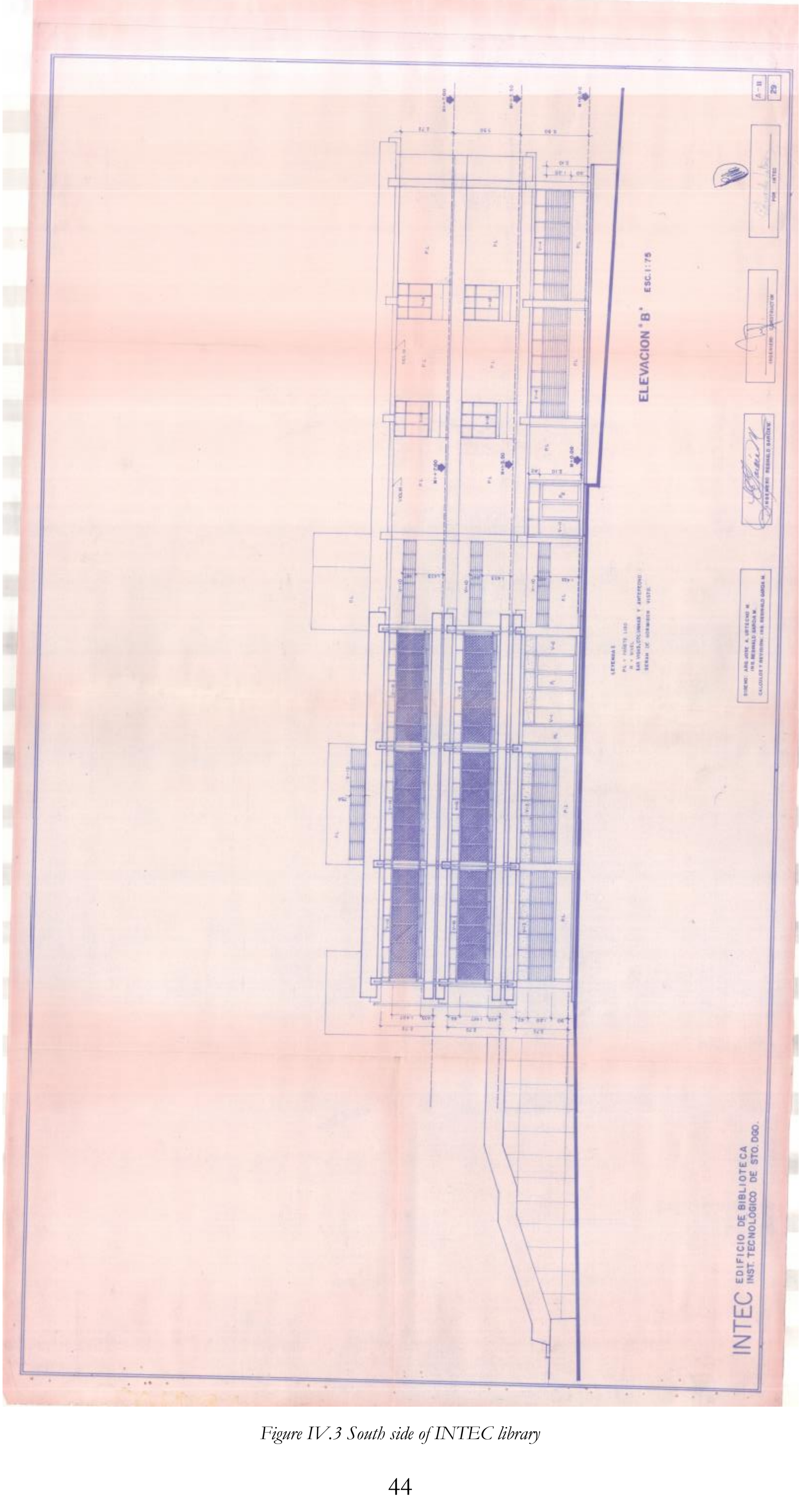

Figure IV.3 South side of INTEC library

