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Design of a control system for a smart building

- A case study in Kenya

Master's thesis in Systems, Control and Mechatronics

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Cover: Picture showing the architectural drawing of the planned youth center, made by Linda Ericsson at White Arkitekter.

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Abstract

The usage of solar energy as energy source is increasing, also in Kenya. In order to use the solar energy in an efficient way and reduce the initial cost of solar panels, one opportunity is to control the use of the electricity. The Wale Wale youth center in Kibera, Kenya plans to build a new, bigger youth center to be able to fit more members and at the same time be a role model for energy efficient buildings in the area. The new center, called Wale Wale Future Center, will be equipped with solar panels on the roof. Wale Wale wants a control system in their new center to lower the costs and energy usage.

To find an optimal solution to decrease the maximum power peaks and thereby the costs for the building's solar photovoltaic system, a controller has been designed. To design the controller the power demand and the energy consumption in the building has to be estimated. This is done by estimating when and for how long each electric device in the building is used. A field study at the current youth center in Kibera was performed, where future plans and daily schedule were discussed with the center's members. A possible solar PV (photo voltaic) system has been used for calculations, but keeping in mind that these products will probably have a higher capacity in a ten year time when the center is planed to be built.

Three different controllers has been modelled and compared to each other. One that switches off devices in stand-by mode, one that reduces the power to some devices during a period of high power demand, and one that schedules and prioritizes devices that has a high power usage.

Due to the dimensioning of the solar PV system, one can see that by reducing the maximum power demand instead of the energy consumption less number of solar panels and batteries will be needed. The critical moment, when a high maximum power is demanded, is when both the kitchen and the music studio are used at the same time. To avoid this, all three controllers have been merged together.

To be able to implement the controller, sensors for measuring and sending information on a single device level will be installed. If not, the controller can only handle a room or a floor at a time.

Keywords: Smart Building, Home Automation, Control System, Solar Power

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Isabelle Nilsson, Gothenburg, June 2017
Josefine Södling, Gothenburg, June 2017

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Nomenclature

WWK Wale Wale Kenya, the organization who runs the youth center.

WWFC Wale Wale Future Center, the new youth center that the organization plans to build, where this master thesis is one part.

PV system Photovoltaic system, the system that generate electricity from the sun.

Irradiance Received power per unit area.

Insolation Irradiance over time.

Solar irradiation Another word for insolation; irradiance over time.

Electrical Device Every device that consumes electricity to work.

1
Introduction

This chapter will explain why the project is performed and present the research question and the purpose. There will also be an overview presented of what will be included in the scope and what will be left out.

1.1 Background

The organization, called *Wale Wale*, is planning to build a sustainable and intelligent building, aimed to be their new youth center in Kibera, Kenya. The project is called *Wale Wale Future Center (WWFC)* . By extending the center, it opens up for the ability to provide further activities and welcome more members from Kibera [2].

Since the center also plans to become a role model of sustainable buildings to the rest of Kenya, the organization desire studies about how to build an energy efficient building in the most cost efficient and environmental friendly way. The center will be using solar panels to produce their electricity. The organization hope that if they can built a center like this in the informal district Kibera slum, everyone can to it.

Using solar energy as energy source to produce electricity for buildings have had a distinct increase world wide. Only in Kenya the usage of solar energy has increased 267% during 2006 to 2015 [1]. Installing solar panels has unfortunately a high initial cost. By controlling the electricity usage in the building, it is possible to decrease the number of solar panels and batteries needed and thereby lower the initial cost.

Wale Wale youth center is a place where kids and youths from Kibera can spend their days doing something meaningful. The activities at the center encourage the members creativity and skill-development to prevent them from idleness and destructive activities [3]. Wale Wale's approach is to be a democratic and transparent organization where all members will be able to influence the organization. The center that is being used today is designed for 40 people, the new center will be designed to fit a flow of approximately 300 people during one day.

1.1.1 Development goals

Wale Wale Kenya (WWK) youth center wants to be a sustainable organization and by their type of work they do connect to some of the United Nations' Sustainable Development goals. Since January 1 2016, the United Nations has put up 17 Sustainable Development goals to be able to reach the *2030 Agenda for Sustainable Development* [5]. The goals focus on to reduce inequalities, eradicate poverty and tackle the global changes and the goals mentioned below fits best to Wale Wale's vision.

Goal 3 Ensure healthy lives and promote well-being for all at all ages
Goal 4 Ensure inclusive and quality education for all and promote lifelong learning
Goal 16 Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

According to Goal 3, WWK runs activities for the members every day. For example football, dance and acting, this to contribute to a more valuable life for the kids. In accordance with goal 4, WWK offers the opportunity for their members to apply for grants to pay for their scholar fees. The scholar fees in Kenya are usually too high for the youths in Kibera and this grant is a useful opportunity for the members to get into high school or university and continue studying. An important goal, Goal 16, describes the youth center well. Opposite to Kenya in general, which suffers a lot from corruption and bribery, WWK wants to create an including and transparent organization; a democratic organization where every member can raise their voice.

By building the new youth center, WWK and this thesis work will match with two other development goals.

Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all
Goal 11 Make cities inclusive, safe, resilient and sustainable

The new youth center will be using solar panels as main energy source and this thesis work will focus on minimizing the energy consumption, this is part of Goal 4. It can also be related to Goal 11, where the center also will be built to fit more people. Since the population in Kibera increases [6], the center wants to welcome more members in the future.

1.2 Aim

The purpose for this master thesis is to design and evaluate different solutions for a controller in order to minimize the power consumption within buildings equipped with a PV system; an intelligent home solution. The purpose of the evaluation is to offer Wale Wale, which is going to proceed with this building, a sustainable proposition of how the electricity system can be designed. The building is supposed to be a youth center combined with a high school. The organization requests a cheap and energy efficient power supply with an informative and interactive user interface.

There will be investigations according to whether it is efficient to:

- Schedule some of the electrical devices to decrease the maximum power, but still offer a flexible living at the center.
- Switch off standby modes on electrical devices

If electricity from the solar panels will be limited, it may be useful to only allow electricity to the most important devices in the building when there is a lack of energy. The control system will control these devices, in order to decide which and when a device will be delivered electricity from the solar panels or batteries. There will be an input to the controller from a monitor where it is possible to make requests by the users.

1.3 Scope

To make the building energy efficient, this thesis work will be directed to make a study of how an intelligent control system for the electricity can be constructed to fulfill the purpose in a youth center.

The project will include a model of the building with its power loads and power source; solar panels. The model will be used for a simulation that constitutes the base of the control system that will be used in the building.

The scope of the project is summarized in one question.

What is the optimal solution in order to decrease maximum power usage and costs, by controlling the power supply of the building's solar panels.

The focus in the project will be to control the consumption of energy produced by the solar panels that will be installed on the new center. The control system is supposed to be user friendly and cheap, since the center is located in an informal district of Nairobi and the organization is mostly financed by aid and fundraising.

The model of the control system is based on an estimation of the energy consumption of all electrical appliances in the new center. This contributes to an assumption of how much energy that needs to be produced by the solar panel, or stored in batteries. It is important to calculate both the maximum power consumption and the energy consumption for the center, to be able to use as few batteries and solar panels as possible but still be able to deliver enough electricity.

1.4 Method

To get an understanding of how to control the electricity within a building, research about existing solutions is to be made. Solutions found will be a guideline for how the controller could be constructed. To see how the energy consumption could be controlled in the most efficient way a visual interface, GUIDE, will be used to make decision within the building and visualize the result of the different options. What to implement in the building will be decided by the team members together with the youths who run the center. How the different devices will operate will be dependent on the climate, weather and usage. A timeline of how this will be proceed is presented in Figure 1.1.

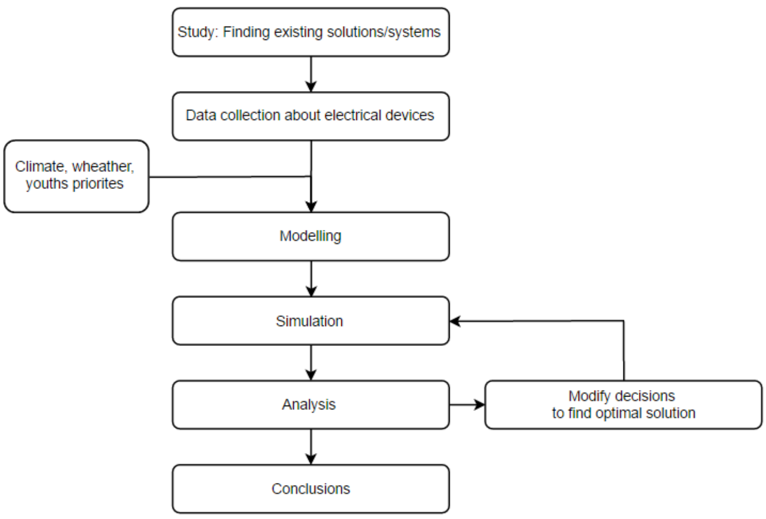

Figure 1.1: Flowchart of methodology in order to create an energy efficient controller.

In collaboration with the board at the center, this project is designed to contribute to their plan of building a new youth center to educate and to get the youths involved. In order to create a more sustainable and qualitative project, the non-profit organization *Engineers Without Borders* will be a supporter. This, by connecting the engineering company Bengt Dahlgren to the developing part of the project. Bengt Dahlgren will offer working hours for one of their employee, to share their experiences in construction of smart buildings.

1.5 Limitations

In order to design the control system, there is a need to estimate how much energy can be generated by the PV system that is planned to be installed on the roof top of the center. Also an evaluation how much electricity from the PV system is worth to save in batteries, depending on electricity usage and costs.

The work will result in a model of how a complete and robust control system can be implemented. Not an implementation of the system since the thesis work will be finished before the center is to be built. Calculations and assumptions of how the center will look is made by the youths at the center, which contributes to a uncertainty of how the plans will actually be in ten years when the center is supposed to be built. According to the estimation based on the electrical devices, these are devices that are being sold today, which may not be the same in ten years.

The electrical devices that will be used for estimation, will not be the most energy efficient ones on the market. This because it is preferred to have locally produced and not too expensive products in the center.

1.6 Outline

The report includes seven chapters, to present the procedure and results of this thesis work. It starts with Chapter 1 which introduces the project. Followed by Chapter 2, where information about parts that are considered specific to this project are presented. Chapter 3 presents the current construction plans of the center and how the PV system is dimensioned. Based on these chapters, Chapter 4 presents the parts included in the home automation system, followed by the project procedure to create a model of the center and how the controllers will be designed. After that, the results of how the controller should be designed is presented in Chapter 5. The next chapter is a discussion about the results, followed by a conclusion.

2
Specific Aspects

This chapter will include some of the specific aspects of doing this thesis work in Kibera, airobi, Kenya. To connect this thesis work to similar research, a few topics are discussed at the end of this chapter.

