Professional Bachelor Electromechanics

SUSTAINABLE ENERGY REDUCTION, PRODUCTION AND MANAGEMENT AT PXL-TECH

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The student takes full responsibility for this dissertation. Dissertation supervision and process coaching does not eliminate incomplete information and/or inaccuracies which have been taken into account in the final evaluation, but which have not been modified in the final version of the dissertation.

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Title: Sustainable energy reduction, production and management at PXL-Tech

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This project is about the energy reduction, production and management of the PXL-Tech building in Diepenbeek. Its aim is to focus on geothermal energy and analyse if this energy production system would be viable for the building.

PXL-Tech building has an energy consumption which is over its real heating needs. Therefore, it is losing money and creating an environmental damage which can be avoided.

The main research question of this project is to know if it is profitable to install a geothermal system in the surroundings of the PXL-Tech building, in order to reduce the heating consumption. At the same time, this project will help to analyse the current heating system.

In order to get the results, a primary research was done about the characteristics of the building as well as, the technologies and machines that are related to geothermal energy. Moreover, some measurements to obtain data related to infiltration heat losses were made, as I will explain later.

Basing on this information, calculations to see the energy needs of the building were made and they were compared with the PXL-Tech's current figures, so as to ensure that they were realistic. After that, the suitable geothermal system to fulfill these values was chosen.

Finally, an economic and environmental analysis of the new technology was made. In this way, it was possible to break down which improvements would suppose for the building the geothermal installation and also, which would be the negative aspects.

The results revealed that the new installation would suppose an important saving in terms of economy (%40, 74) and pollution (%29, 86). Nonetheless, there would be difficulties in terms of technology and available area for this installation. The building needs to have a considerable heating ability and there is not a big offer in the market among this kind of heat pumps. Likewise, the investment that has to be done would be considerable and the payback would be long (32 years).

Finally, some cogeneration technologies and suggestions were mentioned. It is said it could be interesting to make future analysis in this branch, owing to the fact that the energy needs either for electricity or heating are substantial and therefore, it could be a more suitable system for PXL-Tech.

i. Acknowledgements

First and foremost, I would like to thank Mr. Vanheusden and Mr. Vandormael for their guidance and help. At the same time, I would like to acknowledge the help of Mr. Vrancken for his all-time attention and disposition during all my internship. I would like to thank also, Mr. Hendrickx, Mr. Camps, Ms. Dierickx, Ms. Nele Houben and Mr. Vanherck for their advices. I would like to mention, all my colleagues for their huge support in my internship and all the staff of PXL-Tech, too, for their friendly and kind attitude from the very beginning.

Special thanks go to Mr. Aitor Urresti who has been a great help in the technical part of my project and to the University College of Technical Industrial Engineering of Eibar for all their commitment and support. Moreover, I would like to outline the effort that the University of the Basque Country and PXL University College have done in order to give the students the opportunity to enjoy this magnificent experience.

Finally, I would like to express my greatest gratitude to my family and friends for their constant support and caring and because they always inspire and encourage me to go my own way, without whom I would be unable to complete my project.

ii. List of symbols and abbreviations

COP: Coefficient of performances

EER: Energy Efficiency Radio

PVGIS: Photovoltaic Geographical Information System

UTC: Coordinated Universal Time

PV: Photovoltaic

CMSAF: The satellite application facility on climate monitoring

**The other symbols and abbreviations are explained next to each equation

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1. Introduction

Recent developments have been done in energy policies all around the world in order to support renewable energy. A clear example, which is the European 20-20-20 target, can be found in the webpage of the European commission in climate action. It sets three key objectives for 2020: to reduce gas emissions 20% from basing on the values of 1990, to raise the EU's energy efficiency 20% and to increase the energy consumption produced from renewable resources 20%.

These policies have been fixed mainly with the aim of reducing the bad impact that human activities have caused, so far. Moreover, these measurements have made people think about the situation and have pushed them forward to act.

According to some data, such as the information that gave Jochen Müller in 13th of November 2014, the council of the European Union, the environmental objectives of the 20-20-20 will be reached successfully.

Nonetheless, PXL University College has a heating consumption which is over the real energy needs of the building and so, its gas emission and efficiency can be improved.

PXL-Tech's directorate is aware of this situation and they have decided to start acting. There, different students with the help of their lecturers have done research with the intention of reaching a greener building. One of them is this current project "Sustainable energy reduction, production and management at PXL-Tech". It covers two renewable energy technologies: solar energy and geothermal energy. This paper focuses mainly on the latter part. The aim is to analyse if a geothermal energy system at PXL-Tech Diepenbeek, will be viable.

First of all, an analysis of the building's heating energy needs is made. The focus on this branch is done without taking into account the hot water system, because this is researched in another study.

So as to do the analysis, a calculation of the energy losses and energy gains of the engineering college for one year is made. In this way, the heat energy balance is measured. But, the energy gains and losses don't happen at the same time and so, the installation is dimensioned for the worst case, that is, when there are no heat gains.

Then, the heat pump is chosen taking into account its price, efficiency and the warranty. After that, a decision on the heat exchanger's length is taken and an economic and environmental analysis of the heating system is made.

Hypothesis might be: that a geothermal system at PXL-Tech is possible because of different reasons. Firstly, the heating energy costs of the building would be reduced drastically. Secondly, safety at the building would be increased because dangerous fluids would be avoided. Lastly, the CO2 amount raised would be hugely declined.

2. Method

First of all, I am going to start my work making a study of the source's that PXL-Tech building can take advantage of.

Two characteristics that should be taken into account in a sun energy installation will be analysed: sun energy that arrives to the building and wind speed.

After knowing this data about solar energy, I am going to focus fully in geothermal energy. The ground's either physical or thermal characteristics will be broken up, so as to know better the current situation of the source.

Then, all the heating losses of the building will be measured. They are divided in three groups: Transmission losses, Ventilation losses and Infiltration losses.

After that, heating gains of the building will be estimated. Likewise, they are based on three different teams which are gains due to human presence, gains owing to electrical devices and gains because of sun energy.

Once knowing these values, I am going to calculate the energy balance of the building comparing the heat losses and gains.

Later, taking into account the worst case for the building the most suitable heat pump will be decided. Moreover, basing on all the information, the length of the heat exchanger will be fixed.

Once knowing all the prices, both economic and environmental analysis of the installation will be done.

Finally, I am going to analyse all the positive aspects of this system, as well as, the negative ones and I will arrive to general conclusions.

3. Results

To start with, a primary research was done about the building's nature resources, either for photovoltaic energy or for geothermal energy.

First of all, I prepared all the information for the PV system so as to keep abreast of the situation of the building.

3.1. Photovoltaic system

3.1.1. Sources' information

Sun energy

I obtained information about the sun energy that the building gets all the year from the next website: [1]. To find these values inserting the next data was essential.

1. Latitude and longitude.

   Latitude: 50.927767º and Longitude: 5.384941º

2. Irradiation angle.
   I chose the Irradiation angle: 0º, due to the fact that I didn't know the optimum angle value to reach as much solar energy as possible, yet.

3. Radiation database.
   There were two options to choose and so, be able to obtain the needed data. The alternatives were PVGIS-classic and PVGIS-CMSAF. Both were used and a comparison was made which is shown in the table below (table 1).

Table 1: Comparison between PVGIS-classic and PVGIS-CMSAF

Solar radiation database used	Optimal inclination angle	Hopt average year (Wh/m^2/day)
PVGIS-classic	34º	2960
PVGIS-CMSAF	36º	3380

As we can see in the Table 1 each of them gave us a different optimal inclination angle.

In the article "A new solar radiation database for estimating PV performance in Europe and Africa" it is said that PVGIS-CMSAF is a new version of PVGIS (Photovoltaic Geographical Information System) with CM-SAF data. This CM-SAF method only relates the top of atmosphere to the surface irradiance, only for cloudy skies and not for clear sky. Besides, in an example of a single measurement station that is made in the article, it is stated that PVGIS-classic is more accurate than PVGIS-CMSAF.

After reading this information, I determined to take into account the PVGIS-classic method. As a result, the optimal inclination angle for PXL-Tech is 34 º. Consequently, the angle that our PV should have is 34º.

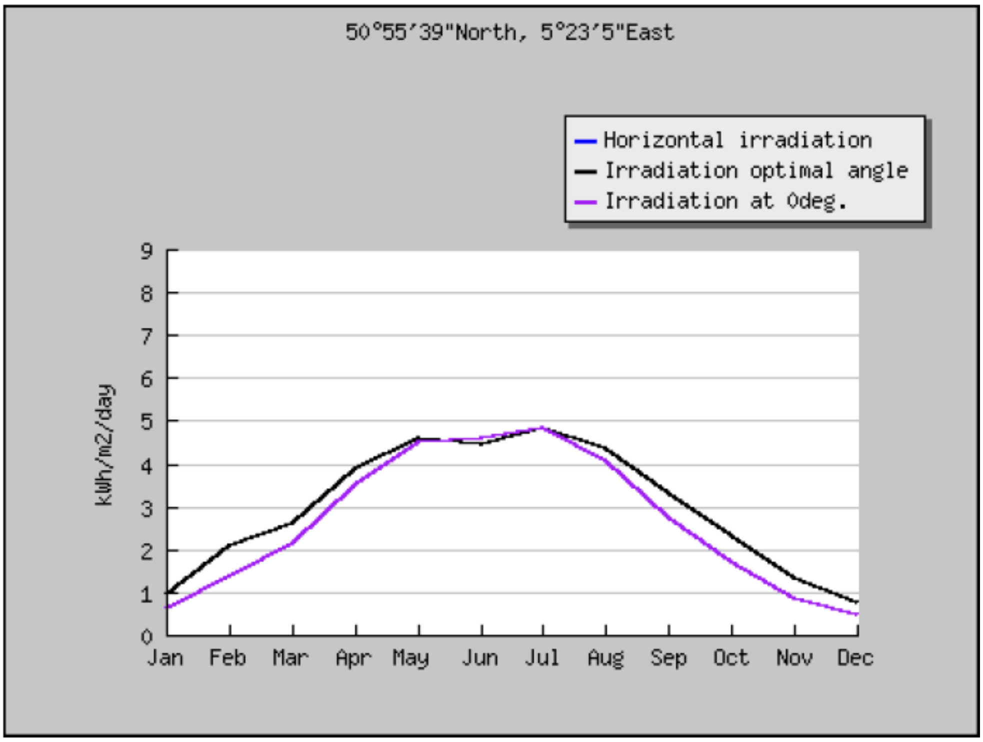

Figure 1: Comparison of solar energy that our PV system can catch

In this figure 1, the horizontal axis shows the months of a year and the vertical axis shows the energy per square meter that arrives per day at PXL-Tech.

If we look at the graphic, we can see that the horizontal irradiation and the irradiation at 0º are the same. Over almost all the year, the amount of the sun energy obtained in the optimal orientation is bigger than the other orientations.

Nevertheless, we can realise that around June this pattern is changed. In this particular period, the sun is in its highest position of the year and so, the sun waves arrives from the most perpendicular position of the whole year; consequently, in this particular period, the horizontal orientation is able to obtain higher sun energy values.

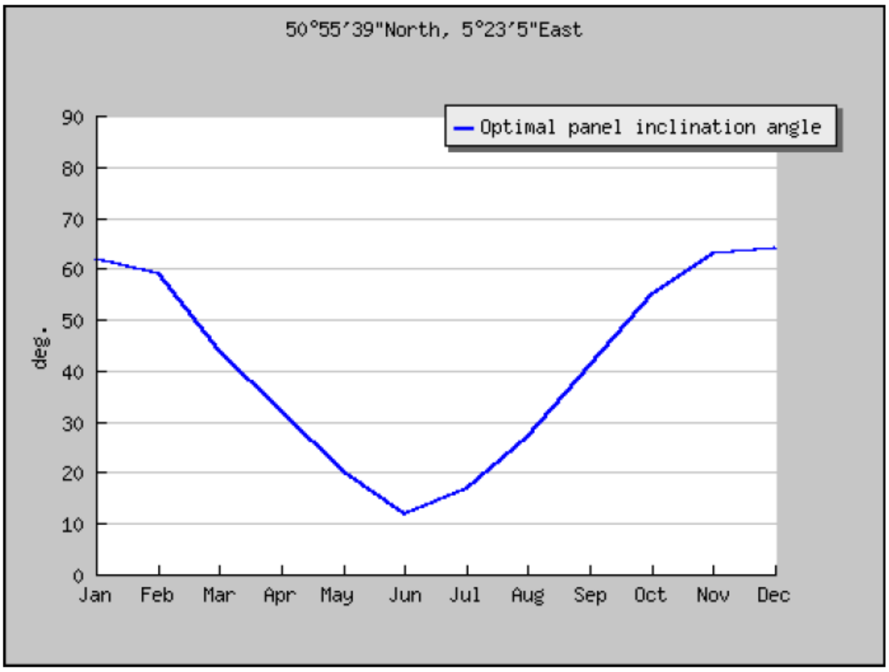

Figure 2: Optimal panel inclination angle depending on the months

In figure 2, the horizontal axis shows the months of a year and the vertical axis shows the optimal inclination angle of the PV.

This graph is clearly related to the figure 1. Around December 21 the sun is in the lowest height for us and so, its waves come from a lower elevation; that´s the reason why around these days the optimal panel inclination angle is high. The opposite happens around June. This factor needs to be taken into account when choosing the type of PV and in order to avoid shadows between different PV.

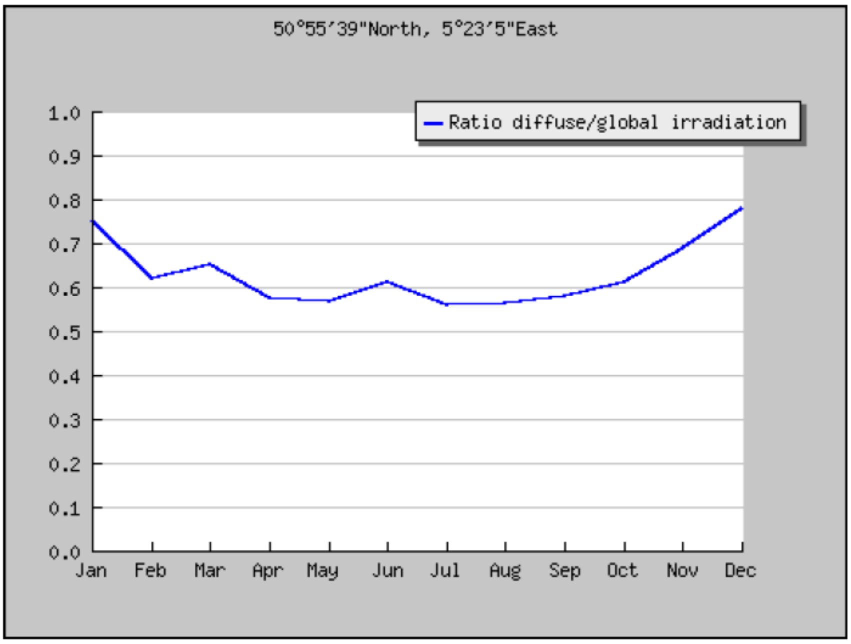

Figure 3: Ratio diffuse/global irradiation

In this graph (figure 3), the horizontal axis shows the months of a year and the vertical axis shows the ratio between the diffuse and global irradiation.

This line chart shows the importance of the diffuse irradiation. The bigger is the number of the ratio, the more importance the diffuse irradiation has. As we can see in the graphic, the diffuse irradiation supposes more than half of the total irradiation during the whole year. This value even considerably increases during the winter when it reaches the value of 0.8. We will have to take into account this factor too, when choosing the type of PV and make different hypothesis.

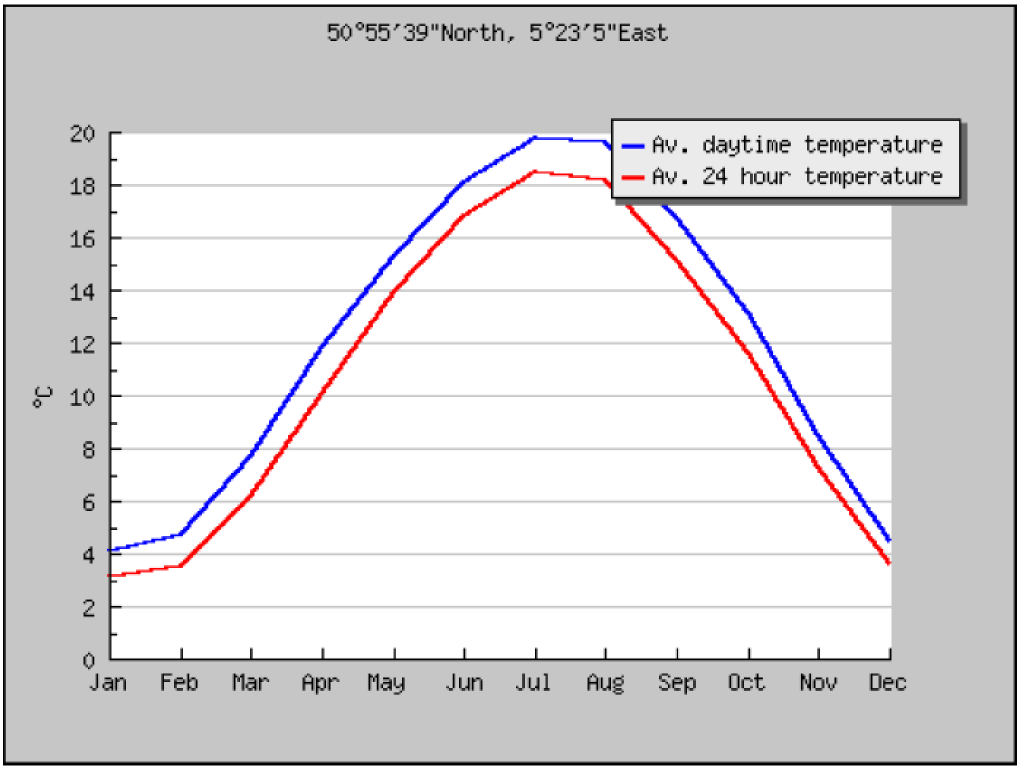

Figure 4: Average temperature

In figure 4, the horizontal axis shows the months of a year and the vertical axis shows the average daytime temperature, in blue, and 24 hour temperature, in red.

This chart depicts the values of average outside temperature over the year. The temperature is a crucial factor, because depending on its value the efficiency of our PV can vary. For instance, when the PV´s temperature is too high, the PV´s efficiency will decrease significantly. This is clearly represented in the next graph, where most energy produced is when the outside air has the lowest temperature (20ºC) (see figure 5) taken from [2].

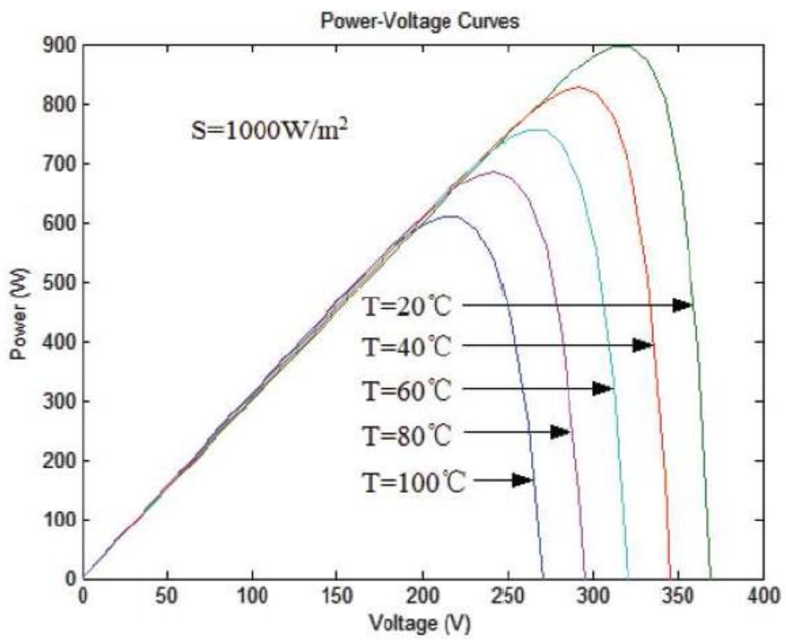

Figure 5: Temperature vs. Power obtained from PV

Sun energy results

Once making all the analysis, I continued looking for information, but in this case, the orientation that I took was 34ºC, that means, the optimal one.

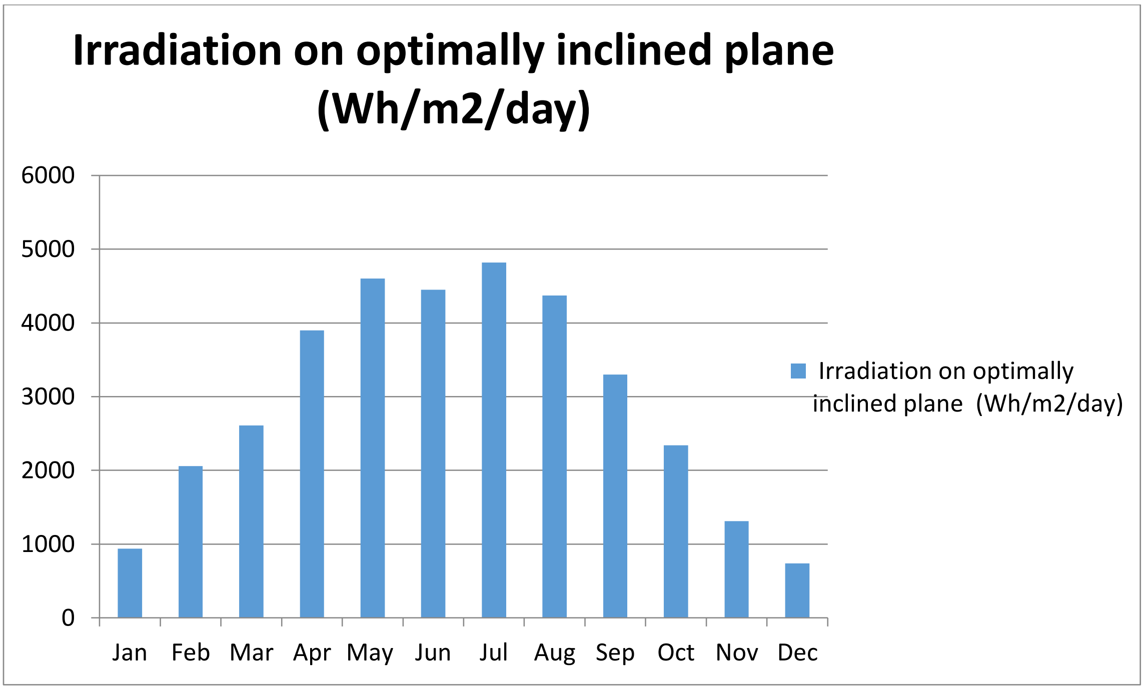

Figure 6: Irradiation that our building can catch

In this chart (figure 6), the horizontal axis shows the months of a year and the vertical axis shows the irradiation that PXL-Tech building can take advantage of.

This bar chart breaks down the data of irradiation that our PV system will be able to use to produce electricity when are orientated in the optimal angle (34º).

Basing on the figure 1, the peak of the solar energy that our PV can take advantage of will be in July. So, our energy production peak also will be in July. Normally, as in this month there are no classes, it is likely that it couldn´t be consumed by the building holders so it will be given to the grid. Nevertheless, in May or June it may produce a big quantity of energy that can be consumed in the building. However, as I mentioned before, either the temperature or other factors will affect the production system and so, maybe some facts that I mentioned in this paragraph will vary.

Solar chart

After all the examinations, I continued finding our building's solar chart. I checked the website mentioned below for that: [3]

Firstly, I entered the same latitude and longitude. After that, I chose the Time zone UTC + 1h and the data from December to June, so as to be able to see them in local standard time.

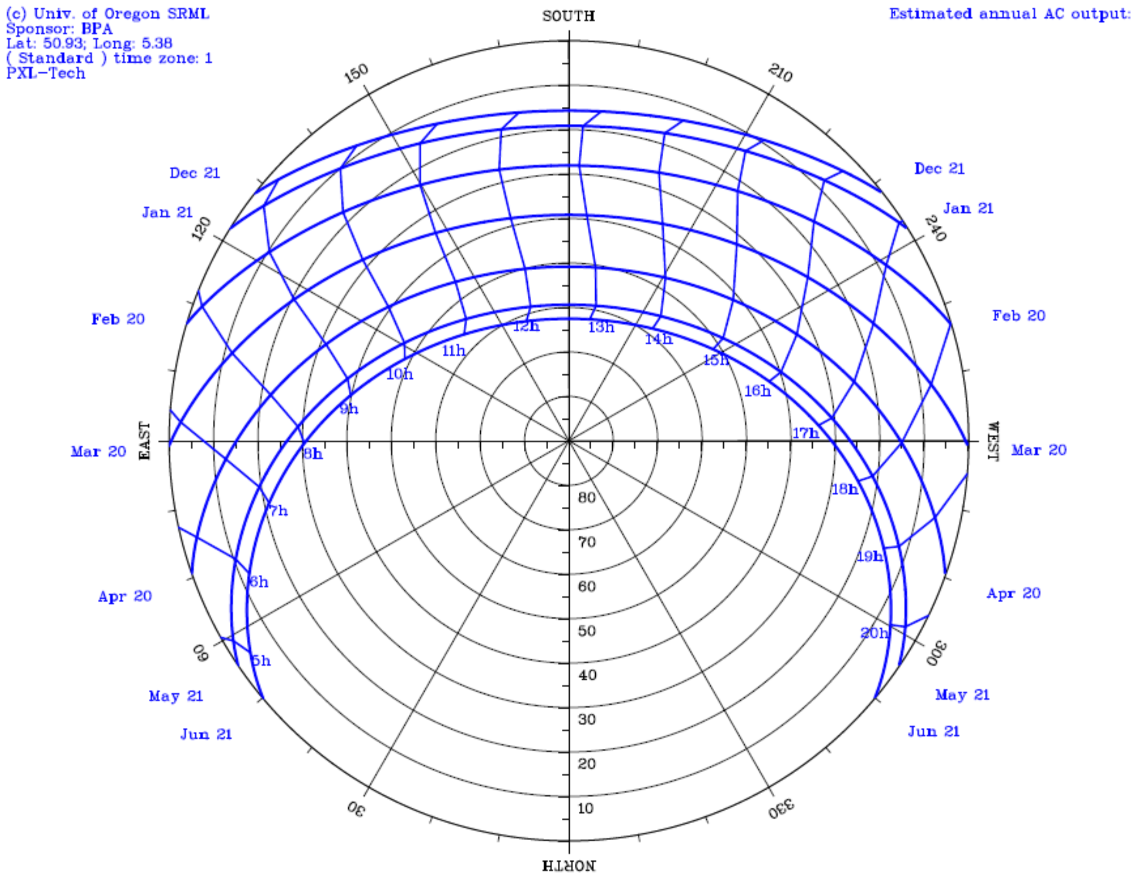

Figure 7: Solar chart in PXL-Tech

This chart (figure 7) shows the position of the sun during the year. This position is shown using different kind of axis. Firstly, on the X-axis West and East are shown. At the same time, in the Y-axis South and North are represented. Our building is located in the middle of the graph, while its north façade is looking at the North side of the graph, in other words, looking at the keyboard of the computer.

The altitude that the sun will have is exposed by the circle of the degrees that are around the middle point of the chart. When the radio is the biggest, the sun's height is the lowest. As the diameter decreases, the height of the sun from the ground boosts.

If we pay attention to the graphic (figure 7), we can see that on 21th of December we have the less available solar hours and on 21th of June the most solar hours in a day. This is because in December the sun lights will arrive to the building from 9 a.m. until around 4:30 p.m.; due to its low height. In contrast, in June the sun lights will arrive to the PV from 5 a.m. until around 8 p.m., owing to its high elevation.

Moreover, we can realise that the bigger shadow we will have in December because the sun is in the lowest height. We will take into account this to measure the distance that we have to leave from one PV to other in order to avoid shadows between each PV. To calculate the distance that we must keep between each PV we are going to base in the next picture.

