Sergio Cuadra

Feasibility study on renewable energy systems, and selected insulation applications.

Smart solutions for energy saving

Helsinki Metropolia University of Applied Sciences

Engineering

Environmental Engineering

Bachelor Thesis

5 April 2013

Abstract

Author(s) Title Number of Pages Date	Sergio Cuadra Feasibility study on renewable energy systems and selected insulation applications: smart solutions for energy saving. 51 pages + 1 appendices 5 April 2013
Degree	Bachelor of Engineering
Degree Programme	Environmental Engineering
Specialisation option	Renewable Energy
Instructor(s)	Antti Tohka, Senior Lecturer

Energy represents a big challenge for future generations; not only mineral and fossil energy sources are being exhausted, but also GHG emissions pollute the environment and disrupt life natural cycles bringing serious irreversible impacts on earth.

Renewable energy sources, on the other hand, are unexhausted and free of pollution; solar power systems play an important role in the generation of clean energy, being one of the most cost-effective solutions. Besides, solar power systems have other beneficial features, for example low running cost, long lifetime, and silent non-polluting energy generation.

Improving the insulation efficiency of buildings by retrofitting materials is an energy reduction technique. The materials are used to reduce heat transfer by conduction, radiation or convection and are employed to achieve thermal comfort with reduced energy consumption.

The purpose of the thesis project was to analyze the effectiveness of clean energy technologies related with the generation of solar power and with thermal insulation. During the project, the properties, functioning mechanisms and energy outputs of solar power systems and insulation materials supported by different technologies were defined. The goal of the thesis was achieved by determining which technologies were feasible to implement at the Myyrmäki and Leppävaara campuses of the Helsinki Metropolia University of Applied Sciences to optimize energy consumption and GHG emissions.

Keywords	GHG, renewable energy, solar power systems, insulation materials, retrofitting materials.

Dedication

For all those little things we take for granted.

To my Family.

Contents

Appendices

1 Introduction

Energy represents an important input in our everyday life. It has been forecasted by the IEA committee of energy research and technology that ‘’by year 2050 the global energy demand will double’’, and since even oil industry lobbyists admit that the age of mineral oil may last for only a few decades, it is for us to find energy technology alternatives to balance the incoming energy shortages [1].

The sun provides free renewable energy, which makes it one of the most cost-effective solutions compared to traditional resources, such as coal, oil or nuclear power. Furthermore, the sun represents an inexhaustible energy source. Solar energy technologies are characterized by such beneficial features as low running cost, long lifetime, and silent non-polluting energy generation.

The purpose of this thesis was to analyze the effectiveness of technologies related with the production of renewable energy and thermal insulation. The goal of the thesis was to determine which technology would be more feasible to apply at the Myyrmäki and Leppävaara campuses of the Helsinki Metropolia University of Applied Sciences to optimize energy consumption and GHG emissions.

The analysis consisted of defining the properties, functioning and energy output of each product. The material used in the analysis included results of previous tests conducted by manufacturer, output data collected from projects, and general product information found on the internet.

2 Helsinki Metropolia University of Applied Sciences

Helsinki Metropolia University of Applied Sciences is Finland’s largest university of applied sciences. It is run by Metropolia Ammattikorkeakoulu Oy, and owned by the cities of Helsinki, Vantaa, Espoo and Kauniainen and the municipality of Kirkkonummi.
Helsinki Metropolia has a total of 1 200 staff members and 16 700 students distributed among 15 campuses and 20 locations. [2]

This thesis was completed for the ”Smart Campus” project in conjunction with a feasibility study conducted at the Myyrmäki and Leppävaara campuses of the Helsinki Metropolia University of Applied Sciences.

2.1 ”Smart Campus” at Helsinki Metropolia

In autumn 2012 the ”Smart Campus” project was introduced to the Degree Programme of Environmental Engineering at Helsinki Metropolia. The ”Smart Campus” project concept is to improve the wellbeing and energy efficiency at Leppävaara and Myyrmäki campuses by demonstrating how intelligent ICT solutions can be used to control the energy costs according to the actual use of the building as well as by motivating the different users to save energy.

”Smart Campus” aims to design an integrated socio-ecological environment by interacting with Metropolia social and technical degree programs to ensure that graduates address social and ecological sustainability in their everyday life decisions. Another important aim of “Smart Campus” is to find renewable energy technology alternatives and optimize the energy consumption and GHG emissions in the infrastructure of Leppävaara and Myyrmäki campuses.

Leppävaara and Myyrmäki campuses have been functioning and growing during the last 20 years. They both play a key role in Metropolia when the campuses are developed and redesigned. They have been growing all the time, and they are facing many challenges due to ever growing number of students and the limited available space.

2.1.1 Myyrmäki Campus

The Helsinki Metropolia, Myyrmäki campus is located on Leiritie 1, Vantaa. The older part of the campus (Building A) was built in 1988 and the newer one (Building B) in 2002, and has an area of 15 220 m^2. Four buildings divided in A and B buildings host classrooms, laboratories, auditoriums, negotiation rooms, a gym and a restaurant. The Myyrmäki campus has a total of 2 300 students and 136 staff members within 12 degree programmes. In 2010, the energy consumption was 1 565 MWh with an average of 10 195 kWh. The buildings have a remote district heating system and a constant HVAC system running depending on the daytime. [3]

2.1.2 Leppävaara Campus

The Helsinki Metropolia Leppävaara campus is located on Vanha maantie 6, Espoo. The campus was built in 1988, and has a 17,530 m^2 area. Three buildings divided in A and B buildings host classrooms, laboratories, auditoriums, negotiation rooms, a gym and a restaurant. The Leppävaara campus has a total of 2,600 students and 185 staff members within 8 degree programmes. In 2010, the energy consumption was 2090 MWh with an average of 13 339 kWh. The buildings have a remote district heating system and a constant HVAC system running depending on the daytime. [3]

3 Methodology and Implementation

Energy audits were carried out on Myyrmäki and Leppävaara campuses to define the baselines and recommendations for improvements, developments and applications with technical issues, and operational practices and processes.

Energy audit consisted of a series of inspections through the campus area to determine if there were U values, air leaks or applications which would need to be restored or replaced in order to reduce the energy consumption inside the buildings.

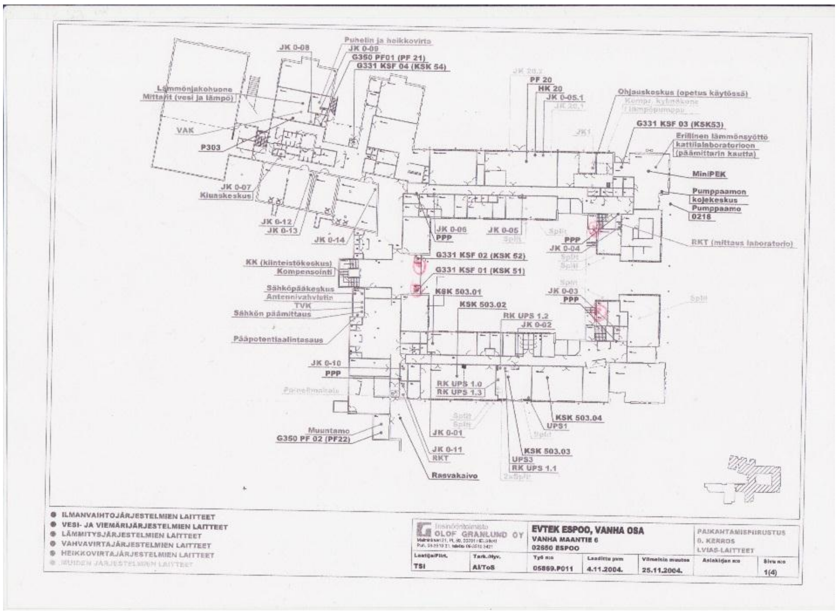
A feasibility study was done on selected applications and technologies, to provide a financial and technical analysis back up. A financial analysis was performed on investment and payback period, and a technical analysis was conducted on energy and CO_2 emissions savings. The chosen technology will be procured and installed by subcontractors or by student groups.

Inspections were focused on A buildings due to their lower energy efficiency.

3.1 Building general inspection

Building inspections provided a more solid background about the buildings' current situation, making it easier to decide which areas and facilities inside the building require retrofitting or replacing.

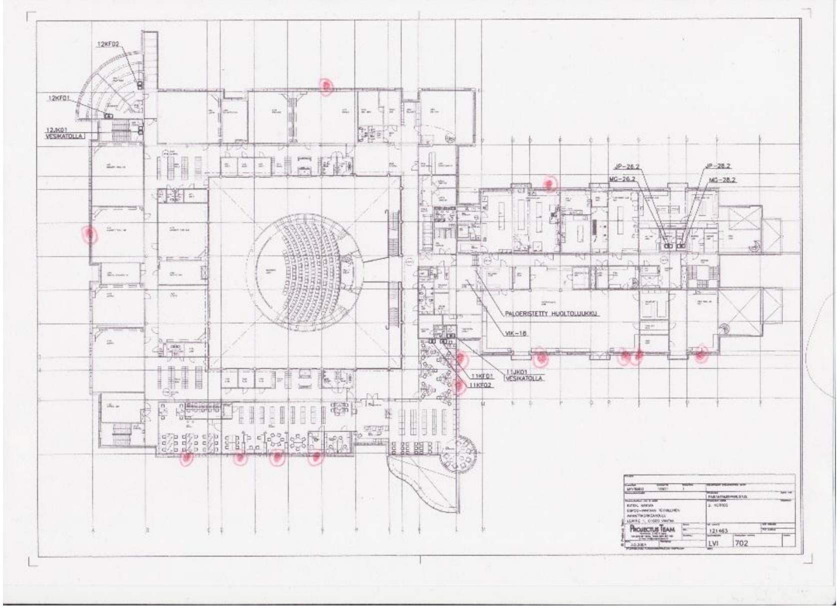
Technology is a big issue since standard heat values for constructing buildings have changed through the years. Indeed, it is a decisive factor when improving energy savings in a facility, for example when comparing A building with B building on both campuses, Myyrmäki and Leppävaara, U values and air leaks differ a lot from one area to another (see Picture 1).



Picture 1. Blueprint of heat losses in Leppävaara A building.

Heaters located in B buildings were designed with latest technology which allows higher heat efficiency. Even though heaters in A buildings in both campuses, Leppävaara and Myyrmäki, are an old version, the ones in Leppävaara are placed in a metal box which reduces the heat transfer to the surroundings through the wall. These metal boxes work in the same way as the newest ones.

Blueprints of both campuses, Myyrmäki and Leppävaara, are shown in Picture 1 and Picture 2; red spots on the blueprints represent the areas where low insulation was detected.



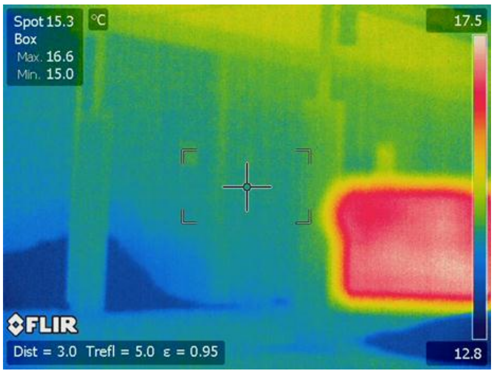
Picture 2. Blueprint of heat losses in Myyrmäki A building.

When in direct contact with the surroundings, single glazing windows separated from each other by a few centimeters’ air layer represent lower energy efficiency than double glazing windows which have argon between the permanently attached glass panes. There is a technology gap between these insulation materials, technically and operatively speaking. In case of two single glazing windows, the inner glass pane must be removed in order to clean the outer one; every time this procedure is completed the lifetime of material used to seal the window decreases and may get damage therefore, the maintenance staff must be sure that windows are properly sealed. The cleaning procedure of double glazing windows is similar to that of a single glazing window (see Picture 3 and Picture 4).