2.1 Kibera as a city

The youth center is located in Kibera, 5 kilometers southwest of the city of Nairobi. Kibera is the second largest slum in Africa, the amount of residents is unknown, but is estimated to 1,2 million people in an area of 2 square kilometers [4]. Some public schools in Kibera are for free but are inadequate, among other things in terms of lack of teacher per pupil. In one class with one teacher, there can be up to 60 pupils and one day in school can continue up to 14 hours. To be able to continue studies after primary school one has to pay for high school, which can be hard to afford for people from Kibera. In combination with the widespread unemployment, this decreases the options for the youths for the future.

All Wale Wale's members have grown up in Kibera and have experienced these problems, which has been a main reason of the organizations vision; of giving the kids and youths in Kibera a more meaningful life.

The center will be an open and welcoming place for all kids and youths in Kibera, but the risk for thefts always have to be considered. To prevent thefts, the equipment will preferably be fixed installations and not too expensive.

2.1.1 Social Aspects

The members at the center do not want the activities held in the center to be dependent on the control system; if someone wants to dance, it should always be possible to start the music. This contributes to some guidelines when forming the requirements for the control system and encourages to prioritize the electrical devices. It is important that the system is not fully automated meaning it is possible to maneuver the devices manually, since there may be a broken sensor or no one around knowing how to use the monitor.

2.1.2 Kenyas electricity grid

The electricity network in Kenya is congested and often suffers from power outages. In order to always access electricity it is therefore necessary to have the ability to store energy, by using batteries. In order to be self sufficient it is preferable to use self-produced electricity by using solar panels. One possible problem by only using self-produced electricity is that there may be conflicts with the company Kenya Power, which has monopoly of the electricity grid in Kenya. If Kenya Power does not generate any money from the electricity produced at the center, there is a risk that they prevent the center from producing their own electricity. Because of this, the center will be connected to the electricity grid.

2.2 Similar projects

A design of a control system in a building can be done in different ways, depending on what the purpose is.

The study [9] has focused on an activity-aware system that listens to information from both historic and real-time sensor data in order to build an energy saving automation system. Another way of design the system can be by scheduling the activities by a Petri Net [10]. In the study an integrated and low cost home automation system was created, by using the tools based on the open system Robotics Integrated Development Environment; RIDE to create the system. Added to this, a schedule is done based on logic by Petri Nets, which contributes to a more energy efficient system. A schedule for some of the electrical devices will also be a evaluated in this study, in order to control the electricity consumption on the center.

In [10], some important subjects of a control system are mentioned for example: security system, flexibility, power saving and intelligent climate control. These subjects are also discussed in [11], but with the approach to evaluate the benefits and risks with a home automation system.

On a study visit to the research project HSB Living Lab at Chalmers, a bigger insight of the control system used in that building was shared. The Living Lab is a housing estate equipped with a lot of sensors, with the purpose to develop environmental friendly and sustainable buildings [13].

HSB Living Lab are using a control system that can measure the energy consumption in every apartment in the building and together with the sensors placed in the rooms they are able to get information about the energy losses. In comparison with this thesis work, HSB are already using solar panels but at this moment there are not yet any home automation system installed in HSB's research project.

A project similar to the dimensioning part of this project, is carried out by a company from Gothenburg[1], where they are producing solar panels used as the construction material instead of a ordinary panel of the walls on a building. This could also be an option at the center.

As the project described in this thesis concerns energy efficiency in a city with inadequate electricity grid and a hotter climate than in Sweden, information is collected about a project in Ghana [14]. That project concerns implementations of mini PV-grids in a few villages and some general conclusions have come up. For example, among others it concludes that when people get a better and more reliable electricity connection, it is common that they want to cool their food in fridges even if this was not requested before. Also, when implementing a PV-grid as a power bank for a whole neighbourhood, people are more concerned about the PV-grid to not break[2]. That is why it can be an option to analyze if it is better to build a power bank together with the neighbours on the street in Kibera, instead of only producing electricity to the youth center.

[1] Archer, D., Emulsionen, Planning and product development, Personal communication, January 2017

[2] Rönnelid, M., Högskolan Dalarna, Personal communication, April 2017

3

Dimensioning

This chapter is about how the center will be designed and used including the daily schedule, the electricity system and the PV system. To be able to design a controller, a PV system has to be estimated even if the system may be changed when the center is about to be built. To decide which parts to use, some parameters about the solar radiation in Nairobi has to be known as well as the energy demand in the center.

3.1 Design and usage of the youth center

Wale Wale Future Center will be designed to fit 300 people during one day. During daytime there will mostly be administrative tasks for the board and high school for the other members, followed by lunch. In the evenings, there will be creative activities for all members, as seen in Table 3.1.

Time of day	Activity Board	Activity Members
00:00 - 06:00		
06:00 - 09:00	Cleaning and breakfast	Cleaning and breakfast
09:00 - 13:00	Administrative work, cooking lunch	High school
13:00 - 14:00	Lunch	Lunch
14:00 - 16:30	Individual work	High School
16:30 - 17:30	Academic Follow-up	Academic Follow-up
17:30 - 19:00	Activities	Activities
19:00 - 00:00		

Table 3.1: Daily schedule at Wale Wale Future Center. The lunch will be cooked in the center's kitchen to all members.

There will be five floors in the main building as shown in the architectural drawing in Figure 3.1, and two floors in the side building. Each floor in the main building will be specialized for a specific activity, starting with the ground floor being used as a playground where everyone is welcomed. The first floor is specialized for study, the second for music conferences, the third for dance and the forth for a library. In the side building the ground floor will be a restaurant, a bike shop, an office and a shop and the second floor will be specialized for a classroom (which is not included in the figure), toilets and a washing room.

3.2 Type of electrical current

Usually the electrical system in a building runs by alternating current since this is used on the electricity grid, but both solar panels and batteries produce direct current. The inverter in the PV system is expensive and consumes energy and if the building only use direct current, the inverter would be unnecessary. This makes it interesting to check if it is an option to build the center with a electrical system powered with direct current [15]. Since a majority of the electrical devices used today in a building is equipped with a transformer to fit in an electrical system with alternating current, the center will be using alternating current.

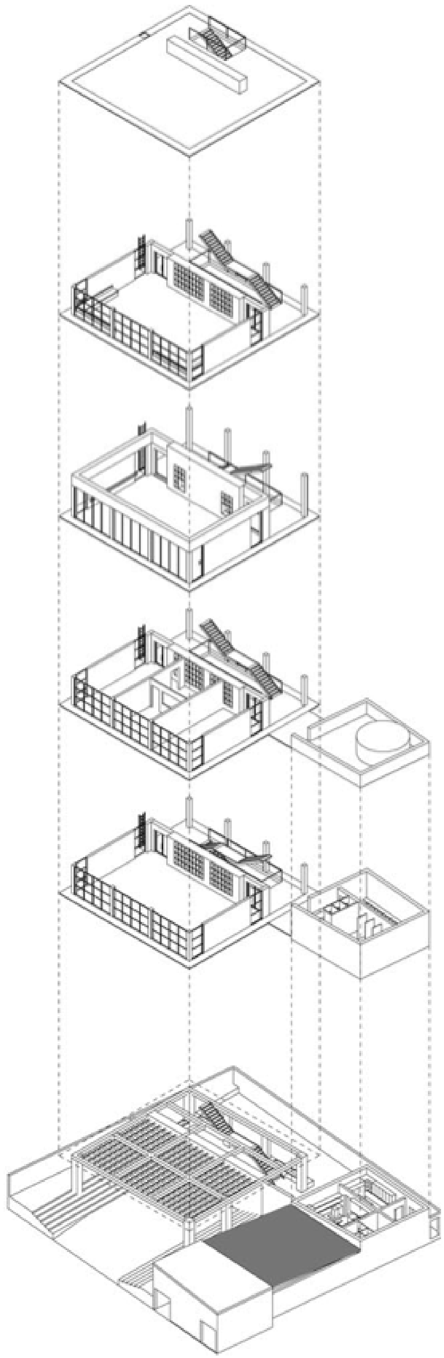

Figure 3.1: View of every floor in the main building of the center [7].

3.3 Ventilation

In the center today, the widows are normally always open and there is only natural ventilation. This is how the youths want it, but due to the air pollution in Kibera it is not how it should be. The air in Kibera is contaminated[1] [8] from a lot of dirty vehicles in the traffic and by burning of garbage along the streets.

In the new center there are a few main areas that have to be considered when dimensioning the ventilation; air purification, moisture, temperature. In collaboration with the Swedish company Bengt Dahlgren[2], a simulation of the ventilation in the center was generated.

The simulation calculates how the temperature will vary in the building, according to the given parameters. It shows that the temperature on the dance floor will vary between 21,5°C and 24,5°C, as shown in Appendix A.

Since the temperature is sufficiently stable, as seen in Appendix B.1, and the windows will be opened a lot during the days, the ventilation system will not be too advanced since that would be too expensive due to energy costs. There will be an air conditioner on the dance floor and in the rest of the center there will be supply fans and exhaust fans with filters to clean the air.

3.4 Power demand estimation

To calculate the energy consumption in the center, it has to be investigated which electrical devices that will be used and for how long. The data collected for this investigation is mostly made during the case study at the center in Kibera, through discussions with the members, meetings, construction plans and analyses of the organization today. The building plans have presented which devices that will be used in each room in the building, but no information about how much. By interviewing the members at the center, a time schedule for all electrical devices was created. On top of this, research was made online to estimate how much energy every device consumed and how much maximum power it needs. All of the parameters taken in to account are presented in Table 3.2. The complete tables of the estimation is presented in Appendix A.

[1] Mellqvist, J., Chalmers University of Technology, Professor, Earth and Space Sciences, Personal Communication, June 2017

[2] Nilsson, J., Bengt Dahlgren Stockholm AB, Engineer, Personal Communication, May 2017

Parameter	Unit
Device	
Type	
Quantity	[pieces]
Time used	[hours/day]
Maximum power	[Watt]
Energy consumed	[kWh/day]
Purchase price	[Kenyan shilling]

Table 3.2: Parameters taken into account when searching for information about every electrical device that are assumed to be used in the center

The time usage was estimated during discussions together with one of the members[3], who is responsible for the construction plans of the center. It is assumed that the main building in the new center will be used in the same way as today, except for also including a high school and more members. The side building is planned to be used mainly as a high school and a restaurant during lunch. The kitchen belonging to the restaurant will consume a lot of energy during weekdays and will be an important part in the design of the controller since it includes a fridge and a freezer which are supposed to always be connected.

3.4.1 Measurements

As an extra check to evaluate whether the information about the device's energy consumption was correct, measurements was made on similar devices in the existing center. To measure the energy consumption, an power meter was used with an accuracy of 0,5 W [27]. All measured standby consumptions are presented in the tables in Appendix A.

