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Master Thesis

Geometric focalization of sunrays: Residential building applications

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Abstract

The study scopes to optimize the use of **sun reflectors** (SR) and integrate them to residential housing buildings. When there is light from the sun the temperature rises. With the reflectivity panels the sun can be directed to specific areas, using light concentrating techniques. The purpose of these SRs is to focalize the light of the sun into specific places of the building that are considered as energy production systems of the building such as solar chimney or greenhouse.
The aim of this thesis project is to measure the temperature before the reflection (ignore the scattering of the light) and after, in order to test the energy that will be produced through the thermal and cooling loads of the building in the urban or suburban site. Methodologically, the testing tools that are used are program simulation and a physical model. At first, a residential building is chosen that can be a typical housing unit of a city centre but also of a semi-rural area. Trnsys 17 software is used to count the thermal and cooling loads of the building, the effects of the sun reflectors, as well as the energy produced. The concentrating reflectivity panels are tested concerning the shape, in order to choose the most efficient one. After deciding on the shape of the reflector, the model is optimised and a 1/10 scale physical model is made in order to cross the simulation results. The last part of the thesis project is the architectural integration of the energy system. A modular system taken from nature is placed in different parts of the building taking into consideration architectural and environmental parameters.

Keywords: sun reflectors, building intergating technologies, reflectivity panel

Nomenclature

Tair	Temperature of the air (°C)
Qh	Power need for heating (kj/h)
Qc	Power need for cooling (kj/h)
LFC	Linear Fresnel Concentrator

Περίληψη:

Στα πλαίσια της παρούσας μεταπτυχιακής διατριβής πραγματοποιήθηκε η σχεδίαση και ο πειραματικός έλεγχος ενεργειακού συστήματος, με στόχο την μείωση της ενεργειακής κατανάλωσης κτιρίων. Το σύστημα βασίζεται στη χρήση της ηλιακής ακτινοβολίας και χρησιμοποιεί την τεχνολογία της ανάκλασης Fresnel. Με τη τεχνολογία των ανακλώμενων επιφανειών Fresnel γίνεται συγκέντρωση της ηλιακής ακτονοβολίας σε συγκεκριμένες περιοχές του μουντέλου-κτιρίου που διαμορφώνονται ως συστήματα δροσισμού ή θέρμανσης, όπως ηλιακή Σιέρα ή ηλιακή καμινάδα.
Μεθοδολογικά, για την πειραματική διαδικασιά και τις μετρήσεις επιλέγεται το πρόγραμμα Trnsys 17. Συμπληρωματικά γίνεται κατασκευή φυσικού μοντέλου σε κλιμακα 1/10 και πειραματική μέτρηση σε φυσικό ουρανό. Συνολικά πραγματοποιούνται μετρήσεις πριν και μετά την τοποθέτηση του συστήματος και γίνεται έλεγχος της απόδοσής του. Το δεύτερο μέρος της μελέτης είναι ο σχεδιασμός και αρχιτεκτονική ενσωμάτωση του ενεργειακού συστήματος στο κτίριο. Επιλέγεται ένα modular συστήμα που προσδίδει λόγω της μορφής του ευελιξία στις περιοχές τοποθέτησης, λαμβάνοντας υπόψη περιβαλλοντικές, σχεδιαστικές παραμέτρους καθώς τις συνθήκες θερμικής και οπτικής άνεσης.

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1. Introduction

Nowadays, residential heating and cooling are responsible for a significant part of the total global energy consumption. In order to create environmentally friendly buildings, the application of renewable energy technologies is recommended [1]. The electricity consumption of buildings is part of the overall energy consumption of a country. Due to this fact, together with the increase of renewable energy resources, there is an interest of their integration in buildings [2]. Solar energy technologies, especially under the Mediterranean climate conditions, can be proved as a productive solution for the reduction of the energy consumption of buildings.

Therefore the present thesis seeks a most efficient solar energy technology for residential use in order to get close to the zero energy building (ZEB) result. The solar energy system that is modeled in this thesis uses the Fresnel technology and specially the outcome phenomenon of the direction of the light in specific spots. The setting of the Fresnel solar system on the building model changed it's geometry, in order to achieve better results in energy production. The architectural design is optimized according to the position of the SRs in order to achieve maximum productivity. The architectural integration of the system as a part of a general approach of integrating small-scale renewable energy technologies to the buildings is also a crucial part of the thesis project.
This research purpose is to evaluate south facing SRs that are applied in a residential building respecting the user's comfort, the efficiency, the energy production and the design.

1.1 Aim of the thesis

In Europe residential buildings account for the 75% of the total building stock, with 64% single family houses and 36% multifamily houses [3]. In 2010, households in the European Union were responsible for 26.6% of the total final energy consumption [4]. Especially in Greece buildings consume more than 36% of total energy [5]. Over the past decade (2000–2010), energy consumption in the residential sector increased by 5% [4]. Energy consumption in households is mainly for heating, cooling, hot water, cooking and appliances. The dominant energy end-use is space heating, accounting for around 70% of total final energy use. Hellenic residential buildings consume over 50% of the electricity and over 90% of the thermal energy required by the entire Hellenic building sector [3]. The Greek residential buildings barely meet any thermal qualities. Almost all buildings manufactured before 1970 haven't got efficient insulation systems or heat capacity materials. The buildings don't meet in context the sustainable design and the energy requirements to support human life. Therefore, the energy reduction is associated with decreased quality of life. The input of energy is a key driver of economic growth and development as the energy services affect various activities of human life.

Therefore, it is essential for environmental and financial reasons to use renewable energy sources (RES) applied to the built environment. This projects is involved with the solar energy and Fresnel technology integrated to residential buildings envelope. The use of RES in buildings can cover the energy consumption and also contribute in the energy generation. The relevance of the theme energy generation on the outer envelope of buildings is due to the fact that of the total energy consumption worldwide, 36% occurs in sectors that consume most of the energy they use in buildings, namely, 27% in the residential sector and 9% in the commercial sector [6]. The use of RES in the buildings can be a solution for the reduction of the total energy needed and their integration in buildings is a rich topic of discussion. The assessment of local RES potential plays a critical role in the development of planning policies and financing schemes for the successful RES in cities that can be lead to partial or total energy independence.

The aim of this project is to design, evaluate and integrate Fresnel technology SRs in the building. The thesis describes the design method of the SRs, connects it with the experimental process, evaluates the results and integrates the SRs in the building.

1.2 Methodology

Methodologically, the **simulation model**, shown in figure 1, and the **physical model** for the daylight experiment, shown in figure 2, are chosen to equally form the study and the results. The simulation model is essential as it takes into consideration all the necessary parameters given such as time, climate, exact

design of the building, solar movement during the year. The goal of creating an accurate model will conduct in the production of validated results after the simulation that will be used to optimize the design.
A detailed physical model will be adopted afterwards to validate and cross the simulation results. Such a model offers predictions of the benefits, easy collector optimization and also the possibility of quantifying the uncertainties of the simulation [7]. The physical model was used in plain sky conditions during sunny days in October 2015.
The building model was also designed and dynamically simulated in Transient System Simulation Tool (TRNSYS 17), which is a software widely used to simulate solar thermal systems. The design of the model was optimised according to the results in order to integrate the SRs at the roof.
The steps that were followed in the thesis project are mentioned bellow:

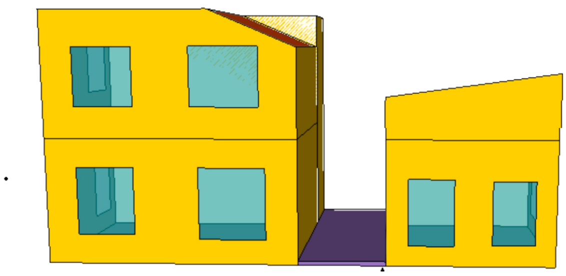


Figure 1: Simulation model

Figure 2: Physical model

Simulation model

a. Choose the model of case study.
b. Modify the case study to adopt the SRs and form the simulation model.
c. Count the thermal and cooling loads of the building in Trnys 17 software for one year.
d. Test the reflectors on the shape, their productivity and inclination
e. Choose the appropriate SRs, which cover the energy required for the case study

Physical model

a. Build a 1/10 scale physical model with materials that approach the original
b. Apply the SRs
c. Take measurements

The model simulation and the physical experiment is the method it is used to cross and validate the results of the energy system that is proposed in this project. After the validation of the results the Fresnel energy system is being optimized and integrated to the building creating a new innovating proposition of applying RES in buildings.

2. Solar energy system. Theoretical background

This chapter is an introduction to the solar model analysis and presents its theory, which is based on the solar science fundamentals. Furthermore the solar architecture of the model is analysed, and the reflectors technology is presented. Finally the relation of the SRs and the energy production system of the model is presented.

2.1 Solar Energy fundamentals

"*Solar energy*, according to the National Science Foundation in 1972, *is an essentially inexhaustible source potentially capable of meeting a significant portion of the nation's future energy needs with a minimum of* *adverse environmental consequences…The indications are that solar energy is the most promising of the unconventional energy sources…''*

The movement of the sun can be represented, through the solar diagram. In this thesis project the solar diagram, represented in figure 3, is used to predict the reflection of the sunrays during the year 2015-2016. The solar energy that reaches earth, at any time depends, on the weather conditions, the position, the orientation and the area of the surface. In fact, several factors like the global radiation on a horizontal surface, the ground reflectance and the day of the year constitute the parameters of a complex function that determine the amount of solar radiation incident on an inclined surface at any time [8]. The incoming hemispherical radiation consists of the direct radiation coming from the direction of the sun and the diffuse radiation, resulting from direct radiation scattered in the atmosphere and reflected from the ground or other surfaces. The diffuse radiation does not incident from a defined direction but has an anisotropic distribution over the field of view [9].

The position of the sun can be described by two angles the altitude (A) and azimuth (As). The A is the angle between the sun-earth axis (through their centres) and the horizontal plane. The As is the angle between the 'real' south line and the site vertical axis towards the sun. The distance between the earth and the sun changes throughout the year, the minimum being $1.471x10^{11}$ m at the winter solstice (December 21) and the maximum being $1.521x10^{11}$ m at summer solstice (June 21) [10].

The altitude and the azimuth during a whole year and for every hour can be printed out at the Solar diagram.

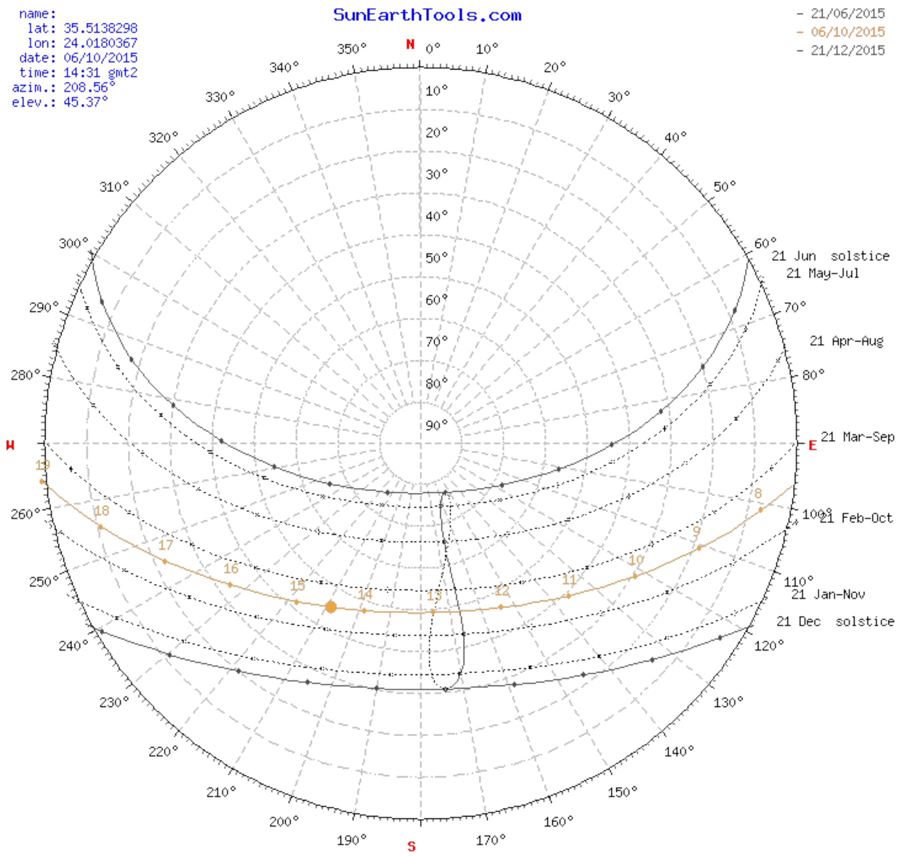
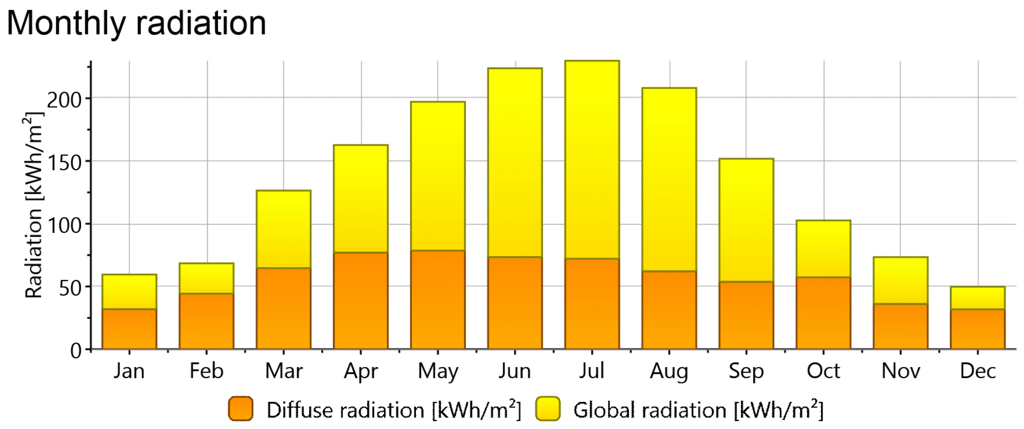


Figure 3: Solar diagram during the experiment

Solar radiation is one of the most significant renewable power sources, which can have numerous applications in the Res technology. The energy systems can be either passive, or active depending on the way they capture and distribute solar energy or convert it into solar power. Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating. Passive solar techniques can be the architectural design process of the building such as its orientation, the quality and the thermal mass of the built materials.

The amount of solar energy that reaches earth depends on the atmosphere and on the length of the axis of the solar beam and it's called global solar radiation. Global solar radiation is the sum of direct, diffuse, and reflected solar radiation. Direct solar radiation passes directly through the atmosphere to the Earth's surface, diffuse solar radiation is scattered in the atmosphere, and reflected solar radiation reaches a

surface and is reflected to adjacent surfaces. The direct sun radiation and the reflected sun radiation that falls in a surface on earth, it's the total available solar energy. The solar energy is the total amount of energy that comes from the sun and falls on a 1sqm surface per time and the measurement unit is the watt/m^2. In figure 4, the monthly radiation (diffuse and global) and daily radiation, are represented, according to Meteonorm* in Souda Chania.
Using this diagram we can predict approximately the total direct solar radiation that reaches the testing model during a year.



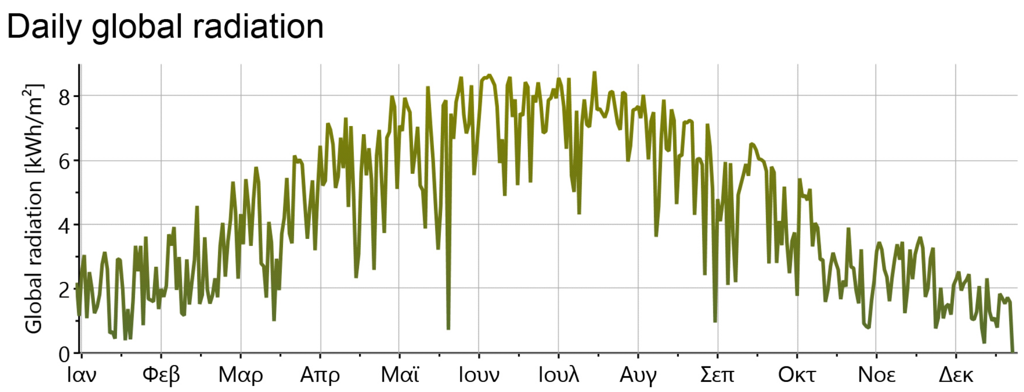


Figure 4: Monthly radiation and daily radiation in Chania. (Metenorm)

The total global radiation for one year in the testing area is:

Gt= 1.685 kWh/ m^2

The total diffuse radiation is:

Dt = 638 kWh/ m^2

So the direct radiation is Rt= 1.685-638= 1.047 kWh/ m^2

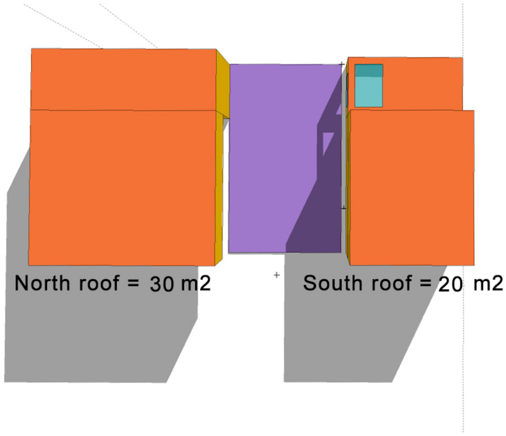


Figure 5: Roof surfaces of the model

The solar energy that a system can absorb in the testing model during a year is approximately:
Total north= 1.047 x 30 = 31.410 kWh
Total south= 1.047 x 20 = 20.940 kWh

For the calculation above we suppose that the roofs have no inclination.
The tilted surfaces receive different amounts of global radiation per day. On the north hemisphere when a surface is tilted towards the South the amount of solar radiation increases. Later on, the roofs of the model are going to be optimized in order to obtain more energy production for the solar system.

2.2 Fresnel Technology

Fresnel lens is an optical system with low focal length and large aperture, and it is named after its inventor the French physicist Augustin Jean Fresnel (1788 – 1827). The reflection of the light, in a concentrated or linear Fresnel lens is high, the focal point is close enough to the lens and due to this feature it has many applications in the lighting and optics field, as shown in figure 6. It was first integrated it into lighthouses, because the lens has the ability to capture light and after reflection makes it visible to high distances (figure 7).

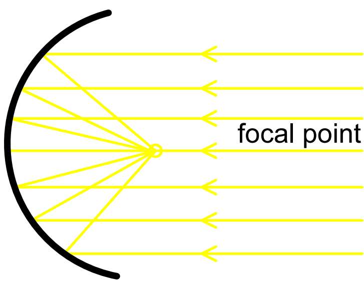


Figure 6: Lens concentration depiction

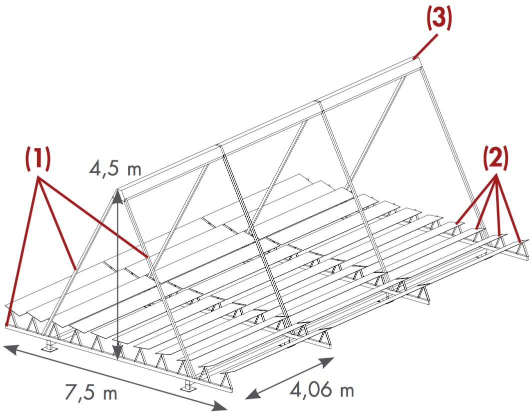
Figure 7: Fresnel lighthouse

In this thesis project the active solar system that is tested, is based on the features of the Fresnel Lens but it uses sun irradiance** to transform it into heat power. The Solar linear Fresnel collector that is used, is a linear focusing solar system for generating process heat in the range of 100 kW to 10 MW at pressures up to 120 bar (standard 40 bar) and temperatures up to 400°C. The LF performance and its reflection system are shown in figure 9. Different heat transfer fluids can be used like pressurized water or thermal oil, but it is also possible to directly generate or even superheat steam. The lightweight, modular system, in

combination with the high heat gain per installed area, makes it optimal for rooftop installation for industrial and utility facilities [11].
The main components of the system are:

- Supporting structure (1)
- Primary reflectors (2)
- Receiver, consisting of secondary reflectors and vacuum absorber tubes (3)
- Control systems for the primary reflector tracking and the solar array output.