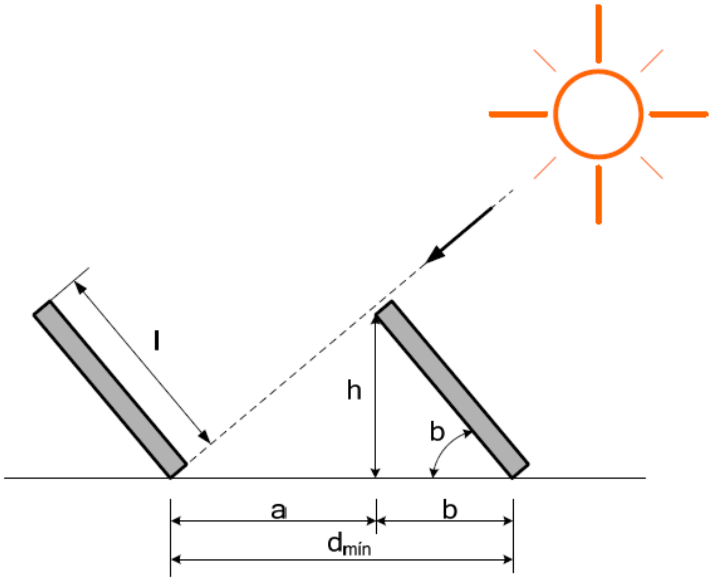

Figure 8: Explanation of the variables for the calculation of the minimum distance

Firstly, I calculated the height of the sun in the lowest case that means, on 21th of December using the next equation (equation 1):

Equation 1: Height of the sun

$$H = (90º - latitude) - 23{,}5º$$

As in our case the latitude is 50.927767º, the height (H) will be 39.0722º.

Once we have this value we can start with the main equation (equation 2):

Equation 2: Minimum distance between different PV

$$dmin = l \times \left(cos\beta + \frac{sin\beta}{tanH} \right)$$

β is the our PV inclination angle, in our case it is 34º.

l is the length of our PV. I still didn´t know this factor because we hadn´t decided yet. So the calculation of the minimum distance was done once we knew this characteristic. This part finished Mr. Mikel Vergara.

Wind speed

After analysing all the aspects of the sun energy that arrives to PXL-Tech, I checked the maximum wind values of the place. These values are important to ensure a safety installation of the PV-System.

PXL-Tech building has its own weather meter. Unfortunately, it was installed in February. As a result, I did not get data enough from this source. Therefore I check the next websites: [4] [5]

[6] [7]

But, after, Mr. Vanheusden recommended me to check the next website where I could find deeper data. [8]

This webpage seemed to be reliable. I took data from different stations and the closest stations from our building were Kleine Brogel Air Base, Schaffen Airfield (Diest, Belgium) and Maastricht Airport.

Figure 9: Distance between PXL-Tech and Maastricht Airport 26,7 km

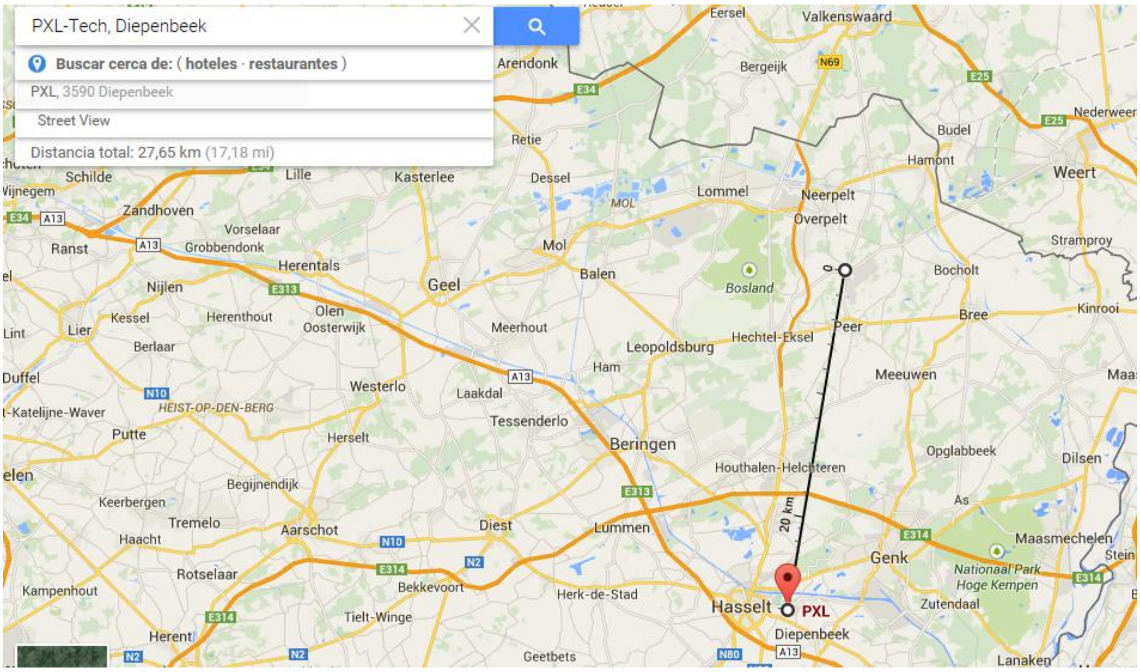

Figure 10: Distance between PXL-Tech and Kleine Brogel Air Base 28 km

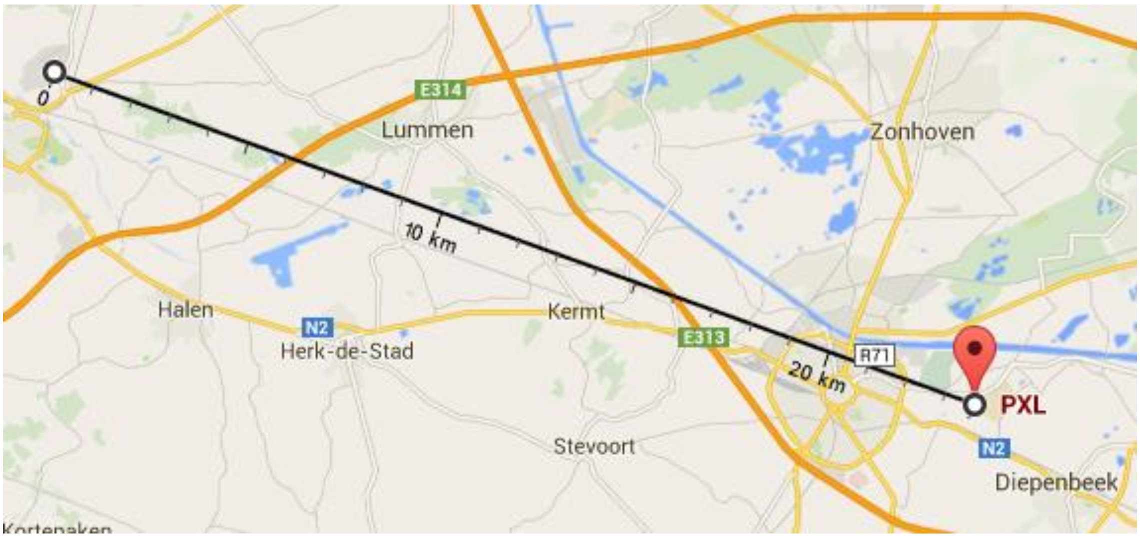

Figure 11: Distance between PXL-Tech and Schaffen Airfield (Diest, Belgium) 24 km

With each station mentioned in figure 9, 10 and 11, I checked the annual data of 2010, 2011, 2012, 2013 and 2014; and I chose the worst case, that means, the biggest wind speed value.

To start with, I analysed Kleine Brogel Air Base (Kleine Brogel, Belgium) data.

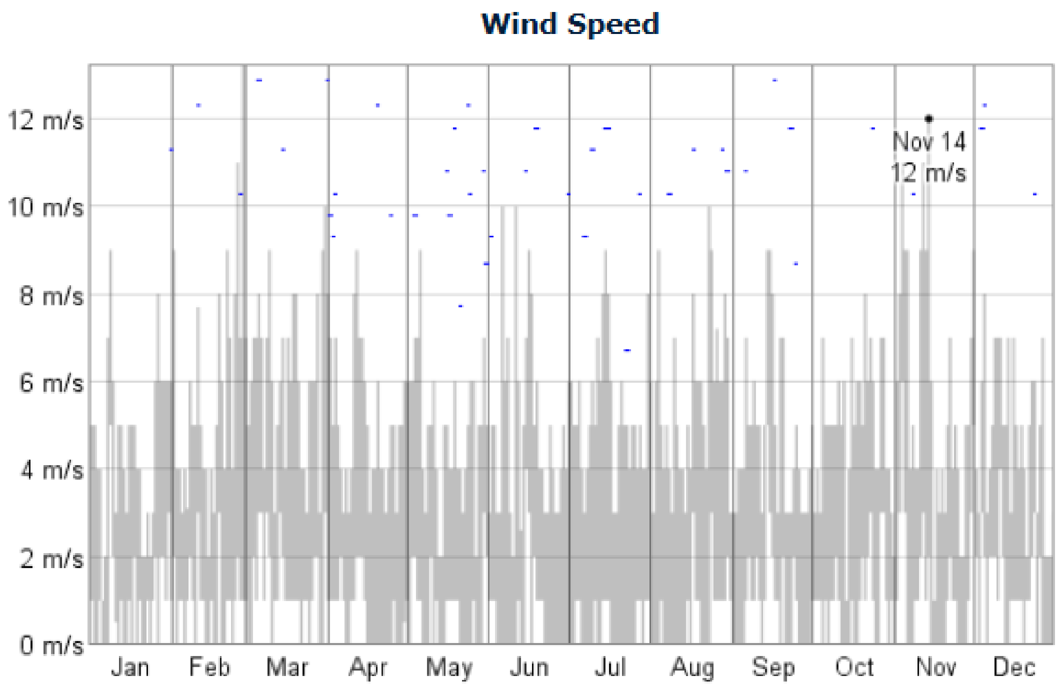

Figure 12: Wind Speed values 2010 Kleine Brogel Air Base

In this year (figure 12) was happened the biggest wind gust speed. It was measured in 28th of February 2010 and the value was 24 m/s. Our PV system has to be a safe and reliable item so it must be always ready to face the maximum wind speed in order to avoid future problems.

Then, I break down figures of Maastricht Airport.

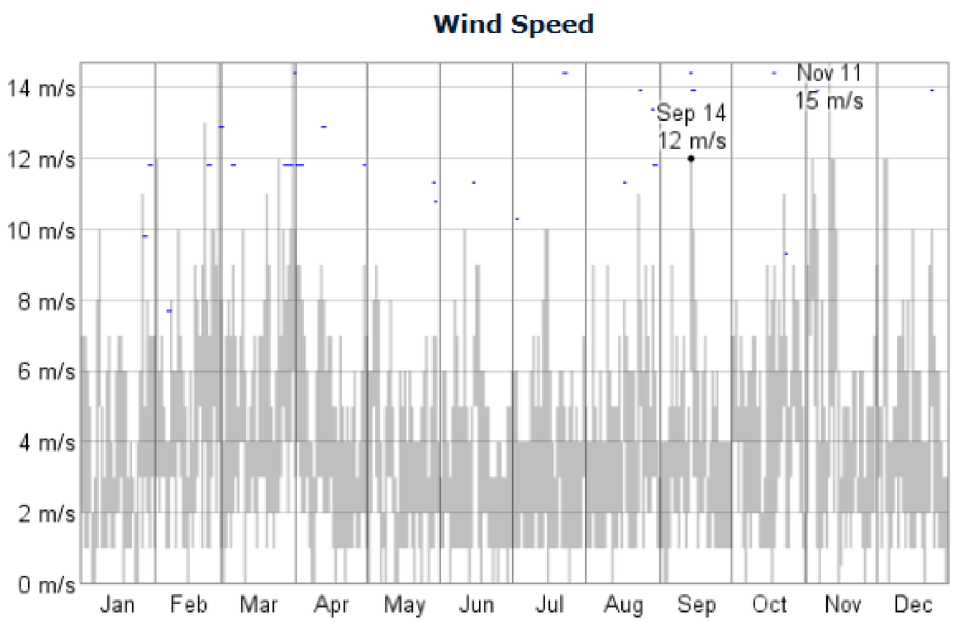

Figure 13: Wind Speed values 2010 Maastricht Airport

In this case, we can see in the figure 13 the values of 2010, where the highest wind gust speed happened, which is 29 m/s measured, likewise, in 28th of February 2010.

Finally, I consulted the records of Schaffen Airfield (Diest, Belgium) (see figure 14).

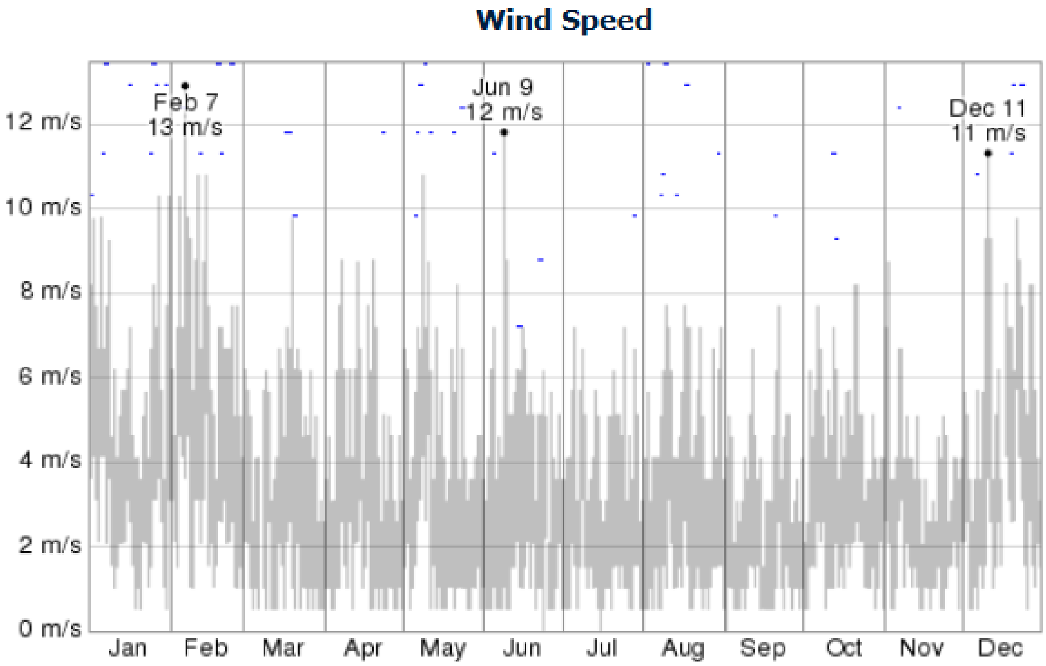

Figure 14: Wind speed values 2014 Schaffen Airfield

The maximum wind gust speed value is 55 m/s, which was measured in 1st of May 2014.

At the same time, I examined the main directions of the wind of each station. The data of Schaffen Airfield was based on the historical records from 2000 to 2012, whereas the data from the station of Kleine Brogel Air Base (Kleine Brogel, Belgium) was based on the historical records between 1974 and 2012 and the data of Maastricht Airport was based on the historical records over 1974 and 2012.

To start with, I checked Kleine Brogel Air Base (Kleine Brogel, Belgium) data (figure 15).

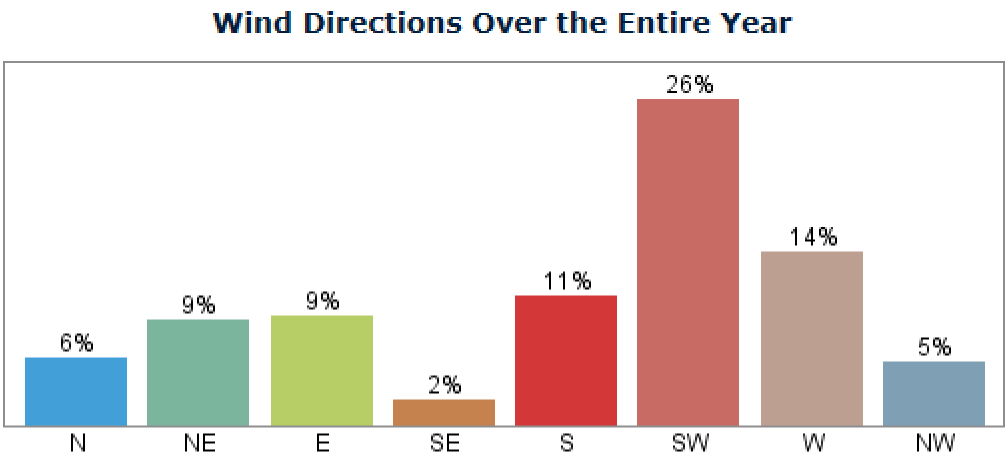

Figure 15: The fraction of time of the wind from each orientation Kleine Brogel

Data of Schaffen Airfield (Diest, Belgium) (figure 16):

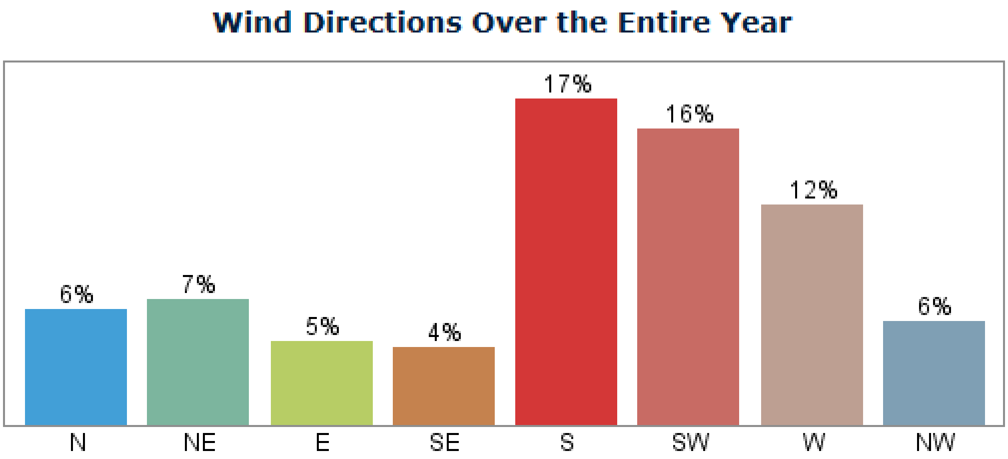

Figure 16: The fraction of time of the wind from each orientation Schaffen Airfield

Maastricht Aachen Airport (Maastricht, The Netherlands) records:

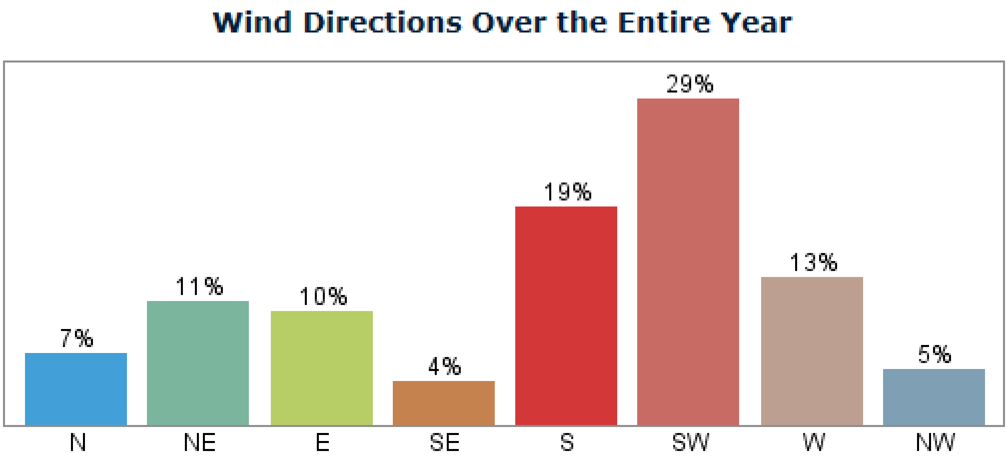

Figure 17: The fraction of time of the wind from each orientation Maastricht

If we analyse the figures 15, 16 and 17 we can see that the most common wind direction is SW. I still hadn't known if our PV would have had a track or it would have been fixed, but we had to bear in mind this factor, especially in case of the SW direction, because our PV would have had to suffer from the wind more in this direction.

I needed to find a way of choosing the most reliable data for our building. Therefore, I decided to make a comparison between the values of each station.

I collected the wind speed and wind direction values of each hour, of each station and also, of PXL-Tech exactly from 26/02/2015 between 10 a.m. and 2 p.m. and 27/02/2015 2 a.m. and 6 a.m. I obtained the wind data of PXL- Tech building using the next programme: Weather Link 6.0.3 exe [9]. With this software, I was able to see the data that our weather station had measured.

Then, I compared our building´s figures with Schaffen Airfield (Diest, Belgium), Maastricht Airport´s data and Kleine Brogel Air Base´s data.

Later, I took into account these values and I made a comparison between them and our PXL-Tech building´s meter results, in order to know the difference that exists depending on the place the meter is located at.

So as to note the dissimilarity between the records, I estimated the absolute error that existed between the values obtained from the general station and our building´s weather meter. To did that, I used the next equation (equation 3):

Equation 3: Absolute error

$$E = xi - xt$$

E : Absolute error

Xi : Measured value

Xt : True value

Then, I measured the relative error using the next equation (equation 4):

Equation 4: Relative error

$$Er = \frac{E}{xt}\ x\ 100$$

Er : Relative error

After that, I represented them in a graphic using excel. I also calculated the average relative error for each station.

In this part, I show the results that I obtained after analysing the different figures of the weather stations (see figure 18):

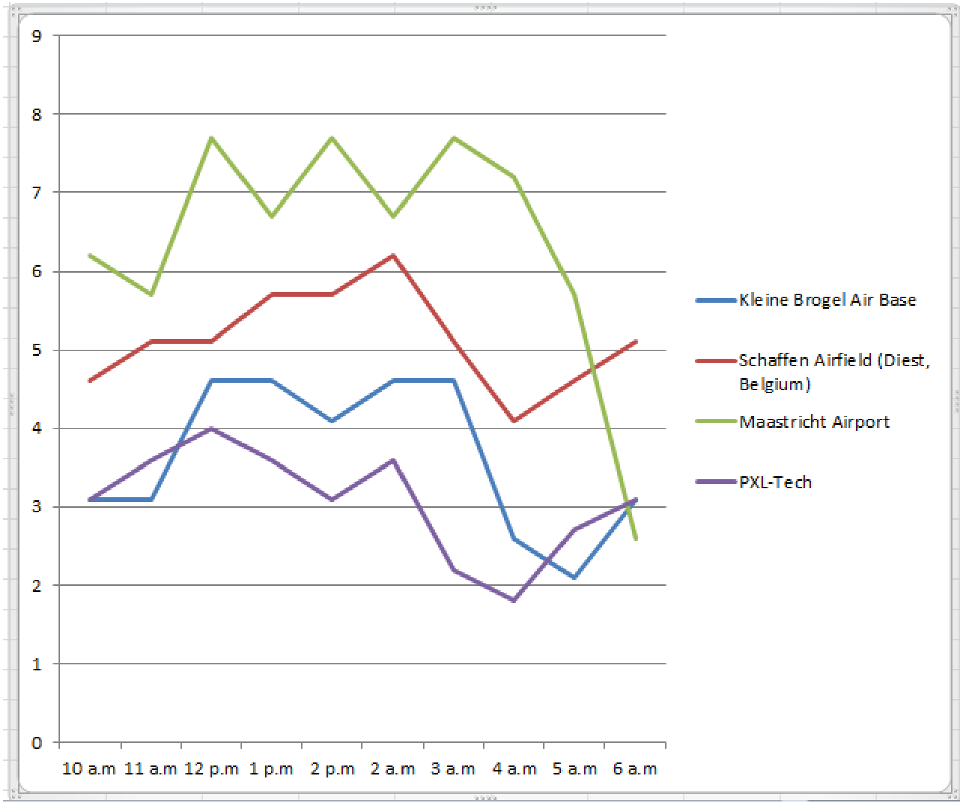

Figure 18: Differences between the Weather Stations

In this graphic, the horizontal axis shows different values of hours, and the vertical axis displays the wind speed values measured in each station.

We can see that the values from Kleine Brogel Air Base are the closest from our PXL-Tech building's values. The most different figures are those which are measured in Maastricht Airport (see figure 19 and 20).

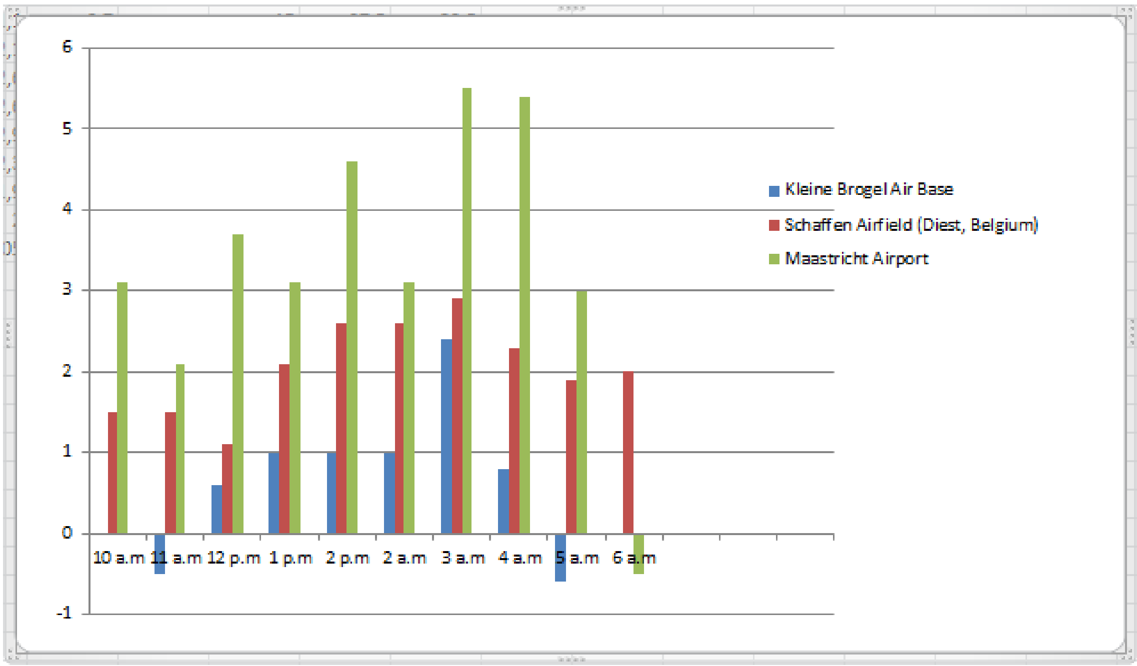

Figure 19: Absolute error of each station compared with PXL-Tech station

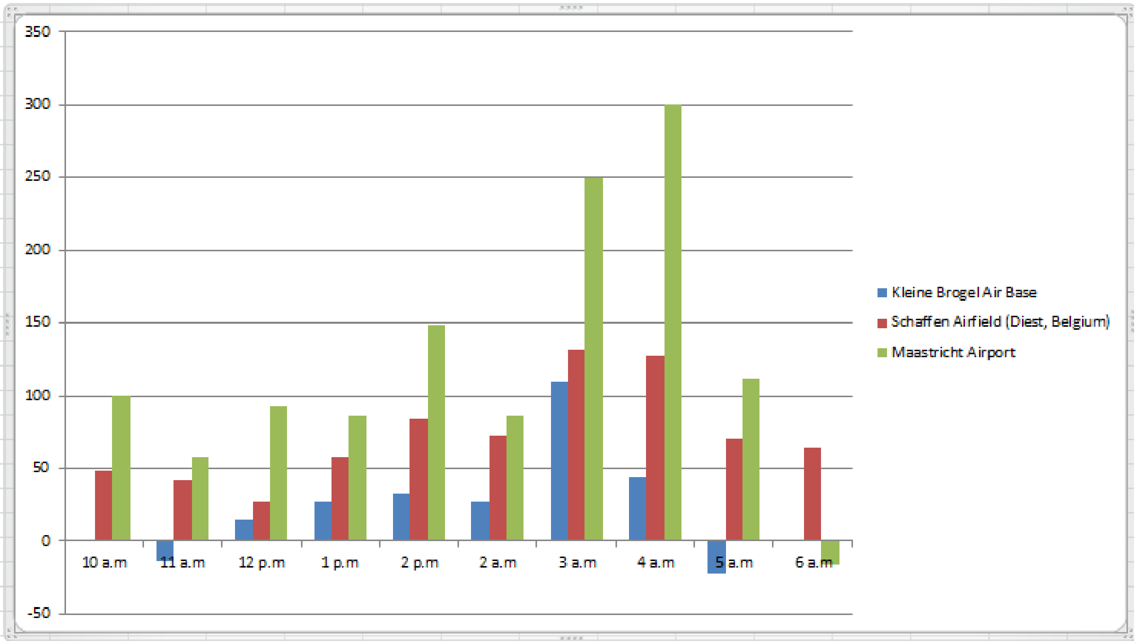

Figure 20: Relative error of each station compared with PXL-Tech station

Table 2: Average absolute error and average relative error value for each weather station.