3.5 Solar panels and batteries

Nairobi is located close to the equator which is a good opportunity to use of the sun as an energy source. To calculate how much electricity that can be generated by a PV system to the center both the systems technical data and the solar insolation has to be considered [16]. A formula to calculate the energy generated by a solar panel is presented in Equation 3.1.

$$E = A * \eta * H * PR \tag{3.1}$$

where:

E Energy [kWh]
A Total area of solar panels [m^2]
η Efficiency of solar cell module [%]
H Solar insolation [kWh/m^2]
PR Performance ratio, due to losses in PV system [%]

[3]Carter, K., Wale Wale Kenya, Personal communication, April 2017

The common efficiency of solar cell modules is said to be 15% [21], which will be used in the calculations. The area of solar panels needed will be known later on in the project and the losses are estimated to 15% due to cables and inverters [16]. The solar radiation will be estimated in the following section.

3.5.1 Solar panels

The Standard Test Conditions (STC) of solar cells is a standard for the manufacturers to test the performance of solar panels [17]. STC includes a solar cell temperature of $25°C$, solar irradiance of 1000 W/m^2 and an air mass coefficient of AM1.0 [18]. The average annual solar insolation (which is solar irradiance multiplied by time) in Nairobi is 2100 kWh/m^2 [20].

To calculate how much electricity that can be generated by solar panels, two different online calculators have been used to estimate the daily power production by a solar panel. The parameters used for estimation can be found in Table 3.3.

Parameters Nairobi	**Value**
Elevation	1679 m
Array Tilt	20°
Azimuth	-1° (optimal)
Slope	2° (optimal)
System losses	15%
PV technology	Crystalline silicon cells
Peak PV power	1 kWp (standard)
Inverter Efficiency	96%
Solar radiation database	PVGIS-CMSAF

Table 3.3: Example parameters to estimate daily power production by solar panels in Nairobi.

The global radiation on a horizontal surface at ground level is roughly 1100 W/m^2 [19], those optimal circumstances are not the common state in reality. According to a previous study performed in Nairobi, the insolation during one day was measured to vary from 2380 Wh/m^2 in cloudy June to 7160 Wh/m^2 in sunny February [20]. Since the solar insolation is lowest in June and highest in February, Table 3.4 presents an estimated irradiance in Nairobi for every hour between 06:00 and 18:00 for two different days of those months of year 2000.

The estimated daily electricity production by the given system, in Nairobi, can be found in Table 3.5. There are values given from two different online calculators, both PVWatts calculator [22] and Photovoltaic Geographical Information System (PVGIS) [23].

	1st of August	**1st of February**
Time of day	**[W/m^2]**	**[W/m^2]**
06:00	30	42
07:00	50	97
08:00	50	50
09:00	120	200
10:00	100	300
11:00	180	400
12:00	400	600
13:00	250	1000
14:00	420	600
15:00	350	600
16:00	180	600
17:00	100	300
18:00	0	150

Table 3.4: Estimated irradiance in Nairobi and here, the 13 most sunny hours is presented and. Febuary is a month with high insolation and August with low insolation.

	PVWatts	**PVGIS**
Month	**[kWh/day]**	**[kWh/day]**
January	5.79	5.40
February	6.27	5.73
March	5.79	5.43
April	4.98	4.78
May	4.42	4.22
June	4.24	3.70
July	4.18	3.42
August	4.43	3.68
September	5.27	4.70
October	5.27	4.94
November	4.63	4.73
December	5.00	5.13
Avg	5.02	4.65

Table 3.5: Estimated daily electricity production (kWh) as an average each months.

To use this information in a controller, that will be based on hours, the energy produced by the PV system, is assumed to follow the same intensity per hour as the solar insolation during a day. Which means that if the insolation at a specific hour is 15% of the daily insolation, it is assumed that also 15% of the energy is produced during this hour. Based on three different days, a percental distribution of the insolation is presented in Table 3.6 divided into hours. Together with the estimated energy produced the same hour, based on the system parameters given in

Table 3.3 and the percental distribution. The given system is said to have a peak power of the standard $1kW_p$, to fit the values to a PV system the values has to be divided by the system's efficiency, here assumed to be 15%.

	Percent of daily	**15%-η system**
Time of day	[%]	[$\mathbf{W}/m^2$]
06:00	0	1
07:00	1	3
08:00	2	25
09:00	3	40
10:00	5	58
11:00	6	75
12:00	9	106
13:00	15	182
14:00	12	140
15:00	11	128
16:00	9	112
17:00	5	64
18:00	3	33

Table 3.6: Percentage of insolation reaching solar panels in Nairobi every hour, based on an average of three different days. Together with the estimated energy generated from one square meter of a solar panel based on parameters given in Table 3.3 with a daily energy generation of the average daily power production given in Table 3.5.

When designing the controller the span between high and low productive days has to be taken into account. The panels will be placed on the roof of the building, which is divided into two parts, as seen in Figure 3.2. The roof has a total area of 100 m^2 plus 88 m^2. 63 m^2 of those are assumed to be used for other things than solar panels, like water tanks and free space for walking. The area left for solar panels is 125 m^2, where 111m^2 of those will assumed to be filled with active area of solar cell modules (89% of the panel area).

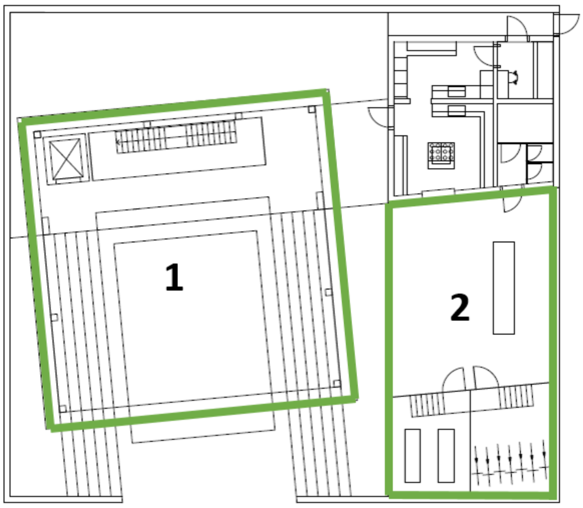

Figure 3.2: Area of the roof that will be possible to use for solar panels

3.5.2 Batteries

To design the PV system a back up system for the power will be needed, which preferably consists of batteries. The number of batteries needed is unknown at this stage, but a specific type of battery is assumed to be used. The type of the battery is a lithium-ion battery produced by Tesla, because of them currently being in the forefront of developing batteries made for PV systems and the center being built in 10 years. The battery can store up to 13,2 kWh in one charge and can handle to be fully emptied before charged again [25]. The battery can deliver a maximum power of 5 kW continuously.

3.5.3 Inverter

As mention in Section 2.1.2, the center will be connected to the grid and use batteries. Which means that an inverter is needed to handle the batteries. The inverter is one of the most expensive parts of the PV system and the size of it depends on how much maximum power the center will use, which will be evaluated later on during the project.

4
Method

This chapter presents how the center will be modelled and how the home automation system is supposed to be designed. Based on this, three different types of controllers will be designed, with different focus areas. The first controller will focus on the standby energy during nights, the second one on prioritizing and scheduling devices and the last one on lowering the power to certain devices during energy critical times.

4.1 Model of the center

Since the center is going to be built in 10 years, it is not possible to do any real implementations. Instead a model of the new center will be created, in order to design different controllers. The groundwork for the model was explained in Chapter 3 in terms of construction plans, organization, assumed electrical devices and an estimated PV system.

4.1.1 Model of power demand

A model of the electrical devices, that for now are assumed to be within the building, will be modelled with GUIDE as an interface in Matlab and Simulink. Through GUIDE it can be chosen to what extent the devices are to be powered on or off. The first model will be an estimation of the energy consumption that will take place in the new center without any improvement on the distribution of the energy. The model is also made with an estimation of 300 people that will visit the center.

In order to make the model, a list of every device within the different rooms of the building is made with the help of the youths from Wale Wale. The list of things is a request from the youths of what they want to be able to do in the center and what devices that are needed in order to make it happen. Then some things, for example ventilation, fire alarm and so on are added, as mentioned in Chapter 3.

The next step is to gather information about the energy consumption for all the appliances. Their maximum power, general energy consumption in everyday usage and the standby energy consumption. The information collected is for the devices that are available at the market today which means that this prototype will not be valid in 10 years when the building is to be built. When choosing the devices the lowest energy consumption is preferred but the price and the accessibility in Kenya is also considered. Due to this the outcome of the model will be time-dependent, which should be kept in mind.

The model will consist of the electrical devices that are assumed to be within the new buildings together with the equipment that will power the building, hence the PV system. This, to be able to compare the energy demand within the center against the energy supplyed to the center. A first model of how the PV system and the controller will be implemented is shown in Figure 4.1.

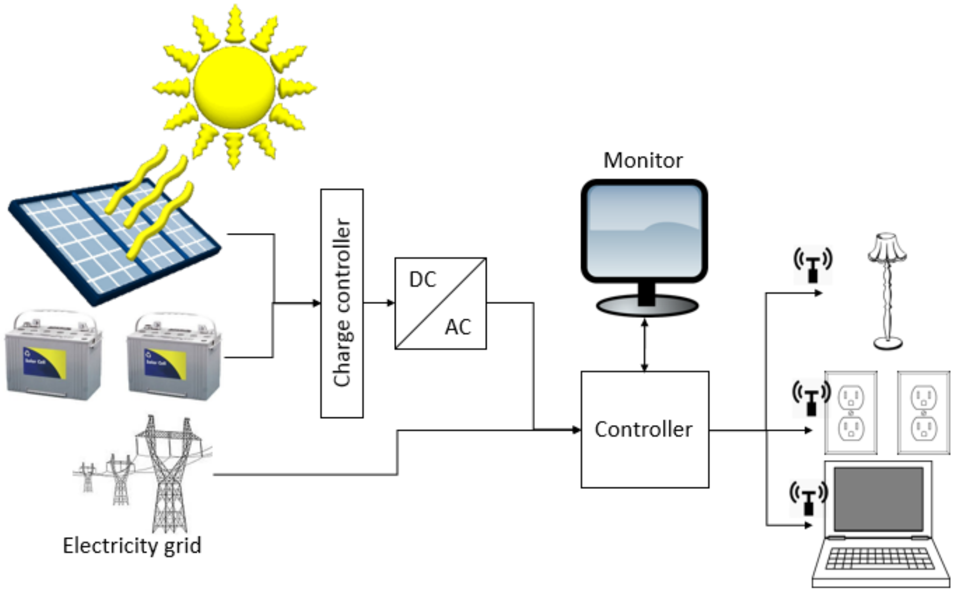

Figure 4.1: Simplified model of how the system that will be designed

The interface of the model, made in GUIDE, is divided into tabs representing different floors. Every floor is filled with buttons each representing a switch for an electrical device. Floor 2, the music floor, is shown in Figure 4.2. On this floor there are: a social room, a room for recording music, a music studio, an office and a stairwell.