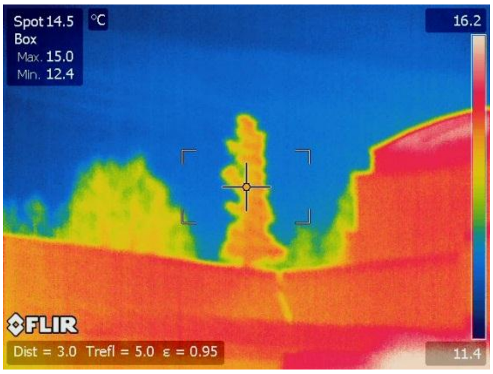
Picture 3. Window air leaks.

Picture 4. Single glazing window.

The following pictures were taken with the thermal camera and show heat losses and air leaks in the buildings due to poor insulation properties or improper sealing:



Picture 5. U values on single glazed windows.



Picture 6. U values on double glazed window.

.

The insulation capacity of the whole structure differs from one building to another depending on the year they were built. For this reason when inspecting B buildings, air leaks and U values were lower than those in A buildings (see Picture 5 and Picture 6).

4 Review on renewable energy systems, and insulation materials

The following chapter provides general information about the working mechanism, components and physical properties of the technologies related with the production of renewable energy and with thermal insulation. First, the basic principles of insulation materials and photovoltaic solar panel will be studied. Then, suitability. Next, system components. After that, design process before installation. Finally, financial analysis tools.

4.1 Basic principles of insulation materials and photovoltaic solar panels

4.1.1 Heat transfer

Radiation, conduction, and convection are the more common ways of heat transfer. Heat transfer through radiation comes from an energy emitting source, for example solar radiation waves. Conduction is the transfer of thermal energy between regions of matter due to a temperature gradient. Heat flows from a region with higher temperature to another with lower one, within the time the temperature measurements become close to approaching a thermal equilibrium. Conduction takes place in all forms of matter, solids, liquids, gases and plasmas. Retrofitting applications like window film acts partly in a similar fashion, and since it is in contact with the glass, it is part of the conduction process absorbing heat (see Figure 3). [4]

Figure 3. Heat losses in a building. [5]

Convection is heat transfer between a solid and a gas; for example, the heat losses there are when buildings are in contact with the surroundings cold air. Cold air being at a lower temperature, the building structure absorbs energy to reach a thermal equilibrium, and since the surrounding area is vast compared to the building dimensions, energy transfer is continuous.

4.1.2 Solar modules and photovoltaic effect

A photovoltaic or PV module is commonly made from a number of cells connected together in series. In accordance with the spectrum of available light, various materials display varying efficiencies. Therefore, depending on the manufacturing material solar modules are optimized for light absorption prior or beyond the Earth's atmosphere [6].

Solar panels use light energy from the sun to generate electricity through the photovoltaic effect (Figure 1). Photovoltaic modules or solar panels are made from semiconductor materials, such as silicon. Impurities are added to simulate a doping effect and increase the number of charge carriers within the semiconductor material. When impurities are added, two different layers are created: one of n-type material, which has too many electrons, and one of p-type material, which has too few [6]. Junction between the two layers is known as a p-n junction. This technique is used to manufacture transistors and integrated circuits (silicon chips).

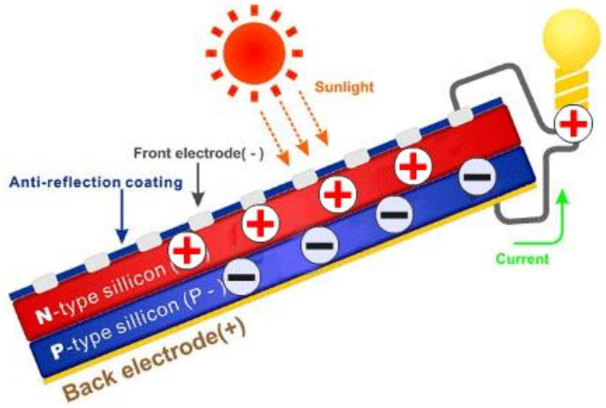


Figure 1. Photovoltaic Effect. [7]

Light consists of packets of energy called photons. Depending on their wavelength, photons are either reflected or absorbed. The energy from the absorbed photons is given to the electrons in the material, which causes some of them to cross the p-n junction. Both cell sides must be connected in order to get a current flow. Current is proportional to the number of absorbed photons and therefore proportional to the light intensity. [6]

4.1.3 Solar system operation

The principles of operation of a typical stand-alone solar power system are shown in Figure 2. The electricity generated by the photovoltaic effect is low voltage direct current (DC) whereas grid electricity is a much higher voltage alternating current (AC). Therefore, additional devices are needed to control the process and to convert the power to the correct voltage. [8]

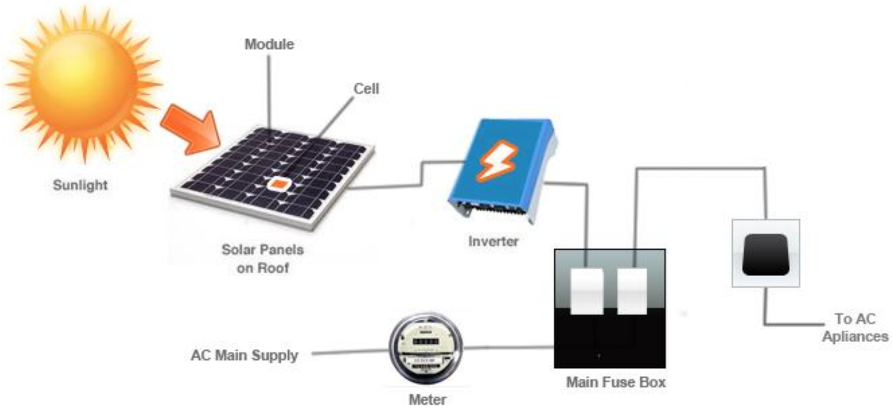


Figure 2. Control and conversion. [9]

The energy flow is routed through an inverter, which transforms DC into AC. The inverter is connected through the switch board to the electricity grid. Power flows into the grid or could also be used for local electricity appliances. The inverter features a software which measures the outgoing power from the solar modules to the grid.

4.2 Suitability

Before starting to design a solar power system it is important to assess whether solar power provides the best solution to the problem at hand. Solar power is best suited to the following applications:

- The energy requirement is modest.
- There is no other source of power available or it is unreliable.
- There is a good solar resource.

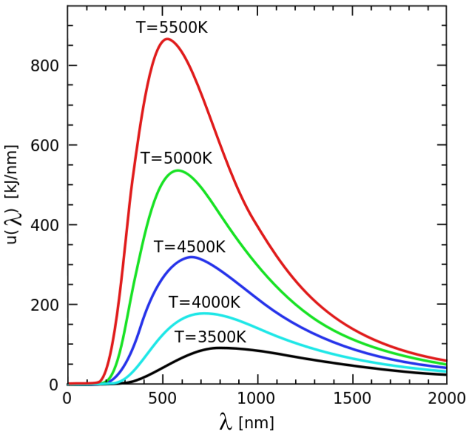
Despite this, there may be other good reasons for using solar power, for instance a concern for the local or global environment, planning constraints, educational purposes or similar issues. [8]

The amount of energy which is required has a direct bearing on the size and cost of any proposed solar power system. The energy requirement can be reduced; however, there are some applications for which solar generated electricity is very rarely suitable. These include space heating, cooking, water heating and any other applications where a large amount of heat is required. It may be possible to meet some of these requirements by more direct capture of solar energy, such as solar water heating systems or passive solar building design. [1]

There are some applications which easily lend themselves to solar power, such as lighting and computing, but most applications will need to be assessed on a case-by-case basis.

4.2.1 Wavelength of light

Visible light is called to the portion of electromagnetic radiation that can be perceived by the human eye. It has a wavelength range between 380 nanometers and 740 nanometers. The first successful measurement of the speed of light was made by the Danish astronomer Ole Roemer in 1676, and since then numerous experiments have improved its accuracy. The currently accepted exact value for the speed of light in vacuum is 299 792 458 m/s. The study of light reveals a number of features and effects by interacting light with matter, thus contributing to the development of theories about the nature of light. Intensity, propagation direction, frequency and polarisation are the primary properties of light. Photon is the elementary particle responsible for electromagnetic quantum phenomena manifestations. It is the carrier particle of all forms of electromagnetic radiation, including gamma rays, X rays, ultraviolet light, visible light, infrared light, microwaves and radio waves. [10]



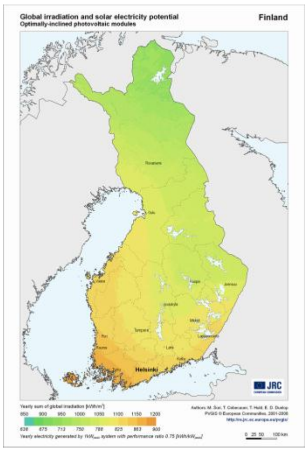
Picture 7. Wavelength. [11]

“The wavelength of the peak of the blackbody radiation curve decreases with increasing temperature” according to Wien's displacement law. Objects, above the absolute zero, emit electromagnetic radiation, and the amount of radiation emitted at each wavelength depends on the temperature of the object. Cold objects emit more of their light at long wavelengths, and hot objects do at short wavelengths. The temperature of an object is related to the wavelength at which the object irradiates the most. [10]

4.2.2 Sunlight availability

The availability of a good solar resource has a strong influence on the cost-effectiveness of a solar power system. A country on the equatorial line offers great possibilities for solar power, not just because of the lack of other forms of power but also because of the high levels of sunshine throughout the year. This does not mean, however, that solar power is impractical in countries further from the equator. In some remote parts of Great Britain, for example the cost of connecting to mains electricity can be prohibitive. In this context solar power can be very competitive for moderate energy requirements. [1]

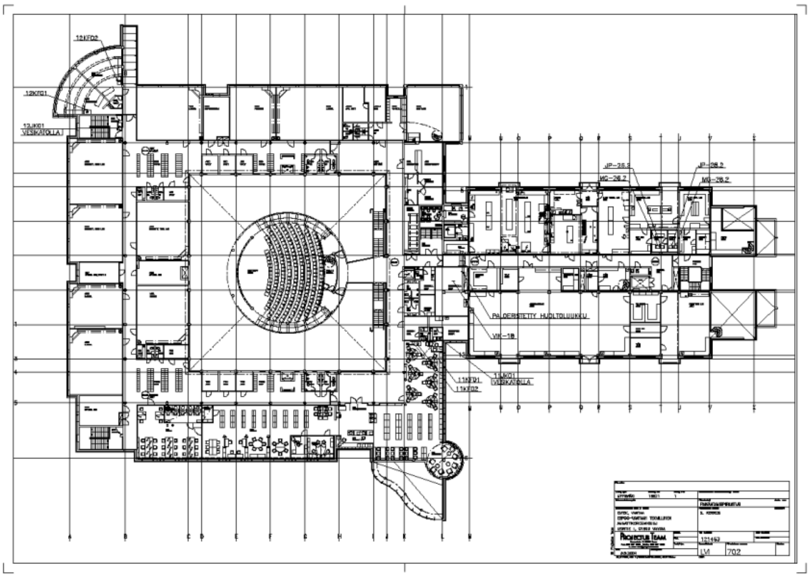
Ultimately, it may be impossible to decide whether or not solar power is suited to a particular application without following the design process. This way an estimate of the likely cost over the life of the project can be produced, which can then be compared with the costs of the alternatives. The capital costs of solar power systems tend to be high; however, the running costs are low owing to the lack of any fuel costs and low regular maintenance requirements. [1]



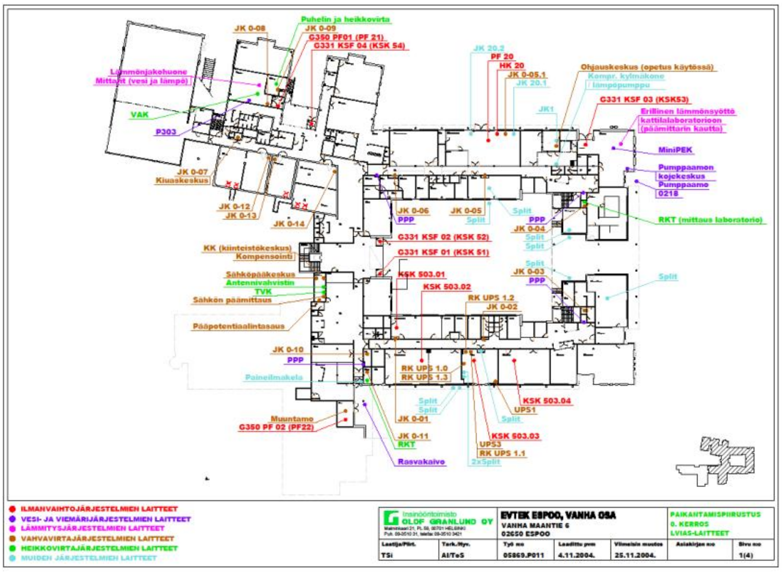
Picture 8. Solar irradiation in Finland. [12]

In Finland the solar radiation from September to March is limited with an average of 50 kWh/m^2, increasing during the summer time up to 170 kWh/m^2. During the entire year the average solar radiation is 940 kWh/m^2 in Helsinki (see Picture 8). [13]

In case a solar power system is installed at Helsinki Metropolia Myyrmäki or Leppävaara campus, it must be oriented to the south. It could be implemented on A or B building side facing south as shown in Picture 9 and Picture 10.



