TALLINN UNIVERSITY OF TECHNOLOGY

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WASTE HEAT MANAGEMENT OF BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM

Master Thesis

Henry Yusinyu Bunyui

Supervisor: **Andri Jagomägi**, chair of semiconductor Materials technology, Research Scientist

Materials and Processes of Sustainable Energetics

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Declaration

Hereby I declare that this master thesis, my original investigation and achievement, submitted for the master degree at Tallinn University of Technology has not been submitted for any degree or examination.

Henry Yusinyu Bunyui

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List of Abbreviations

ACH	Air changes
BEAM	Building Environmental Assessment Method
BiPV	Building integrated photovoltaics
BiPV/T	Building integrated photovoltaics Thermal
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CE	Conformitė Europeenė
CSP	Concentrated solar power
ESGB	Evaluation Standard for Green Building
EU	European Union
FGM	Functional graded materials layer
GaAs	Gallium arsenide
HDPE	High density polyethylene
IPCC	Intergovernmental Panel on Climate Change
I–V	Current –Voltage
Kg / m³	Kilogram per Cubic meter
LEED	Energy and Environmental Design
MIN	Minimum
N / mm^2	Newton per millimeter square
OECD	Organization for Economic Co-operation and Development
PV	Photovoltaics
PVC	Polyvinylchloride
PVT	Photovoltaic thermal system
Si	Silicon
U	Thermal conductance
US	United States
W/mK	Watt per meter per kelvin
W / (m^2K)	Watt per Square Meter per kelvin
kWh/m2/y	Kilo watt hour per square meter per year
ZEBs	Zero energy buildings

λ	Thermal conductivity

1. Introduction

The technology of renewable energy has been the most contributing factor in fighting global warming. Its rapid development and energy efficiency has not only been beneficial in climate change mitigation but has also been very significant in energy security and economic benefits [1].It consist of wind power, solar power, geothermal power and above all, solar power has been the most rapidly growing form. Unlike wind power, it is totally silent, non-polluting, requires little maintenance and generates energy from freely available sunlight. Furthermore, its technology has been well developed and continuous improvement is occurring primarily in the production process. Solar power converts sunlight into electricity either directly using photovoltaics (PV) cells, or indirectly using concentrated solar power (CSP. The photovoltaic cells are made of semi-conducting material, usually silicon (Si) and gallium arsenide (GaAs)[2] which capture sun's energy generating an electric field across the layers. The stronger the sun intensity, the greater the electric output produced. For example a solar panel with an efficiency rate of about 17% produces, at its best operating state, about 170 kWh /m^2[3] in a country like Estonia. Its operating life span is about 25-30[4]. PV systems are either mounted on rooftops or incorporated on the walls of a building hence called building integrated photovoltaic systems (BiPV). This technology has not only created a sustainable impact to the building industry but has also substituted part of the conventional electricity generators. The increase in electricity demand and the growth of the building industry, has significantly improved the application of BIPV technology. In Estonia the growth of this technology has been gradually increasing. Some of the reasons that could have led to this gradual growth may have been a limited knowledge and high investment costs. Today, solar panels alone account below 50% of the system's total cost, leaving the rest to installation labor and to the PV system's remaining segment [5].

Furthermore, solar panels used in BiPV are associated with many factors that results to low efficiencies. Among them are high operating temperatures. The operating temperatures play an essencial role in the photovoltaic conversion process. Both the electrical efficiency and the power output of a PV module depends linearly on the decrease in operating temperature [6]. This is because, as in all other alternative semiconductor devices, solar cells are also very sensitive to temperature. When solar radiation is collected on the solar modules, the rest of the incident radiation is converted into heat, which significantly increases the temperature of the PV module and reduces the PV efficiency of the module. Temperature increases can be as much as 85 to 90oC depending on the degree of solar radiation and geographic location. High operating temperatures leads to thermal stress and hence poor electric performance.

The main aim of this study is to evaluate the amount of heat energy that can be extracted from an operating PV system in an attempt to reduce its high operating temperatures, and to analyze how much heat demand of a residential building in Estonia can be covered by this amount of energy, hence a Building integrated Photovoltaic thermal system(BiPV/T). This combine product of electric and thermal energy from a single system will enhance PV efficiency and reduce the pay back time in relation to cost.

1.1The development of BiPV/T systems so far

The technology of Building integrated photovoltaic thermal (BiPV/T) or photovoltaic thermal systems (PVT) is increasing gradually. Its studies were documented as early as in mid 1970s.

