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Design of photovoltaic systems

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1-INTRODUCTION

Photovoltaic (PV) harvesting of solar energy is based on capturing sunlight and transforming it into electricity. This type of electricity generation does not pollute the environment as much as other types of energy production, that is why nowadays some engineers would like to improve it.

To carry out this change we use solar cells made of semiconductor materials (Silicon) in which it is artificially created a permanent electric field. These cells are connected in series or parallel forming a solar panel responsible for supplying voltage and current needed to meet the demand.

We can divide this energy in two big groups:

- Installations connected to the electric grid: This is a normal form to obtain electricity. The installation provides the energy generated to the grid, as the power plants, nuclear or hydroelectricity. Photovoltaic panels are usually located on big buildings and in big fields.
- Isolated installations: they provide energy only for an individual installation. Energy generated from photovoltaic conversion is used to cover small electricity consumption in the same place where the demand occurs. Nowadays it is an alternative form to obtain electricity than the traditional way of connecting the PV installation to the grid. It is useful for places without electric grid, street lighting, agricultural applications or air and sea traffic signs.

As other forms of energy production, solar plants have some advantages and disadvantages:

- There are not emissions of pollutants to the atmosphere.
- The silicon is abundant.
- There is no necessity for large power lines.
- It is not noisy.
- It is not necessary to use fuel.
- For large installations connected to the grid, it is necessary a big land area.
- Sometimes it is necessary a government grant because an individual installation is expensive.
- There is not much maintenance, so it is cheap.

The main objective of this project is to design and compare the installations for a higher education institute of the University of Pécs (Hungary), an office building, a supermarket and a church. I will also analyze if it is better a fix or a mobile system.

2-HIGHER EDUCATION INSTITUTE

2.1 - INTRODUCTION

I am going to analyze the Pollack Mihály Faculty of Engineering and Information Technology of the University of Pécs (Hungary). This building is located in Boszorkány Street, 2, Pécs (Hungary).

The building has four different floors:

- Floor -1: offices. This floor is smaller than the rest.
- Floor 0: main entrance, lobby, offices, classrooms, coffee shop and print room.
- Floor 1: offices and classrooms.
- Floor 2: offices and classrooms.

Each floor has different loads because they do not have the same rooms or the same uses. In the point 2.2 (Analysis of loads) I am going to calculate all the loads together, without depending on the floor.

The roof is flat, so the system will be easily installed. On the roof there are some chimneys and air extraction systems, so I need study the available area.

Finally I am going to design a tracking system because the conditions of the roof permit it.

2.2- ANALYSIS OF LOADS

I divide the loads into four different sections.

A- HEATING – AIR COOLING

I assume that the heating system of the faculty has two big boilers for all the building, an installation pump and different resistors. Also I suppose that the air cooling is a small system only for specific office (management and meeting room). We see this in Table 1.

Table 1. Heating related consumers at the faculty

Description	Total power
2 boilers (200kW each one)	400kW
Installation pump	20kW
Resistors	15kW
Air cooling system	50kW
Total	485kW

B- ELEVATORS

The Faculty has two elevators, each one for 8 people. I also need to consider the lighting inside the elevator. We see this in Table 2.

Table 2. Elevators related consumers at the faculty

Description	Total power
2 electric engines	30kW
4 light bulbs	240W
Total	30,24kW

C- LIGHTING

I am going to use fluorescents lamps of 36W. We see the distribution of lamps in Table 3.

Table 3. Distribution of the lights in the faculty

Room	Number of rooms	Number of fluorescents	Total
Main entrance	-	15	15
Corridors	-	150	150
Common areas	-	10	10
Offices	120	2	240
Classrooms	20	10	200
Toilets	12	10	120
Print room	1	6	6
Coffee shop	1	6	6
Reception	1	3	3
Total			750

D- INFORMATION TECHNOLOGY

In this part there are computers, printers and projectors. All this elements are distributed in offices and information technology (IT) classrooms. We see this in Table 4.

Table 4. Technological elements in the faculty

Description	Amount	Power	Total power
Computers	200	285W	57kW
Printers	60	600W	36kW
Projectors	10	45W	0,45kW
Total			93,45kW

Finally, in Table 5 is the summary of all loads in the building:

Table 5: Total loads in the faculty

Description	Number of elements	Power	Total
Fluorescents lamps	750	36W	27kW
Light bulbs	4	60W	0,24kW
Computers	200	285W	57kW
Printers	60	600W	36kW
Projectors	10	45W	0,45kW
Boilers	2	200kW	400kW
Installation pump	1	20kW	20kW
Resistance	-	15kW	15kW
Air cooling system	1	50kW	50kW
Electric engines	2	15kW	30kW
Total			636kW

All the loads will not be connected at the same time, so we have to do an approach for it.

The trend of consumption has to be determined during a day, a week and a year.

- Daily: Most of the loads are on during the day, when the faculty is full of people, from 8a.m. to 8p.m. The rest of the time the load is lower as we can see in the Figure 1.

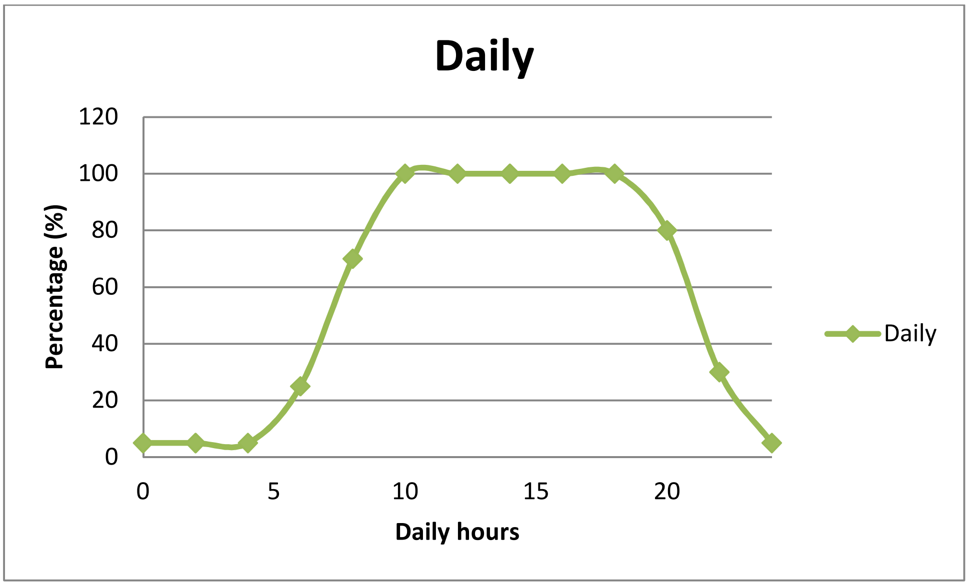

Figure 1. Daily trend of electricity consumption in the faculty

- Weekly: Peak consumption is during the working days of the week. On Saturday there are only a few loads and on Sunday the faculty is closed. We can see it in Figure 2.

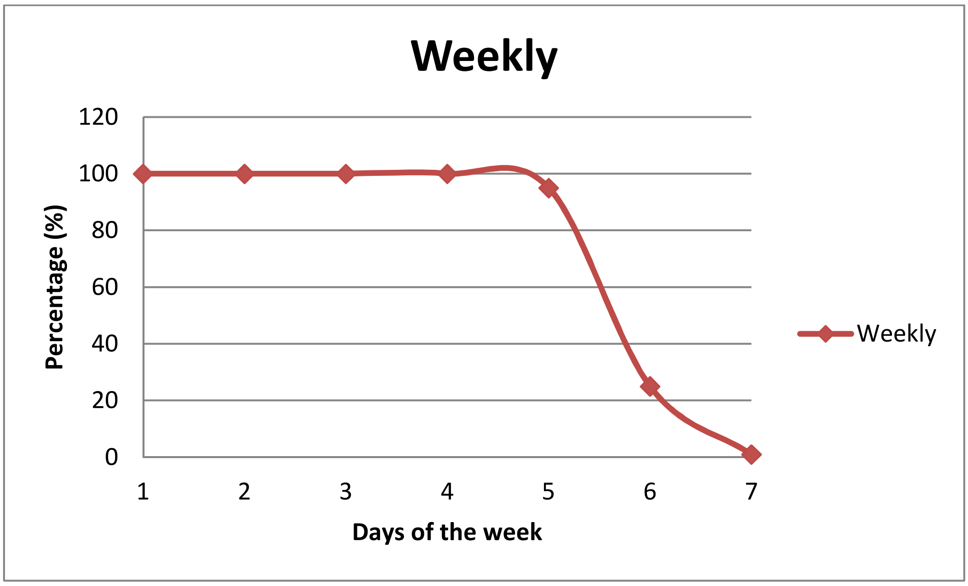

Figure 2. Weekly trend of electricity consumption in the faculty

- Yearly: from September to June I consider that the loads work on the top. In summer there are not courses and the faculty is only open for administration. Also we can see a decrease of the consumption at Christmas, when the Faculty is closed. We can see it in Figure 3.

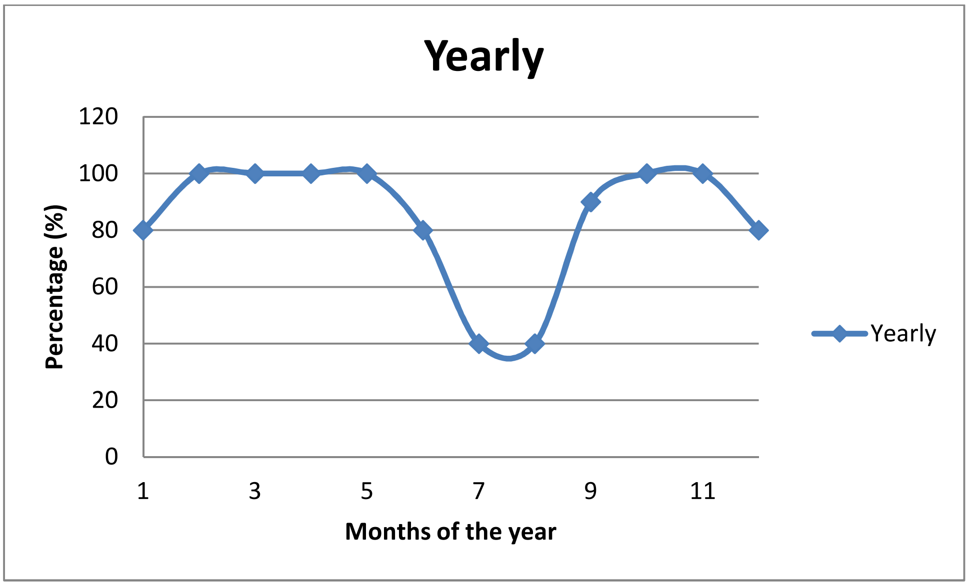

Figure 3. Yearly trend of electricity consumption in the faculty

2.3-STUDY OF THE CHARACTERISTICS OF THE INSTALLATION

Once the trend of loads connected is known, I need the solar radiation reaching our photovoltaic panels, in this case in Pécs (Hungary). I am going to use the Photovoltaic Geographical Information System (PVGIS, http://re.jrc.ec.europa.eu/pvgis/). We only have to use the Europe map and follow Pécs, this software gives us the solar radiation for all the inclinations we want. Due to we only want the best option for a fixed system we tick the option "optimize slope" and I obtain that 35º is the correct inclination.

The radiations obtained are written in Table 6:

Table 6: Radiation in Pécs for 35º

Radiation kWh/día/m2												
	J	F	M	A	M	Jn	Jl	A	S	O	N	D
35º	1,47	2,23	3,37	4,08	4,27	4,39	4,53	4,31	3,51	2,93	1,73	1,16

The loads of each period of the year are different because different systems are connected. Because of this I am going to analyze the loads in 3 periods.

1- July and August

During this period of time the faculty is only open for coming to the secretary to solve problems with the documents. There are not courses and it only opens in the morning. The staff does not need all the fluorescents, computers and printers. Air cooling system is connected too. We see this in Table 7.

Table 7. Analysis of loads in period 1 in the faculty

July - August				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	200	36W	5	36
Light bulbs	4	60W	5	1,2
Computers	40	285W	3	34,2
Printers	10	600W	2	0,9
Air cooling system	1	50kW	2	100
Electric engines	2	15kW	1	30
Total				202,3

The faculty needs 202.3kWh each day but I am going to modify a bit this amount due to possible incidents in the system. I am going to consider that the efficiency of the inverter is 90% and we add a 10% more of amount.

$$G_1 = \frac{E_0 \cdot T_1}{E_i} = \frac{110 \cdot 202.3}{90} = 246.89kWh$$

Where:

- G_1 is the energy with correcting factors.
- T_1 is the energy without correcting factors.
- E_0 is the percentage increase.
- E_i is the efficiency of the inverter.

2- January, February, March, November and December

During this period of time the building is open all the day, so the common loads are bigger than in the summer case. Also the heating elements are needed. It is important to explain that the heating system usually works at 40-50% of its power but it get its peak at the beginning to reach the selected temperature. I can estimate that the installation pumps works about the 60% of the full time that the installation is working. We see this in Table 8.