Kleine Brogel Air Base													
Schaffen Airfield (Diest, Belgium)													
Maastricht Airport													
PXL-Tech													
E: absolute error							E	E	E		Er	Er	Er
Er: relative error		xi	xi	xi	xt		Eavg	Eavg	Eavg		Eravg %	Eravg %	Eravg %
26/02/2015	10 a.m	3,1	4,6	6,2	3,1		0	1,5	3,1		0	48,3871	100
	11 a.m	3,1	5,1	5,7	3,6		-0,5	1,5	2,1		-13,8889	41,6667	58,3333
	12 p.m	4,6	5,1	7,7	4		0,6	1,1	3,7		15	27,5	92,5
	1 p.m	4,6	5,7	6,7	3,6		1	2,1	3,1		27,7778	58,3333	86,1111
	2 p.m	4,1	5,7	7,7	3,1		1	2,6	4,6		32,2581	83,871	148,387
27/02/2015	2 a.m	4,6	6,2	6,7	3,6		1	2,6	3,1		27,7778	72,2222	86,1111
	3 a.m	4,6	5,1	7,7	2,2		2,4	2,9	5,5		109,091	131,818	250
	4 a.m	2,6	4,1	7,2	1,8		0,8	2,3	5,4		44,4444	127,778	300
	5 a.m	2,1	4,6	5,7	2,7		-0,6	1,9	3		-22,2222	70,3704	111,111
	6 a.m	3,1	5,1	2,6	3,1		0	2	-0,5		0	64,5161	-16,129
							0,57	2,05	3,31		22,0238	72,6463	121,642

If we analyse figure 19 and 20, it is clear that the best approximation values will be the ones that have been measured in Kleine Brogel Air Base, due to their low error value.

Besides, in case of the average absolute error and relative error in the table 2, the same fact is shown.

Wind speed result:

In conclusion, basing on the results, I took into account the data of Kleine Brogel Air Base for my calculations. As a result, our PV system should be able to cope with the wind speed of 24 m/s and the most common wind direction will be SW.

To ensure the whole safety, I over dimensioned this value, therefore, the value to bear in mind was 30 m/s.

3.2. Geothermal energy

3.2.1. Source's information

Source's physical characteristics

To start with, I looked for information about the specifications of the surrounding ground in the next website. This website was recommended by Mr. Win Vandormael: [10]

The longitude and latitude of our building were inserted and consequently, the next information was founded (see figure 21):

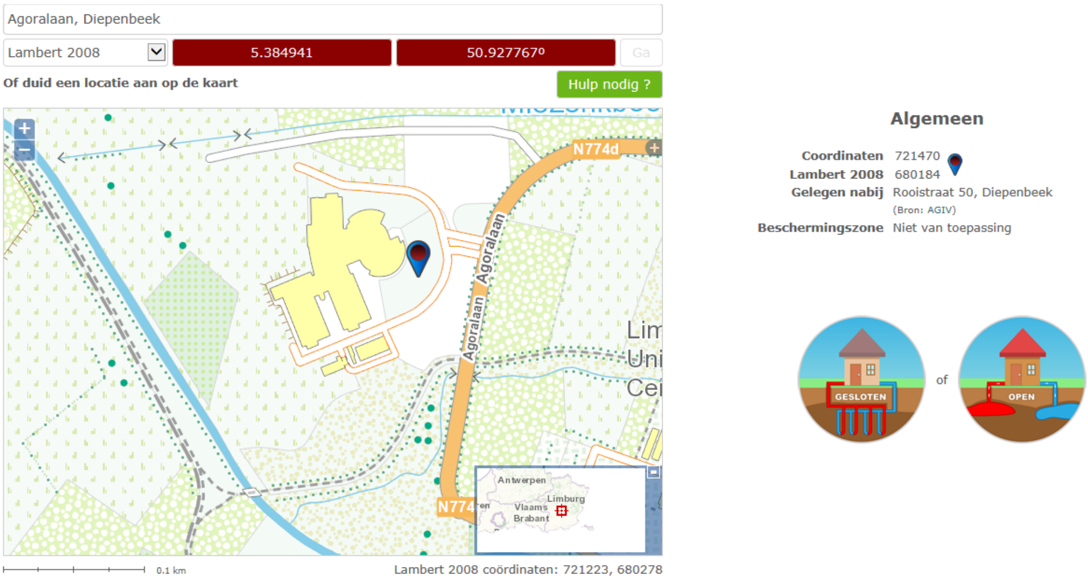

Figure 21: Analysis of the surrounding ground

I focused on the different layers that our ground is shaped with, in order to know the conductivity and analyse their properties, those which are related with the pierce process.

Our ground is shaped in the next manner (see figure 22):

Hydrogeologie

HCOV-data aangeleverd door VMM			Interpretatie WTCB		
Naam HCOV-eenheid	dikte (m)	diepte (m)	type	λ min (W/mK)	λ gem (W/mK)
Alluviale deklagen	4.4	4.4	zandh. klei	1.4	1.7
Deklagen (dekzanden)	2.7	7.1	zand	1.9	2.3
Pleistoceen van de riviervalleien	1.6	8.7	zand	1.9	2.3
Zand van Eigenbilzen	0.4	9.1	kleih. zand	1.8	2.1
Boom Aquitard	22.3	31.4	klei	1.2	1.5
Zand van Kerniel	3.0	34.4	zand	1.9	2.3
Klei van Kleine-Spouwen	1.3	35.7	zandh. klei	1.4	1.7
Ruisbroek-Berg Aquifer	7.8	43.4	kleih. zand	1.8	2.1
Tongeren Aquitard	4.3	47.7	klei	1.2	1.5
Oligoceen Aquifersysteem	17.0	64.7	kleih. zand	1.8	2.1
Landeniaan en Heersiaan Aquitard	46.8	111.6	zandh. klei	1.4	1.7
Heersiaan en Opglabbeek Aquifersysteem	31.8	143.4	kleih. zand	1.8	2.1
Krijt Aquifer	156.6	300.0	tufkrijt	2.3	2.3

De geologische opbouw wordt weergegeven tot een maximale diepte van 300m. Deze opbouw is een interpretatie van onvolledige data. Alle gegevens dienen steeds te worden bevestigd door verder onderzoek

Op basis van het HCOV-model (http://dov.vlaanderen.be)

Figure 22: Analysis of the ground

This table lists the different types of shapes of the ground of PXL-Tech, pointing out their thickness, depth and conductivity values.

As in the picture is said, the data must be verified with new investigations but in our case, we did not follow that step due to mainly lack of time.

Source's thermal characteristics

Once I knew the ground´s physical and conductivity characteristics, I had to find its thermal characteristics.

To find them I used the next equation (equation 5):

Equation 5: Ground's temperature depending on the depth and the day of the year

$$T(z,t) = Tm - As\, e^{-z\sqrt{\frac{\pi}{365\alpha}}} \cos\left[\frac{2\pi}{365}\left(t - t0 - \frac{z}{2}\sqrt{\frac{365}{\pi\alpha}}\right)\right]$$

z : the depth

t : the number of the day of the year, calendar day

Tm : the annual average air temperature

As : the change of the temperature

α : the soil thermal diffusivity

I took this equation from a subject of University of the Basque Country (UPV/EHU) which is called "Geothermal energy" [11]. This formula was created mainly for homogeneous ground. As we have seen before, our ground is not homogeneous; it has different layers with different thickness and so, different thermal diffusivity. In order to reach a visual approximation, I took an average value of diffusivity, as my professor of UPV/EHU Mr Aitor Urresti recommended me.

As the exact depth of our system was going to be measured after knowing the energy needs of the building, I made simulations of the temperature using different depth values in excel. The same calculations for different days of the year were made, too; and then, the average value was measured.

Annual average air temperature

So, to start calculating the values I should have replaced in the formula, I calculated the annual average air temperature. For that, different sources were consulted. Then, I chose one basing on that my tutors agreed the next web-page was reliable:

[12]

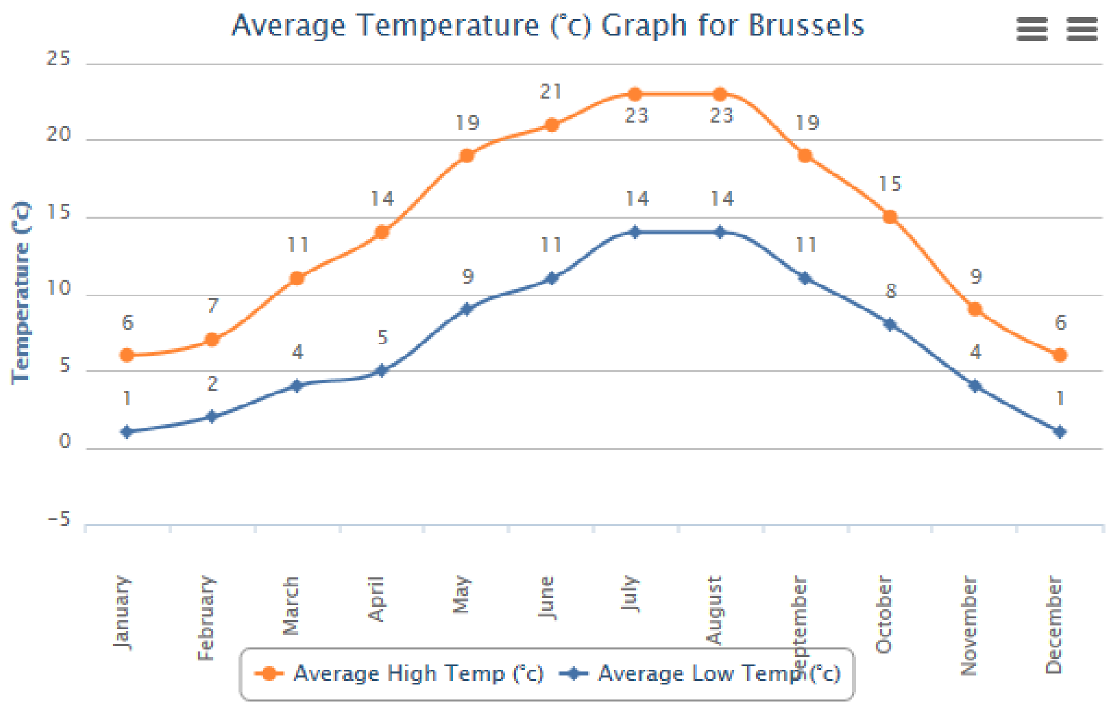

Figure 23: Average monthly Temperature for Hasselt

This line chart (figure 23) shows the months of the year in the horizontal axis and the average temperature values in the vertical axis.

Basing on this information, I calculated the average annual air temperature.

ANNUAL AVERAGE AIR TEMPERATURE VALUE

In order to obtain the average temperature value, I took into account all values of the table and I calculated the medium figure. The result is marked in yellow colour (see figure 24).

Average high tenperature (ºC)	6	7	11	14	19	21	23	23	19	15	9	6
Average low tenperature (ºC)	1	2	4	5	9	11	14	14	11	8	4	1
Average Temperature Tm	10,70833											

Figure 24: Excel calculations to obtain the annual average air temperature

Thermal diffusivity of the ground

After that, the thermal diffusivity was measured. The ground's characteristics are not specifically said and so, some approximations to calculate the thermal diffusivity values were made.

* I have chosen sand dry value to know the density.

**For clay, I chose the most repetitive value of the density of the clay. To know the data of Sand clay and Clay sand some approximations were made. First, I calculated the average value of the thermal diffusivity which is 0,391 (m^2/s) ($x10^{-6}$). After that, I estimated its quarter part which is 0, 1. In the case of Sand Clay as Sand has the biggest part, 0,491 was taken and in the case of Clay Sand, basing in the same theory, 0,291 was chosen. This is only an approximation.

After making a primary research [13], [14], [15] , [16] , [17], [18] next thermal diffusivity values were collected and the next average thermal diffusivity value of the ground were obtained (see table 3):

Table 3: Type of layers and their thermal diffusivity

Type	λmin (W/mk)	λaverage (W/mk)	Thermal diffusivity (m^2/s) ($x10^{-6}$)
Sand clay	1.4	1.7	0,423
sand	1.9	2.3	0,521
sand	1.9	2.3	0,521
Clay sand	1.8	2.1	0,291
Clay	1.2	1.5	0,261
Sand	1.9	2.3	0,521
Sand Clay	1.4	1.7	0,423
Clay Sand	1.8	2.1	0,291
Clay	1.2	1.5	0,261
Clay Sand	1.8	2.1	0,291
Sand Clay	1.4	1.7	0,423
Clay Sand	1.8	2.1	0,291
Limestone	2.3	2.3	1,2
Average Thermal diffusivity			**0,44**

Change of the temperature

Then, I calculated the change of the temperature, in other words, its amplitude. For that, I analysed the three closest station´s values. The data from the station of Maastricht Aachen Airport:

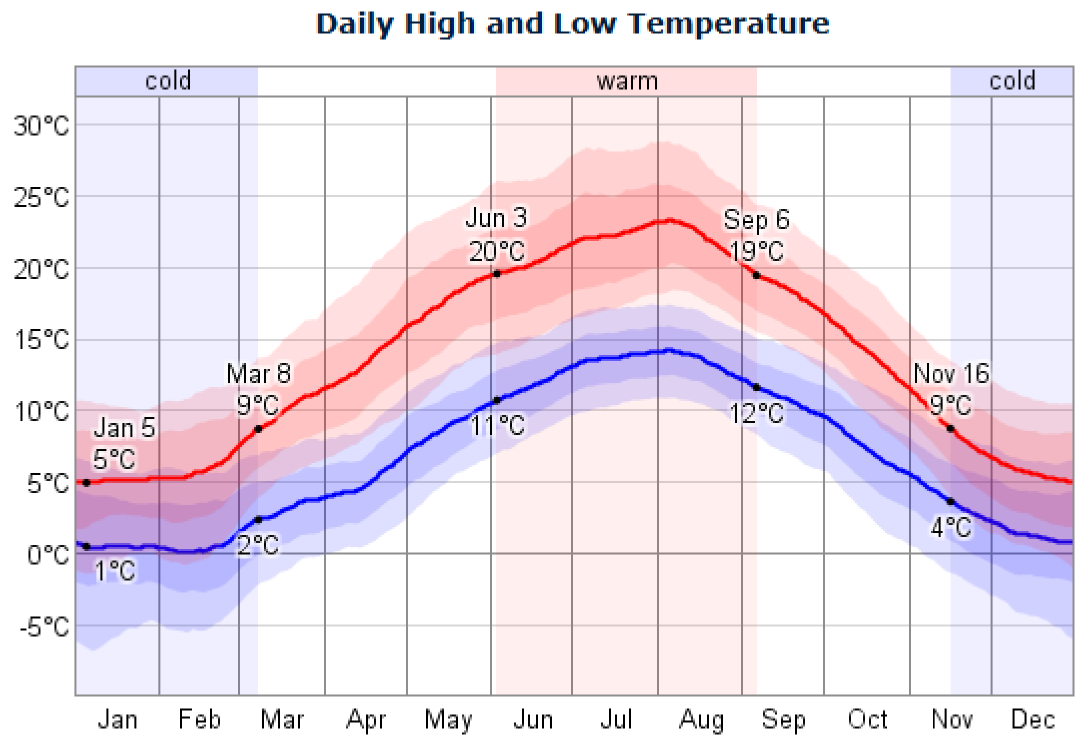

Figure 25: Minimum and maximum temperature values, Maastricht Aachen Airport

These results from the figure 25 were obtained taking into account historical records from 1974 to 2012.

The data from the station of Kleine Brogel Air Base (Kleine Brogel, Belgium):

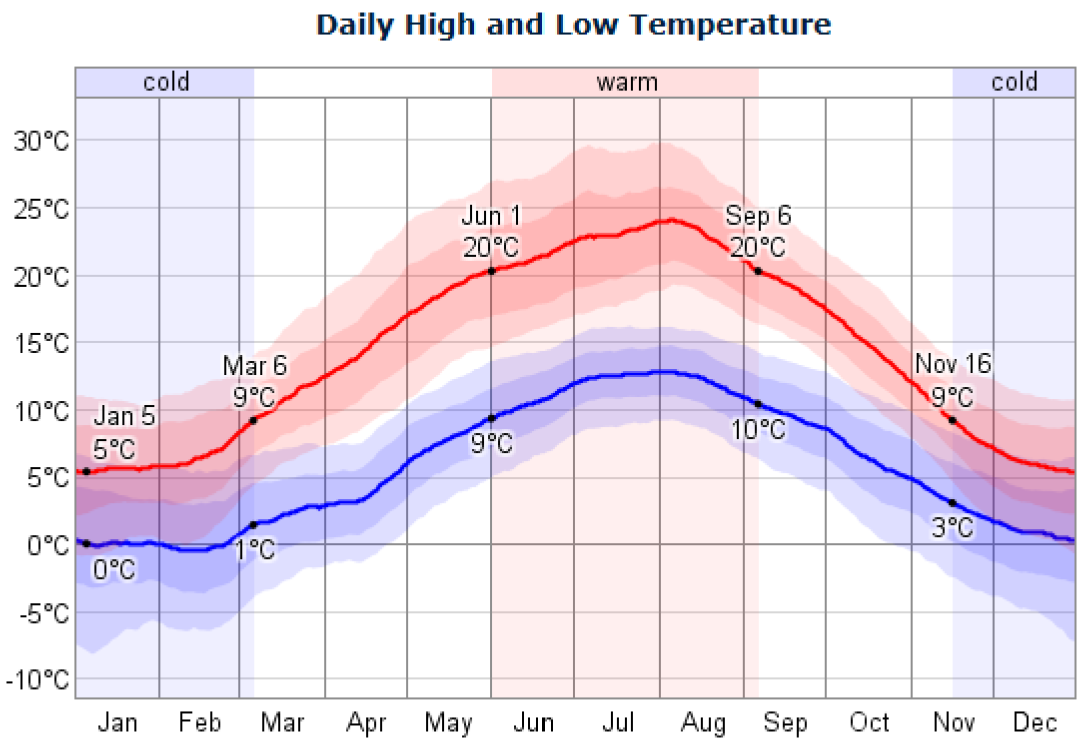

Figure 26: Minimum and maximum temperature values, Kleine Brogel Air Base

The data from the station of Schaffen Airfield (Diest, Belgium):

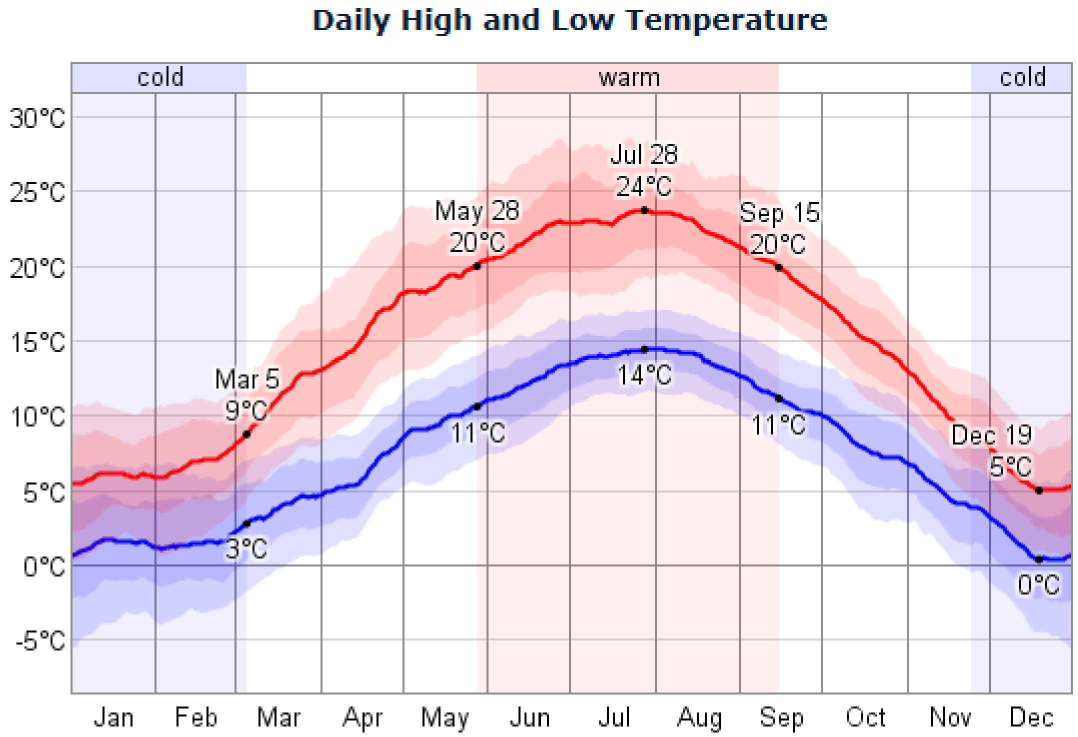

Figure 27: Minimum and maximum temperature values, Schaffen Airfield

As is the amplitude of the temperature, it is the half of the difference between the maximum and minimum temperature of the year.

Equation 6: Temperature's amplitude

$$As = \frac{Tmax - Tmin}{2}$$

If we check picture 25, 26 and 27 the value of the maximum temperature is around 24ºC.

If we see picture 25, 26 and 27 the value of the minimum temperature is around 0ºC.

$$As = \frac{Tmax - Tmin}{2} = \frac{24 - 0}{2} = 12ºC$$

To value

Another value that I had to replace in the formula was To. It depended on the properties of the ground, it was around 25ºC and 45ºC usually, and I took the value of 35ºC as approximation.

Source's thermal characteristics result

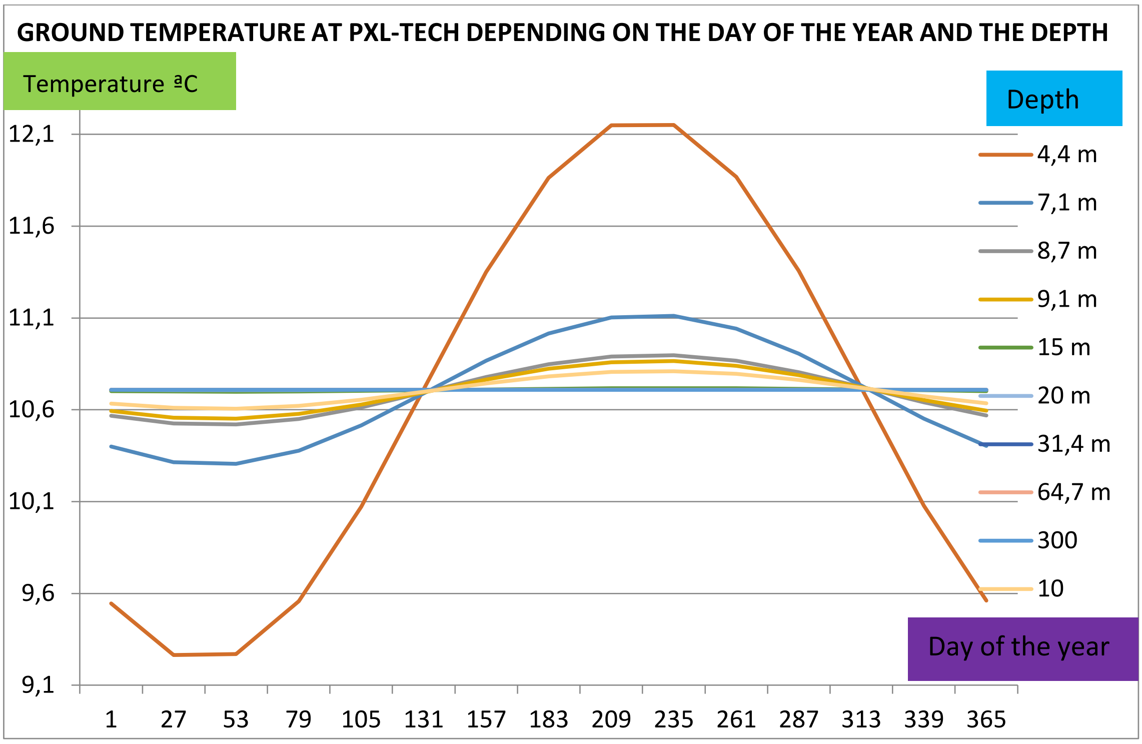

Figure 28: Ground Temperature at PXL-Tech

This figure 28 shows the days of the year in the horizontal axis. In the vertical left axis shows the temperature value and in the vertical right axis shows the depth of the ground.

As we can see in the figure 28, the ground temperature changes a lot the first meters, but after around 10 meters, it remains constant. So we will have the same temperature 10 meters down from the surface or 300 meters down from the surface because it remains flat.

After that, I analysed in which depth exactly started to be constant our temperature due to the fact that, after this value the temperature will remain on a plateau.

t (day of the year)	z(m)	8	9	10	11	12	13	14	15
1		10,50972884	10,587	10,634	10,663	10,681	10,692	10,698	10,702
27		10,45237731	10,55	10,611	10,648	10,671	10,685	10,694	10,7
53		10,44544784	10,545	10,606	10,645	10,669	10,684	10,693	10,699
79		10,4903055	10,571	10,622	10,654	10,674	10,687	10,695	10,7
105		10,57811345	10,625	10,655	10,674	10,686	10,694	10,699	10,703
131		10,69157374	10,695	10,698	10,701	10,703	10,705	10,706	10,707
157		10,80833497	10,768	10,743	10,729	10,721	10,715	10,713	10,711
183		10,90539547	10,829	10,782	10,753	10,736	10,725	10,718	10,715
209		10,96363456	10,866	10,806	10,768	10,745	10,731	10,722	10,717
235		10,97157928	10,872	10,81	10,772	10,748	10,733	10,724	10,718
261		10,92766453	10,846	10,795	10,763	10,743	10,73	10,722	10,717
287		10,84054143	10,793	10,763	10,743	10,73	10,722	10,717	10,714
313		10,727373	10,723	10,719	10,716	10,714	10,712	10,711	10,71
339		10,61045314	10,65	10,674	10,688	10,696	10,701	10,704	10,706
365		10,51281479	10,589	10,635	10,664	10,681	10,692	10,698	10,702

Figure 29: Ground's temperature around 10 meters

If we see the figure 29, we realize that the constant temperature of 10.7 ªC is reached at around 15 meters. Nevertheless, at 10 meters depth also, it has considerable steady values. So, after this depth the temperature values would be the same and our temperature would not increase.

As I have seen when I was doing primary research, the constant temperature value of the ground and the air's average temperature are the same. In fact, we can see in the figure 29 that the steady value which is 10.7ºC is the same as the average air temperature that we saw before. Moreover, the temperature keeps the same value after a depth of 10 meters. This is exactly what I saw in the primary research.

Therefore, I conclude that my calculations are well done.

3.3. Heat gains and heat losses balance

After knowing the characteristics of the ground, I started with the main calculations. I collected all data in order to make the balance between the heat gains and the heat losses of the building.