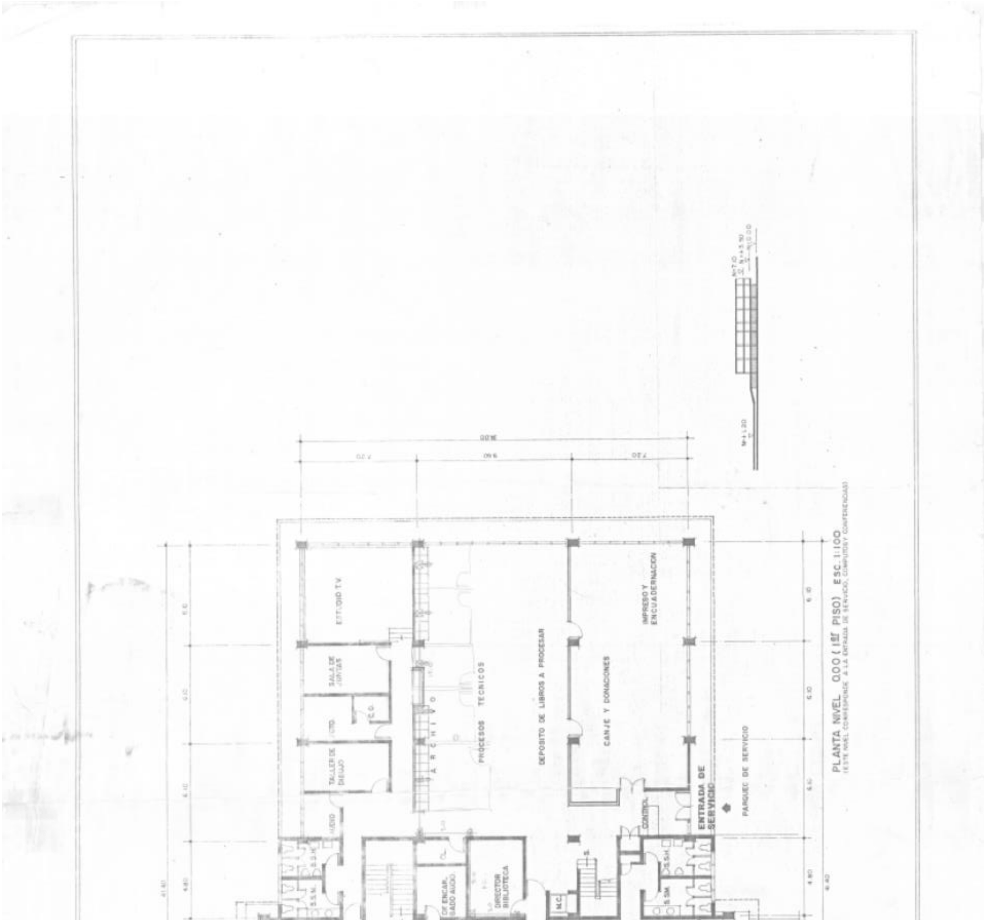

Figure IV.4 First floor of the INTEC Library.