Table 8. Analysis of loads in period 2 in the faculty

January - February- March - November - December				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	750	36W	8	216
Light bulbs	4	60W	10	2,4
Computers	200	285W	3	171
Printers	60	600W	0,5	18
Projectors	10	45W	1	0,45
Boilers	2	200kW	4	1600
Installation pump	1	20kW	4	60
Resistance	-	15kW	4	60
Electric engines	2	15kW	3	90
Total				2217,85

I need to increase a bit the total amount with the same approximation I did in the other case.

$$G_2 = \frac{E_0 \cdot T_2}{E_i} = \frac{110 \cdot 2217.85}{90} = 2709.5kWh$$

3- April, May, June, September and October

In this period of time the faculty staff does not need heating or air cooling system, so the total load will be lower. We see this in Table 9.

Table 9. Analysis of loads in period 3 in the faculty

April - May - June - September - October				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	750	36W	8	216
Light bulbs	4	60W	10	2,4
Computers	200	285W	3	171
Printers	60	600W	0,5	18
Projectors	10	45W	1	0,45
Electric engines	2	15kW	3	90
Total				497,85

I use correcting factors again:

$$G_3 = \frac{E_0 \cdot T_3}{E_i} = \frac{110 \cdot 497.85}{90} = 607.44kWh$$

Once the yearly trend of operation loads is known I am going to calculate which month is the most restrictive. With this value I can start to calculate the characteristics of the system, as we can see in Table 10.

Table 10. Comparison of loads and radiation during the year for the faculty

35º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
R_t	1,47	2,23	3,37	4,08	4,27	4,39	4,53	4,31	3,51	2,93	1,73	1,16
G_t	2709,5	2709,5	2709,5	607,4	607,4	607,4	246,9	246,9	607,4	607,4	2709,5	2709,5
D	1843,2	1215,0	804,0	148,9	142,2	138,4	54,5	57,3	173,0	207,3	1566,2	2335,8

Where:

- R_t is the radiation in Pécs. Measurement unit: kWh/day/m^2
- G_t is the energy with correcting factors. Measurement unit: kWh/day
- D is the relation between R_t and G_t. Measurement unit: m^2

The loads of this building are huge for only a photovoltaic system, so I also need connect it to the electric grid. The contribution of solar cells will be only a bit of the needed energy, so I will calculate the maximum number of panels that I can install and after that I will obtain the percentage of contribution.

It is known that the roof of the building is flat and very big, so I am going to analyze a fixed system and a tracking system and compare which one is better.

2.4- DESIGN OF THE INSTALLATION

2.4.1- FIXED SYSTEM

I have to consider the position and location. The building has a West-East orientation, so I can install the panels facing South with an Azimuth of 10º. It is also known that the faculty does not have buildings or big trees near, so it is not going to have problems due to shadows.

We see the plan of the building with Google Maps in Figure 4.

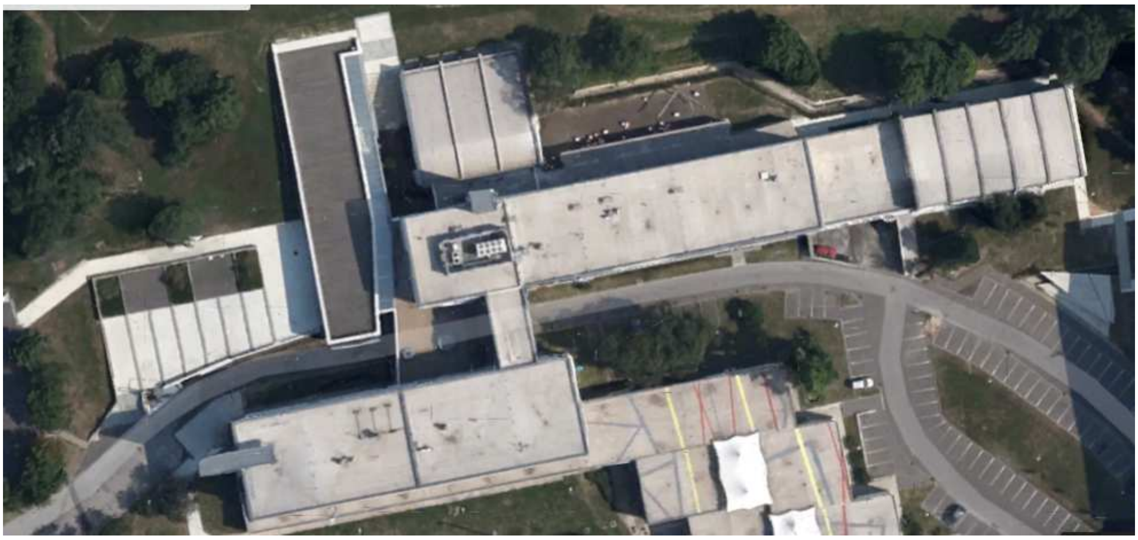

Figure 4. Top view of the faculty building

We have two different zones where I am going to install the photovoltaic panels.

Zone 1: It is divided in the middle, so we have to separate the cells in the middle of the roof. Also there are more elements on the roof, so we have to be careful with the shadows they produce. The lengths of this zone are 20x65m, but it is not possible to use all of this area. I am going to use the red zone to install the panels, as we can see it Figure 5.

Figure 5. Top view of the zone 1 of the faculty building

Zone 2: However it has some elements in one side of the roof we can install cells. We can see the zone where we can install the panels in the Figure 6:

Figure 6. Top view of the zone 2 of the faculty building

Once I have defined the available zone, I am going to select the solar cells we will use. In this case I will install photovoltaic panels Isofoton Isf-250, with the features of the Table 11:

Table 11. Features of the photovoltaic panel Isofoton Isf-250

Lengths	1667*994*45mm
Area	1.657 m^2
Weight	19kg
Efficiency	15.1%
Voltage with open circuit	37.8V
Current with short circuit	8.75A
Voltage with maximum power	30.6V
Current with maximum power	8.17A

Now, I have to see how many panels I can install on the roof, so I need the minimum distance between panels. We know that latitude of Pécs is 46.07º. The correct form of calculate this is as we can see in Figure 7:

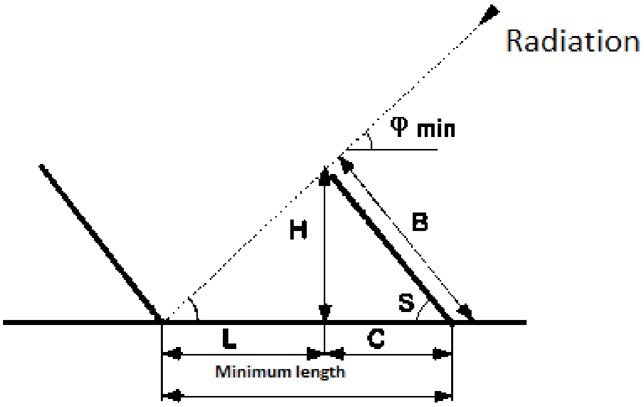

Figure 7. Incidence of radiation

Considering the position and location of the building we obtain:

$$C = B \cdot cos35º = 0.994 \cdot \cos 35 º = 0.814m$$

$$H = B \cdot sin35º = 0.994 \cdot sin35º = 0.57m$$

$$\emptyset_{min} = 90º - 46.07º = 43.93º$$

$$tan\emptyset_{min} = \frac{H}{L} = \frac{B \cdot sinS}{D_{min} - B \cdot cosS}$$

$$D = B \cdot cosS + \frac{B \cdot sinS}{tan\emptyset_{min}} = 0.994 \cdot cos35º + \frac{0.994 \cdot sin35º}{tan43.93} = 1.406m$$

To calculate the number of panels I can install, I am going to divide zone 1 in 4 different parts, as we can see in Figure 8.

Figure 8. Top view of the divisions of zone 1 of the faculty building

Considering the lengths of the panels and the minimum distance between them, we obtain the next results:

- Zone 1.A: 6 lines of 16 panels. Total: 96 panels.
- Zone 1.B.1: 6 lines of 16 panels. Total: 96 panels.
- Zone 1.B.2: 1 line of 11 panels. Total: 11 panels.
- Zone 1.B.3: 3 lines of 16 panels. Total: 48 panels.

Thus, in zone 1 we can put 251 panels.

We can see in Figure 9 how I divide zone 2 to analyze it:

Figure 9. Top view of the divisions of zone 2 of the faculty building

- Zone 2.A: 7 lines of 32 panels. Total: 224 panels.
- Zone 2.B: 1 line of 32 panels. Total: 32 panels.

Thus, in zone 2 we can put 256 panels.

Finally, I add the two amounts and I have a total of 507 panels.

We can see the distribution of the panels in the Figure 10:

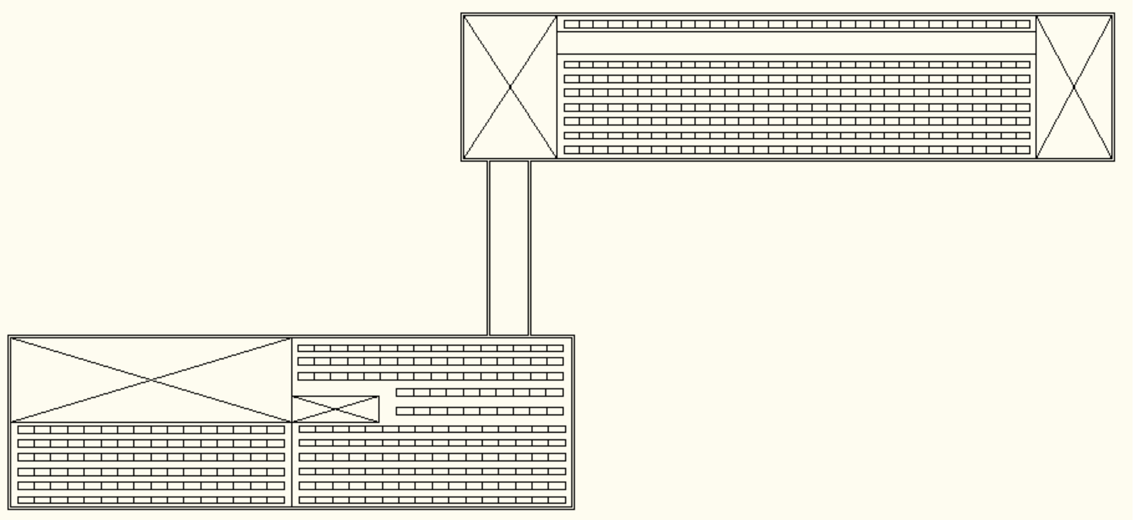

Figure 10. Distribution of the panels of the faculty building in the fixed system

Now, I calculate the total power of the installation.

$$Total\ power = 507 \cdot 250 = 126750Wp = 126.75kWp$$

Once the number of panels is calculated I am going to obtain the necessary amount of inverters. The maximum quantity of power is 126.75kWp, so I am going to use 13 inverters Isofoton 10 (10kW) with an efficiency of 96.8%.

In this case I do not need batteries because the system is connected to the electric grid and the solar cells only support a part of the total power needed.

Now, I am going to compare the power obtained with the energy needed. We have 126.75kWp, so in one hour we have 126.75kWh. The results are in Table 12.

Table 12. Comparison of loads and radiation for the fixed system in the faculty

35º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,47	2,23	3,37	4,08	4,27	4,39	4,53	4,31	3,51	2,93	1,73	1,16
Gt	126,8	126,8	126,8	126,8	126,8	126,8	126,8	126,8	126,8	126,8	126,8	126,8
D	86,2	56,8	37,6	31,1	29,7	28,9	28,0	29,4	36,1	43,3	73,3	109,3

Finally, I compare the solar energy and the total energy to know the percent of the energy provided by the sun. The results are in Table 13.

Table 13. Comparison of percentage of contribution of the fixed system in the faculty

35º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Solar	86,2	56,8	37,6	31,1	29,7	28,9	28,0	29,4	36,1	43,3	73,3	109,3
Total	1843,2	1215,0	804,0	148,9	142,2	138,4	54,5	57,3	173,0	207,3	1566,2	2335,8
%	4,677	4,675	4,677	20,89	20,89	20,88	51,38	51,31	20,87	20,89	4,68	4,679

2.4.2- TRACKING SYSTEM

The solar tracker is a mechanic device which is used to orient photovoltaic panels, because we would like that they are always perpendicular to the sunlight. Tracking sun from east in the morning to west in the evening will increase the efficiency of the solar panel up to 45%.

These systems have some advantages over the fixed systems:

- They increase the efficiency of the panel.
- Easy installation and startup.
- Different options to the installation.
- Some systems can be controlled by the Internet if you have the appropriate software.
- High solar tracking precision.
- It is suitable for panels with low and high power.
- Low power consumption.

However they also have the disadvantage of being more expensive than the fixed ones.

In this case I have decided for a system with two axes and a pole for the movement and support.

