Open University of Cyprus

Faculty of Pure and Applied Sciences

Master Programme *Sustainable Energy Systems*

Master Thesis

Solar Energy in Industrial Processes

Anastasia Filippou

Supervisor professor
Paris Fokaides

May 2019

Open University of Cyprus

Faculty of Pure and Applied Sciences

Master Programme *Sustainable Energy Systems*

Master Thesis

Solar Energy in Industrial Processes

Anastasia Filippou

Supervisor professor
Paris Fokaides

The present master thesis was submitted to partially fulfill the requirements to obtain the master's degree title
to Anastasia Filippou
from the Faculty of Pure and Applied Sciences
of Open University of Cyprus.

May 2019

BLANK PAGE

Summary

This dissertation is about solar systems used in industrial processes. In our case, the process that has been studied is the yogurt maturation. This industrial process requires temperatures at 45 ^{o}C. The purpose of the dissertation is to create a solar system that can cover the energy needs of the process.

First, it was necessary to evaluate what are the needs of the process under study. The needs have been evaluated using the temperatures that it requires, and the heating and cooling loads required for the building of the dairy industry.

There have been developed two models. One is developed in Revit which enable the evaluation of the heating and cooling analysis and the other one in T-Sol. The second model is the development of the solar system that can cover a high percentage of the energy needs of the procedure.

In this dissertation there is an analysis of how that models have been developed and at the Appendix there are the extracts of each software. Closing this Master thesis there is the efficiency of the developed system and its evaluation regarding its use. At Appendix B, there is a financial analysis of the solar system too.

Acknowledgements

First of all, I would like to thank my Supervisor Professor, Mr Fokaides Paris for all his help and support for the completion of this Master Thesis.

Also, I would like to thank my family for their support and understanding.

My deepest gratitude to Papadopoulos Nikolaos, to PhD Candidate Polycarpou Kyriacos and to my good friend Kalloudis Georgios for their precious help.

Contents

Appendix

Introduction

The solar heating and cooling technologies are being applied to many industrial processes, but not unchallenged. In any industrial process the requirement for heating and cooling never ceases to exist. In the contrary they are required in very large numbers, with no periods of zero requirements. The used applications for their control are very complex and must control the procedures very strictly. The temperature levels, which vary across all the industrial procedures, have also applications which further control them. For the heating processes, it is expected, that the required temperatures are going to be very high. For this particular reason the concentrators and all the other equipment are built so that the temperature may rise and remain high the whole time of the procedure. Solar energy is studied to be applied to the industrial processes, but the high costs of its application, compared to the low costs of coal or gas heating, delay its use. This explains why in the last thirty years, these technologies (solar energy) have limited development.

Selection of a solar collector

For the selection of a solar collector, the following criteria must be met:

- The operating temperatures of the system
- The thermal efficiency of the system
- The energy capacity of the system
- The cost of the system
- The occupied space for its installation

The technology used for the heating/cooling services is another important aspect to be considered.

Some parameters which are important in solar heating and cooling technologies are the following:

- The risk of the instability of the price of some natural resources such as coal, oil and natural gas
- The absence of fuel costs
- The reduction of carbon emissions
- The localized production that requires energy

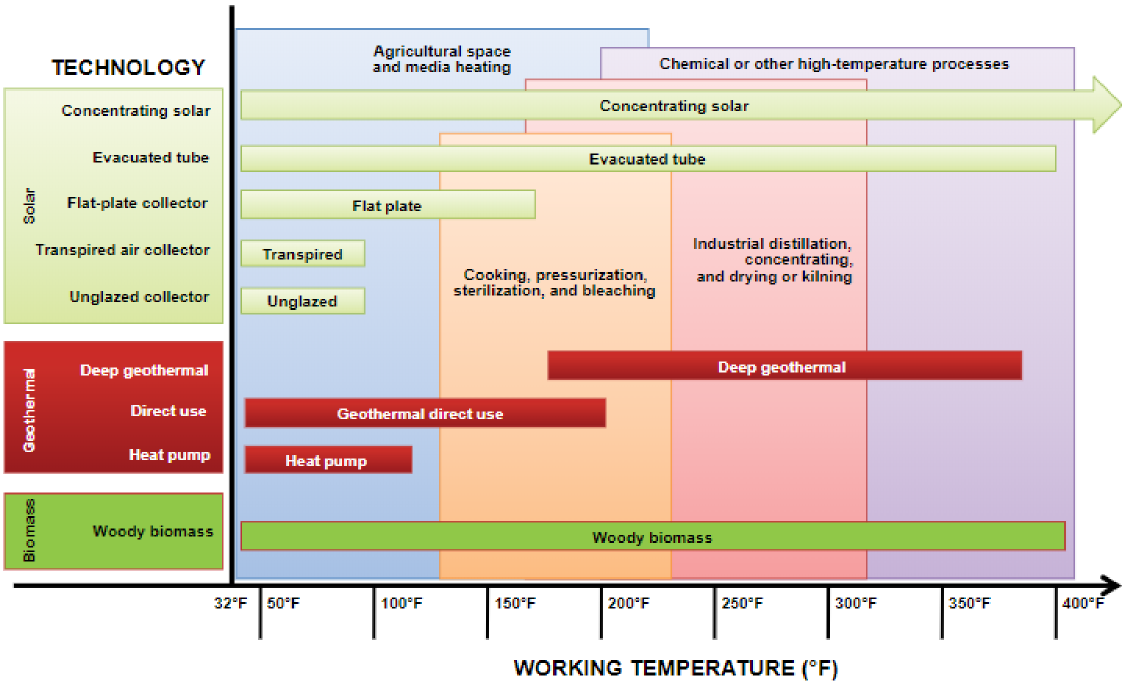


Figure 1: Renewable Industrial Process Heat Technologies and Applications (EPA 2019a,1)

The diagram includes the following nine technologies with approximate temperature ranges:

- Concentrating solar collectors: approximately 0 to more than 204.44 degrees Celsius (32 to 400 degrees Fahrenheit)
- Evacuated tube solar collectors: approximately 0 to more than 204.44 degrees Celsius (32 to 400 degrees Fahrenheit)

- Flat-plate solar collectors: approximately 0 to 76.66 degrees Celsius (32 to 170 degrees Fahrenheit)
- Transpired air solar collectors: approximately 0 to 35 degrees Celsius (32 to 95 degrees Fahrenheit)
- Unglazed solar collectors: approximately 0 to 35 degrees Celsius (32 to 95 degrees Fahrenheit)
- Deep geothermal energy: approximately 79.44 to 193.33 degrees Celsius (175 to 380 degrees Fahrenheit)
- Direct use geothermal: approximately 0 to 93.33 degrees Celsius (32 to 200 degrees Fahrenheit)
- Geothermal heat pump: approximately 0 to 48.88 degrees Celsius (32 to 120 degrees Fahrenheit)
- Woody biomass: approximately 0 to 204.44 degrees Celsius (32 to 400 degrees Fahrenheit) (EPA 2019b,1)

Figure 2 represents the industrial processes that requires low temperature to be achieved.

Market Potential

Industrial sector	Process	Temperature level [°C]
Food and beverages	drying	30 – 90
	washing	40 – 80
	pasteurising	80 – 110
	boiling	95 – 105
	sterilising	140 – 150
	heat treatment	40 – 60
Textile industry	washing	40 – 80
	bleaching	60 – 100
	dyeing	100 – 160
Machinery industry	cleaning	40 – 80
	drying	30 – 90
Chemical industry including pharmaceutical	boiling	95 – 105
	distilling	110 – 300
	various chemical processes	120 – 180
All sectors	pre-heating of boiler feed water	30 – 100
	heating of production halls	30 – 80

based on: K4RES-H; IEA Task 33; Solare Prozesswärme in Industrie und Gewerbe, FhG-ISI, etc., and own research by ESV

Figure 2: Low temperature processes (Krmelj 2019,2)

This master thesis was inspired from the master's degree "Sustainable Energy Systems" and its purpose is to determine how effective will the installation of a solar energy system in an industrial unit. The industrial unit chosen is a dairy faculty, which more specifically processes milk and produces yogurt. The study is enlisted in the renewable energy sources and aims in finding the exact percentage of energy coverage, provided by solar energy, in the chosen procedure.

To accompany this study, we developed a model, using the following programs: "Revit" and "T-Sol". The Revit model is the representation of the building, which is to be studied, concerning the size of the building and its construction elements. In the T-Sol model we developed the proposed solar collectors' system and their efficiency.

Chapter 1

Solar Systems Applications in the Dairy Industry

Solar thermal systems could contribute to energy savings in the dairy industry, where the production procedures demand water temperatures of over 80 Celsius degrees. The produced hot water can also be applied in the installation's steam boiler as a pre-heating medium for the entering water. In this case, it is obvious that the energy contribution of the solar thermal system is low and doesn't cover much of the total energy demand.

We can divide the processes in two groups: the low temperature and the high temperature ones.

The low temperature processes require temperatures lower than 80 Celsius degrees. Some indicative processes of this group are the following:

- Bottle washing (60 ^{o}C)
- Pasteurization (70 ^{o}C)
- Yogurt maturation (40-45 ^{o}C)
- CIP (Cleaning-in-Place 70-80 ^{o}C)

The high temperatures processes require temperatures higher than 100 Celsius degrees. Some indicative processes for this group are the following:

- Bottle sterilization
- UHT treatment (milk sterilization)
- Spray drying. (CRES 2019, 2)

1.1 Yogurt maturation

The process of making yogurt follows these steps:

- Modifying the composition of the milk, while pasteurizing it
- Fermenting it at warm temperatures
- Cooling
- Adding materials (such as fruit or sugar)

1.1.1 Modifying milk composition

Before the milk is made into yogurt, it first must be modified. This is a standard process and involves the reduction of the fat content and the increase of the total solids. A standardizing clarifier and a separator are the used equipment for this procedure. To create the yogurt, the solid contents have an increase up to 16%, with 1-5% being fat and the rest 11-14% being solids-not-fat (SNF). This result can be accomplished by evaporating water or by adding concentrated milk/ milk powder. Another reason for the solids content increase is the improvement of its nutritional value as well as the better quality of the firmer yogurt produced. After this procedure the milk is fermented until it reaches its final form. At this point fruits and other flavors may be added to the product and after this, comes the packaging.

1.1.2 Pasteurization and homogenization

To begin the pasteurization, some stabilizers are added to the milk. The pasteurization is a very important step for the yogurt production and has also many benefits for the product. All the microorganisms that could affect the fermentation, are being exterminated through the pasteurization. The denature of the whey proteins offer the final yogurt a firmer body and texture. It should be noted that the pasteurization doesn't alter the flavor of the product. To start the pasteurization, we must heat the milk in high temperature and then keep that temperature for a set period of time. In a specific pasteurization method, the milk is poured in a stainless steel vat and is heated to 85 ^{o}C for 30 minutes.

1.1.3 Homogenization

During this phase the larger fat globules in the milk are divided in smaller ones, giving the yogurt a smoother and creamier form in its final form. Homogenization also helps in the packaging process, since the product has a more stable form. The procedure is conducted in special equipment called homogenizer or viscolizer. These machines force the milk trough small openings at high pressures, so that the fat globules may disperse into smaller ones and give the product the wanted form.

1.1.4 Fermentation

After the pasteurization and homogenization, the milks temperature is high and needs to be cooled down to 43-46 ^{o}C. Then to start the fermentation, a fermentation culture of a 2% concentration is added to the mix. The mixture remains at standard temperature for three to four hours. During this process the product gets its characteristic yogurt flavor from some compounds which are metabolized from the bacteria. A byproduct of high importance is the lactic acid.