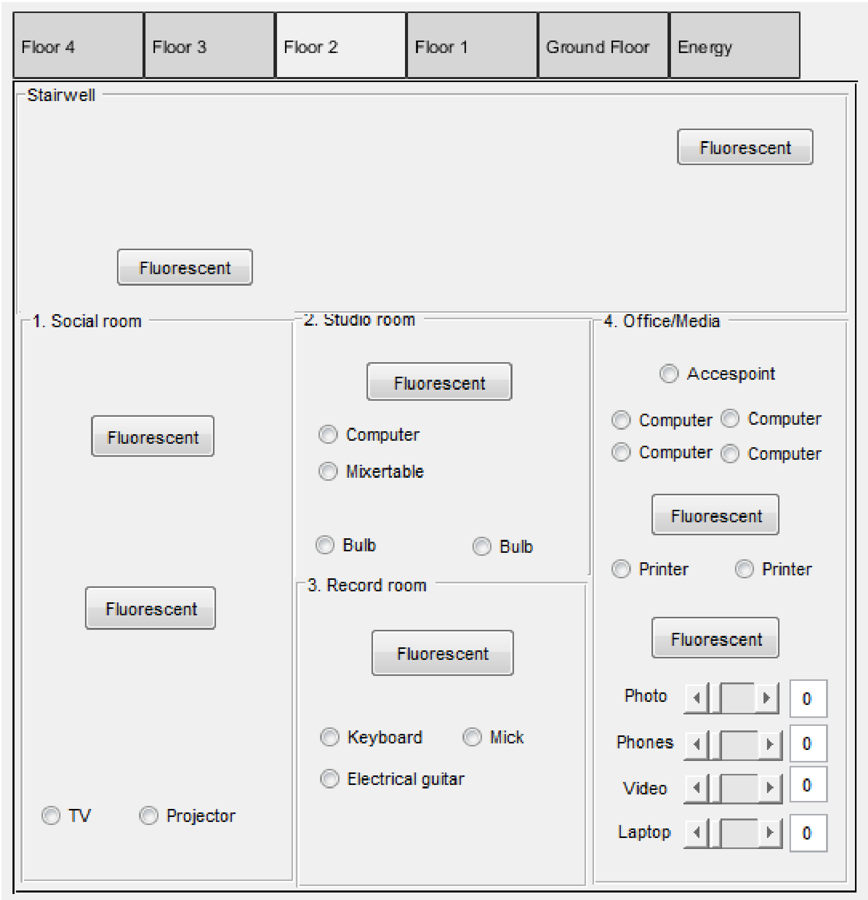

Figure 4.2: Floor 2 in the main building, modelled in GUIDE in Matlab

4.2 Energy consumption without controller

To be able to evaluate the quality of a controller, it will be evaluated against the energy consumption in the center when no controller is used. The energy consumption is estimated based on the information in the previous section. In order to reduce the number of solar panels needed, the maximum power peaks need to be reduced. Looking at Figure 4.3 the maximum power, without optimization, goes above 16000 W. This peek depends on the cooking of lunch, using an electrical stove. This would mean that the area needed for the solar panels to provide this power peak would be approximately 130 m^2 and exceed the area of the roof top, as explained in Section 3.5.1.

As a first step to reduce this peak, a simple solution could be to use a gas stove instead of an electrical one, but still have an electrical oven. This would decrease the max power significantly as seen in Figure 4.3. Another solution could be to use the power grid but the aim is to avoid this as much a possible since the center is supposed to be self-sufficient.

One can also see a peak at 8 o'clock in the morning in Figure 4.3. This is mostly because of the kettle being used and all cellphone and laptop chargers starts, since the centers opens up at this time.

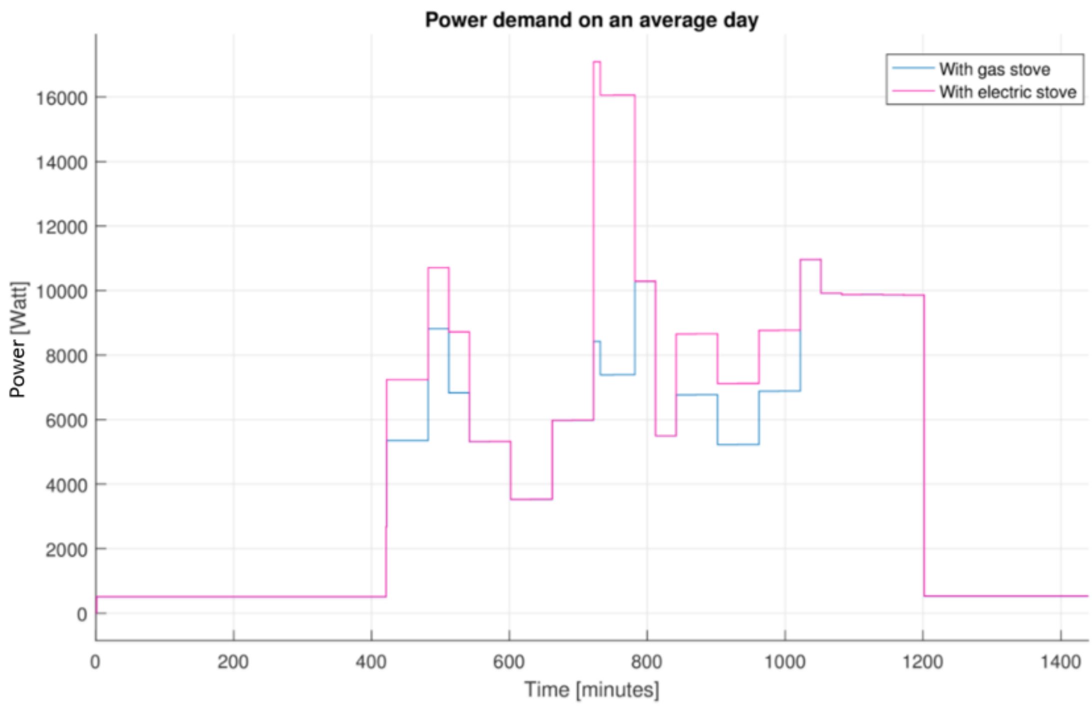

Figure 4.3: Power demand for the building on an average day. The magenta line represents the consumption when an electrical stove is included and the blue line represents the consumption when a gas stove is used instead

The total energy consumption for all electrical devices is also presented in Figure 4.4. Here, every device is shown by a significant color. By the graph, one can see that the critical times are during the evening when both the air condition in the dance floor and there are a lot of laptops being charged in the silent space. As mentioned in Table 4.2 the center is closed during the night from 20:00 until 07:00.

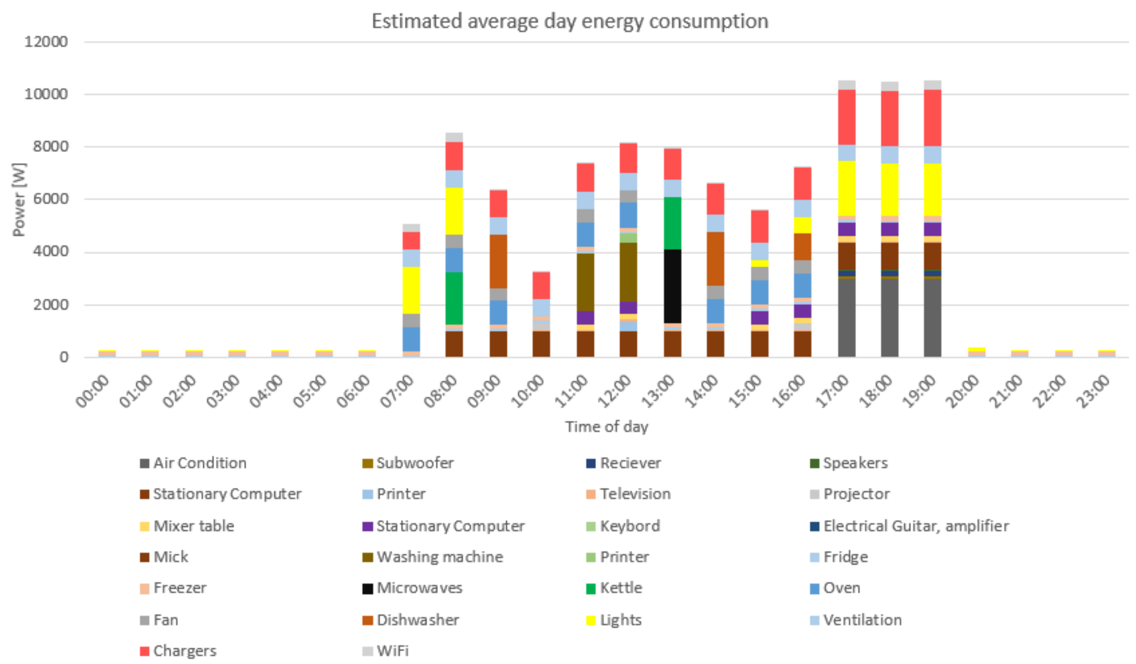

Figure 4.4: Estimated energy consumption of an average weekday in the center. Chargers icludes chargers for laptops and cell phones, colored in red

4.3 Home automation system

To make the center smarter and more interactive, it is supposed to be equipped with sensors and actuators in the control system. Sensors that will be used are energy meters to measure and control the energy consumption of the electrical devices. There will also be motion sensors to measure at what time there are people in the rooms.

4.3.1 Monitor

Interaction with the controller will happen through a monitor mounted inside of the main building. The monitor will make it possible to present the energy consumption for the members and it is also the device where all manual decisions are taken. If the energy supply from the PV system is about to get low in the upcoming hours, it will be possible to schedule the low prioritized devices to a time where there will be more energy available. The monitor will also be connected to WiFi, which means that it will be possible to connect to it from a cell phone.

4.3.2 Sensors

By implementing smart energy meters it will be possible to control and monitor the outlets, in order to have a home automation solution to decrease the power consumption. An energy meter draws 0.5 W [28], which may lead to that the meter should not be installed on a device that have a standby value lower then this. However, even if the standby value is lower, it could still be beneficial to have an energy meter for a certain device. For example, in order to schedule devices to decrease the maximum power demand during the day, i.e. distribute out the power demand during more hours of the day.

4.4 Controller 1; by standby mode

The first controller will be designed to find and switch off devices in standby modes with the help of the energy meters. To estimate how much standby energy every device consumes, values were found online and then compared to a measured values of the devices used in the current center. Since the standby modes do not consume a lot of energy, it will also be investigated whether it is worth to have an energy meter (considering the energy consumption) on every single device or not. Summarized, this means that the controller will eliminate stand-by modes during nights and early mornings and this could be implemented by either a simple switch in the entrance [1], or included in the controller.

When the clock turns 20:00 and the center is to close, then the controller will check if there are any devices that are in standby mode and turn those devices off.

To evaluate whether a device is in standby, the controller via the energy meters will check the energy consumption. If it measures within an range of $\pm 20\%$ of the measured standby mode, alternatively the given value from the data sheet of the device, the device will be turned off. However there are some devices that will have a certain priority that are not possible to be turned off. This would be devices that would take harm or for some reason have a valid reason to not be switched off. For example a computer with important programs running. There is no device in this center at this time that would have this priority but it is supposed to be possible to add this through the monitor.