For this installation I am going to use a photovoltaic panel Atersa A-150P, 150W with the features that we can see in Table 14:

Table 14. Features of the photovoltaic panel Atersa A-150P

Lengths	1476*659*35mm
Area	0.9727 m^2
Weight	11.9kg
Efficiency	15.4%
Voltage with open circuit	22.6V
Current with short circuit	8.69A
Voltage with maximum power	17.84V
Current with maximum power	8.41A

I am going to join 9 of these panels to form a group, and each group will be installed on a pole. So, finally we have lengths of 4428*1977mm and the total power of each group will be 1350Wp.

The distance between poles has to be calculated, thus I use the same expressions as in the fixed case. I calculate the distances for the two extremes situations, in the sunrise and in the sunset and in noon.

Option 1: sunrise and sunset:

The North-South distance should only be the lengths of the panels, so we need 4.6m. On the other hand, to calculate the East-West distance I need the expression that I used in the fixed system. The top inclination of the panel will be 70º, so I use this amount. We see this in Figure 11.

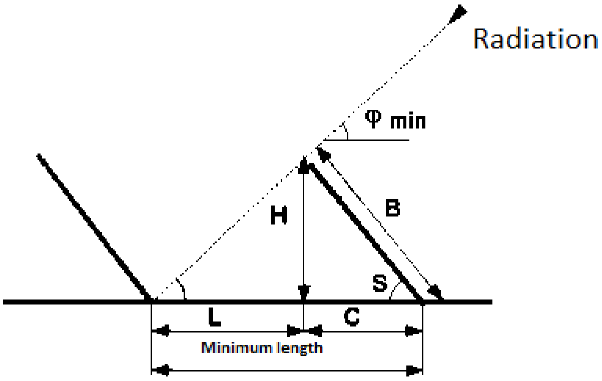

Figure 11. Incidence of radiation

$$D_{min} = B \cdot cosS + \frac{B \cdot sinS}{tan\emptyset_{min}} = 1.977 \cdot cos70 + \frac{1.977 \cdot sin70}{tan43.93} = 2.604m$$

Option 2: noon:

In this case the East-West distance is the length of the panels, 4.6m. I use the same expression to calculate the North-South distance.

$$D_{min} = B \cdot cosS + \frac{B \cdot sinS}{tan\emptyset_{min}} = 1.977 \cdot cos15 + \frac{1.977 \cdot sin15}{tan43.93} = 2.44m$$

So, finally I need the same separation between poles, a distance of 4.6m.

The objects on the roof will not disturb the installation of the poles, and they will not have problems with shadows too, because they are higher and sunlight reaches them directly.

I have to take into account the distance between poles to calculate how many I can install. I divide all the building in two zones to obtain the available area:

- Zone 1: In this place I am going to install 4 lines of 14 poles each one. Total: 56 poles. We see this in Figure 12

Figure 12. Top view of the zone 1 of the faculty for the tracking system

- Zone 2: I am going to install 3 lines of 12 poles each one. Total: 36 poles. Figure 13.

Figure 13. Top view of the zone 2 of the faculty for the tracking system

The situation of the poles is the next:

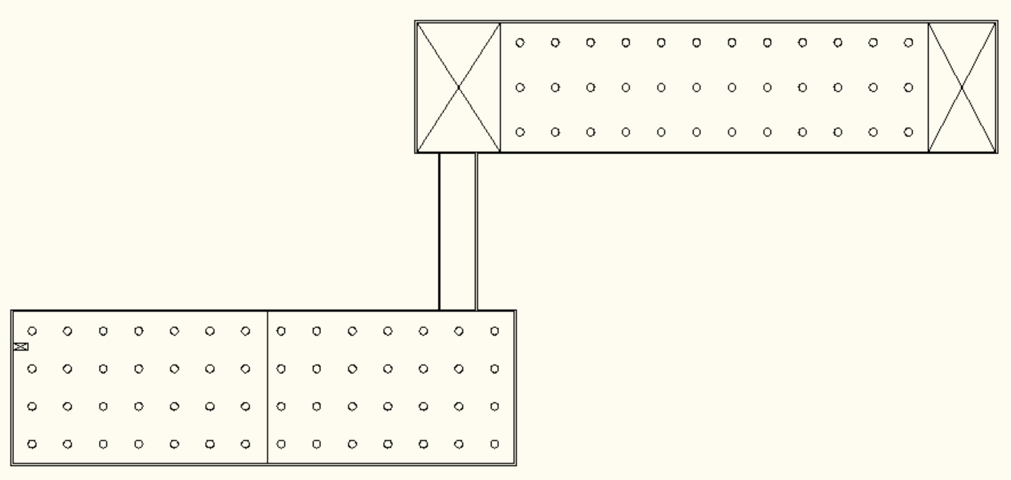

Figure 14. Distribution of the panels of the faculty building in the tracking system

Finally, we add up the two amounts and we have a total of 92 groups of panels.

$$Total\ power = 92 * 1350Wp = 124.2kWp$$

Once the power is calculated, I have to increase this value depending on the month with corrective factors due to the different quantity of radiation reaching in the panels during the day. In Hungary these factors for tracking systems are between 1.3 in winter and 1.8 in summer. I obtain the next results of Table 15 for each month.

Table 15. Total power produced per month in the tracking system in the faculty

Power per month (kWp)												
	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Factor	1,3	1,4	1,48	1,65	1,65	1,75	1,8	1,8	1,7	1,6	1,45	1,3
Total power	161,5	173,9	183,8	204,9	204,9	217,4	223,6	223,6	211,1	198,7	180,1	161,5

Now the inverters for the system have to be chosen. The maximum quantity of power is 223.6kW, thus I am going to use 14 inverters Isofoton 23 (10kW) with an efficiency of 96.8%.

In this case I do not need batteries because the system is connected to the electric grid and the solar cells only cover a part of the total power needed.

The values for the irradiation in Pécs (Hungary) for a tracking system are the in Table 16:

Table 16. Radiation per month for the tracking system in the faculty

Radiation kWh/día/m2												
	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Tracking	1,79	2,71	4,17	5,32	5,81	6,09	6,26	5,87	4,42	3,65	2,09	1,38

Now, I divide this power between the irradiation to see the contribution to the system. We see this in Table 17.

Table 17. Comparison of loads and radiation for the tracking system in the faculty

Tracking	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,79	2,71	4,17	5,32	5,81	6,09	6,26	5,87	4,42	3,65	2,09	1,38
Gt	161,5	173,9	183,8	204,9	204,9	217,4	223,6	223,6	211,1	198,7	180,1	161,5
D	90,2	64,2	44,1	38,5	35,3	35,7	35,7	38,1	47,8	54,4	86,2	117,0

Finally I compare the solar energy and the total energy to know the percent of the energy provided by the sun. We see this in Table 18

Table 18. Comparison of percentage of contribution of the tracking system in the faculty

	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Tracking	90,2	64,2	44,1	38,5	35,3	35,7	35,7	38,1	47,8	54,4	86,2	117,0
Total	1843,2	1215,0	804,0	148,9	142,2	138,4	54,5	57,3	173,0	207,3	1566,2	2335,8
%	4,894	5,281	5,483	25,87	24,8	25,79	65,53	66,47	27,61	26,26	5,502	5,009

2.5- CONCLUSIONS

- The main elements of the fixed installation are 507 panels and 13 inverters of 10kW; and for the tracking system are 92 poles with 9 panels each one, and 23 inverters of 10kW.
- In the tracking system I can use more area because the solar panels are not installed on the floor of the roof, they are in a higher position without being shadowed by other objects of the roof.
- The comparison of the contribution of the fixed and the tracking system is in Table 19:

Table 19. Comparison of the contribution from the fixed and the tracking system

%	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Fixed	4,68	4,67	4,68	20,89	20,89	20,88	51,38	51,31	20,87	20,89	4,68	4,68
Tracking	4,89	5,28	5,48	25,87	24,80	25,79	65,53	66,47	27,61	26,26	5,50	5,01

As we can see, the contribution of the tracking system is bigger than the contribution of the fixed one.

- In summer the percentage of contribution is higher because we have more radiation from the sun and the loads are lower.
- The solar system only contributes with a small quantity of power to the system, especially in winter, but we do not have to pay the fee for this power.
- The tracking system is more expensive than the fixed one but they produce more energy. Depending on the budget we have to select one or other.

3-OFFICES

3.1- INTRODUCTION

I am going to analyze a typical office building for a company. It has three floors:

- Ground floor: main entrance, reception, waiting room, coffee room.
- First floor: offices, meeting room.
- Second floor: offices.

Each floor has different loads because they do not have the same rooms or the same uses. In the point 3.2 (Analysis of loads) I am going to calculate all the loads together, without depending on the floor.

The roof has a slope of 52º and the panels will be installed on it, so they will have the same inclination. In this case it is not possible install tracking system because of the features of the roof are not the best to this system.

3.2- ANALYSIS OF LOADS

I describe all the loads of the building together in the next tables.

A- HEATING – AIR COOLING

I assume that the air conditioning system is used for heating and for air cooling. The parts are enumerated in Table 20.

Table 20. Heating related consumers at the office

Description	Total power
3 systems with inside units (15kW)	45kW
Split system	35kW
Air heat recovery	15kW
Extractors and ventilators	5kW
Total	100kW

B- ELEVATORS

The building only has an elevator for 6 people with the loads of Table 21.

Table 21. Elevators related consumers at the office

Description	Total power
Electric engine	11kW
2 light bulbs	120W
Total	11,12kW

C- LIGHTING

I am going to use fluorescents lamps of 36W. We see the distribution of lamps in Table 22.

Table 22. Distribution of the lights in the office

Room	Number of rooms	Number of fluorescents	Total
Offices	10	3	30
Corridors/stairs	-	20	20
Toilets	6	4	24
Reception	1	2	2
Meeting room	1	6	6
Coffee room	1	4	4
Total			86

D- INFORMATION TECHNOLOGY

In this part there are computers, printers, projectors and also a coffee machine. We see this in Table 23.

Table 23. Technological elements in the office

Description	Amount	Power	Total power
Computers	13	285W	3,7kW
Printers	11	600W	6,6kW
Projectors	1	45W	0,045kW
Coffee machine	2	1500W	3kW
Total			13.35kW

Finally, the summary of all the loads of the building are in Table 24.

Table 24: Total loads in the office

Description	Number of elements	Power	Total
Fluorescents lamps	86	36W	3,1kW
Light bulbs	2	60W	0,12kW
Computers	13	285W	3,7kW
Printers	11	600W	6,6kW
Projectors	1	45W	0,045kW
Air cooling system	3	15kW	45kW
Split system	1	35kW	35kW
Air heat recovery	1	15kW	15kW
Extractors and ventilators	1	5kW	5kW
Coffee machine	2	1500W	3kW
Electric engine	1	11kW	11kW
Total			127,57kW

All the loads will not be connected at the same time, so I have to do an approach for it.

The trend of consumption has to be determined during a day, a week and a year.

- Daily: I consider that the office is open from 7a.m to 7p.m. Also the employers have a rest to having lunch from 2p.m. to 4p.m. We can see this in Figure 15.

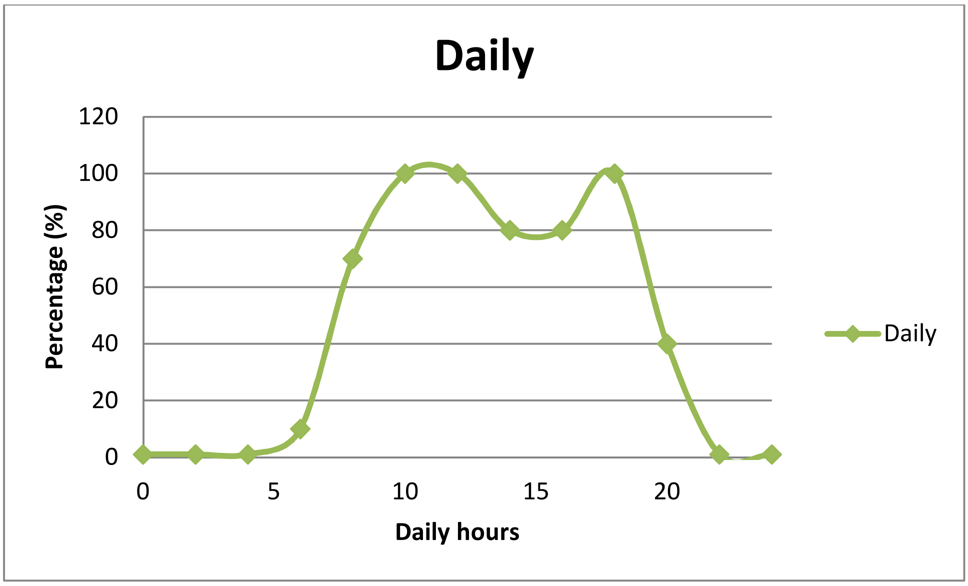

Figure 15. Daily trend of electricity consumption in the office

- Weekly: the office is open from Monday to Friday. At the weekend it is closed. We can see this in Figure 16.