1.1.5 Incubation

This process has different methods for each type of yogurt. It can be done in large tanks of hundred gallons or in individual containers which are also going to be the product's final container. For example, stirred yogurt is fermented in bulk and then is poured to its selling containers. Set yogurt or commonly known French style, can be fermented in the final container. To determine if the fermentation is done and the yogurt is ready, the acidity of the product is checked. The acidity gets lower with the production of lactic acid. A small portion is tested with sodium hydroxide and if the pH is right, then the product is cooled, modified if required and then packaged for sale. (Romanowski 2019, 1)

Chapter 2

Solar Systems

2.1 Solar energy

It can be applied to every area of Greece. The annual solar radiation is accounted for 1200 kWh/m^2 to 1900 kWh/m^2. The average solar energy radiation is shown on Figure 3. The solar thermal system harnesses the solar energy to heat water for use and supportive room heating. These thermal systems are more economic concerning energy consumption, a lot eco-friendlier and are used more often. It is often that there aren't many updates on the amounts of thermal energies provided by technologically updated solar systems. By installing solar collectors, it is possible to exploit a big amount of solar energy in the production of thermal energy. This way, a reduction in the use of fuel is possible, alongside with a reduction in environmental harmful wastes.(Logasol 2007, 2)

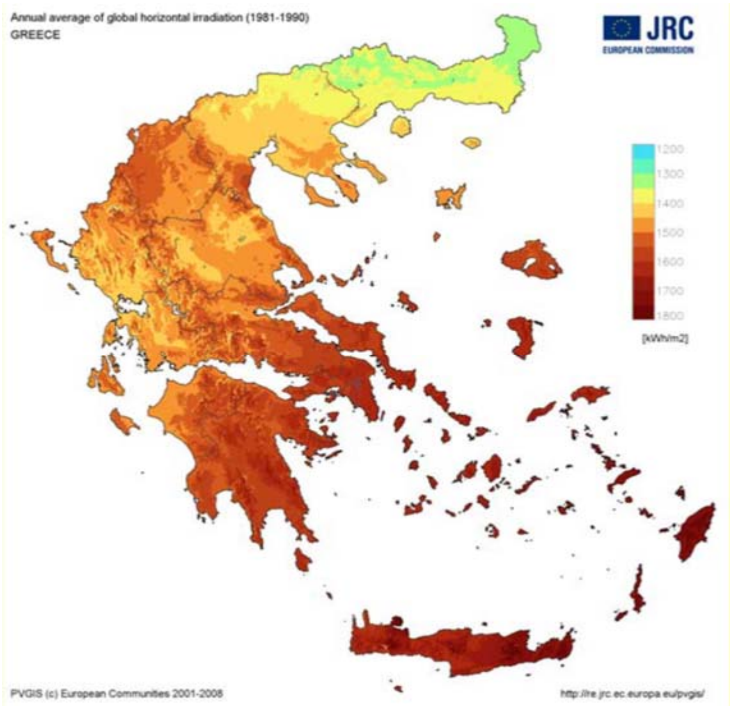


Figure 3: The map of Solar radiation (Logasol 2007, 2)

2.2 Solar Energy Systems

In order to improve everyday day quality of life, an increased energy consumption is required, to make easier some activities. Mankind's anxiousness about the environment, plus the fact that the traditional energy sources will be depleted one day, led the common interest to the renewable energy sources. Among the renewable energy sources, solar energy is one of the outmost interests, due to the fact that it has nearly no impact to the environment. The mature technological advancement on gathering and storing the solar energy, has deemed it a good replacement for the traditional ones (such as oil and electricity).

The European Committee adopted on December 1997 the White Bible for a "Social Strategy and Action Plan, Future Energy: Renewable Energy Sources", placing a target of 12% coming from the addition of Renewable Energy Sources (RES) on the total energy consumption of the European Union until the year 2010.

The general strategy described in the White Bible, contains a “Take off Campaign” to make the total success ratio higher. The wanted increased private investments on RES will be toned up through activities from public relationships and informative public programs, which will fulfill the campaign’s targets. The target for the solar thermal department is the production and sale of 15 million m^2 of solar collectors until the year 2010.

The solar energy system can be divided in many categories – according to their exclusive application, their technology, the size of their system, the climatic conditions etc. The variety of the system synthesis come from the different ways in which the systems store the solar energy. In the end, the main parts of the solar energy systems remain the same in every system synthesis, and they conduct the same basic functions of the thermal procedure.

A summary of a solar energy system’s main part is the following:

- The collector: is the part which absorbs the solar radiation and transforms it into heat, which then is transmitted into a heat transfer fluid (water or even gas) which resides inside the collector
- The tank: is the storage heat facility, where the collected thermal energy is stored, in a way which the solar system can function independent from the thermal needs, allowing the solar energy to be collected and stored, whenever it is available. In some exceptional cases, like the heating of swimming tanks or daily air heating etc., is the non-continuous function acceptable and there is no need for thermal savings.
- The pump: is the device in which the heat transfer fluid circulates in between the collectors and the heat exchangers.
- Control panel: are the devices (such as thermostats, valves etc., which ensure the efficiency and the correct function of the system
- A heat exchanger may be added between the collector and the tank to transfer heat from one fluid to the other.

In the industry, the active central solar energy systems are more common than the passive ones. It must be noted that in the industrial solar energy systems, a regular service and check is advised since they possess moving and electromechanical parts.

The active solar energy systems are using electric pumps, valves and control panels to circulate the water or the other heat transfer fluids (for example water-glucose) from the collectors. There are two types of active systems:

- The active systems with an open circuit use pumps to circulate the water at the collectors. This system is suitable for areas where the outer temperature isn't dropping under 0 ^oC for a big period of time and its water isn't hard or acidic.
- The active systems with a closed circuit transfer the heat transfer fluid in a mixture of glucose and water to the collectors. The heat exchangers transfer the heat from the fluid to the water stored in the tanks.

The central solar energy systems are designed usually from air-conditioning system mechanics or mechanics who specialize in solar energy. In general, the size of the collectors is over 50 m^2 and their storage volume is over than 2000 liters.

For the simpler home water heating systems (for example houses and hotel rooms), simple systems without moving electromechanical parts are efficient to cover their needs. These systems offer the advantage of less need for regular checks and service.

The systems where the water or the heat transfer fluid circuit to the collectors without the use of a pump are called passive systems. Since there are no electromechanical parts in these systems, they are considered to be the most trustful and require less maintenance. They have also a larger lifespan.

The two types of passive solar energy thermal systems are the following:

- The systems with an integrated storage tank are consisted of one or more storage tanks placed in a single larger one, with a surface covered with glass, while facing the sun. During the winter they must be protected from the cold or the water should be evacuated from the system in order to avoid freezing and causing damage to the collector.
- The thermosyphonic systems are based on heat transfer for the circulation of the water to the collectors and the tank, which is placed over the collector. Since the water in the solar collector is being heated, it becomes lighter and elevates to the tank using natural circulation due to the density difference. In the meantime the colder water of the tank is being poured through pipes to the bottom of the collector. (Karagiorga 2000, 3)

Chapter 3

Revit Model

As it has already been mentioned, for this master thesis has been created a model in Revit with the goal to create a solar system that will be located at the roof of the building and it will cover the energy needed for the maturation of yogurt. The procedure has been chosen because it requires low temperatures and following its energy needs can be covered by a solar system. This model is representing the building of a small dairy industry located in the city of Thessaloniki. At figures 4 and 5 is representing the building, as constructed.

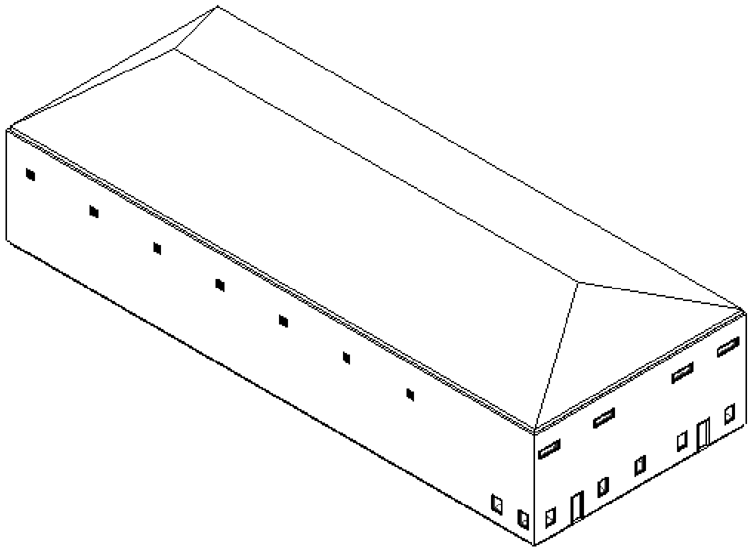


Figure 4: 3D Model of Daily Industry in Revit – South

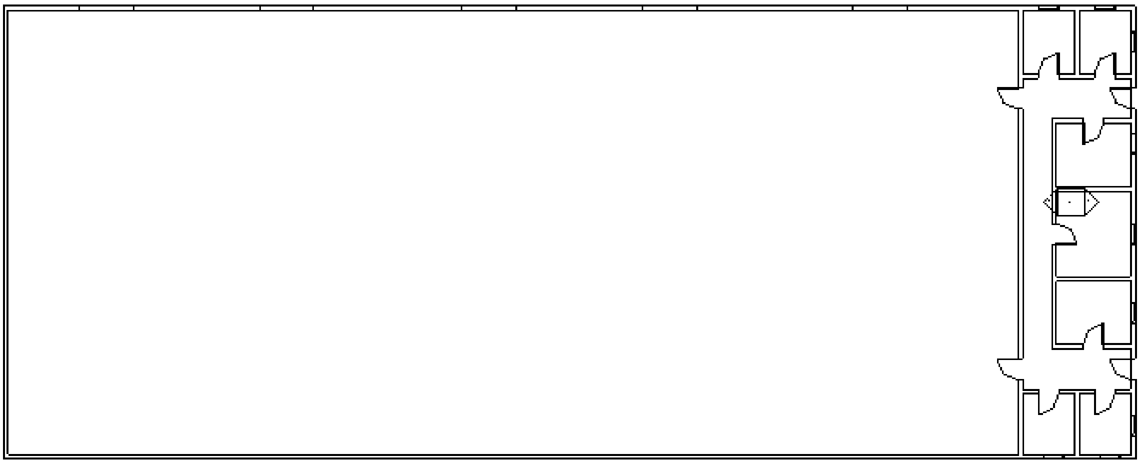


Figure 5: Top view of the building

The building covers an area of 979 m^2 and is constructed by the construction materials that are used in most of the industries.

For the master thesis, a new construction element has been developed that simulates the properties of the solar system that was about to be located at the roof of the building. The new element has been located at the South of the roof and heating and cooling analyses has been performed. The outcome of the analyses is going to be shown at next chapter. The properties of the model along with the analysis that has been extracted can be found at Appendix A.

Chapter 4

Heating and Cooling Analysis

The simulation of the model occurred twice. The only elemental of the building that changed was the roof which has its South side covered with solar system's element. This elemental has been constructed using the following materials:

- Concrete Masonry Units. The thickness of the bottom material is 0.2032m
- Tile, Mosaic, Gray. The thickness of the material is 0.0010m
- Stone wool. The thickness of the material is 0.0500m
- Aluminum. The thickness of the material is 0.0020m
- Si. The thickness of the material is 0.0050m
- Metal Stud Layer. The thickness of the material is 0.0050m
- Si. The thickness of the material is 0.0050m
- Glass. The thickness of the cover material is 0.0100m

The total thickness of the material is 0.2812m.

Following, there is the representation of the heating and cooling analysis of the main building construction and the results coming from the change of the roof. (Appendix A)

4.1 Analysis of the model without the solar system on the roof

Given that the constructional materials that have been used at the model are those that are used at the most industrial buildings, the building's heating and cooling demands, regarding the area of Thessaloniki, is 216 kWh/m^2/year.