The dimensions of figure 8 are indicatory



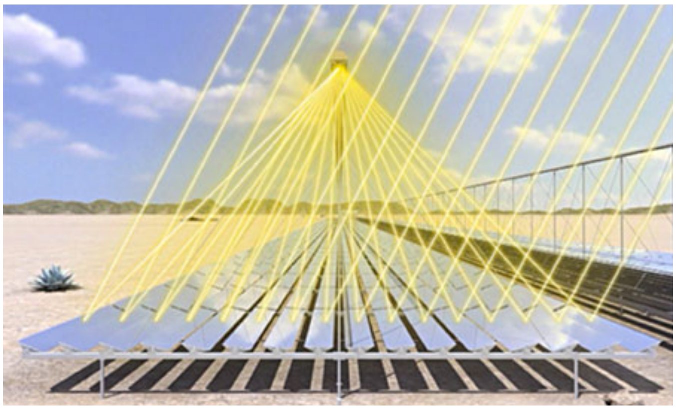


Figure 8: Fresnel supporting structure

Figure 9: Fresnel reflection system

Fresnel lenses are optical devices for solar radiation concentration and are of lower volume and weight, smaller focal length and lower cost, compared to the thick ordinary lenses. The advantage to separate the direct from the diffuse solar radiation makes Fresnel lenses suitable for illumination control of building interior space, providing light of suitable intensity level and without sharp contrasts [12].
Fresnel lenses combined with multifunctional absorbers can perform solar control of building atria. Linear Fresnel lenses can achieve illumination and temperature control of buildings and are suitable to extract the surplus solar radiation from the interior space in the form of electricity and heat [13]. The linear Fresnel lens can be combined with linear multifunction absorbers that convert the concentrated solar radiation into heat electricity or both [12].
Parabolic concentrators consist of the focusing collector on the form of paraboloid and the absorber, which is located in its focus. Focusing collectors with Fresnel lenses consist of absorption pipes, thermo-insulation and Fresnel lenses. In these collectors solar radiation concentration is performed by Fresnel lenses, which instead of a continuous curved surface have the curved segments in the flat surface. Fresnel concentrators with mirrors consist of a mirror in whose focal points absorption tube is located [13].
The linear Fresnel lenses can be combined with linear absorbers that convert the concentrated solar radiation into heat, electricity or both. These systems can be used for illumination control during day, storing the surplus energy for space heating during night, can contribute in the ventilation needs during day and apply illumination by artificial light during night or they can cover other building electrical loads [12].
The Fresnel lens system should include an absorber for the absorption and conversion of the concentrated solar radiation into heat, in order to extract the thermal energy from the interior space [12].
Depending on their design, solar systems with solar radiation concentrators can be divided into: spherical concentrators, parabolic concentrators, focusing collectors with Fresnel lenses and Fresnel concentrators with mirrors [13]. Each Fresnel collector is affected by air temperature, wind speed, and radiation falling on the mirrors [14].

2.3 Scientific experience on the subject

Among the publications on the Fresnel lenses, according to Y. Tripanagnostopoulos, Ch. Siabekou, J. K. Tonui, we can refer the studies on one axis linear Fresnel lens concentrator (Nelson et al., 1975), on curved surface lens to minimize focal length (Kritchman et al., 1979), on Fresnel optics (James and Williams, 1978) and on the development (Lorenzo and Sala, 1979) and on the design and use (Nabelek et al., 1991) of glass type Fresnel lenses. Other studies on Fresnel lenses are on the chromatic dispersion of them (Sassi, 1980), the fabrication, installation and system operation (O'Neil et al., 1990), the truncated stationary Fresnel lenses (Leutz et al., 1999) and the linear Fresnel lens concentrator combined with linear cells (Bottenberg et al., 2000). Further works that could be referred are the performance study of a flat linear Fresnel lens collector (Khalil and Munadhil, 1998) and design aspects of these systems with ray tracing technique (Leutz et al., 1999) [12].

Building integration (BI) of solar energy systems are considered the systems that are part of the building structure and provide energy to the building. Solar energy systems are suitable for the built environment but due to their visibility specific architectural requirements are needed to be adapted [13].

2.3.1 Applying RES in buildings

Res technology can, to a certain point, substitute the nonrenewable fossil fuel technology and this is a goal of the scientists and the engineers of the present and future. Over recent decades numerous applications of Res technology in the built environment have emerged as the wind power and the solar power have already many integrated applications in the urban environment. Although the matter of integration new technologies in the built environment is an evolving interdisciplinary topic of discussion, that concerns scientists and artists, with very promising new discoveries in the future. Some examples of Res technology successfully integrated to buildings are presented to the figures below (figure 10-11-12-13).

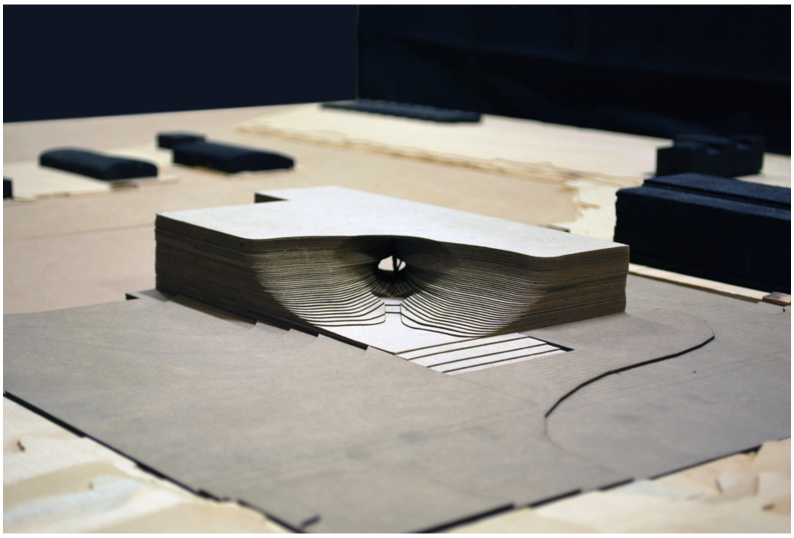


Figure 10: Kara Knechtel-Wind Turbine Integration in Architecture and the Urban Environment Exhibition | wind energy

Figure 11: London Strata Tower | wind energy

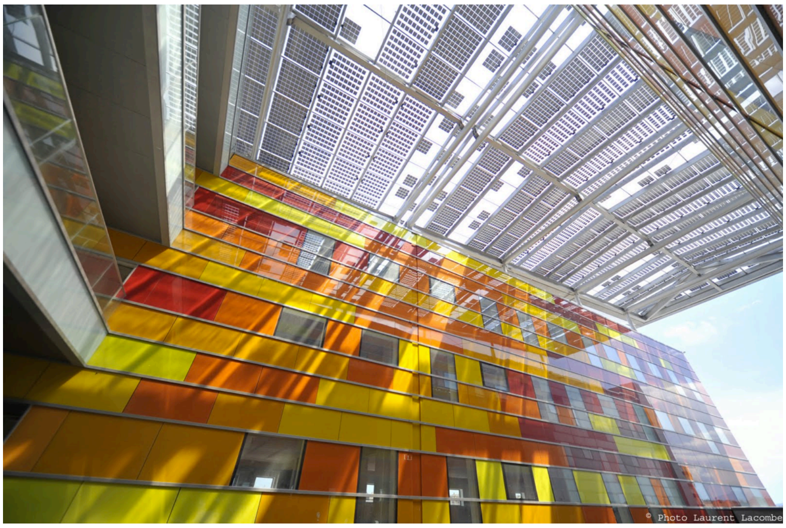


Figure 12: Perpignan station, Southern France | solar energy

Figure 13: Roof PVs in Germany | solar energy

The horizontal and vertical walls of the buildings can be used as possible position of applying energy systems such as photovoltaic panels, solar panels, sun absorbers or reflectors, which can produce energy and control the sunlight and help to obtain sufficient user's comfort. The awareness of the available area on vertical walls, which in a modern city far exceeds the available area on roofs thus of setting the relatively lower irradiation falling in non-optimum inclination, has recently lead to the development of methodologies for the analysis of the solar assessment of facades [15].

2.3.2 Architectural Integration of Fresnel Technology

Flat plate collectors, compound parabolic concentrating collectors, photovoltaic systems have widely been used and tested on many types of buildings. There are several possible ways of integrating the SRs to the buildings such as the roof, the facades or as extra shading units.

The Fresnel lenses are suggested to be combined with small width absorbers of thermal, photovoltaic, or hybrid photovoltaic/thermal type solar collectors to extract the concentrated solar radiation in the form of heat, electricity or both, for simultaneous or later use in greenhouses (Tripanagnostopoulos et al., 2005b) and also in buildings (Tripanagnostopoulos et al., 2005c). The Fresnel lens concept is suggested for solar control of building interior spaces in order to keep the illumination and the temperature at the comfort level. The lighting level of an atrium (or of other space with transparent cover) can be controlled by absorbing the greater part of the incident solar radiation and leaving the rest radiation – mainly the diffuse – to keep a minimum illumination level of the internal space. In this way the Fresnel lens system is a kind of an active shading device by which an amount of the transmitted solar radiation is not reflected or rejected to ambient (as it is done by most shading techniques), but it can be also used to cover thermal and electrical needs of the building, *as shown in figure 14* [11].

According to *designroom.com (July 2016)* the architect Javier Galindo, adapts lighthouse Fresnel lens into a resort concept. He explores the potential of an existing technology in 'fresnel resort' (figure 15), originating from the faceted-triangulation (fresnel) lens of a lighthouse. The concept develops a narrative that results in architectural intervention. Small-scale fragmented buildings mimic the lighthouse's 'fresnel', similarly reflecting and emitting light through interiors and into the surroundings [16].

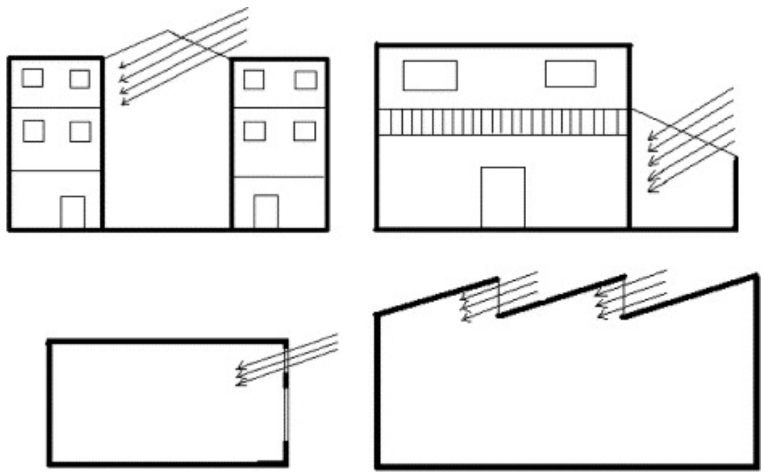


Fig 14. Examples of Fresnel lens application on transparent covers of buildings, with atrium and sunspace (up) and also room and industrial building (down).[5]

Fig 15. Fresnel resort Javier Galindo

2.4 Solar reflectors and the case study

Solar energy is considered to be the future of electricity worldwide. More and more architectural applications are based on solar energy with the prospect to get rid of fossil fuel and obtain the ZEB. **Solar architecture** is the integration of passive solar, active solar or solar panel technology with modern building techniques. This project uses the solar architecture of Fresnel lenses and the solar reflection principles. The idea is to conduct sunrays to specific focal points. This consideration has to estimate several important parameters such as the time of the day, the season, the inclination of the roofs, the type of the building and the design.

This study takes for granted that the angle of the incoming radiation is the same with the reflectance angle based on Snell's law (figure 16). Additionally this thesis ignores the diffuse solar radiation from a surface after reflection. So it is based on the case of the ideal specular reflection.

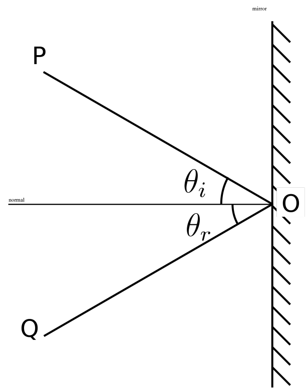


Figure 16: Reflection angle

The object of our analysis is a residential building in a suburb of Chania called Kolimpari in the island of Crete, which is located south of Athens. It is located in a sparsely built area of the city. It originally consists of two levels of a total area of 120 m^2, 70 m^2 the ground level and 50 m^2 the second floor, as shown in figure 18.

The house-testing model is chosen to be in accordance with Greek Buildings Regulation KENAK [17] concerning the materials, the type of windows the cooling and heating loads.

The ground floor is provided with two separated entrances and a staircase for the upper level. Conventional materials like cement and aluminum framing system constitute the building envelope almost entirely. The orientation of the model is shown in figure 17.

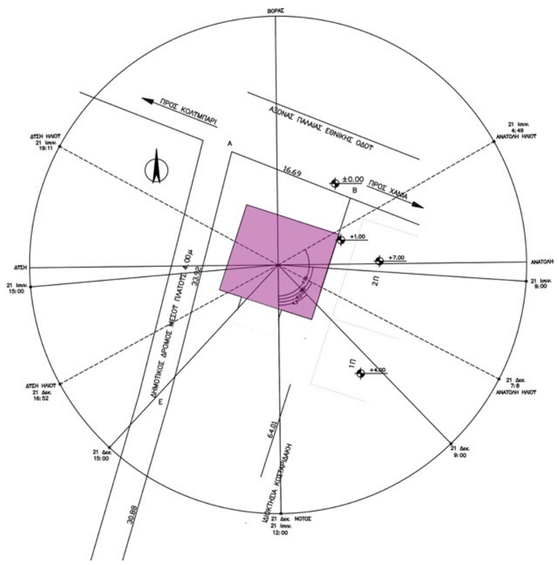


Figure 17: Model site orientation

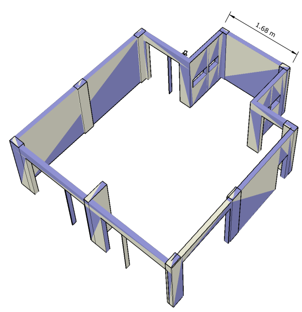


Figure 18: Original model design

The building has a conventional heating and cooling system, which consists of oil central heating for the winter and air-conditioning for the summer. This entails quite high management costs for the maintenance of the building's indoor comfort, especially during summer.
The design is simple and typical of a house of a residential or semi-rural area. In order to apply the Fresnel reflection system it was considered essential to transform the design, so that the SRs can provide the concentrating effect needed. So the one block building was transformed to a two-block building maintaining its orientation, surface, windows and doors frames, built materials, this will be explained later further on.

2.5 Energy production systems of the model

One of the goals of this thesis project is to conduct the energy of the Fresnel, that is produced and transferred through the absorber into some thermal fluid, to specific parts of the model that are characterised as energy systems. Due to the focalization of the light in these places, the steam generator will generate significant higher energy production.
Mainly Fresnel technology system is used in large solar power plants, which are solar energy generating systems (figure 19-20).

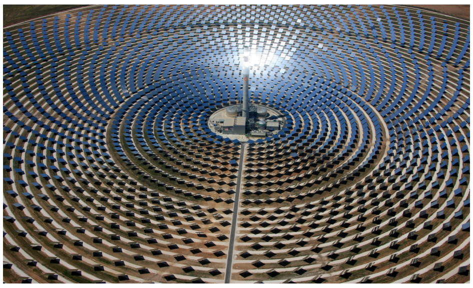


Figure 19: Reflection power plant

Figure 20: Reflection tower

The use of Solar Fresnel panel in small scale and their architectural integration in residential buildings is a challenge for the future and a big topic to investigate. Traditionally, supplying energy to cities requires large devices outside cities to capture the energy from a natural source and a complex infrastructure network to transport the captured energy to the city, where it is needed. Both the factories and the infrastructure have a significant presence in the landscape and imply other negative environmental impacts [6]. This thesis describes the alternative approach, in which the goal is to produce energy within the city and in each building.
When talking about energy production and light sufficiency, there is a need to clarify the type of the building and specify the use of space. This research concerns residential housing units facing south. The demand of energy and visual comfort differs from an office building to a housing unit. The space of an office is usually limited to an exclusive use, on the contrary, the living room of a house may have several everyday uses, in variable hours of the day that require a different design approach, which will be discussed further more.

2.5.1 Spatial greenhouse / Glass veranda

Glass verandas, built during last centuries at the south side of living houses and summer cottages are appreciated as original use of solar energy. Veranda as light and warm room was used for different household needs and also for social activities [18]. In this study the glass veranda is tested as a thermal core of the building. The transformation of temperature when the SRs are located is considered as possible energy collector during the summer.

2.5.2 Solar Chimney

Roof integrated solar chimneys use solar radiation to heat air and induce natural ventilation through a house. They can improve the performance of roof integrated photovoltaic arrays by removing heat absorbed by the panels, and enhance buoyant free cooling at night [19]. In this project the solar chimney is proposed, but not yet tested, to be used as an energy core that ventilates the building during the summer and reduces the cooling loads to an important percentage.

3. Calculation methodology

This chapter describes the whole evolution of the design process of the building model and the methodology of the computer simulation, its execution with Trnsys 17 and the methodology of the physical experiment. It describes also the simulation of the Fresnel mirrors, the Linear and Concentrated SRs focusing on the total energy production of each system. Finally the results of the simulation and the daylight experiment are presented.

3.1 Design process

The compact shape of the building changes. The new shape has two roofs because the free space in between them is very important as a **reflection area,** presented in figure 21. The reflection area is one of the areas where the energy systems can be placed. This space can be also very functional for the users, as a semi open space, which is mandatory for Mediterranean climate zones.

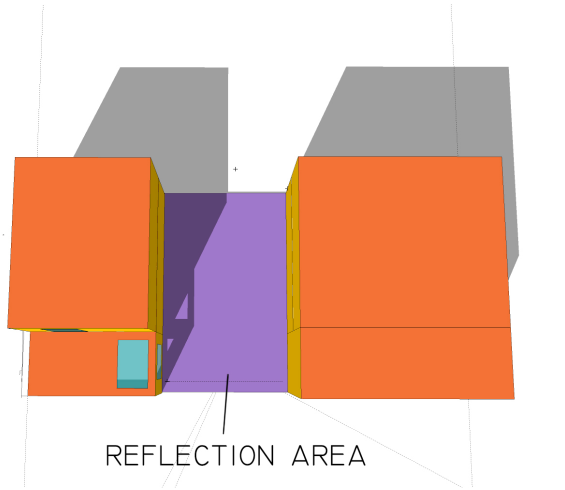


Figure 21: Reflection area indicated with purple

The first block (Block A) consists of a double level building of a total area of 60m2. The second block consists of a double level building of total area of 40m2. The division of the building in two blocks provides the model with a free space in between, suitable for applying the energy systems and very functional for a Mediterranean climate characteristics as people live outside more than six months per year. The transformations of the original model are shown in figure 22. The simulation model, as well as the physical model is created, according to the new double-block building.
As it was mentioned before the southern tilted roofs, which are at the north hemisphere, receive much more solar radiation during the day. So the roofs of the model are given an inclination according to the latitude and longitude of the testing area, which is located in Chania Crete (35° 30' 49.787" N 24° 1' 4.932" E).