Picture 9. Helsinki Metropolia Myyrmäki campus, A building.



Picture 10. Blueprint of heat losses in Leppävaara A building.

4.3 Solar system components

In order to design a solar power system, it is helpful to have a basic understanding of the various system components and their operation. The following paragraphs describe those components which will commonly be encountered.

4.3.1 Solar panels

A crystalline module is made from a large number of solar cells. These cells are manufactured by hand, which explains the relatively high price of crystalline modules. Cells are made from semiconductor materials. Silicon is the most common raw material. Monocrystalline cells have higher efficiency and higher manufacturing costs than polycrystalline. [1]

CIGS is a semiconductor material composed of copper indium selenite and copper gallium selenite. CIGS is commonly manufactured as polycrystalline thin films. CIGS solar cells consist of a molybdenum layer, which serves as the back contact and reflects light back into the absorber. The Mo deposition creates the p-type side of the junction and a thin n-type buffer layer to complete the n-p junction. The buffer is deposited via chemical bath deposition; the most common buffer used is cadmium selenite. The buffer is overlaid with thin layer and capped by a thicker one; intrinsic zinc oxide and aluminium doped zinc oxide are the compounds used to create both layers. The intrinsic zinc oxide layer protects the cadmium selenite and the absorber layer from leaking or breaking during the manufacturing process while depositing the aluminium zinc oxide layer. The aluminium doped zinc oxide collects and moves electrons out of the cell. [14]

Amorphous alloys of silicon and carbon are used as photovoltaic solar cells for electronic devices which perform on low energy levels. Amorphous silicon manufacturing techniques have been improved lately, making the technology more attractive for large scale projects. Its manufacturing costs are lower compared to other solar power technologies available on the market. Higher efficiencies could be reached by stacking several thin film cells on top of each other and tuning them to work a specific frequency of light. [1]

The efficiencies of solar cells vary between 6% amorphous silicon to 44% multi junction cells. Conversion efficiencies of solar cells used in commercial photovoltaic modules, monocrystalline or polycrystalline silicon, are around 14 to 22%. [15]

Solar cells efficiency depends essentially on the intensity of light radiation and on the temperature of the solar cells. The current generated by the panel increases with radiation, and the voltage remains approximately constant. In order to reach high efficiency levels, it is important to position the panels in the optimum inclination angle. [8]

The efficiency of a solar cell decreases with increasing temperature. There is an increase in current when the temperature rises in the cells, but at the same time, a much larger decrease occurs in proportion to the heat strain. The overall effect is that the panel power decreases with the increase of panel temperature. [15]

4.3.2 Inverter

The function of an inverter is to transform the direct current into alternate current to power up standard mains appliances. An inverter is suitable for large power generation systems, for example for running high voltage appliances.

A simple inverter consists of an oscillator which controls a transistor. Transistors are used to interrupt the incoming stream and generate a rectangular wave. This rectangular wave is fed to a transformer to smooth its shape, making it appear a sine wave and produce the output voltage required. The waveforms of the voltage output of an inverter should ideally be sinusoidal. A good technique to accomplish this is to use the technique of PWM. Achieving the main sinusoidal component is much larger than the higher harmonics. [1]

4.3.3 Design process before installation

The uses of photovoltaic solar solutions on roofs are the most common in buildings, both industrial and residential. The following aspects have to be taken into consideration before choosing a suitable option [8]:

- Analysis of the site. A detail analysis on the accessibility to the area where the photovoltaic solar power system will be implemented. Other aspects to check are orientation and shadows that may decrease the energy generation yield.

- Design of the facility. It is important to choose a technology and a product that fits the weather conditions and the place where the solar installation will be located. Radiation rates are not equal throughout the Finnish geography. It is also necessary to calculate static and dynamic loads, and optimizing search installation. The design always seeks the improved system performance.
- Running the installation. Once it has been decided the type and performance of the solar power system it is time for its implementation. To be successful in implementing the system it is important to follow highly qualified and proven systems guides or to hire an experienced company that provides confidence.
- Maintenance. Photovoltaic installations have a lifespan of about 20 to 30 years. Currently there is a very advanced system that monitors and controls the output of the plant and maintains the customer informed of any mishap.

Often the controller, inverter and other control equipment are wall-mounted. An indoor location will be needed. Inverters in particular are often quite heavy. The chosen wall should be assessed so as to ensure that it will be able to take the likely weight of the equipment. It is important to consider likely routes for the cabling, especially the heavy cables running from the controller to the solar array and the mains electricity. The approximate length of the cables should be measured so that they can be correctly sized. [8]

4.4 Retrofitting solutions

Retrofitting solutions improve the performance of existing systems by adding new technologies or features to old ones. The following products are retrofitting solutions which improve the energy savings on buildings.

4.4.1 ThermoShield by Thermogaia.

ThermoShield (Thermal insulation) is used in the construction or retrofit of buildings. Heat flow occurs when objects with differing temperature get in contact. Thermal insulation reduces and reflects thermal conduction and thermal insulation between the bodies at different temperature. [16]

Thermal conductivity measures the insulating capability of a material. High thermal conductivity is equivalent to low insulating capability. Product density and specific heat capacity are additional properties of insulating materials.

Lower energy consumption can be achieved by employing materials to reduce heat transfer by conduction and convection. These materials have insulation properties which reduces the energy losses from the inside to the outside. The most common insulation materials are blankets, loose-fill, spray foam, concrete forms, straw bales and panels. [16]

Improving energy efficiency in buildings may be achieved by adding retrofitting components; for example, the transfer of heat through radiation and conduction can be reduced by adding a thermally reflective surface called a radiant barrier.

4.4.2 Sun control window film

Window film is a retrofit upgrade usually installed on glass surfaces. There are many colors and types available to meet the customer’s needs. For example, in the automotive industry is referred to as window tinting due to the fact that most of the films are dark coloured in contrast to commercial applications where window films are clear. [17]

Heat rejection films are applied to the interior of glass surfaces to reject the incoming solar radiation through the windows to the exterior. Ceramic window films are dyed to reduce the energy transmission by up to 80 percent, but the cost is higher than that of the standard version. [18]

There are some things that must be taken into account before choosing a film for a window to avoid cracking by thermal stress. Absorptivity of the glass and the film, the size of the pane and the thickness of the glass play important roles; for example, the transfer of heat through radiation and conduction can be reduced by adding a thermally reflective surface called a radiant barrier. Thermal stress is a common source of glass cracking and breaking subsequent to the installation.

4.5 Financial analysis tools

Financial analysis refers to an assessment of the viability, stability and profitability of a business or project to determine its suitability for investment.
One of the most common ways of analysing financial data is to calculate ratios and compare them with the company's performance in previous periods or against the performance of other companies in the same line of business.

4.5.1 Payback period

The purpose of return on investment analysis is to analyze the rate and period of time it would take to recover the initial investment. It is a static view of evaluating an investment. This method is useful to calculate the time it may take to recover an investment of high uncertainty. It is calculated by the cumulative sum of the cash flows, until it equals the initial investment. The payback period does not account for the time value of money, risk, financing and the opportunity cost. Payback period does not specify any required comparison to other investments or even to not making an investment. [19]

4.5.2 Return on investment (ROI)

This ratio is widely used in the analysis of financial institutions as it measures the return on average total assets or the ability to generate value, thereby showing the ability to get the benefit of the total assets of the company and thus putting the benefit relative to the size of its balance sheet. [20]

Comparing the years ROI can measure whether the increasing size of a company is accompanied by the maintenance or increase profitability or if, on the contrary, this growth is implying a progressive deterioration in the company's profitability.

5 Products analysis

5.1 Sun control window film by 3M (Implemented)

The average temperature in Vantaa varies from -10°C during the winter to 22°C during the summer time; in rare occasions, the temperature has exceeded these limits. During spring and summer, the amount of sun hours increases significantly, compared to winter and autumn and, thereby, also the solar radiation. Solar heat absorbed by buildings during this period of time represents an issue for the infrastructure users and staff due to excessive heat and harmful UV rays as deterioration of valuable furnishings and creation of uncomfortable heating zones.

Temperature inside Helsinki Metropolia Myyrmäki campus building may increase significantly specially in those areas of the cafeteria where cooking equipment is being used. When the cafeteria staff was interviewed about the working conditions during spring 2012, they all agreed the temperature in the area was very high particularly during the lunch time when it might rise up to 30°C.

Sun control window film is a retrofit upgrade which provides superior heat rejection reducing excessive heat, uncomfortable hot spots and intensive sun reflection during the summer and decreases heat transfer from the buildings to the surroundings during the winter. Window film provides abundant natural light allowing up to 70% visible light through windows creating a more comfortable environment for tenants and helps to control energy costs. [17]

The prestige series 70 was the film model applied on the glass surfaces of the cafeteria at Helsinki Metropolia Myyrmäki campus. According to the product specifications Prestige series window films “reject up to 97% of the sun's heat-producing infrared light and 99.9% of UV rays and create low reflectivity that's actually lower than glass”. The window film performance was based upon 1/4 clear glass and the IR rejection measured from 900-1000 mm. [17]

5.1.1 Implementation and data collection

The aim of the analysis was to measure the heat flow through the window where the film was installed and compare the results with measurements collected on windows without, a thermal camera was used to measure through the window the difference in temperature between the building and the surroundings.

The cafeteria window area is divided into a 6-by-12 structure, each window has a 123 cm by 123 cm height/length dimension. The total window area is about 111m^2 (see Picture 11).

Physical Properties

The heat losses were calculated according to equation 1; here, ϕ_{Losses} represents the heat losses in the area (kWh), ΔT the difference in temperature between the building and the surroundings (°C), R the sum of the resistivity of all the materials between the inside and the outside (R) and A the dimensions of the place (m^2).