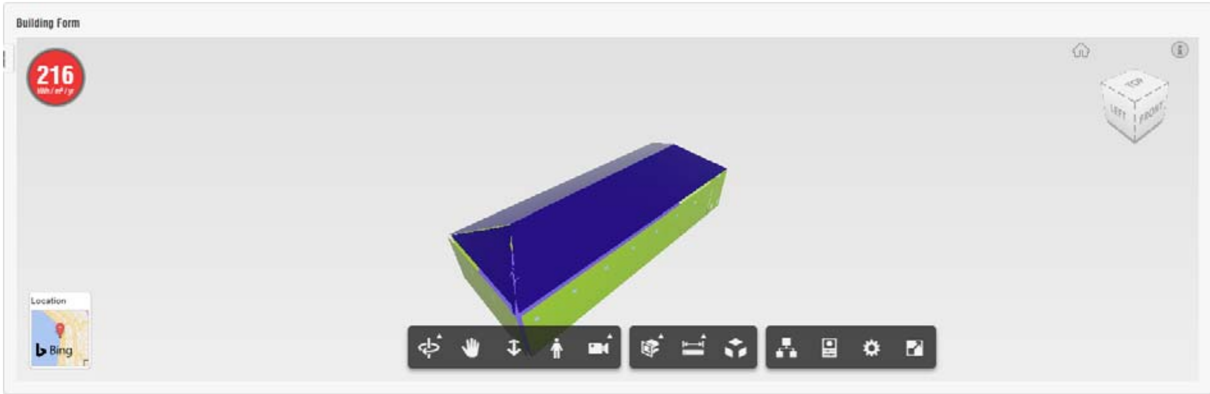


Figure 6: The energy demands of the building per year

The components of the building that will return that value is analyzed at the figures below.

4.1.1 Building orientation

According to the current orientation of the building, 216kWh/m^2/year are required for covering the energy demands of it. If the orientation was slightly changed, then the energy demand will be increased or decreased as figure 7 represents.

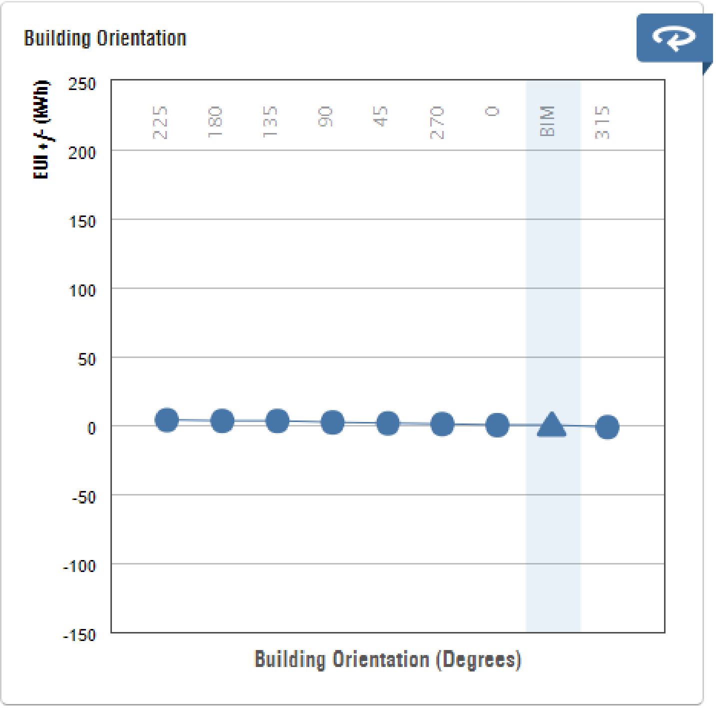


Figure 7: Representation of buildings parameter and the scenarios of changing them

4.1.2 WWR – Southern Walls

According to the current status of WWR – Southern Walls of the building, 216kWh/m^2/year are required for covering the energy demands of it. Same as before, figure 8 represents the current status of the model and the scenarios of changing it.

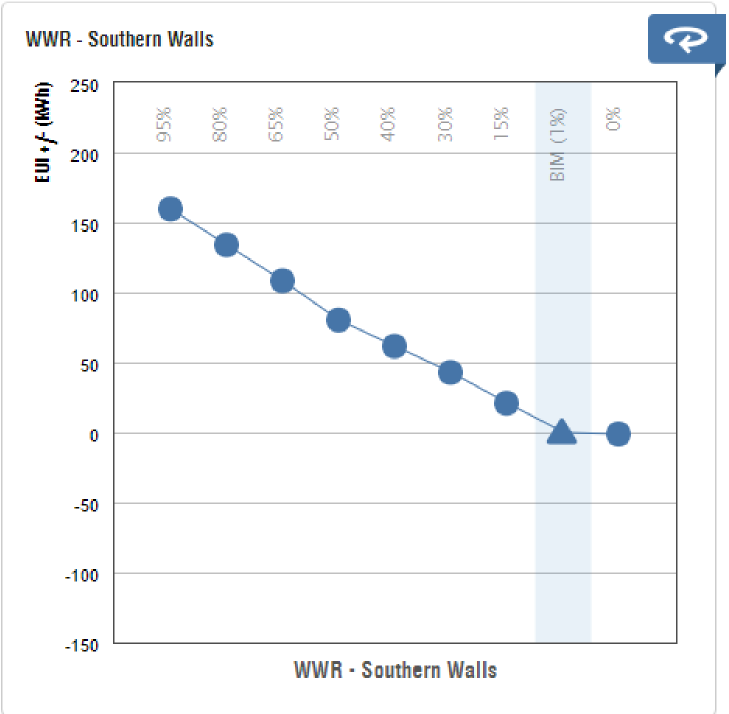


Figure 8: Representation of buildings parameter and the scenarios of changing them

4.1.3 Windows Shades-South

According to the current status of Windows Shades-South of the building, 216kWh/m²/year are required for covering the energy demands of it. Figure 9 represents the current status of the model and the scenarios of changing it.

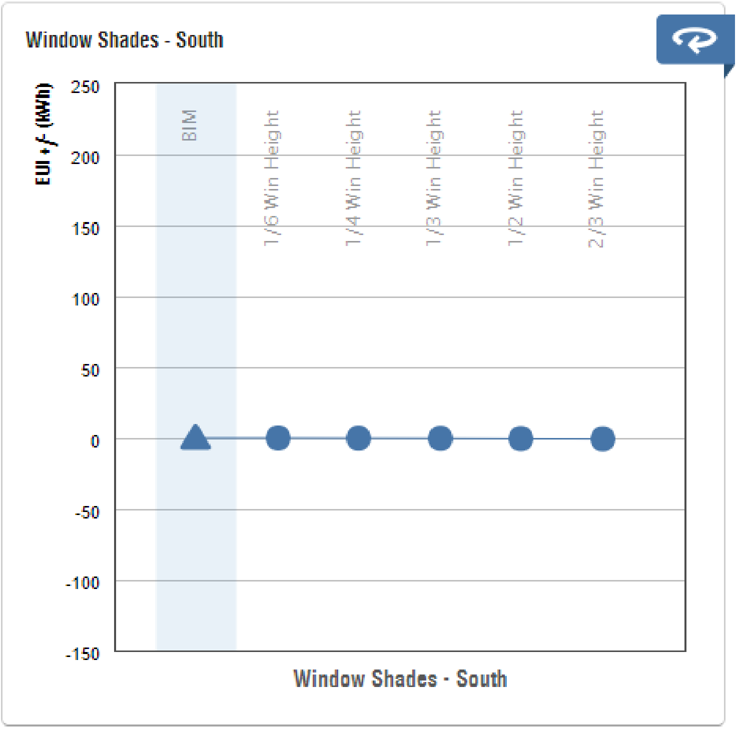


Figure 9: Representation of buildings parameter and the scenarios of changing them

4.1.4 Windows Glass – South

According to the current status of Windows Glass – South of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 10 represents the current status of the model and the scenarios of changing it.

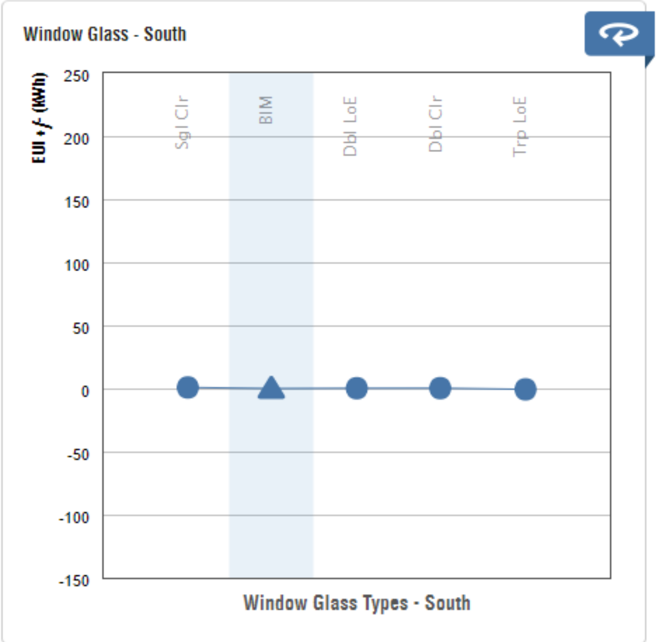


Figure 10: Representation of buildings parameter and the scenarios of changing them

4.1.5 WWR-Northern Walls

According to the current status of WWR-Northern Walls of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 11 represents the current status of the model and the scenarios of changing it.

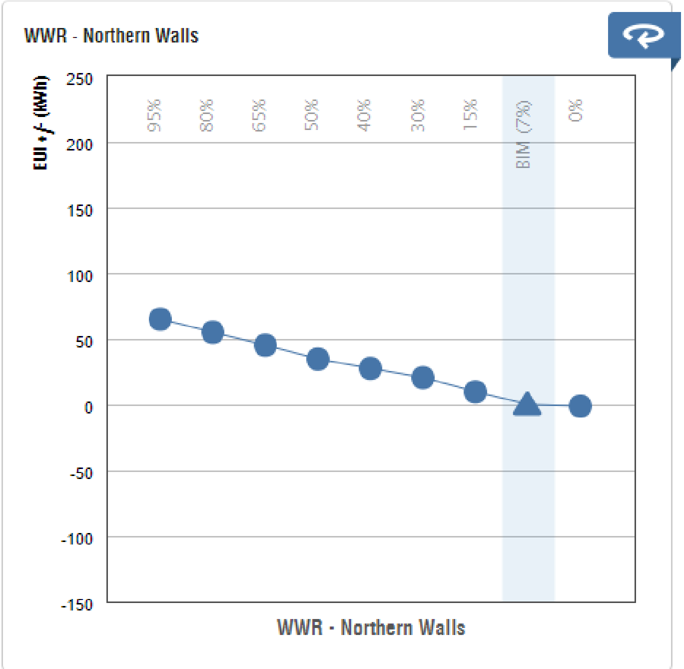


Figure 11: Representation of buildings parameter and the scenarios of changing them

4.1.6 Windows Shades – North

According to the current status of Windows Shades – North of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 12 represents the current status of the model and the scenarios of changing it.

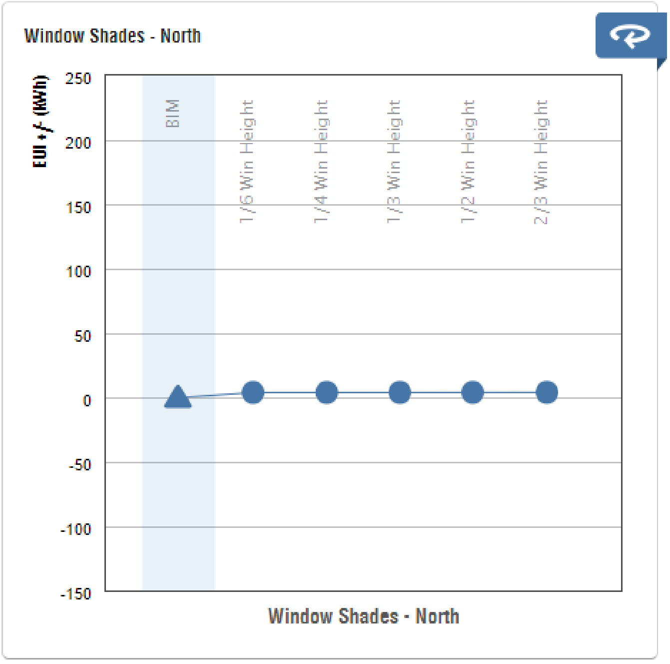


Figure 12: Representation of buildings parameter and the scenarios of changing them

4.1.7 Window Glass -North

According to the current status of Window Glass -North of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 13 represents the current status of the model and the scenarios of changing it.