Winter best roof inclination
$\Theta p = 35° - 10 \approx 25°$
Summer best roof inclination
$\Theta p = 35° + 10 \approx 45°$

The roofs changed in order to coincide with the best angular for higher solar radiation, as shown in figure 23, during the whole year and in order to integrate the reflectors in a more efficient way. The new inclination of the roofs is also squared with the architectural appearance of the building and the appropriate height for supporting, a second floor mainly in the north building [N].
The N, whose roof is facing south, has two inclination roofs. R1=20 ° R2 = 45 °
The south block [S], whose roof is facing north, has an inclination of R3= 20°.

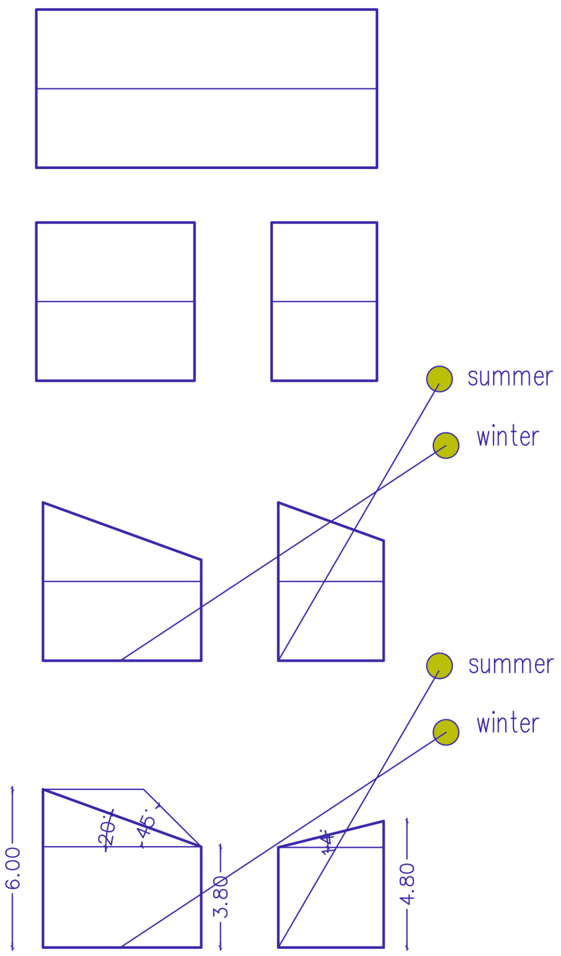


Figure 22: Model Geometry transformation

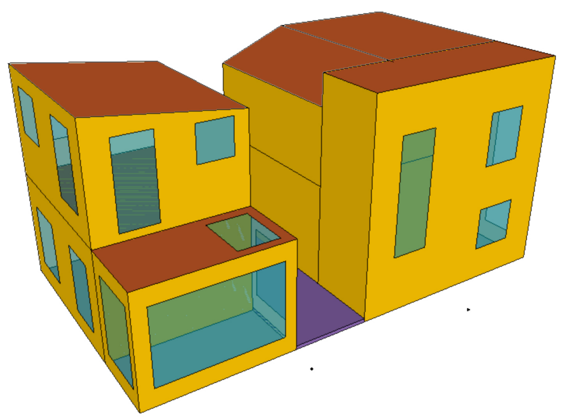


Figure 23: Simulation model

3.1.1 General assumptions

The two building blocks consists of six different spaces-zones. Half of them have North orientation, half of them have South and a typical height of 3 m each. Only one has 6 m height, the “2floors”. The design system that is being simulated at this project is the greenhouse (zone greenhouse) glass veranda that can be transformed according to the season. The six zones are simulated with Trnsy 17 simulation engine.

The external walls of the building are of 0.27 m total thickness
Layers from the inside to outside:

1. Plasterboard 0.02 m
2. Concrete slab 0.09 m
3. Air insulation 0.07 m
4. Foam insulation 0.07m
5. Concrete slab 0.09 m
6. Plasterboard 0.02 m

The external roof is of 0.33 m total thickness and zero inclination.
Layers from the inside to outside:

1. Plasterboard 0.02 m
2. Concrete slab 0.2 m
3. Foam insulation 0.06 m
4. Sand gravel 0.05 m

3.2 Modelling simulation

Methodology

3.2.1 Trnsys 17

The model is simulated in Transient System Simulation Tool (TRNSYS 17). TRNSYS, according to it’s official manual, *is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems).* The engine that Trnsys uses for simulation is called Simulation studio. In Simulation studio the whole project is consisted of different components called **types**. These types are graphically connected with each other through the Simulation Studio environment and they form a diagram based on the logical series that the components are actually used*. Each Type of component*, according to the official manual, *is described by a mathematical model in the TRNSYS simulation engine and has a set of matching Proforma's in the Simulation Studio The proforma has a black-box description of a component: inputs, outputs, parameters, etc.*

The tool that is used to simulate the multi-zones buildings is called TRnBuild. This tool allows you to specify everything that has to do with the model, such as the orientation, the structure, the doors and windows, the thermal and cooling systems, the behavior of each zone. TRnBuild has a proforma in the simulation studio that is called type 56. The type 56 gets connected through the input and output diagram with the other components of simulation studio such as weather data, thermal and cooling means, solar systems, energy systems and everything that requires simulation.

The model was initially designed in Google Sketchup application and then used to construct the model's type56 in TRnBuild, which was imported to Simulation studio.

3.2.2 Simulation process

The building was firstly inserted to Simulation studio in order to calculate the total Qc, Qh and Tair for every different zone for one year.
The simulation input and output diagram is shown in figure 24.

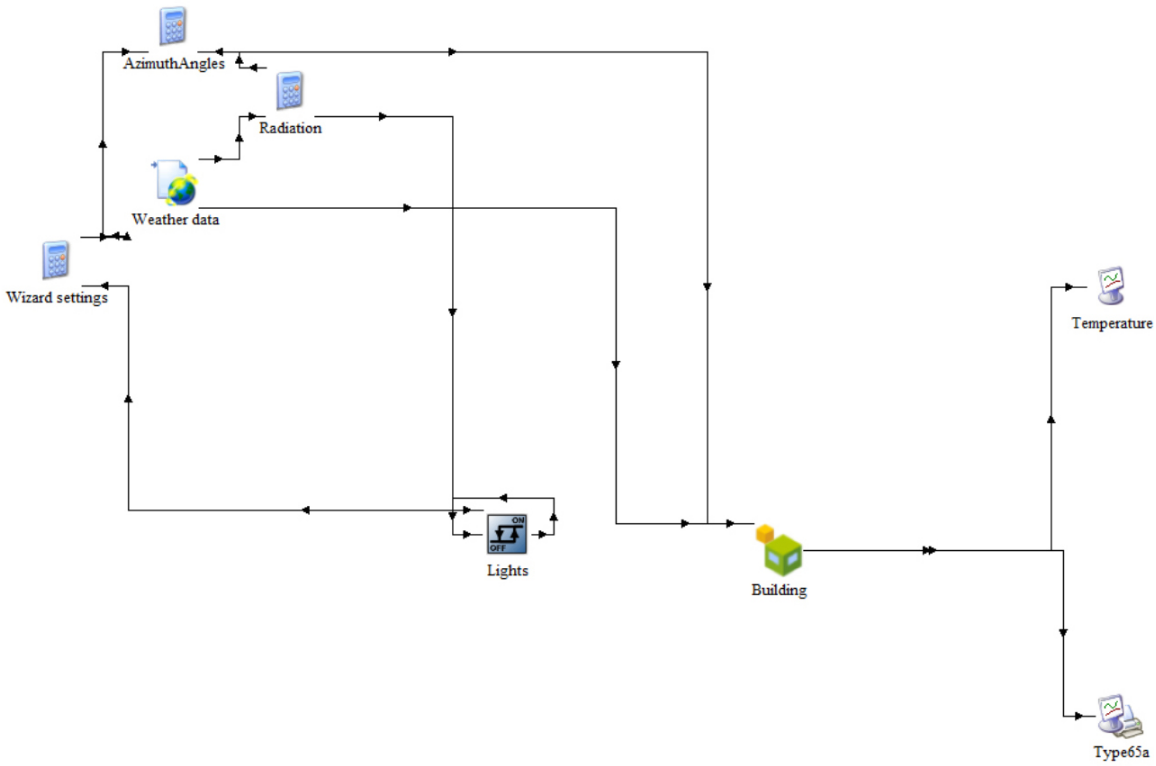


Figure 24: Building simulation diagram

3.2.3 Fresnel Reflectors performance

The second part of the simulation concerns the type of Fresnel mirrors that will be used. The Fresnel mirrors were tested according to their efficiency, in order to choose between the Linear and the Parabolic concentrators.
The type 1288 is used to model the solar thermal collectors. The different SRs, which were tested according to their efficiency, are: **Type 1288 Linear Fresnel** and **Type 1288 concentrator.** They are tested for one number in series and area of 4m2, every hour for one-year period, for 3 different inclinations of the roofs 0°-45°-90°.
The purpose is to choose which type of SR is going to be used at the physical model.
The simulation diagrams are shown below in figure 25 and 26.

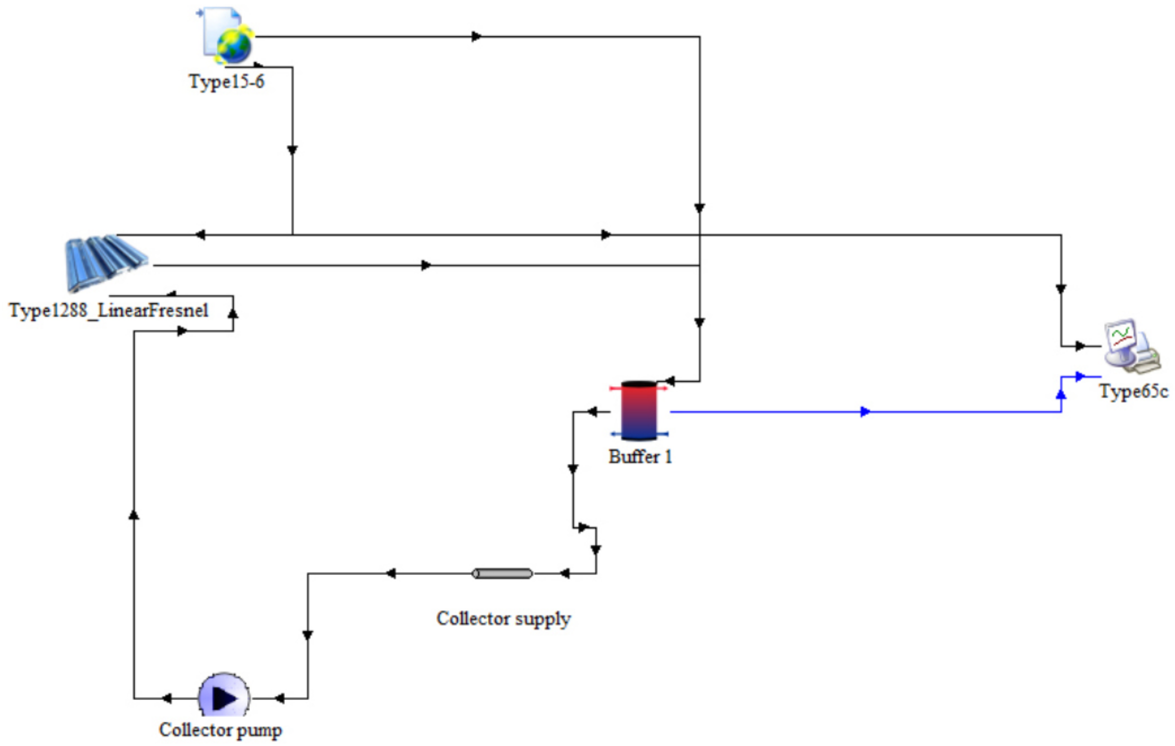


Figure 25: LFC simulation diagram

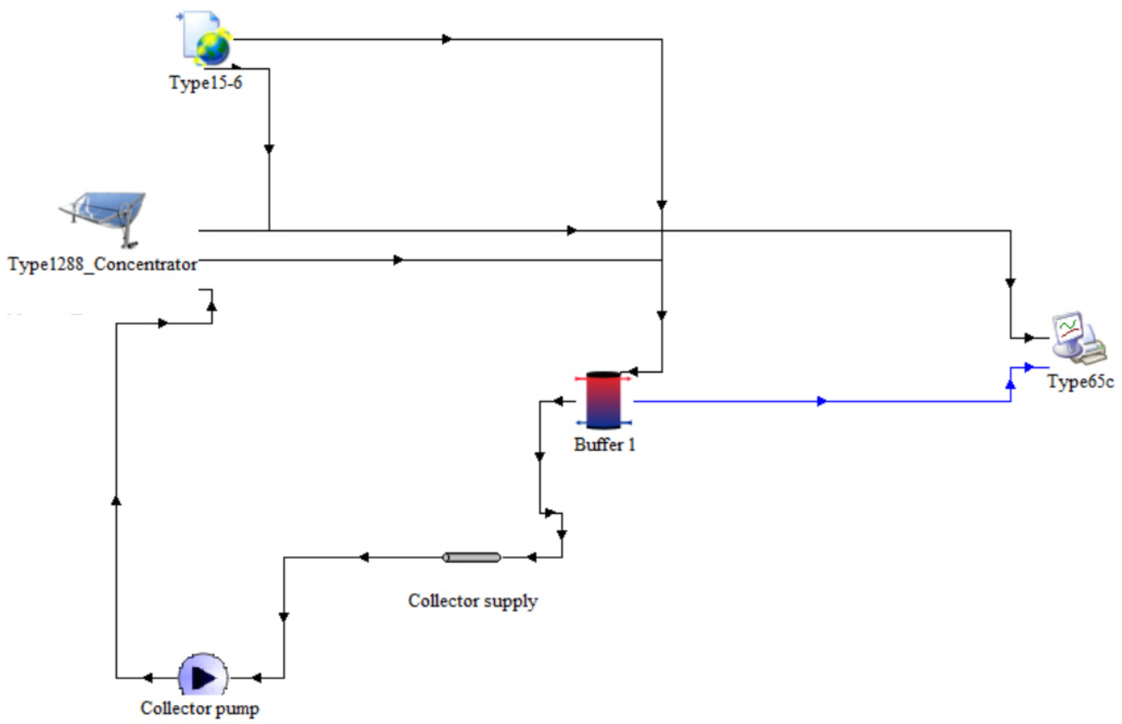


Figure 26: Concentrator simulation diagram

The diagrams of the simulation are shown below:

Performance for 45° roof inclination for parabolic concentrator.