3.3.1. Heat losses

Our building suffers from three different types of heat losses (see figure 30):

- Transmission
- Ventilation
- Infiltration

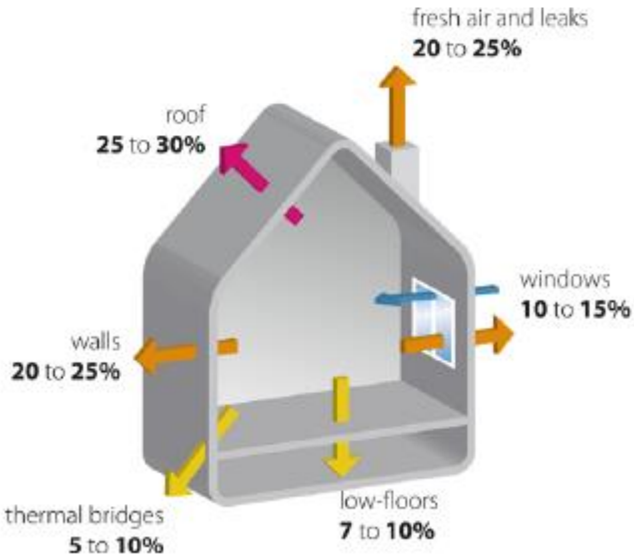

Figure 30: Heat losses of a building

Our building has two different periods of heat losses:

- Winter. Around half of the year, our building losses heat because energy goes outside the building.
- Summer. The other half of the year, our building earns heat, which means a loss too, because energy enters to the building.

Ti: I fixed some values basing on what are the most popular values used in different softwares, for instance, in PEB.

To: To choose these temperature figures for outside the building.

Temperature inside the bulding

I took into account the next values for the temperature inside (see table 4).

Table 4: Temperature values for inside the building

Duration	Ti
October-March	19ºC
April-September	23ºC

These are the temperature values that I fixed for our building. They can be changed but in my view, they are the most reasonable values. Moreover, these are the values that most softwares use, for instance, EPB software tool and my tutors agree with my decision.

Temperature outside the building

To choose the temperature figures for outside the building, I analysed the historical temperature data from the next webpage: [12]

I calculated an average temperature taking into account the mean low temperature values for the period between October-March and at the same time; I estimated an average temperature taking into account the mean high temperature values for the period between April-September (see figure 31).

	Ti ºC	To ºC					
October-March	21	3,333333					
April-September	23	19,83333					
To October-March	8	4	1	1	2	4	3,333333
To April-September	14	19	21	23	23	19	19,83333

Figure 31: Ti and To values for each period

Transmission heat losses

It is the heat loosed through the walls.

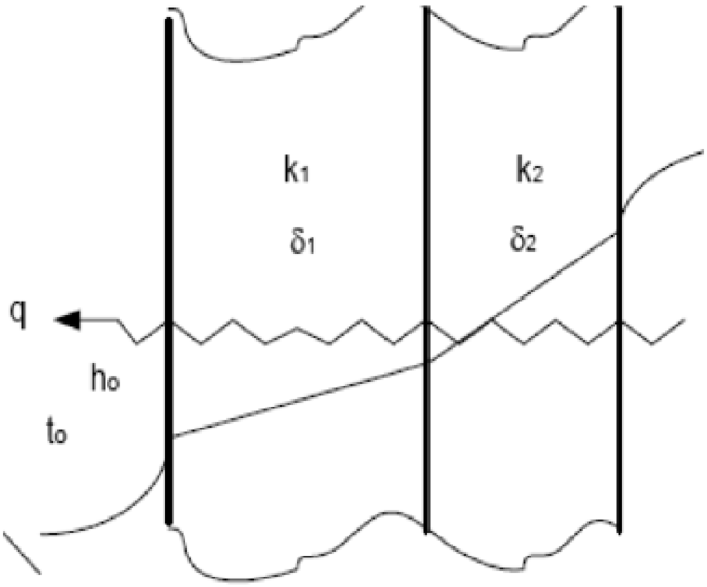

Figure 32: Representation of the heat loss through a wall

In the figure 32 we can see a heat loss that happens throughout the wall which is made of two materials with the conductivity value of k1 and k2.

To calculate the transmission heat losses of the building, I followed the next equation (equation 7):

Equation 7: Transmission heat losses

$$\dot{Q}trans = UA(Ti - To)$$

U: Thermal transmittance of the walls.

A: The area where the transmission heat loss is happened.

Ti: Temperature inside the building.

To: Temperature outside the building.

Each kind of wall had its own characteristics, and in consequence, its thermal transmittance. For instance, the walls were made with a group of some materials and the roof had another ones. Therefore, I calculated the heat losses for each kind of material's group: Roof, ground, surrounding walls and windows and glasses (see equation 8).

Equation 8: Total transmission heat losses

$$\dot{Q}transTotal = \dot{Q}transroof + \dot{Q}transground + \dot{Q}transSurroundingWalls + \dot{Q}transWindowsGlasses$$

In case of the ground, I had to calculate the To for it. To do so, I collect information from different sources.

Datos de temperatura del terreno a una profundidad de
20 cm, 4 datos/día a las 0, 6, 12 y 18 h.

Figure 33: "Ahorro y Eficiencia Energética en Climatización" [18]

The aim of the book was to have handy reliable data which are used in Refrigeration, Ventilation and Heating projects.

As we can see in the figure 33, the method to find data about ground temperature consists on measuring ground temperature 20cm far from the 0 level, and measure it at 0, 6, 12 a.m. and 18 p.m. every day.

Consequently, I used the excel program, the same formula that I showed before when analysing the surrounding ground. I calculated every day's ground temperature values for 20cm far from the ground.

Then, I took into account the values from October to November to calculate the ground's average winter temperature. The same was done for the remained period of the year, so as to reach the ground's average summer temperature.

Tground average winter	4,7309	ºC
Tground average summer	16,7186	ºC

Figure 34: Results of ground's temperature

Thermal transmittance

Equation 9: Thermal Transmittance

$$U = \frac{1}{R} (\mathrm{W}/m^2\mathrm{K})$$

Equation 10: Thermal Resistance

$$R = \frac{\text{thickness of each material}}{\text{thermal conductivity of each material}} \; (m^2\mathrm{K}/\mathrm{W})$$

R: Thermal resistance

This factor (R) shows how easy the material transmits or not transmits the heat. A bigger thermal transmittance value means a lower isolation capacity of the material.

If we check equation 9 and 10, firstly I should have known the thermal resistance value. For that, I should have checked the thickness of each material and the thermal conductivity too. First of all, I collected data about the layers that the walls, roof, glass and ground are made with. I used the next design that Mr. Roger Vrancken gave me.

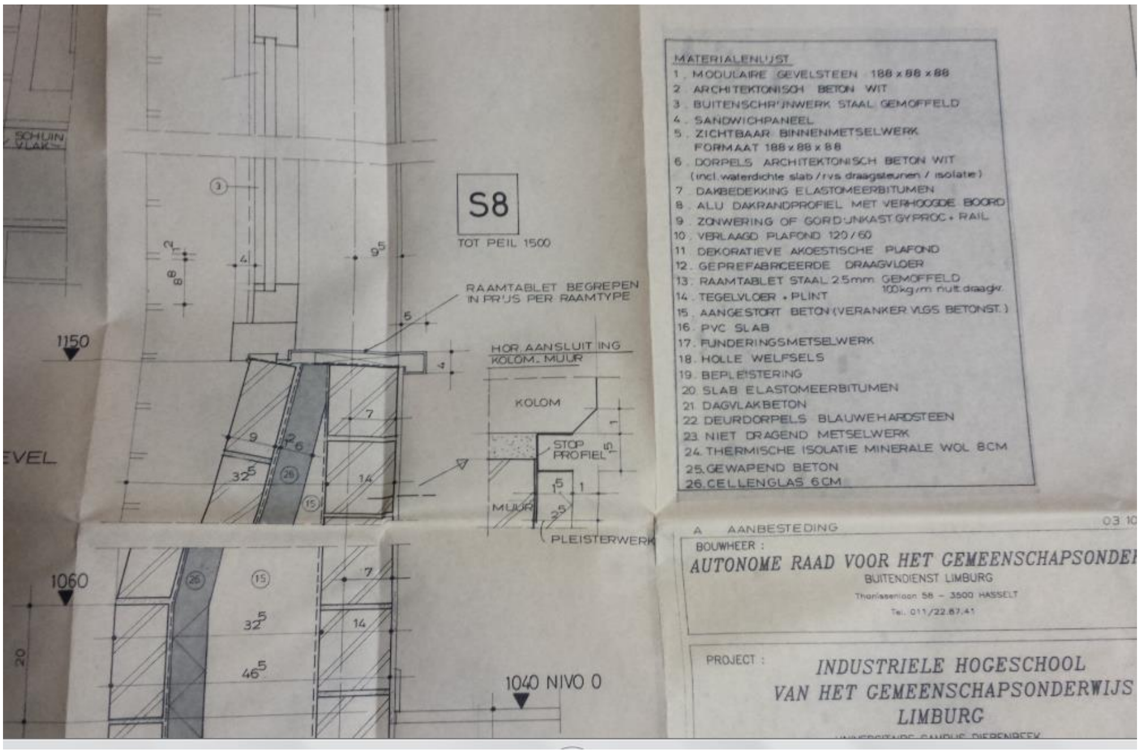

Figure 35: Example walls' composition

Taking this picture (see figure 35) as an example of what I did, we can see that the data is written in Dutch and to have clearer information, I used either the translator or my colleagues' and tutors explanations. Basing on this information, I looked for these materials' thermal conductivity. The model of the materials or the producing year was not written in the designs; as a result, I took the most suitable conductivity values. The conductivity value shows also how easy a material transmits heat.

The thermal conductivity values of different materials were chosen from the websites that are mentioned in the references [19], [20], [11], [21], [22] and [16]. Besides, Ms. Nele Houben helped me with the thermal resistance values of the stones.

I had to take into account the convection factors as well, ho and hi.

$$U = \frac{1}{\frac{1}{h_o} + \frac{\delta_1}{k_1} + \frac{\delta_2}{k_2} + \frac{1}{h_i}}$$

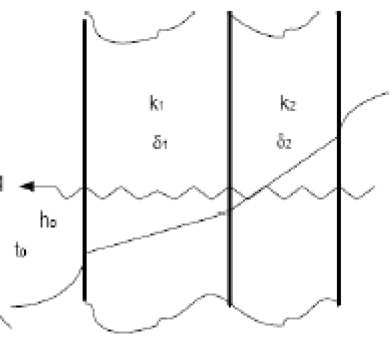

Figure 36: Explanation of thermal transmittance calculation

In figure 36, Ho is the convection factor between the outside shape of the room and the outside, and hi is the convection factor between the inside shape of the room, and the inside part of the building. K1 and K2 are the conductivity values of each material.

Therefore, once knowing the total thermal transmittance value of each part, I added the values that are shown in the next table. Depending on each case, different values were added.

Tabla E.1 Resistencias térmicas superficiales de cerramientos en contacto con el aire exterior en m^2K/W

Posición del cerramiento y sentido del flujo de calor	Rse	Rsi
Cerramientos verticales o con pendiente sobre la horizontal >60° y flujo horizontal	0,04	0,13
Cerramientos horizontales o con pendiente sobre la horizontal ≤60° y flujo ascendente	0,04	0,10
Cerramientos horizontales y flujo descendente	0,04	0,17

Figure 37: Thermal resistance in contact with air

This table (figure 37) lists the different values that should be taken into account when calculating the thermal resistance of a building. Rse is used to take into account the contact between the outside air and the exterior part of the building. Rsi is used to bear in mind the connection among the interior air and the interior part of the building. The first line is for horizontal movements of the air, the second, for vertical upwards movement and the third one, for vertical downward movement.

As a result, the first line values were added in the wall's thermal resistance calculations, the second line and the third line, in the case of the roof and ground respectively; due to the fact that the energy goes from the hottest place to the coldest area.

Ground's case is special due to the fact that its exterior area is not in contact with the exterior air. Therefore, I didn't add its Rse value of the table to its thermal resistance value. A kind of the same happened with the glass and windows too; the values of the table weren't added, due to the fact that the datasheet gave the last figure straigtway. All the windows, glasses and the automatic doors have the same conductivity value as we have seen in the data that I obtained. I found their thermal transmittance value in the next datasheet that Mr. Roger Vrancken gave me (see figure 38)

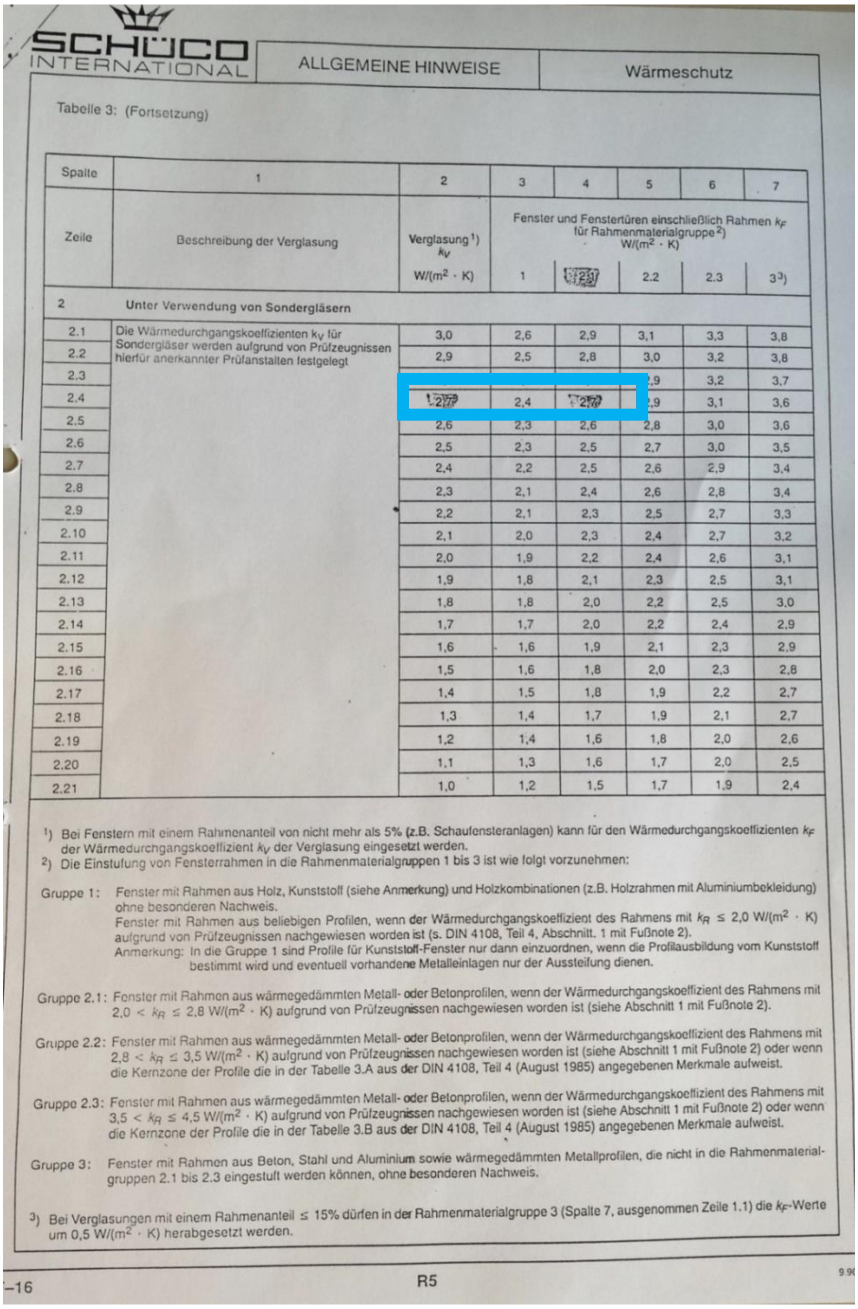

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Tabelle 3: (Fortsetzung)

Spalte	1	2	3	4	5	6	7
Zeile	Beschreibung der Verglasung	Verglasung 1) k_V W/(m² · K)	Fenster und Fenstertüren einschließlich Rahmen k_F für Rahmenmaterialgruppe 2) W/(m² · K)				
			1	2.1	2.2	2.3	3 3)
2	Unter Verwendung von Sondergläsern						
2.1	Die Wärmedurchgangskoeffizienten k_V für Sondergläser werden aufgrund von Prüfzeugnissen hierfür anerkannter Prüfanstalten festgelegt	3,0	2,6	2,9	3,1	3,3	3,8
2.2		2,9	2,5	2,8	3,0	3,2	3,8
2.3		[illegible]	[illegible]	[illegible]	[illegible]	3,2	3,7
2.4		2,7	2,4	2,7	[illegible]	3,1	3,6
2.5		2,6	2,3	2,6	2,8	3,0	3,6
2.6		2,5	2,3	2,5	2,7	3,0	3,5
2.7		2,4	2,2	2,5	2,6	2,9	3,4
2.8		2,3	2,1	2,4	2,6	2,8	3,4
2.9		2,2	2,1	2,3	2,5	2,7	3,3
2.10		2,1	2,0	2,3	2,4	2,7	3,2
2.11		2,0	1,9	2,2	2,4	2,6	3,1
2.12		1,9	1,8	2,1	2,3	2,5	3,1
2.13		1,8	1,8	2,0	2,2	2,5	3,0
2.14		1,7	1,7	2,0	2,2	2,4	2,9
2.15		1,6	1,6	1,9	2,1	2,3	2,9
2.16		1,5	1,6	1,8	2,0	2,3	2,8
2.17		1,4	1,5	1,8	1,9	2,2	2,7
2.18		1,3	1,4	1,7	1,9	2,1	2,7
2.19		1,2	1,4	1,6	1,8	2,0	2,6
2.20		1,1	1,3	1,6	1,7	2,0	2,5
2.21		1,0	1,2	1,5	1,7	1,9	2,4

1) Bei Fenstern mit einem Rahmenanteil von nicht mehr als 5% (z.B. Schaufensteranlagen) kann für den Wärmedurchgangskoeffizienten k_F der Wärmedurchgangskoeffizient k_V der Verglasung eingesetzt werden.

2) Die Einstufung von Fensterrahmen in die Rahmenmaterialgruppen 1 bis 3 ist wie folgt vorzunehmen:

Gruppe 1: Fenster mit Rahmen aus Holz, Kunststoff (siehe Anmerkung) und Holzkombinationen (z.B. Holzrahmen mit Aluminiumbekleidung) ohne besonderen Nachweis.
Fenster mit Rahmen aus beliebigen Profilen, wenn der Wärmedurchgangskoeffizient des Rahmens mit $k_R \leq 2,0$ W/(m² · K) aufgrund von Prüfzeugnissen nachgewiesen worden ist (s. DIN 4108, Teil 4, Abschnitt. 1 mit Fußnote 2).
Anmerkung: In die Gruppe 1 sind Profile für Kunststoff-Fenster nur dann einzuordnen, wenn die Profilausbildung vom Kunststoff bestimmt wird und eventuell vorhandene Metalleinlagen nur der Aussteifung dienen.

Gruppe 2.1: Fenster mit Rahmen aus wärmegedämmten Metall- oder Betonprofilen, wenn der Wärmedurchgangskoeffizient des Rahmens mit $2,0 < k_R \leq 2,8$ W/(m² · K) aufgrund von Prüfzeugnissen nachgewiesen worden ist (siehe Abschnitt 1 mit Fußnote 2).

Gruppe 2.2: Fenster mit Rahmen aus wärmegedämmten Metall- oder Betonprofilen, wenn der Wärmedurchgangskoeffizient des Rahmens mit $2,8 < k_R \leq 3,5$ W/(m² · K) aufgrund von Prüfzeugnissen nachgewiesen worden ist (siehe Abschnitt 1 mit Fußnote 2) oder wenn die Kernzone der Profile die in der Tabelle 3.A aus der DIN 4108, Teil 4 (August 1985) angegebenen Merkmale aufweist.

Gruppe 2.3: Fenster mit Rahmen aus wärmegedämmten Metall- oder Betonprofilen, wenn der Wärmedurchgangskoeffizient des Rahmens mit $3,5 < k_R \leq 4,5$ W/(m² · K) aufgrund von Prüfzeugnissen nachgewiesen worden ist (siehe Abschnitt 1 mit Fußnote 2) oder wenn die Kernzone der Profile die in der Tabelle 3.B aus der DIN 4108, Teil 4 (August 1985) angegebenen Merkmale aufweist.

Gruppe 3: Fenster mit Rahmen aus Beton, Stahl und Aluminium sowie wärmegedämmten Metallprofilen, die nicht in die Rahmenmaterialgruppen 2.1 bis 2.3 eingestuft werden können, ohne besonderen Nachweis.

3) Bei Verglasungen mit einem Rahmenanteil ≤ 15% dürfen in der Rahmenmaterialgruppe 3 (Spalte 7, ausgenommen Zeile 1.1) die k_F-Werte um 0,5 W/(m² · K) herabgesetzt werden.

–16 R5 9.90

Figure 38: Windows' datasheet

Our group was "gruppe 2.1: Fenster mit Rahmen aus wärmegedämmten Metall-oder Betonprofilen, wenn der Wärmedurchgangskoeffizient des Rahmens mit 2,0< k_R ≤ 2,8 W/(m^{2}K) aufgrund von Prüfzeugnissen nachgewiesen worden ist (siehe Abschnitt 1 mit FuBnote 2)."

That means, these values were for window frames made of insulated metal or concrete sections and in the case where the heat transfer of the frame was 2,0< k_R ≤ 2,8 W/(m^{2}K), this was detected on the basis of test certificates (see section 1 with footnote2).

There the value U of the window is given straightway U= 2,7 W/m^{2}K, and so I didn't take into account the values of the table that I mentioned above.

Thermal transmittance results:

The thermal transmittance values for different parts of the surrounding area are the next ones:

- Roof

  Thermal Resistance:

Material	Thickness plan (cm)	Thickness Reality (m)	Conductivity (W/mK)	Thermal Resistance (m2K/W)
Stones	1,4	0,07	3	0,023
Slab elastomer	0,4	0,02	0,09	0,222
Celular glass	1,2	0,06	0,041	1,463
Beton wit	2	0,1	0,38	0,263
			U (W/m2k)	0,473

Figure 39: Roof's thermal resistance

- Ground

  Thermal Resistance:

Material	Thickness plan (cm)	Thickness Reality (m)	Conductivity (W/mK)	Thermal Resistance (m2K/W)
Hollow core slabs	2,8	0,14	0,9	0,156
Slab elastomer	0,2	0,01	0,09	0,222
Concrete	2,8	0,14	0,38	0,368
			[illegible]	[illegible]

Figure 40: Ground's thermal resistance

- Surrounding walls

  Thermal Resistance:

Material	Thickness plan (cm)	Thickness Reality (m)	Conductivity (W/mK)	Thermal Resistance (m2K/W)
Modular brick	1,8	0,09	0,8	1,186
Sandwich panel	0,7	0,035	0,022	1,591
Wool	1,6	0,08	0,07	0,537
Modular brick	3,7	0,185	0,45	0,529
Slab elastomer	0,2	0,01	0,09	0,222
			U (W/m2k)	0,236

Figure 41: Surrounding walls' thermal resistance

- Windows and Glasses

  Thermal Resistance: 2,7 W /m^2K

Surrounding area

In order to calculate the value of the area where the heat is lost, I used the buildings' designs that Mr. Roger Vrancken provided me.

Mr. Mikel Vergara wasn't able to continue with his part of the project because he was waiting for some data. Therefore, he helped me and calculated the total area of glass surface and the total area of windows' surface. I calculated the total surrounding area of the building.

There is a future project where PXL-Tech will probably be got bigger. I didn't take into account this project. So, all my calculations are based on the current situation of the building.

Surrounding area result

- Roof: 4563,598 m^2
- Ground: 4563,598 m^2
- Surrounding walls: 3437, 526 m^2
- Windows and Glasses: 1519,605 m^2

Transmission heat losses result

Table 5: Transmission heat losses result

HEAT LOSSES	WINTER	SUMMER
WALLS	12716,81938	2570,420939
ROOF	33850,39439	6842,100994
GROUND	71091,78938	31295,55482
GLASS AND WINDOWS	64279,2915	12992,62275
TOTAL LOSSES (W)	181938,2947	53700,6995

Infiltration heat losses

It is when air gets in the building from little holes that are throughout the building, for instance, in roofs, windows or walls.

To calculate the infiltration value I used the next equation (equation 11):

Equation 11: Infiltration heat losses

$$\dot{Q}inf = \rho \, Cp \, \dot{V}(Ti - To)$$

ρ: Air density (kg/m^3)

Cp: Specific heat capacity of air (J/kgºC)

$\dot{V}$: Ventilation volumetric air flow (m^3/s)

Ti: Temperature inside the building and To: Temperature outside the building.

Ventilation volumetric air flow

To calculate the ventilation volumetric air flow (m^3/s) I checked University of the Basque Country (UPV/EHU)'s documents, in particular, the information of the subject called Energy Efficiency. There appear different methods to calculate the ventilation volumetric air flow and I chose the "Air change method".

Equation 12: Ventilation volumetric air flow (m^3/s)

$$\dot{V} = \frac{ACH \, V}{3600}$$

ACH: Air Changes per Hour, V: Volume of the building (m^3)

Basing on the information of this method and as our building is around twenty years old, I decided at first to take this value:

$ACH = 0{,}2$ new/hour

Nevertheless, I consulted this value with my tutors and Mr. Jorn Vanherck, and we decided to make a blower door test to obtain a real value.

These measurements are based on the next. Firstly, the blower-door fan is temporarily sealed into an exterior doorway using the door-panel system.

Secondly, all the exterior doors and windows have to be closed and all the interior doors and windows have to be opened.

Thirdly, all the wholes of the doors and windows have to be closed using zeal, for instance. Consequently, a closed area is obtained.

Figure 42: Example of an exterior door

As we can see in the figure 42, it is ensured that the door is properly closed using zeal in order to not let air go through little gaps that exist on the top, bottom and middle of the door.

After all the measurements, the machine starts working and it measures the pressure inside and outside the building and basing on that, gives the air values' results.

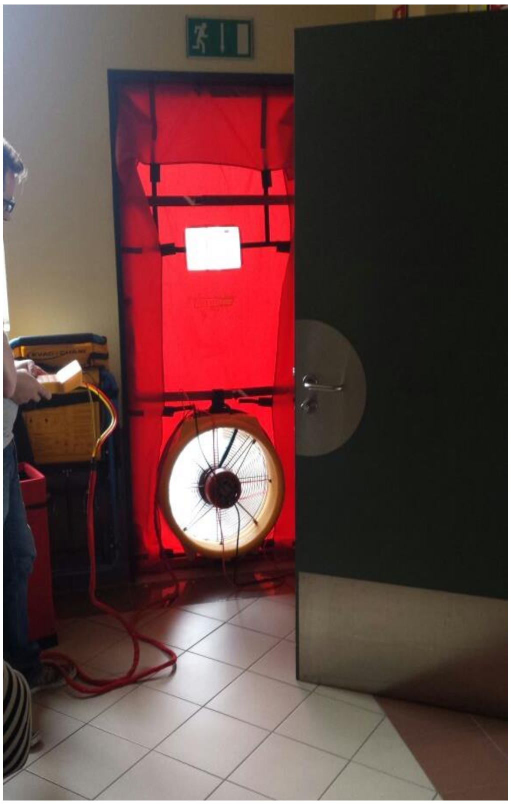


Figure 43: Illustration of our measurements

In the middle of the picture 43, we can see the blower-door fan. In the right part an interior door is shown. Thus, it is opened.

In our case, it would be very expensive to make this kind of calculations for the whole building. As a result, we made the calculations for the E and F building in each floor and after that, we extrapolate the results that we reached. We made each measurement twice. The difference between them was just the orientation of the machine. In this way we were able to compare both results and see if the data we obtained were reliable.

$$\dot{V} = 5{,}5 \frac{m^3}{(h * m^2)} x\ 3\ x\ 4563{,}598\ \mathrm{m}^2\ (\mathrm{roof}'s\ area) = 20{,}916\ \frac{m^3}{s}$$

Air density (kg/m^3) and specific heat capacity of air (J/kgºC)

I have taken into account the standard values:

$$\rho = 1{,}2\ kg/m^3$$
$$Cp = 1000\ J/kgK$$

Infiltration heat losses results

Table 6: Infiltration heat losses result

INFILTRATION HEAT LOSSES	WINTER	SUMMER
(W)	393313,6936	79566,33113

Ventilation heat losses

This happens when the windows or doors, for example, are opened in order to get fresh air in the building. Ventilation is necessary in a building. Nonetheless, it has the negative effect that doing it, we will loss energy.