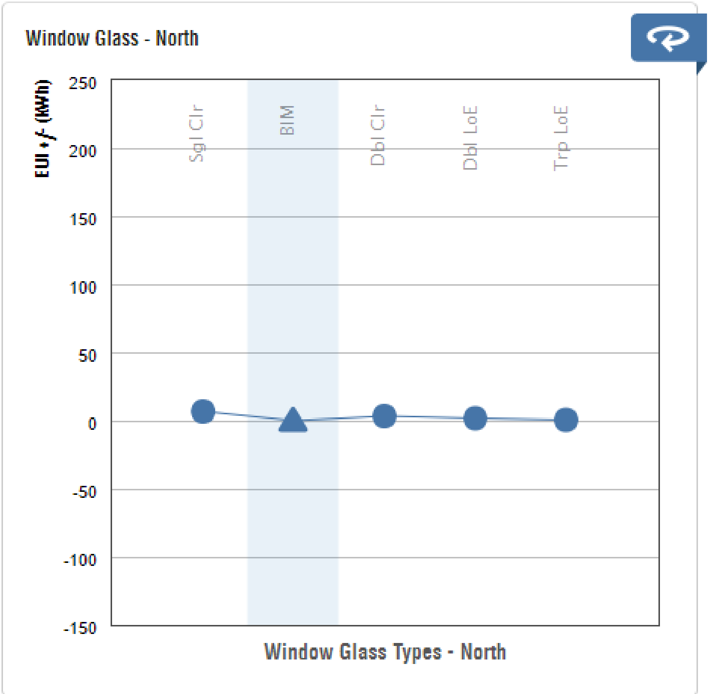


Figure 13: Representation of buildings parameter and the scenarios of changing them

4.1.8 WWR – Western Walls

According to the current status of WWR – Western Walls of the building, 216kWh/m²/year are required for covering the energy demands of it. Figure 14 represents the current status of the model and the scenarios of changing it.

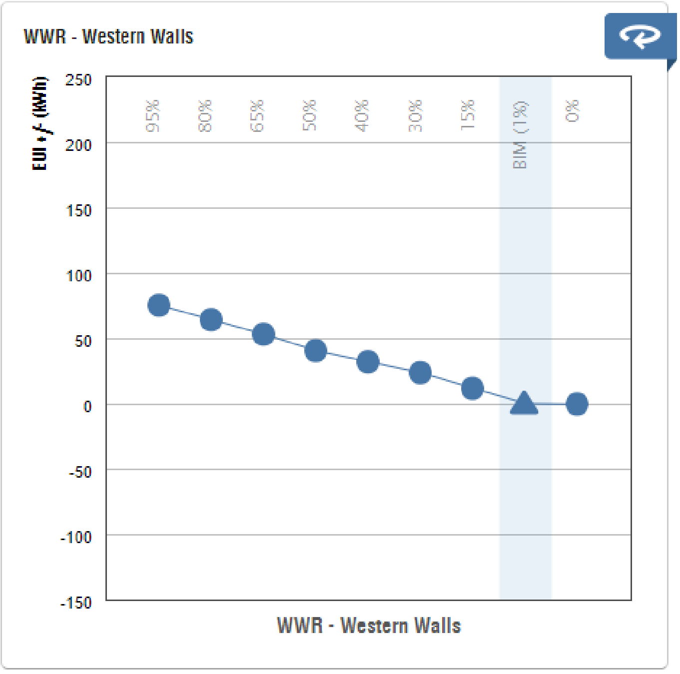


Figure 14: Representation of buildings parameter and the scenarios of changing them

4.1.9 Window Shades – West

According to the current status of Window Shades – West of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 15 represents the current status of the model and the scenarios of changing it.

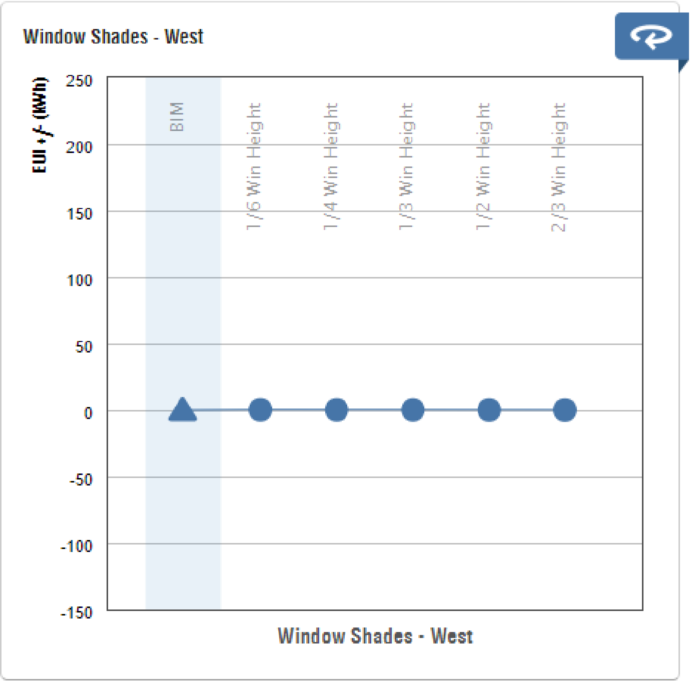


Figure 15: Representation of buildings parameter and the scenarios of changing them

4.1.10 Window Glass- West

According to the current status of Window Glass- West of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 16 represents the current status of the model and the scenarios of changing it.

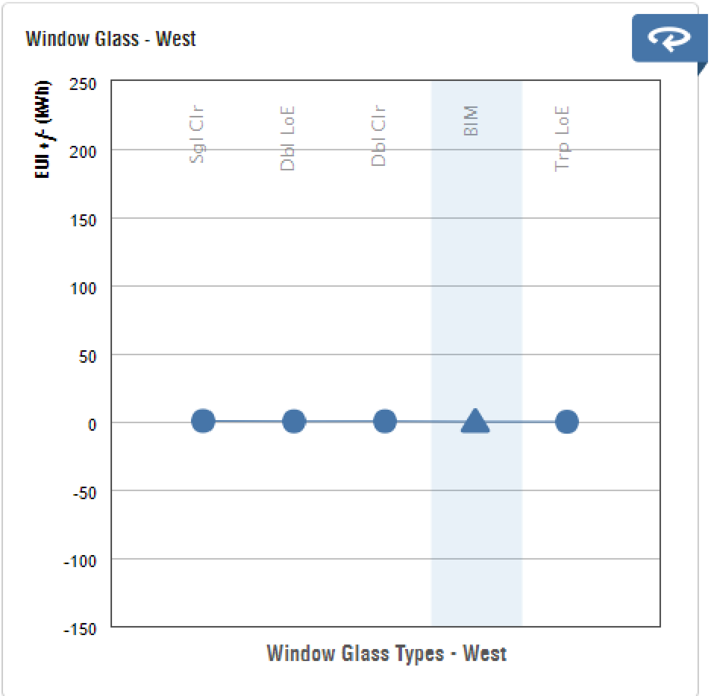


Figure 16: Representation of buildings parameter and the scenarios of changing them

4.1.11 WWR -Eastern Walls

According to the current status of WWR -Eastern Walls of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 17 represents the current status of the model and the scenarios of changing it.

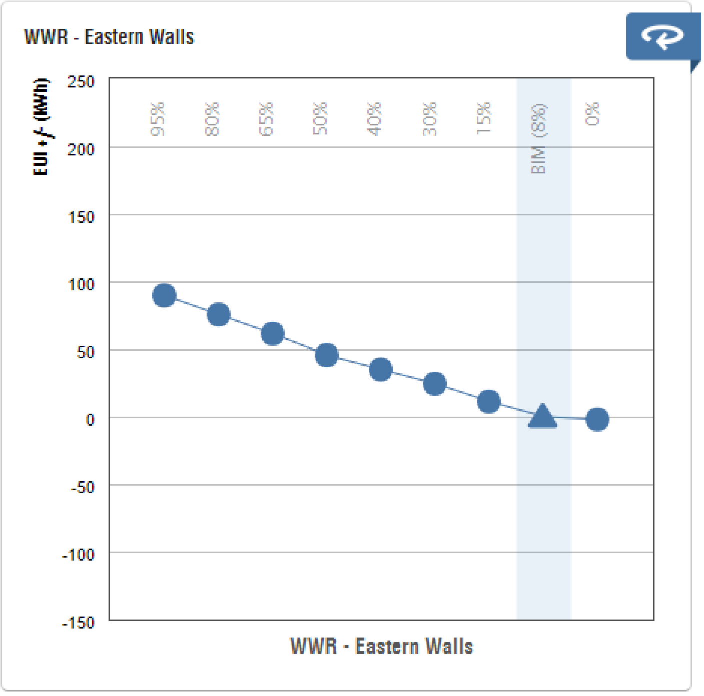


Figure 17: Representation of buildings parameter and the scenarios of changing them

4.1.12 Window Shades -East

According to the current status of Window Shades -East of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 18 represents the current status of the model and the scenarios of changing it.

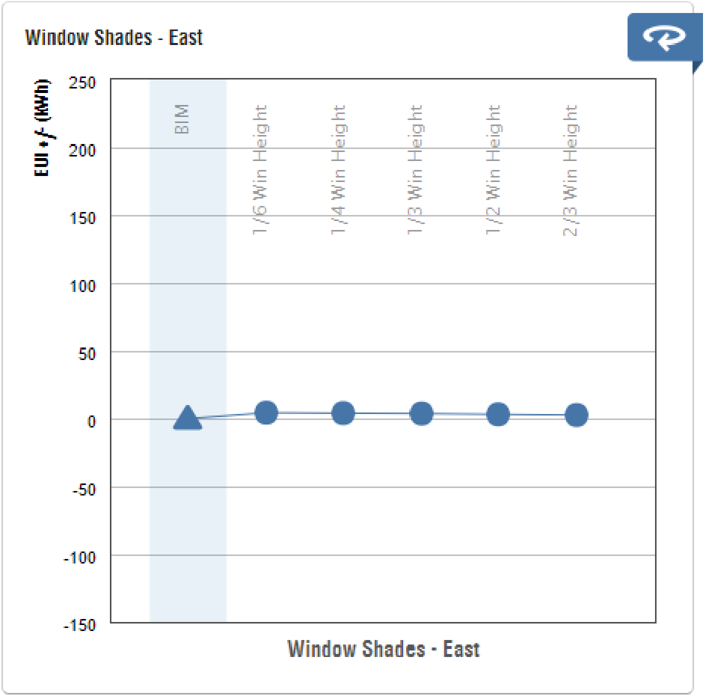


Figure 18: Representation of buildings parameter and the scenarios of changing them

4.1.13 Window Glass – East

According to the current status of Window Shades -East of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 19 represents the current status of the model and the scenarios of changing it.

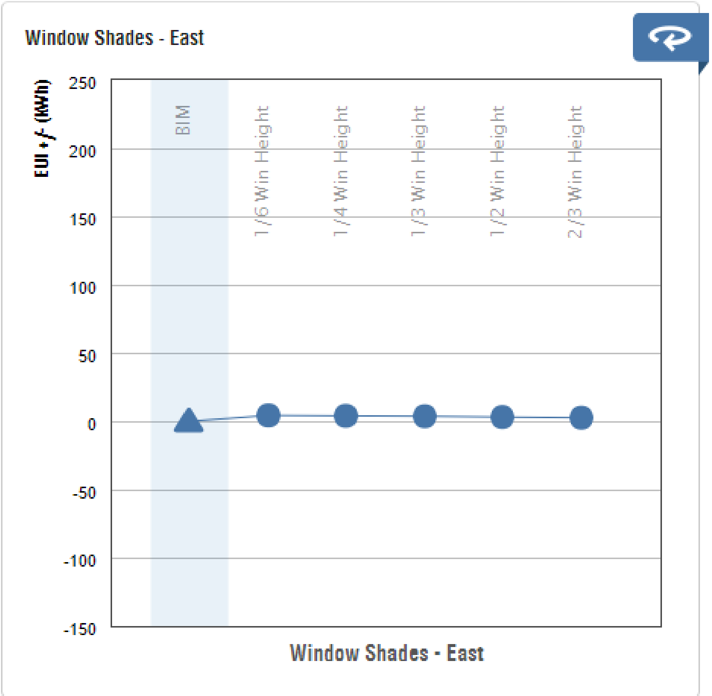


Figure 19: Representation of buildings parameter and the scenarios of changing them

4.1.14 Window Glass – East

According to the current status of Window Glass – East of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 20 represents the current status of the model and the scenarios of changing it.