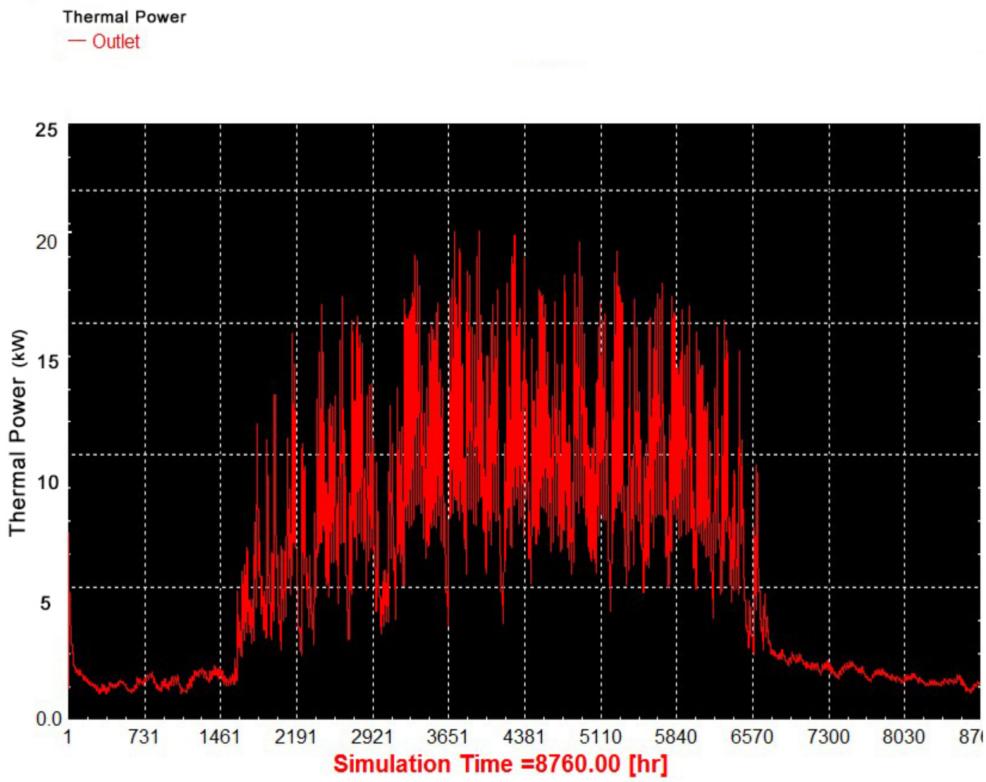


Figure 27: Parabolic Concentrator simulation diagram, for 45°

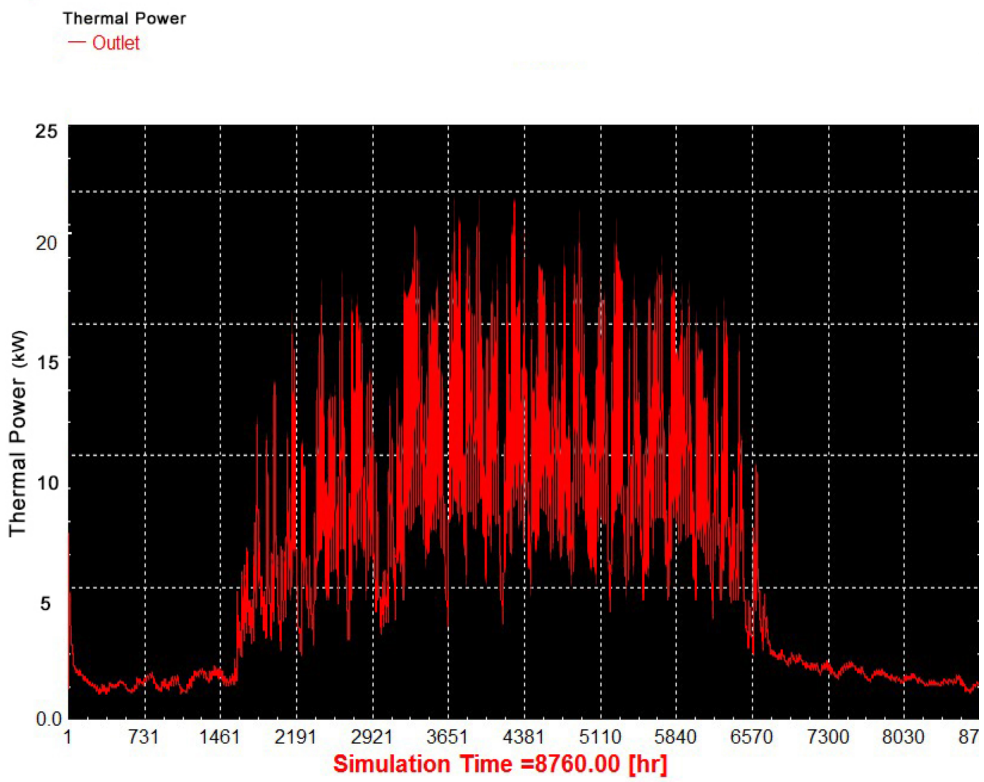


Figure 28: Linear Concentrator simulation diagram, for 45°

Performance for 0° roof inclination

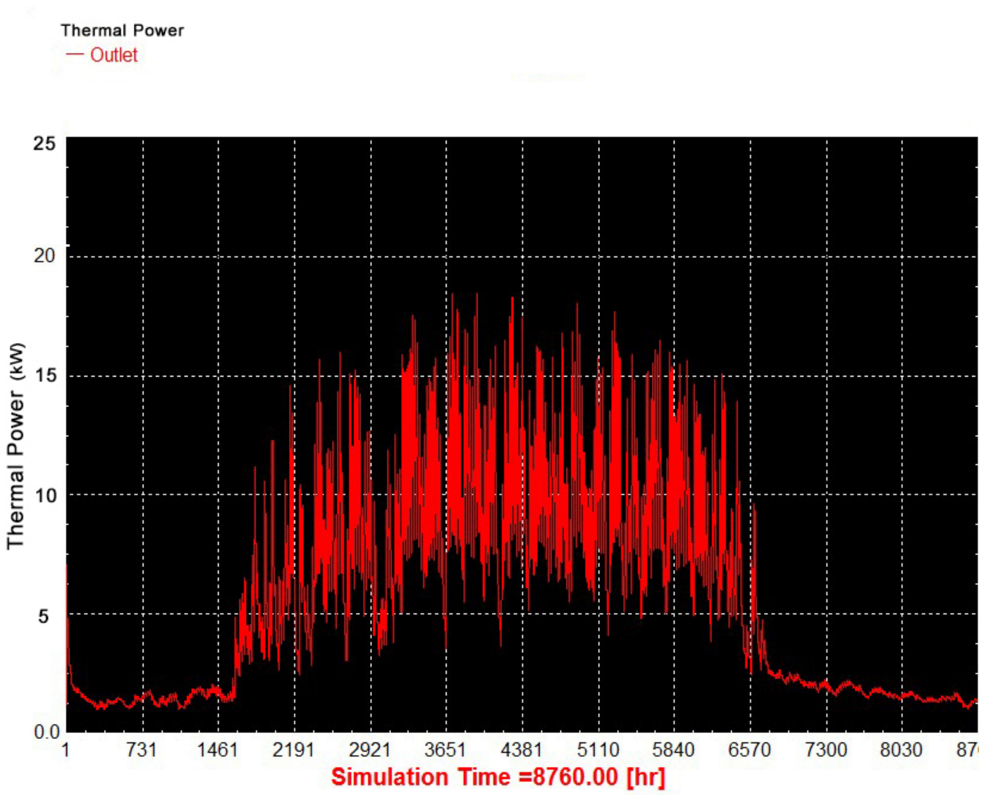


Figure 29: Parabolic Concentrator simulation diagram, for 0°

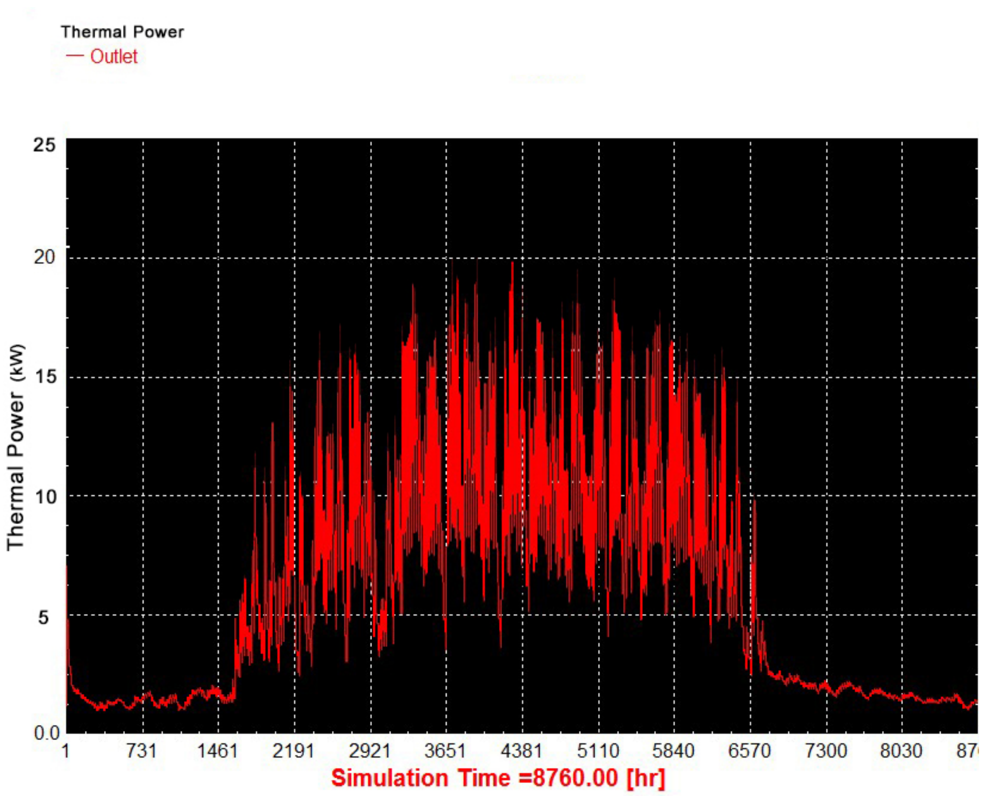


Figure 30: Linear Concentrator simulation diagram, for 0°

Performance for 90° roof inclination

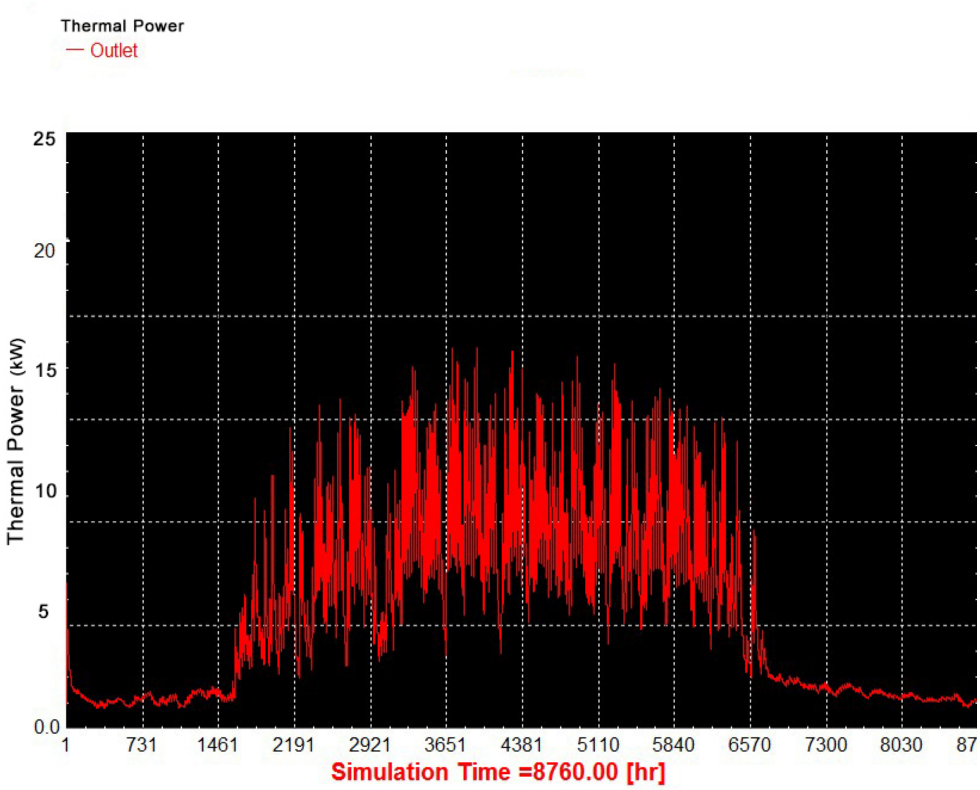


Figure 31: Parabolic Concentrator simulation diagram, for 90°

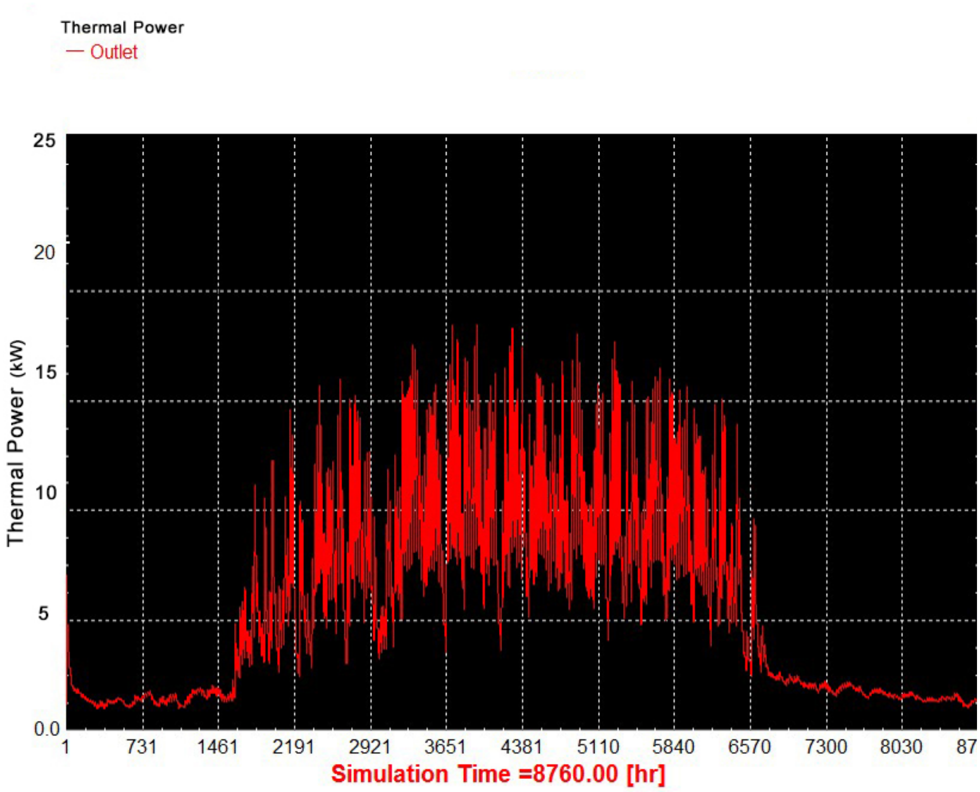


Figure 32: Linear Concentrator simulation diagram, for 90°

As proven from the diagrams above the LFC is in general more productive than the PC at this case. Additionally a general 45 ° roof inclination can lead to more efficient solar systems at this climate.

In the table below the results of the Fresnel Lenses simulation are tested according to their characteristics (Linear on Parabolic) for 3 different inclinations, are presented. The power is calculated as a total for each case.

Inclination	0°	45°	90°
Type 1288 Linear Fresnel	7.900	11.400	6.290
Type 1288 Parabolic concentrator	7.590	9.740	5.840

Table 1: Power for one year (kWh).

Hence, the acceptance about the roof inclinations is validated. The most efficient inclination is somewhere between 10°- 45° in this longitude and latitude. And Linear Fresnel concentrator turned to be more efficient than the parabolic.

3.3 Physical model

In this part of the thesis the daylight experiment is presented. Firstly the model design is described with all the references to the simulation model and process. The process of the experiment is described as well and the methodology. In the figure 33 the experiment model is shown.

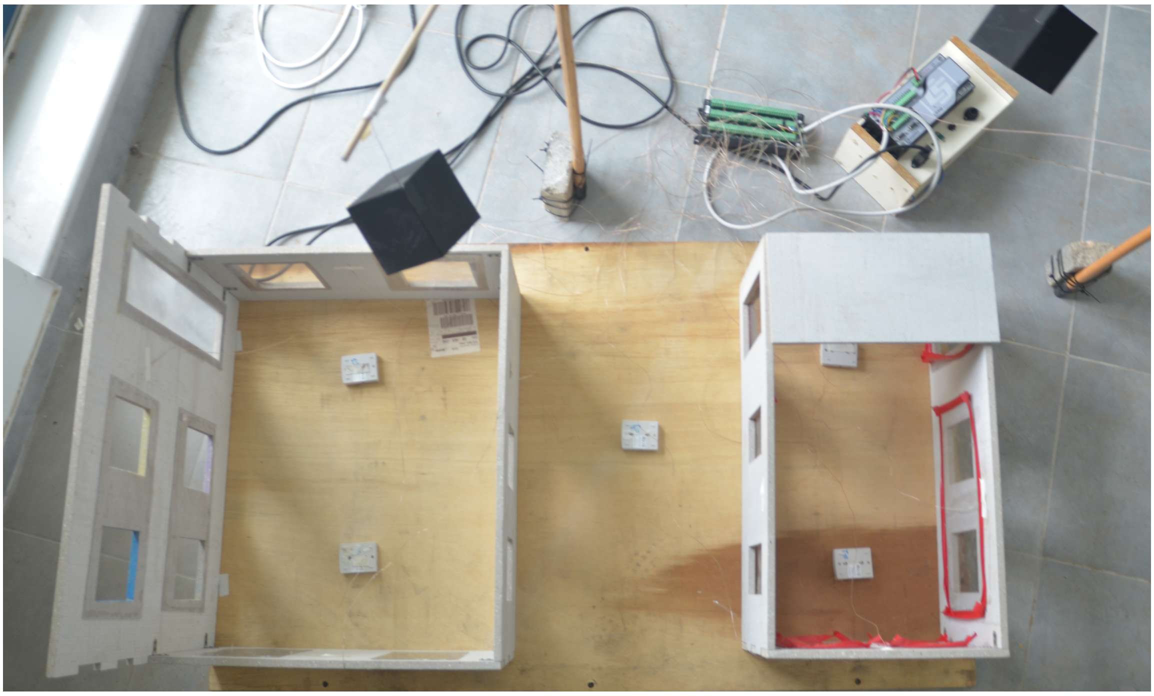


Figure 33: Experiment model

3.3.1 Physical model design

The physical model of 1/10 scale was constructed according to the specific instructions for making day lighting models and was tested in real sky conditions [20]***. A physical model is a simple, quick, and inexpensive tool for determining approximate daylight levels in a space and is useful at all stages of design [21]. The model is constructed from concrete panels and cut with water jet techniques at the appropriate machine. The layout of the design is shown in figure 34. The daylight model consists of two buildings like the simulation model with the same characteristics as much as possible.

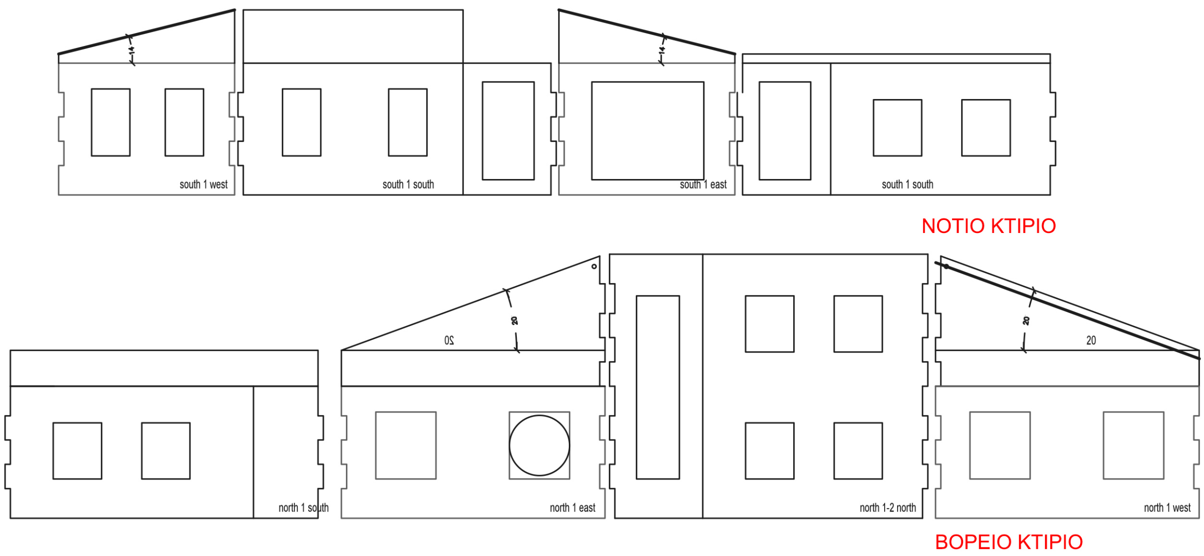


Figure 34: Physical model design

The joints of the walls were created to unite the two parts, so as to eliminate sun lighting in the inside and the windows were closed tightly with tape. Each building is tested for two different roof inclinations. The reason of creating two inclinations for the roof is to specify the focal point of the reflectors and check which roof is more efficient after the reflection. The linear Fresnel collectors are represented with mirrors. Mirror has a high reflection factor and it is one of the best materials to simulate Fresnel collectors.

Methodologically experiment's parameters were separated in two categories, **stable** and **variable**. The stable is the south orientation, the location and the type of glazing (sun) and the variable roof inclination and the position of the SRs. The parameters examined are the **temperature** of the day, the focal point according to the **position** of the SRs.

The experiment takes place in Technical University of Crete site situated in Chania Crete (35.5167° N, 24.0167° E) in a semi-residential coastal area. In Chania the extreme positions of the sun are about 77° height in the summer and about 30° height in the winter at 12 o'clock for a south facing plane.

The physical method is prefered to be more accurate as it is being held on the exact under study environment. The scale of the physical model is 1/10.

3.3.2 General assumptions

For this project all windows are considered not to be shaded by opposite or neighbour buildings, this might not be realistic for all inner city locations, but it results in higher solar heat gains and is therefore a safe assumption regarding the evaluation of thermal comfort and view [11]. The windows of the models are represented with thick transparent material and during the experiment they are tightly closed. The walls are constructed from cement like the original building but without insulation. The roofs are also created from concrete panels without insulation. The floor is made from wood and protects the model from humidity.

3.3.3 Physical model Experiment process

Methodology

For the measurements we used 5 data loggers**** for temperature, which were placed two in each building and one in the reflection area, as shown in figure 35. With this equipment the temperature of each spot was calculated.

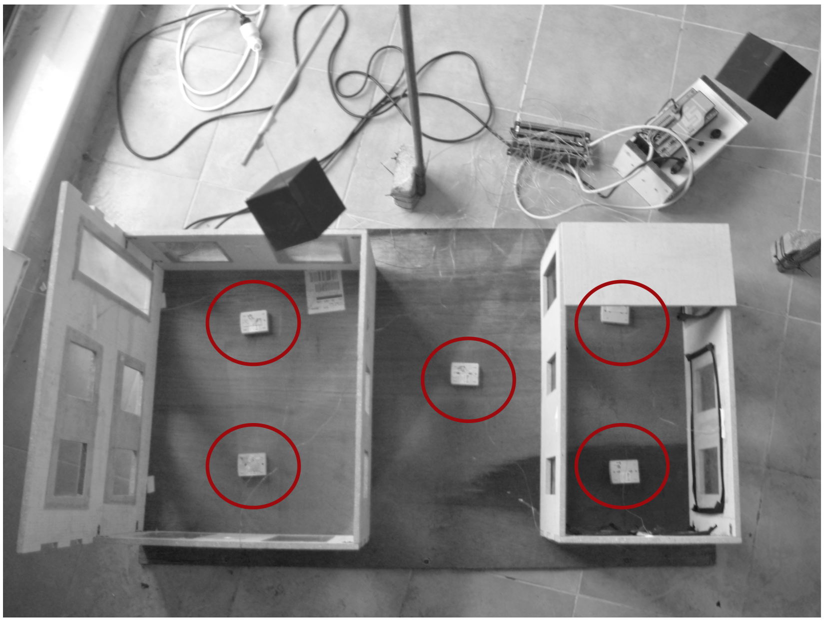


Figure 35: Data loggers position

Additionally we used 18 thermocouples***** in order to calculate the temperature of each wall inside and outside and were placed as shown in figure 36-37. The measurements were made every ten minutes.