To calculate the ventilation losses I am going to use the next equation 13:

Equation 13: Ventilation heat losses

$$\dot{\mathrm{Q}}\mathrm{vent} = \rho\ \mathrm{Cp}\ \dot{\mathrm{V}}(\mathrm{Ti} - \mathrm{To})$$

ρ: Air density (kg/m^3)

Cp: Specific heat capacity of air (J/kgºC)

$\dot{V}$: Ventilation volumetric air flow (m^3/s)

Ti: Temperature inside the building and To: Temperature outside the building.

As you probably realise, this formula is the same as the one that I used to calculate the infiltration losses. The difference between them is the ventilation volumetric air flow.

Ventilation volumetric air flow

Equation 14: Ventilation volumetric air flow (m^3/s)

$$\dot{V} = \frac{ACH\ V}{3600}$$

So as to decide the air values for ventilation, firstly, I consulted Spanish Government's regulations.

[23]

In the Spanish regulation about thermal installations in buildings, there appears that university buildings are part of the group IDA 2. We can see it in the next figure 44.

IT 1.1.4.2.2. Categorías de calidad del aire interior en función del uso de los edificios

En función del uso del edificio o local, la categoría de calidad del aire interior (IDA) que se deberá alcanzar será, como mínimo, la siguiente:

IDA 1 (aire de óptima calidad): hospitales, clínicas, laboratorios y guarderías.

IDA 2 (aire de buena calidad): oficinas, residencias (locales comunes de hoteles y similares, residencias de ancianos y de estudiantes), salas de lectura, museos, salas de tribunales, aulas de enseñanza y asimilables y piscinas.

IDA 3 (aire de calidad media): edificios comerciales, cines, teatros, salones de actos, habitaciones de hoteles y similares, restaurantes, cafeterías, bares, salas de fiestas, gimnasios, locales para el deporte (salvo piscinas) y salas de ordenadores.

Figure 44: Explanation for IDA

Tabla 1.4.2.1 Caudales de aire exterior, en dm³/s por persona	
Categoría	dm³/s por persona
IDA 1	20
IDA 2	12,5
IDA 3	8
IDA 4	5

Figure 45: Minimum outside air quantity per person for ventilation Spain

The values from figure 45 are taken from the Spanish government

However, as our building is in Belgium I took into account standard values, which are the next:

Categorie	Eenheid	Niveau van buitenlucht per persoon			
		Niet-rokers zone		Rokers zone	
		Typische waarde	Standaard waarde	Typische waarde	Standaard waarde
IDA 1	m³/h.persoon	>54	73	>108	144
	l/s.persoon	>15	20	>30	40
IDA 2	m³/h.persoon	36 – 54	45	72 – 108	90
	l/s.persoon	10 – 15	12,5	20 – 30	25
IDA 3	m³/h.persoon	22 – 36	29	43 – 72	58
	l/s.persoon	6 – 10	8	12 – 20	16
IDA 4	m³/h.persoon	<22	18	<43	36
	l/s.persoon	<6	5	<12	10

Tabel 7.11. **Hoeveelheid buitenlucht per persoon**

Figure 46: Minimum outside air quantity per person for ventilation Belgium

This table (see figure 46) is used in the subject 3 Klima: Ventilatietechnieken en luchtbehandeling 2 – 7. Niet-residentiële ventilatie PXL-Tech – Lecturer: Mr. Andy Camps [24]"

If we take into account figure 44, figure 45 and figure 46, it is clear that data from Mr. Camps and data from the Spanish Government are the same. Both are based on EN 13779.

We can see the difference between countries there, because in Spain the minimum air value for classrooms was IDA2 36 m^3/hperson but as Mr. Camps told me, in Belgium the value was 22 m^3/hperson, IDA3.

Nevertheless, I followed the method that Mr. Camps used in his subject called "Ventilatietechnieken en Luchtbehandeling 2" [24]"and in his book, as well.

The algorithm that I had to follow with rooms where it is expected people to be there for long periods was the next:

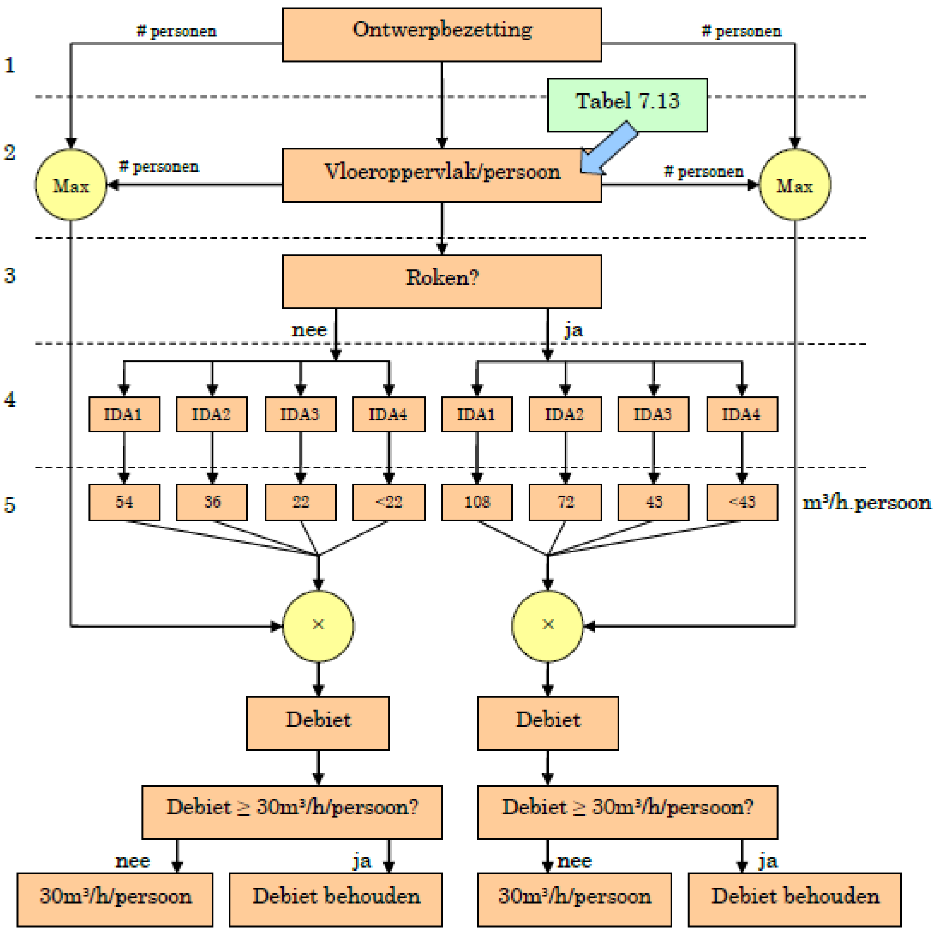


Figure 47: Algorithm for common rooms

This flow-chart (figure 47) shows the succession of operations in the process of choosing the correct air value for each room.

Onderwijsinstellingen	
leslokalen	4
polyvalente zaal	1

Figure 48: Floor's area per person (m^2 / person)

To start with,

1. Ontwerpbezetting was the number of chairs. It represents the quantity of people. This was the approximation that Mr. Camps recommended me to do.
2. Vloeroppervlak/persoon was the value that we took from the picture 48. I had to divide our room's area with the value of the table, in this way I was able to obtain the number of person.

Then, I compared 1, 2 values that I mentioned above, and I chose between them the biggest quantity.

After that, I multiplied the value I chose with 22 m^3/h person. This was the "debiet".

In our classrooms and laboratories are teachers and students, so they are working areas. In conclusion, I had to follow the last step of comparison between Debiet and 30m^3/h person. The same happened with the canteen and the offices.

I had to compare:

A. The number of chairs (Ontwerpbezetting) multiplied by 30 m^3/h person.
B. The Debiet that I had obtained.

If B was bigger than A, (B>A); I had to take into account B. If not, I had to choose A.

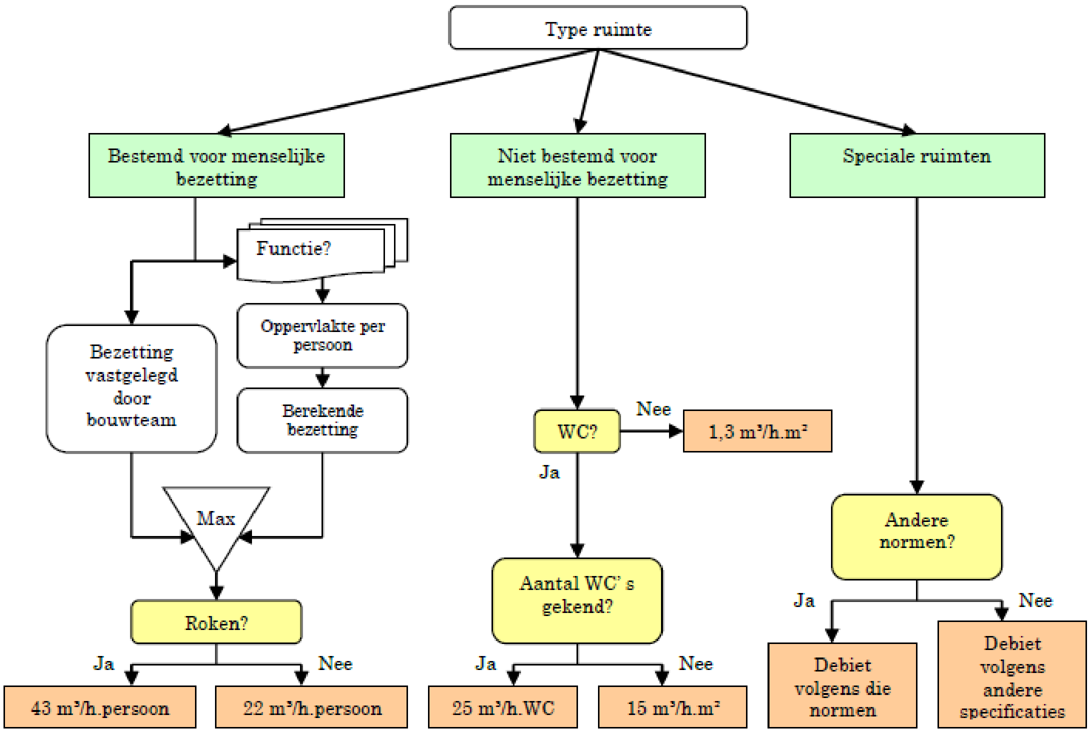


Figure 49: Algorithms for all kind of rooms

In the figure 49 we can see the different ways that I had to follow for the ventilation air value calculations of common rooms, rooms not designed for long human occupation and special rooms.

In case of the rooms where people are not there for a long time, I had to follow the second column of the picture 49. Special rooms where particular characteristics should be kept, I should have followed the third column. Nonetheless, I didn't know their special air values. I consulted with Mr. Camps and he suggested me to consult it with Mr. Roger. After discussing the topic with him, he claimed me to take some of this kind of rooms as current ones (if they are designed for human occupancy) and to not take into account if it is not expected that people will be there for long periods, for instance, the storage areas.

Once I understood what data I needed to obtain my results, I started collecting information. First of all, I had to know all areas of all rooms of the University College. For that, Mr Roger provided me the designs of all the rooms of all the floors of the PXL-Tech.

After knowing these values, I decided for each of them which column I had to follow so as to get the results that I needed.

I had to do a lot of calculations and so, basing on my previous knowledge of the software MATLAB, I decided that the best option would be to create a file there, which was able to give me the values that I was looking for just entering the data.

KIND OF AREAS IN THE BUILDING	0 FLOOR (m2)		Ventilation value	Number of chairs
Restaurant	542,29	Restaurant	1,5 m2/person	352

Figure 50: Example of a room of the building

I followed the same procedure with all the rooms. Therefore, I created a file in Matlab. I inserted all the data that I needed for my calculations there and in this way, I obtained straightway the results.

```
disp ('Welcome.')
disp('Choose the type of the room that you want to do the calculations for from the next list:')
disp('1 if it is intended for human occupancy (e.g. classrooms, common laboratories, restaurant, kitchen, common storages, offices etc.')
disp('2 if it is a corridor, hall or WC')
disp('3 if it is a special room where special components are used (e.g. chemical products)')
disp ('4 if you want to end the programme')
aukera=input('Insert your choice: ');
```

Figure 51: Main menu

In the figure 51, it is shown the main menu of the file I built in MATLAB, in order to follow the algorithms and obtain the results easier.

The whole document that I created is attached in the final part of the Research Paper, see attachment 1.

Ventilation volumetric air flow result

The results that I got are the next:

0 FLOOR	10,35	
1 FLOOR	9,12	
2 FLOOR	8,22	
	27,69	m3 /s

Figure 52: Air value results

Ventilation heat losses results

TOTAL VENTILATION LOSSES W	
520572	WINTER (W)
105222	SUMMER (W)

Figure 53: Ventilation heat losses results

3.3.2. Heat losses results

TOTAL LOSSES WINTER	1095,823988	1095823,988	WINTER (W)
TOTAL LOSSES SUMMER	238,4890306	238489,031	SUMMER (W)

Figure 54: Total heat losses results

3.3.3. Heat gains

Every building has heat gains due to sun irradiation that arrives to the building, the human presence and the use of electrical machines and lightning system. These all factors are better shown in the picture 55 below.

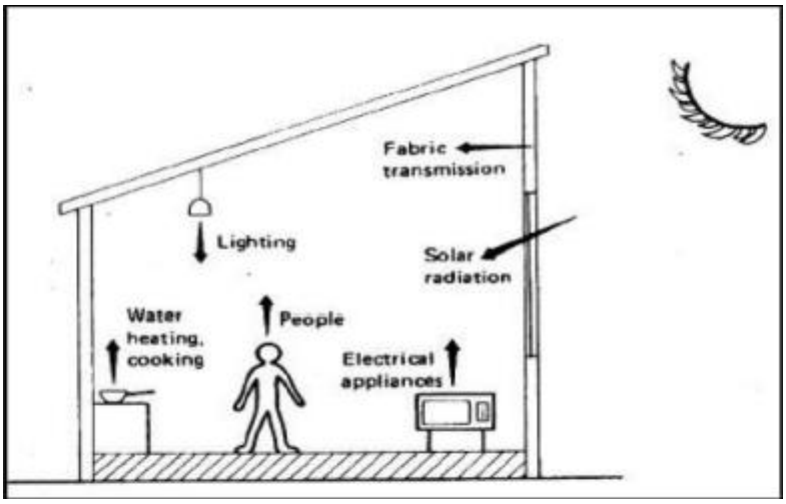


Figure 55: Heat gains explanation

Sun gains

Equation 15: General equation to calculate sun gains

$$Qs = \sum_j Q_{S_J} = \sum_j I_{S_J} \sum_j A_{Sn_J}$$

I_{S_J}: Irradiation that arrives to the building with j orientation.

A_{Sn_J}: Area of the building which is orientated in j direction and is able to catch sun energy.

Likewise, to calculate the sun gains, I divided the year in two different parts:

- Winter
- Summer

In summer, I had to take into account the sun gains through the walls and the sun gains through the glasses and windows.

In winter, I had to take into consideration only glass and windows gains, due to the fact that the gains through the walls are very little because the irradiance is not strong enough.

From October-March I followed the equation 16:

Equation 16: Total heat gains of the building in Summer

$$Qgains = Qwalls + Qglass + Qwindows$$

From April-September the equation 17 was used:

Equation 17: Total heat gains of the building in Winter

$$Qgains = Qglass + Qwindows$$

In case of the walls, to calculate the heat gains due to sun, the next formula is used equation 18:

Equation 18: Heat gains through the walls

$$Qgainswall = \propto A\, I\, \frac{U}{ho}$$

Alfa (∝) is the transmission coefficient of the wall, ho is the convection coefficient between the walls and the air, and U is the thermal transmittance of the wall. A and I are the same from the formula before.

From October-March the total heat gains are shown in the equation 19:

Equation 19: Total heat gains of the building in Winter

$$\begin{aligned}\dot{Q}gains = \dot{Q}walls + \dot{Q}glasswindows \\ = \dot{Q}wallsNorth + \dot{Q}wallsEast + \dot{Q}wallsWest + \dot{Q}wallsSouth \\ + \dot{Q}glasswindowsNorth + \dot{Q}glasswindowsWest \\ + \dot{Q}glasswindowsEast + \dot{Q}glasswindowsSouth\end{aligned}$$

From April-September the total heat gains are displayed in the equation 20:

Equation 20: Total heat gains of the building in Summer

$$\begin{aligned}Qgain = Qglasswindows = \\ QglasswindowsNorth + QglasswindowsWest + QglasswindowsEast + \\ QglasswindowsSouth\end{aligned}$$

Calculation of area

Glasses

In case of the glass and windows, as they are sheer materials, I had to calculate the area using the equation 21:

Equation 21: The area of the building that has j orientation

$$As = A\, Fw\, g$$

The parameter g is the transmission coefficient of the material. Fw is the factor of the window, that is, which is the amount of real glass, taking into account the amount of the whole physical window. To calculated this factor, the equation 22 was followed

Equation 22: Window factor

$$Fw = \frac{Area\ glass}{Area\ window}$$

To calculate it, Mr Roger provided me another designs of the windows. The results, see figure 56:

f factor calculation	TYPE 1	0,894825688
	TYPE 1 STUK	0,738765071
	TYPE 2 STUK	0,774418605
	TYPE 3 1 STUK	0,799751553
	TYPE 4 8 STUK	0,791455577
	TYPE 4 1 STUK	0,763864161
	TYPE 5 1 STUK	0,787652174
	NIEUWE LICHTSTRAT	0,824630542
	AVERAGE VALUE	0,796920421

Figure 56: Results of the windows' f factor

After consulting with Mr. Jorn Vanherck, I took the value of 0.7 as transmission coefficient (g) of the glasses and windows.

The area of the windows was more or less the same as I used in transmission losses. Nevertheless, because of the position of some windows, they will receive an amount of irradiation from more than one orientation or less. I have taken into account this factor (see figure 57).

ORIENTATION	AREA OF THE WINDOWS (M2)	f	g absortivity of the windows
North	341,369	0,796920421	0,7
East	487,4945	0,796920421	0,7
South	282,48	0,796920421	0,7
West	652,18	0,796920421	0,7
Roof	0	0,796920421	0,7
Ground	0	0,796920421	0,7

Figure 57: Results of Windows' area, f factor, and absorptivity

Walls

The area of the walls was the next (see table 7):

Table 7: Area of the walls

Wall orientation	Area of the wall m^2
North	1422,425
East	1530,293
South	1106,37
West	1576,813
Roof	4563,598
Floor	4563,598

Because of the position of some walls, some of them will receive an amount of irradiation from more than one orientation or less. I have taken into account this factor.

Calculation of irradiation

To calculate the irradiance values depending on the orientation, I used the next webpage: [1]

There I inserted our building’s position:

Latitude: 50.9277679º and Longitude: 5.384941º.

I was only able to obtain monthly average values for each orientation. And so, I inserted all the information in an excel file, and an average irradiation value for each period of the year (summer and winter) was calculated. Likewise, was done with each orientation.

The irradiance average values depending on the orientation of the roof are the next ones:

Table 8: Irradiance value for each wall

Wall orientation	Inclination	Orientation	Value W/m^2
North	90º	180º	57,01317
East	90º	-90º	115,37146
South	90º	0º	168,81927
West	90º	90º	115,52228
Roof	0º	0º	224,33419
Floor	0º	0º	0

Sun gains results

TOTAL SUN GAINS	
WINTER (W)	SUMMER (W)
79505,19604	209259,8409

Figure 58: Sun gains results

Human gains

These are the gains that are caused due to human presence in the building. The equation 23 was used for its calculation.

Equation 23: Human gains

$$\dot{Q}pers = N\dot{P} = N\ x\ Power\ x\ \frac{duration\ of\ the\ usage\ in\ the\ period}{total\ duration\ of\ the\ period}$$

N: Number of people in the building
P: The power that each person releases

Human quantity

I have taken into account the next data my tutor Mr. Gwen Vanheusden provided me. There were 90 college lecturers and 836 students in the PXL-Tech building maximum. Besides, I checked the PXL-Tech academic calendar and timetables in order to know more about the hours that students spend in the building (see table 9).

Table 9: Human presence’s period

PERIOD	LECTURES	EXAMS
WINTER	19 weeks	3 weeks
SUMMER	9 weeks	3 weeks

I discussed this topic with my other tutor Win Vandormael, too; and finally, I made the next hypothesis:

I took into account that 2/3 of the whole amount of the students came to class every day from 8 to 15:30. At the same time, %20 students are still in class every day from 15:30 to 17:45

Apart from that, 2/3 of the whole amount of the teachers came to class from 8 to 15:30 and %20 of them were still in class from 15:30 to 17:45.

In exam periods, I considered that students take in average 3 exams per week and they are for 3 hours in the building per each exam and teachers spend 12 hours per week in the building.

In case of Kitchen and maintenance employees, I took that they are 10 people. I supposed that they spent 8 hours in the building every day and that in exam period they didn't come to the building (it is not that crowded or it is closed).

Power quantity

In order to choose the power that each produces I based my calculations in the next table (see figure 59). It is taken from "Energia Geotermikoa" University of the Basque Country Professor: Mr Aitor Urresti.

Rates of Heat Gain from Occupants of Conditioned Spaces - ISO 7730

No.	Degree of Activity	Typical Application	Total Heat Adjusted		Sensible Heat		Latent Heat	
			Watts	Btu/h	Watts	Btu/h	Watts	Btu/h
01	Seated at rest	Theatre, Movie	100	350	60	210	40	140
02	Seated, very light writing	Office, Hotels, Apts	120	420	65	230	55	190
03	Seated, eating	Restaurant	170	580	75	255	95	325
04	Seated, light work, typing	Office, Hotels, Apts	150	510	75	255	75	255
05	Standing, light work or working slowly	Retail Store, Bank	185	640	90	315	95	325
06	light bench work	Factory	230	780	100	345	130	435
07	walking 1,3 m/s (3 mph) light machine work	Factory	305	1040	100	345	205	695
08	Bowling	Bowling Alley	280	960	100	345	180	615
09	moderate dancing	Dance Hall	375	1280	120	405	255	875
10	Heavy work, lifting Heavy machine work	Factory	470	1600	165	565	300	1035
11	Heavy work, athletics	Gymnasium	525	1800	185	635	340	1165

OK Cancel

Figure 59: Rated of Heat Gains from Occupants of Conditioned Spaces

All these people that I mentioned above were all these hours standing, doing light work or working slowly.

Apart from that, I took into account that there were always around 5 people seated and taking rest.

Human gains results

After that, the values that I obtained had been divided by the total hours of each period (see figure 60).

3 weeks of exams in winter								
EXAMEN WEEK								
Kind of people		Percentage	Number of people	Degree of Activity	Power (W)	Duration (h)	Total energy gains (Wh)	Total W
Kitchen closed								
Students around 3 hours (wait, do the exam and me	836	1	836	Seated, light work	150	27	3385800	775,1373626
Teachers around 12 hours per week	90	1	90	Seated, light work	150	36	486000	111,2637363

Figure 60: Example of human gains calculations

The total results are the next:

17754,01213	**TOTAL HUMAN GAINS WINTER W**
8827,817623	**TOTAL HUMAN GAINS SUMMER W**

Figure 61: Total human gains' results

Electrical machine's gains

In order to be able to calculate these gains, I followed the next equation 24:

Equation 24: Electrical machine's gains

$$\dot{Q}electricalmachines = N\ x\ Power\ x\ \frac{duration\ of\ the\ usage\ in\ the\ period}{total\ duration\ of\ the\ period}$$

N: Number of electrical devices

P: Electrical device's power

I found some data in the next webpage [25].

In case of fluorescence lamps, a factor of 1,25 had to be multiplied because due to its characteristics they transmit more heat (see equation 25).

Equation 25: Special case, fluorescent lamps gains

$$\dot{Q}electricalmachines = 1{,}25\ x\ N\ x\ Power\ x\ \frac{duration\ of\ the\ usage\ in\ the\ period}{total\ duration\ of\ the\ period}$$

Therefore, so as to do all the calculations, I have checked room by room the electrical items that are in the building. I was not able to check some rooms, such as the offices. And so, I took an area's light amount and I extrapolate this value for all the rooms that I had no access basing on the value of their area.

Electrical machine's gains results

206524,9253	108648,4251
TOTAL GAINS WINTER W	TOTAL GAINS SUMMER W

Figure 62: Gains due to electrical devices

3.3.4. Gains results

TOTAL GAINS	W
WINTER	303784,1334
SUMMER	424612,5838

Figure 63: Total gains

3.4. Heat gains and heat losses balance results

The energy balance that I have obtained is the next:

Winter: 792,3439414 kW Heating needs

Summer: -185,8194666 kW Cooling needs. The minus value refers to the direction of the heat flow.

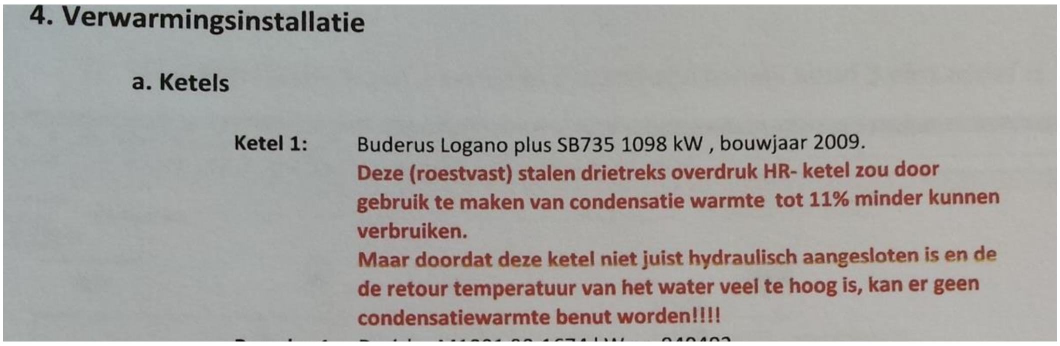
The biggest absolute value was that from winter, so I focused on it in order to know our heat pumps power.

In summer, without taking into account the heat gains; that means, the worst case, the heating needs were the next:

1095823,988 WINTER (W)

So as to know, if the value that I have obtained was right or not, I have consulted with Mr Roger the current power capacity of the heat system.

I have had the chance to consult the book "PXL Gebouw H" written by Richard Ectors.



4. Verwarmingsinstallatie

a. Ketels

Ketel 1: Buderus Logano plus SB735 1098 kW , bouwjaar 2009.
Deze (roestvast) stalen drietreks overdruk HR- ketel zou door gebruik te maken van condensatie warmte tot 11% minder kunnen verbruiken.
Maar doordat deze ketel niet juist hydraulisch aangesloten is en de de retour temperatuur van het water veel te hoog is, kan er geen condensatiewarmte benut worden!!!!

Figure 64: PXL Gebouw H book's part of the information

There appears that there are 3 kettles, but one of them is the one who is working most of the time. Its capacity is 1098kW, and so, almost the same as the value that I have obtained. Moreover, this power was also to fulfill the warm water of the kitchen and my calculations were done for the worst case.

In consequence, I concluded that my value was correct.

I over dimensioned this value in order to ensure that the system will be able to face extraordinary situations, too.

$1095823{,}988 \ \mathrm{x} \ \frac{100}{80}$ = 1369,779 kW for heating

For cooling, the worst case will be the one that we have seen before; due to the fact that, we almost always will have ventilation, infiltration and conductivity movements. The worst case will be taking into account all the gains, and this is the case which I have analysed before. So, the value for cooling is:

Summer: -185,8194666 kW Cooling needs

I over dimensioned this value, too for the same reasons:

$185{,}8194666 \ \mathrm{x} \ \frac{100}{80} = 232{,}26$ kW cooling needs

3.5. Choose the heat pump

When choosing the Heat Pump I have to answer the next questions:

- Where I want to install it?
- Which is the power that our Heat Pump must have?

I will have to bear in mind that the heat pump will must suit in the available area. Apart from that I will have to consider the price, as well as, its efficiency. In case of the efficiency, I will only focus on COP, due to the fact that our building's cooling needs are much lower that the heating needs. The best heat pump will be the one that has the highest efficiency, the lowest price and the highest warranty.

Once I knew the values that my geothermal system must fulfill, I started looking for information about heat pumps and collecting data.