4.5 Controller 2; by prioritizing

By listing all devices in the center according to priority, the most important devices gets the highest priority. A high priority means that the device is not expected to loose electricity even if there is lack of energy. The batteries are supposed to maintain for the energy to those devices. The devices with the highest priority are presented in Table 4.1

[1] Rönnelid, M., Högskolan Dalarna, Personal communication, April 2017

Priority	Device
1	Freezer
2	Fridge
3	Router and Access points
4	Lights
5	Outlets in one office

Table 4.1: Priority list of the highest prioritized devices in the center

In combination with the priority list, it will also be possible to schedule a few devices that are decided to not be important at a specific time of the day, presented in Table 4.2

Devices possible to schedule
Dishwasher
Washing machine
Kettle
Printer 1
Printer 2

Table 4.2: Devices that are possible to schedule to a time later of the day

The overall function of the controller is summarized below:

- Put low-prioritized devices in a queue
- Priority order made by the youths and analyses of the power demand estimation

To evaluate this type of controller, the dishwasher is used as an example. A wash will be requested at a specific time and the controller will check if it is possible to start it. To make the decision, the controller will check how high the current energy consumption is, how much energy there is left in the batteries and how much sun that is expected in the upcoming hours. It will also compare with an average day, to see if there is a period of high consumption expected in the upcoming hours.

By measuring the energy consumption throughout the days for about 10 days, an estimation on every hour can be calculated and stored in the memory of the controller. The estimation of the average energy consumption during one day can look somewhat like what is presented in Figure 4.4. The value that will be stored should be the median of the values in every time instant. This ought to give a more correct view of the estimated usage per day, since the average value could be misleading if there is a deviation one day.

With given information about how the energy usage for the day may look, more information about the coming day can help in order for the controller to predict and make reasonable and helpful decisions. By also taking the batteries into account, the controller can estimate for how long the batteries will be able to backup the PV system with the energy demanded by a device.

Knowing how much energy that can be received by the PV system during the coming hours, the weather report from the area is collected. With this information and the solar insolation [23], the energy from the sun generated by the solar panels can be predicted. Based on this input, the controller will make a decision how to best handle the request. If the requested device energy consumption cannot be provided by the solar panels, together with the batteries, the controller will try to schedule the activity. This by putting it later in the day, or the next, when there is a good chance that the PV system can supply for the energy consumption.

Priority lists are used in order to know what can be scheduled and what can be prioritized down in favor for other devices. Two lists are needed for the controller to make the scheduling. One is a list with every electrical device within the center. It needs to contain the devices with given energy consumption. It is possible that a timeline could be necessary since the priority can change during the day, this would contribute to a dynamical list but is not added in this case. The list is supposed to be changeable from the monitor if new devices are added or old ones are removed. This is the static list that is needed for comparison with the second list.

The second list is supposed to be dynamical and include the devices used at this time instance. The list updates when a device is turned on and will lay in order based on the priority as the first list. If for example the newly requested device cannot be powered by the PV system and do not have higher priority then the last device in the list, the system will not provide it with any electricity. But if the device do have a higher priority, the controller will add up the energy for the devices already existing on the second list. If the energy is less or equal, the energy consumption of the higher prioritized device they will be turned off and the higher prioritized device will be turned on. There could however be cases where the lower prioritized device should be kept on for the person using it may need some time to finish what he or she has started. These low prioritized devices are grouped up and can't be turned of.

4.6 Controller 3; by power decreasing

The third controller will focus on decreasing the power to some selected devices. Some devices are not working properly with a lower power input than demanded, those devices will not be controlled. For example, decreasing the power to the projector and the musical keyboard can effect the performance of the devices in a negative and noticeable way. The controller's task is to improve the energy supply without interfere too much, why the musical keyboard and projector are not to be controlled.

The power will only be decreased by a few percent, since it should not be a too big impact to the user. By decreasing the power to a phone charger it will have to charge for a longer time, but it will still charge and the time is assumed to be indifferent.

Devices that are possible to run with a lower power without breaking is presented in Table 4.3. This lists the devices that can have their energy supply lowered without affecting their behavior in any noticeable way.

Device	**Power decreased**
Charger Laptop	20%
Charger Phone	20%
Charger Camera	20%
Charger Video Camera	20%
Fluorescent	20%
Kettle	30%
Microwave	20%
Stationary Computer	10%

Table 4.3: These devices will be delivered a lower power when there is lack of energy in the center.

The controller will measure when there is lack of energy delivered by the solar cells and lack of energy stored in the batteries, in comparison with the current power demand in the center. If there is a higher demand than the PV system can deliver, the controller will decrease the power to the mentioned devices. When there is more available energy, the power will be set to normal again.

The controller will need to have the dynamical list that is explained in the section above. When the controller notices that there is lack of energy for the running devices or a request of a new device is made which the PV-system can not supply, some decisions need to be made.

A new request: If the device that is requested is on the list of devices that can work with less power and if so, will the newly calculated energy supply for this device be able to run? If not the dynamical list is checked to see if any device matches the list for Controller 3 (Table 4.3). Starting from the last product on the list, lowest prioritized item, to compare if a diminished power supply would be enough to power the requested device, the controller will go through the dynamic list to see if lowering the power supply on certain devices is enough to add the requested device to the queue, hence powering the device.

Low power: If there is device on the dynamical list that also matches the third list (Table 4.3) these devices will be given less power. Starting from the bottom of the list until the power supply is manageable or there are no more devices on the dynamical list that matches the third list.

5
Results

This chapter presents the results of the evaluated controllers and in order to do that, an alternative PV system.

5.1 Control system

All three controllers has been designed and compared to the energy consumption during an average day.

5.1.1 Controller 1

In Figure 5.1 the energy consumption for an average day without any optimization is compared against the energy consumption while energy meters are installed and the standby consumption on devices that has a standby value higher then 0.5 W is controlled. During the night and early morning one can see that this would be beneficial. This is before anyone has started to work and the building is to be cleaned. It is based on the schedule that are used in the center today, but may of course be changed in the future. When turning off the standby modes the total energy consumption does not change dramatically, but it will kill unnecessary energy usage.

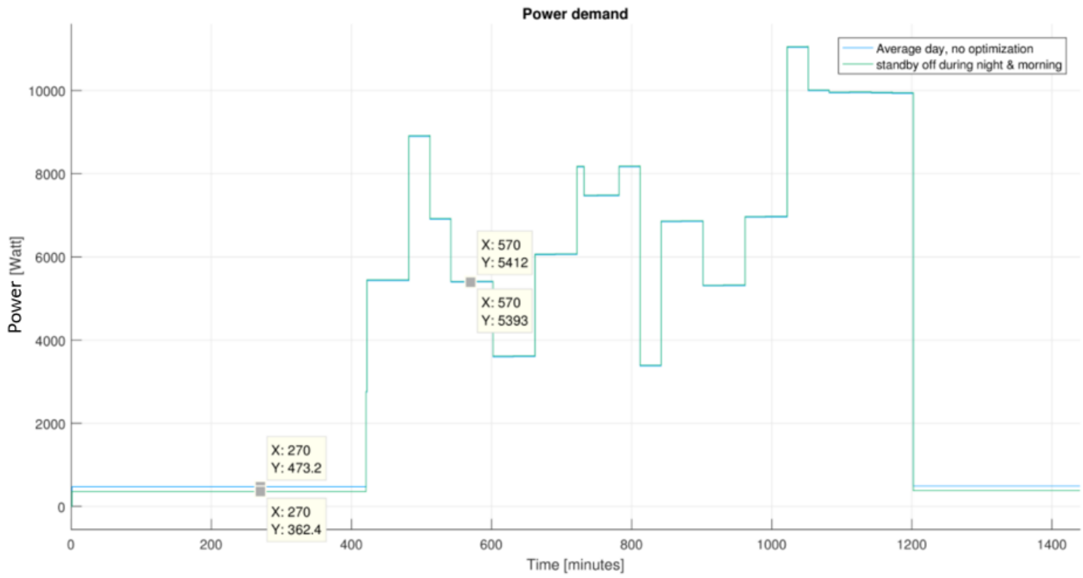

Figure 5.1: Energy consumption of an average day in the center, with and without controlling the standby energy. The energy consumption for the monitor is also included.

Looking at the time 16:30 ($x = 270$) in Figure 5.1, the power value differs by $500 - 360 = 140W$ from 00:00 - 07:00 and 20.00 - 24.00. This would decrease the energy consumption by 777 Wh, as shown in Equation 5.1. This could be an optimization problem, but are chosen not to.

$$
\begin{aligned}
&Energy\ consumption\ saved = \\
&standby\ off\ \times hours - energy\ meters\ \times hours - monitor \times hours \\
&= 111W \times 11h - 23\,pieces \times\ 0.5\,W \times 24\,h\ - 7W \times 24h \\
&= 777\,Wh
\end{aligned} \tag{5.1}
$$

The devices with a lower standby value than 0.5 W is a projector with 0.08 W in standby and a musical keyboard with 0.3 W. Their standby mode could be controlled during the days, but this is assumed to not be beneficial since the projector are not supposed to be scheduled or controlled individually during the rest of the day.

This also gives the information that it is not worth having an energy meter on every single device in the buildings. Instead only the devices with the highest energy consumption will be equipped with an energy meter. The rest of the consumption in the center will instead be measured and controlled at each floor by power guards. It is possible that multiple devices that for a reason can be grouped together also can be controlled together, as an example the fluorescents in one room or musical instruments that together makes a high energy consumption. However, this will not be beneficial for this controller within this building.

5.1.2 Controller 2

By scheduling certain devices, as mentioned in Section 4.5, the maximum power demand can be lowered in order to reduce the cost for the PV system. To try this type of controller, the dishwasher was used for scheduling. The dishwasher was requested to start at 12:00, but since the current power demand was too high compared to the power supply the washer is to be scheduled. The controller continues by checking the expected weather and the estimated average day to compare with for the upcoming hours. Since the sun will go down and the dance floor will consume a lot of power soon, the controller suggests the dishwasher to start next day at 10:00 instead as seen in Figure 5.2.

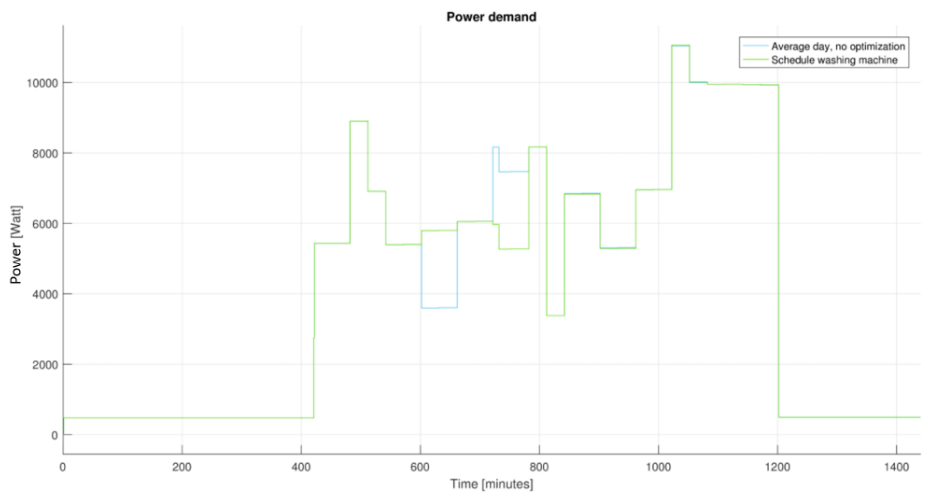

Figure 5.2: Controller 2 will move the requested dishwasher from 12:00 to 10:00 the next day when there will be more energy available. The blue line represents the energy consumption before the dishwasher is moved, and the green line after it is moved.