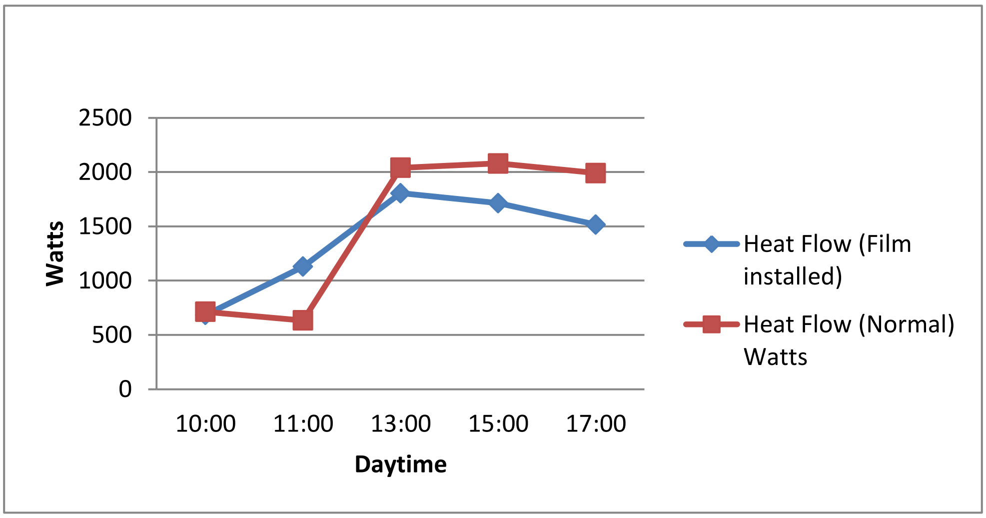
$$\phi_{Losses} = \frac{\Delta T}{R} * A \qquad (1)$$

Picture 11. Area where the sun control window film was applied.

The first sets of measurements were taken at 10 am. The sun was shining and the area was getting warmer. It can be observed on Graph 1 how close to each other the heat flows of both window surfaces are. In the surface where the film was applied, the exterior temperature rises more slowly than in the surface without the film, but the inside temperature was higher in all the measurements taken from the windows with the film.

Close to 11 am, the sun was shining more intensely, and the temperature of the window began to rise rapidly. Surfaces were getting warmer at different rates, and some areas were warmer than others due to different resistivity on the windows. Measurements taken during this time are characterized by this behavior. Heat flow calculations were smaller on surfaces without film cover due to the fact these were getting warmer faster than on the surfaces with film cover.

The third sets of measurements were taken at 1pm. The exterior temperatures of both windows were very similar, which means the surface covered with film reached a balanced temperature. It can be seen in Table 1 below that the increment of the heat flow difference during the following hours.



Graph 1. Heat losses measurements.

When the mean heat losses were calculated, results remained similar to the ones obtained individually and suggest the expected benefits from the film manufacturer are real. Some variables like angle, wind speed and emissivity were not taken into consideration due to lack of equipment which may have caused slight variation in the measurements of the product of the film manufacturer as shown in Graph 1.

Table 1. Heat losses calculation.

Time\Power	Heat flow on surface with film (Wh)	Heat flow on standard surface (Wh)	Difference in heat losses (Wh)	Inside film T° C	Outside film T° C	Inside standard T° C	Outside standard T° C
10:00	683.99	713.94	29.96	17.31	11.77	16.65	12.08
11:00	1128.50	633.17	∞	27.03	17.88	25.38	21.33
13:00	1804.78	2040.21	235.43	29.53	14.90	27.78	14.73
15:00	1714.33	2079.30	364.96	26.27	12.37	25.27	11.97
17:00	1517.00	1990.70	473.70	22.87	10.57	23.13	10.40
Total (Watts per hour)			***1104.06***				

The lower the temperature gets in the surroundings, the higher the heat losses from the inside to the outside are. The results corroborated the effectiveness of the product and showed that the benefits are real. The film retained heat, which decreases the heat transfer to the outside during the winter and the heating effect of the incoming sunlight as the temperature rises during the summer.

5.1.2 Energy and CO_2 emissions savings

The following assumptions and details information about energy costs were taken in consideration when calculating the energy and CO_2 emissions savings as the investment and payback period:

- When calculating the CO_2 annual savings the temperature difference between the window surfaces, with and without the film were taken into consideration. Measurements were taken at the beginning of spring, and even though, sun was shining for few hours, the values provided enough data to calculate a result. Higher inside temperature values were measured from window surface covered with film, the difference in temperature was considered as the energy the film reflected back to the outside.
- According the Vantaa Energy website the average annual district heating consumption for an area between 201-250 m^2 is about 29 192 kWh. The maximum amount of degrees to increase or decrease during winter or summer time is 10°. [21]
- The average solar radiation when measurements were taken was 78 kW/m^2 a month. It was 165 kw/m^2 a month for 4 months during the summer and 23 kW/m^2 on winter time. [13]
- A cooling system was taken into account despite the actual conditions in the cafeteria. Heating is strictly obtained from district heating, not from any other source. Cooling is strictly generated by electrical equipment.

- Vantaa Energy price list was set as the average for electricity sales (see Appendix 1).
- Marginal CO_2 equivalent factor for electricity generation in EU, 600 kg CO_2 eq. / MWh. [22]
- Marginal CO_2 equivalent factor for district heating generation in EU, 217 kg CO_2 eq. / MWh. [22]

Energy consumption for cooling buildings varies from 150 to 250 kWh/m² per year. When doing the calculations, 230 kWh/m² per year was regarded as the average measure, and the energy percentage reduction to decrease the temperature of 1m² by 1 degree was considered to be 2.7 %. Different types of materials inside the building structure were not taken into account. Results of the energy savings calculations for summer time are shown in Table 2.

The energy savings were calculated according to equation 2, where $\mathrm{E}_{Savings}$ is the annual average energy savings (kWh), $\mathrm{E}_{consumptionA}$ is the annual average energy consumption in areas with standard windows during summer (kWh), and $\mathrm{E}_{ConsumptionB}$ is the annual average energy consumption in areas with sun control window film during summer (kWh).

$$\mathrm{E}_{Savings} = \mathrm{E}_{consumptionA} - \mathrm{E}_{ConsumptionB} \qquad (2)$$

Table 2. Energy savings during the summer time when installing the sun control window film.

Data	Yearly average energy consumption (kWh/m²)	Energy consumption for cooling the area 10◦C	Energy consumption on surfaces with film	Energy savings in the area (kWh per year)
M1	230.00	6831.00	6660.23	170.78
M2	230.00	6831.00	6045.44	785.56
M3	230.00	6831.00	5977.13	853.87
M4	230.00	6831.00	5738.04	1092.96
M5	230.00	***6831.00***	***4918.32***	***1912.68***
M6	230.00	6831.00	6250.37	580.64
M7	230.00	6831.00	5874.66	956.34
M8	230.00	6831.00	5533.11	1297.89
M9	230.00	6831.00	6352.83	478.17
M10	230.00	6831.00	5874.66	956.34
M11	230.00	6831.00	6216.21	614.79
M12	230.00	6831.00	6557.76	273.24
Measurement number 5 shows higher energy savings				***1912.68***

According to Table 2, energy savings during the summer go close to 2 000 kW. This value is based on the collected data during the analysis. Values could be higher when considering to have a cooling system strictly run by mains electricity in the area.

Table 3 shows the savings in GHG would be 1.15 t of CO_2 during the summer if sun control window film was applied on the windows. Energy savings values were used as reference in the previous calculations, the conversion factor represents the CO_2 equivalent per kWh.

The CO_2 emissions savings were calculated according to equation 3; here, $\mathrm{CO_2Emissions}_{Savings}$ represents the annual average CO_2 emissions savings (tons per year), $\mathrm{C}_{\mathrm{CO_2}}$ the carbon emission factor of the energy source (kgCO_2/MWh) and $\mathrm{E}_{Savings}$ the annual average energy savings (kWh).

$$\mathrm{CO_2Emissions}_{Savings} = \mathrm{C}_{\mathrm{CO_2}} * \mathrm{E}_{Savings} \qquad (3)$$

Table 3. Estimated emissions savings during the summer time when installing the sun control window film.

CO_2 conversion factor (kg CO_2 ekv/MWh)	Energy savings (kW/h per year)	CO_2 emissions savings (tons per year)
600.00	1912.68	1.15

Energy consumption for heating buildings varies from 13 to 46 kWh/m². When doing the calculations, 25 kWh/m² was assumed as the average measure. Different types of materials inside the building structure were not taken into account. Table 4 shows the results of energy savings calculations for summer time.

Table 4. Energy savings during the winter time when installing the sun control window film.

Data	Yearly average energy consumption (kWh/m²)	Energy consumption for heating the area	Energy consumption on surfaces with film	Energy savings in the area (kWh per year)
M1	25.00	2750.00	2681.25	68.75
M2	25.00	2750.00	2433.75	316.25
M3	25.00	2750.00	2406.25	343.75
M4	25.00	2750.00	2310.00	440.00
M5	25.00	***2750.00***	***1980.00***	***770.00***
M6	25.00	2750.00	2516.25	233.75
M7	25.00	2750.00	2365.00	385.00
M8	25.00	2750.00	2227.50	522.50
M9	25.00	2750.00	2557.50	192.50
M10	25.00	2750.00	2365.00	385.00
M11	25.00	2750.00	2502.50	247.50
M12	25.00	2750.00	2640.00	110.00
Measurement number 5 shows higher energy savings				***770.00***

According to Table 4, energy savings during the winter go up to 700 kW. This value is based on the data collected during the analysis. Values could be higher when considering that the weather varies a lot in Finland, and there may be extremely low temperatures, thus increasing the heat losses from the buildings to the surroundings. Besides, winter could also be prolonged for many months.

Table 5 shows the savings in GHG emissions would be close to 0.2 t of CO_2 during the winter if sun control window film was applied on the windows. Energy savings values were used as reference in the previous calculations, the conversion factor represents the CO_2 equivalent per kWh.

Table 5. Estimated CO_2 savings during the winter time when installing the sun control window film.

CO_2 conversion factor (kg CO_2 ekv/MWh)	Energy savings (kWh per year)	CO_2 emissions savings (tons per year)
217.00	770.00	0.17

The data was collected in spring during daytime; evening and early morning measurements were not taken, when the weather conditions were tougher due to lower temperature. Therefore, heat losses values, energy consumption and CO_2 savings could be higher depending on the weather conditions. GHG emissions estimated savings could be up to 1 tons of CO_2 per year if the product was installed on the campuses.

5.1.3 Investment and payback period

The following parameter information about energy costs and, passive and active, systems prices was taken into consideration when calculating the investment and payback period for installing the sun control film:

- Product lifetime warranty is 5 years and lifetime expectancy is 8 -10 years.
- Higher heat losses calculated during the analysis are 2 676 W/h.
- The average Watt/hour price in Finland. 7.04 cents € Per kWh. [23]

The energy costs were calculated according to equation 4, where $C_{\phi_{Losses}}$ is the total energy cost by heat losses during the product lifetime (€), $E_{Savings}$ is the annual average energy savings (kWh), E_{Price} is the average energy price in Finland (€ per kWh) and the product lifetime (years).

$$C_{\phi_{Losses}} = E_{Savings} * E_{Price} * \text{Lifetime} \tag{4}$$

Since only heat losses calculated from the collected data were used during the analysis, the implementation costs are higher than the monetary benefits as shows table 6.

Table 6. Cost of implementing sun control window films.

Product lifetime warranty 5 years	Sun control window film	
Implementation cost	3 500.00 €	
Product price	8 000.00 €	
Interest rate (5% annual)	2 875.00 €	
Sub - total		14 375.00 €
Monetary savings by implementing the retrofitting solution	8 251.50 €	
Sub - total		8 251.50 €
Total		- 6 123.50 €

Savings are higher than the values obtained from the collected data. Just during night time, the heat losses could be triple the daytime values, as can be verified by comparing the energy savings during summer and winter. In 5 years the initial investment could be feasibly recovered

The following aspects should be to be considered when looking at the calculated savings presented above:

- Life expectancy is for 8 years, almost twice the values used for the financial analysis. Finland is a country characterized by its winter time, and the lower the surrounding temperatures are, the higher the heat losses would be.
- Savings on energy consumption due to excessive heat in some of the areas inside the buildings were not taken into account; the measurements represent a percentage of the real savings that could be achieved during the summer.
- During winter time, savings would exceed the values in three times, which brings added value to the investment.
- Films not just reduced the heat transfer but also reflect the sunlight and trap energy during the winter time.

The analysis corroborates the effectiveness of the product. Sunlight reflection, energy losses reduction, energy retainment are some of its properties. It is recommended to test the product in a different area at different temperatures to corroborate the final results.