Since then research in this area has followed several trends. Early work by Kern and Russell [7]was concerned with the important concepts and information about the utilization of either water or air as the coolant(heat exchanger). His findings were further expanded by Garg and his co-workers who executed a detailed analytical study on hybrid PVT air and liquid[8]. Clarke et al on the other hand examined different alternative coolants that are suitable for a building integrated photovoltaic (BiPV) thermal system[9]. Additional works by Bhargava et al [8],Sopian et al.[10] , Prakash[11] , Bergene and lovvik [12] and Agarwal[13] were based on experimental analysis of the efficiency of PVT systems using different variety of techniques. Naveed et al. [14] further examined the effect of airflowing as coolant on the electric productivity of the PV system. His findings were an improved electrical performance as a result of a temperature reduction of 3-9^{o} C. Similarly, studies by Yang et al.[15] and Chow et al.[16] were concerned with investigating the effect of both air flow and weather conditions on eletric productivity of PVT.

Today the applications of these early studies on BiPV/T systems is expanding from residential to industrial settings[17]. Projects have already been developed like the Mataro library outside Barcelona [18] and the Elsa building in Ispra [19]. Furthermore,continuous studies on PVT technology are still being carried out like JRC in Ispra, Universities of Cardiff and Strathclyde in the United Kingdom[20]. There has been however, no market transmission of commercially accessible products. The Basic reason may be apparently the variations in weather and insolation. All through cold temperatures, substantial regions of Europe are noted by reduced quantities of insolation and minimal temperature, while large regions of Japan and the USA have large insolation and reduced temperatures which might be suitable for this technology [21]. Nevertheless, small scale market size of BiPV/T systems have been accomplished lately; for instance the PV:VENT and INNOPEX program in Denmark which may pave the way for commercial products in the near future [22].In Estonian very few related studies have been conducted so far. Inspite of this, little attention in previous studies have been paid on analyzing the energy demand of a building and evaluating how much of this energy can be covered by the heat energy that could be harnessed from a BiPV/T system.

This study presents an analytical framework for evaluating the amount of energy demand of a building in Estonia that can be covered by thermal energy generated from BiPV/T system. Typically, the increasing demand in electricity and the rigorous growth of the building industry in Estonia, will make the application of PVT technology an important and wise approach.

1.1.1. BiPV/T system assessment and Applications

The assessment of the electrical efficiencies of a BiPV/T system is simple since the utilization of electricity could be instant and the storage facility optional. However this is not the case when it comes to assessing thermal performance. The BiPV/T air collector is only a single component of a complete heat-supply system which consist of many individual systems (or the balance of system), like thermal storage and mechanical device.

Once the setup is described, the sensors for information recording, the algorithms for data evaluation, failure detection could be defined. The efficiency of the system can also be monitored by temperature receptors that measure the heat being input to the heat storage or heating system of the building

Precise and reliable tracking of thermal productivity is a fundamental necessity for bigger commercial systems especially those that gain alternative motivation for the generation of green forms of heat. Nevertheless, managing and controlling the movement of heat energy is of maximum significance for cost conscious users. These systems should conform to higher standards of business acknowledgement.

The key problem in assessing photovoltaic thermal efficiency air as a collector is based on the estimation of the thermal behavior [23]. When the temperature profile and the sunlight covering situation has been handled, the efficiency is then easily determined. Nevertheless the thermal computation may be problematic. The external wind load on the panels further complicates the situation [24].

Other real life applications of PVT systems products have the solar hot-water system in which a glazed Photovoltaics thermal collector combines immediately the electric and thermal production of PV for domestic hot-water system. It is used in reservation systems like hotels to heat swimming pools.[21] And the Solar hot-water/space system similarly compared to solar hot water system, but also supplies heat for space heating, and requires a more substantial roof space for the Photovoltaics thermal collector[21]

Further numerous benefits of this technology have been:

- Cost of Installation savings, because several techniques of energy generation are contained in one module and how big the entire system is will undoubtedly be reduced. This will decrease installation time and mounting equipment necessary
- Space saving, however this really is not a problem at the moment within most of Europe, Australia or North America, but remains a factor to some other countries like Japan. As PV technologies are increasingly covering the market place, this may demonstrate crucial impact in the near future.
- Stability of system savings: Also, because several techniques of energy generation are contained in one module, the Balance of system components could be mutual or shared.

1.1.2 Alternative use of water to extract heat

Up to now, most widely used photovoltaics thermal collector systems use water tubes for cooling and thermal energy collection. Generally, the water tubes are embedded in insulation materials and covered by absorber materials in touch with the PV layers on top. These previous models have encountered poor heat conduction between the absorber and water tubes as a result of little contact area.