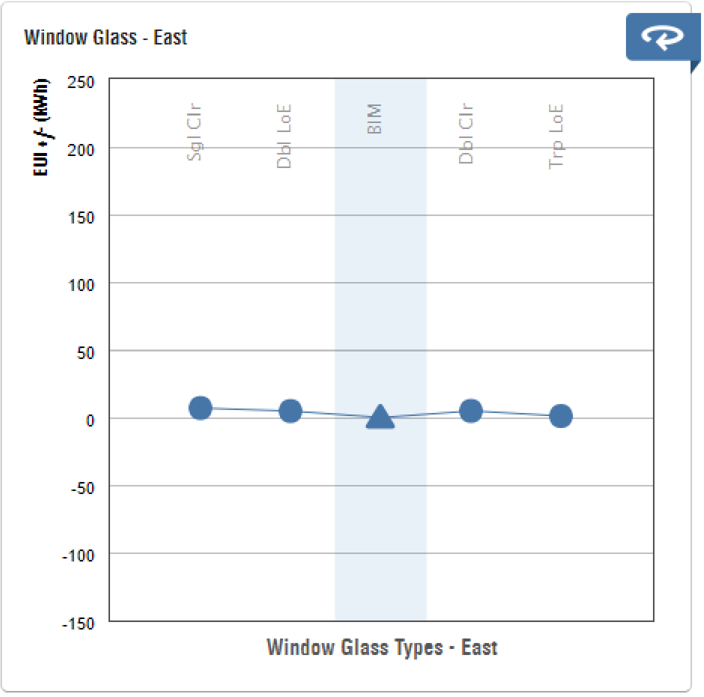


Figure 20: Representation of buildings parameter and the scenarios of changing them

4.1.15 Wall Construction

According to the current status of Wall Construction of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 21 represents the current status of the model and the scenarios of changing it.

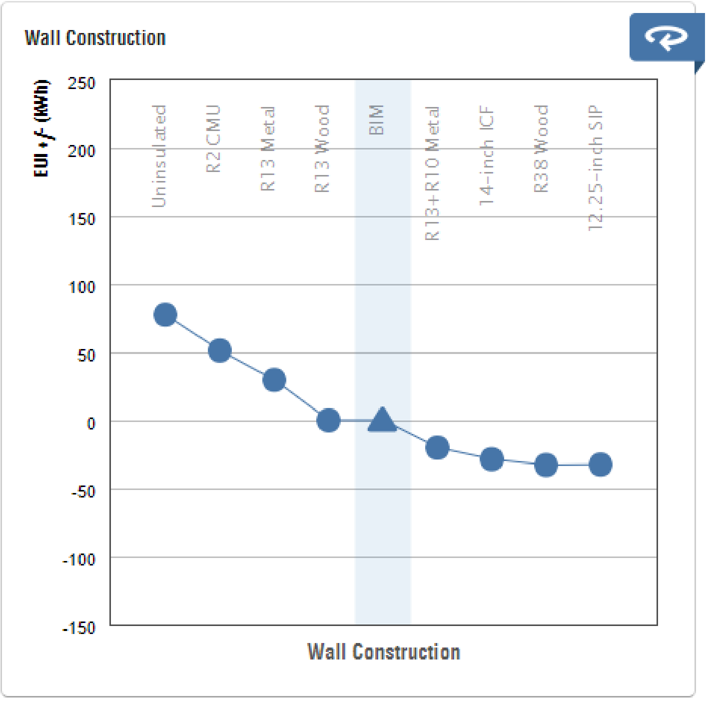


Figure 21: Representation of buildings parameter and the scenarios of changing them

4.1.16 Roof Construction

According to the current status of Roof Construction of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 22 represents the current status of the model and the scenarios of changing it.

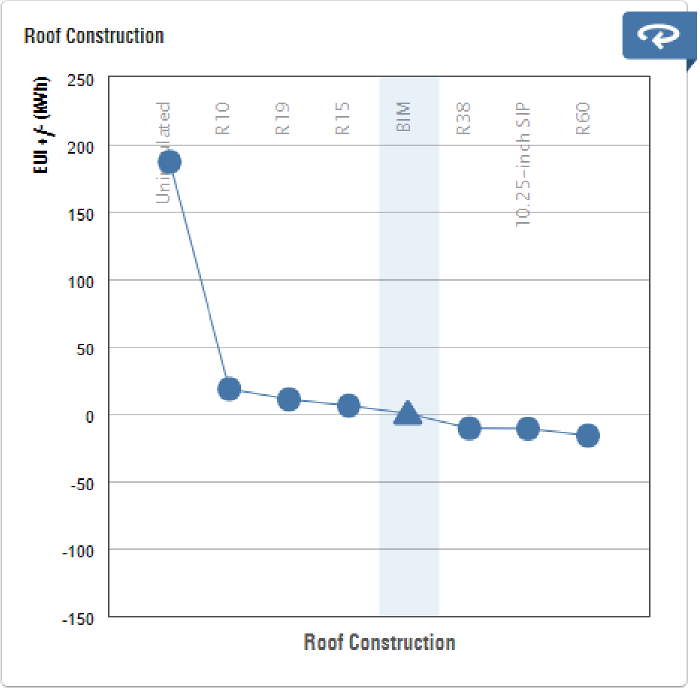


Figure 22: Representation of buildings parameter and the scenarios of changing them

4.1.17 Infiltration

According to the current status of Infiltration of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 23 represents the current status of the model and the scenarios of changing it.

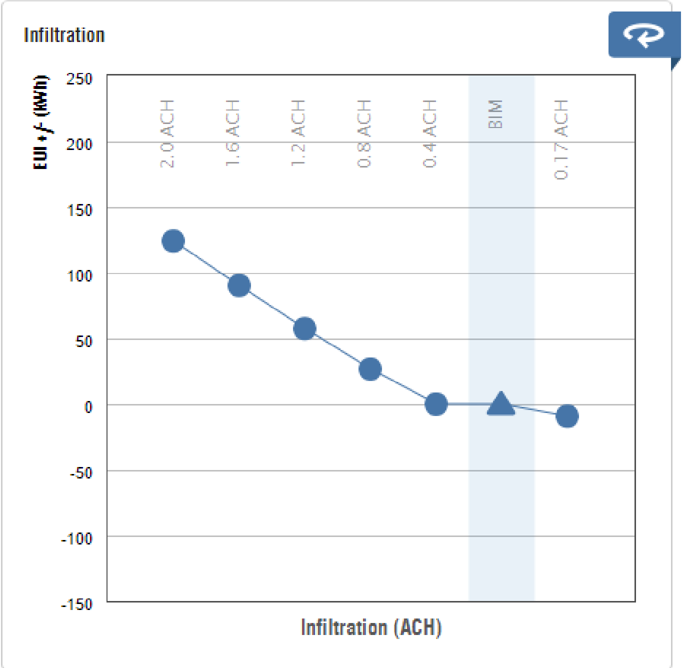


Figure 23: Representation of buildings parameter and the scenarios of changing them

4.1.18 Lighting Efficiency

According to the current status of Lighting Efficiency of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 24 represents the current status of the model and the scenarios of changing it.

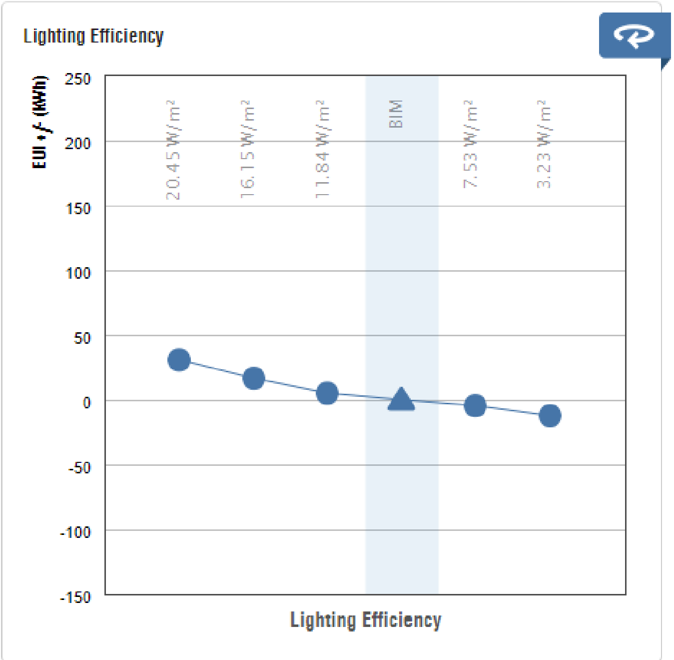


Figure 24: Representation of buildings parameter and the scenarios of changing them

4.1.19 Daylighting &Occupancy Controls

According to the current status of Daylighting &Occupancy Controls of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 25 represents the current status of the model and the scenarios of changing it.

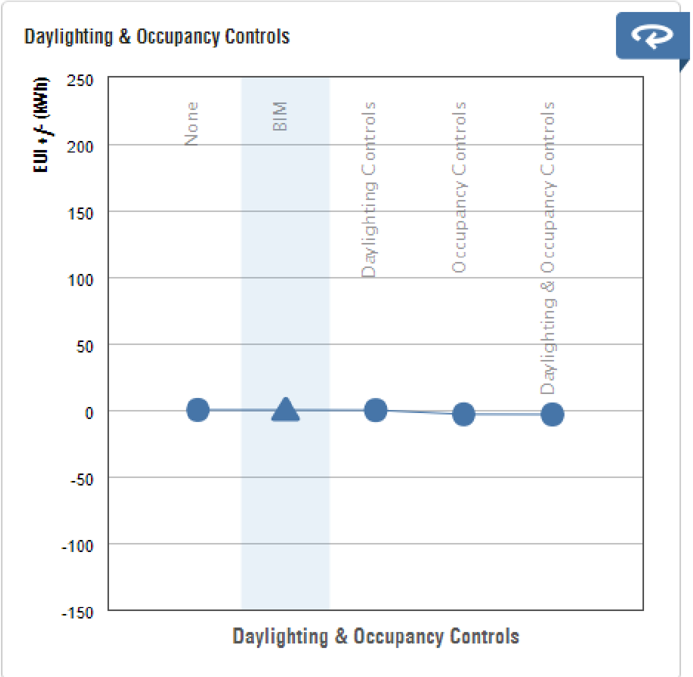


Figure 25: Representation of buildings parameter and the scenarios of changing them

4.1.20 Plug Load Efficiency

According to the current status of Plug Load Efficiency of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 26 represents the current status of the model and the scenarios of changing it.

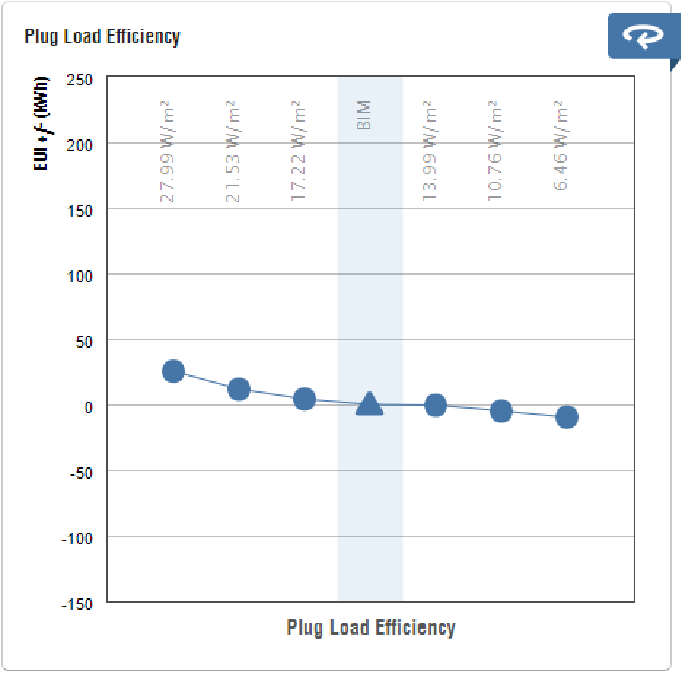


Figure 26: Representation of buildings parameter and the scenarios of changing them

4.1.21 HVAC

According to the current status of HVAC of the building, 216kWh/m^2/year are required for covering the energy demands of it. Figure 27 represents the current status of the model and the scenarios of changing it.