5.2 ThermoShield wall coating manufactured by Thermogaia

ThermoShield is a ceramic coating with the ability to save energy by regulating radiation and moisture. The scientific term is "surface coating with endothermic effects". The term *endothermic effect* means that the thermal protection reduces heat loss in buildings and may contribute to reductions in energy consumption for heating up to 30 percent. After the coating is applied to a thickness of 0.3 mm and dried, it is polymerized into a strong, elastic and variable moisture permeable layer (see Figure 4).

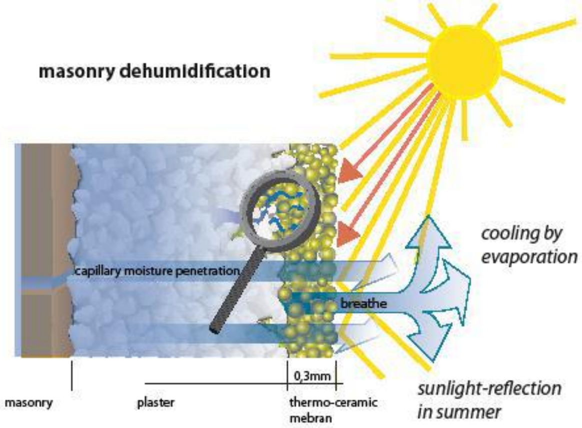


Figure 4. ThermoShield effects on a wall. [24]

Heat losses in a building are caused by convection, evaporation, radiation and conduction. Historically, builders have succeeded in counteracting conduction by insulating the buildings. Another cause of heat loss is moisture. All types of insulation materials are more or less affected by moisture in different forms. Porous materials such as brick, concrete and wood are materials that absorb moisture and their insulation capability radically deteriorates when humidity rises. [25]

Moisture-related heat flow inside a building depends not only on moisture dependent thermal conductivity but also on the ambient air movement. The heat flow through the material occurs when the water evaporates and thereby absorb heat on one side of the material and release heat when condensation is formed on the other side. This type of heat transfer is often described as latent heat. Dry walls insulate better than moist ones and have a higher ability to store heat. [25]

Basic requirements for building materials should be to protect against moisture, to create paths for moisture transport out of the structure, to maintain moisture balance and to act as a protection against absorption. Materials must counteract hydrothermal induction and should produce heat diffusion to the surface in order to save energy and create a healthier indoor environment. [25]

Thermal protection improves the thermal economy of a building. It is not based primarily on its thermal insulation capacity, which is certainly good but gives a marginal effect due to its protective thickness of 0.3 mm. The energy savings that thermal protection provides depends on the following factors [25]:

- Moisture control, i.e. water resistance when it rains and the diffusion and capillary suction when dry, which means that the underlying material is dried out and kept dry
- Ability to reflect, to issue and distribute heat waves
- Conduction in the underlying materials decreases when their moisture content is reduced

The thermal protection coating Thermoshield consists of millions of tiny vacuum insulated ceramic balls, with a diameter of 10 to 120 micron which reflect and spread infrared radiation and short-wave heating. These beads draw moisture out of the walls by capillary force, do not attract dirt and are fire resistant. Each square contains between 12 to 20 million bullets, depending on the layer thickness (Figure 5). [25]

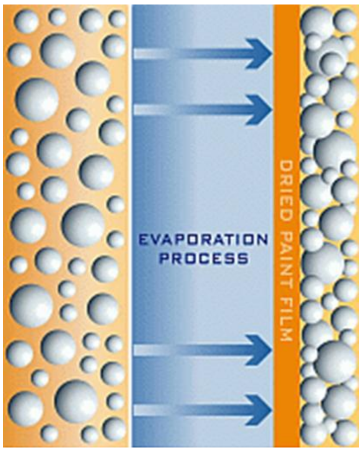


Figure 5. Drying process [26].

In addition, ThermoShield contains high quality pigments that do not fade out. The white pigment consists of zinc oxide, titanium dioxide and calcium carbonate, which is resistant to fading and fire and have a high reflectivity. The pigment is found in all the bright colors. [25]

5.2.1 Energy and CO_2 emissions savings

The following assumptions and details about energy costs were taken in consideration when calculating the energy and CO_2 emissions savings as the investment and payback period:

- When calculating the energy and CO_2 annual savings, the temperature difference between both rooms, with and without ThermoShield were taken into consideration. Energy and CO_2 emissions savings calculations are based on the analysis and series of tests done on ThermoShield by Professor Dr. Peter Marx from the University of Berling.

- Dr. Marx's analysis consisted of identifying and measuring the different factors that influence the human body according to comfort climate levels in a room. [25]
- According to the Vantaa Energy website, the average annual district heating consumption for an area between 41-60 m^2 is about 8 288 kWh. [21]
- Vantaa Energy's price list for electricity sales was set as the average for electricity sales and utilized in the calculations (see Appendix 1).
- Marginal CO_2 equivalent factor for electricity generation in EU, 600 kg CO_2 eq. / MWh. [22]
- Marginal CO_2 equivalent factor for district heating generation in EU, 217 kg CO_2 eq. / MWh. [22]

The perceived indoor climate depends on a combination of several different factors. In order to measure the thermal comfort, the following factors were defined and measured:

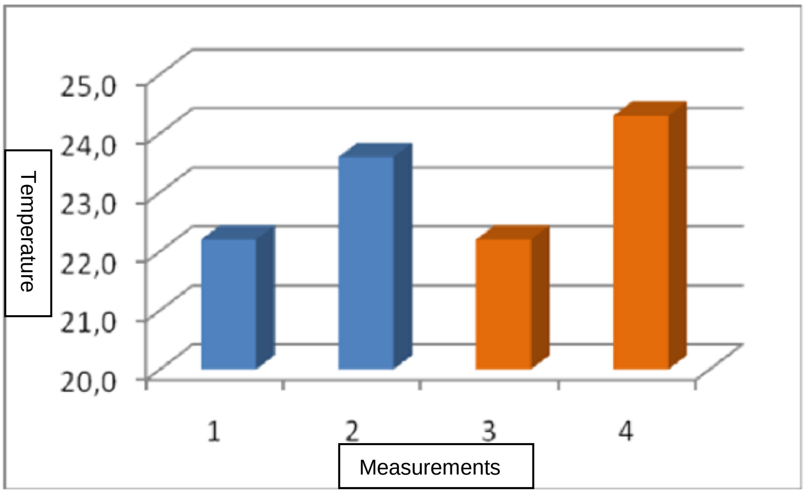
- wet air temperature
- dry air temperature
- relative humidity
- infrared radiation temperature (average temperature of the room enveloping areas)
- air movement
- perceived temperature (an objective physical value which is the combination of all above measurements and not a subjective value) [25].

The test consisted of measuring environmental atmospheric properties inside two different rooms. Both rooms had the same dimensions and were located in the same part of the building next to one another; also furniture and radiators were as similar as possible to those found in a normal office environment.

During the analysis, the room numbers were taken as reference. Both the ceiling and the walls of Room 615 was coated with ThermoShield Interior, whereas Room 613 was painted with traditional paint. The objective was to measure the heating-up performance, the climate behavior after opening a window, and the behavior of the room when adding humidity.

When doing the measurements, both rooms were closed the day before and the radiators were adjusted at the same level. The results were the following:

- R1 – When comparing both room climates the start values showed that the room coated with ThermoShield was 1.4 °C warmer than the painted room.
- R2 – After opening the window for exactly 15 minutes the measurements showed changes in both values. The cooling down process was faster in the ThermoShield coated room with a larger difference than in the painted room.
- R3 – Heating up process was faster in 615 than in 613 after heating up the rooms with heat a fan, at the same time and at the same power level.



Graph 2. Changes in temperature.

The analysis showed that the Room 615 was 9.1% warmer than Room 613. In order to gain the same temperature both rooms were cooled. Opening the window shows a faster cooling process and a larger temperature difference in Room 615 than in Room 613. The temperature increase is 50 % higher in Room 615 compared to Room 613 (see Table 7).

Table 7. Temperature measurements taken for the analysis.

Measurements	Room number	Temperature °C
1	613	22.2
2	613	23.6
3	615	22.2
4	615	24.3

The temperature measurements taken in both rooms during the analysis were essential for estimating energy and CO_2 emissions savings when installing the ThermoShield product.

The energy savings were calculated according to equation 5; here, $\mathrm{E}_{Savings}$ represents the annual average energy savings (kWh), $\mathrm{E}_{consumption613}$ the annual average energy consumption inside a room painted using standard paint (kWh), and $\mathrm{E}_{Consumption615}$ the annual average energy consumption inside a room where Thermoshield coating was applied (kWh).

$$\mathrm{E}_{Savings} = \mathrm{E}_{consumption613} - \mathrm{E}_{Consumption615} \tag{5}$$

Table 8. Estimated energy savings in a 50 m^2 room.

Data	Average energy consumption (kWh/m²)	Difference in temperature	Savings (kWh/m²)	Savings in the area (kWh per year)
M1	25	1.4	4	175
M2	25	2.1	5	263
Difference in energy consumption				***88***

On the basis of the analysis, the energy savings would be up to 80 kWh in a year on a 50 m^2 room. When doing the investment analysis and calculating the payback period, the total dimension of the building were taken into account (see Table 8).

The CO_2 emissions savings were calculated according to equation 3; here, $\mathrm{CO_2Emissions}_{Savings}$ represents the annual average CO_2 emissions savings (tons per year), $\mathrm{C}_{\mathrm{CO_2}}$ the carbon emission factor of the energy source (kgCO_2/MWh), and $\mathrm{E}_{Savings}$ the annual average energy savings (kWh).

$$\mathrm{CO_2Emissions}_{Savings} = \mathrm{C}_{\mathrm{CO_2}} \cdot \mathrm{E}_{Savings} \tag{3}$$

Table 9 shows the savings in GHG emissions would be 0.02 t of CO_2 per year if ThermoShield coating was added to a 50 m^2 room. Energy savings values were used as reference in the previous calculations, the conversion factor represents the CO_2 equivalent per kWh.

Table 9. Estimated CO_2 savings in a 50 m^2 room.

CO_2 conversion factor (kg CO_2 ekv/MWh)	Energy savings (kWh per year)	CO_2 emissions savings (tons per year)
217.00	88.00	0.02

5.2.2 Investment and payback period

The following parameter information about energy costs and prices of passive and active systems was taken into consideration when calculating the investment and payback period for the Thermoshield coating:

- Product lifetime warranty is 2 years and lifetime expectancy is 5 years. The analysis was based on that number of years even though the lifetime expectancy would be higher. Higher Heat losses calculated were 10.04 watts per hour in a 50 m^2 room.
- The average Watt/hour price in Finland is 7.04 cents € per kWh. [23]
- Building dimensions are in total 12 750 m^2 (areas for adding the coating) including Myyrmäki and Leppävaraa campuses together.
- Price of regular paint in is Finland 139 € per 9 liters. [27]
- Price of ThermoShield coating in is Finland 250 € per 10 liters.

The energy costs were calculated according to equation 4, where $\mathrm{C}_{\phi_{Losses}}$ is the total energy cost by heat losses during the product lifetime (€), $\mathrm{E}_{Savings}$ is the annual average energy savings (kWh), E_{Price} is the average energy price in Finland (€ per kWh) and the product lifetime (years).

$$\mathrm{C}_{\phi_{Losses}} = \mathrm{E}_{Savings} * \mathrm{E}_{Price} * \mathrm{Lifetime} \qquad (4)$$

Table 10. Cost of implementing Thermoshield coating at Helsinki Metropolia Myyrmäki and Leppävaraa campuses.

Product lifetime warranty 3 years	Thermoshield coating	
Implementation cost	9 500.00 €	
Product price	63 750.00 €	
Interest rate (5% annual)	10 987.50 €	
Sub - total		84 237.50 €
Monetary savings by implementing the retrofitting solution	2 162.82 €	
Costs on applying a standard paint	44 306.00 €	
Sub - total		46 468.82 €
Total		- 37 768.68 €

Savings are higher than the values obtained by implementing Thermoshield coating at the campuses. Values were gathered from Dr. Marx's case of study. Savings from humidity reduction and stable energy flow were not included.