There were different options for our installation which I want to cut in short in three main groups:

- Install only one heat pump which is powerful enough.
- Install different heat pumps.
- Install a lot of different "little" heat pumps.

I realized that the first one is not very suitable for our building, due to the fact that, the heat pump would work most of the time under its total capacity. Besides, the whole system would depend on just one heat pump and if there were any problem with it, there wouldn't be possible to heat PXL-Tech, neither a bit nor completely. The investment also would have to be done at once.

Related to the third choice, the negative parts are that we would need more maintenance for our system, owing to having more machines. Moreover, there would be needed more space and to make them work together successfully would be more difficult. The control system and the installation would be more complicated. The investment would be able to be done little by little.

Therefore, I chose the middle option. I checked different suppliers' websites [26] , [27] [28], [29], [30], [31], [32] , [33] , [34], [35], [36], [37] , [38], [39] and [40] and I arrive to the conclusion that there is a huge offer among heat pumps which are below 500kW, but not above 500 kW. I sent a lot of messages to suppliers, too; but after analyzing the data that I obtained, I concluded that their capacity was below the needs of the system or some other cases, I haven't received answers. I would like to get more information and so, I asked for help to my tutors and also, to Mr. Chris Hendrickx, but I wasn't provided with any further information about heat pumps. I consulted also to my home-universities' lecturer, Mr. Aitor Urresti, and he advised me that there is no a big offer in the industry with these specifications.

As a result, I chose the next systems:

Table 10: Main heat pump's choices for our installations

BRAND	MODEL	HEATING CAPACITY	COP (EN 14511)	COOLING CAPACITY	EER (EN 14511)	PRICE	WARRANTY
Danish Renewable Energy	NGH1200BT2 NGH130BT2 NGH50BT2	1200 kW 130 Kw 50Kw Total: 1380kW	5,62 5 5,25	924 kW 79 kW 50 kW	4,7 4,2 4,2	269.487,00 € 41.906,00 € 21.990,00 € **TOTAL PRICE: 333.383,00 €**	2 years, life time of 20 years without problems. Possibility to make it longer 3, 4, 5 or 10 years with charges.
Danish Renewable Energy	NGH500BTM2 (x2) NGH280BT2 NGH130BT2	500 kW (x2) 280 kW 80 kW 15 kW Total: 1375 kW	5,125 4,625 5,25 5	446 kW (x2) 250 kW 78 kW 15 kW 1235 kW	4,2 3,85 4,2 4,4	139.900,00 € (x2) 82.199,00 € 28.209,00 € 15.990,00 € **TOTAL PRICE: 406.198,00 €**	2 years, life time of 20 years without problems. Possibility to make it longer 3, 4, 5 or 10 years with charges

Available area for the heat pump would be in the "Stookplats". There are the current kettles, in an area of 80, 6 m2. The kettles themselves take around a quarter of the room.

Figure 65: Current kettles

There are next to it the control system of the temperature and heating flow, so it would be perfect to place the heat pumps there.

Figure 66: Part of the control system

Therefore, the available area would be around 20,15 m^2. It could be a good option to replace the kettles with the heat pumps.

3.6. Choose of heat pump result

Basing on the data I analysed, I chose the second choice.

Danish Renewable Energy: two of NGH500BTM2, one of NGH280BT2 and one of NGH130BT2. We would have 1375 kW for heating and 1235 kW for cooling. The total price of the machines would be 406.198,00 € and we would have a warranty of 2 years, life time of 20 years without problems. There would be a possibility to make it longer 3, 4, 5 or 10 years with charges.

The main reason for choosing these pumps is that the installation would be more flexible. It would be safer and more reliable, because the building would have two different machines to provide 1000kW and as I mentioned above, it is essential for the cases where the machine is broken or some maintenance work are needed. Moreover, the investment could be done little by little in different steps. The price is reasonable, is among the values of other supplier, as I found doing the primary research.

Revision 09-01-2015

DANISH RENEWABLE ENERGY

Technical data:

Reversible brine to water or water to water heat pumps for heating / cooling / domestic hotwater	15kW	30kW	50kW	80kW	130kW	280kW	500KW	1200kW
Model / Type	NGH15BTM2	NGH30BT2	NGH50BT2	NGH80BT2	NGH130BT2	NGH280BT2	NGH500BTM2	NGH1200BT2
	Plug & Play!							
Colour of cabinet: b=blue w=white	b/w	w	w	w	w	w	w	w
Max. flow temperature heating	55 °C	55 °C	55 °C	55 °C	55 °C	55 °C	55 °C	75 °C
Min. flow temperature cooling	7 °C	7 °C	7 °C	7 °C	7 °C	7 °C	7 °C	7 °C
Operating temperatures of the heat source	-5 ... 25 °C	-5 ... 25 °C	-5 ... 25 °C	-5 ... 25 °C	-5 ... 25 °C	-5 ... 25 °C	-5 ... 25 °C	-5 ... 25 °C
Operating temperatures of the heat sink	10°... 40 °C	10°... 40 °C	10°... 40 °C	10°... 40 °C	10°... 40 °C	10°... 40 °C	10°... 40 °C	10°... 40 °C
Temperature spread of heating water (return flow)	6 K	5 K	5 K	5 K	5 K	5 K	5 K	15 K
Temperature spread of cooling water (return flow)	5 K	5 K	5 K	5 K	5 K	5 K	5 K	5 K
Heating capacity B0/W35 / COP B0/W35*	14 kW / 4,0	27 kW / 3,9	46 kW / 4,2	72 kW / 4,2	132 kW / 4,0	231 kW / 3,7	423 kW / 4,1	1056 KW / 4,5
Heating capacity B0/W65 / COP B0/W65***	-	-	-	-	-	-	-	1032 kW / 2,8
Heating capacity W10/W45 / COP W10/W45	17,5 kW / 4,2	34,5 kW / 3,8	58 kW / 3,9	90 kW / 4,0	165 kW / 4,0	320 kW / 4,02	536 kW / 4,1	1226 kW / 4,9
Power consumption at B0/W35*	3,5 kW	6,4 kW	11,0 kW	17,2 kW	32,8 kW	62,4 kW	103 kW	234 kW
Parallel DHW capacity in heating mode	-	-	-	-	79,6 kW	31,3 kW	128 kW	-
Recovery heat capacity in cooling mode HW55°C	-	-	-	-	76,7 kW	-	125 kW	-
DHW output W10/W55 / COP W10/W55	16,2 kW / 3,2	14 kW / 3,2	27 kW / 3,2	40 kW / 3,1	78 kW / 3,2	74 kW / 3,0	120 kW / 3,2	-
Cooling output B20/W9 / EER B20/W9*	18,1 kW / 7,5	33 kW / 5,9	57 kW / 6,3	88 kW / 6,0	89 kW / 6,0	304 kW / 5,8	548 kW / 6,4	1128 kW / 7,3
Cooling capacity W30/W18 / EER W30/W18*	21,4 kW / 6,7	40 kW / 6,1	66 kW / 5,7	104 kW / 5,7	105 kW / 5,7	-	666 kW / 5,8	1400 kW / 7,1
Cooling capacity W30/W7 / EER W30/W7*	15 kW / 4,4	26 kW / 4,1	50 kW /4,2	78 kW / 4,2	79 kW / 4,2	250 kW / 3,85	446 kW / 4,2	924 kW / 4,7
Protection mode / Installation I=inside o=outside	IP44 / I	IP21 / I	IP21 / I	IP21 / I	IP21 / I	IP21 / I	IP21 / I	IP21 / I
Sound power level emission acc. to EN 12102	< 40 dB (A)	55 dB (A)	57 dB (A)	60 dB (A)	65 dB (A)	68 dB (A)	68 dB (A)	82 dB (A)
Refrigerant / Amount of refrigerant	R410A / 6,4 kg	R410A / 4,0 kg	R410A / 6,9 kg	R410A / 9,0 kg	R410A / 13,0 kg	R404A / 23,5 + 24 kg	R410A / 42 + 42,5 kg	R134A / 124 + 124 kg
Flow in the heat source (min) / Pressure drop	3,1 m^3/h / 10 kPa	6,3 m^3/h/ 22kPa	10,8 m^3/h/ 27 kPa	16,6m^3/h / 39 kPa	29,1 m^3/h / 40kPa	54,0 m^3/h / 50 kPa	95,0 m^3/h / 83 kPa	144 m^3/h / 50 kPa
Flow in the user side (max) / Pressure drop	2,5 m^3/h / 10 kPa	5,3 m^3/h / 20 kPa	9,1 m^3/h / 17 kPa	13,9 m^3/h / 29 kPa	24,1 m^3/h / 30 kPa	43,0 m^3/h / 40 kPa	78,0 m^3/h / 60 kPa	59,2 m^3/h / 70 kPa****
Flow of DHW	0,34 m^3/h	1,6m^3/h / 7kPa	2,7m^3/h / 8kPa	3,9m^3/h / 9kPa	6,2m^3/h / 4kPa	6,5 m^3/h / 15 kPa	20,6 m^3/h / 40 kPa	-
DHW tank connection	G 1"	G 1"	G 1-1/4"	G 1-1/2"	G 2"	G 1-1/2"	DN100 flange	-
Controller	Siemens	Carel	Carel	Carel	Carel	Carel	Siemens	Carel
Dimensions in mm (W x H x D)**	1392 x 1825 x 786	915 x 1515 x 780	1165 x 1680 x 790	1165 x 1680 x 825	1284 x 1846 x 726	1346 x 1962 x 1220	1519 x 2282 x 1515	-
Weight (transport weight w. empty tanks)	830 kg (480 kg)	360 kg	480 kg	550 kg	850 kg	1550 kg	2800kg	-
Rated voltage, frequency	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz	3/N/PE ~400 V, 50 Hz
Inrush current (A) / Type	64A / Softstart	64A / Softstart	111A / Softstart	158A / Softstart	260A / Softstart	215A / Softstart	408A / Softstart	Star - Delta
Fuse protection	20A	36A	63A	80A	circuit breaker	circuit breaker	circuit breaker	circuit breaker
Connection heating side	G 1-1/4" I	G 1-1/2"	G 1-1/2"	G 2-1/2"	G 3"	G 4-1/8"	DN125 flange	DN125 flange
Connection auxiliary heat sources	G 1-1/4"	-	-	-	-	-	-	-
Connection heat source (brine/water circuit)	G 1 "	G 1 1/2"	G 2"	G 2-1/2"	G 4"	G 4-1/8"	DN125 flange	DN 200 flange

*Heat-, cooling load and rated power figures (COP/EER) according to EN 14511

**Please note, that additional space should be provided for tube connection, operation and service

*** Radiator operation condition

**** Flow at radiator operation condition

DHW = domestic hot water

GROSS PRICE (EUR)	15.990,00 €	18.803,00 €	21.990,00 €	28.209,00 €	41.906,00 €	82.199,00 €	139.900,00 €	269.487,00 €

Figure 67: Datasheets of Danish Renewable Energy's heat pumps

**The values of COP are not the current ones. As Michael Spitzlei from Danish Renewable Energy told me, the COP's are increased roughly by 0,8 because they have optimized the machines for heating. In these tables they are still optimized for cooling.

In addition to this, they could do make the installation. The facts, so far, were not enough to make a qualified offer. Nonetheless, Danish Renewable Energy told me that basing on their experience the project would cost roughly 5,7 Mio €, including installation, radiators and boreholes for the heat pumps. Besides, if there wasn't any need to change the radiators, they would deduct roughly 0,5 Mio €, and so, the installation would cost roundabout 5,3 Mio €.

Apart from that, they also made me an offer for an Energy Management Contract, means PXL-Tech pay just a monthly fee and they take all the investment costs, care for the system for 15 years and after that the college can buy the system for 1€ symbolic. This is their business model. But they do also EPC (Engineering Procurement Construction) as offered above.

Related to the place to fix our heat pumps there would not be any problem to replace them with the current kettles in the available area of 20,15 m^2 that I mentioned before.

The space that the heat pumps would need would be the next of the table 11:

Table 11: Area of the heat pumps

HEAT PUMPS	AREA (m^2)
1 500 W	1,519 x 1,515 = 2,3012
2 500 W	1,519 x 1,515 = 2,3012
3 280 W	1,346 x 1,220 = 1,6421
4 80 W	1,165 x 0,825 = 0,9611
5 15 W	1,392 x 0,786 = 1,0941
TOTAL AREA	**8,2997 m^2**

The height of the current kettles, such as, Buderus Logano plus SB735 is 2 meters, and as we have seen in the figure 65, there is more room available between the top part of the machine and the top of the room. The tallest heat pump's height is 2,282 m. Therefore, I can say that the heat pumps would suit in this room correctly.

The energy need would be most of the time around 1000 kW, therefore, the control system would be designed in the next way. The first heat pump working would be the one with a capacity of 500 W and the last one, the heat pump of 15 kW, this is better explained in the picture 68.

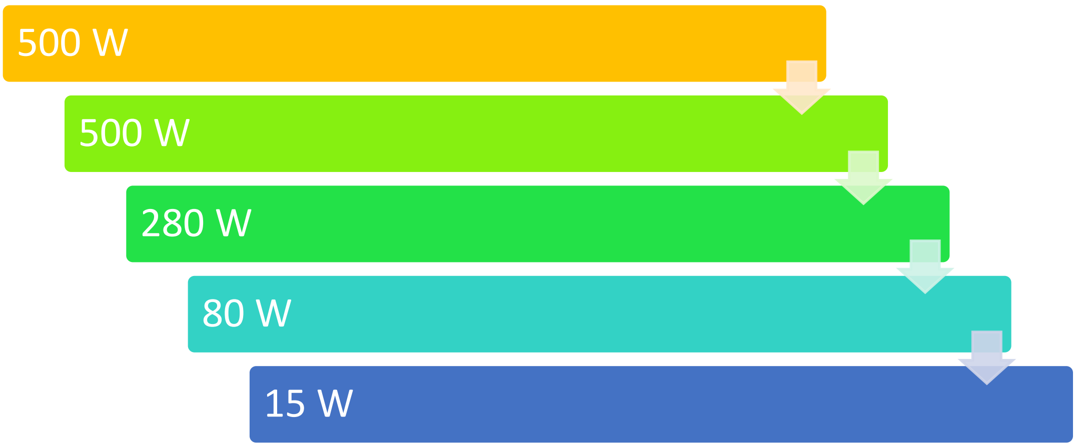


Figure 68: Control system of the heat pumps

3.7. Characteristics of the heat exchanger

In this part of the project I fixed which kind of system would have our geothermal installation in order to catch the heat that is underground and so as to use it to produce energy by the chosen heat pump.

There were different kinds of heat exchangers and I took into account different factors to take a decision.

- Which is our available area for the heat exchanger?
- Which are the characteristics of our heat pump?

Mr. Roger Vrancken explained me how the pipes are installed around the College. There is a big pipe which transports the used water to the river in the available area that Mr. Mikel Vergara calculated. The pipe took around %5 from our area and in consequence, I removed this part from our available area. Apart from this pipe, there were no more pipes in our available area.

So, as I didn´t have to take into consideration the f2 and f3 parts of the amplification project, the available area was the next one:

Available area: 4794, 83 m2 – (4794, 83 m2 x 0, 05) = 4555, 0885 m2

Figure 69: Area for the heat exchangers

In the figure 69 we can see in red, the available area for the heat exchangers. I have to mention that all the calculations we made were based on the supposition that there will be a train road, and so there won´t be the trees that are just in the border of our available area. If it wasn´t the case, we would have to change the available area, it would be littler.

Therefore, there is a huge area that we can take advantage of and it would make easier all the process.

The heat exchanger installation can be:

- Horizontal or vertical. The horizontal installation takes more area, the depth of the underground wholes is around 2-3 meters, maximum around 5meters; and they are commonly for little installations. The vertical ones need less area, the depth is between 80-100 meters in general and they are for big installations.

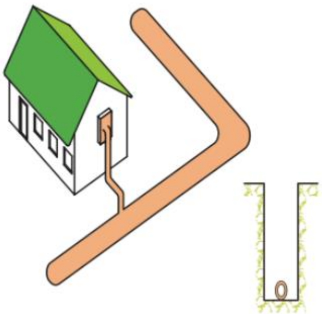


Figure 70: Example of a horizontal heat exchanger installation

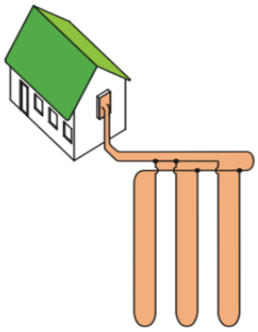


Figure 71: Example of a vertical heat exchanger installation

- Series or parallel.
 In the series installation the flow of the fluid is better specified, the whole amount of fluid does the whole way and so, the diameter is bigger, and there is a better thermal use per length unit. In addition, the purge operation is easier. As the diameter is bigger, the cost of the tubes also, is higher. The pressure losses fix the length of the installation.

 In the case of the parallel installation, the diameter is littler, due to the fact that the flow is divided in the process, but it is more difficult to balance the flow of the fluid and the purge operation is, at the same time, more complicated.

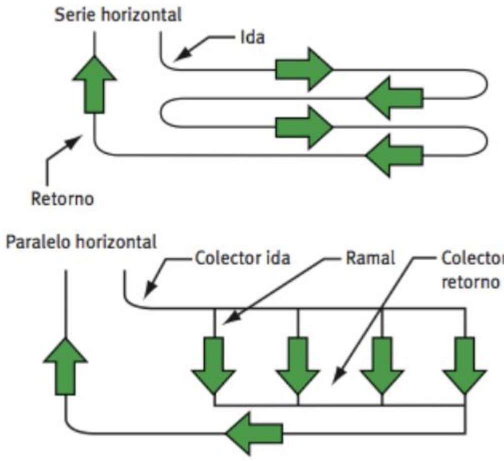


Figure 72: Example of a series and parallels installation (horizontal heat exchangers)

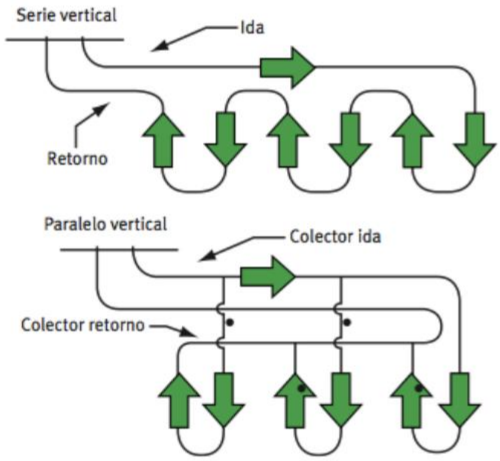


Figure 73: Example of a series and parallels installation (vertical heat exchangers)

Our building's energy needs are huge; as a result, I chose a vertical heat exchanger for our installation. Besides, in the case where there was a want to build more buildings or other installations, there would be still available room for them and our installation would not be affected by future projects. In addition to this, I chose the series option, owing to the points that I mentioned above. We would have a huge installation and so, the parallel option would be hugely complicated. Besides, the thermal use per length is better.

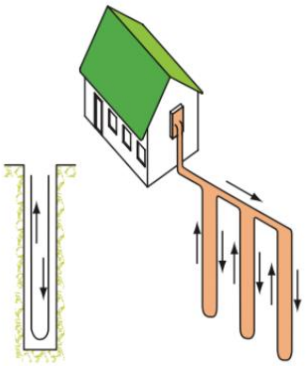


Figure 74: Example of our hypothetical vertical and series system

The materials that are commonly used are the polyethylene and polybutylene pipes. I chose the polyethylene (PEX) pipes, because basing on the information that I obtained in the primary research process, in different articles, such as one of the Plastic Pipe Institute, it is said that polyethylene pipes provide superior reliability and safety when compared to polybutylene (PB) piping systems used in plumbing and heating applications in Canada and USA until the mid-1990. Moreover, they use reliable connection systems and PEX industry is highly regulated. According to product standards from organizations such as ASTM International, CSA International and NSF International, the testing requirements for PEX systems are far more stringent than for PB systems.

Once knowing that, I started with the heat exchanger's length calculations. The formulas that I used are taken from the subject *Energia geotermikoa* from the University of the Basque Country (UPV/EHU).

Equation 26: Length of the heat exchanger for heating

$$Lheating = \frac{\dot{Q}heating\ \frac{COP-1}{COP}\ (R\rho + RgFheating)}{Tmin,g - Tmin,HP}$$

Equation 27: Length of the heat exchanger for cooling

$$Lcooling = \frac{\dot{Q}cooling\ \frac{EER+1}{EER}\ (R\rho + RgFcooling)}{Tmax,HP - Tmax,g}$$

$\dot{Q}heating$: Heating needs of the building (W)

COP: Heat pump's heating performance

EER: Heat pump's cooling performance

$Tmin,g$: Ground's minimum temperature (K)

$Tmax,g$: Ground's maximum temperature (K)

$Tmin,HP$: Heat pump's minimum temperature (K)

$Tmax,HP$: Heat pump's maximum temperature (K)

$R\rho$: Pipes' resistance (mK/W)

Rg: Ground's resistance (mK/W)

$Fheating$: Heat pump's using factor for heating

$Fcooling$: Heat pump's using factor for cooling

$\dot{Q}cooling$: The cooling needs of the building (W)

As we can see in the equation 26 and 27, they depend on the heating and cooling system's efficiency for winter and summer respectively. I had to choose the biggest value between them for knowing the length of the heat exchanger, and as a result, the number of wholes and depth too.

All my calculations are based on a system which would be able to provide 1369779,985 W for heating and 232,26 kW cooling.

The system that I chose had different heat pumps, with different characteristics. Nonetheless, my calculations are based on the whole system, due to the fact that all the heat pumps' together would have one heat exchanger system. These calculations were made with the aim of obtaining an approximation value of the quantity of the wholes, their depth and the area that our system would need.

Heat pump's minimum and maximum temperature values, EER and COP were taken from the datasheets.

To calculate the grounds' minimum and maximum values I used the next formula:

Equation 28: Ground's minimum temperature

$$Tmin\ (z) = Tm - Ase^{-z\sqrt{\frac{\pi}{365\alpha}}}$$

Equation 29: Ground's maximum temperature

$$Tmax\ (z) = Tm - Ase^{-z\sqrt{\frac{\pi}{365\alpha}}}$$

Nonetheless, in case of the vertical heat exchanger installation, it is taken that As's value is zero. Therefore, the minimum and maximum temperature values of the ground are the same as the average air temperature.

3.7.1. Using factor's calculations

To calculate $Fheating$ and $Fcooling$ I have analysed one year's temperature values, from 1 of January 2015 until 31 of December 2015. For that, I used the next web-page that I also mentioned in other parts of this project [12].

There I checked the next data:

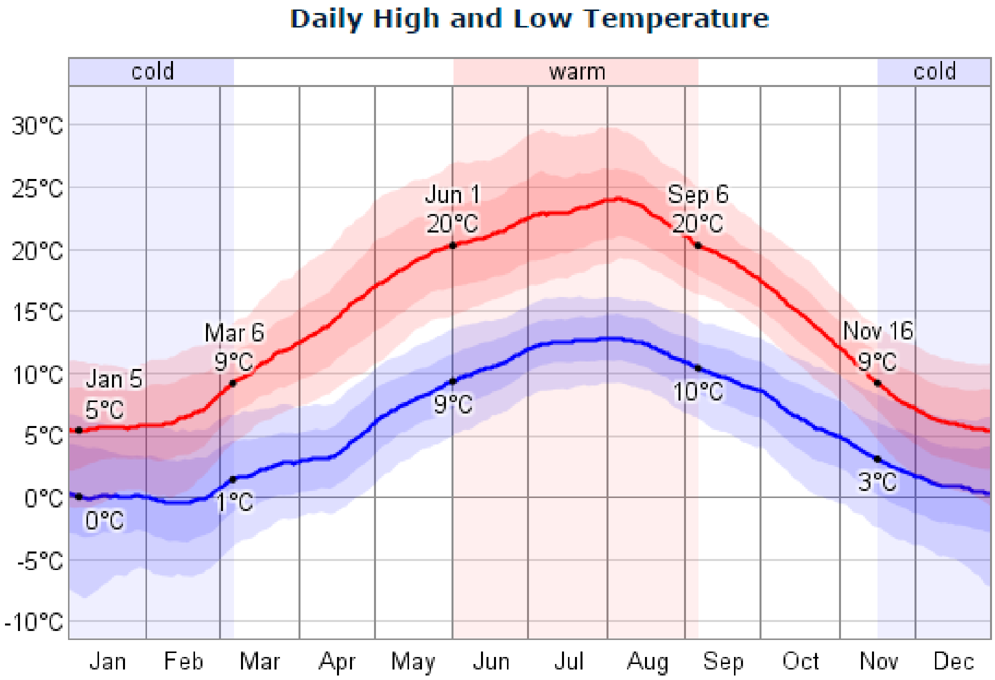


Figure 75: The daily average low (blue) and high (red) temperature

Basing on figure 75, I made some approximations there. I bearded in mind the temperature values are more or less the same in some parts of the year. I decided that January and December, November and March, May and September and June and August had almost the same characteristics. Therefore, I analysed only the values of one partner of the couples. In case of February, April, October and July, I analysed each month separately. I have consulted this decision with Mr. Vanheusden and he agreed with it.

I took the temperatures of two months from the weather station that PXL-Tech has. I took the data of February and March 2015. As the station was installed in 3 of February, I was not able to use the data from January.

Despite having different reliable weather station around PXL-Tech, we have seen before that some of them are more accurate than others. Therefore, I have used data from Kleine Brogel Air Base to analyse the other months.

First of all, I focused on the maximum and minimum values for each month and I divided the temperatures in different ranges. After that, I have checked how many hours is the outside temperature between each value, in other words, Bin hours' values tell us during how many hours the temperature values were among these ranges. These are called, bin hours. These steps are shown in the figure 76, see below.

Temperature range (ºC	To average (ºC)	Bin hours
-4 - 4.9	-4,5	0
-3 - 3.9	-3,5	0
-2 - 2.9	-2,5	0
-1 - (1.9)	-1,5	0
0 - (-0.9)	-0,5	0
0 - 0.9	0,5	0
1 - 1.9	1,5	0
2 - 2.9	2,5	0
3 - 3.9	3,5	0
4 - 4.9	4,5	0
5 - 5.9	5,5	0
6 - 6.9	6,5	0
7 -7.9	7,5	53
8 - 8.9	8,5	108
9 - 9.9	9,5	138
10 - 10.9	10,5	121
11 - 11.9	11,5	85
12 - 12.9	12,5	64
13 - 13.9	13,5	59
14 - 14.9	14,5	52
15 - 15.9	15,5	39
16 - 16.9	16,5	34
17 - 17.9	17,5	8
18- 18.9	18,5	0

Figure 76: Example of the temperature ranges. Bin hours' values

Apart from that, I have calculated the heating needs that the building has for each range of temperature and I also have written down the heat pump's heating capacity for each range. This last one is constant every time. Using these both values, I have been able to calculate the working fraction of the heat pump for heating, see equation 30.

Equation 30: Working fraction equation

$$\text{Working fraction } = \frac{Heating\ needs\ of\ the\ building}{Heat\ pump's\ heating\ capacity}$$

Building's load HEATI	Building's load COOLING	Heat pump's pov	Heat pump	Working fracti	Working fra
1654,054996	-1631,812138	1375	1235	1	0
1583,669677	-1561,426819	1375	1235	1	0
1513,284358	-1491,0415	1375	1235	1	0
1442,899039	-1420,656181	1375	1235	1	0
1372,51372	-1350,270862	1375	1235	0,998191796	0
1302,128401	-1279,885543	1375	1235	0,947002473	0
1231,743082	-1209,500224	1375	1235	0,89581315	0
1161,357763	-1139,114905	1375	1235	0,844623828	0
1090,972444	-1068,729586	1375	1235	0,793434505	0
1020,587125	-998,3442674	1375	1235	0,742245182	0
950,201806	-927,9589484	1375	1235	0,691055859	0
879,8164871	-857,5736295	1375	1235	0,639866536	0
809,4311681	-787,1883105	1375	1235	0,588677213	0
739,0458491	-716,8029915	1375	1235	0,53748789	0
668,6605302	-646,4176726	1375	1235	0,486298567	0
598,2752112	-576,0323536	1375	1235	0,435109245	0
527,8898922	-505,6470346	1375	1235	0,383919922	0
457,5045733	-505,6470346	1375	1235	0,332730599	0
387,1192543	-435,2617157	1375	1235	0,281541276	0
316,7339353	-364,8763967	1375	1235	0,230351953	0
246,3486164	-294,4910778	1375	1235	0,17916263	0
175,9632974	-224,1057588	1375	1235	0,127973307	0
105,5779784	-153,7204398	1375	1235	0,076783984	0
35,19265948	-83,33512086	1375	1235	0,025594661	0

Figure 77: Example of the working fractions for cooling and heating

**In the case where the working fraction is bigger than a unit, I have only written down a unit value, because it is impossible for the heat pump to work above its capacity, it will work in its maximum ability.