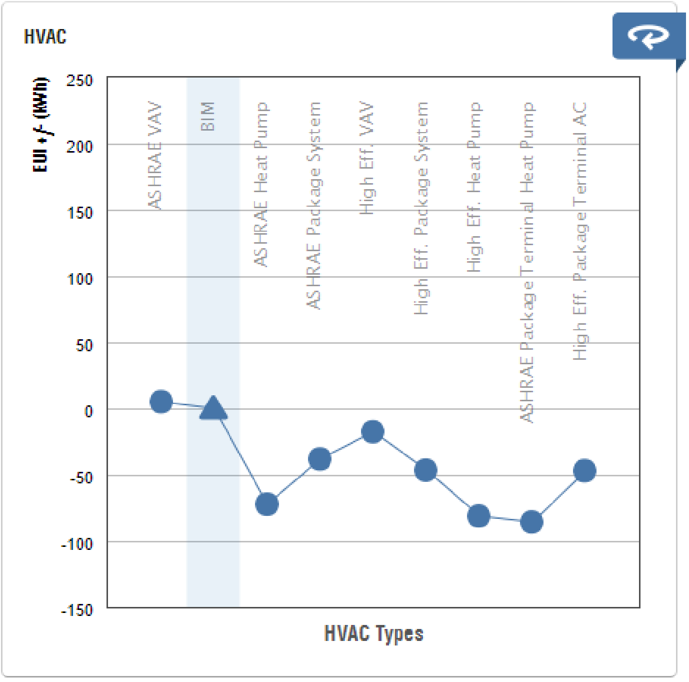


Figure 27: Representation of buildings parameter and the scenarios of changing them

4.1.22 Operating Schedule

According to the current status of Operating Schedule of the building, 216kWh/m2/year are required for covering the energy demands of it. Figure 28 represents the current status of the model and the scenarios of changing it.

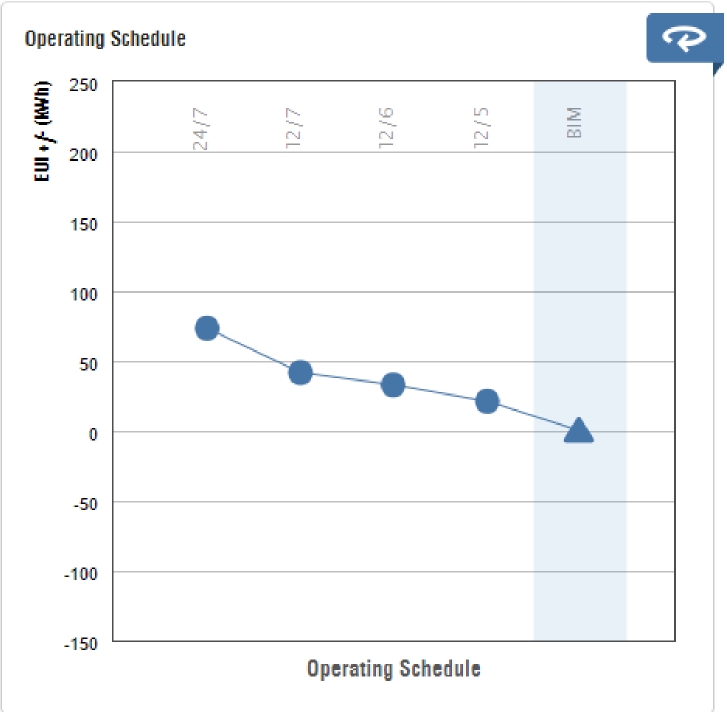


Figure 28: Representation of buildings parameter and the scenarios of changing them

4.2 Analysis of the model with the solar system on the roof

The second simulation of the model took place after the replacement of the South side of the roof with the material that had been constructed for simulating the solar system. Given that there are no other changes at the model, the new energy demands of the building are resulting by this change. The solar system will be extended 458.171m^2.

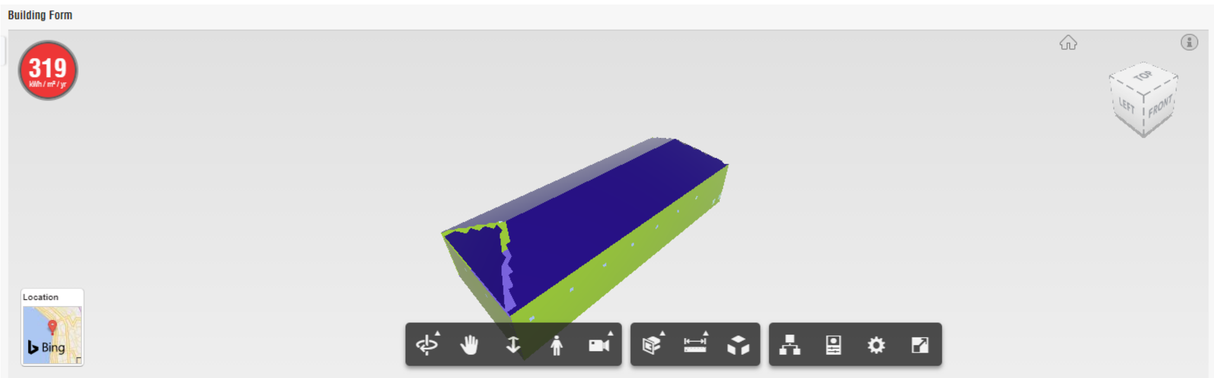


Figure 29:The energy demands of the building per year

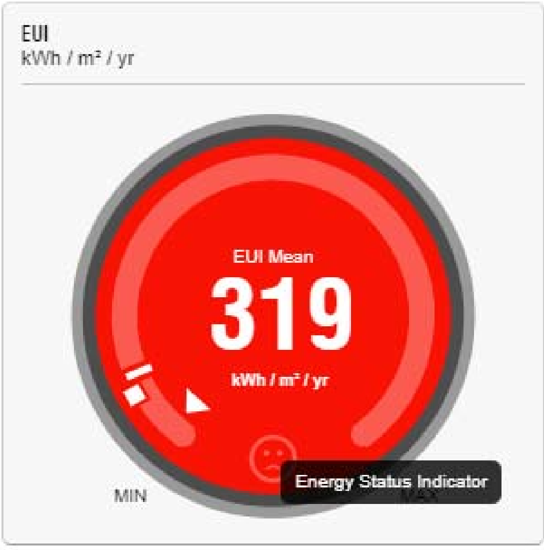


Figure 30: Energy demands for heating and cooling of the building

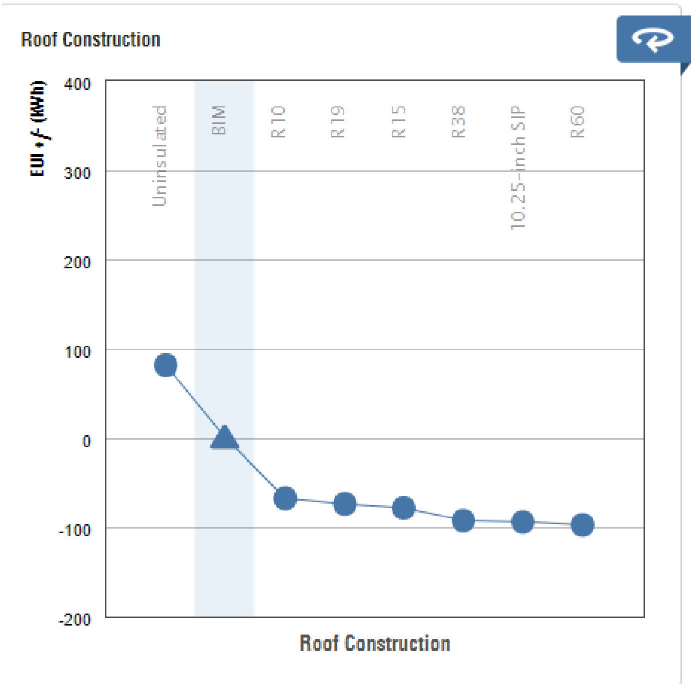


Figure 31: Representation of buildings parameter and the scenarios of changing them

According to the current status of Roof Construction of the building, 319kWh/m^2/year are required for covering the energy demands of it (Figure 30). Figure 31 represents the current status of the model and the scenarios of changing it.

The demands for the energy need of the building have been slightly increased which was expected due to the fact that the construction element is created for the solar system and not for the insulation of the building.

Chapter 5

T-Sol Model

As it is mentioned, the industrial process that has been chosen for this Master Thesis is the yogurt maturation. This process requires 45 ^{o}C to be completed. Given that the dairy industry will process 500 lt of milk per day and it will operate for 5 days per week and 24 hours per day, it has been calculated the amount of energy required for the fulfillment of the process.

The amount of energy that the process requires is given by: (Zagnaferis 2018, 36)

$$Q=m*C_p*\Delta T$$

m=500lt/d = 0.138 lt/s

$C_{p,milk}$ = 3.85 kJ/kg* ^{o}C

$C_{p,water}$ = 4.182 kJ/kg* ^{o}C

ΔT = (45 ^{o}C – 5 ^{o}C) = 40 ^{o}C

The mean that will be used for the heat at the desire temperature will be water in our system.

Q = 0.138 * 3.85 *40= 21.4kW

Q'=Q*h= 21.4 *24 = 513kWh

So, the process requires 513kWh for the maturation of yogurt per day. But, the mean that will be used at the solar system is water and it is going to be used a heat exchanger. That means, that the energy required for the process will be slightly increased and it will be calculated as:

Q= 0.138*4.182*40 = 23.1kW

Q' = 23.1 *24=560kWh

Finally, the energy that the process will need is 560kWh/day.

5.1 Model's Characteristics

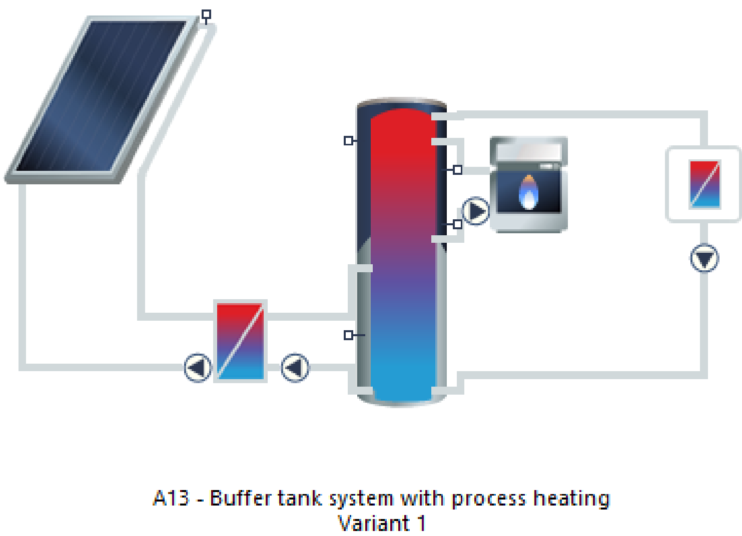


Figure 32: Model of the Solar System

The model that has been created at T-Sol has the above form. It consists of:

- Solar Panels – 100 panels
- Collector Loop Heat Exchanger – 31.91K
- Buffer tanks – 10 tanks
- Gas – Fired Boiler – 1 boiler
- Process Heat

5.1.1 Solar Panels

There was the space at the roof of the dairy industry, as it has been designed at Revit, to locate more panels. Although, the solar system uses 100 panels because that number is enough to cover the energy needs of the maturation of yogurt.

5.1.2 Collector Loop Heat Exchanger

For the calculation of the Collector's Loop Heat Exchanger has been used the equation: (Fokaides 2019,4)

$$\Delta T_{\mathrm{lm}} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

Where:

$\Delta T_1 = T_{h,in} - T_{c,in} = 65 - 25 = 40\ ^{o}C$

$\Delta T_2 = T_{h,out} - T_{c,out} = 50 - 45 = 5\ ^{o}C$

$\Delta T_{lm} = 16.83\ ^{o}C$

5.1.3 Buffer tanks

The buffer tanks have been chosen to be 10 because that would enable a more efficient solar system.