Here the water pipes are embedded in the top section of a functional graded material (FGM) layer, where the high aluminum concentration generates high thermal conductivity to ensure that heat can be efficiently transferred to water pipes in every directions, clear defensive layer operates as a water-proof membrane. Functional graded materials (FGM*)* layer supplies the polymer matrix for the heat exchange system. Heat energy is then captured in the FGM layer and collected with an insulated pipe.

In general, the extraction of heat energy behind a photovoltaic system reduces the operating temperatures and enhances electric efficiency of the PV module. However, the utilization of this thermal energy depends on the heat demands of a building. In order to analyze the heat demands of building there is need to specify the class of building. Buildings are classified based on their energy performance or efficiency.

1.2 Efficient energy buildings.

In view of global crises on energy and sustainability, interest on energy efficient buildings has been a common understanding in many countries today. They are building operating with low emissions and the use of environmentally friendly building materials. However, different definitions and classifications of high performance energy buildings in various countries with respect to quality requirements and calculation methods are used.These forms of buildings can be categorized into the following;

low energy consumption (low energy house, energy saving house, ultra-low energy house,3-litre-house, zero-heating energy house, zero energy house, plus-energy house, very low energy house, energy self-sufficient house, energy autarkic house); Low emissions (zero-emission house, zero-carbon house, emission-free house, carbon-free house); Sustainable or green aspects (eco-buildings, green buildings, bioclimatic house, and climate: active house). Among the most routinely used options in Estonia, are low energy house, passive house, (net) nearly zero-energy building, plus energy building. [25] The most commonly used class of building are;

- Low energy house defined in most countries in terms of calculated energy consumption of a building that is largely lower than buildings meeting the essential building rules.
- Passive house whose basic principle is heating and primary energy demand per square metre of the house. It can also be considered as a standard of a building in which its inner climate can be retained without an active heating system (self-heating and cooling by the house). Comparatively residential buildings built in the 1980s, are found throughout Central and Eastern Europe, to consume 12 times more heating energy than a passive house [26]. No official classification of passive house are defined in Estonia, however, voluntary designers and builders aim to achieve the passive house standard described by the Passive House Institute in Germany [27].
- In addition a nearly zero-energy building which in accordance with the European Union legislation, means a building with a very high energy performance. That is, the significant amount of the energy produced is gotten from renewable sources, including those produced on-site or nearby [28]. In Estonia, the legislation defines nearly zero-energy buildings and came into force on 9th of January 2013[29] The specifications of energy consumption for nearly zero-energy buildings are; 50 kWh/m2/y (small residential buildings), 100 kWh/m2/y (apartment buildings) up to 270 kWh/m2/y for healthcare centres and clinics.[24]
- Another class of energy performance building is a plus energy building energy which produces more than its own consumption. In the case of electricity excess, it can be fed into the power grid and then the electricity bill is calculated by the difference in the outflow and inflow of energy[30]

- Lastly, a Zero energy buildings (ZEBs) referred to as buildings which have zero carbon emissions on an annual basis. In practice this is feasible by reducing the energy need of the building, the use of Green Energy resources and by applying suitable technologies to meet up power requirements. The ZEB concept is anticipated to contribute considerably towards the achievement of the future smart towns, created by the European Union and endorsed through its regulatory framework. Based on the Directive on the energy efficiency of buildings [31] all new buildings should be almost zero-energy from 2020

The building sector is one of the greatest energy consumers in the European Union (EU) and accounts for significantly more than 40% of total energy use [31]. The majority of the energy consumed by Estonian homes is employed for building services. Huge amount of the power and fuels used by Estonian homes are employed for heating. Also the energy statistics of Organization for Economic Co-operation and Development (OECD) shows that in general 30 to 50% of primary energy is consumed in non-industrial buildings (i.e. in dwellings, offices, hospitals, schools etc.) [32]. Of this, as much as 50% is dissipated from the building into the outgoing air stream. Nevertheless, as buildings become more thermally efficient, the proportion of energy loss (either heating or cooling losses) associated with ventilation and air infiltration becomes the only means of thermal loss mechanism [33]. Additional losses may be however associated with the energy needed to operate mechanical ventilation systems. It is, therefore, essential to understand the role that air change rate plays in contributing to energy loss, and to identify methods to improve the energy efficiency of ventilation. One sufficient strategy could be to upgrade regulatory demands for insulation levels, to set up heat recovery systems of exhaust air and a more effective heating system [34]. Planning and design choices also have a substantial effect on the energy usage of buildings. The type of the building, its orientation, location, control infiltration techniques decrease the negative heat effects of outdoor weather on the thermal stability of the building.

1.2.1Building Energy rating.