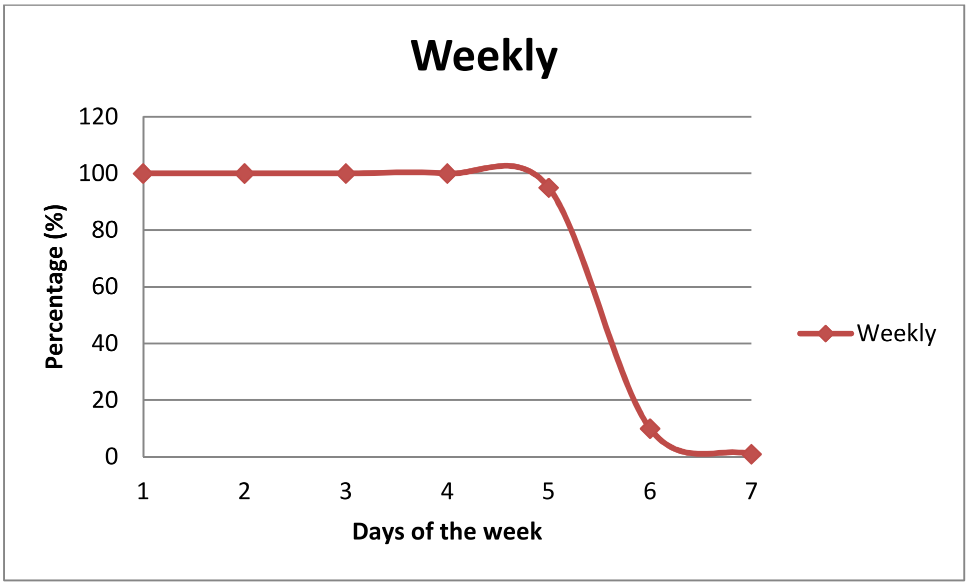

Figure 16. Weekly trend of electricity consumption in the office

- Yearly: the office is open during all the year but in summer most of employers are on holidays. Also it is closed during Christmas. We can see this in Figure 17.

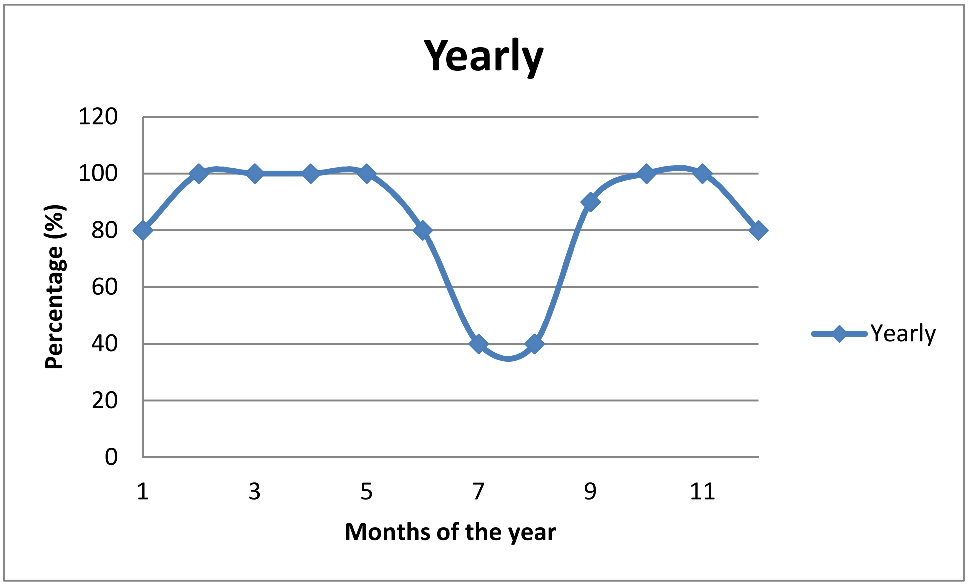

Figure 17. Yearly trend of electricity consumption in the office

3.3- STUDY OF THE CHARACTERISTICS OF THE INSTALLATION

The loads of each period of the year are different because we connect different systems. Because of this I am going to analyze the loads in 3 periods.

1- July – August

During this period of time some of the employers are on holidays, that is why I do not use all the common loads. On the other hand the air cooling system is connected with the splits and also the extractors and ventilators to renew the air of the office. I can consider that the splits are working the 60% of the time at the full power, and the air cooling only the 50%. To approximate the loads of the ventilators and the extractors are used 30 minutes each 8 hours. The enumeration of these loads is in Table 25.

Table 25. Analysis of loads in period 1 in the office

July - August				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	40	36W	5	7,2
Light bulbs	2	60W	5	0,6
Computers	5	285W	5	7,125
Printers	1	600W	2	1,2
Air cooling system	3	15kW	2,5	112,5
Split system	1	35kW	3	105
Extractors and ventilators	1	5kW	0,5	2,5
Coffee machine	2	1,5kW	2	6
Electric engine	1	11kW	0,5	5,5
Total				247,625

Using the correcting factors of the efficiency of the inverter and a global increase I obtain:

$$G_1 = \frac{E_0 \cdot T_1}{E_i} = \frac{110 \cdot 247.625}{90} = 302.6kWh$$

2- January, February, March, November and December

In this period the office is full of employers, so the common loads are in the top of energy needed. Also I have to include the heating system and we approximate it with a 40% of the full time. We can see these loads in Table 26.

Table 26. Analysis of loads in period 2 in the office

January - February - March - November - December				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	86	36W	8	24,5
Light bulbs	2	60W	8	0,96
Computers	13	285W	8	29,64
Printers	11	600W	0,5	3,3
Projectors	1	45W	1	0,045
Split system	1	35kW	4,5	157,5
Air heat recovery	1	15kW	4	60
Extractors and ventilators	1	5kW	0,5	2,5
Coffee machine	2	1,5kW	3	9
Electric engine	1	11kW	2	22
Total				309,445

I need to increase a bit the total amount with the same approximation we did in the other case.

$$G_2 = \frac{E_0 \cdot T_2}{E_i} = \frac{110 \cdot 309.445}{90} = 378.21kWh$$

3- April, May, June and September

During this period of time the heating or air cooling system is not connected. We can see this in Table 27.

Table 27. Analysis of loads in period 3 in the office

April - May - June - September				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	86	36W	8	24,5
Light bulbs	2	60W	8	0,96
Computers	13	285W	8	29,64
Printers	11	600W	0,5	3,3
Projectors	1	45W	1	0,045
Extractors and ventilators	1	5kW	0,5	2,5
Coffee machine	2	1,5kW	3	9
Electric engine	1	11kW	2	22
Total				91,945

The total energy is:

$$G_3 = \frac{E_0 \cdot T_3}{E_i} = \frac{110 \cdot 91.945}{90} = 112.38kWh$$

3.4- DESIGN OF THE INSTALLATION

The roof has an inclination of 52º, so I will overlay panels on the roof. Obviously the panels will have 52º of inclination, and I reject the others inclinations and the flexible system.

I use PVGIS to know the radiation in Pécs to this inclination and we obtain the next results.

With this value we can start to calculate the characteristics of our system, as we can see in Table 28.

Table 28. Comparison of loads and radiation during the year for the office

52º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,59	2,35	3,38	3,9	3,89	3,91	4,07	4,03	3,47	3,06	1,86	1,25
Gt	378,2	378,2	378,2	112,4	112,4	112,4	302,6	302,6	112,4	112,4	378,2	378,2
D	237,9	160,9	111,9	28,8	28,9	28,7	74,3	75,1	32,4	36,7	203,3	302,6

The top view of the roof of the building is in Figure 18.

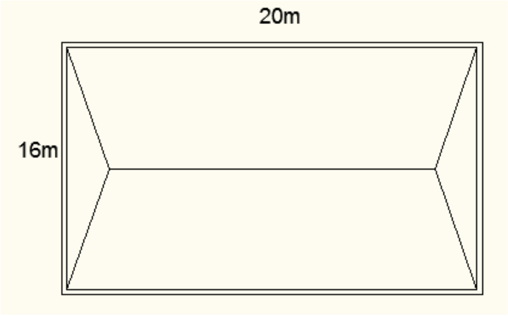

Figure 18. Top view of the roof of the building of the office

I am going to install the photovoltaic panel Isofoton Isf-250, that has the features of Table 29.

Table 29. Features of the photovoltaic panel Isofoton Isf-250

Lengths	1667*994*45mm
Area	1.657 m^2
Weight	19kg
Efficiency	15.1%
Voltage with open circuit	37.8V
Current with short circuit	8.75A
Voltage with maximum power	30.6V
Current with maximum power	8.17A

Now I calculate the available area to put the panels and I obtain approximately a square of 16x10m. Comparing this lengths with the ones of the panels with obtain that we can put 10 lines of 9 panels each one. The scheme of the roof is in Figure 19.

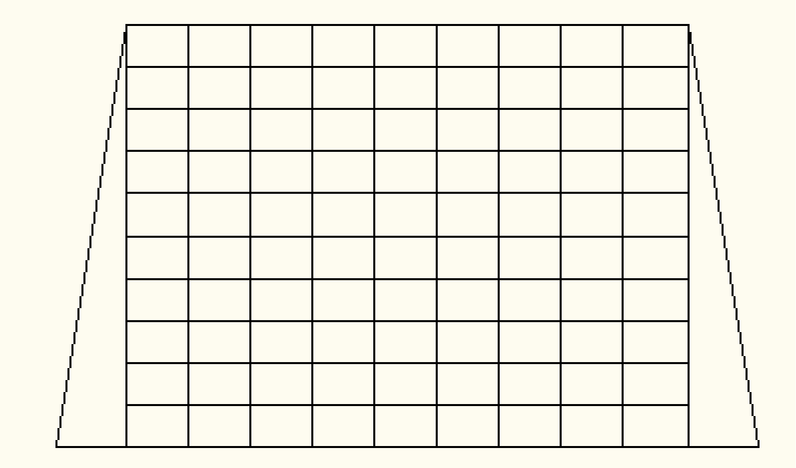

Figure 19. View of the distribution of the panels on the roof of the office

It is not necessary space between the cells because they are nail down the roof.

The total power we have is:

$$Power = 250 \cdot 90 = 22500Wp = 22.5kWp$$

It is not possible to install all the necessary panels to cover all the power demand, so the system will be mixed; some energy will be taken from the solar installation and the rest from the electric grid.

To calculate the needed inverters is necessary taking into account the total power obtained with the photovoltaic panels. So I only need to invest a maximum of 22.5kWp. I select 5 inverters Isofoton 5 (5kWp), with an efficiency of 97%.

Finally I can calculate the percentage of the solar system to cover the needed loads. The results are in Table 30.

Table 30. Comparison of loads and radiation for the fixed system in the office

52º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,59	2,35	3,38	3,9	3,89	3,91	4,07	4,03	3,47	3,06	1,86	1,25
Gt	22,5	22,5	22,5	22,5	22,5	22,5	22,5	22,5	22,5	22,5	22,5	22,5
D	14,2	9,6	6,7	5,8	5,8	5,8	5,5	5,6	6,5	7,4	12,1	18,0

And the percentage is obtained is in Table 31.

Table 31. Comparison of percentage of contribution of the fixed system in the office

	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Fixed	14,2	9,6	6,7	5,8	5,8	5,8	5,5	5,6	6,5	7,4	12,1	18,0
Total	237,9	160,9	111,9	28,8	28,9	28,7	74,3	75,1	32,4	36,7	203,3	302,6
%	5,95	5,95	5,95	20,02	20,02	20,02	7,44	7,44	20,02	20,02	5,95	5,95

3.5- CONCLUSIONS

- The main elements of the installation are 90 panels and 5 inverters of 5kW.
- If we have any problem with the solar installation we should have energy as well because we are connected to the grid. Of course, the same advantage but in the other side, if we have problems with the grid we can support the system with the solar cells.
- The panels are only installed facing to the South because it is the correct form.
- In this case it is not necessary use batteries because the system is connected to the electric grid.
- The biggest contribution of the solar panels is in Autumn and in Spring because we have the lower loads.

4-SUPERMARKET

4.1 - INTRODUCTION

In this part I am going to design an installation for a supermarket. It only has one floor and it is divided in the purchase zone, the store and an office.

The roof is flat, so the system will be easily installed. On the roof there are some chimneys, air extraction systems and a big area that is not available to install the solar cells.

Finally I am going to design a tracking system because the conditions of the roof permit it.

4.2-ANALYSIS OF LOADS

I am going to analyze a medium supermarket. It has the main area to purchase, offices and the store.

A- HEATING – AIR COOLING

It will have two different systems, once for the supermarket and the other one for the office. We can see this in Table 32.

Table 32. Heating related consumers at the supermarket

Description	Total power
3 heating/Air cooling system (30kW)	90kW
Office air conditioning	10kW
Total	100kW

I include in this part the refrigeration for meat, fish and milk products, and the freezers. We can see this in Table 33.

Table 33. Refrigeration and freezers at the supermarket

Description	Total power
6 refrigeration systems for food	40kW
6 freezers	20kW
Total	60kW

B- ELEVATORS

It is not normal have elevators in a supermarket, so I ignore it.

C- LIGHTING

I am going to use fluorescents lamps of 36W. We see the distribution of lamps in Table 34.