This controller will lower the power peaks, but not necessarily the highest peak. This depends on whether there are any of the devices that is possible to schedule being requested to start during the highest peak or not.

It will not decrease the energy consumption but it was a try to lower the peaks in order to reduce the number of solar panels needed. Since, as mentioned, it is the peaks that are the critical aspect when dimensioning the PV system.

A field study was made and it was possible to see that the sun was never gone for more then 12 hours during a period of two months. This includes one month of the rain period as well. Though it is hard to predict the cloudy days, the conclusion is that the solar panels will receive sunlight every day but perhaps reduced. Hence the conclusion is that the batteries will be powered during some part of the day. Depending on the energy usage within the building, but with the data of an average day (Figure 4.4) this then shows that the batteries should get enough power to be fully charged. There could be that the batteries are not fully charged and that the sunlight is reduced, then it would be useful to schedule electrical devices.

The controller schedules based on priority and since it is difficult to predict exactly in what order devices should be prioritizes these list are to be changeable thru the monitor. For example if you have not been able to run the dishwasher you can change the priority and for that reason it could be runned earlier in time.

To schedule the different activities/devices may not be the best solution for this youth center. The center is for the youths to be creative and they want to be able to have the flexibility during the days. It could however be a more suitable solution for another type of building.

5.1.3 Controller 3

By lowering the power supply to some of the devices as mentioned in Section 4.6, the daily energy consumption will decrease since the chargers are expected to be used all hours when there are people in the center. As seen in Figure 5.3 there will not be a huge difference in the maximum power demand.

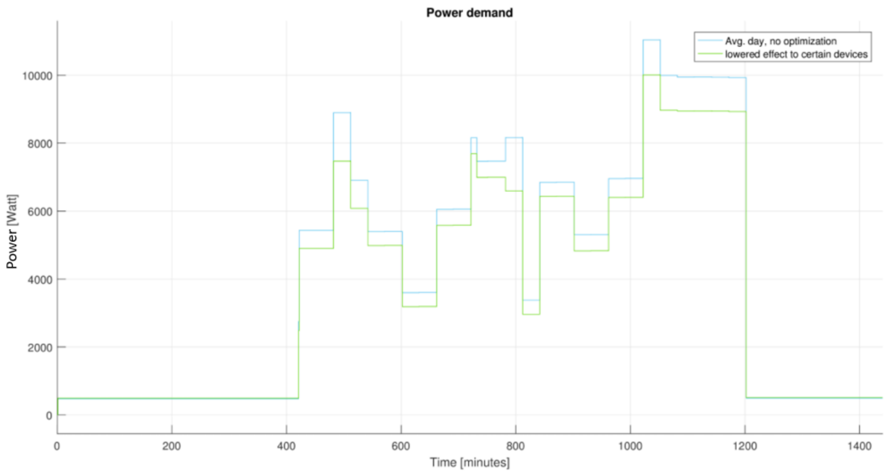

Figure 5.3: Graph showing how the energy consumption decreases when the controller is used (green line), compared to the uncontrolled estimated consumption (blue line).

The disadvantage with this controller is that the devices being charged needs to be charged for a longer time if the power is decreased, which has not been considered. The controller at least decreases the maximum power demand at times during the day when the sun is not delivering a lot of electricity, which makes it possible to use less energy from the batteries.

5.1.4 Merged controller

Another possibility compared to the three controllers mentioned above, could be to merge all of them to a single one, that controls both the standby modes, the scheduling and the power decreasing. The physical equipment needed for all the controllers will be the same, which makes it easy to just merge the code. This controller will in that sense be the controller that lowers the consumption at most, as shown in Figure 5.4.

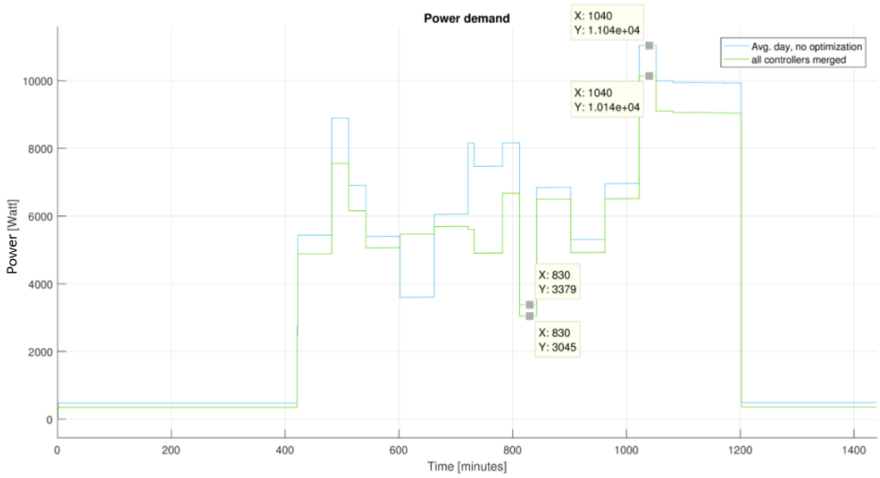

Figure 5.4: Graph of a comparison between the average energy consumption without a controller (blue line) and the consumption with the merged controller of the three different controllers evaluated (green line).

Merging the controllers together will lead to that the unnecessary standby energy when the center is not used will be reduced. Scheduling will only be done for the the washing machine. The reduction of the power to certain devices is on the other hand a possible solution to this center.

When the controllers are merged some withdraws from Controller 2 can be compensated for with Controller 3. When Controller 2 checks if the requested device can be powered by the PV system and this is not possible, the merged controller can see if perhaps the power supply will be enough if some devices have decreased power supply. All the controllers put together will also decrease the power supply more when needed than individually. This may not be that surprising but the good thing is that the controllers do not interfere with each other.

5.2 PV system

In Figure 5.5 the expected power from the PV system with an active solar panel area of 111 m^2 is compared to the estimated power demand using the merged controller without any batteries. As seen, there will be some lack of energy during the night and a lot during the first hours when the center is open. During the sunny hours at noon there will be more electricity produced than demanded. At the evening before the center closes, the energy demand will be much higher than the energy supply again. The shortage will continue after closing time but decrease a lot.

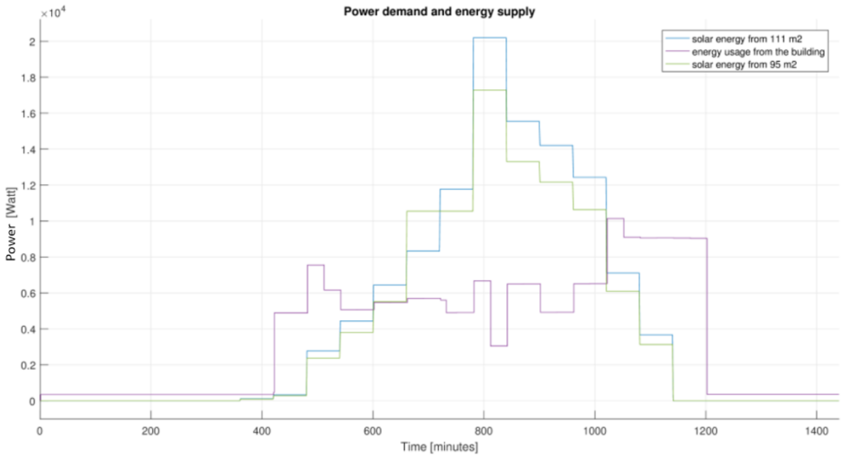

Figure 5.5: Expected energy supply from PV system with an area of 111 m^2 (blue) and 95 m^2 (green), compared to energy demand controlled by the merged controller (purple). Without using any batteries.

The daily energy consumption is compared in Figure 5.6, with and without a control system installed.

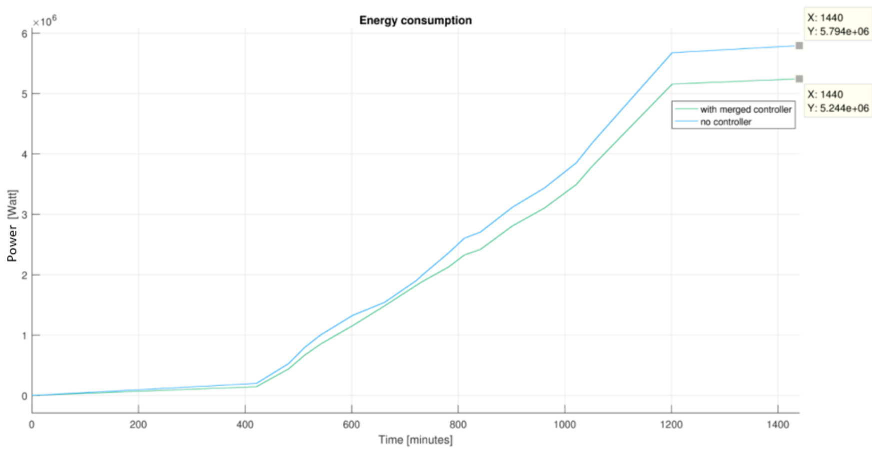

Figure 5.6: Estimated energy consumption at the center. Green line is the controlled consumption and blue line is the uncontrolled.

To dimension the PV system the maximum power peaks and the daily energy consumption will be considered, in combination with the power supply from the solar panels. Since it is hard to fit the energy consumption completely to the solar insolation curve (as seen in Table 3.6), it is easier and cheaper to compensate with batteries when there is a high consumption instead. As seen in Table 5.1 the energy consumption and in Table 5.2 the result is presented with and without the control system. According to the consumption one can see that the energy will be enough with the controller, but not without. The maximum power, on the other hand, will not be enough even if there is a controller.

	Consumption [kWh]		Supply [kWh]
	Without controller	Controller	111 m^2
Day	103,3	87	92
Year	37 700	32 000	34 000

Table 5.1: Estimated total energy consumption and supply as a comparison with and without controller.

To clarify Table 5.2, the maximum power delivered by the PV system is higher at other hours of the day, but not at 17:00, when the demand is at maximum.

	Maximum power demand [W]		Supply at same time [W]
	Without controller	Controller	111 m^2
17:00	11040	10140	7060

Table 5.2: Estimated maximum power peaks with and without controller, compared to how much the PV system delivers at the same time. It is not enough without batteries.