I have done the same to calculate the cooling needs of the building. Nevertheless, in this case, I have taken into account the heat losses, as well as, the heating gains; since for cooling, the worst case is when there are gains in the building.

I have obtained the working hours of the heat pump multiplying bin hours with the fraction that I have mentioned before, see equation 31 below.

Equation 31: Working hours equation

$$\text{Working hours} = bin\ hours\ x\ working\ fraction$$

We can see an example of these calculations in the figure 78.

Working fraction Heating	Working fraction Cooling	Bin hours	Working hours Heating	Working hours Cooling
1	0	0	0	0
1	0	0	0	0
1	0	0	0	0
1	0	0	0	0
0,998191796	0	0	0	0
0,947002473	0	0	0	0
0,89581315	0	0	0	0
0,844623828	0	0	0	0
0,793434505	0	0	0	0
0,742245182	0	0	0	0
0,691055859	0	0	0	0
0,639866536	0	0	0	0
0,588677213	0	53	31,1998923	0
0,53748789	0	108	58,04869215	0
0,486298567	0	138	67,1092023	0
0,435109245	0	121	52,64821859	0
0,383919922	0	85	32,63319334	0
0,332730599	0	64	21,29475832	0
0,281541276	0	59	16,61093528	0
0,230351953	0	52	11,97830155	0
0,17916263	0	39	6,987342574	0
0,127973307	0	34	4,351092445	0
0,076783984	0	8	0,614271875	0
0,025594661	0	0	0	0

Figure 78: Example of calculations of the working hours

Later, I summed all the hours of each process of each period, heating and cooling respectively, and I divided them with the whole amount of hours of each period summer and winter. In this way, I obtained the use of factor of the machine for heating and for cooling.

3.7.2. Using factor's calculations results

Table 12: Using factor's results

Use of factor:	Results
Heating	0,649
Cooling	0,113

3.7.3. Pipes' resistance calculations

The formula that is used for these calculations is the next (see equation 32 below):

Equation 32: Pipe's resistance calculation

$$Rp = \frac{1}{2\pi kp}\ln(\frac{Do}{D1})$$

Do: Outside diameter of the pipe

$D1$: Inside diameter of the pipe

kp: Conductivity of the pipes

Calculation of the outside and inside diameter of the pipe

These kinds of installations don't suffer from big pressures. For instance, as my installation would be below 90 meters, the pipes would have to face a pressure of 9 bar, in the deepest part.

Therefore, I knew that a heat pump of 1200kW of needs a diameter of DN125 in the part of the heat source that means, in the ground. The heat pumps that I chose, the ones of 500kW also needed the same diameter, but the others, needed a littler one (see figure 67). As we would have different types of heat pumps, and all of them would create a system which would be able to provide 1375kW, I chose a diameter of DN125 for my calculations, as approximation.

Nevertheless, I ensure that it is suitable with the Reynolds value. In other words, it would be better for our installation to have a turbulent flow, due to the fact that in this way, the heat transfer would be bigger than in the case off the laminar flow. As we can see in the figure 79, there is a bigger contact within the fluid and the ground in the turbulent case than in the laminar.

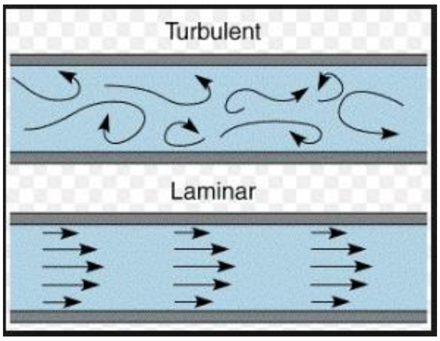


Figure 79: Example of laminar and turbulent flow

Therefore, I used the formula of Reynolds in order to know which would be the maximum diameter value for our case, so as to have a turbulent flow. For that I used the next formula:

Equation 33: Reynolds formula for turbulent flow

$$Re = \frac{4\dot{V}}{\pi D v} \geq 2300$$

V =0,041667 m3/s, it is the minimum flow required by the heat pump system that I chose. I took this value from the datasheet.

v is the cinematic viscosity of the water, in our case, at 10ºC. Cinematic viscosity of water at 10ªC = $1{,}306^{-6}$ m^2/s.

Replacing the 2300 value in the equation 33, I obtained the maximum diameter to reach turbulent flow in the heat exchanger.

Table 13: Reynolds' maximum diameter result

Reynolds, maximum diameter	30,12403908 m

The value that the heat pump's datasheet gave me was far below from the value of the table, and so, it was suitable.

To choose the thickness of the pipe I have looked on the internet different information [41]. After obtaining several data, I chose the next one (see figure 80 below):

	PE-100 espesor (mm)						PE-80 espesor (mm)			PE-40 espesor (mm)		
PRESIÓN [bar] / Ø exterior en mm	6	10	12,5	16	20	25	6	10	16	4	6	10
20	---	---	---	2,0	2,3	3,0	---	---	2,3	---	2,0	3,0
25	---	---	---	2,3	3,0	3,5	---	2,0	3,0	---	2,3	3,5
32	---	2,0	2,4	3,0	3,6	4,4	---	2,4	3,6	2,0	3,0	4,4
40	---	2,4	3,0	3,7	4,5	5,5	---	3,0	4,5	2,4	3,7	5,5
50	---	3,0	3,7	4,6	5,6	6,9	---	3,7	5,6	3,0	4,6	6,9
63	---	3,8	4,7	5,8	7,1	8,6	---	4,7	7,1	3,8	5,8	8,6
75	---	4,5	5,6	6,8	8,4	10,3	---	5,6	8,4	4,5	6,8	10,3
90	---	5,4	6,7	8,2	10,1	12,3	---	6,7	10,1	5,4	8,2	12,3
110	4,2	6,6	8,1	10,0	12,3	15,1	---	8,1	12,3	---	---	---
125	4,8	7,4	9,2	11,4	14,0	17,1	---	9,2	14,0	---	---	---
140	5,4	8,3	10,3	12,7	15,7	19,2	---	10,3	15,7	---	---	---
160	6,2	9,5	11,8	14,6	17,9	21,9	7,7	11,8	17,9	---	---	---
180	6,9	10,7	13,3	16,4	20,1	24,6	8,6	13,3	20,1	---	---	---
200	7,7	11,9	14,7	18,2	22,4	27,4	9,6	14,7	22,4	---	---	---
225	8,6	13,4	16,6	20,5	25,2	30,8	10,8	16,6	25,2	---	---	---
250	9,6	14,8	18,4	22,7	27,9	34,2	11,9	18,4	27,9	---	---	---
280	10,7	16,6	20,6	25,4	31,3	38,3	13,4	20,6	31,3	---	---	---
315	12,1	18,7	23,2	28,6	35,2	43,1	15,0	23,2	35,2	---	---	---
355	13,6	21,1	26,1	32,2	39,7	48,5	16,9	26,1	39,7	---	---	---
400	15,3	23,7	29,4	36,3	44,7	54,7	19,1	29,4	44,7	---	---	---
450	17,2	26,7	33,1	40,9	---	---	---	---	---	---	---	---
500	19,1	29,7	36,8	45,4	---	---	---	---	---	---	---	---
560	21,4	33,2	41,2	50,8	---	---	---	---	---	---	---	---
630	24,1	37,4	46,3	57,2	---	---	---	---	---	---	---	---
710	27,2	42,1	---	---	---	---	---	---	---	---	---	---
800	30,6	47,4	---	---	---	---	---	---	---	---	---	---
900	34,4	53,3	---	---	---	---	---	---	---	---	---	---
1000	38,2	59,3	---	---	---	---	---	---	---	---	---	---

Figure 80: The thickness of the pipe that I chose

The reasons of choosing this pipe were first of all, that it suited the needs of the heat pump and secondly, that it would be able to face the pressure that I mentioned before.

Calculation of the outside and inside diameter of the pipe results

Table 14: Diameter of the pipes, outside and inside

DIAMETER	VALUE (m)
Inside	0,125
Outside	0,1324

Conductivity of the pipe

As I mentioned before, the material of the pipe is polyethylene. Therefore, I found its value.

Conductivity of the pipe result

Table 15: Pipes' conductivity result

Pipe's conductivity	0,42 W/ mK

3.7.4. Pipes' resistance calculation result

Table 16: Pipes' resistance

Pipes' resistance	0,021794288 mK/W

3.7.5. Ground's resistance calculations

After knowing the working factor, I calculated the ground's resistance. The ground's properties change during the year, and so, they are not the same in summer and winter. Therefore, I calculated the ground's resistance value for these two different periods.

For that, I used the next formula:

Equation 34: Ground's resistance's formula

$$Rs = \frac{1}{4\pi ks} Ei(\frac{-r^2}{4\propto t})$$

Ks: The conductivity of the ground (W/mK)

α: Thermal diffusivity of the ground (m^2/s)

t: For how long the heat exchanger is working during a year (s). I used t for cooling and t for heating. In this way, as I mentioned before, I obtained two different ground's resistances values depending on the period of the year.

To calculate the next formula (equation 35, see below), I used the website wolfram: [42]

Equation 35: Exponential integral function

$$Ei(x) = \int_{-\infty}^{x} \frac{e^t}{t} dt$$

r: It is the distance between different pipes.

Conductivity of the ground

To calculate this value, I took data from the website that I mentioned before: [10]

There I focused on the thermal conductivity values of the ground:

dikte (m)	diepte (m)	type	λ min (W/mK)	λ gem (W/mK)
4.4	4.4	zandh. klei	1.4	1.7
2.7	7.1	zand	1.9	2.3
1.6	8.7	zand	1.9	2.3
0.4	9.1	kleih. zand	1.8	2.1
22.3	31.4	klei	1.2	1.5
3.0	34.4	zand	1.9	2.3
1.3	35.7	zandh. klei	1.4	1.7
7.8	43.4	kleih. zand	1.8	2.1
4.3	47.7	klei	1.2	1.5
17.0	64.7	kleih. zand	1.8	2.1
46.8	111.6	zandh. klei	1.4	1.7
31.8	143.4	kleih. zand	1.8	2.1
156.6	300.0	tufkrijt	2.3	2.3

Figure 81: Thermal conductivity values of the ground

As I said before, I supposed that our pipes would be 90 meters deep and so, I took into account the conductivity values until 90 meters and I calculated an average value.

Thermal conductivity (W/mK)
1,7
2,3
2,3
2,1
1,5
2,3
1,7
2,1
1,5
2,1
1,7

Figure 82: Thermal conductivity values

Conductivity of the ground result

Table 17: Conductivity of the ground result

Thermal conductivity of the ground until 90 meters	1,936 W/mK

Thermal diffusivity of the ground

I followed the same steps as with conductivity of the ground. I took the values that I mentioned in the figure 83 as basis, and after that, basing on the values which are until 90 meters, I calculated an average value.

Thermal diffusivity α
0,423
0,521
0,521
0,291
0,261
0,521
0,423
0,291
0,261
0,291
0,423

Figure 83: Thermal diffusivity values

Thermal diffusivity of the ground result

Table 18: Thermal diffusivity of the ground result

Thermal diffusivity of the ground until 90 meters	3,84273E-07 m^2/s

Heat exchanger's working hours

To make the calculations of this part, I took into account the same values that I obtained when calculating the using factor of the machine, because our installation of 1375kW for heating and 1235 kW for cooling is new and I can't search real data. As a result, I bearded in mind the values of the year that I made my calculations with and I used them as a basis for our installation.

Therefore, I added all the working hours of heating and the same did with the working hours of cooling.

Heat exchanger's working hours results

Table 19: Heat exchanger's working hours results

Working hours	Results (s)
Heating	10163384
Cooling	1797011

Exponential integral function

I based all my calculations, first of all, calculating the x factor; which is the next:

Equation 36: Formula to calculate the x

$$x = (\frac{-r^2}{4\propto t})$$

Equation 37: Exponential integral function

$$Ei(x) = \int_{-\infty}^{x} \frac{e^t}{t} dt$$

Distance between different pipes

To calculate this part, I used the "mirror method". As I chose the vertical system option, the pipes are located between 80-100 meters usually, and so, I took 90 meters value below the ground. Then, I place imaginary pipes in parallel from those real ones. This is better explained in the figure 84. They are 90 meters above the ground, too. Later, each distance between each couple of pipes it is measured. Using these values, different ground's resistances are obtained.

Finally, the overall result is obtained adding each real pipe's thermal resistance value and deducting the values of the imaginary pipe's values. The result is divided with the quantity of the real pipes. A visual example of the "mirror method" is the next, see picture 84 below.

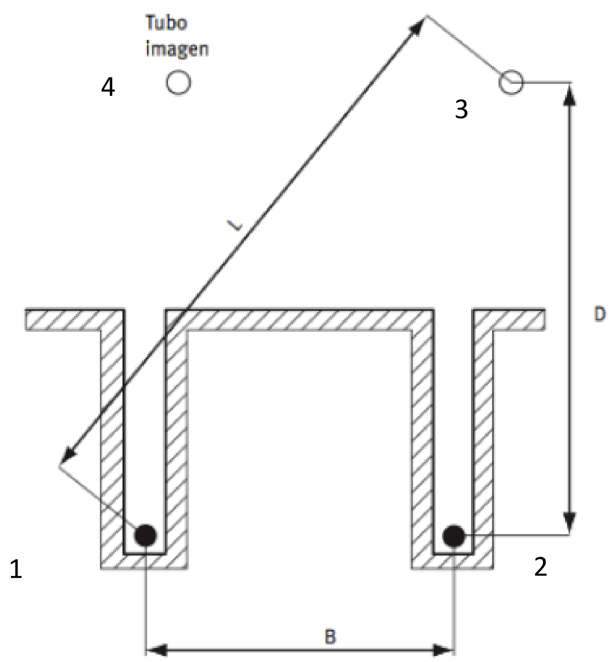


Figure 84: Explanation of the pipe's method

As I mentioned before, the pipes would be 90 meters below the ground's surface. Therefore, the value of D would be 180 meters. Besides, as our installation would be a vertical one, we would have to leave 6 meters between the pipes. So, the value of B would be 6 meters.

3.7.6. Ground's resistance calculations results

As a result, taking that we had two vertical U pipes, these are the calculations I made (figure 85). There appear all the results of each step.

	r (m)	x_uda	Ei_uda		Rs_uda	x_negua	Ei_negua		Rs_negua
1 1	0,1324	-0,00635	-4,48842	4,48842	0,184457	-0,00112	-6,21833	6,21833	0,25555
1 2	6	-13,0332	-1,56516E-07	1,57E-07	6,43E-09	-2,30444	-0,03231	0,032309	0,001328
1 3	180,1	-11742,9	0	0	0	-2076,3	0	0	0
1 4	180	-11729,9	0	0	0	-2073,99	0	0	0
2 1	6	-13,0332	-1,56516E-07	1,57E-07	6,43E-09	-2,30444	-0,03231	0,032309	0,001328
2 2	0,1324	-0,00635	-4,48842	4,48842	0,184457	-0,00112	-6,21833	6,21833	0,25555
2 3	180	-11729,9	0	0	0	-2073,99	0	0	0
2 4	180,1	-11742,9	0	0	0	-2076,3	0	0	0
					0,184457				0,256878

Figure 85: Calculations of the ground's resistance

Table 20: Ground resistance's value results

Period	Ground resistance's value (mK/W)
Winter	0,256878
Summer	0,184457

3.8. Characteristics of the heat exchanger results

As I have mentioned a lot of data and calculations in this process, I will review again the equation 38 and 39 below and I will show the values that I used in the formula in one table (table 21).

Equation 38: Length of the heat exchanger for heating

$$Lheating = \frac{\dot{Q}heating\ \frac{COP-1}{COP}\ (R\rho + RgFheating)}{Tmin,g - Tmin,HP}$$

Equation 39: Length of the heat exchanger for cooling

$$Lcooling = \frac{\dot{Q}cooling\ \frac{EER+1}{EER}\ (R\rho + RgFcooling)}{Tmax,HP - Tmax,g}$$

Table 21: The values I used to obtained the results

$\dot{Q}heating$: Heating needs of the building (W)	1369779,985
COP: Heat pump's heating performance	5,025
EER: Heat pump's cooling performance	4,17
$Tmin, g$: Ground's minimum temperature (K)	283,701
$Tmax, g$: Ground's maximum temperature (K)	283,701
$Tmin, HP$: Heat pump's minimum temperature (K)	268
$Tmax, HP$: Heat pump's maximum temperature (K)	298
$R\rho$: Pipes' resistance (mK/W)	0,021794288
Rg: Ground's resistance (mK/W)	Rs_summer 0,18445724 Rs_winter 0,25687784
$Fheating$: Heat pump's using factor for heating	0,649899251
$Fcooling$: Heat pump's using factor for cooling	0,11365433
$\dot{Q}cooling$: The cooling needs of the building (W)	232,26

The results are shown in the next table 22:

Table 22: Length of the heat exchanger values

Period	Length of the heat exchanger
Winter (Heating)	13189,12773 m
Summer (Cooling)	0,861085049 m

The conclusions that I have obtained are the next, table 23:

Table 23: Conclusions about the results obtained

Quantity of U	Length of each U (m)	Depth of the holes (m)
2	6594,563866	3297,281933
10	1318,912773	659,4563866
74	180	90
55	**240**	**120**

I chose make deeper holes in order to have less U heat exchanger quantity, due to the fact that as a result, we would have to need less area for our installation. This is because, as I mentioned before, we have to leave 6 meters between different heat exchangers. So, the area of each heat exchanger is the next (equation 40):

Equation 40: Area of each heat exchanger U block

$$AreaHEU = \pi r^2 = (6 + 2rpipeoutside)^2$$

Taking this into account I concluded the next (see table 24):

Table 24: Area of the heat exchanger system

U quantity	Area m^2
1	118,08
74	8738,2067
55	**6494,61**

Therefore, I chose that our system would need 55 holes of a depth of 120 meters. The area that it would need would be 6494,61 m^2 and the total length of the pipes would be around 13189,12773 m.

The pipe's depth would change and so, their diameter value, ground's thermal conductivity and thermal diffusivity, too; due to the fact that all my calculations were made for a whole of 90 m. Therefore, to ensure my result, I made the calculations again, following the same process and taking into account a depth of 120 m. In this case the pipes would have to face a pressure of 12 bar, in the deepest part.

	PE-100 espesor (mm)						PE-80 espesor (mm)			PE-40 espesor (mm)		
PRESION (bar) / Ø exterior en mm	6	10	12,5	16	20	25	6	10	16	4	6	10
20	---	---	---	2,0	2,3	3,0	---	---	2,3	---	2,0	3,0
25	---	---	---	2,3	3,0	3,5	---	2,0	3,0	---	2,3	3,5
32	---	2,0	2,4	3,0	3,6	4,4	---	2,4	3,6	2,0	3,0	4,4
40	---	2,4	3,0	3,7	4,5	5,5	---	3,0	4,5	2,4	3,7	5,5
50	---	3,0	3,7	4,6	5,6	6,9	---	3,7	5,6	3,0	4,6	6,9
63	---	3,8	4,7	5,8	7,1	8,6	---	4,7	7,1	3,8	5,8	8,6
75	---	4,5	5,6	6,8	8,4	10,3	---	5,6	8,4	4,5	6,8	10,3
90	---	5,4	6,7	8,2	10,1	12,3	---	6,7	10,1	5,4	8,2	12,3
110	4,2	6,6	8,1	10,0	12,3	15,1	---	8,1	12,3	---	---	---
125	4,8	7,4	9,2	11,4	14,0	17,1	---	9,2	14,0	---	---	---
140	5,4	8,3	10,3	12,7	15,7	19,2	---	10,3	15,7	---	---	---
160	6,2	9,5	11,8	14,6	17,9	21,9	7,7	11,8	17,9	---	---	---
180	6,9	10,7	13,3	16,4	20,1	24,6	8,6	13,3	20,1	---	---	---
200	7,7	11,9	14,7	18,2	22,4	27,4	9,6	14,7	22,4	---	---	---
225	8,6	13,4	16,6	20,5	25,2	30,8	10,8	16,6	25,2	---	---	---
250	9,6	14,8	18,4	22,7	27,9	34,2	11,9	18,4	27,9	---	---	---
280	10,7	16,6	20,6	25,4	31,3	38,3	13,4	20,6	31,3	---	---	---
315	12,1	18,7	23,2	28,6	35,2	43,1	15,0	23,2	35,2	---	---	---
355	13,6	21,1	26,1	32,2	39,7	48,5	16,9	26,1	39,7	---	---	---
400	15,3	23,7	29,4	36,3	44,7	54,7	19,1	29,4	44,7	---	---	---
450	17,2	26,7	33,1	40,9	---	---	---	---	---	---	---	---
500	19,1	29,7	36,8	45,4	---	---	---	---	---	---	---	---
560	21,4	33,2	41,2	50,8	---	---	---	---	---	---	---	---
630	24,1	37,4	46,3	57,2	---	---	---	---	---	---	---	---
710	27,2	42,1	---	---	---	---	---	---	---	---	---	---
800	30,6	47,4	---	---	---	---	---	---	---	---	---	---
900	34,4	53,3	---	---	---	---	---	---	---	---	---	---
1000	38,2	59,3	---	---	---	---	---	---	---	---	---	---

Figure 86: Choice of the pipe in red circle

The values that had been changed are highlighted with yellow colour in the table 25.

Table 25: The values I used to obtained the results

$\dot{Q}heating$: Heating needs of the building (W)	1369779,985
COP: Heat pump's heating performance	5,025
EER: Heat pump's cooling performance	4,17
$Tmin, g$: Ground's minimum temperature (K)	283,701
$Tmax, g$: Ground's maximum temperature (K)	283,701
$Tmin, HP$: Heat pump's minimum temperature (K)	268
$Tmax, HP$: Heat pump's maximum temperature (K)	298
Ground's thermal conductivity W/mK	1,95
Ground's thermal diffusivity m2/s	3,765E-07
Outside diameter of the pipe m	0,1342
$R\rho$: Pipes' resistance (mK/W)	0,026911
Rg: Ground's resistance (mK/W)	Rs_summer 0,181267185 Rs_winter 0,252989431
$Fheating$: Heat pump's using factor for heating	0,649899251
$Fcooling$: Heat pump's using factor for cooling	0,11365433
$\dot{Q}cooling$: The cooling needs of the building (W)	232,26

Table 26: The results I obtained

Depth of each U m	**Length of each U m**	**U quantity = hole quantity**	**Total area m^2**
120	**240**	**56**	**6612,697025**

Therefore, as it is listed in the table 26, the installation would have 56 holes where 120 U heat exchangers would be placed. Each exchanger would be 240 meters long and the total area they would take would be 6612,697025 square meters.

3.9. Economic and environmental analysis

Mr. Roger Vrancken provided me some data of the consumption of the heating system of the building. These figures were from 2011, 2012 and 2013. At that time, there were 3 kettles and they produced heat for the building, but also warm water for the kitchen. There wasn't any data calculated separately from the consumption of warm water.

Therefore, I took the next figures into account and I made some approximations:

VERBRUIK VAN GAS

	Begindatum	Einddatum	kWH
2011	1/jan	27/jan	167587
	28/jan	24/feb	156503
	25/feb	30/mrt	145392
	31/mrt	27/feb	48520
	28/apr	30/mei	32400
	31/mei	29/jun	28117
	30/jun	28/jul	22298
	29/jul	30/aug	19266
	31/aug	26/sep	30691
	27/sep	27/okt	57525
	28/okt	28/nov	116485
	29/nov	21/dec	100798
2012	22/dec	30/jan	212889
	31/jan	28/feb	185145
	29/2	28/mrt	112483
	29/mrt	22/apr	91482
	23/apr	30/apr	12219
	1/mei	23/mei	36061
	24/mei	22/jun	33643
	23/jun	26/jul	29389
	27/jul	27/aug	16634
	28/aug	27/sep	46752
	28/sep	29/okt	79924
	30/okt	29/nov	153268
	30/nov	20/dec	120832
2013	21/dec	28/jan	266839
	29/jan	25/feb	159312
	26/feb	27/mrt	201402
	28/mrt	30/apr	15070
	1/mei	30/mei	69257
	31/mei	27/jun	35617
	28/jun	29/jul	25898
	30/jul	29/aug	19014
			2848712 kWh

Figure 87: Gas consumption values of 2011, 2012 and 2013

As we can see in the figure 87, there is written the gas consumption of each month. A point to mention is that in July or August, for instance, there wasn't a heating need, neither the need of warm water. However, it is clear in the figure 87 that the system still continued working and consuming GAS even if there wasn't a demand for that. I made the next approximations for my calculations:

- I took into account the values between May and September to calculate the warm waters' average heating needs (kWh and m^3 gas), because in this period the building would have been full of people and the kitchen would have worked in their common rates. Besides, the heating needs wouldn't have almost existed.
- I erase this average value to the monthly consumption values (kWh and m^3 gas).
- I added all the heating consumption values of each year.
- After that, I calculated an average year consumption value; in the case of 2013, as I didn't have the values of the whole year, I didn't take it into account for this calculation.

The results of my approximations are listed in the next table 27:

Table 27: Annual average kWh and m^3 consumption values

AVERAGE	VALUE
Warm water's average heating needs kWh	**43032,2**
2011, annual kWh consumption for heating	491584,6
2012, annual kWh consumption for heating	658517,4
Average annual kWh consumption for heating	**575051**
Warm water's average heating needs m^3	**4007**
2011, annual m^3 consumption for heating	45769
2012, annual m^3 consumption for heating	61313
Average annual m^3 consumption for heating	**53541**

Taking the worst case for my calculations, the installation's efficiency was %100 that means the average kWh consumption and consequently, the m^3 quantity would be the real energy needs of the building. In the table 28 below are shown these values.

Table 28: Annual average kWh and m^3 consumption values

AVERAGE ANNUAL	VALUE
kWh consumption = energy needs	674594,5333
m^3 consumption GAS	62811,83333

If there would be installed the geothermal system with a COP of 5,025, the electricity consumption would be the next (see table29):

Table 29: Annual average kWh and m^3 consumption values with geothermal installation

AVERAGE ANNUAL	VALUE
kWh energy heating needs	674594,5333
kWh consumption of energy	$\frac{674594{,}5333}{5{,}025} = 134247.66$

Therefore, PXL-Tech would save the next values annually:

Table 30: Annual savings at PXL-Tech

ANNUAL SAVINGS	VALUES
kWh consumption	674594,5333 - 134247.66 = 540346.865
m^3 consumption GAS	62811,83333

At the same time, it would earn the next electricity consumption: 134247.66 kWh.

Nonetheless, I discussed these approximations with my tutors and Mr. Win Vandormael suggested me to only take the data of 2012 into account, which would have been more accurate, because he had checked the number of degree-days for 2011 and 2012, which had revealed that 2011 had been 15% warmer than an average year and that 2012 had been quite normal.

Therefore, the gas consumption for tap-water in winter would be an average of 4000m³ per month. The entire gas consumption between May and September was due to the heating of the boiler. Taking this into account I obtained the next results (see figure 88):

AVERAGE ANNUAL HEATING M3	61016 m3	655327,5 kWh
AVERAGE ANNUAL WATER M3	44266 m3	475428,2 kWh
TOTAL GAS CONSUMPTION	105282 m3	1130756 kWh

Figure 88: Annual GAS m^3 consumption, for heating and warm tap-water

As we can see in these values, they are considerably huge for warm water. This is because that time the boiler didn't stop any time in the year. So, when there wasn't even a real need, it used to continue working and consuming energy. It supposed the %42 of the total GAS consumption of the year, which, for us, is really huge and probably, it is not that accurate. Even though, it is what the data say.