The following aspects should be to be considered when looking at the calculated savings presented above:

- Lifetime expectancy is for 4 years, twice the values used for the financial analysis. Finland is a country characterized by its winter time, and the lower the surrounding temperatures are, the higher the heat losses will be.
- Films not just reduce the heat transfer but also decrease the moisture, distribute the heat flow and trap heat.

The analysis corroborates the effectiveness of the product. Thermal protection saves energy, draws moisture out of the walls, protects building materials and provides a healthier living environment and a comfortable climate in all types of real estate. This is accomplished without changing the appearance of the surface. It increases the value of your property while reducing energy consumption, eliminating moisture problems, increasing the comfort factor and ensuring a long shelf life. Additionally, the eco-friendly products increased in indoor comfort.

5.3 Liberta solar façade (CIGS) manufactured by Ruukki

Liberta Solar panel facade is a building integrated photovoltaic system functionally and visually integrated to facade surface. Nearly black glass surface and slim 8 mm joints enable high architectural standards. Solar facade helps to fulfil new requirements for higher energy efficiency. It can be implemented in office, commercial, industrial and residential constructions (see figure 6). [28]

Figure 6. Liberta solar façade. [29]

Liberta Solar panel is standard size and part of the Ruukki Design Palette architectural claddings, allowing greater flexibility in design options when completing facade colours for the building under construction or renovation. The area producing solar power is unified to the glass façade. [28]

Liberta Solar system depends on solar radiation. Higher power efficiencies could be reached if the system is facing to the south. Some of the production capacity would be lost when installed on walls facing east or west. Any obstacles casting a shadow, either on the building itself or other objects, should also be taken into consideration; any solar radiation reflected from water of snow cover will increase the panels' output. [28]

Produced electricity is used directly to real-estate own purposes or fed to general grid.
Used PV (photovoltaic) modules are based on CIGS (copper indium gallium selenide) film technology which is a prevailing technology in solar cells. Liberta Solar panels convert radiation directly to electricity. Electricity is gathered via cables behind the wall, and it is transmitted to an inverter which converts the electricity into alternating current

(AC). No visible cables, no penetrations to wall (all cables are in space behind the panels).

5.3.1 Energy and CO_2 emissions savings

The following assumptions and details about energy costs were taken into consideration when calculating the energy and CO_2 emissions savings as the investment and payback period:

1. The energy and CO_2 annual savings calculations are based on information provided by Ruukki about the average solar power generation by the system during a year in Finland's weather conditions.
2. The system orientation is to the south, with a 37 m^2 dimension and a generation capacity of 3.5 kWp.
3. System specifications:
    - Panel size: 1190x630x39 (mm) PV-module type: Q-Cells UF-90 (CIGS)
    - Module power: 90 Wp Power per m^2: 120 Wp/m^2
    - Net area for 1 kWp: 8.3 m^2/kWp
4. Vantaa Energy's price list for electricity sales was set as the average for electricity sales and utilized in the calculations (see Appendix 1).
5. Marginal CO_2 equivalent factor for electricity generation in EU, 600 kg CO_2 eq. / MWh. [22]

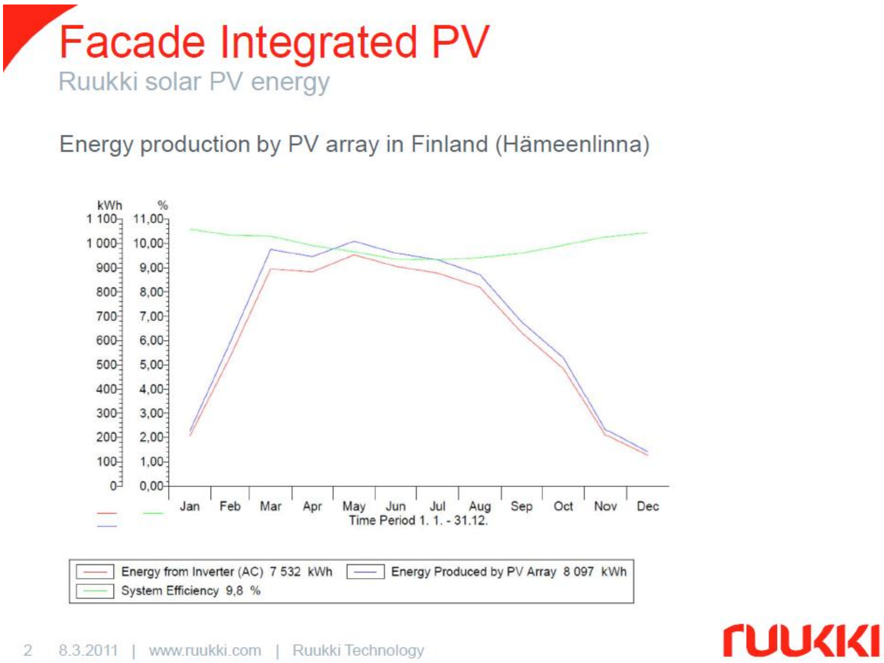
According to the data provided by Ruukki, the monthly average energy generation of Liberta solar panels is shown in Table 11.

Table 11. Monthly average energy generation by Liberta solar panels.

Monthly average energy generation (kWh)			
January	210	July	909
February	415	August	875
March	850	September	625
April	902	October	588
May	873	November	291
June	922	December	166

Solar radiation reaches its peak in Finland during May, June and July. In Helsinki when the solar radiation is perpendicular to the surface the average monthly solar radiation is between 160-170 kWh/m^2 therefore, the energy output from the solar power systems during these months remain steady at a very similar generation rhythm (see Graph 3).

From October to December the solar radiation intensity decreases considerably until reaching its lowest point during winter time. During the entire year, the average solar radiation is 940 kWh/m^2 in Helsinki. [13]



Facade Integrated PV

Ruukki solar PV energy

Energy production by PV array in Finland (Hämeenlinna)

2 8.3.2011 | www.ruukki.com | Ruukki Technology

ruukki

Graph 3. Energy generation by Liberta solar power systems. [30]

In Finland, the sun's radiation energy is approx. 1 000 W/m^2 at noon, meaning that every square meter absorbs about 1 kWh of energy in an hour. Finland has about 1 000 sunshine hours a year. Consequently, every square meter absorbs about 1000 kWh of solar energy per year. As the efficiency rate of a solar panel is about 9%, a square meter of solar collector will produce, at its best, about 90 kWh of energy. [13]

The CO_2 emissions savings due to generation were calculated according to equation 6; here, $\mathrm{CO_2Emissions}_{Savings}$ represents the annual average CO_2 emissions savings (tons per year), $\mathrm{C}_{\mathrm{CO_2}}$ the carbon emission factor of the energy source (kgCO_2/MWh), and $\mathrm{E}_{Generation}$ the annual average energy generation (kWh).

$$\mathrm{CO_2Emissions}_{Savings} = \mathrm{C}_{\mathrm{CO_2}} * \mathrm{E}_{Generation} \qquad (6)$$

Table 12. Estimated CO_2 savings from energy generation by Liberta solar power systems.

CO_2 conversion factor (kg CO_2 ekv/MWh)	Energy savings (kWh per year)	CO_2 emissions savings (tons per year)
600.00	7532.00	4.52

The solar power system's annual average generation on 2012 was 7 532 kWh/year and an estimated savings of 4.52 tons of CO_2 in GHG emissions. These values were used when calculating the investment and payback period (see Table 12).

5.3.2 Investment and payback period

The following parameter information about energy costs and the prices of passive and active systems was taken in consideration when calculating the investment and payback period of Liberta solar façade:.

- The implementation costs of regular PV solar panels, solar façade with Liberta integrated energy production and ready glass facade surface solution were compared.
- Product lifetime warranty is 12 years, and lifetime expectancy is 20 years.
- The average year energy generation is 7 532 kWh/year.
- The average Watt/hour price in is Finland. 7.04 cents € per kWh. [23]
- Price of regular glass façade in is Finland 150€. [31]
- Price of PV solar panel in Finland 250-300 € per m^2. [32]

The generation incomes from Liberta solar façade were calculated according to equation 7, where $\mathrm{G}_{\mathrm{Incomes}=}$ the total incomes due to generation during the product lifetime (€), $\mathrm{E}_{Generation=}$ the annual average generation (kWh), $\mathrm{E}_{Price=}$ the average energy price in Finland (€ per kWh) and the product lifetime (years).

$$\mathrm{G}_{\mathrm{Incomes}=}\ \mathrm{E}_{Generation} * \ \mathrm{E}_{Price} * \mathrm{Lifetime} \qquad (7)$$

Table 13. Cost of implementing Liberta solar facade at Helsinki Metropolia Myyrmäki or Leppävaraa campuses.

Product lifetime warranty 12 years	Liberta solar facade	
Implementation cost	9 500.00 €	
Product price	16 576.00 €	
Interest rate (5% annual)	15 645.60 €	
Sub - total		41 721.60 €
Incomes and savings, solar power generation	6 235.26 €	
Price of regular building facade	5 550.00 €	
Price of regular solar power system	9 250.00 €	
Implementation cots	12 500.00 €	
Interest rate (5% annual)	16 380.00 €	
Sub - total		49 915.26 €
Total		8 193.66 €

According to Table 14, the feasibility study on the Liberta solar façade suggests benefits from energy generation will surpass the initial investment within the lifetime warranty of the product therefore, it is recommended to implement this product.

However, it should be considered that lifetime expectancy is 20 years, almost twice the values used for the financial analysis, which means benefits would be higher.

The analysis corroborates the effectiveness of the Liberta solar façade. Due to the fully integrated solar facade system - simple fastening system, fully integrated energy production and ready glass facade surface - the system provides the most overall cost efficient solution. Competing solutions are add-ons for the existing facade or roof surfaces. Due to its medium term payback, it is recommended implementing Liberta solar façade at Helsinki Metropolia campuses.

5.4 Crystalline photovoltaic glass manufactured by Onyx Solar

Onyx Solar develops building integrated photovoltaic solutions which are used for the replacement of conventional construction materials from different parts of the building's exterior such as skylights, façades, windows, curtain walls or roofs. ''The cheapest energy is the energy that is not consumed''; Therefore, Onyx Solar offers multifunctional photovoltaic constructive solutions which can be integrated perfectly into any type of building, provide greater both acoustic and thermal insulation and at the same time produce clean, free energy in situ, all thanks to the power of the sun. [33]

Onyx Solar has developed a wide range of photovoltaic glass specifically designed for installation in buildings. The photovoltaic properties allow these glasses to generate electricity even in those buildings where the orientation and inclination is not at its optimum (for example, north façade):

- It is not a traditional photovoltaic module designed for ground installation. It has been designed specially as safety glass for buildings in order to comply with the Technical Code of the Building.
- It is available in different thicknesses, sizes and grades of transparency.
- It works in all weather conditions, including low light and cloudy conditions.
- It produces low cost electricity (kWh), allowing lower capital investment and increased output per rated watt.
- It is environmentally friendly and has a shorter energy payback period (the amount of time it takes to generate enough energy to equal the energy used to produce it) than traditional photovoltaic modules.
- It is frameless and has a uniform colour that is aesthetically appealing. It is ideal for building integrated photovoltaic (BIPV) and other high-visibility applications.