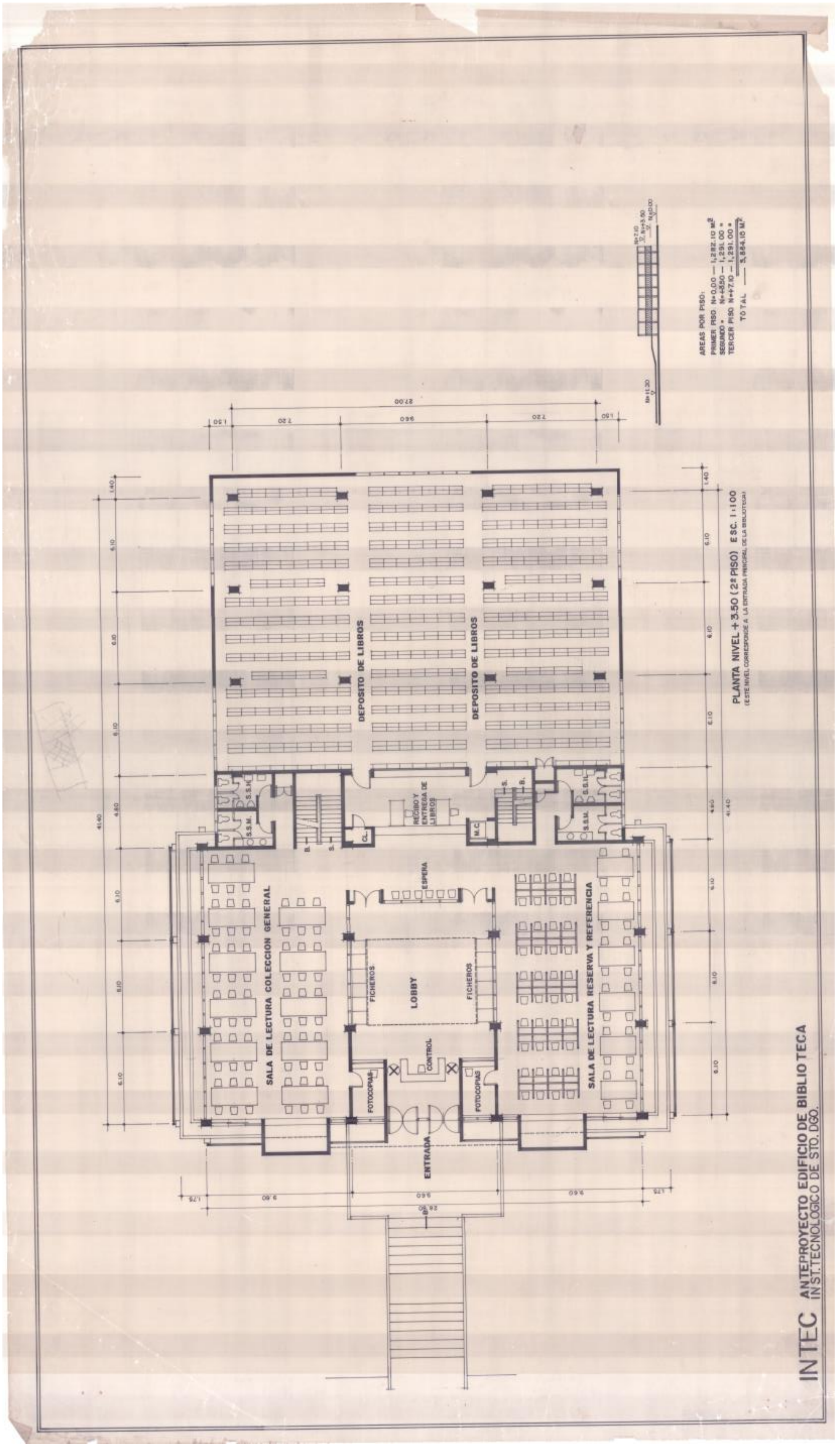

Figure IV.5 Second floor of the INTEC Library.