Based on information on both the energy consumtion and the power peaks mentioned in Table 5.1 and 5.2, together with the the PV system, it can result in a decreasing of the area of panels. Instead of using $111m^2$, it could be possible to produce enough electricity in $95m^2$ if batteries is used.

There will be at least two Tesla batteries, mentioned in Section 3.5.2, needed when the control system is installed, since the lack of power exceeds 5 kW which is the maximum power a single battery can deliver continuously. By calculating the difference between how much energy that is missing during a day, it gives a hint about how many batteries is needed, shown in Figure 5.7. By using batteries, no energy is added to the center, only moved to times when it is needed and storing energy in batteries will of course contribute to some energy losses.

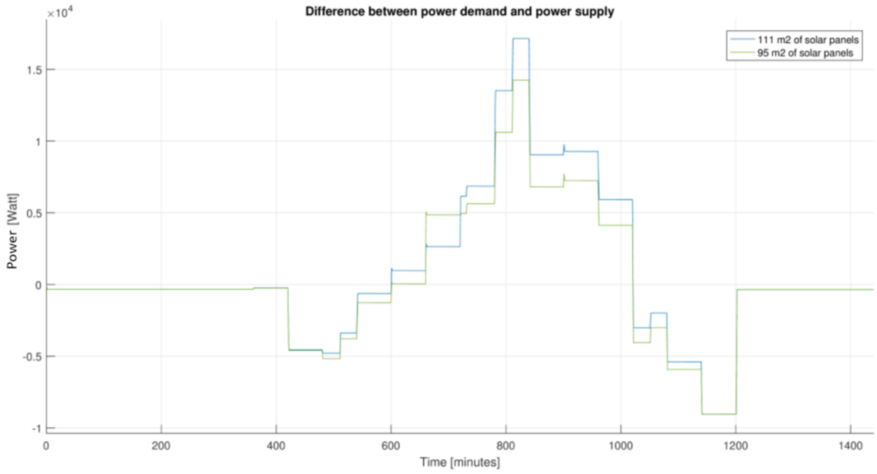

Figure 5.7: Graphs presenting the difference between how much energy is demanded, compared to energy available when using solar panels with an area of 111 m^2 versus 95 m^2. This energy is supposed to be maintained by batteries.

5.2.1 Economical aspect using the grid

A PV system has a high initial cost but a low yearly cost, compared to using only the electricity grid. A comparison between the cost for those alternative is presented in Table 5.3. The expected cost is an assumption based on systems available on the market today. When comparing the electricity grid, the energy consumption without any controller is being used and when comparing the PV system the energy consumption with the merged controller is being used.

Electricity grid		Solar power	
Energy [kWh]	Price [kr]	Cost	Price [kr]
1	1,65 [34]	Initial	175 000 [31]
37 700	60 200	Batteries	130 000 [25]
		Installation	30 000 [30]
		Control system	13 000
		Grid; 7660kWh	13 000
Total			
1 year	60 200		363 000
2 years	120 400		376 000
3 years	180 600		389 000
4 years	240 800		402 000
5 years	301 000		415 000
6 years	361 500		428 000
7 years	421 400		441 000
8 years	481 600		454 000

Table 5.3: Example cost of use electricity from a PV system versus from the electricity grid. Acording to this calculation, the PV system will be paid off after 8 years.

5.3 Backup

If there will not be any sun for a whole day at the same time as there is a break out at the electricity grid, the prioritized devices in Table 4.1 must still be able to work for a few days based on power from the batteries. This is not a big risk in Nairobi since they usually do not have days without any sunlight. But, by having 2 batteries á 10.5 kWh the prioritized devices will be able to work for almost 2 whole days. During these days there will be lights and WiFi in the main building and computers can be charged in one office, at the same time as the freezer and the fridge will work properly. The total consumption of this is 10.8 kWh during one day.

6

Discussion

In this chapter the results will be discussed. First the main result, followed by an interpretation, an explanation and some consequences of the result. The chapter will finish with a comparison with results from similar studies and what could be a possible future work.

6.1 Main result

Controlling the electricity in the center results in a lower energy consumption and a lower maximum power, but there will still be batteries needed to compensate for the power peaks.

The merged controller, which turned out to be the most useful one, is able to reduce the daily energy consumption by 11% and the highest power peak by 8%. This is done by lowering the power to the chargers and lights, and also by getting rid of unnecessary energy consumed by devices in standby mode.

One changed that also contributed to the reduced consumption was to use the washing machine less. After another discussion with Wale Wale, it turned out that the washing machine could be used 2 times less every day.

6.2 Interpretation of result

The results lead to a possibility to decrease the size of the PV system in a few different ways. Instead of having 111 m^2 of solar panels (according to the parameters mentioned in Section 3.5.1), it can be decreased to an area of $95m^2$ and still be able to have enough backup power from the batteries which delivers maximum 5 kW per battery.

There are other ways to decrease the PV system, it depends on how Wale Wale wants to do it. There is also an option to decrease the number of solar panels even more and back up with another battery, which could be a good option if there is a risk of many days in a row with lack of sunlight.

It could also be an option to back up with even more energy from the grid, since the center must use the grid to something (see Section 2.1.2), and then to decrease both the number of batteries and solar panels.

6.3 Explanation of result

The energy saved by using a controller, is only an estimation and there are many elements that can change the results. All devices being used in the project is available on the market today and may not be avaliable in 10 year, but hopefully similar devices will be cheaper and more efficient than today. The results evaluate the function of the mentioned controllers and a method to use them, not the exact implementation and what hardware to use.

To control the standby during the day when the center is running it will be a specific case for every device, instead of just turning everything off. This has not been done for this controller since it is assumed to not be as energy efficient compared to scheduling the devices. Due to time limitation this option was excluded from Controller 2.

The result gives an indication of how the center will be used in the future and how it is possible to provide it with energy in a cost and energy efficient way, having in mind a plan of being a high technological center.

6.4 Consequence of result

The weekends have not been evaluated in the project, but are assumed to use less energy and have lower power peaks than the weekdays. There have been a lot of assumptions made in this project, since there are still 10 years until the center will be built. This may lead to big differences in the result when a control system is supposed to be implemented. To avoid too big problems, we have tried to analyze methods to get our results, not the specific products that will be used. As an example according to the trends in PV systems, they will be much cheaper and more efficient in those years. Even the batteries will be more beneficial to use, that is why we did choose one of the best batteries at the market regardless of the price.

On the other hand, by just analyzing the function of the controller and not every single implementation, there may be problems to implement some parts of the control system. Like when reducing the power to the chargers 4.5, we have not specified how to do this practically. It is assumed that there will be products to make it possible.

The price of installing a PV system and a control system will be high for the center and more studies has to be done before it is sure that this will be beneficial. The organization is currently dependent on aid from donors and also on the government to not take their land area into possession, in order to afford this.

6.5 Result in comparison to other results

This project have had a few specific aspects that where not included in other similar projects, why it is hard to compare not looking at these aspects. As an example, it would be great to schedule the devices even more as mentioned in the study of using Petri nets (see Section 2.2), but this is not an option since the members really evaluate the flexibility using the electricity whenever they want to almost every device.

By installing the solar panels vertically on the walls of the center, instead of ordinary panels, may have been cheaper but since the vertical panels are assumed to be easier to break this option was excluded. If thefts have not been that common and there were not expected new buildings to be built right next to the center shadowing the walls, this would have been evaluated further.

6.6 Future work

There is plans to look at an interface of the monitor for the youths in the center. How it is possible to make them more aware of the power consumption of the different electrical devices, how it can be possible to lower the energy consumption etc. An interface for the different choices of the electrical devices that affects the controller exist with GUIDE as interface as already mentioned. What would be requested is a solution for the connection between the controller and the monitor and how they can operate together with the demand in our controller and decisions made from the monitor. What could be chosen from the monitor in order to improve the function of the controller?

Another work that would be interesting to continue with, is to implement the merged controller in reality, by installing a home automation system that communicates with the central electricity system in the house. Here, extra applications can be used, like use more sensors to make the system more intelligent and able to make better decisions.

By controlling the electricity system, it is also possible to implement more filters and predicting solutions, in order to make a more accurate estimation of how the centers consumption will look like in the upcoming hours. This could be made by including more data from sensors, previous daily consumption, connect to all cell phones in the building to figure out how many people that are usually visiting the building.

7 Conclusion

In this chapter a conclusion of an energy efficient control system in the new youth center is presented, together with recommendations for the PV system and other aspects that could affect the result.

It is possible to decrease the energy consumption and the maximum power of the center by controlling the electricity, which was the main purpose of this project. Unfortunately, the controls that have been evaluated are probably not the optimal ones, which was wished for before the project started. Instead, more specific aspects for this project has been taken into account and the final solution is more customized to this building, instead of a general solution.

What will make a big impact on lowering the energy consumption in the center is the increased interest of the subject among the members at the center. To keep up this interest, the monitor will be important in order to present all information about the energy consumption. This will make it easier for all members to get an insight of how the energy is used and how it is possible to use less of it.

If none of the controllers are possible to implement, maybe due to lack of local knowledge about programming, it is a good backup plan to install a switch at the entrance[1] in order to turn every device off that are not expected to be used, when closing the center for the day. This would not require a control system, nor a PV system, but will still save energy for the center.

Most important to enable this center to be built, is a stable organization, knowing how to expand and still manage the center. As seen in the field study that we made, there are many empty buildings in Kibera meant for these kind of activities. When the people responsible for the construction part of the building leave, it is common that there is no organization able to continue to manage the center. This is why Wale Wale is a local organization with members and a board filled with people living in Kibera.

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A

Appendix

Figures A.1 - A.7 shows tabels of all electrical devices that will be included in the new youth center. Their expected power demand and energy consumption is presented.