5.4.1 Energy and CO_2 emissions savings

The following assumptions and details about energy costs were taken in consideration when calculating the energy and CO_2 emissions savings as the investment and payback period:

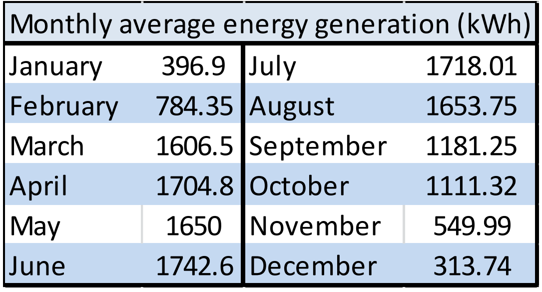
1. The energy and CO_2 annual savings calculations are based on information provided by Onyx Solar about the average solar power generation by the system during a year in Finland’s weather conditions.
2. The system orientation is to the south, with a dimension of 37 m^2 and a generation capacity of 7 kWp.
3. System specifications:
    - Panel size: 1680x990x50(mm) Power per m^2: 200 Wp/m^2
    - PV-module type: Solarwatt P210-60 GET AK
    - Module power: 180 Wp

- Net area for 1 kWp: 4.12 m^2/kWp

4. Vantaa Energy’s price list for electricity sales was set as the average for electricity sales and utilized in the calculations (see Appendix 1).
5. Marginal CO_2 equivalent factor for electricity generation in EU, 600 kg CO_2 eq. / MWh. [22]

Onyx Solar provided data and specifications about the average energy generation of photovoltaic polycrystalline solar panels, from this data the estimations presented in Table 14 were concluded.

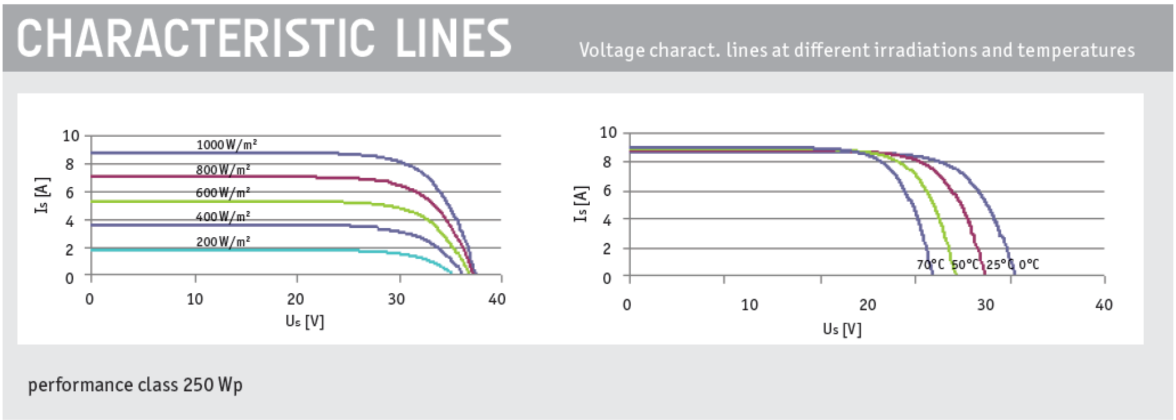
Table 14. Estimated monthly average energy generation by Onyx Solar panels.



Monthly average energy generation (kWh)			
January	396.9	July	1718.01
February	784.35	August	1653.75
March	1606.5	September	1181.25
April	1704.8	October	1111.32
May	1650	November	549.99
June	1742.6	December	313.74

Solar radiation reaches its peak in Finland during May, June and July. In Helsinki when the solar radiation is perpendicular to the surface, the average monthly solar radiation is between 160-170 kWh/m^2; therefore, the energy output from the solar power systems during these months remain steady at a very similar generation rhythm.

Solar radiation is less than 30 kWh/m^2 from January to February. From October to December the solar radiation intensity decrease considerably until reaching its lower point during winter time. During the entire year, the average solar radiation is 940 kWh/m^2 in Helsinki [13]. Graph 4 shows the energy generation of crystalline photovoltaic cells at different solar radiation.



Graph 4. Energy generation by Onyx Solar power systems. [34]

In Finland, the sun's radiation energy is approximately 1 000 W/m^2 at noon, meaning that every square meter absorbs about 1 kWh of energy in an hour. Finland has about 1 000 sunshine hours a year. Consequently, every square meter absorbs about 1 000 kWh of solar energy per year. As the efficiency rate of a solar panel is about 15-17%, a square meter of solar collector will produce, at its best, about 150-170 kWh of energy. [13]

The CO_2 emissions savings due to generation were calculated according to equation 3; here, $\mathrm{CO_2Emissions}_{Savings}$ represents the annual average CO_2 emissions savings (tons per year), $\mathrm{C}_{\mathrm{CO_2}}$ the carbon emission factor of the energy source (kgCO_2/MWh) and $\mathrm{E}_{Generation}$ the annual average energy generation (kWh).

$$\mathrm{CO_2Emissions}_{Savings} = \mathrm{C}_{\mathrm{CO_2}} \cdot \mathrm{E}_{Generation} \qquad (6)$$

Table 15. Estimated CO_2 savings from energy generation by Onyx Solar power systems.

CO_2 conversion factor (kg CO_2 ekv/MWh)	Energy savings (kWh per year)	CO_2 emissions savings (tons per year)
600.00	14235.48	8.54

Table 15 shows that the solar power system’s average annual energy generation by m^2 is 384.74 kWh/year, and the total solar power generation for a 37 m^2 system is 14 235.48 kWh/year. The estimated savings of GHG emissions are 8.5 t of CO_2. These values were used when calculating the investment and payback period.

5.4.2 Investment and payback period

The following additional parameter information about energy costs and the prices of passive and active systems was taken in consideration when calculating the investment and payback period for the crystalline photovoltaic glass manufactured by Onyx Solar:

- The product lifetime warranty is 15 years, and the lifetime expectancy is about 25 years.
- The average annual energy generation is 14 235 kWh/year.
- The average Watt/hour price in Finland is 7.04 cents € per kWh. [23]
- The price of PV solar panel in Finland is 250-300 € per m^2, and the power output is low. [32]

The generation incomes from crystalline photovoltaic cells were calculated according to equation 7, where $\mathrm{G}_{\mathrm{Incomes}=}$ the total incomes due to generation during the product lifetime (€), $\mathrm{E}_{Generation=}$ the annual average generation (kWh), $\mathrm{E}_{Price=}$ the average energy price in Finland (€ per kWh) and the product lifetime (years).

$$\mathrm{G}_{\mathrm{Incomes}=}\ \mathrm{E}_{Generation} *\ \mathrm{E}_{Price} * \mathrm{Lifetime} \qquad (7)$$

Table 16. Cost of implementing Crystalline photovoltaic solar power system at Helsinki Metropolia Myyrmäki or Leppävaraa campuses.

Product lifetime warranty 15 years	Crystalline photovoltaic solar power system	
Implementation cost	5 500.00 €	
Product price	17 879.00 €	
Interest rate (5% annual)	17 534.25 €	
Sub - total		40 913.25 €
Incomes and savings, solar power generation	18 038.59 €	
Sub - total		18 038.59 €
Total		- 22 874.66 €

The feasibility study on the crystalline photovoltaic glass systemsuggest benefits from energy generation does not surpass the initial investment within the lifetime warranty of the product; by changing the amount of years to the lifetime expectancy of the product, the investment becomes reliable, but the payback period time is too long. The analysis corroborates the efficiency of the product, but the investment payback time is too high due to Finland's weather conditions. Before implementing this product on Helsinki Metropolia campuses, additional added value need to be determined for researching on solar power system efficiency or for using the system for other study purposes.

5.5 Photovoltaic window film (a-SI) by 3M

The film has two strong energy conservation features, the first is that it generates electricity, the second is that it blocks heat. The film generates electricity so it can be used to power things like LED lights. As for blocking heat, this can help to conserve heat because if heat is blocked then air conditioning in a building can be lower, saving energy. Those are the two main advantages of energy conservation. The film blocks and absorbs about 80% of the visible light and 90% of the UV light. In a demonstration at CEATEC in Japan, the company showed the temperature in each side of the inner glass was about 10° degrees lower than of outer one. [35]

The technology behind the film layer is amorphous silicon (a-Si), which is the non-crystalline allotropic form of silicon. It can be deposited in thin films at low temperatures onto a variety of substrates, offering some unique capabilities for a variety of electronics. The cost of the film is lower than that of standard photovoltaic technologies available on the market, but their efficiency is lower. In order to perform at a high efficiency level, several films must be used. [35]

The film comes in flexible sheets and can be glued onto the windows, the prototype has a greenish tint, but 3M plans to make it clear by the time it brings the product to the market. The film generates about 1/5 of the electricity that traditional silicon panel does and will cost half as much. [35]

5.5.1 Energy and CO_2 emissions savings

The following assumptions and details information about energy costs were taken in consideration when calculating the energy and CO_2 emissions savings as the investment and payback period:

1. The energy and CO_2 annual savings calculations are based on data collected or estimated from product testing by the 3M Company.

2. The system orientation is to the south, with a dimension of 37 m^2 and a generation capacity of 1.16 kWp.
3. System specifications:
    - Panel size: 1680x990x50(mm) Power per m^2: 35 Wp/m^2
    - PV-module type: 3M PV window film
    - Module power: 30 Wp
    - Net area for 1 kWp: 25 m^2/kWp
4. Vantaa Energy's price list for electricity sales was set as the average for electricity sales and utilized in the calculations (see Appendix 1).
5. Marginal CO_2 equivalent factor for electricity generation in EU, 600 $kgCO_2$ eq. / MWh. [22]

According to the data collected by 3M [35], the estimated monthly average energy generation of photovoltaic polycrystalline solar panels is shown in Table 17.

Table 17. Estimated monthly average energy generation by 3M photovoltaic window film.

Monthly average energy generation (kWh)			
January	150.03	July	649.41
February	296.48	August	625.12
March	607.26	September	446.51
April	644.41	October	420.08
May	623.69	November	207.90
June	658.70	December	118.59

Since the window film not only generates energy but also blocks and retains heat, the benefits on energy and GHG emissions are higher. The calculations and savings used to add value to the investment were similar to those used in the analysis of the sun control film.

The CO_2 emissions savings due to generation were calculated according to equation 3, where $\mathrm{CO_2Emissions}_{Savings}$ the annual average CO_2 emissions savings (tons per year), $\mathrm{C_{CO_2}}$ the carbon emission factor of the energy source ($kgCO_2$/MWh), and $\mathrm{E}_{Generation}$ the annual average energy generation (kWh).

$$\mathrm{CO_2Emissions}_{Savings} = \mathrm{C_{CO_2}} * \mathrm{E}_{Generation} \qquad (6)$$

Table 18. Estimated CO_2 savings from energy generation.

CO_2 conversion factor (kg CO_2 ekv/MWh)	Energy savings (kWh per year)	CO_2 emissions savings (tons per year)
600.00	2847.10	1.71

The solar power system's average annual energy generation by m^2 is 64.12 kWh/year, the total solar power generation for the 37 m^2 system is 2 372.58 kWh/year. The estimated GHG emissions savings are 1.7 t of CO_2. These values are used when calculating the investment and payback period (see Table 18).

5.5.2 Investment and payback period

The following parameter information about energy costs the prices of passive and active systems was taken into consideration when calculating the investment and payback period for installing photovoltaic window film:

- The product lifetime warranty is 5 years, and the lifetime expectancy is 8 to10 years.
- The average year energy generation is 2 372.58 kwh/year.
- The average annual energy savings for blocking and retaining energy are 1 100 kWh.
- The average Watt/hour price in Finland is 7.04 cents € per KWh. [23]
- The price of photovoltaic solar panel in Finland is 250-300 € per m^2 and the power output is lower. [32]

The generation incomes from photovoltaic window film were calculated according to equation 7, where $\mathrm{G}_{\mathrm{Incomes}}$ the total incomes due to generation during the product lifetime (€), $\mathrm{E}_{Generation}$ the annual average generation (kWh), E_{Price} the average energy price in Finland (€ per kWh) and the product lifetime (years).

$$\mathrm{G}_{\mathrm{Incomes=}}\ \mathrm{E}_{Generation} * \ \mathrm{E}_{Price} * \mathrm{Lifetime} \qquad (7)$$

Table 19. Cost of implementing photovoltaic window film at Helsinki Metropolia Myyrmäki or Leppävaraa campuses.