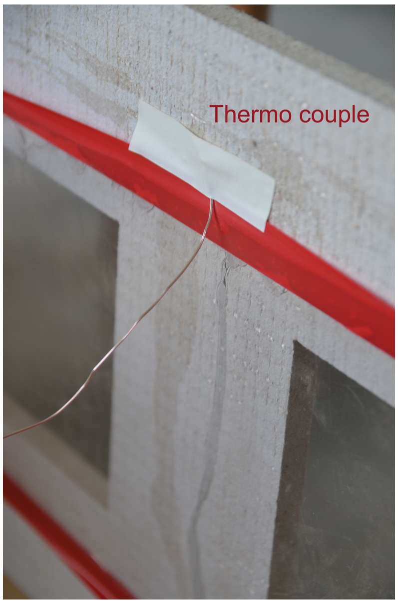


Figure 36: Thermo-couples on the walls

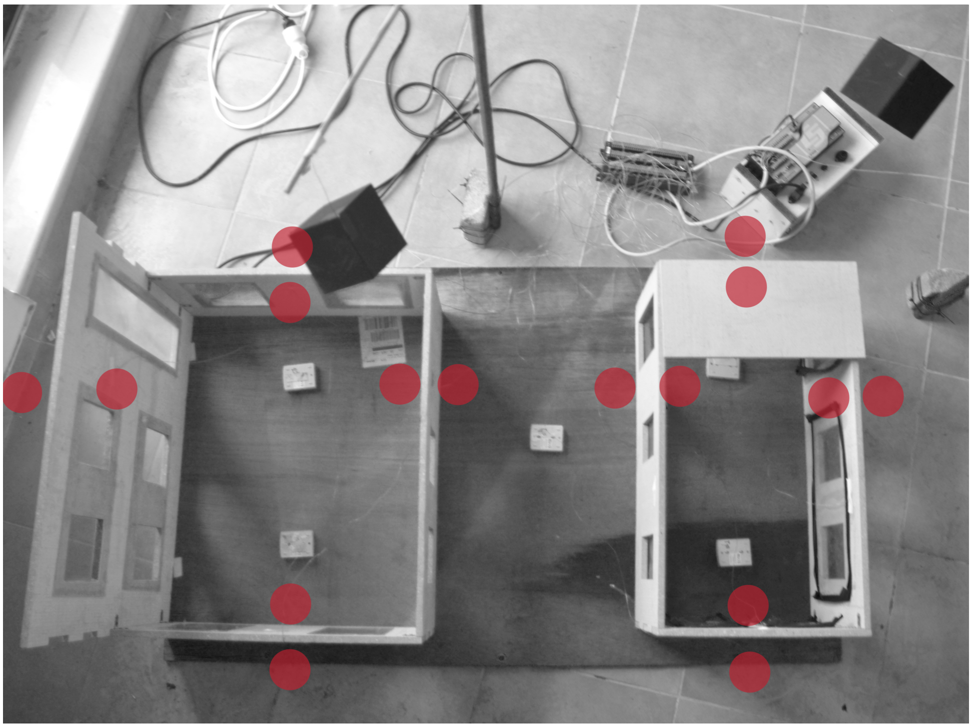


Figure 37: Thermo-couples position

In order to calculate the temperature change before and after reflection we created two black boxes. One thermo-couple is put in each box. The first box **(box 1)** calculates the temperature from reflection and the second box **(box 2)** calculates the ambient temperature (figure 38).

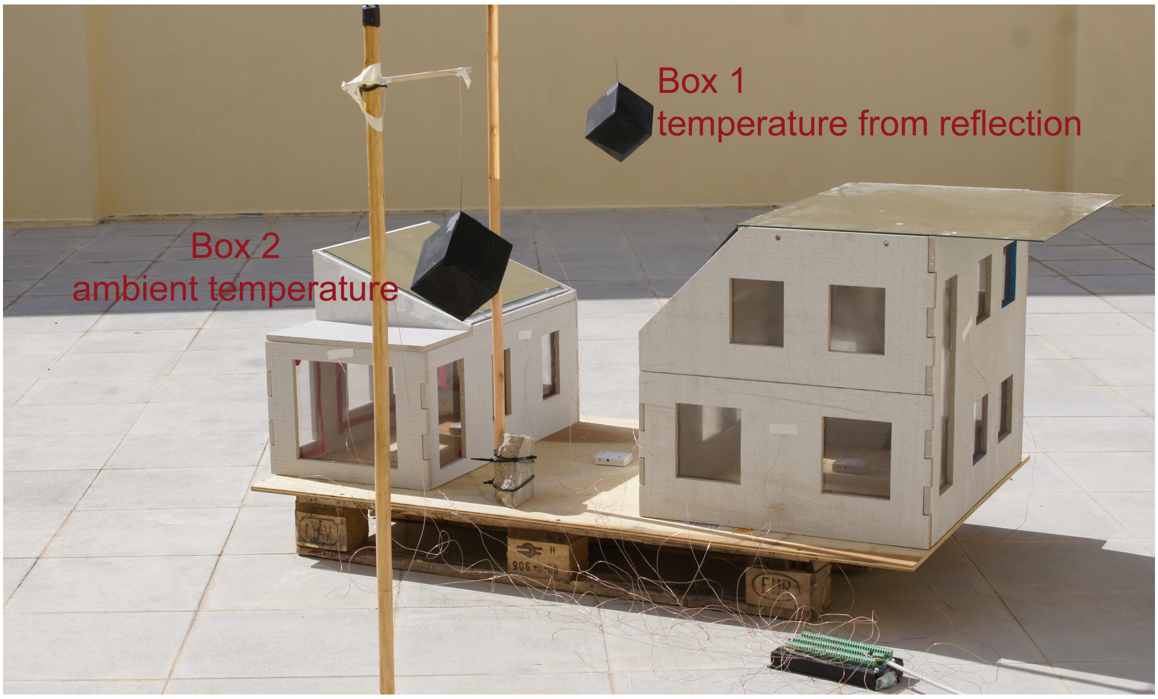
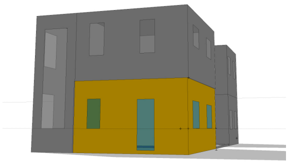


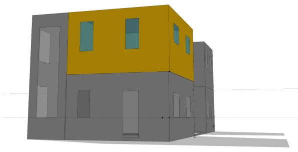
Figure 38: Model on site

4. Results

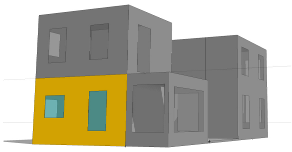
In this chapter the results, of the simulation and the physical experiment, are presented with tables and diagrams. Firstly the total heating and cooling loads of each zone is presented together with the temperatures. Secondly the measurements of the experiment are shown, after two different calculations. It the pictures above the zones of the model are presented.



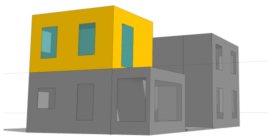
Zone: North 1 [N1]
Area = 30 m^2
Height = 3m



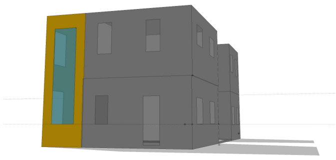
Zone: North 2 [N2]
Area = 30 m^2
Height = 3m



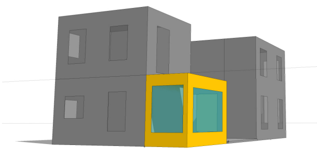
Zone: South 1 [S1]
Area = 20 m^2
Height = 3m



Zone: South 2 [S2]
Area = 20 m^2
Height = 3m



Zone: 2Floors
Area = 12 m^2
Height = 6 m



Zone: Greenhouse
Area = 8 m^2
Height = 3m

Figure 39: Simulation Zones

4.1 Simulation results

In this part of the thesis the temperature diagrams for each zone are presented. The model as mentioned, consists of 6 zones, according to their orientation and position on the model.

The lower temperatures are around 10 ° C and the highest are over 40° C as shown in Table 2.

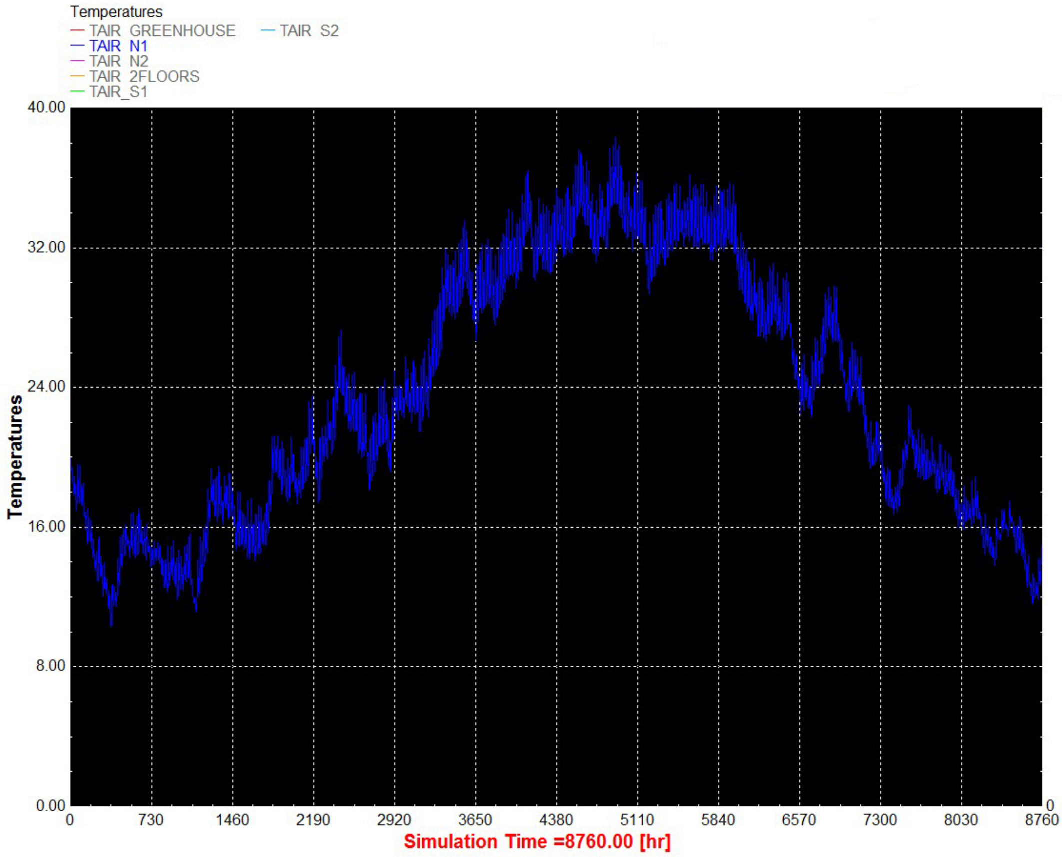


Figure 40: North1 temperature diagram.

The month October is highlighted in every diagram because it is the month of the physical experiment. So it is very important to cross the temperatures of the simulation with the temperatures of the experiment. The zone N1 has rising temperature after February and it starts descending after the August peak.

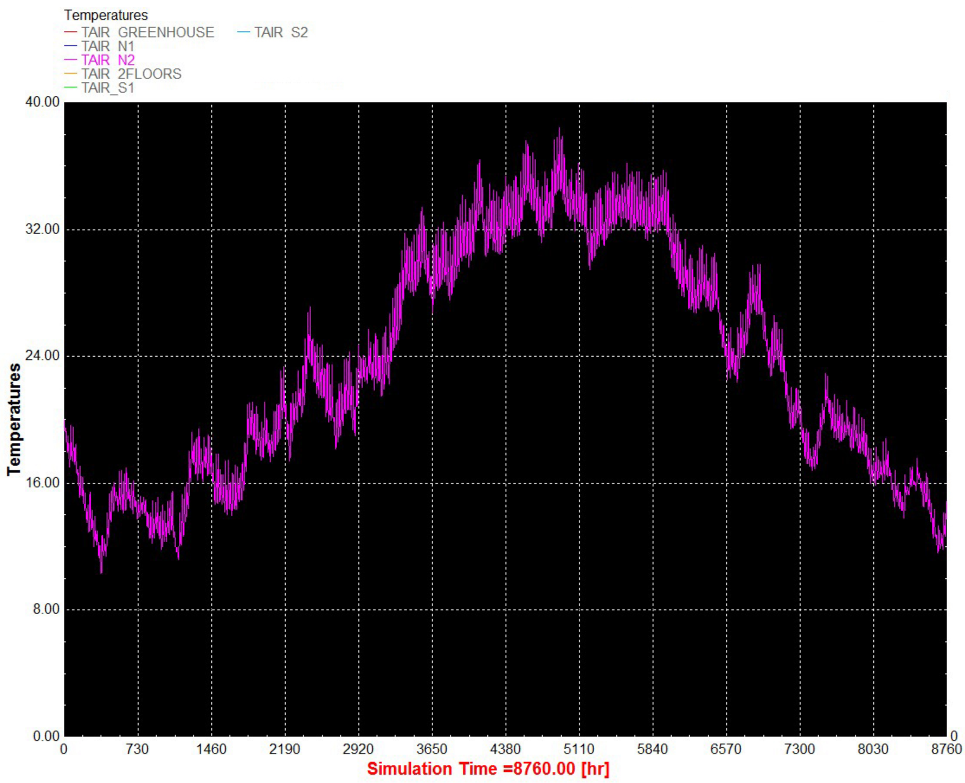


Figure 41: North2 temperature diagram.

The same rising is found in the zone N2. There is a small peak at October. There are no temperatures lower than 10 ° C.

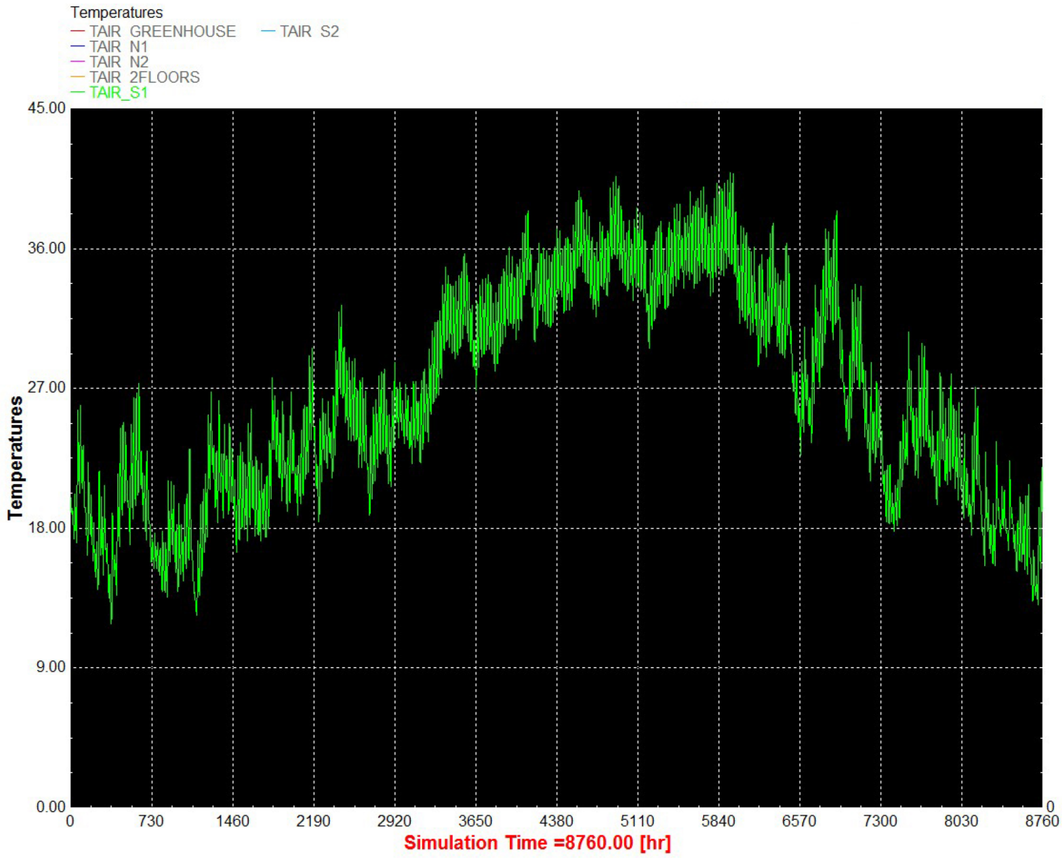


Figure 42: South1 temperature diagram.

The South zone S1 has in general higher temperatures and it is remarkable a high rise on October.

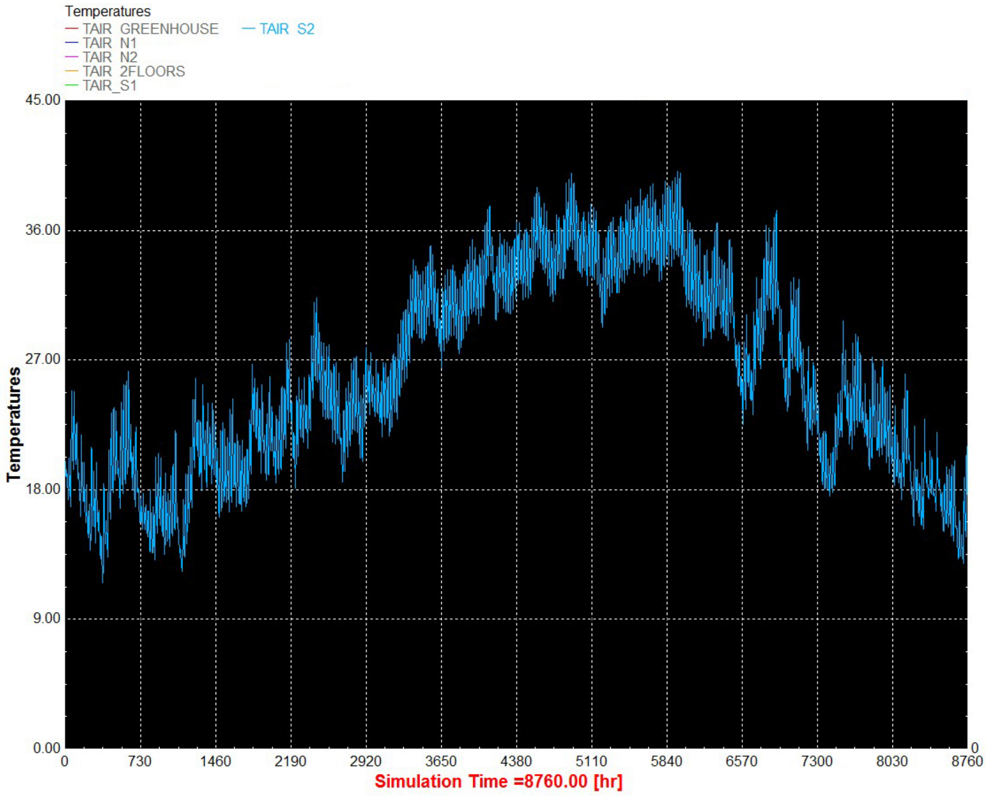


Figure 43: South2 temperature diagram.

During October there are also high temperatures in zone S2, where the lowest temperature is over 12° C.