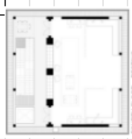
Main Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]
Forth Floor	Silent space	Smoke detector	Battery	1	24	0	0		24	0	10545
		Ventilation	Fan	1	7-20	108	108	1	12	1,296	
		Lighting	Flourescent	6	7-9, 18-20	36	216		4	0,864	2131,2
		Lighting	LED	8	7-9, 18-20	7	56		5	0,28	1332
		Charger	Laptop	25	17-20	25	625		3	1,875	
		Charger	Phone	15	17-20	5	75		5	0,375	
		Accesspoint - WiFi	UniFi AC	1	7-20	6,5	6,5	1	14	0,091	8880

Figure A.1: Electrical devices that are planned to be used on the fourth floor in the main building

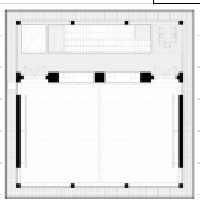
Main Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]
Third Floor	Dance space	Smoke detector	Battery	1	24	0	0		24	0	10545
		Ventilation	Fan	1	16-21	108	108		5	0,54	
		Lighting	Flourescent	8	17-20	36	288		4	1,152	2575,2
		Air Condition	Panasonic CE	1	17-20	3000	3000		3	9	91008,9
		Subwoofer	Sony 10" SA-(	1	17-20	115	115		3	0,345	27694,5
		Reciever *	Sony 5.1 STR	1	17-20	200	200		3	0,6	24364,5
		Speakers *	Audio Pro Add	1	17-20	30	30		3	0,09	33189
THIRD FLOOR - DANCE		Accesspoint*	UniFi AC	1	7-20	6,5	6,5		13	0,0845	8880
		Charger	Phone	4	17-20	5	20	0,5	3	0,06	

Figure A.2: Electrical devices that are planned to be used on the third floor in the main building

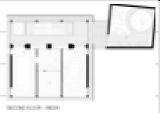
Main Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]
Second Floor	**Media center**	Smoke detector	Battery	1	24	0	0		24	0	10545
		Ventilation *	Fan	1	7-20	108	108		12	1,296	
		Lighting *	Flourescent	8	7-9, 5-20	36	288		4	1,152	2575,2
		Lighting *	LED	2	7-20	7	14		5	0,07	333
	Office	Accesspoint *	UniFi AC	1	8-20	6,5	6,5		24	0,156	8880
		Stationary Computer *	https://www.kj	4	8-20	500	2000		10	2,5	
		Speaker	Logitech S150	8	8-20	2	16		8	1,024	26551,2
		Charger	Camera	5	(1.5 h/camera.	5	25		3	0,075	22144,5
		Charger	Videocamera	4	(1.5 h/camera.	12	48		3	0,144	17715,6
		Charger	Laptop	10	8-20	25	250		6	1,5	55389
		Charger	Phone	30	8-20	5	150		5	0,15	26307
		Printer		2	12.00-12.10	365	730		2	1,46	72216,6
	Projection/Social	Television	Hitachi 49" 4K	1	10-20	71	71		6	0,426	55389
		Projector	Panasonic PT	1	10-11, 16-17	240	240	8	2	0,432	38850
*	Studioroom	Mixer table	http://rdn.harn	1	11-13, 15-20	200	200		2	0,4	0
*		Stationary Computer *	http://www.lea	1	11-13, 15-20	500	500		8	2,4	0
	Recording	Keybord *	Yamaha PSR-	1	11-13, 15-20	6	6		4	0,024	10778,1
		Electrical Guitar, amp	Fender MUST/	1	4 h/3days a we	20	20		3	0,06	13875
		Mick	Battery	1	4 h/3days a we	0	0		3		

Figure A.3: Electrical devices that are planned to be used on the second floor in the main building

Main Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]
First floor	Study space	Smoke Detector	Battery	1	24	0	0		24	0	10545
		Ventilation	Fan	1	6-20	108	108		12	1,296	0
		Lighting	Flourescent	8	7-9, 17-20	36	288		4	1,152	2575,2
		Router	ASUS RT-AC5	1	07-20	6,5	6,5		24	0,156	13320
		Charger	Laptop	20	7-17	25	500		10	5	

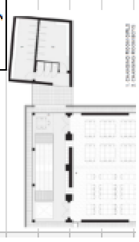


Figure A.4: Electrical devices that are planned to be used on the first floor in the main building

Main Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]	Comments
Ground floor	Playground	Lighting	LED	4	00-07, 18-00	11,5	46		12	0,552		

Figure A.5: Electrical devices that are planned to be used on the ground floor in the main building

Side Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]
First Floor	Bathroom *2	Lightning	LED	2	18:00-19:30	7	14		5	0,07	0
	Shower/changing	Washing machine	Sharp ES-FE5	1	11-14 fotball, d	2200	2200		3,3	7,26	
		Lightning	Flourescent	4	17-20 (dancing	36	144	*	4	0,576	
	High school	Lightning	Flourescent	10	7-9, 16-18	36	360		4	1,44	
		Smoke detector	Battery	1	00-24	0	0		24	0	0
		Accesspoint	UniFi AC	1	7-20	6,5	6,5		24	0,156	

Figure A.6: Electrical devices that are planned to be used on the first floor in the side building

Side Building		Electrical Device	Type	Qty.	Hours	Max Power per device [W]	Total max Power [W]	Standby Power [W]	Drift [h/day]	Energy [kWh/day]	Cost [KES]
Ground Floor	Kitchen	Fridge	Electrolux ERI	2	00-24	40	80		24	1,92	
		Freezer	Elektro Helios	1	00-24	160	160		24	3,84	
		Lighting	flourescent	1	7-9 17-20 (che	36	36		5	0,18	
		Ventilation	Fan	1	7-20	108	108		12	1,296	
		Microwave	Severin MW78	4	13-13:30	700	2800		1	2,8	0
		Kettle	Matsui Vatten	1	7-9(30min), 13-	2000	2000		0,3	0,6	0
		Stove	Gas	1	7-9, 12-13, 14-	0	0	0	6	0	
		Oven		1	7-9, 12-13, 14-	930	930		6	5,58	
		Charger	Phone	2	07-19	5	10		12	0,12	
		Cooker hood fan	OMNEJD	2	7-8:30, 12:30-1	240	480		8	3,84	
	Dishroom	Dishwasher	LAGAN 00299	2	5 washes	1020	2040		2	4,08	
	Office	Printer		1	20 min	365	365	2.7	2	0,73	0
		Accesspoint	UniFi AC	1	07-20	6,5	6,5		24	0,156	
		Charger	Laptop	5	7-20	25	125	15	13	1,625	
		Charger	Phone	5	7-20	5	25	0,5	13	0,325	
		Lightning	Flourescent	3	depend on win	36	108		4	0,432	
	Bike workshop	Lightning	Flourescent	2	17-19	36	72		4	0,288	
		Smoke detector	Battery	1	00-24	0	0		24	0	0
	Restaurant	Lightning	Flourescent	10	7-9, 17-20	36	360		4	1,44	

Figure A.7: Electrical devices that are planned to be used on the ground floor in the side building

B
Appendix

Data sheet showing parameters used for the simulation made for estimate the ventilation in the center [1] are showed in Figure B.2 and B.1.
Temperature estimation on the dance floor, showing that the temperature will vary between 21,5°C and 24,5°C

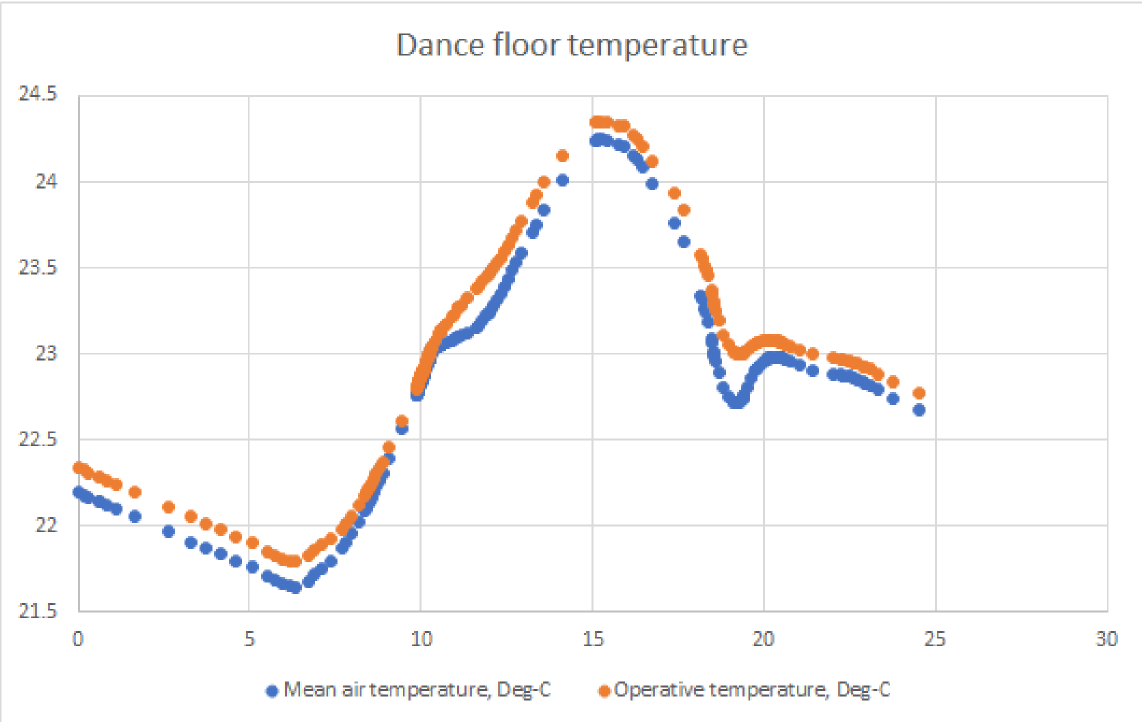


Figure B.1: Temperature estimation on the dance floor, showing that the temperature will vary between 21,5°C and 24,5°C

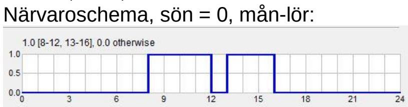
[1]Nilsson, J., Bengt Dahlgren Stockholm AB, Engineer, Construction, May 2017

VVS Energi & Miljö Styr & Övervakning Brand & Risk Teknisk Förvaltning

BENGT DAHLGREN

Indatalista – Wale Wale Future Center

Upprättad av: Johan Nilsson
Datum: 2017-06-02

Typ	Värde/beskrivning	Kommentar
Grundförutsättningar		
Beräkningsprogram	IDA ICE 4.7.1	
Ort	Nairobi	
Klimatfil	KEN_NAIROBI-KENYATTA-AP (IW2)	
Inomhusyta	560 m²	
Antal beräkningszoner	10 st	
Byggnadsegenskaper		
U-värde fasad	0,55 W/m²K	Antaget BDAB
U-värde tak	0,17 W/m²K	Antaget BDAB
U-värde grund	0,22 W/m²K	Antaget BDAB
Infiltration (vinddriven)	0,5 ACH vid 50 Pa tryckskillnad	Antaget BDAB
Fönsterdata		
U-värde fönster	2,9 W/m²K	Antaget BDAB
g-värde fönster inkl. solskydd	25 %	Beräknat i IDA med antagen (av BDAB) indata
Fönsteröppning	50 % i x- och y-led	Antaget BDAB
Fönsteröppningsförutsättningar	Inomhustemperatur > 21 °C Inomhustemperatur < utomhustemperatur Endast under tidpunkter mellan 08-22	Antaget BDAB
Zonindata		
P01 utbildning	Area: 91 m² **Personlaster** Antal: 40 st MET: 1,2 CLO: 0,5 ± 0,25 Närvaroschema, sön = 0, mån-lör:  **Elutrustning** Effekt per enhet: 150 W	Antaget BDAB

Bengt Dahlgren Stockholm AB
Hammarby Allé 47
120 30 STOCKHOLM
Telefon 08-588 88 100
Fax 08-588 88 101
Org.nr. 556150-0751
Momsreg.nr. SE556150075101
Styrelsens säte Stockholm
Adresser till våra övriga kontor hittar du på www.bengtdahlgren.se

Figure B.2: Parameters used to estimate the ventilation in the center. Here, the first floor is presented