This reflects the issue with the boiler at that period the building had.

In addition to this, he told me the kitchen of the school was not operational in the first 2 weeks of September, but during the winter period there would have been another 6 weeks where the kitchen would have been closed (e.g. Christmas – Eastern), too.

Therefore, the GAS consumption for warm water would have been lower. Just for an approximation we decided to take the next values into account.

AVERAGE ANNUAL HEATING M3	70282 m3	754846,8 kWh
AVERAGE ANNUAL WATER M3	35000 m3	375909 kWh
TOTAL GAS CONSUMPTION	105282 m3	1130756 kWh

Figure 89: Annual GAS m^3 consumption, for heating and warm tap-water

So, making a calculation between the old installation and this new one, I obtained the next:

Table 31: The energy the geothermal system would consume and would produce

AVERAGE ANNUAL	VALUE
kWh energy needs	754846,7683
kWh consumption of electricity	$\frac{754846,7683}{5,025} = 150218,2686$

To obtain the electricity and gas prices I checked the next website: [43]

The electricity prices in Belgium from 2012 to 2014 were the next, see figure 90 below:

	Electricity prices (per kWh)						Gas prices (per kWh)					
	Households (1)			Industry (2)			Households (3)			Industry (4)		
	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1	2012 s1	2013 s1	2014 s1
EU-28*	0.188	0.199	0.205	0.115	0.120	0.123	0.063	0.065	0.067	0.037	0.041	0.039
EU-27*	0.189	0.200	0.205	0.115	0.120	0.124	0.063	0.065	0.067	0.037	0.041	0.039
Euro area*	0.198	0.211	0.218	0.121	0.127	0.133	0.069	0.073	0.073	0.038	0.043	0.040
Belgium	0.233	0.217	0.210	0.108	0.108	0.109	0.069	0.066	0.066	0.035	0.040	0.032

([1]) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.

([2]) Annual consumption: 500 MWh < consumption < 2 000 MWh; excluding VAT

([3]) Annual consumption: 20 GJ < consumption < 200 GJ.

([4]) Annual consumption: 10 000 GJ < consumption < 100 000 GJ; excluding VAT.

Source: Eurostat (online data codes: nrg_pc_204, nrg_pc_205, nrg_pc_202 and nrg_pc_203)

Figure 90: Gas prices for Belgium from 2012 until 2014

It is said there that, the price for electricity in 2014 was:

- Electricity price 0.108 €/kWh

For the GAS price, I took the price that is mentioned in the book AUDIT “PXL Gebouw H” as a value of 2012.

- Gas price 0.05 €/kWh

Nevertheless, the system’s real efficiency was not 100%, and so, the real energy needs of the building would have been lower. Therefore, I took its efficiency also into account, to be more accurate.

The efficiency value was 94.78%. This value was taken also from the book AUDIT “PXL Gebouw H” as a value of 2012.

In short, the factors I calculated were the next:

- Economic savings in € and in percentage value.
- Environmental savings in €, in percentage value and also, in the amount of trees that we would save. This was made to have more visual information.

For calculating that, I took the values from the subject "Introduction to Renewable energy" [44]of the University of the Basque Country.

The kettles use Natural Gas. It is composed by a gas mixture, and the main element is Methane which takes the biggest part, around 90%. This is better explained in the next figure 91.

Component	Typical Analysis (mole %)	Range (mole %)
Methane	95.0	87.0 - 97.0
Ethane	3.2	1.5 - 7.0
Propane	0.2	0.1 - 1.5
iso - Butane	0.03	0.01 - 0.3
normal - Butane	0.03	0.01 - 0.3
iso - Pentane	0.01	trace - 0.04
normal - Pentane	0.01	trace - 0.04
Hexanes plus	0.01	trace - 0.06
Nitrogen	1.0	0.2 - 5.5
Carbon Dioxide	0.5	0.1 - 1.0
Oxygen	0.02	0.01 - 0.1
Hydrogen	trace	trace - 0.02
Specific Gravity	0.58	0.57 - 0.62
Gross Heating Value (MJ/m^3), dry basis *	38.0	36.0 - 40.2

Figure 91: Composition of Natural Gas

Therefore, the most important part is the Methane's chemical reaction. Its range in moles is much higher than all the other components, and I took into account just its process for my calculations.

The natural gas's chemical reaction is the next:

Equation 41: Gas natural chemical reaction

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ + Energy

After doing stoichiometric analysis and process, it is obtained that we need 64 grams of oxygen to burn sixteen grams of methane, using four grams of hydrogen.

This means that we would have to have four times more oxygen than methane for producing energy from methane.

Therefore, I calculated how many grams of Gas the building needs in a year, and basing on that, I calculated how many oxygen it needs and consequently, how many trees it burned per year.

Commonly, the Gas consumption of a building is measured in 15ºC and 1013 mbar. Therefore, I took into account the Gas's density in these values which is 0,712 kg/m^3.

NATURAL GAS	
Density (kg/m3)	0,712
Natural gas quantity kg	47428,655
Natural gas quantity g	47428655
Required oxygen quantity g	189714620

Figure 92: Annual Gas consumption

In the figure 92 is shown how many grams of Gas are used per year to fulfill the energy needs.

Then, I took the Ideal Gas Law, which unlike the other gas laws; it doesn't have an initial and final state. Therefore, it doesn't need the situation to change to determine a value for Pressure, Volume, amount of gas or Temperature.

Equation 42: Ideal Gas Law formula

$$P\,V = n\,R\,T$$

P: Pressure (atm)

V: Volume (l)

n: Amount of gas (g/mol)

R: Constant value 0.082 $\frac{atm\ l}{mole\ K}$

T: Temperature (K)

As it is said in the book [44] "Introduction to Renewable Energy" of the University of the Basque Country, in average, one square meter of leaf of a tree releases an average of 3 liters per hour when it is able to catch sun energy.

TREES CALCULATION	
Pressure (atm)	1
Volume (l)	3
R	0,082
Mol quantity n (g/mol)	32
Temperature (K)	283,7
Oxygen grams per hour per square meter	4,1266539

Figure 93: The values that I have used in

We can see in the figure 93, I used the Standard Pressure value which is 1 atm and I took the average air temperature of the year of Diepenbeek. I obtained that, a leaf of Diepenbeek in average, releases 4,12 grams of oxygen per square meter and per hour when it's able to catch sun.

We have analysed in the figure 7 the solar chart of PXL-Tech. From there, I obtained the average sun hours of the PXL-Tech building. The average value is around 12 sun hours per day.

Sun hours	12	
Sun hour per year	4380	
Oxygen grams per square meter per year	18074,744	g/m2

Figure 94: Oxygen results per year and per leaf square meter

As a result, in the figure 94 is shown that a leaf of 1 m^2 which is in Diepenbeek releases an average of 18074,744 g/m^2 per year.

Apart from that, I took the next data, see picture 95, from the subject [22] Energy Efficiency of University of the Basque Country (UPV/EHU) where the lecturers are Mr. Aitor Urresti and Álvaro Campos. These values were taken from the "Well to tank Report, version 4.0" of the Joint Research Institute.

Amaierako energia	CO_2-ko isuri baliokide espezifikoak (g CO_2/kWh)
Elektrizitatea*	399
Gas naturala**	252
Gasoleoa**	311
GLP orokorra**	254
Inportazioko ikatza**	472
Biomasa **	18

Figure 95: CO2 releases per kWh

To make clear my values and results I will explain them step by step.

AVERAGE ANNUAL HEATING M3	61016	m3	655327,5436	kWh
AVERAGE ANNUAL WATER M3	44266	m3	475428,2326	kWh
TOTAL GAS CONSUMPTION	105282	m3	1130755,776	kWh
AVERAGE ANNUAL HEATING CONSUMPTION GAS	70282	m3	754846,7683	kWh
AVERAGE ANNUAL WARM WATER	35000	m3	375909,0079	kWh
TOTAL GAS CONSUMPTION	105282	m3	1130755,776	kWh
GAS CONSUMPTION IN ECONOMIC TERMS	0,05	€/kWh	37742,33842	€
GAS CONSUMPTION IN ENVIRONMENTAL TERMS	252	g CO2/kWh	190221385,6	g CO2

Figure 96: Average energy and money consumption (GAS, old installation)

In the figure 96 are listed the energy consumption values of the building if there wasn't done any change in the installation.

Nonetheless, this installation had not an efficiency of 100% and so, the system had to consume a bigger amount of energy to provide these values.

There is shown also, the average amount of money per year that PXL-Tech pays for its heating needs. At the same time, appears the CO2 releasing amount per year in gram units.

Efficiency of the heating system	0,9478
Real energy heating needs kWh	715443,767
Real energy heating needs m3	66613,2796

Figure 97: Real energy needs of the building

The figure 97 shows the value of efficiency which is 0,9478 and consequently, the values of the real energy needs of the building which are lower than the values of figure 96.

NEW INSTALLATIONS ELECTRICITY VALUES				
EFFICIENCY OF THE INSTALLATION	5,025			
AVERAGE ANNUAL ELECTRICITY CONSUMPTION kWh	142376,869	kWh		
AVERAGE ANNUAL ELECTRICITY CONSUMPTION IN ECONOMIC TERMS	0,108	€/kWh	15376,7	€
ELECTRICITY CO2 QUANTITY	399	g CO2/kWh	56808371	g CO2

Figure 98: New installation values

The figure 98 presents, the electricity consumption values of the geothermal system. We can see that the energy consumption value is much lower than the picture 96. In terms of the released C02, it is clear that the new system would be environmentally friendlier.

Nevertheless, in order to say exactly if the new system is worth it, more aspects must be taken into account, such as, the Payback.

- Payback: It shows how many years have to pass so as to recover all the invested money and normally, it is lower than the payback complex which takes into account the time value for money.

The investment to be done would be the next, see picture 99 below. It would depend on the material used. I took into account that the drilling including the filler material would cost around 42€ per meter.

I looked for information about the subsidies, [45], [46], [47], [48], [49] too. However, all the calculations are done for the worst economical case in terms of grants, due to the fact that they are changed and moreover, I didn't found related data for this project.

INVESTMENT €	
HEAT PUMP	406.198,00
PIPES	25831,68
HOLES	282240
HEAT PUMP + PIPES + HOLES	714.269,68
Including installation, radiators and boreholes for the heat pumps	5700000
All without radiators	5300000

Figure 99: Investment values

3.10. Economic and environmental analysis results

SAVINGS				
ECONOMIC	22365,64	€	40,74125373	%
ENVIRONMENTAL	1,33E+08	g CO2	29,86434494	%
PAY BACK HEAT PUMP	18,1617			
PAY BACK HEAT PUMP + PIPES + HOLES	31,93603			
PAY BACK Including installation, radiators and boreholes for the heat pump	254,8553			
PAY BACK All without radiators	236,9707			

Figure 100: Economic and environmental results

In the picture 100 are shown the results of the economic and environmental analysis and the picture 101 (see below) displays the amount of trees that the PXL-Tech current heating consumes.

TREES		
Area of leaves needed	10496,12	m2
1 tree	20	m2
Quantity of trees	524,8058	TREES

Figure 101: Amount of trees consumed per year

3.11. Cogeneration technologies - Introduction

Cogeneration is a system known because of its high efficiency, owing to the fact that it produces heating energy and electricity at the same time from a single source.

It is used in any kind of processes where there is heating need, due to the fact that the consumer can use the electricity but if there is no need for it, there is always the possibility to get money introducing it to the grid. It would depend on each place's policies if the owner would be able to earn money in every case.

There are plenty of different technologies [50] [51] [52] for cogeneration, these are the main ones:

- Fuel cells
  - PEMFC: Proton Exchange Membrane Fuel Cell
  - DMFC : Direct Methanol Fuel Cell
  - AFC : Alkaline Fuel Cell
  - PAFC : Phosporic Acid Fuel Cell
  - SOFC : Solid Oxide Fuel Cell
  - MCFC : Molten Carbonate Fuel Cell
  - Regenerative Fuel Cell
- Stirling motors
- Gas micro turbines
- The internal combustion engine
  - Otto-cycle
  - Diesel-cycle
  - Rotary-engine

4. Conclusions

In this project, I have obtained several data which have helped me to answer if a geothermal energy system would be viable or not for PXL-Tech building.

The new installation would cause a considerable saving to PXL-Tech, in both, environmental and economic aspect. It would be able to save 22365,64 € per year (40,74 %) and it would release 1,33 x 10^{8} g CO_2 less per year (29,86%).

Moreover, if the electricity that the heat pumps consume was produced using renewable energy, such as, wind energy, PXL-Tech would save in average, 525 trees per year.

Nevertheless, the investment that would have to be done is large. In addition to this, the current system has a good efficiency value, around %95 and as a result, the savings would not be that enormous.

In consequence, there is a fact presented in the picture 100 related to the payback. The most suitable payback would be the second one, which bears in mind the price of the heat pumps, the price of the pipes and the price of the drilling process with their filler materials. The main reason would be that PXL-Tech would not have a necessity of changing all the radiators either the heating system in general, at first sight.

Therefore, the payback would be 32 years which would be long; firstly, because the heat pumps have an estimated life of 20 years without problems, and secondly, because the heat exchangers work properly for 50 years or so. As a result, the payback value is not very attractive. In addition to this, if I took into account the time value for money, the payback value would be even higher.

Apart from that, the room to place the heat pumps would be very suitable, replacing the current kettles. However, the heat exchanger would need an area of 6612,70 m^2 and the available space that I mentioned at first, would be 4555, 0885 m^2. As a result, there would have to take more area from the east side of the building.

I would like to mention that all my calculations were done without taking into account any subsidy, owing to the fact that I haven't found any kind of financial help for this kind of installation. As a result, all my economical calculations were done for the worst case.

However, if in the school would be in the future able to get any kind of grant, the economical results would be lower.

In conclusion, bearing in mind the current data, I can say that the geothermal installation at PXL-Tech is not viable because of reasons mentioned before. The main reason would be the payback value. Consequently, I can say that my hypothesis was wrong. On one hand, it was right because the savings would be important but, as the investment would be considerable, the economical return would take long.

I would like to finish my project suggesting studying the cogeneration technologies mentioned before. There are plenty of choices, and the most suitable for PXL-Tech would be the one which was the most respectful with environment and which was able to give sustainable economic results.

References

[1] European Comission JRC and CMSAF The Satellite Application Facility on Climate Monitoring, „Photovoltaic Geographical Information System - Interactive Maps," 10 February 2012. [Online]. Available: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php.

[2] J. A. C. U. o. t. B. Country, Energiaren Bihurtze Prozesuetako Sistema Elektronikoak, 2014.

[3] University of Oregon, Solar radiation monitoring laboratory, „Polar sun path chart program," 2008. [Online]. Available: http://solardat.uoregon.edu/PolarSunChartProgram.html.

[4] WWEA, IRENA REsource, GlobalData, Smartwatt, WindTurbines-MarketPlace.com, Spares in Motion, April 2015. [Online]. Available: http://www.thewindpower.net/windfarm_en_248_hasselt-godsheide.php.

[5] Vestas Wind Systems A/S, „Wind data explorer," 2014. [Online]. Available: http://winddataexplorer.com/.

[6] NREL, National laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC, „National Renewable Energy Laboratory: Dinamic Maps, GIS Data & Analysis Tools," April 2015. [Online]. Available: http://www.nrel.gov/gis/data_wind.html.

[7] Department of Wind Energy, Technical University of Denmark DTU, „Database of wind characteristics," 2015. [Online]. Available: http://www.winddata.com/.

[8] J. D. a. J. Norda, „Weather Spark," 2015. [Online]. Available: https://weatherspark.com/#!dashboard;a=Belgium/Hasselt.

[9] P.-T. W. L. Network, „Weather Link Network," 2015. [Online]. Available: www.weatherlink.com/user/pxltech/.

[10] Ngi, National Geografisch Instituut Institute Geographique National, „Geothermische Screeningstool," 2014. [Online]. Available: http://tool.smartgeotherm.be/alg.

[11] A. U. a. A. C. U. Country, Energia Geotermikoa, 2013.

[12] W. w. o. line, „World weather on line Ltd.," 2015. [Online]. Available: http://www.worldweatheronline.com/Hasselt-weather-averages/BE.aspx .

[13] Transportation Research Board. 500 Fifth St. NW, Washington, D.C. 20001, „National Academy of Sciences," 2015. [Online]. Available: http://trid.trb.org/view.aspx?id=128208.

[14] U. S. a. c. o. e. C. r. r. a. e. l. H. N. H. U. Omar T.Farouki, „Thermal properties of soils," December 1981. [Online].

[15] e. A. y. l. E. (. O. Asociacion Espanola para la Cultura, „Geologia," 2015. [Online]. Available: http://www.natureduca.com/geol_petrograf_rocasexog8.php.

[16] M. a. J. C.-E. D. d. F. ,. U. d. G. Alatorre-Zamora, „Estructura subsuperficial inferida mediante deconvolucion de Euler e interpretacion de anomalias de gravedad medidas en la confluencia de Guadalajara y Tonala, Occidente de Mexico," 2003. [Online]. Available: http://www.ugm.org.mx/publicaciones/geos/pdf/geos03-3/Alatorre.pdf.

[17] Civil and Environmental Engineering Madrid, „Propiedades termicas de materiales," 2008. [Online]. Available: http://www.miliarium.com/Prontuario/Tablas/Quimica/PropiedadesTermicas.asp.

[18] M. S. U. Anna Gvozdovka and Tatiana Arkhangelskaya Soil Science Faculty, „Theral diffusivity of peat, sand and their mixtures at different water contents," 2014. [Online]. Available: http://meetingorganizer.copernicus.org/EGU2014/EGU2014-8494.pdf.

[19] R. Construction, „Sandwich panels for energy-efficient buildings," 2015. [Online]. Available: http://www.ruukki.com/~/media/Files/Building-solutions-brochures/Ruukki-Sandwich-panels-for-walls-and-roofs.pdf.

[20] F. Building, „Foamglas slab catalogue," 2015. [Online]. Available: http://www.foamglas.co.uk/building/products/product_overview/foamglas_slabs/.

[21] Departamento de Costruccion Arquitectonica, Escuela de Arquitectura, Universidad de Las Palmas de Gran Canaria, „Conductividad termica y densidad," 2008. [Online]. Available: http://editorial.cda.ulpgc.es/ftp/icaro/Anexos/2-%20CALOR/4-Construccion/C.6.4%20Conductividad%20t%E9rmica%20y%20densidad.PDFand .

[22] A. U. a. A. C. U. o. t. B. Country, Eraginkortasun Energetikoa, 2014.

[23] I. I. p. l. D. y. A. d. l. Energia, „Guia tecnica de condiciones climaticas de proyecto," 2010. [Online]. Available: http://www.minetur.gob.es/energia/desarrollo/EficienciaEnergetica/RITE/Reglamento/RDecreto-1027-2007-Consolidado-9092013.pdf4.

[24] A. Camps, 3 Klima: Ventilatietechnieken en luchtbehandeling 2 – 7. Niet-residentiële ventilatie PXL-Tech, November : 8, 2012.

[25] NEC Display Solutions, „Datasheets pf V300W/260W," 2015. [Online]. Available: http://www.nec-display.com/ap/en_projector/v300w/index.html.

[26] National Heat Pump Organisation, „IEA Heat Pump Centre c/o SP Technical Research Institute of Sweden," 2015. [Online]. Available: http://www.heatpumpcentre.org/en/links/nationalheatpumprelorg/Sidor/default.aspx#belgium.

[27] D. I. L. a. D. E. N.V., „Daikin operation mannual," 11 October 2002. [Online]. Available: http://www.daikintech.co.uk/Data/Split-Sky-Air-Indoor/FHQ/2004/FHQ-BUV1B/FHQ35-60BUV1B_OM.pdf.

[28] Daikin Europe N.V., „Daikin air conditioners for shops, restaurants and offices," [Online]. Available:

http://klimasbt.com/daikin_CD/1_Split_SkyAir_Rendszerek/2_Belt%C3%A9ri_Egys%C3%A9gek/05_Mennyezet_alatti_Burkolatos/FHYP-B/Documents/2_[Angol]_Egy%C3%A9b_dokument%C3%A1ci%C3%B3k/Product_leaflet.pdf.

[29] Thermea, „Product information High Temperature Heat Pumps and Liquid Chillers Series HHR 45-HHR 1000," 2014. [Online]. Available: http://www.thermeco2.com/en/products/high-temperature-heat-pumps.

[30] Vaillant, „Pompes a chaleur," 2015. [Online]. Available: http://www.vaillant.be/produits/pompes-a-chaleur/.

[31] Ardenne energie, „Pompes a chaleur," [Online]. Available: http://www.ardenne-energie.com/#!/c161y.

[32] Dauvister, „La pompe a chaleur: une chaleur naturelle et performance," 2014. [Online]. Available: http://www.dauvister.com/pompe-a-chaleur/.

[33] Mitshubishi electric Belgium, „Pompes a chaleur," 2012. [Online]. Available: http://www.mitsubishi-electric.be/fr/product/.

[34] Climatrix, 2015. [Online]. Available: http://www.climatrix.be/producten/warmtepompen.

[35] Viessman, „Pompes a chaleur jusqu'à 1500 kW," 3 2010. [Online]. Available: http://www.viessmann.be/content/dam/internet-be/Media_en_Francais/Brochures_marketing/mug/kwt_wp_1500kw_03-10d-korr14-15frv3kwtgrotewarmtepompen.pdf.

[36] Ns Technics, „Warmtepomp," 2012. [Online]. Available: http://www.nstechnics.be/Energie/Warmtepompen.aspx.

[37] Washington State University, „Industrial Services Factsheets," December 2008. [Online]. Available: http://www.energy.wsu.edu/Documents/IndustServFactsheet-HeatPumps-May%2009.pdf.

[38] B. T. Corp., „WT and WW Models," 2014. [Online]. Available: http://www.bosch-climate.us/files/76P993058-WW-WT-Brochure-8-28-14-Rev1-WEB_US.pdf.

[39] Danish renewable energy, „Technical data overview with price English," 1, 9, 2015.

[40] I. P. H. T. C. a. t. I. o. B. E. H. o. D. f. H. P. a. H. V. T. University of Stuttgart, „Independent testing of heat pumps is needed for reliable COP," October, 2012.

[41] Tuyer Group, „Tuberias de polietileno para presion," 2004.

[42] Wolfram Alpha LLC—A Wolfram Research Company, „Integral calculations," 2015. [Online]. Available: https://www.wolframalpha.com/.

[43] Eurostat statistics explained, „Half-yearly electricity and gas prices, first half of year, 2011–13," March 2014. [Online]. Available: http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_price_statistics.

[44] J. M. A. a. J. J. S. M. U. o. t. B. Country, Energia Berriztagarrieatarako Sarrera, 2012.

[45] iea International Energy Agency, „Ecological investment subsidy,” 29 April 2014. [Online]. Available: http://www.iea.org/policiesandmeasures/pams/belgium/name-24570-en.php?s=dHlwZT1yZSZzdGF0dXM9T2s,&return=PGRpdiBjbGFzcz0ic3ViTWVudSI-PGRpdiBjbGFzcz0iYnJlYWRjcnVtYnMiPjxhIGhyZWY9Ii8iPkludGVybmF0aW9uYWwgRW5lcmd5IEFnZW5jeSZ6d25qOzwvYT4mbmJzcDsmZ3Q7Jm5ic3A7PGE.

[46] Geoservices Warmtepomp -Geothermische Warmtepomp, „Premies and subsidies,” 2015. [Online]. Available: http://www.aardwarmtepompen.be/premies-warmtepomp-subsidies/.

[47] Agentschap Ondermen, „Ecologiepremie (EP-PLUS),” [Online]. Available: http://www.agentschapondernemen.be/maatregel/ecologiepremie-ep-plus. [Geopend 2 April 2015].

[48] European Geothermal Energy Council, „EGEC's response to the EC Public consultation exercise on the Promotion,” 6 10 2006. [Online]. Available: http://egec.info/wp-content/uploads/2011/02/Egecs-response-to-consultation.pdf.

[49] J. Espinoza, „Shedding Light on Subsidies - What incentives exist for renewables? And how exactly do they work?,” 17 September 2012. [Online]. Available: http://www.wsj.com/articles/SB10000872396390443659204577575203384685874.

[50] F. J. A. d. M. U. o. t. B. Country, Sorkuntza banatuko teknologiak, 2014.

[51] EUR-Lex, PreLex and Europe Direct, „Summaries of EU legislacion,” [Online]. Available: http://europa.eu/legislation_summaries/about/index_en.htm. [Geopend 18 10 2011].

[52] AChEE Agencia Chilena de Eficiencia Energetica, „Tecnologia de cogeneracion,” [Online]. Available: http://www.cogeneracioneficiente.cl/informacion-tecnica/tecnologia-de-cogeneracion/.

Attachments

1. Matlab file

```
function [  ] = AIRVALUE(  )
%menu errepikakorra
auk=0;
k=0;
j=0;
u=0;
h=0;
i=0;
area=0;
chairs=0;
aukera=0;
kont=0;
k=0;
p=0;

while (auk~=1)

    while (aukera~=1&aukera~=2&aukera~=3&aukera~=4 )

    disp ('Welcome.')
    disp('Choose the type of the room that you want to do the 
calculations for from the next list:')
    disp('1 if it is intended for human occupancy (e.g. classrooms, 
common laboratories, restaurant, kitchen, common storages, offices 
etc.')
    disp('2 if it is a corridor, hall or WC')
    disp('3 if it is a special room where special components are used 
(e.g. chemical products)')
    disp ('4 if you want to end the programme')
    aukera=input('Insert your choice: ');
    end

    while (aukera~=1&aukera~=2&aukera~=3&aukera~=4 )
        disp ('Please insert any letter or number different to 1, 2 
and 3 if you want to end the programme or insert well your choice')
        aukera=input('Insert your choose: ');
    end
    if (aukera==4)
        auk=1;
    end
    while (aukera~=4 & k<1 & auk~=1 )

        switch (aukera)

        case 1
            o=0;
            aux=0;
            chairs=input('Insert the number of chairs ');
            area=input('Insert the area of the room in m2 ');
            k=input('Insert the value of the table ');
            z=area/k;
            if(z>chairs)
                j=z;
            end
            if(z<chairs||z==chairs)
```

```
                  j=chairs;
              end
              u=j*22;

              disp('Insert 1 if in the room there is an employee. Insert
    any letter or number different to 1 if there is no employee in the
    room') ;
              iep=input('Insert your choice:  ');

                  if (iep==1)
                      h=30*chairs;
                      if(u>h)
                       i=u;
                      end
                      if(u<h||u==h)
                       i=h;
                      end
                  else
                      i=u;
                  end
          disp('The air value for this room is the next: ')
          disp(i)
          p=input('How many rooms are with the same characteristiques?
    ')
          i=p*i;
          disp('The air value for all the quantity of the same room is
    the next: ')
          disp(i)
          kont=kont+i;
          k=3;
          case 2
              bai=0;
              az=0;
              azz=0;
              disp('Is it a WC?')
              bai=input('Insert 1 if it is a WC and insert any letter or
    number different to 1 if it is not: ');

              if(bai==1)
                  batte=0;
                  az=0;
                  disp('Do you know the number of WCs? ')
               batte=input('Insert 1 if you know and insert any letter
 or number different to 1 if you do not know: ');

               if(batte==1)
                   kum= input('Insert the number or WCs ');
                   i=kum*25;
                   kont=kont+i;
                   disp('The air value for this room in cubic meter per
 hour is the next: ')
                   disp(i)
               else
                   az=input('Insert the area of the WC ');
                   i=az*15;
                   kont=kont+i;
                   disp('The air value for this area in cubic meter per
 hour is the next: ')
                   disp(i)
```

```
            end
        else
            azz=input('Insert the area of the room ');
            i=azz*1.3;
            kont=kont+i;
            disp('The air value for this room in cubic meter per hour
is the next: ')
            disp(i)
        end
        k=3;
    case 3
        k=3;
    end


    em=kont/3600;
    disp('The total result of the air quantity in m3/h is the next:')
    disp(kont)
    disp('The total result of the air quantity in m3/s is the next:')
    disp(em)
    auk=input('Have you finished? If you want to end insert 1');
end

aukera=0;
k=0;
end
```