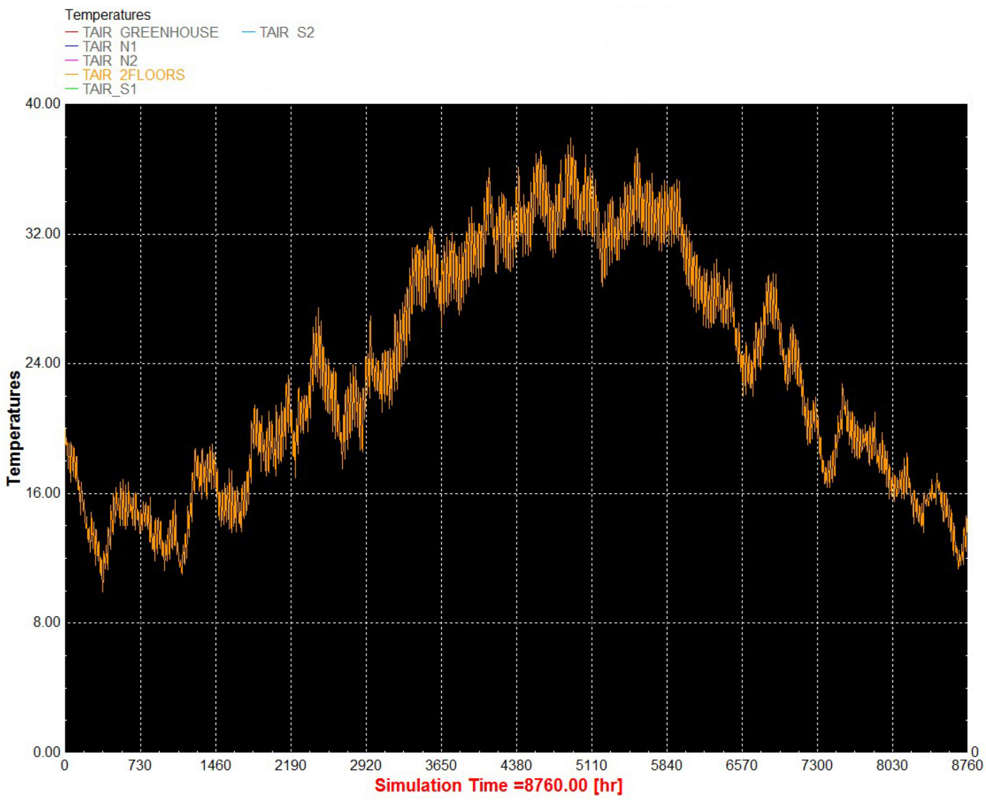


Figure 44: Double floors temperature diagram.

The 2Floor zone has a north orientation, and thus the temperature descent is obvious in almost every month.

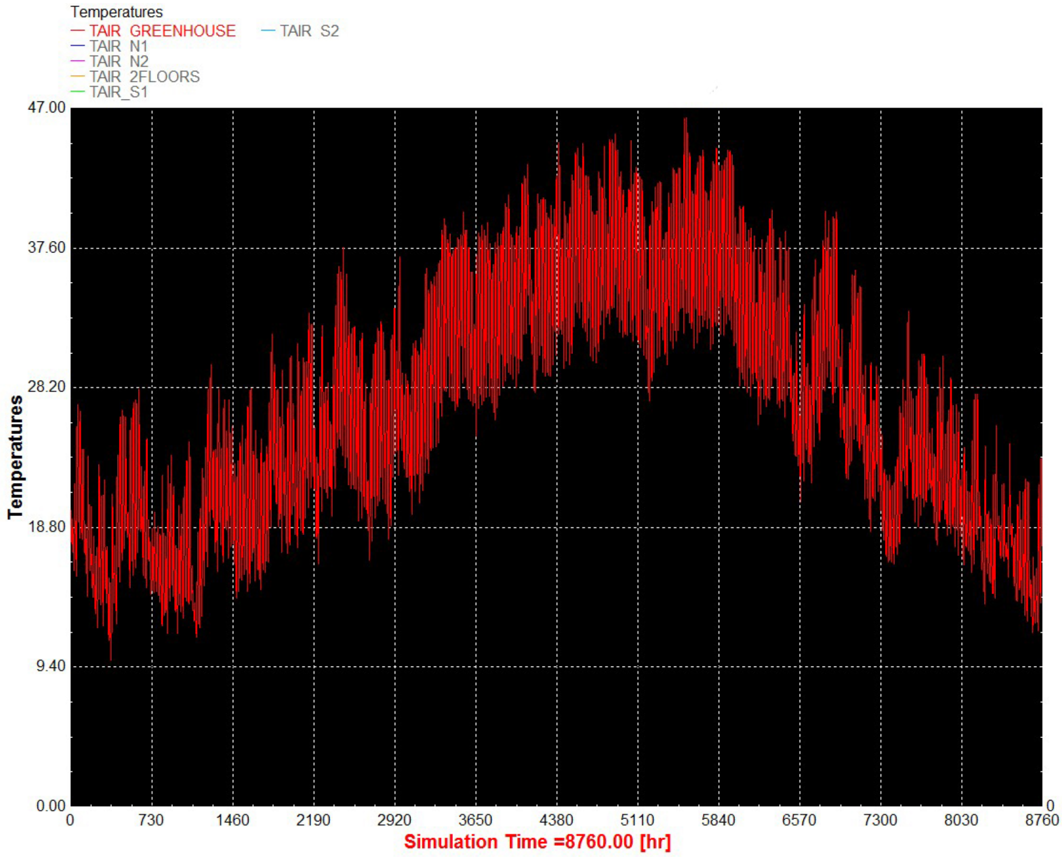
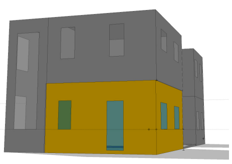
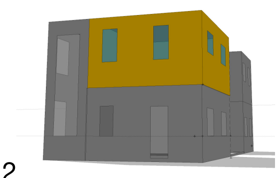


Figure 45: Greenhouse temperature diagram

The Greenhouse, as expected, has the higher temperature of each zone during the summer and the lower during the winter. This is expected, as it is a glass room. All the top temperatures of the zones are over 35 °C, which means that the Qc is expected to be also high.

Name of Zone Position	Simulation Temperatures °C High	Low	Area / m^2
 N1	36.7	12	30
 N2	38.1	10	30

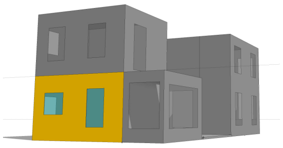
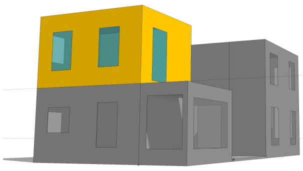
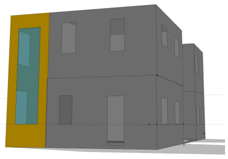
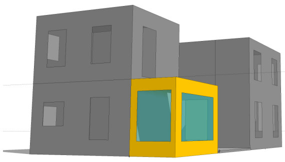
 S1	41.5	12	20
 S2	40.3	10.9	20
 2floor	36.7	10.2	8
 Greenhouse	45.3	9.8	12

Table 2: Higher and lower temperatures per zone

Building Loads

The building as mentioned is divided into 6 thermal zones, which were created according to their use and orientation in the model. The internal and external walls have different materials and thickness, which are in accordance with the Kenak rules.

The aim if the first simulation was to count the loads of the model and the temperatures of each zone for one year – 8.760 hours. The characteristics of each zone are shown at the table 3 below and the heating and cooling loads of six different spaces (zones).

Name of zone	**Area / m^2**	**Volume / m^3**	**Qh kWh/ m^2**	**Qc kWh/ m^2**
1. North1	30	90	22.21	31.21
2. North2	30	90	26.43	33.46
3. South1	20	60	12.02	64.22
4. South2	20	60	20.12	69.92
5. Greenhouse	8	24	49.50	234.94
6. 2floors	12	72	74.91	101.74

Table 3: Zones simulation results.

Table 3 summarises the results of the simulation, where the total Qh and Qc is calculated. The analytical diagram of the calculation that was held for one year every hour is presented in table 4 for total Qh and table 5 for the total Qc.

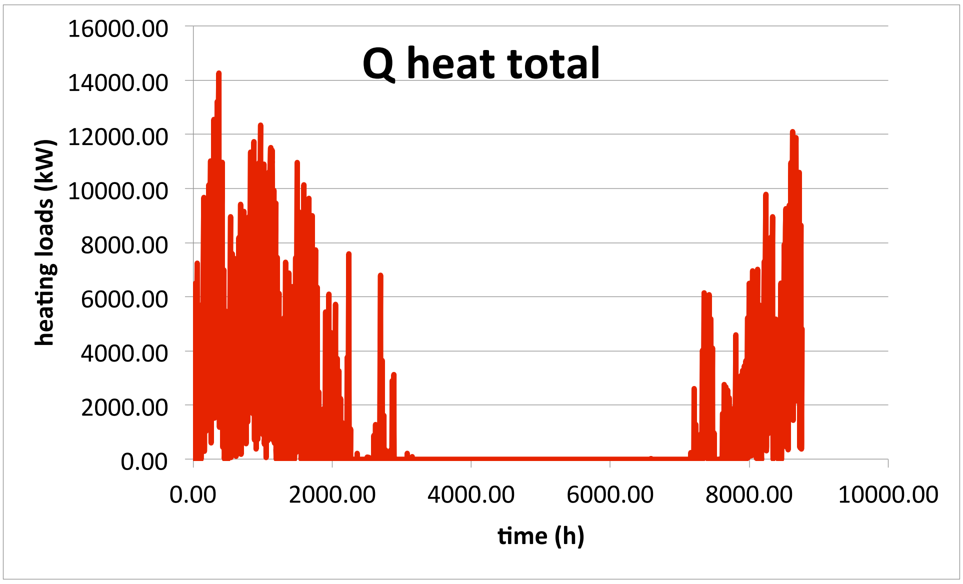


Table 4: Heating loads demand in hourly base.

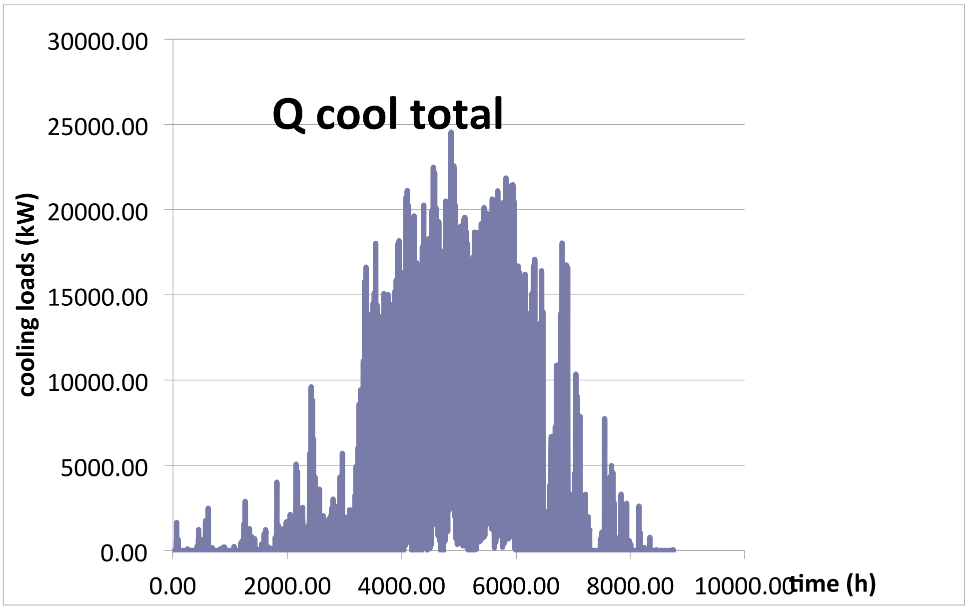


Table 5: Cooling loads demand in hourly base.

As we are on a Mediterranean climate zone the total Qc is higher from the total Qh. The energy needed to cool the building is more than double from the energy for heating during the winter.

Total Qh= 155,69 kWh/ m^2

Total Qc = 300,55 kWh/ m^2

At the Total Qc and Qh we dont count the loads of the greenhouse, because its loads are extremely high, as it is a space that is being tested.

The Greenhouse needs 49.50 kWh/ m^2 for heating during the winter. So the greenhouse is an ideal energy system to test its behavior in the winter after the reflection. In the summer also the Qc is extremely high but this is normal as it is a glass veranda with west orientation. During the summer the glass is removed in order to maintain low temperature and obtain user's comfort.

4.2 Daylight experiments results

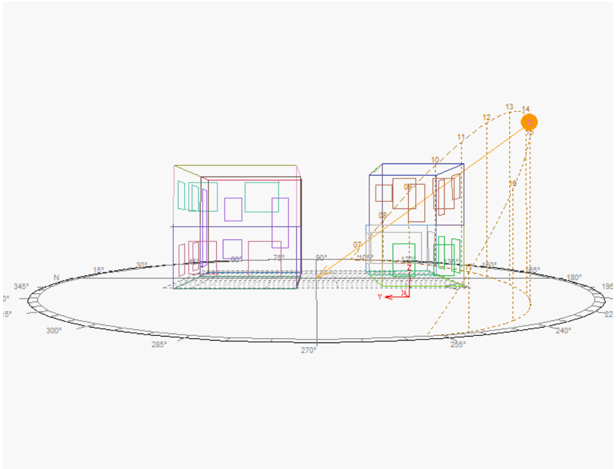


Figure 46: Sun position in October

The measurement took place in October 2015 from 22-10 to 28-10. The experiment was realised with two different type of roofs. But the measurements spots were stable.

<u>Case 1 22/10- 25/10</u>

Variable parameter Stable parameter

25° roof inclination measurement spot

<u>Case 2 25/10- 28/10</u>

Variable parameter Stable parameter

45° roof inclination measurement spot

In order to get results after the calculation, we had to choose two thermocouples for each orientation, as shown in figure 47.

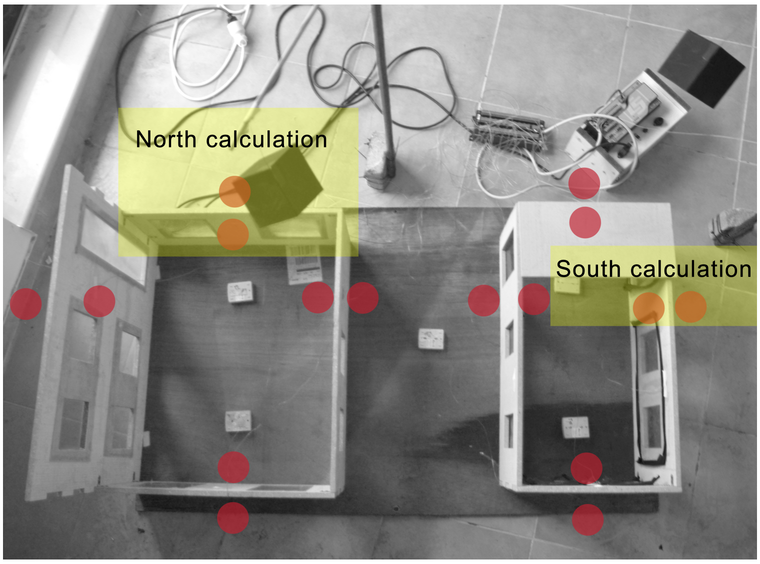


Figure 47: Chosen thermocouples for temperature calculation

During the experiment temperatures for each building were calculated as well as the ambient temperature and the temperature after reflection. According to the meteorological station in Souda (figure 48) the highest temperatures were found from 26-28 October. Also according to the temperatures of the simulation experiment, during October they exceed 30°C. October is a really hot month in Crete, it is a good season to make the daylight experiment.

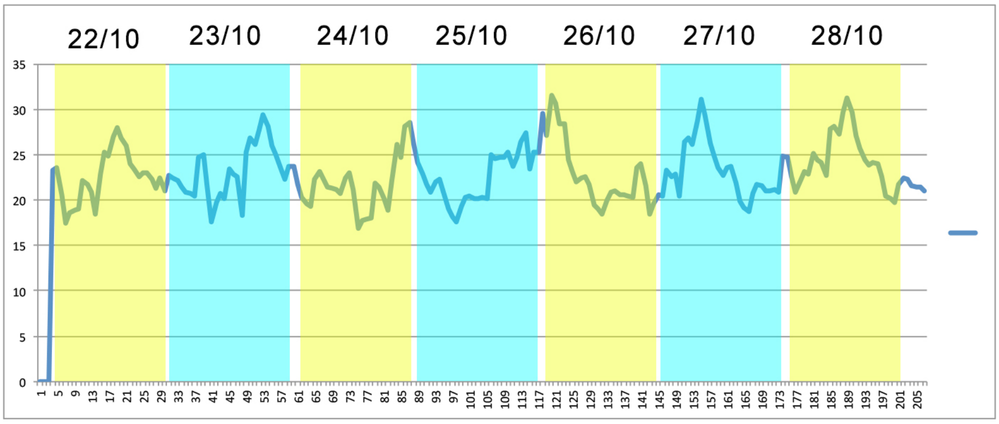


Figure 48: Weather data during the experiment

The simulation validates the temperatures as we can see at the figure 49 during October 2015.

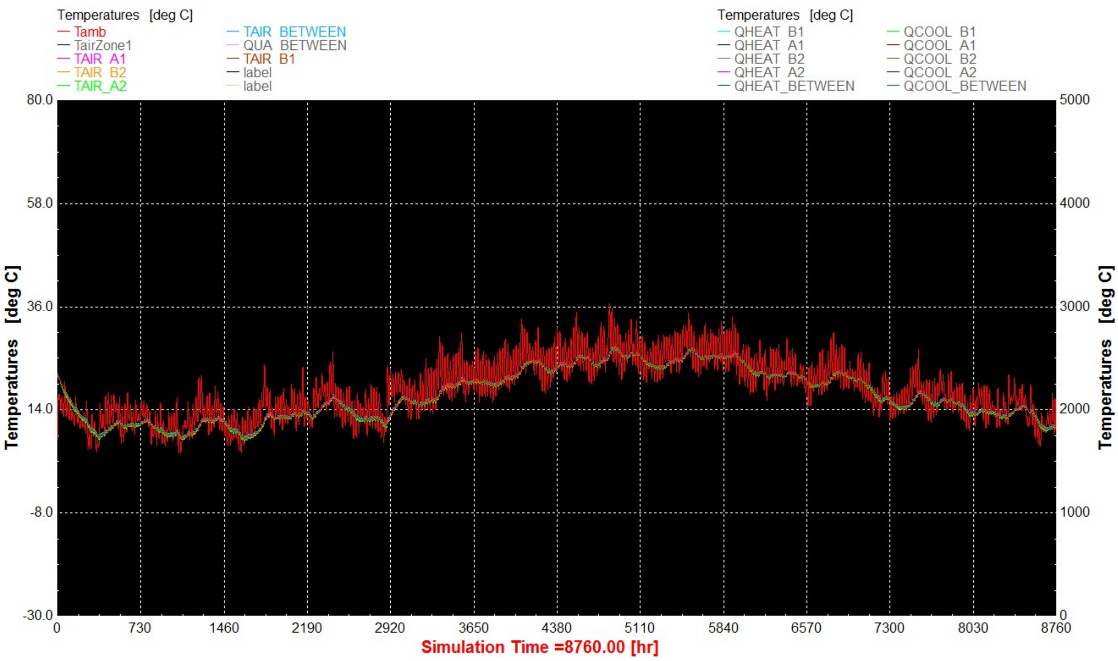


Figure 49 Simulation for Tamb

4.2.1 First measurement

The first measurement took place from 22 to 25 October. According to figure 48 and 49 the highest temperature is around 29°C and the lowest is around 17°C.

Table 6: North orientation

The highest temperature according to the measurements for the week at the end of October 2015, at the north oriented building, during the first measurement is 28.07 °C. The lower temperature is 17 °C.