5.1.4 Gas – Fired Boiler

One gas fired is in use for the system. The boiler is in use from November to February, the months that the solar energy is the less.

5.1.5 Process Heat

The heat process has been calculated before and it is set at 560kWh.

5.2 Results

The solar system as it has been analyzed above has efficiency at 47.6%. The efficiency is acceptable. The system's parameter and the results are shown at Appendix B.

Results of annual simulation

Installed collector power:		141.40 kW
Installed solar surface area (gross):		202 m^2
Irradiation on collector surface (active):	308,500.92 kWh	1,676.64 kWh/m^2
Energy delivered by collectors:	162,580.20 kWh	883.59 kWh/m^2
Energy delivered by collector loop:	158,025.68 kWh	858.84 kWh/m^2
Process heating energy supply:		137,200.00 kWh
Solar contribution:		146,893.67 kWh
Energy from auxiliary heating:		55,358.6 kWh
Total solar fraction:		**72.6 %**
System efficiency:		**47.6 %**

Figure 33: Results of annual simulation from T-Sol

Conclusions

In conclusion, this Master Thesis has analyzed two models. The first one coming from Revit, has set the ground of the load requirements regarding the building which will house the industrial process under study, yogurt maturation. At the same time, it sets the available space on which we could set the solar system and after choosing a territory for it, we extracted the energy requirements of the building with the system on it. The result showed that the panels will actually increase the needs for heating and cooling loads at the building.

Keeping the above result in mind, we studied the second model, coming from T-Sol. The energy requirements for the industrial procedure has been analyzed above and for that result has been set the minimum temperature at 5 ^{o}C. This value was resulting by the first analysis.

After creating the model of Solar System, the analysis showed that the efficiency of it is 47.6%. The system considered effective. It will cover a big amount of energy required for the industrial process that it will created for and it can be suggested for installation for this industrial process.

References

EPA, United States Environmental Protection Agency, (2019a), Renewable Industrial Process Heat. https://www.epa.gov/rhc/renewable-industrial-process-heat [Access: 16.05.2019]

EPA, United States Environmental Protection Agency, (2019b), Industrial Process Heat Technologies and Applications: Text Version of the Diagram. https://www.epa.gov/rhc/industrial-process-heat-technologies-and-applications-text-version-diagram [Access: 16.05.2019]

Krmelj,V., (2019), Selected industrial processes which require low temperature heat, http://www.solar-process-heat.eu/fileadmin/redakteure/So-Pro/Events/Krmelj_09062011.pdf [Access: 16.05.2019]

CRES, (2019a), Solar Systems Applications in the Dairy Industry, http://www.cres.gr/kape/pdf/download/dairy_leaflet.pdf [Access: 16.05.2019]

Romanowski, P., (2019), Yogurt, http://www.madehow.com/Volume-4/Yogurt.html [Access: 16.05.2019]

Logasol, (2007), Solar systems technology Logasol for preparation hot water and hot water heating support, https://www.buderus.gr/files/201106211547430.%CE%95%CE%B3%CF%87%CE%B5%CE%B9%CF%81%CE%AF%CE%B4%CE%B9%CE%BF%20%CE%B7%CE%BB%CE%B9%CE%B1%CE%BA%CF%8E%CE%BD%20%CF%83%CF%85%CF%83%CF%84%CE%B7%CE%BC%CE%AC%CF%84%CF%89%CE%BD%20%CE%92uderus%20Solar.pdf [Access: 16.05.2019]

Karagiorga, M., (2000), Technical and Economic Report on the Applications of Solar Thermal Systems in the Dairy Industry, http://www.bonair.gr/data/11_19.pdf [Access: 16.05.2019]

Zagnaferis, I., (2018), Energy Savings and using Renewable Sources in small farms, Thessaloniki, Auth

Fokaides, P., (2019), Industrial Processes, Nicosia, Frederick University

Appendix A

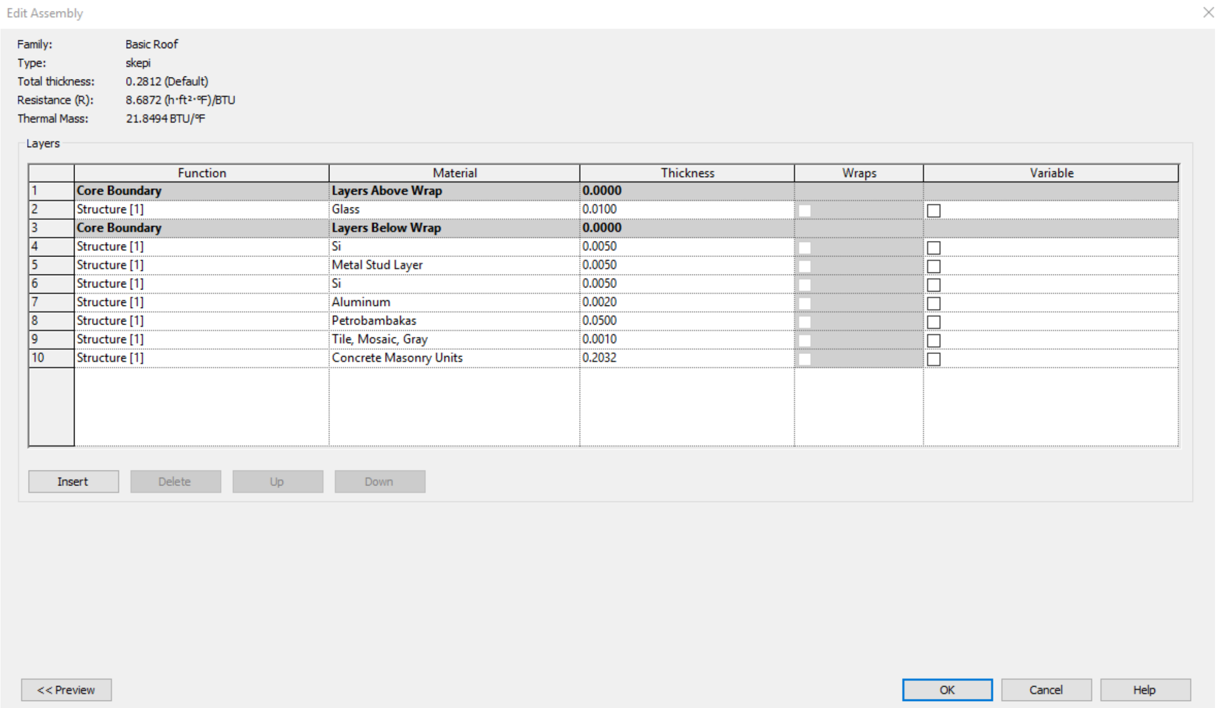
Revit Model

A.1 Properties of the model

General | Details

Parameter	Value
Building Type	Manufacturing
Location	Thessaloniki, Greece
Ground Plane	Level 1
Project Phase	New Construction
Sliver Space Tolerance	0.3048
Building Envelope	Use Function Parameter
Building Service	VAV - Single Duct
Schematic Types	<Building>
Building Infiltration Class	None
Report Type	Standard
Use Load Credits	☐

A.2 New Element's structure


Edit Assembly

Family: Basic Roof
Type: skepi
Total thickness: 0.2812 (Default)
Resistance (R): 8.6872 (h·ft²·°F)/BTU
Thermal Mass: 21.8494 BTU/°F

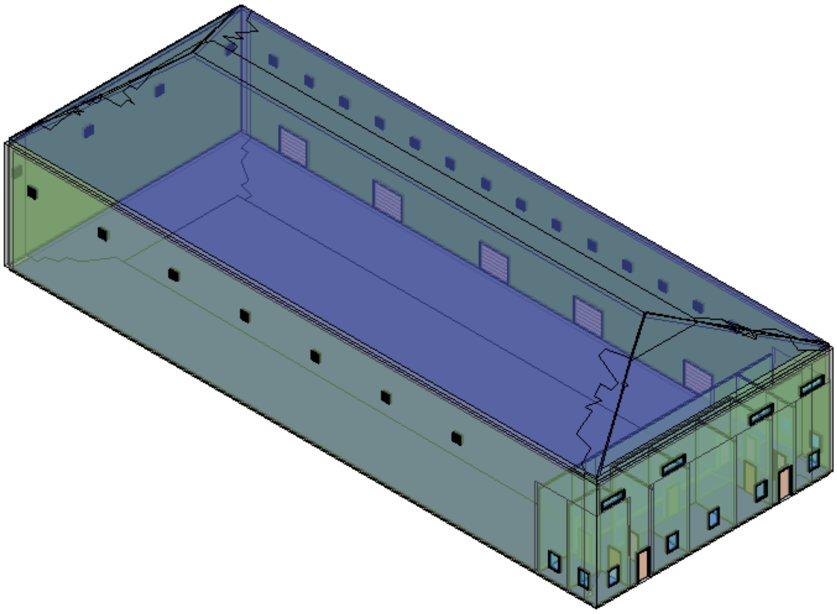
Layers

	Function	Material	Thickness	Wraps	Variable
1	**Core Boundary**	**Layers Above Wrap**	**0.0000**		
2	Structure [1]	Glass	0.0100	☐	☐
3	**Core Boundary**	**Layers Below Wrap**	**0.0000**		
4	Structure [1]	Si	0.0050	☐	☐
5	Structure [1]	Metal Stud Layer	0.0050	☐	☐
6	Structure [1]	Si	0.0050	☐	☐
7	Structure [1]	Aluminum	0.0020	☐	☐
8	Structure [1]	Petrobambakas	0.0500	☐	☐
9	Structure [1]	Tile, Mosaic, Gray	0.0010	☐	☐
10	Structure [1]	Concrete Masonry Units	0.2032	☐	☐

Insert Delete Up Down

<< Preview OK Cancel Help

A.3 Energy Model



A.4 Outcome from load analysis with located solar system

Load calculation summary report

Summary of heating and cooling loads for spaces

Project summary

Location and Weather	
Project	Project Name
Location	THESSALONIKI - GRC IWEC Data WMO#=166220
Latitude	40,52
Longitude	22.97

Building summary

Inputs	
Area (SF)	10340.96
Volume (CF)	352980.44
Calculated Results	
Peak Cooling Total Load(Btu/h)	223878.52
Peak Cooling Month and Hour	7/21 17:00:00
Peak Cooling Sensible Load(Btu/h)	209339.31
Peak Cooling Latent Load(Btu/h)	14539.19
Peak Heating Load(Btu/h)	-257963.70
Checksums	
Cooling Load Density (Btu/(h·ft²))	21.65
Heating Load Density (Btu/(h·ft²))	-24.95

Space Summary "Space_9"

Inputs	

Area (SF)	10340.96
Volume (CF)	352980.44
Cooling Setpoint (°F)	75.02
Heating Setpoint (°F)	64.93
Relative Humidity (%)	45.67
Calculated Results	
Peak Cooling Total Load (Btu/h)	223878.52
Peak Cooling Month and Hour	7/21 17:00:00
Peak Cooling Sensible Load (Btu/h)	209339.31
Peak Cooling Latent Load (Btu/h)	14539.19
Peak Heating Load (Btu/h)	-257963.70
Checksums	
Cooling Load Density (Btu/(h·ft²))	21.65
Heating Load Density (Btu/(h·ft²))	-24.95

Components	Cooling		Heating	
	Loads(Btu/h)	Percentage of Total	Loads(Btu/h)	Percentage of Total
Wall	-360032.41	-160.82	-112657.90	43.67
Window	8747.43	3.91	-4828.10	1.87
Door	-10864.10	-4.85	-4953.40	1.92
Roof	57408.20	25.64	-110718.00	42.92
Partition	0.00	0.00	0.00	-0.00
Floor	-24650.00	-11.01	20560.74	-7.97
Infiltration	17162.31	7.67	-144816.41	56.14
Ventilation	0.00	0.00	0.00	-0.00
Lighting	208833.02	93.28	41246.11	-15.99
Power	242447.56	108.29	44665.69	-17.31
People	84826.50	37.89		
Other	0.00	0.00	0.00	-0.00