Table 34. Distribution of the lights in the supermarket

Room	Number of fluorescents
Supermarket	50
Office	10
Store	20
Total	80

D- INFORMATION TECHNOLOGY

The supermarket has 4 computers to collect the money of the purchase, another one in the office, a loudspeakers system and 3 automatic doors. The resume of these elements is in Table 35.

Table 35. Technological elements in the supermarket

Description	Amount	Power	Total power
Computers	5	285W	1,43kW
Automatic doors	3	100W	0,3kW
Loudspeakers	6	200W	1,2kW
Microphone	3	80W	0,24kW
Total			3,17kW

Finally, the summary of all loads of the supermarket is in Table 36:

Table 36: Total loads in the supermarket

Description	Number of elements	Power	Total
Fluorescents lamps	80	36W	2,9kW
Computers	5	285W	1,43kW
Automatic doors	3	100W	0,3kW
Loudspeakers	6	200W	1,2kW
Microphone	3	80W	0,24kW
Refrigeration system for food	6		40kW
Freezers	6		20kW
Heating/Air cooling system	3	30kW	90kW
Office air conditioning	1	10kW	10kW
Total			166,07kW

The trend of consumption has to be determined during a day, a week and a year.

- Daily: the supermarket is open during the day, but at night it also has consumption because of the freezers and the refrigeration systems for food. We can see this in Figure 20.

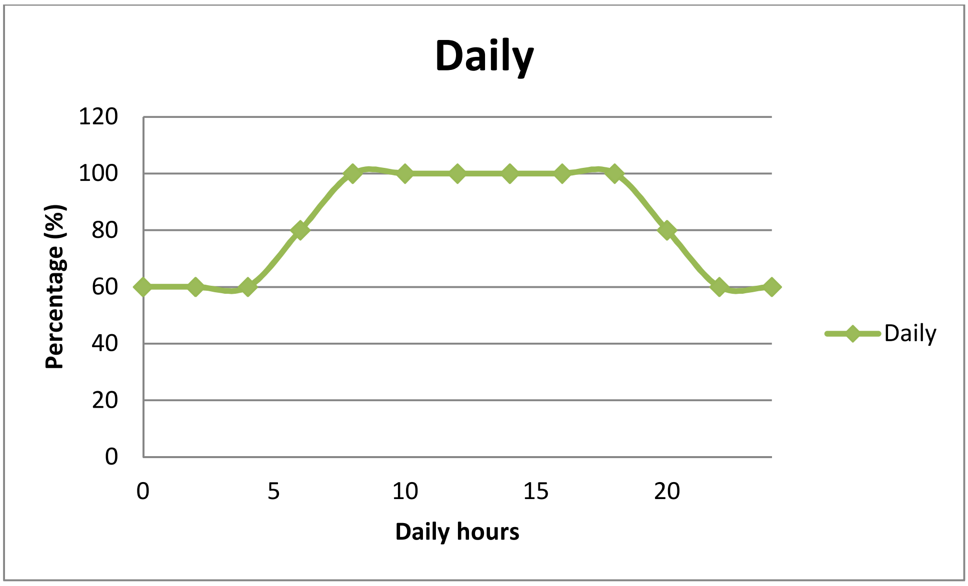

Figure 20. Daily trend of electricity consumption in the supermarket

- Weekly: the supermarket is open less hours on Saturday and it is closed on Sunday, but it needs power to the freezers and refrigeration systems. We can see this in Figure 21.

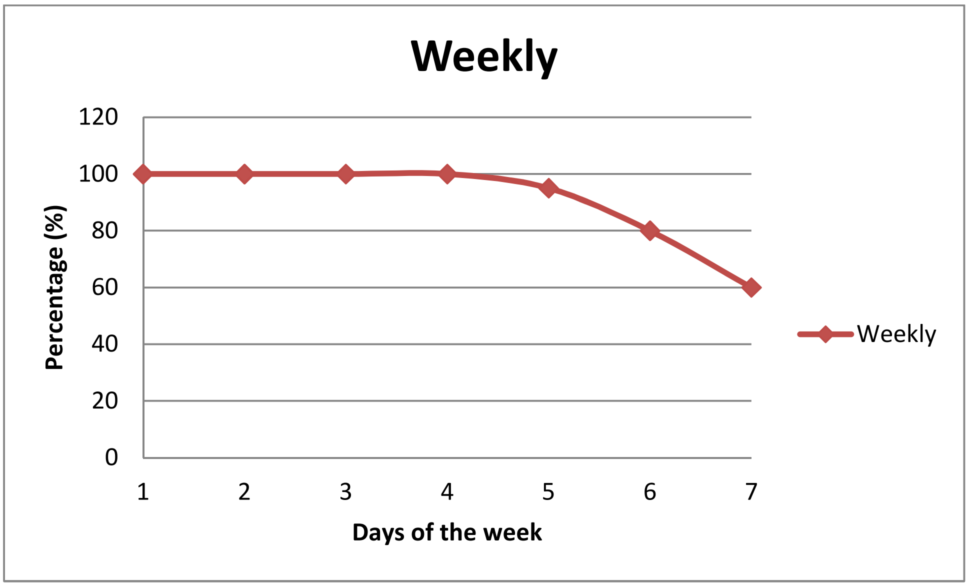

Figure 21. Weekly trend of electricity consumption in the supermarket

- Yearly: the consumption during all the months is constant. We can see this in Figure 22.

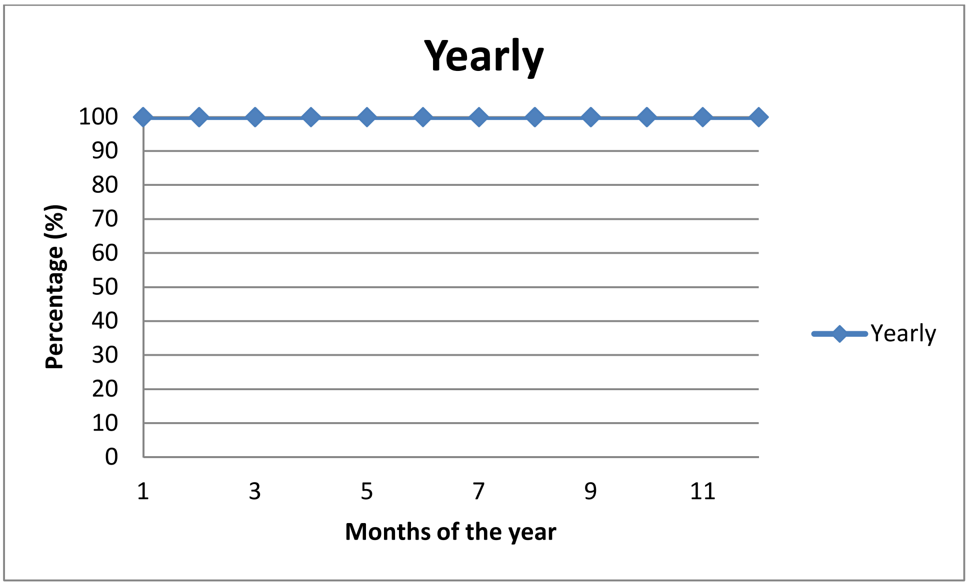

Figure 22. Yearly trend of electricity consumption in the supermarket

4.3 - STUDY OF THE CHARACTERISTICS OF THE INSTALLATION

The timetable of the supermarket is the same for all the year, so all the common loads will be the same. The refrigeration system for food and the freezers works 24 hours per day, but I estimate that they work 16 hours with the top power.

1- July and August

The air cooling system for the purchase zone and the office is working during this period. All the loads are resumed in Table 37.

Table 37. Analysis of loads in period 1 in the supermarket

July - August				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	80	36W	12	34,56
Computers	5	285W	12	17,1
Automatic doors	3	100W	4	1,2
Loudspeakers	6	200W	3	3,6
Microphone	3	80W	3	0,72
Refrigeration system for food	6	40kW	16	3840
Freezers	6	20kW	16	1920
Heating/Air cooling system	3	30kW	5	450
Office air conditioning	1	10kW	2	20
Total				6287,18

With the correcting factors I obtain:

$$G_1 = \frac{E_0 \cdot T_1}{E_i} = \frac{110 \cdot 6287.18}{90} = 7684.33kWh$$

2- January, February, March, November and December

The heating system is connected and it needs the same energy than the air cooling system. We can see this in Table 38.

Table 38. Analysis of loads in period 2 in the supermarket

January - February - March - November - December				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	80	36W	12	34,56
Computers	5	285W	12	17,1
Automatic doors	3	100W	4	1,2
Loudspeakers	6	200W	3	3,6
Microphone	3	80W	3	0,72
Refrigeration system for food	6	40kW	16	3840
Freezers	6	20kW	16	1920
Heating/Air cooling system	3	30kW	5	450
Total				6267,18

With the correcting factors we obtain:

$$G_2 = \frac{E_0 \cdot T_2}{E_i} = \frac{110 \cdot 6267.18}{90} = 7659.89kWh$$

3- April, May, June, September, October

As we can see in Table 39, it is not necessary the heating system.

Table 39. Analysis of loads in period 3 in the supermarket

April - May - June - September - October				
Description	Number of elements	Power	Hours	Total (kWh)
Fluorescents lamps	80	36W	12	34,56
Computers	5	285W	12	17,1
Automatic doors	3	100W	4	1,2
Loudspeakers	6	200W	3	3,6
Microphone	3	80W	3	0,72
Refrigeration system for food	6	40kW	16	3840
Freezers	6	20kW	16	1920
Total				5817,18

With the correcting factors we obtain:

$$G_3 = \frac{E_0 \cdot T_3}{E_i} = \frac{110 \cdot 5817.18}{90} = 7109.89kWh$$

Once we have the loads of all the year I am going to calculate which month is the most restrictive. With this value I can start to calculate the characteristics of the system, as we can see in Table 40.

Table 40. Comparison of loads and radiation during the year for the supermarket

35º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,47	2,23	3,37	4,08	4,27	4,39	4,53	4,31	3,51	2,93	1,73	1,16
Gt	7660	7660	7660	7110	7110	7110	7684	7684	7110	7110	7660	7660
D	5211	3435	2273	1743	1665	1620	1696	1783	2026	2427	4428	6603

The loads of this building are huge for only a photovoltaic system, so it needs be connected to the electric grid. The contribution of solar cells will be only a bit of the needed energy, so I will calculate the maximum number of panels that I can install and after that I will obtain the percentage of contribution.

4.4- DESIGN OF THE INSTALLATION

4.4.1- FIXED SYSTEM

When I know the loads and the radiation I can start to design the installation of the supermarket. First of all I should calculate the number of photovoltaic cells I need. This amount will be huge due to a lot energy is needed to cover all the necessities. That is the main reason because we are going to install as much panels as I can but the rest of energy will be cover by the electric net.

The roof of the supermarket is a plane surface conducive to the installation of photovoltaic panels. In the roof there is a zone that is not available to put the cells. I divide the other area in two parts to calculate all the available area. The diagram is in Figure 23.

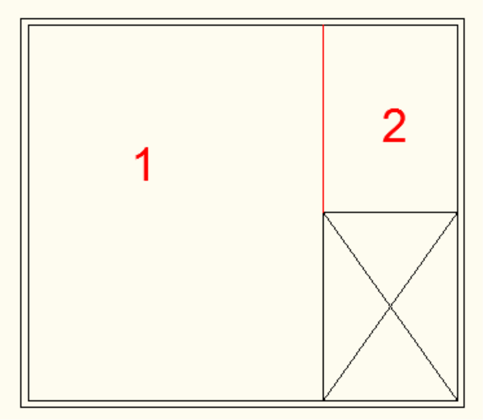

Figure 23. Top view of the roof of the supermarket

The total area of the roof is:

$$A = 33 \cdot 29 = 957m^2$$

Where:

- A is the total area of the roof

And the available area is:

$$A_1 = 25 \cdot 20 = 500m^2$$

$$A_2 = 15 \cdot 8 = 120m^2$$

$$A_T = A_1 + A_2 = 500 + 120 = 620m^2$$

Where:

- A_1 is the available area of zone 1.
- A_2 is the available area of zone 2.
- A_T is the available area of all the roof.

Due to the position of the supermarket, the panels with be in a southerly direction with an Azimuth deviation of 10º.

First of all I select the photovoltaic panel Isofoton Isf-250 with 250Wp. The features are in Table 41.

Table 41. Features of the photovoltaic panel Isofoton Isf-250

Lengths	1667*994*45mm
Area	1.657 m^2
Weight	19kg
Efficiency	15.1%
Voltage with open circuit	37.8V
Current with short circuit	8.75A
Voltage with maximum power	30.6V
Current with maximum power	8.17A

Now, I calculate the minimum distance between panels. We know that latitude of Pécs is 46.07º. The correct form of calculate this is as we can see in Figure 24.