Product lifetime warranty 5 years	Photovoltaic window film	
Implementation cost	3 500.00 €	
Product price	4 626.00 €	
Interest rate (5% annual)	2 031.50 €	
Sub - total		10 157.50 €
Incomes and savings, solar power generation	1 001.46 €	
Energy savings (Sunlight blocking/heat retainer)	3 680.35 €	
Sub - total		4 681.81 €
Total		- 5 475.69 €

The feasibility study on photovoltaic window film suggests benefits from energy generation will not surpass the initial investment within the lifetime warranty of the product, so implementation of this product is not recommended. This product's lifetime expectancy is for 10 years, which guarantees a higher return rate on the investment but still does not guarantee it (see Table 19).

The analysis corroborates the effectiveness of the photovoltaic film. Sunlight reflection, energy losses reduction, energy retainer are some of the secondary characteristics of such a product, not to mention its main feature which is solar power generation.

6 Conclusions

When studying the feasibility of the various solar power generation and insulation retrofitting systems available on the market, the best options became quite clear. All the different methods had positive and negative aspects when applying them to energy generation or retrofitting insulation purposes.

The efficiency of CIGS (copper indium gallium selenide) film technology is lower than that of crystalline photovoltaic solar panels, but both technologies are just as durable and long-lived. The installation of Liberta solar panels become feasible in a scenario where replacing old solar facades is needed due to remodeling or damages suffered by the structure. The financial analysis took into account the cost of buying new glass facades and PV solar panels to produce the similar power output than Liberta solution, which is an integrated surface which combines both solutions. The analysis corroborates the effectiveness of the product, and its implementation is recommended in Helsinki Metropolia campuses.

Crystalline photovoltaic solar panels perform at a high efficiency level; the panels are characterized by their durability and longevity and by their performance at low levels of solar radiation. Finland’s changing weather conditions and low level of solar radiation, during most of the year, prolong the investment payback time; however, it is possible to implement this technology for researching on solar power system efficiency, for study purposes or through government financing with the purpose of acquiring clean energy systems. The feasibility study corroborated the effectiveness of the product and installation is recommended in countries closer to the equator where solar radiation levels are higher and steadier during most of the year. As shown in the financial analysis, the payback time of the investment will require the lifetime expectancy of the product, about 20 years.

Amorphous silicon (a-Si) solar panels cost less than standard photovoltaic technologies, and they are less efficient, durable and long-lasting. High efficiency levels can be achieved by adding more films, but the photovoltaic window film not only generates but also acts like a visible light and UV ray protector, blocking the sunlight and reducing the incoming radiation inside the building. Thus, it reduces the energy consumption for cooling during hot seasons and for heating during cold seasons due to its property of retaining heat. The feasibility study corroborated the effectiveness of the product, and its implementation is recommended in Helsinki Metropolia campuses; the technology allows easy and simple installation and maintenance processes. Benefits for energy savings and generation make this product feasible to install.

Sun control window film is a retrofit upgrade which was installed on the Helsinki Metropolia Myyrmäki campus, a series of heat loss measurements were taken to verify the product’s effectiveness and reliability. The analysis corroborates the effectiveness of the product: sunlight reflection, energy losses reduction and energy retainment are some of its properties, all related to energy saving. Regarding the financial analysis which was based on the collected data, the benefits of the product may surpass the investment within a few years, and even though this suggests a non-profitable investment, and there were many factors which were not taken into account, implementation of this product is recommended on the remaining areas of the campus.

ThermoShield wall coating is used in the construction or retrofit of buildings. It is a thermally reflective surface which reduces the transfer of heat through radiation and conduction. The analysis corroborates the effectiveness of the product. Thermal protection saves energy, draws moisture out of the walls, protecting building materials and providing a healthier living environment and comfortable climate in all types of real estate. All this can be achieved without changing either the appearance or the surface. It increases the value of the property while reducing energy consumption, eliminating moisture problems, increasing the comfort factor and ensuring a long shelf life. Regarding the financial analysis which was based on Dr. Marx study case, the benefits of the product may surpass the investment, and even though this suggests a non-profitable investment, and there were many factors which were not taken into account, the implementation of this product could be recommended on Helsinki Metropolia campuses.

The purpose of the thesis project was to analyze the effectiveness of technologies related with the production of renewable energy and thermal insulation. Properties, functioning and energy output of solar power systems and insulation materials, supported by different technologies, were defined. The goal of the thesis was achieved by determining which technology were feasible to implement at Helsinki Metropolia Myyrmäki and Leppävaara campuses for optimizing energy consumption and GHG emissions.

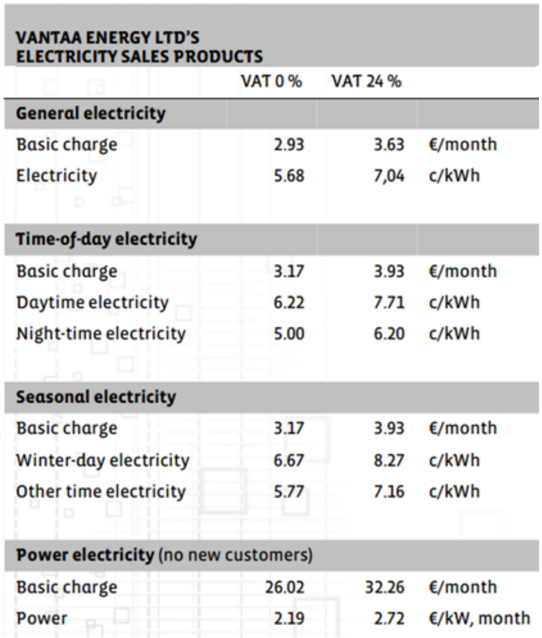
7 References

1. Dako. Solar panel installation [online]. [Cited 2010 January 7]. Available from: http://www.dako.co.za/index.html
2. Helsinki Metropolia University of Applied Sciences. General information [online]. [Cited 2010]. Available from: http://www.metropolia.fi/en/
3. ”Smart Campus”. ”Smart Campus” general information. [Documents provided by Asko Kippo].
4. Wikipedia. Heat transfer [online]. [Cited 2013 February 17]. Available from: http://en.wikipedia.org/wiki/Heat_transfer
5. Wikipedia. Heat transfer [online]. [Image published 2002 September 17]. Available from: http://en.wikipedia.org/wiki/Heat_transfer
6. Wikipedia. Photovoltaic effect [online]. [Cited 2013 January 3]. Available from: http://en.wikipedia.org/wiki/Photovoltaic_effect
7. Wikipedia. Photovoltaic effect image [online]. [Image published 2004 January 28]. Available from: http://en.wikipedia.org/wiki/Photovoltaic_effect
8. Amazon solar. Solar suitability [online]. [Cited 2010 November 23]. Available from: http://www.amazon-solar.com/3-suitability/
9. Dako. Control and conversion image [online]. [Image published 2010 January 7]. Available from: http://www.dako.co.za/index.html
10. Wikipedia. Wavelength [online]. [Cited 2013 March 3]. Available from: http://en.wikipedia.org/wiki/Wavelenght
11. Wikipedia. Thermal Radiation image [online]. [Image published 2007 January 28]. Available from: http://en.wikipedia.org/wiki/Thermal_Radiation
12. Solar feed in tariff. Solar irradiation in Finland image [online]. [Image published 2005 August 21]. Available from: http://www.solarfeedintariff.net/finlandmap.htm
13. Ground Energy. Solar radiation energy [online]. [Cited 2009 June 25]. Available from: http://www.groundenergy.fi/en2/solar-radiation-energy-in-finland/
14. Wikipedia. Copper indium gallium solar cells [online]. [Cited on 2010 July 29]. Available from: http://en.wikipedia.org/wiki/Copper_indium_gallium_selenide_solar cells.
15. Solar power. Solar cells efficiency [online]. [Cited 2013 April 2]. Available from: http://www.solarpower2day.net/solar-cells/efficiency/
16. Wikipedia. Thermal insulation [online]. [Cited 2013 January 1]. Available from: http://en.wikipedia.org/wiki/Thermal_insulation

17. Wikipedia. Window film [online]. [Cited 2012 July 14]. Available from: http://en.wikipedia.org/wiki/Window_film
18. Window film and more. How does window film lower heating [online]? [Cited 2010 November 11]. Available from: http://www.windowfilmandmore.com/how-does-window-film-lower-heating-bills.aspx
19. Wikipedia. Payback period [online]. [Cited 2011 June 20]. Available from: http://en.wikipedia.org/wiki/Payback_period
20. Investopia. Return on investment [online]. [Cited 2007 November 24] http://www.investopedia.com/terms/r/returnoninvesment.asp#axzz2MkXxmmbP
21. Vantaa Energy. Services [online]. [Cited 2005 June 27]. Available from: http://www.vantaanenergia.fi/fi/Kaukolampo/hinnastotjaehdot/Documents/Kaukol%C3%A4mm%C3%B6n_myyntihinnasto_1.1.2013_alv24.pdf
22. Motiva. Carbon dioxide equivalent factors [online]. [Cited 2012 September 27] Available from: http://www.motiva.fi/files/6817/CO$_2$laskenta_yksittainen_kohde.pdf
23. Vantaa Energy. Services [online]. [Cited 2005 June 27]. Available from: http://www.vantaanEnergy.fi/en/electricity/pricelists/Pages/default.aspx
24. ThermoShield. Effects on wall image. Analysis by Professor Dr.-Ing. Peter Marx [online]. [Image published 2011 June 23]. http://thermogaia.nu/
25. ThermoShield. Analysis by Professor Dr.-Ing. Peter Marx [online]. [Cited 2011 June 23]. http://thermogaia.nu/
26. ThermoShield. Drying process image. Analysis by Professor Dr.-Ing. Peter Marx [online]. [Image published 2011 June 23]. http://thermogaia.nu/
27. Starkki. Prices of regular paints in Finland. [online]. [Image published 2012 June 23]. http://starkki.fi/
28. Ruukki. Liberta Solar facade [online]. [Cited 2011 August 18]. Available from: http://www.ruukki.com/Products-and-solutions/Building-solutions/Facade-cladding-systems/Liberta-Solar-facade---building-integrated-photovoltaic-panels
29. Ruukki. Liberta Solar facade picture [online]. [Image published 2011 August 18]. Available from: http://www.ruukki.com/Products-and-solutions/Building-solutions/Facade-cladding-systems/Liberta-Solar-facade---building-integrated-photovoltaic-panels
30. Ruukki. Liberta Solar facade power generation graph [online]. [Graph published 2011 August 18]. Available from: http://www.ruukki.com/Products-and-solutions/Building-solutions/Facade-cladding-systems/Liberta-Solar-facade---building-integrated-photovoltaic-panels

31. Glass global. Prices of regular facades in Finland [online]. [Cited 2008 September 16]. Available from: http://www.glassglobal.com/recent/
32. EV Power. Prices of regular solar panels [online]. [Cited 2012 September 27]. Available from: http://www.ev-power.eu/Solar-Panels/Solar-Pannels-GWL-Sunny-Mono-140-Wp.html?cur=1
33. Onyx Solar. Crystalline photovoltaic solar panels [online]. [Cited 2011 December 28]. Available from: http://www.onyxsolar.com
34. Onyx Solar. Crystalline photovoltaic solar panels power generation graph [online]. [Graph published 2011 December 28]. Available from: http://www.onyxsolar.com
35. 3M. Innovations [online]. [Cited 2012 November 11]. Available from: http://solutions.3m.com/wps/portal/3M/en_US/WW3/Country/

Appendix 1. Vantaa Energy price list for electricity sales



VANTAA ENERGY LTD'S ELECTRICITY SALES PRODUCTS

	VAT 0 %	VAT 24 %	
General electricity			
Basic charge	2.93	3.63	€/month
Electricity	5.68	7,04	c/kWh
Time-of-day electricity			
Basic charge	3.17	3.93	€/month
Daytime electricity	6.22	7.71	c/kWh
Night-time electricity	5.00	6.20	c/kWh
Seasonal electricity			
Basic charge	3.17	3.93	€/month
Winter-day electricity	6.67	8.27	c/kWh
Other time electricity	5.77	7.16	c/kWh
Power electricity (no new customers)			
Basic charge	26.02	32.26	€/month
Power	2.19	2.72	€/kW, month