Total	**223878,52**	100,0	**-257963,70**	100,0

Outcome With New Element.pdf

A.5 Outcome from load analysis without located solar system

Load calculation summary report

Summary of heating and cooling loads for spaces

Project summary

Location and Weather	
Project	Project Name
Location	THESSALONIKI - GRC IWEC Data WMO#=166220
Latitude	40.52
Longitude	22.97

Building summary

Inputs	
Area (SF)	10340.96
Volume (CF)	352635.66
Calculated Results	
Peak Cooling Total Load(Btu/h)	257941.91
Peak Cooling Month and Hour	7/21 17:00:00
Peak Cooling Sensible Load(Btu/h)	243233.72
Peak Cooling Latent Load(Btu/h)	14708.17
Peak Heating Load(Btu/h)	-310937.00
Checksums	
Cooling Load Density (Btu/(h·ft²))	24.94
Heating Load Density (Btu/(h·ft²))	-30.07

Space Summary "Space_9"

Inputs	
Area (SF)	10340.96
Volume (CF)	352635.66
Cooling Setpoint (°F)	75.02
Heating Setpoint (°F)	64.93
Relative Humidity (%)	47.36
Calculated Results	
Peak Cooling Total Load (Btu/h)	257941.91
Peak Cooling Month and Hour	7/21 17:00:00
Peak Cooling Sensible Load (Btu/h)	243233.72
Peak Cooling Latent Load (Btu/h)	14708.17
Peak Heating Load (Btu/h)	-310937.00
Checksums	
Cooling Load Density (Btu/(h·ft²))	24.94
Heating Load Density (Btu/(h·ft²))	-30.07

Components	Cooling		Heating	
	Loads(Btu/h)	Percentage of Total	Loads(Btu/h)	Percentage of Total
Wall	-339702.50	-131.70	-83329.00	26.80
Window	7858.29	3.05	-4635.70	1.49
Door	-10246.30	-3.97	-3922.00	1.26
Roof	101808.91	39.47	-159203.50	51.20
Partition	0.00	0.00	0.00	-0.00
Floor	-26797.30	-10.39	23253.91	-7.48
Infiltration	17321.78	6.72	-147405.41	47.41
Ventilation	0.00	0.00	0.00	-0.00
Lighting	196897.42	76.33	26751.61	-8.60

Power	229476.69	88.96	28969.28	-9.32
People	81324.92	31.53		
Other	0,00	0,00	0,00	-0,00
Total	**257941.91**	100.0	**-310937.00**	100.0

Outcome Without
New Element.pdf

Appendix B

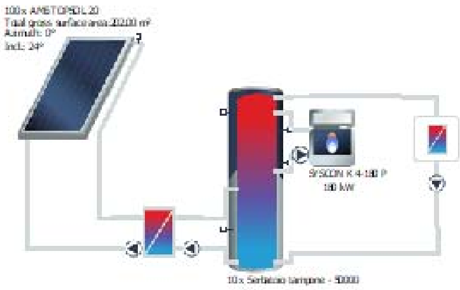
T-Sol Model

B.1 T-Sol Outcome Report

-

-

Variant 1



Results of annual simulation

Installed collector power:		141.40 kW
Installed solar surface area (gross):		202 m²
Irradiation on collector surface (active):	308,500.92 kWh	1,676.64 kWh/m²
Energy delivered by collectors:	162,580.20 kWh	883.59 kWh/m²
Energy delivered by collector loop:	158,025.68 kWh	858.84 kWh/m²
Process heating energy supply:		137,200.00 kWh
Solar contribution:		146,893.67 kWh
Energy from auxiliary heating:		55,358.6 kWh
Total solar fraction:		**72.6 %**
System efficiency:		**47.6 %**

T*SOL 2018 (R2) 15-May-19

Valentin Software GmbH Page 1 from 8

-

-

Variant 1

Site Data

Climate data

Location:	Thessaloniki
Climate data record:	Thessaloniki
Total annual global irradiation:	1555.569 kWh/m²
Latitude:	40.52 °
Longitude:	-22.97 °

Process heat

Average daily consumption:	560 kWh
Supply temperature:	45 °C
Minimum outlet temperature:	20 °C
Return temperature:	20 °C
Consumption profile:	Custom
Days without water consumption:	120

T*SOL 2018 (R2) 15-May-19

Valentin Software GmbH Page 2 from 8

-

-

Variant 1

System

Collector loop

Manufacturer:	A.M.E. GmbH
Type:	AME-TOPSOL 20
Number:	100.00
Total gross surface area:	202 m²
Total active solar surface area:	184 m²
Inclination (Tilt Angle):	23.6 °
Orientation:	180 °
Azimuth:	0 °

Buffer tank

Manufacturer:	Riello
Type:	10 x Serbatoio tampone - 50000
Volume:	10 x 50 m³

Auxiliary heating

Manufacturer:	Thermital
Type:	SYSCON K 4-180 P
Nominal output:	180 kW

Legend

With test report

Solar Keymark

T*SOL 2018 (R2) 15-May-19

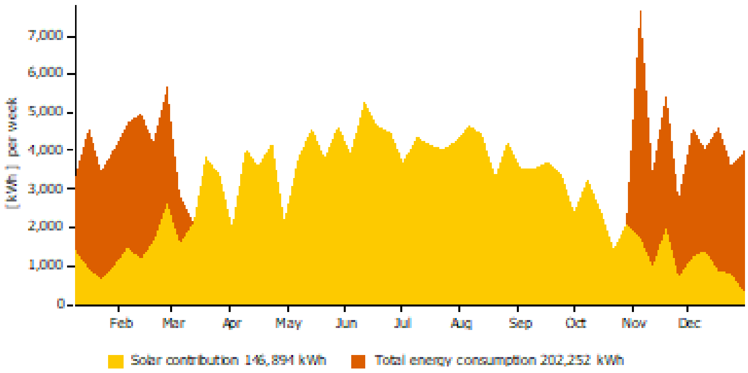
Valentin Software GmbH Page 3 from 8

-

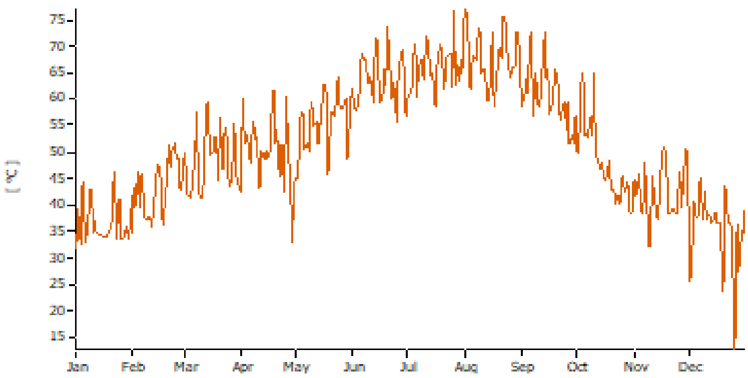
-

Variant 1

Solar energy consumption as percentage of total consumption



Daily maximum collector temperature



These calculations were carried out by T*SOL 2018 (R2) - the simulation program for solar thermal heating systems The results are determined by a mathematical model calculation with variable time steps of up to 6 minutes. Actual yields can deviate from these values due to fluctuations in climate, consumption and other factors. The system schematic diagram above does not represent and cannot replace a full technical drawing of the solar system.

T*SOL 2018 (R2) 15-May-19

Valentin Software GmbH Page 4 from 8

-
-

Variant 1

Financial analysis

System

Active solar surface:	184 m²
System yield:	146,893.67 kWh
Annual fuel savings:	18,796.4 m³ Natural gas (H)

Financial analysis parameters

Life span:	20 Years
Interest on capital:	2.5 %
Reinvestment return:	2.5 %
Energy cost escalation rate:	2.0 %
Running cost escalation rate:	1.0 %

Financing

Total investments:	73,600 $
Subsidies:	0 $
Loan capital:	0 $
Remaining investment:	73,600 $
Running costs in first year:	0 $
Savings in first year:	9,398 $

Financial analysis

Cost of solar energy:	0.032 $/kWh
Capital return time:	7.3 Years
Amortization period:	8.2 Years

Profitability

Return on assets:	310.3 %
Return on equity:	310.3 %
Internal rate of return rate, IRR:	13.17 %
Net present value:	101,525 $

Reinvestment premise

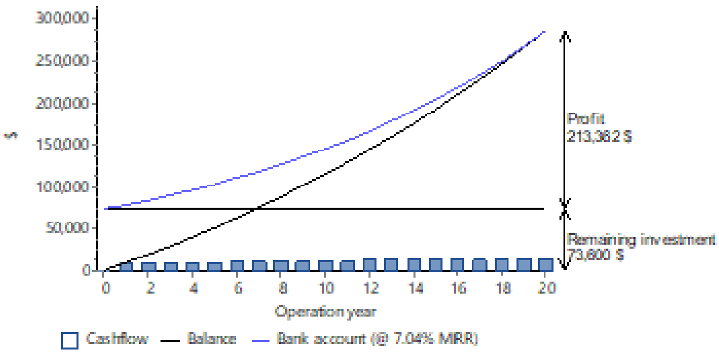
Profit:	213,362 $
Modified internal rate of return, MIRR:	7.04 %

T*SOL 2018 (R2) 15-May-19
Valentin Software GmbH Page 5 from 8

-

-

Variant 1

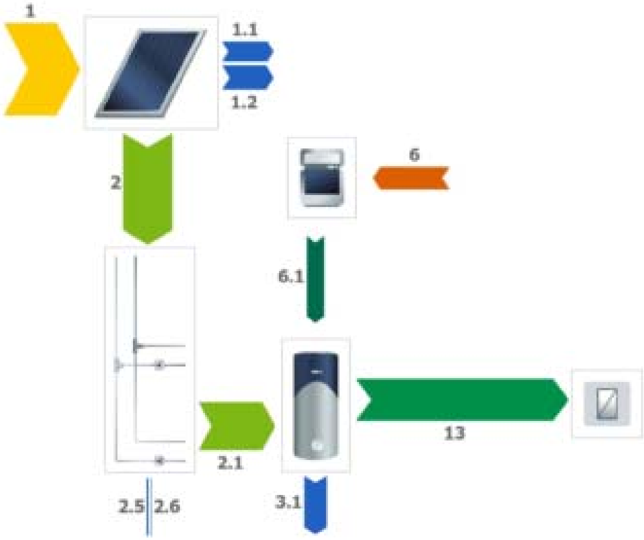

300,000
250,000
200,000
150,000
100,000
50,000
0
$
0
2
4
6
8
10
12
14
16
18
20
Operation year
Profit
213,362 $
Remaining investment
73,600 $
Cashflow
Balance
Bank account (@ 7.04% MIRR)

-

-

Variant 1

Energy balance schematic



Legend

1	Irradiation on collector surface (active)	308,501 kWh
1.1	Optical collector losses	65,501 kWh
1.2	Thermal collector losses	80,423 kWh
2	Energy from collector array	162,580 kWh
2.1	Solar energy to storage tank	158,026 kWh
2.5	Internal piping losses	3,509 kWh
2.6	External piping losses	1,046 kWh
3.1	Tank losses	75,149 kWh
6	Final energy	73,815 kWh
6.1	Supplementary energy to tank	55,359 kWh
13	Tank to process heating	137,200 kWh

-

-

Variant 1

Glossary

1	Irradiation on collector surface (active) Solar energy irradiated onto tilted collector area (active surface area)
1.1	Optical collector losses Reflection and other losses
1.2	Thermal collector losses Heat conduction and other losses
2	Energy from collector array Energy output at collector array outlet (i.e. before piping)
2.1	Solar energy to storage tank Energy from collector loop to storage tank (minus piping losses)
2.5	Internal piping losses Internal piping losses
2.6	External piping losses External piping losses
3.1	Tank losses Heat losses via surface area
6	Final energy Final energy supply to system. This can be supplied from natural gas, oil or electricity (not including solar energy) and takes efficiency into account.
6.1	Supplementary energy to tank Supplementary energy (e.g. boiler) to tank
13	Tank to process heating Tank energy to process heat consumers