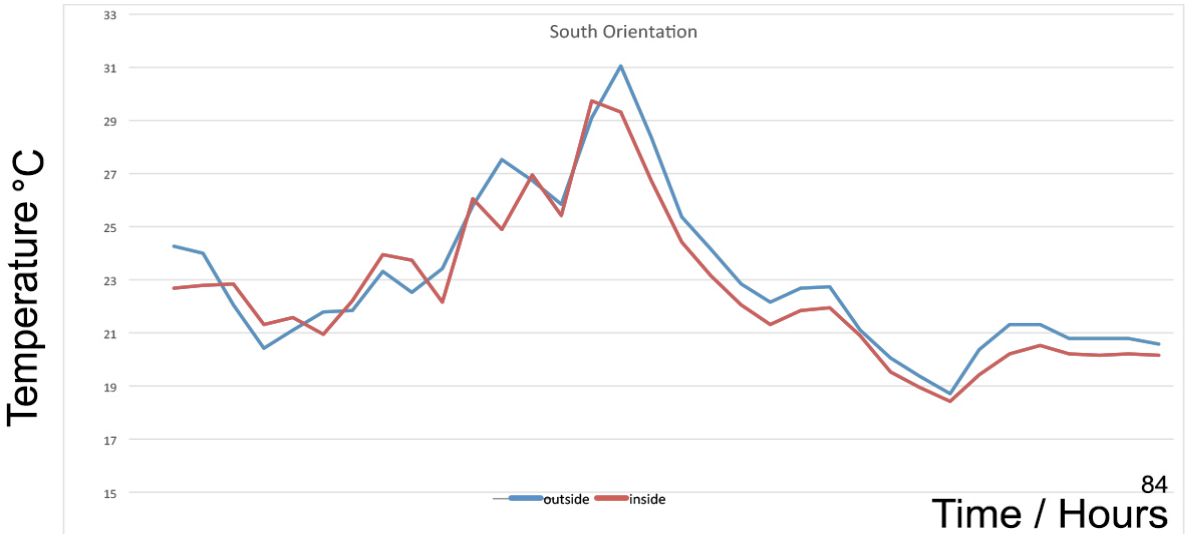


Table 7: South orientation

For the south orientation the higher temperature is 30.3°C and the lower 19.02 °C according to table 6.

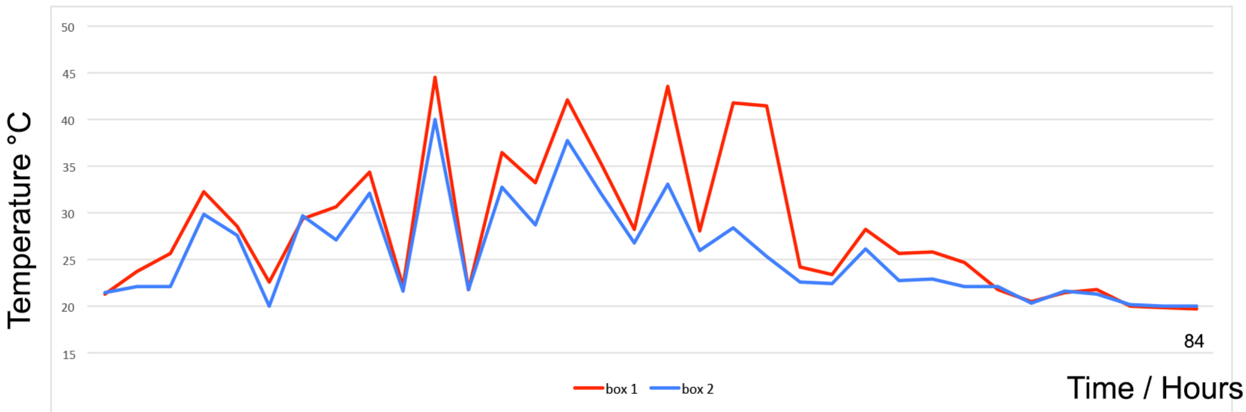


Table 8: Boxe's temperature

It is remarkable that the higher temperature of the black box before reflection 40 °C and after reflection is

44.89 °C.

The higher temperatures are notified at 24/210/2015 at 13.20 pm. According to the weather station in Souda the Tair at the same day and time was 28.7 °C. So with the system we obtained almost 20 °C higher than the Tair temperature. The temperature calculated in the reflection area is in general higher. The experiment shows that it is possible to direct sunlight in specific places, raise the temperature and consequently the efficiency of the SRs in the area.

4.2.2 Second measurement

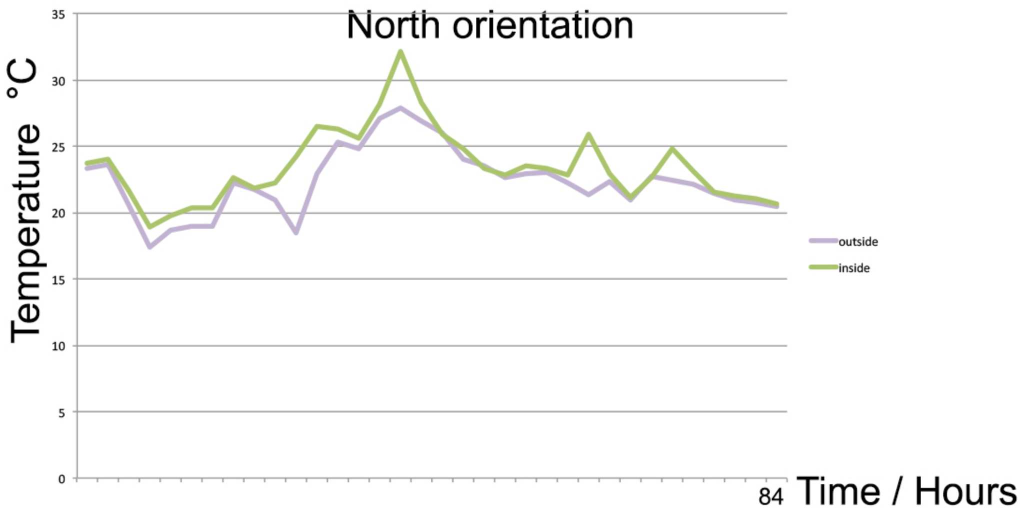


Table 9: North orientation

The highest temperature according to the measurements for the week at the end of October 2015, at the north oriented building, during the second measurement is 31.6 °C. The lower temperature is 18.7 °C.

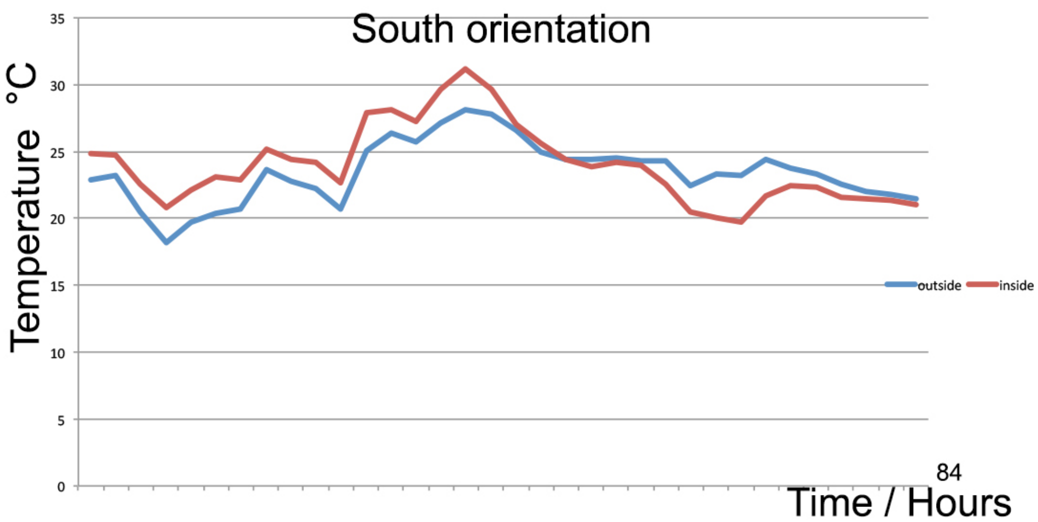


Table 10: South orientation

For the south orientation the higher temperature is 32.6°C and the lower 18.7 °C.

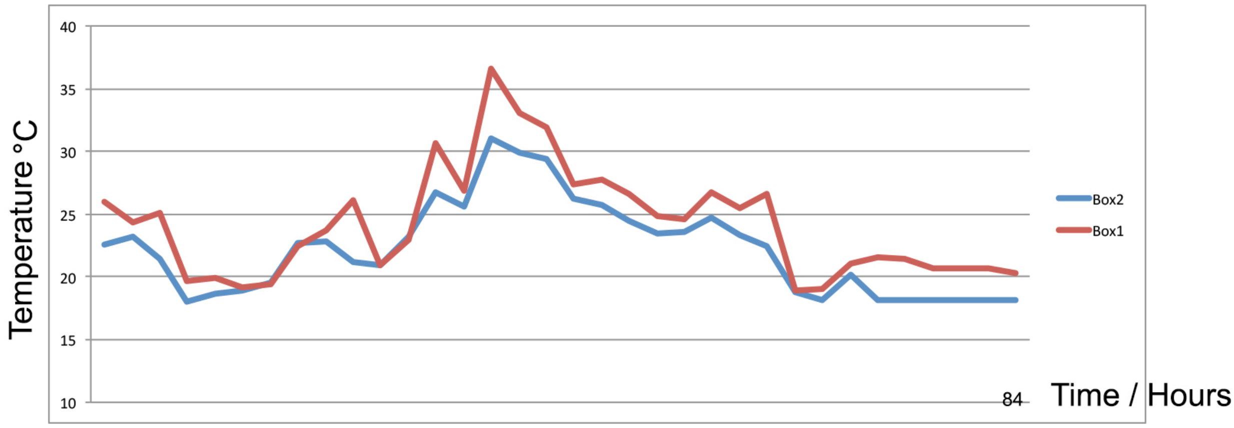


Table 11: Boxes' temperature

Even if the temperatures were quite high, it is remarkable the temperatures of the black box are not as high as at the pervious experiment. Before reflection the highest temperature is 31 °C and after reflection is 36.8 °C.

The higher temperatures are notified at 27/10/2015 at 13.20 pm. According to the weather station in Souda the Tair at the same day and time was 30.9 °C. So with the system we obtained only 5 °C higher than the Tair temperature. The temperature calculated in the reflection area is in general higher. According to the experiment the 25 ° roof inclination system is possible to be more productive during this season of the year.

		Case 1 22/10-25/10 Inclination 25 °	Case 2 25/10-28/10 Inclination 45 °
	T amb max	29 °C	32 °C
	T amb min	17 °C	18 °C
	NorthOrientation		
INSIDE	T max	31 °C	33 °C
	T min	21 °C	18 °C
OUTSIDE	T max	28 °C	27.5 °C
	T min	19 °C	17.5 °C
	SouthOrientation		
INSIDE	T max	31 .5°C	32 °C
	T min	18°C	20 °C
OUTSIDE	T max	30 °C	27 °C
	T min	17.5°C	23 °C
	Box 1		
	T max	44 °C	36.5 °C
	T min	25 °C	19 °C
	Box 2		
	T max	40 °C	31 °C
	T min	22 °C	17 °C

Table 12: Results

Figure 50: Reflection of the mirrors

The results of the simulation and the physical model validated the basic idea of the system. The energy system, which was designed during this thesis project, can be productive and integrated to the building. In figure 50 we can see the reflection captured by the camera on site.

5. Architectural integration

Architectural integration quality is defined as the result of a controlled and coherent integration of the solar collectors simultaneously from all points of view, functional, constructive, and formal (aesthetic), I.e. when the solar system is integrated in the building envelope (as roof covering, façade cladding, sun shading, balcony fence), it must properly take over the functions and associated constraints of the envelope elements it is replacing (constructive/functional quality), while preserving the global design quality of the building (formal quality) [22].

All the system characteristics affecting building appearance (i.e. system formal characteristics) should be coherent with the overall building design. The position and dimension of collector field(s) have to be coherent with the architectural composition of the whole building (not just within the related façade)

- Collector visible material(s) surface texture(s) and color(s) should be compatible with the other building skin materials, colors and textures they are interacting with.
- Module size and shape have to be compatible with the building composition grid and with the various dimensions of the other façade elements.
- Jointing types must be carefully considered while choosing the product, as different jointing types underline differently the modular grid of the system in relation to the building [22].

Well designed, active and passive solar energy systems could become an important part of the building design and the building's energy balance and thus contribute to both, the energy supply and high quality solar architecture [23]. In the figure 51, below, there are some successful examples of architectural integration.

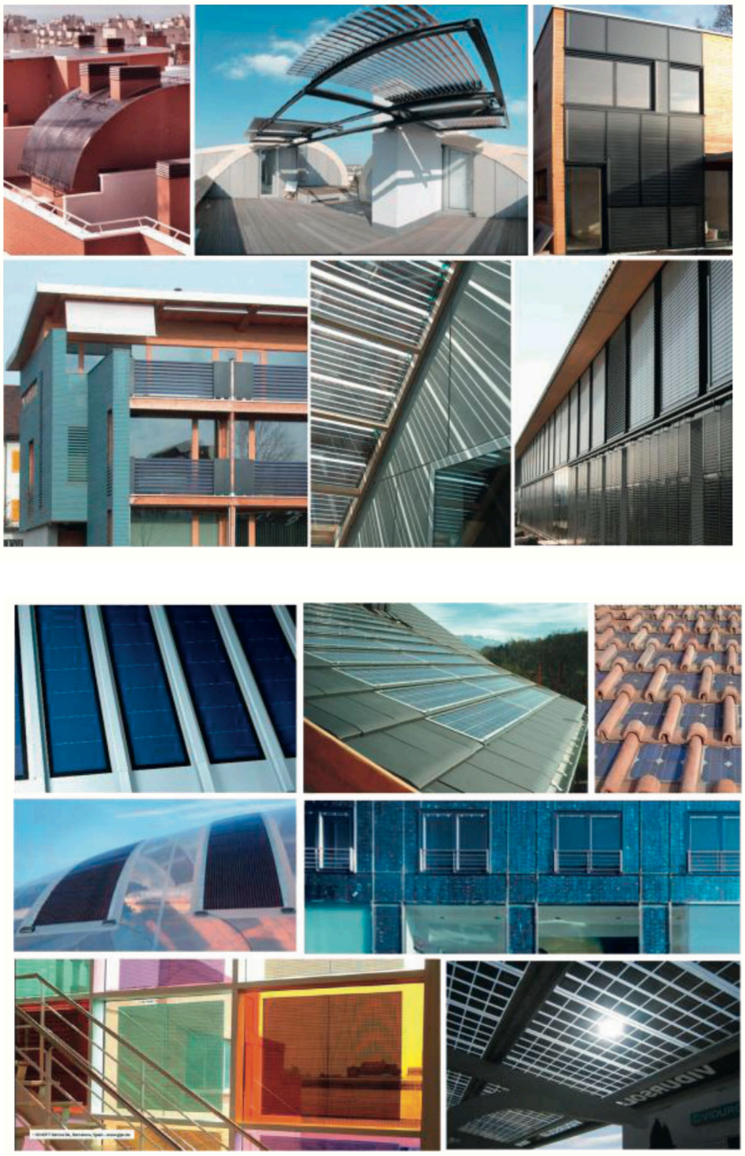


Figure 51. Examples of architecturally integrated solar systems (solar thermal left; PV right)

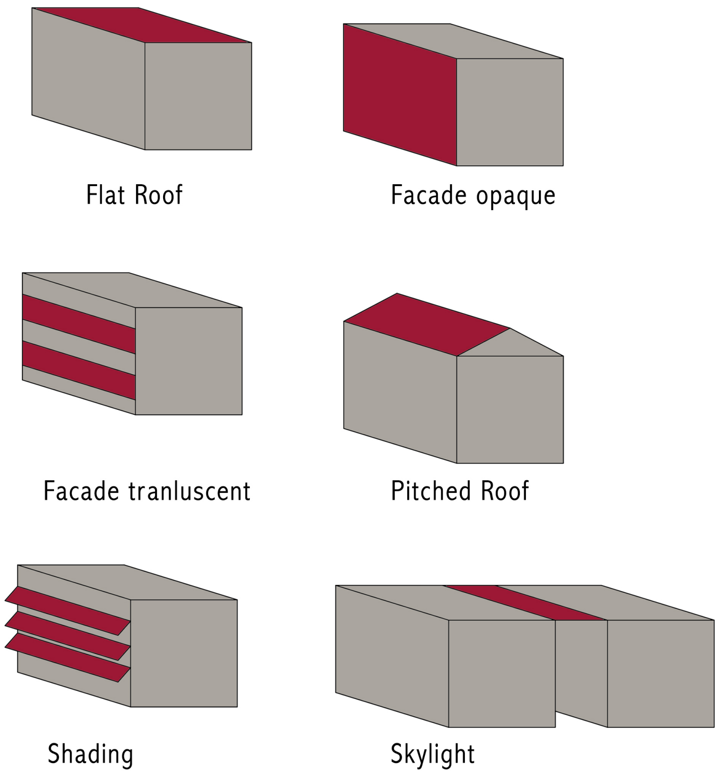


Figure 52: Position on the building

Roofs provide enormous potential for utilizing solar energy. Their appearance, including their shape, inclination and roof cover, is strongly influenced by regional aspects, i.e. specific climatic and material-related conditions, and provide a lasting feature characterizing towns and villages. Their exposure and inclination, but also their ability to provide contiguous and large-scale installations, means that roofs in particular enables solutions that are both architecturally harmonious and sensible in energy efficiency terms [24]. Façades are becoming more and more popular for solar systems integration. There are many parameters to take into consideration when integration RES in façades. Such parameters are the orientation of the façade, the doors and windows, the user's view, the sunlight, the external shading devices. The possible position of lacing Res in the buildings is presented in figure 52, with red color.

5.1 Model description

The model is based on the theory of the modular design. It consists of functional devices partitioned into discrete scalable modules of well-defined interfaces. The initial unit is a hexagon***** with reflective solar panels, that are multiplied into a system of modules forming the final composition of the panel, as shown in figure 53.

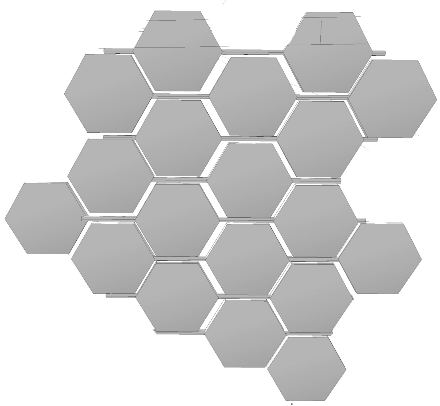


Figure 53: Modular design

The hexagon module is divided into two equal parts (figure 54), which are connected with a hinge. As the hinge is connected vertically to the main rail it moves vertically, making the parts between 0-180 degrees. The shape of the modular is transformed during the day in order for the sunrays to be directed exactly on the focal point. The thermal liquid is always placed on the focal point of the reflectivity panels over the rail. The construction detail is shown at the figure below.