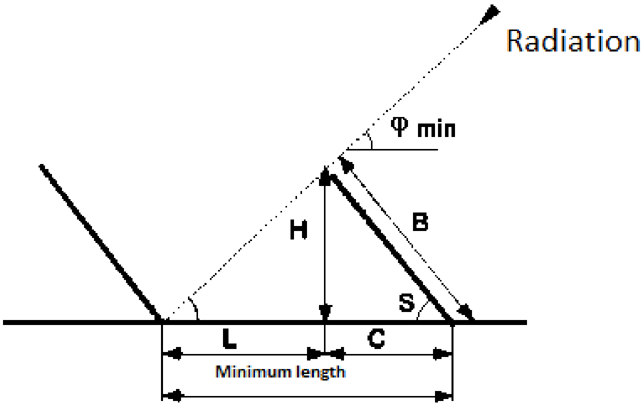

Figure 24. Incidence of radiation

Considering the position and location of the building I obtain:

$$C = B \cdot cos35^{º} = 0.994 \cdot \cos 35\,^{º} = 0.814m$$

$$H = B \cdot sin35^{º} = 0.994 \cdot sin35^{º} = 0.57m$$

$$\emptyset_{min} = 90^{º} - 46.07^{º} = 43.93^{º}$$

$$tan\emptyset_{min} = \frac{H}{L} = \frac{B \cdot sinS}{D_{min} - B \cdot cosS}$$

$$D = B \cdot cosS + \frac{B \cdot sinS}{tan\emptyset_{min}} = 0.994 \cdot cos35^{º} + \frac{0.994 \cdot sin35^{º}}{tan43.93} = 1.406m$$

With this distance I can install 12 lines, 5 of them with 9 panels and the other 7 with 14 panels. So finally the installation will have 143 panels on the roof of the supermarket, as we can see in Figure 25.

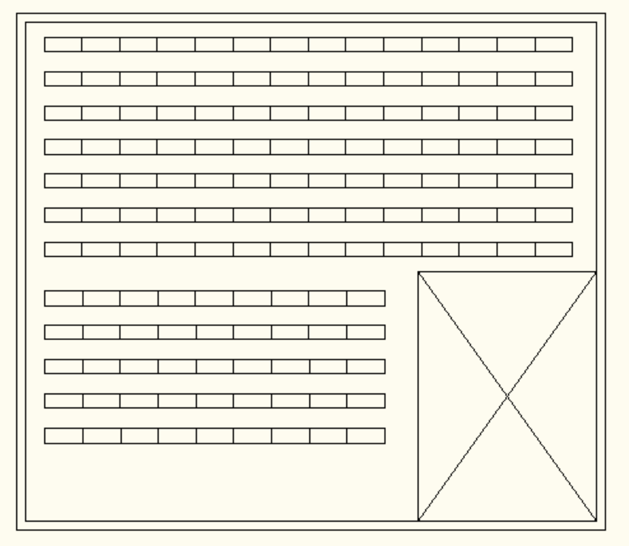

Figure 25. Distribution of the panels for the fixed system on the roof of the supermarket

$$Total\ power = 143\ panels \cdot 250Wp = 35750Wp = 35.75kWp$$

I divide this amount of power between the irradiation to know the contribution to the system. It is summarized in Table 42.

Table 42. Comparison of loads and radiation for the fixed system in the supermaket

35º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,5	2,2	3,4	4,1	4,3	4,4	4,5	4,3	3,5	2,9	1,7	1,2
Gt	35,75	35,75	35,75	35,75	35,75	35,75	35,75	35,75	35,75	35,75	35,75	35,75
D	24,32	16,03	10,61	8,76	8,37	8,14	7,89	8,29	10,19	12,20	20,66	30,82

In Table 43 it is calculated the percentage of contribution for the fixed system:

Table 43. Comparison of percentage of contribution of the fixed system in the supermarket

%	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Fixed	24,3	16,0	10,6	8,8	8,4	8,1	7,9	8,3	10,2	12,2	20,7	30,8
Total	5211	3435	2273	1743	1665	1620	1696	1783	2026	2427	4428	6603
%	0,47	0,47	0,47	0,50	0,50	0,50	0,47	0,47	0,50	0,50	0,47	0,47

Finally I obtain the necessary amount of inverters. The maximum quantity of power is 35.75kWp, so I am going to use 4 inverters Isofoton 10 (10kW) with an efficiency of 96.8%.

4.4.2- TRACKING SYSTEM

The solar tracker is a mechanic device which is used to orient photovoltaic panels, because we would like that they are always perpendicular to the sunlight. Tracking sun from east in the morning to west in the evening will increase the efficiency of the solar panel up to 45%.

These systems have some advantages over the fixed systems:

- They increase the efficiency of the panel.
- Easy installation and startup.
- Different options to the installation.
- Some systems can be controlled by the Internet if you have the appropriate software.
- High solar tracking precision.
- It is suitable for panels with low and high power.
- Low power consumption.

However they also have the disadvantage of being more expensive than the fixed ones.

In this case I have decided for a system with two axes and a pole for the movement and support.

For this installation I am going to use a photovoltaic panel Atersa A-150P, 150W with the features of the Table 44:

Table 44. Features of the photovoltaic panel Atersa A-150P

Lengths	1476*659*35mm
Area	0.9727 m^2
Weight	11.9kg
Efficiency	15.4%
Voltage with open circuit	22.6V
Current with short circuit	8.69A
Voltage with maximum power	17.84V
Current with maximum power	8.41A

I am going to join 9 of these panels to form a group, and each group will be installed on a pole. So, finally the groups are 4428*1977mm and the total power of each group will be 1350Wp.

The distance between poles has to be calculated, thus I use the same expressions as in the fixed case. I calculate the distances for the two extremes situations, in the sunrise and in the sunset and in noon.

Option 1: sunrise and sunset:

The North-South distance should only be the lengths of the panels, so I need 4.6m. On the other hand, to calculate the East-West distance I need the expression that I used in the fixed system. The top inclination of the panel will be 70º, so I use this amount. The explaining picture is in Figure 26.

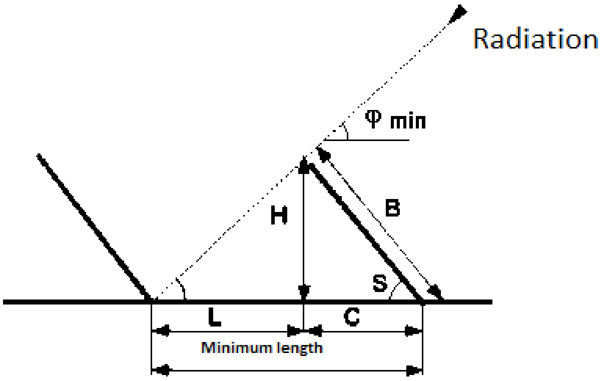

Figure 26. Incidence of radiation

$$D_{min} = B \cdot cosS + \frac{B \cdot sinS}{tan\emptyset_{min}} = 1.977 \cdot cos70 + \frac{1.977 \cdot sin70}{tan43.93} = 2.604m$$

Option 2: noon:

In this case the East-West distance is the length of the panels, 4.6m. I use the expression to calculate the North-South distance.

$$D_{min} = B \cdot cosS + \frac{B \cdot sinS}{tan\emptyset_{min}} = 1.977 \cdot cos15 + \frac{1.977 \cdot sin15}{tan43.93} = 2.44m$$

So, finally I need the same separation between poles, a distance of 4.6m.

The objects on the roof will not disturb the installation of the poles, and they will not have problems with shadows too, because they are higher and sunlight reaches them directly.

It is necessary taking into account that the distance between poles to calculate how many I can install. The available area is in Figure 27:

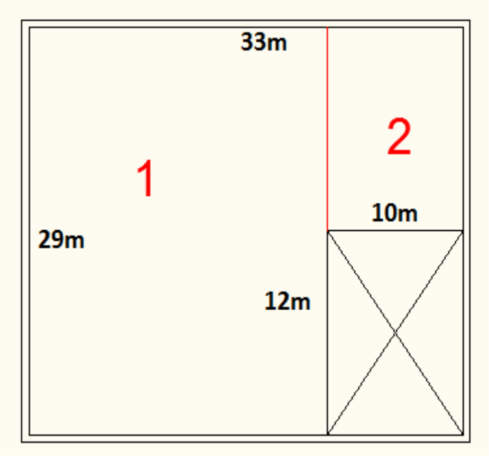

Figure 27. Top view of the available area of the roof of the supermarket

Taking into account the distance between poles I am going to install 36 groups. The scheme is in Figure 28:

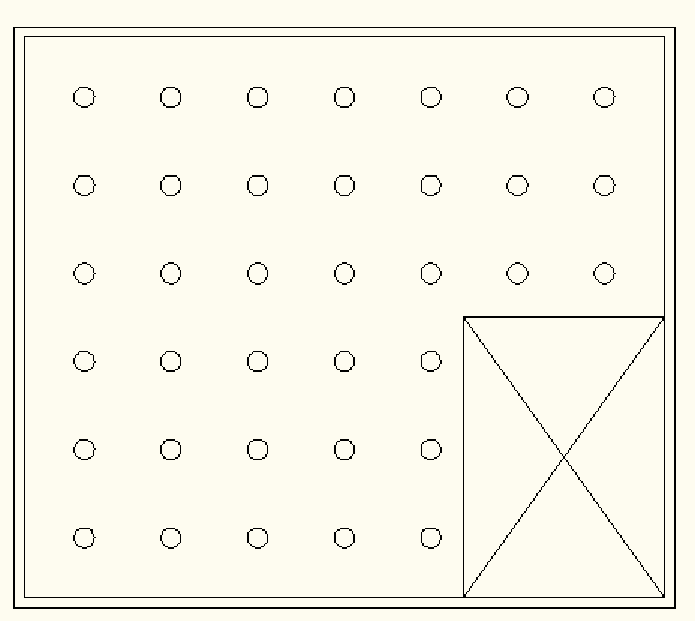

Figure 28. Distribution of the poles for the tracking system on the roof of the supermarket

The total power installed is:

$$Total\ power = 36 groups * 1350Wp = 48600Wp = 48.6kWp$$

Once I have calculated the power, we have to increase this value depending on the month with corrective factors due to the different quantity of radiation receive in the panels during the day. In Hungary these factors for tracking systems are between 1.3 in winter and 1.8 in summer. I obtain the results of Table 45 for each month.

Table 45. Total power produced per month in the tracking system in the supermarket

Power per month (kWp)												
	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Factor	1,3	1,4	1,48	1,65	1,65	1,75	1,8	1,8	1,7	1,6	1,45	1,3
Total power	63,18	68,04	71,93	80,19	80,19	85,05	87,48	87,48	82,62	77,76	70,47	63,18

Now, I divide this power between the irradiation to see the contribution to the system. We can see this in Table 46.

Table 46. Comparison of loads and radiation for the tracking system in the supermarket

Tracking	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	1,79	2,71	4,17	5,32	5,81	6,09	6,26	5,87	4,42	3,65	2,09	1,38
Power	63,18	68,04	71,93	80,19	80,19	85,05	87,48	87,48	82,62	77,76	70,47	63,18
D	35,3	25,11	17,25	15,07	13,8	13,97	13,97	14,9	18,69	21,3	33,72	45,78

I obtain the percentage of contribution for the tracking system in Table 47.

Table 47. Comparison of percentage of contribution of the tracking system in the supermarket

	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Tracking	35,3	25,11	17,25	15,07	13,8	13,97	13,97	14,9	18,69	21,3	33,72	45,78
Total	5211	3435	2273	1743	1665	1620	1696	1783	2026	2427	4428	6603
Percentage	0,677	0,731	0,759	0,865	0,829	0,862	0,824	0,836	0,923	0,878	0,762	0,693

Finally I calculate the needed inverters for the system. The maximum quantity of power is 46.17kW, so I am going to use 5 inverters Isofoton 10 (10kW) with an efficiency of 96.8%.

In this case the installation does not need batteries because the system is connected to the electric grid and the solar cells only support a part of the total power needed.

4.5-CONCLUSIONS

- The main elements of the fixed installation are 143 panels and 4 inverters of 4kW each one; for the tracking system we have 36 groups and 5 inverters of 10kW.
- The comparison of the contribution of the fixed and the tracking system is in Table 48:

Table 48. Comparison of the contribution from the fixed and the tracking system

%	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Fixed	0,467	0,467	0,467	0,503	0,503	0,503	0,465	0,465	0,503	0,503	0,467	0,467
Tracking	0,677	0,731	0,759	0,865	0,829	0,862	0,824	0,836	0,923	0,878	0,762	0,693

As we can see, the contribution of the tracking system is bigger than the contribution of the fixed one.

- The solar system only contributes with a small quantity of power to the system, but during the months we do not have to pay the fee for this power. In big installation like a supermarket the percentage of power contribution is really small.
- The tracking system is more expensive than the fixed one but they produce more energy. Depending on the budget it is possible select one or other.

5-CHURCH

5.1 - INTRODUCTION

This installation will be design for a small church in a neighborhood in Pécs. The law does not permit to install photovoltaic systems on churches under protection of historic buildings.

The church only has the ground floor, so all the loads will be there. The roof has a slope of 60º and I am going to install the cells on this place, so they will have this inclination. In this case the shape of the roof does not permit install tracking system, so I will only analyze the fixed one.