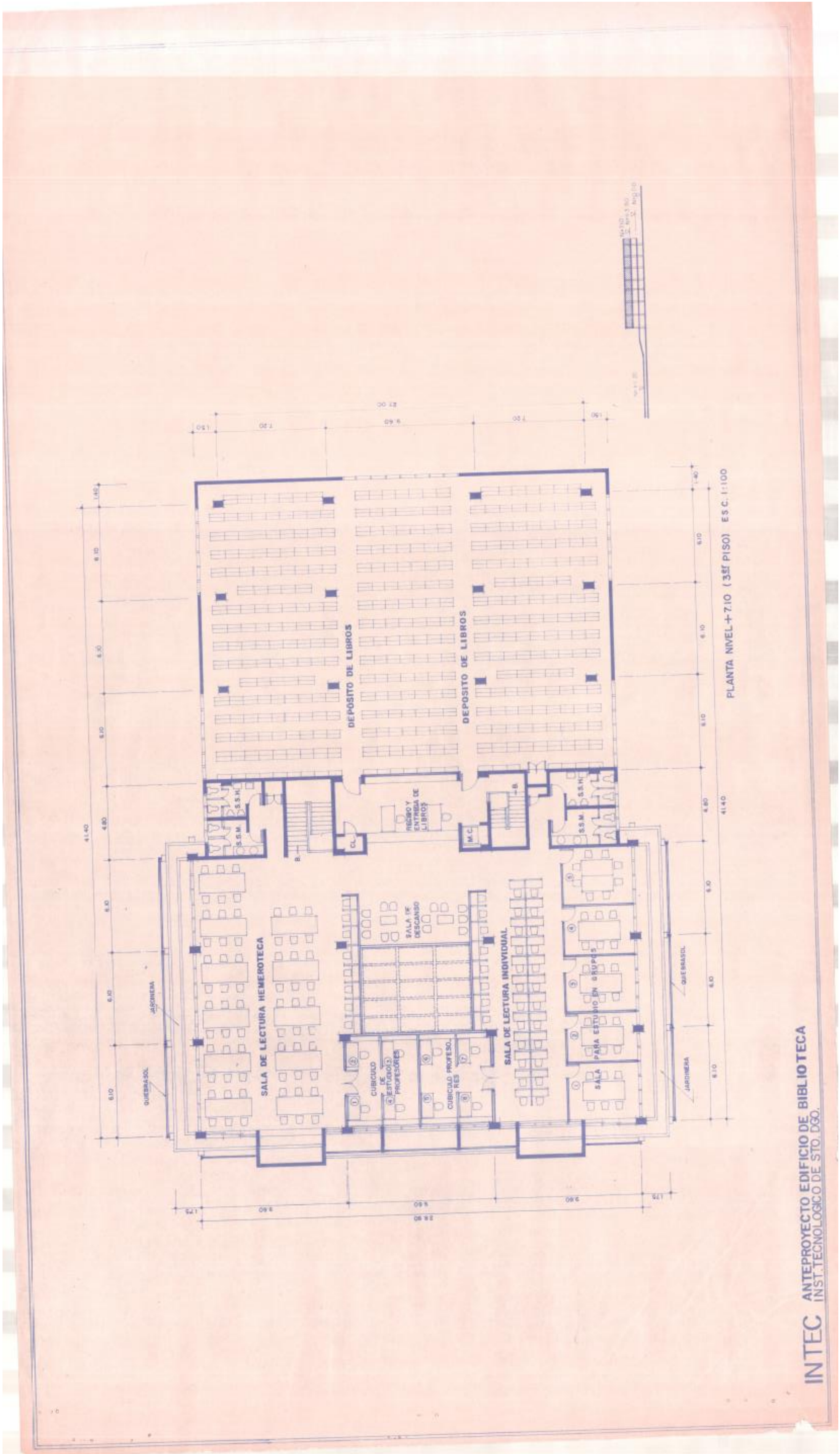

Figure IV.6 Third floor of the INTEC Library.

Appendix V. Specifications for solar panels

Physical characteristics of the module SI-ESFM-M200W	
Width (mm)	1069
Height (mm)	1580
Thickness (mm)	45
Weight (Lbs)	55

Table V.1 Physical characteristics of the module SI-ESFM-M200W

Electrical Characteristics Module SI-ESFM-M200W	
Maximum Power (Wp)	200 (± 3%)
Short Circuit Current $_{Isc}$ (A)	4.80
Maximum Power Current $_{Imp}$ (A)	4.21
Open Circuit Voltage $_{Voc}$ (V)	57.8
Voltage Maximum Power V_{mp} (V)	47.5
Maximum System Voltage (VDC)	1000

Table V.2 Electrical Characteristics Module SI-ESFM-M200W

Inverter Model	**SMA Sunny Boy 7000US**
Maximum Power	**7.45 kW**
Nominal Power	**7.0 kW**
Nominal/Range Voltage	**183 – 229 V @208 V**
Maximum Input Voltage	**600 V DC**
Power Factor	**0.99 @ nominal power**
Peak Efficiency	**97.1%**
Work Temperature	**-25 a 45°C**
Consumption Standby/Night	**< 7 W / 0.1 W**
Dimensions W x H x T in cm	**46.74 x 61.21 x 24.13**
Weight	**141 lbs**
Protection	**NEMA 3R / IP65**
Warranty	**10 Years**

Table V.3 Inverter Specifications

Appendix VI. Installed climate systems

Figure VI.1 AC-units on rooftop, top photos show the 15 ton units, bottom photo are the 5 ton units.

Appendix VII Observations from the library

Figure VII.1 Ventilation and AC-duct in the library.

Figure VII.2 Single paned doors at the front entrance.

Figure VI.3 Single panel windows at the library

Figure VII.4 Window that cannot be fully closed.