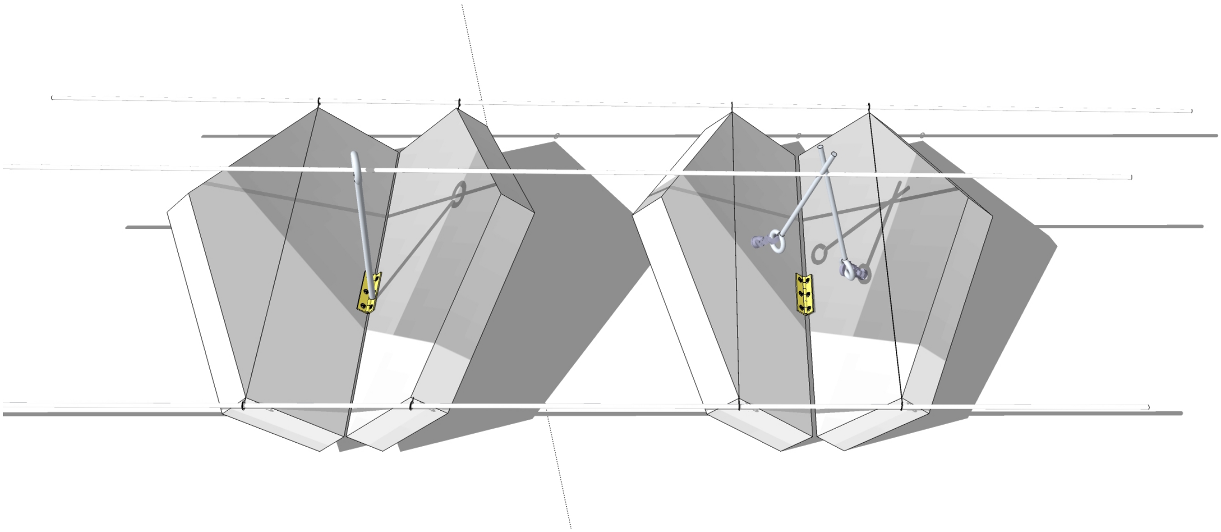


Figure 54: Construction detail

Each panel is begird by a stable symmetric frame, with two of it's opposite sides containing a mechanism, and a transformable part that consists of rails. Those rails are placed transverse in the parts of the mechanism, whose role is to provide movement to the modules upon them. As a result the module turns rotary of its self, according to the time of the day and the season. The ultimate goal is that the envisioned methodology can be applied in the design of the outer envelope of any type of buildings [6].

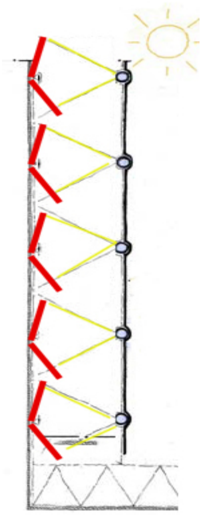


Figure 55: Section of he reflectors and the absorber tube.

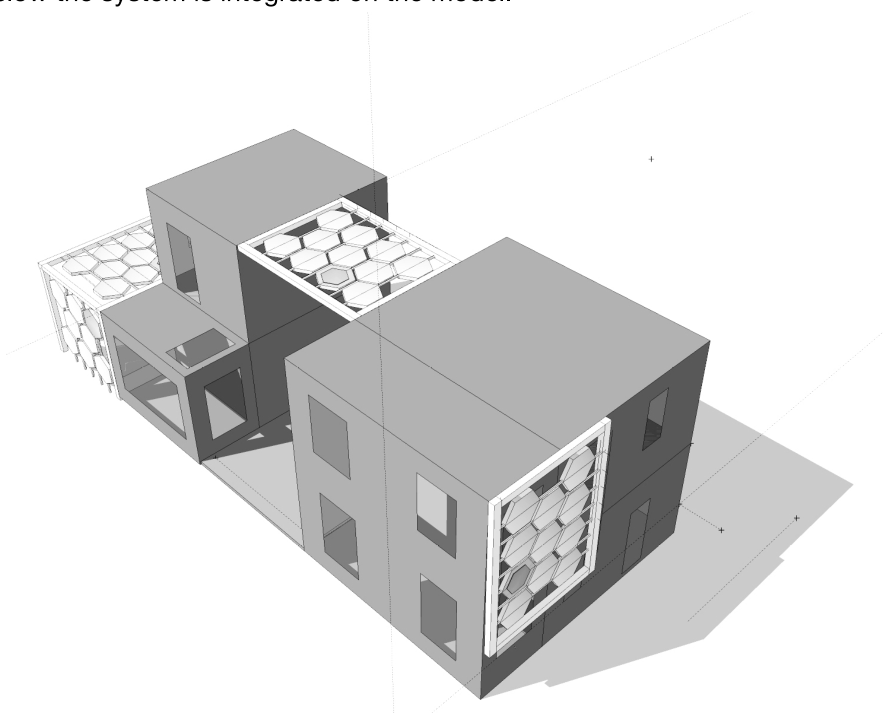
The use of the module into architectural façade gives to the final design great flexibility. Due to the modular shape of the construction the integration at the building can be a palpable issue. In architectural facades this model can be used in many cases, as long as the designer needs to achieve the minimal energy consumption of the building.

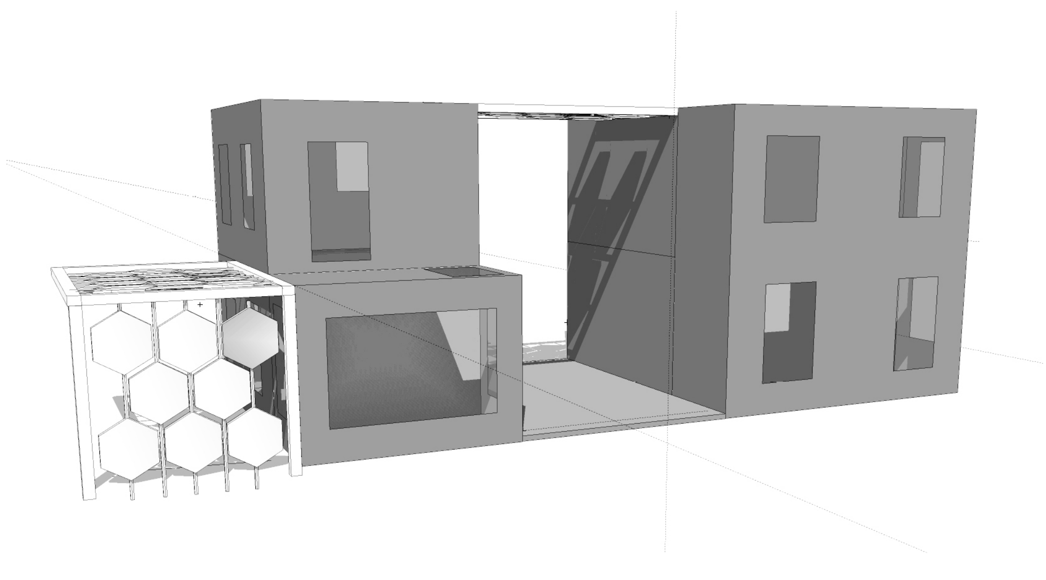
This frame can be multiplied and cover a surface of the façade or the roof, either horizontally or vertically. The fact that the module moves (opens and closes) takes into consideration several parameters such as the **efficiency** of the system, the **user's comfort**, the control of **sunlight**, the aesthetic **appearance of the building**.

When the hexagons are wide open, they form a shell and therefore eliminate the heat that the wall receives and as an implication the interior of the building. If, on the other hand, the model has a specific angle it means that the sun gets through the open space of the frame and the reflected material guide the sunrays at specific areas (figure 55).

5.2 The Description of the Fresnel into the model

Fresnel lenses add a new perspective in architectural design, as it is a new application in zero energy constructions. The use of Fresnel in the model is crucial since the whole system's goal is to collect solar energy from the focal point, which coincides with a pipe system that is incurred by a fluid. The collective sunrays hit the focal points, where the absorber of the system exists. Through the absorber the energy is transferred into the thermal fluid. The system is connected with a heat exchanger that gives power to a stem generator. This is one possible way that the system works.
In this chapter, the thesis focuses on the integration of the Fresnel energy system into the testing model. The modular hexagon Fresnel mirror is repeated on the roof the façade and the reflection area of the model. It can easily be a part of the envelope of each building, and be a way of producing energy, control the light and shade, give an final aesthetic result that reminds of a nature motif.
At the pictures below the system is integrated on the model.





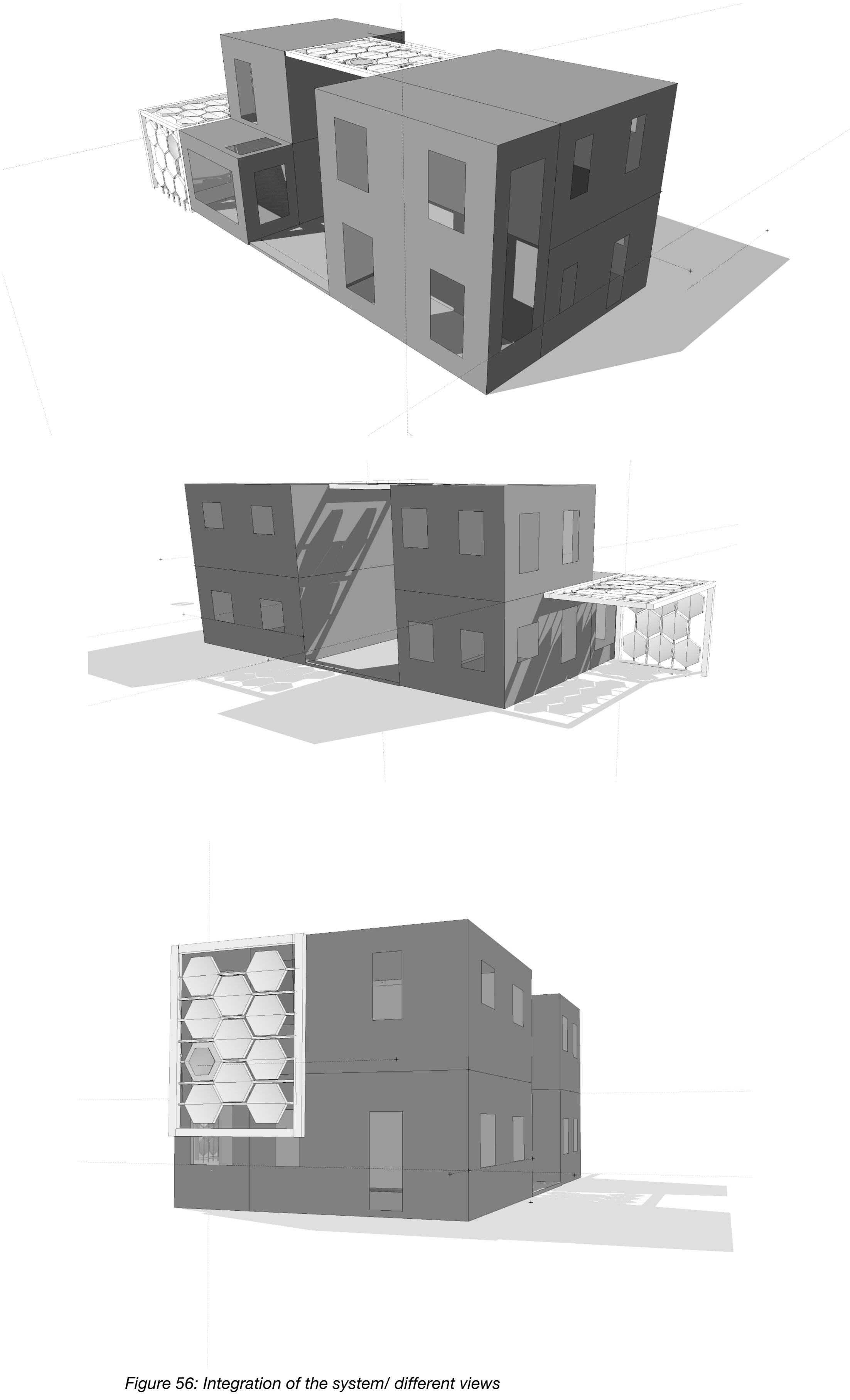


Figure 56: Integration of the system/ different views

The surface, as it is mentioned above, is a reflective Fresnel lens, that changes the direction of the sunrays towards a particular focal point. Upon the main rail that is included in the main frame, is infused with liquid that is heated by the solar panels based on the basic operative principle of Fresnel.

Some of the proposed uses of this mechanism is energy production on the west, south or east side of the building and as a vertical cover on the north side. This arises from the fact that the sun follows elliptical orbit over south points beginning from east to west. On the north side, the sunrays are not incident directly and this allows the module to capture and redirect the light.

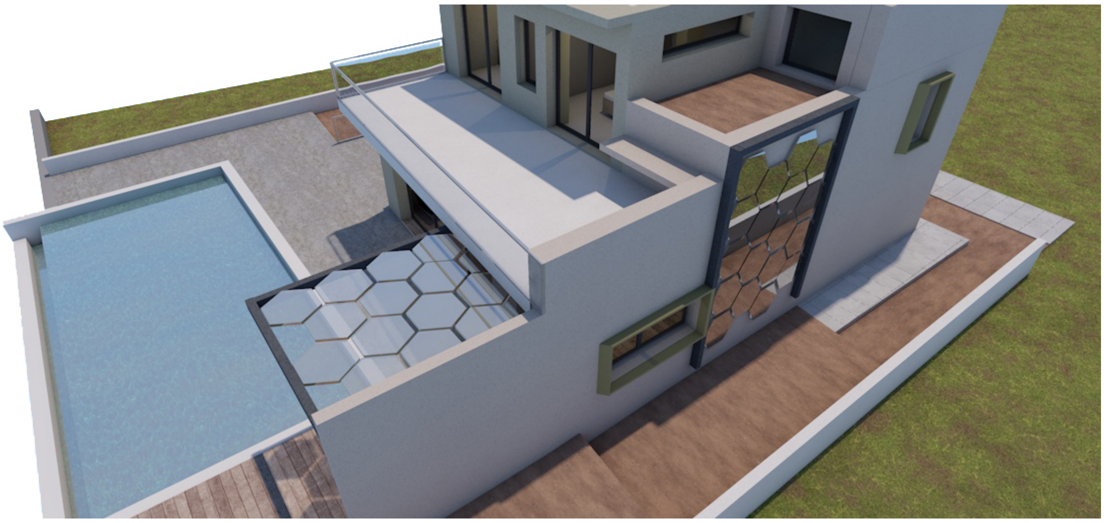


Figure 57: Integration of the system in an existing project

6. Conclusion | further research

This presented research work leads to the conclusion that the energy system designed during this project, can bring about temperature rise in specific selected areas. The performance of the system has been evaluated using measurements collected from a local weather station. This can lead to optimization of the solar energy systems, design and construction, as well as changes in the architecture of a new building, in order to integrate an energy system.
Nowadays more and more of the everyday activities oblige people to spend time in interior environments where sun light, thermal and cooling comfort is very important. In Mediterranean countries, solar heat should be combined with energy production during some time of the day. Despite many good examples, today, architects often see solar energy systems as unnecessary and not compatible with the design or too complex and expensive to be used. Consequently, solar energy systems are not considered in the early stages of the architectural design and thus, most probably won't find its way into the building. Also, there is a big lack of confidence from clients' side. Considering these facts, it will be very important to clearly communicate the qualities of solar energy systems in architectural designs and to showcase the design process to stimulate an increased use of solar energy systems in energy conscious buildings [25].

After counting the cooling and thermal loads of the building, choosing the SRs, taking measurements of the physical model and optimize the reflectors the next step is to run a simulation with the integrated system in order to optimize it. Additionally another step of this research is the physical model testing, of the integrated SRs, which will show the exact area of the sun.
The aim of the project is to propose a method for reducing the energy of the building and produce a new energy system, which can be integrated in existing or new buildings. Existing buildings should be suitably renovated, following energy sustainability investigations and aiming to the reduction of energy consumption. New buildings should be constructed in the frame of the rules for ZEB [4].

Further topics for discussion:
· Carry out the experiment during the summer, so as to find out the how the system works during the high temperature months.
· Check how the mirrors have an effect on the luminosity of the inside spaces.
· Try different roof inclinations and different building distances
· Investigate how the architecture of the residential buildings is affected.
· Find out methods for increase the production of the system.

Despite many good examples of solar architecture, there is still need for further developments in terms of products and tools as well as know-how and skills. Also, it is of key importance, that all stakeholders, clients, architects, specialists, municipalities and manufacturers work together to achieve the ambitious goal of a broad spread of trend setting and inspiring architecture with well integrated solar energy systems [23].

Clearly defined goals, well-balanced decisions and a design team with good communication habits and common understanding will help to achieve designs with well integrated solar energy systems, even though the goals are tempered by financial constraints. Also, it is vital that solar energy strategies are considered at the early design stage, in order to well integrate the technology into the design process, to make best use of the various options and to develop the buildings full potential [23].

7. References

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8. Appendix

* Meteonorm is a comprehensive meteorological reference. It gives you access to a catalogue of meteorological data for solar applications and system design at any desired location in the world. It is based on more than 25 years of experience in the development of meteorological databases for energy applications. Meteonorm addresses engineers, architects, teachers, planners and anyone interested in solar energy and climatology. http://www.meteonorm.com/

** The amount of solar radiant energy falling on a surface per unit area and per unit time is called irradiance. [9]

*** According to: Tips for daylighting, the integrated approach, by Ernest Orlando Lawrence Berkeley National Laboratory.

Four methods to quantify daylighting levels and energy impacts

1. Scale Model.

a. Ensure materials and joints are opaque— cover joints with black tape; paint or cover exterior surfaces if not opaque. b. Be sure to model all 3D features of the windows, like sills and reveals.

c. Glazing can be left out if you don’t have a sample of the actual glazing, but see item i. below. If diffusing materials are intended, use tracing paper or a uniformly translucent plastic for glazing.

d. If possible, build in a modular fashion to allow easy variations. Scale: 1"=10' for small rooms, 1/2"=1' for larger rooms.

e. Cut a porthole in the sidewall adjacent to window for eye and camera.

f. Take outdoors, preferably to actual site or some place where sky exposure and obstructions are similar, position in proper orientation, and observe interior for several minutes as your eye adapts to the lower interior illuminance level. Qualitatively assess four things: character of the space, adequacy of illumination, glare, and balance across the room depth. Be sure to measure under an appropriate variety of sun and sky conditions (e.g., clear, overcast, etc.).

g. Take photographs with a wide-angle lens and fast film—results are highly realistic and helpful for analysis later. Black and white film is recommended if model colors are not the intended final colors.

h. Add furniture and other details for realism and scale. If you have access to photometric equipment, measure illumination and calculate daylight factor (horizontal indoor illuminance divided by horizontal outdoor illuminance) for several different task locations.

i. If you have not included glazing in the model, multiply your readings by the visible transmittance of intended glazing.
j. Ask at local utility or architecture school for possible assistance. Otherwise, see books listed below for more tips. Surface reflectances in model should equal intended interior finishes, and solid wall and roof materials of model must not transmit light Hole for light cell cable Light meter (to display illumination levels) Light cell (to measure illumination levels, scale the model so that cell is at desk height) Ground cover (reflectance should equal actual site conditions near building) Table (locate outdoors in open area away from obstructions).

**** Data loggers for temperature: a **temperature data logger**, also called **temperature** monitor, is a portable measurement instrument that is capable of autonomously recording **temperature** over a defined period of time. The digital **data** can be retrieved, viewed and evaluated after it has been recorded.

***** Thermocouple: a thermoelectric device for measuring temperature, consisting of two wires of different metals connected at two points, a voltage being developed between the two junctions in proportion to the temperature difference.

***** The hexagon shape: according to Zack Patterson and Andy Peterson: << *Honeybees are some of nature's finest mathematicians. Not only can they calculate angles and comprehend the roundness of the earth, these smart insects build and live in one of the most mathematically efficient architectural designs around: the beehive*>>. The bees need space efficiency in order to be productive. They choose little storage units, big enough to fit into and to store as much honey as possible spending the less wax for building.
The modular shape needed for the Fresnel reflectors should have the largest surface with the less material for construction. So the modular shape that is chosen is the hexagon, but to be accurate the most efficient shape would come up after calculations and simulations. (https://www.youtube.com/watch?v=QEzlsjAqADA)