All the system will be isolated, so it is not necessary to connect it to the electric grid. The main elements of the system are going to be the photovoltaic cells, the inverters and also the batteries, because maybe it is needed more energy that the once produced in this moment and it is not possible take it from the net. Finally I am going to use a regulator to prevent the batteries still receive power when it is fully charged.

A scheme of the installation would be as follows in the Figure 29:

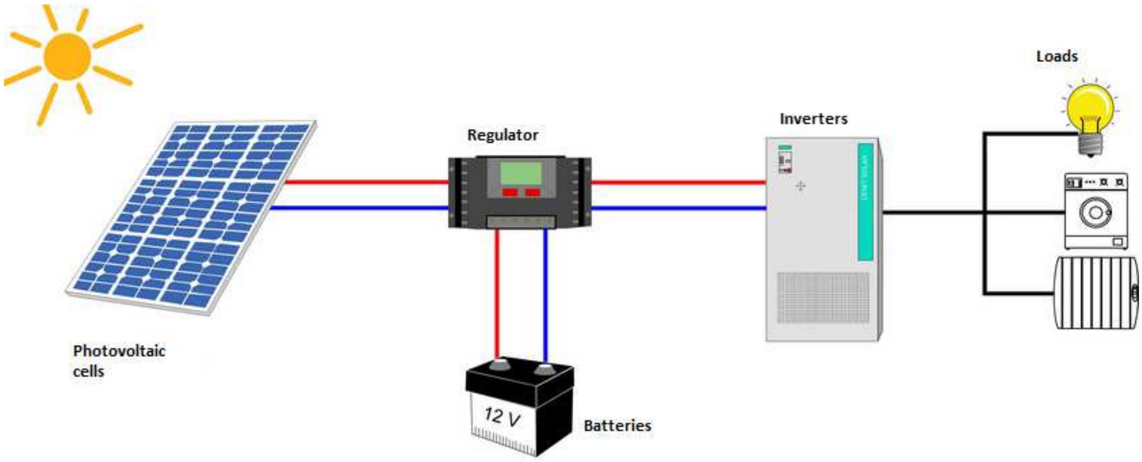

Figure 29. Scheme of the installation

The load during the week has a lot of oscillation because most of the use is during Saturday and Sunday. During winter it is normal to switch on the heating system one hour before the masses.

5.2-ANALYSIS OF LOADS

A- HEATING – AIR COOLING

The church does not have a heating system and it only has 4 electric heaters (3 in the main area of the church and the other one in the sacristy). We can see this in Table 49.

Table 49. Heating related consumers at the church

Description	Total power
4 electric heaters (2000W each one)	8000W
Total	8kW

B- ELEVATORS

Small churches rarely have elevator, so it is not included in this case.

C- LIGHTING

The building is divided in different places: the main area and the sacristy. I am going to use bulbs of 12W. We can see the distribution in Table 50.

Table 50. Distribution of the lights in the church

Room	Number of rooms	Number of bulbs	Total
Main area	1	50	50
Sacristy	1	10	10
Total			60

D- INFORMATION TECHNOLOGY

It is necessary to install a loudspeakers system in the main area. I also include a radio in the sacristy for the priest. We can see this in Table 51.

Table 51. Technological elements in the church

Description	Amount	Power	Total power
Loudspeakers	12	400W	4,8kW
Microphone	2	80W	0,16kW
Radio	1	100W	0,1kW
Total			5,06kW

Finally, the summary of all building loads is in Table 52:

Table 52: Total loads in the church

Description	Number of elements	Power	Total
Heaters	4	2000W	8kW
Bulbs	60	12W	0,72kW
Loudspeakers	12	400W	4,8kW
Microphone	2	80W	0,16kW
Radio	1	100W	0,1kW
Total			13,78kW

The graphs of loads are as follows.

- Daily: the top of the loads is during the day. At night the church is closed, as we can see in Figure 30.

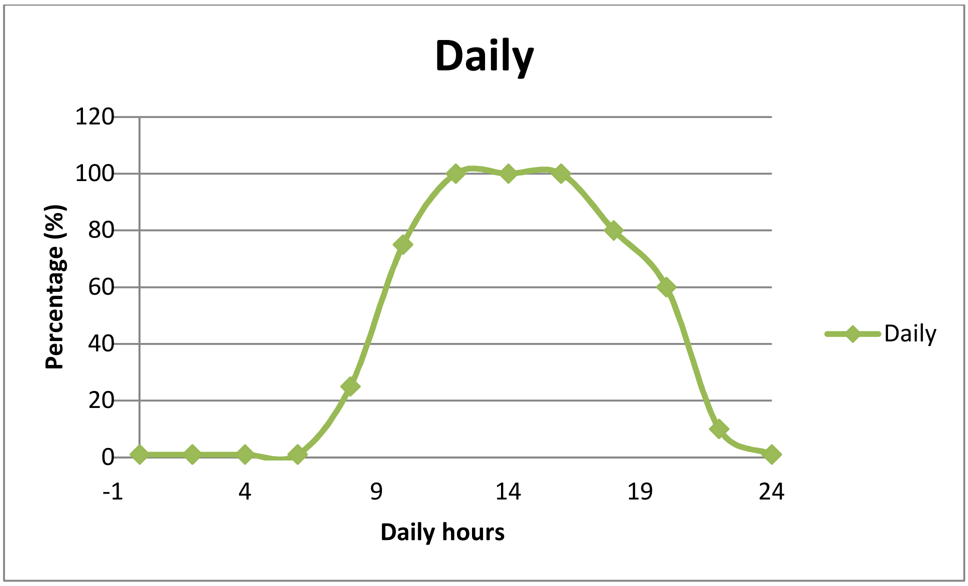

Figure 30. Daily trend of electricity consumption in the church

- Weekly: the peak of consumption is at the weekend, especially on Sunday. We can see this in Figure 31.

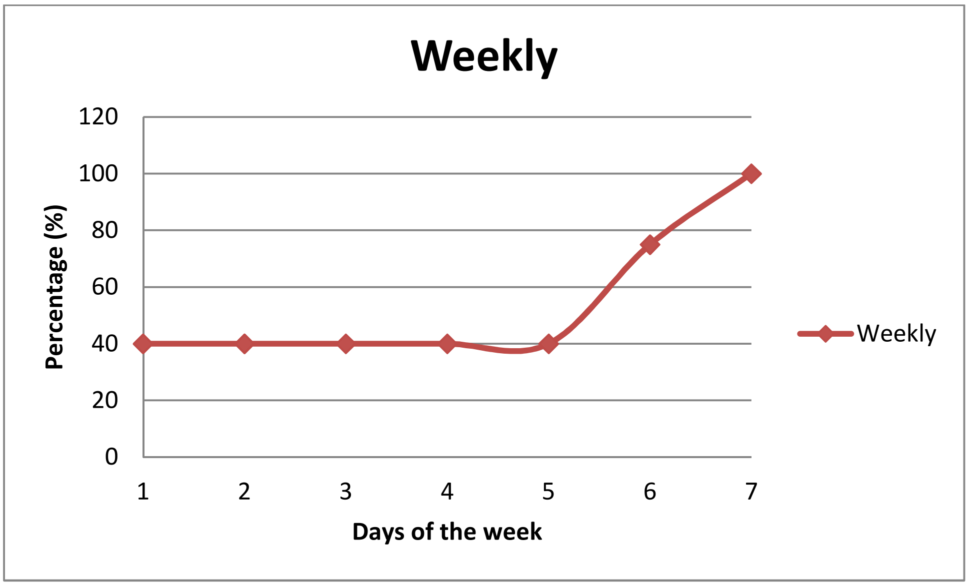

Figure 31. Weekly trend of electricity consumption in the church

- Yearly: it is a big difference between winter and summer because of the electric heaters. In the rest of places the differences are not so bigger because I suppose that the other buildings also have air cooling system. We can see this in Figure 32.

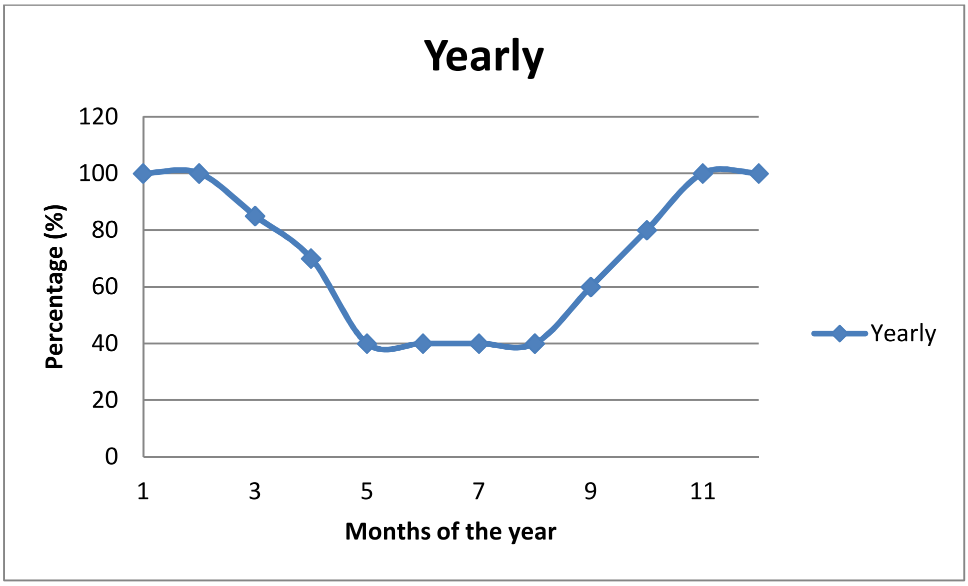

Figure 32. Yearly trend of electricity consumption in the church

5.3- STUDY OF THE CHARACTERISTICS OF THE INSTALLATION

I divide the months in two groups depending on the heaters. I am going to suppose that all the days of the week are similar, that is why the number of hours is very small, because at the weekends the church will be open more time than during the week.

1- January, February, March, November, December

During these months we need the heaters, as we can see in Table 53.

Table 53. Analysis of loads in period 1 in the church

January - February - March - November - December				
Description	Number of elements	Power	Hours	Total (kWh)
Heaters	4	2000W	1	8
Bulbs	60	12W	3	2,16
Loudspeakers	12	400W	0,5	2,4
Microphone	2	80W	0,5	0,08
Radio	1	100W	0,5	0,05
Total				12,69

I use the correcting factors.

$$G_1 = \frac{E_0 \cdot T_1}{E_i} = \frac{110 \cdot 12.69}{90} = 15.51kWh$$

2- April, May, June, July, August, September, October

It is not necessary use the heaters, so the energy is lower than in the other case. We see this in Table 54.

Table 54. Analysis of loads in period 2 in the church

April - May - June - July - August - September - October				
Description	Number of elements	Power	Hours	Total (kWh)
Bulbs	60	12W	3	2,16
Loudspeakers	12	400W	0,5	2,4
Microphone	2	80W	0,5	0,08
Radio	1	100W	0,5	0,05
Total				4,69

We use the correcting factors again.

$$G_2 = \frac{E_0 \cdot T_2}{E_i} = \frac{110 \cdot 4.69}{90} = 5.73kWh$$

5.4- DESIGN OF THE INSTALLATION

In this case I am going to overlay the panels on the roof. So I need the radiation for 60º, because it is the inclination of the roof. We obtain the comparison between loads and radiation in Table 55.

Table 55. Comparison of loads and radiation during the year for the church

60º	J	F	M	A	M	Jn	Jl	A	S	O	N	D
Rt	2,05	3,19	4,03	4,76	4,94	4,89	5,03	5,08	4,44	3,79	2,45	1,6
Gt	15,51	15,51	15,51	5,73	5,73	5,73	5,73	5,73	5,73	5,73	15,51	15,51
D	7,57	4,86	3,85	1,20	1,16	1,17	1,14	1,13	1,29	1,51	6,33	9,69

Such as in the other buildings I am going to use the photovoltaic panel Isofoton Isf-250 with 250Wp. It has the characteristics written in Table 56.

Table 56. Features of the photovoltaic panel Isofoton Isf-250

Lengths	1667*994*45mm
Area	1.657 m^2
Weight	19kg
Efficiency	15.1%
Voltage with open circuit	37.8V
Current with short circuit	8.75A
Voltage with maximum power	30.6V
Current with maximum power	8.17A

The orientation of the church is East-West, so I am going to install de panels in the Southern direction with an Azimuth of 5º. An approximately scheme of the church is in Figure 33.

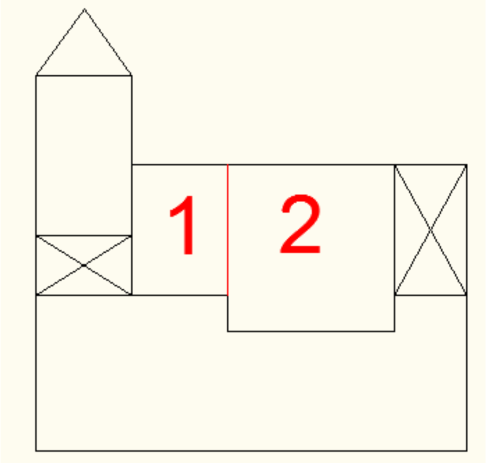

Figure 33. Available area of the roof of the church

Zones 1 and 2 are where the panels will be installed. In the part with the cross I prefer do not install anything because it is curve and the orientation is not good. The available total area is 95.6m^2.

Now I to obtain the needed area:

$$S = \frac{1.1 \cdot D}{\rho} = \frac{1.1 \cdot 9.69}{0.151} = 70.59m^2$$

Where:

- S is the total area
- D is the relation between R_t and G_t. Measurement unit: m^2
- ρ is the efficiency of the panel.

$$Number\ of\ panels = \frac{S}{A} = \frac{70.59}{1.667 \cdot 0.994} = 42.6 \rightarrow 43\ panels$$

Where:

- S is the total area.
- A is the area of each panel

$$Total\ power = 250Wp \cdot 43panels = 10750Wp = 10.75kWp$$

We can see the position of the panels in Figure 34.

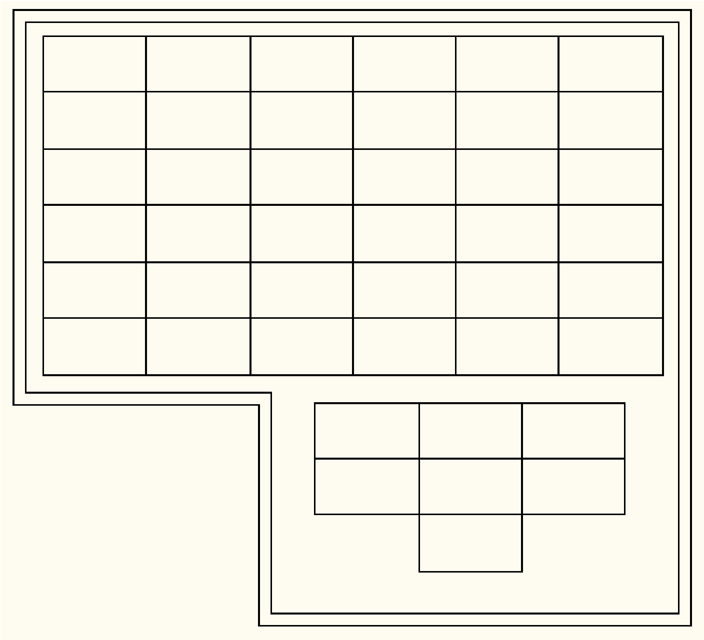

Figure 34. Distribution of the panels on the roof of the church

Once I have calculated the number of panels, I select the inverters. For this problem we suppose that all the loads are connected at the same time. Due to it is normal in a church have everything connected during the masses we have the results in Table 56.

Table 56. Total loads of the church

Description	Number of elements	Power	Total
Heaters	4	2000W	8kW
Bulbs	60	12W	0,72kW
Loudspeakers	12	400W	4,8kW
Microphone	2	80W	0,16kW
Radio	1	100W	0,1kW
Total			13,78kW

It is not possible to have so bigger inverters, so I use three inverters Isofoton 5 (5 kW), obtaining a maximum of 15kW.

Finally I need obtain the number of batteries needed. Each battery will have 48V in total and 2V for each section inside it, so I need 24 sections for each battery. We select the model Rolls 48V S460 460Ah C100 with maximum discharge capacity of 70%.

Now I obtain the accumulation capacity:

$$C_{100} = \frac{110 \cdot G \cdot D}{T \cdot M} = \frac{110 \cdot 15510 \cdot D}{48 \cdot 70} = 507 \cdot D\ Ah$$

Where:

- C_{100} is the accumulation capacity
- G is the energy with correcting factors
- D are the days of autonomy
- T is the voltage
- M is the maximum capacity of discharge

We have to calculate the autonomy days with some tests:

- Load current:

$$I_{load} < 10\% \cdot C_{100}$$

  Where:
    - I_{load} is the current to load
    - C_{100} is the accumulation capacity

$$I_{load} = \frac{CT}{T} = \frac{10750}{48} = 223.96A < 50.7 \cdot D \rightarrow D > 4.42\ days$$

Where:

- I_{load} is the current to load
- CT is the total power of the panels
- T is the voltage

- Download current:

$$I_{download} < 10\% \cdot C_{100}$$

Where:

- $I_{download}$ is the current to download
- C_{100} is the accumulation capacity

$$I_{download} = \frac{P_{inv}}{T} = \frac{15000}{48} = 312.5A < 50.7 \cdot D \rightarrow D > 6.16\ days$$

Where:

- $I_{download}$ is the current to download
- P_{inv} is the total power of the panels
- T is the voltage

- Night loads:

$$Night\ loads < 20\% \cdot C_{100}$$

Where:

- C_{100} is the accumulation capacity

$$Night\ loads = \frac{G_{night}}{T} = 0 \rightarrow D > 0\ days$$

Where:

- G_{night} is the total loads at night
- T is the voltage

So, finally it is necessary have batteries with 7 autonomy days.

The accumulation capacity is:

$$C_{100} = 507 \cdot D\ Ah = 507 \cdot 7 = 3549Ah$$

Now I obtain the number of batteries:

$$Number\ of\ batteries = \frac{3549}{460} = 7.7 \rightarrow 8\ batteries$$

5.5- CONCLUSIONS

- The main elements of the installation are 43 solar panels, 3 inverters, 1 regulator and 8 batteries.
- The installation is isolated, so all the power will be produced by this elements.
- During winter we have the biggest amount of power needed and the lowest amount of energy produced, so we need the batteries full charged for this period of time. In summer we do not have this problem because the quantity of radiation is bigger.
- The solar panels are only faces Southern because it is the best option. It has no sense put it faces Northern because they will not have a good efficiency.
- It is not necessary power lines because the energy will be consumed in the same place where it is produced.
- We have to pay the initial investment but after that we do not have to pay monthly instalments.

6- COMPARISON OF THE CONSUMPTIONS

I am going to probe that the consumption of the different buildings is really different.

- Yearly: we can see that the office and the faculty have the same graphic of consumption. The amount of power needed oscillate because of the summer holidays. The church varies too, but this is because we consider that it is not necessary the air cooling and the electric heaters need a lot of energy to work correctly. On the other hand the consumption of the supermarket is always the same more or less during the year. We can see this in the Figure 35.

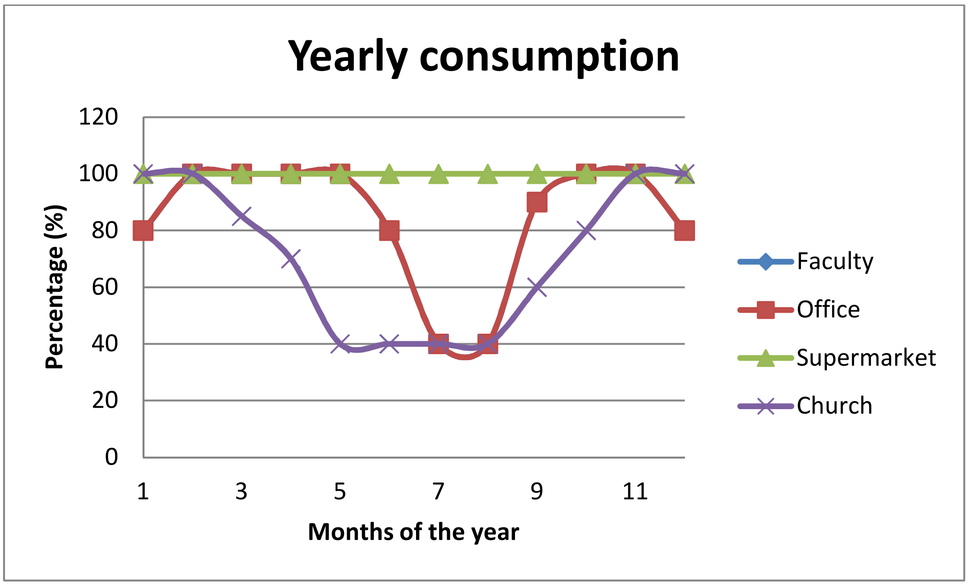

Figure 35. Comparison of the consumptions during a year

- Weekly: we can see that all the buildings have their top of consumption during the week. The exception is the church because most ceremonies are during the weekend, as we can see in the Figure 36.

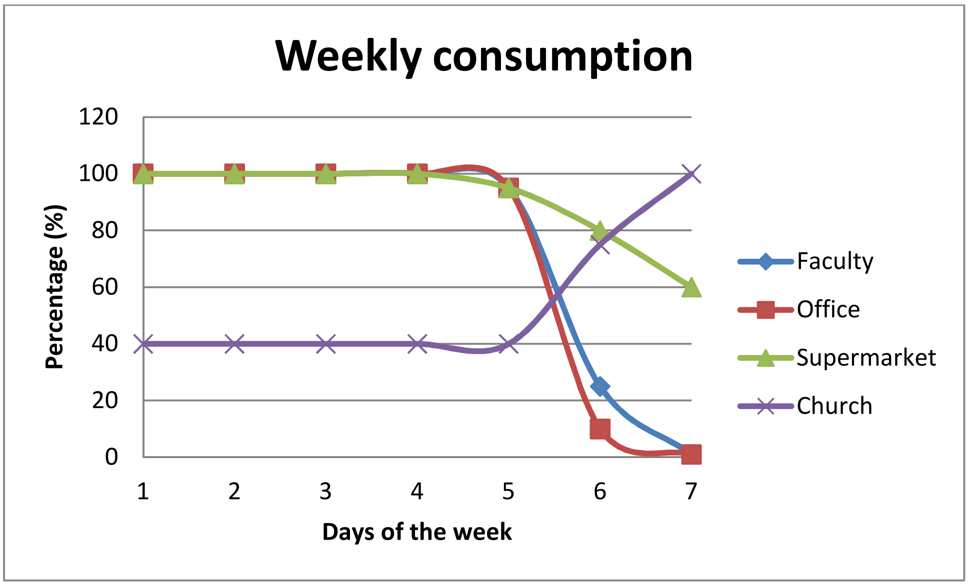

Figure 36. Comparison of the consumptions during a week

- Daily: during the day all the buildings have a similar graph, but the supermarket has its minimum at the 60% of consumption because of the freezers and the refrigeration systems. We can see this in the Figure 37.

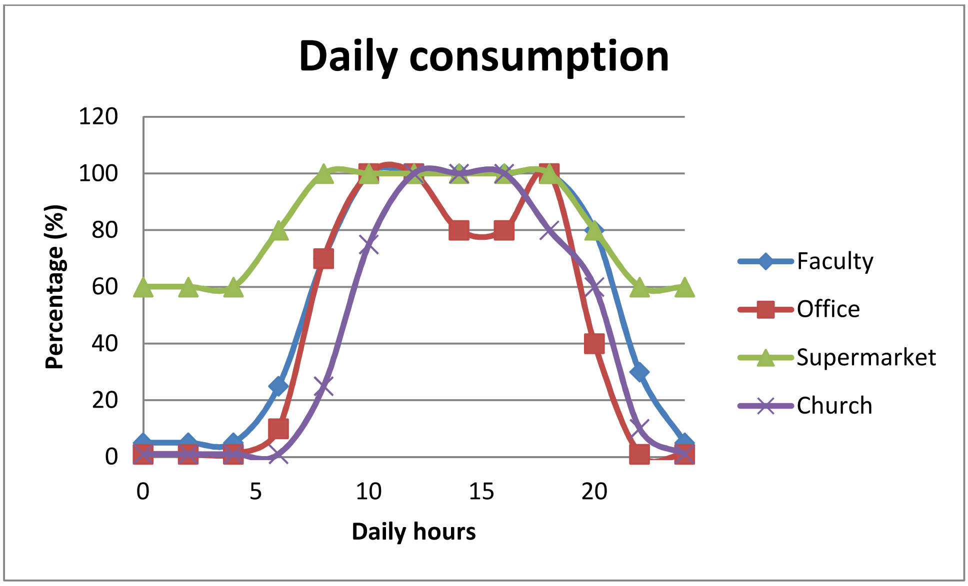

Figure 37. Comparison of the consumptions during a day

7- REFERENCES

1- “Interactive book about solar energy and its applications”. Danny Andrés Arenas Sánchez and Hodman Steven Zapata Castaño. University of Pereira, Faculty of Technology. Electrical Technology Program. 2011

2- http://www.miliarium.com/Bibliografia/Monografias/Energia/EnergiasRenovables/EnergiaSolarFotovoltaica.asp

3- Website http://re.jrc.ec.europa.eu/pvgis/

4- Website http://www.solar-tracking.es/

5- Website http://www.suntracking.es/en

6- Website http://www.isofoton.com/sites/default/files/250-black_es_.pdf

7- Website http://www.atersa.com/img/201328103610.pdf

8- Website http://www.isofoton.com/sites/default/files/isokit_web_.pdf

9- Website https://autosolar.es/baterias/bateria-48v/bateria-rolls-48v-460ah-s460_precio

10- Notes of the subject “Renewable Energies”. University of Valladolid, Spain.