A building energy rating is a rating on the overall energy efficiency of a residential or commercial building [35]. The rating is similar to the energy label on a fridge and is denoted on scale of A to G, with A1 being the most energy efficient and G being the least energy efficient. The Building Energy Rating calculation measures the energy performance of the building based on the building fabrics such as the walls, roof, floors, windows and doors, the construction type and the levels of insulation used. While energy needs in all other areas grew, the building and construction segment grew at the faster projection rate. Building Energy rating has for ages been an area with combined initiatives from the federal government and the industry sectors.

There are numerous energy performance rating techniques effectively developed in several nations , for example Energy and Environmental Design (LEED) in the United States, Building Research Establishment Environmental Assessment Method (BREEAM) in the United Kingdom, Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan, Evaluation Standard for Green Building (ESGB) in China and Building Environmental Assessment Method (BEAM) Plus in Hong Kong and Green Mark in Singapore[36].

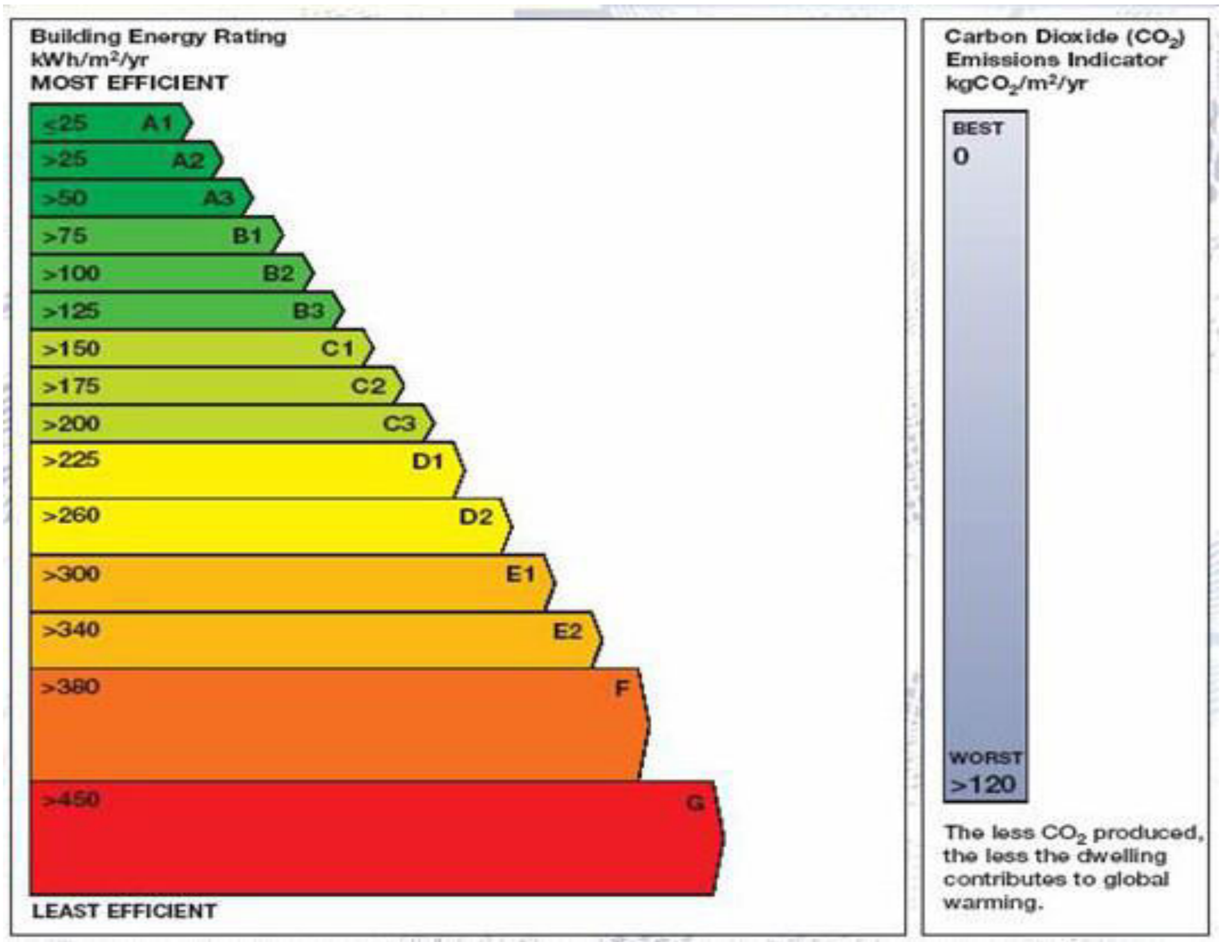

Figure 5: The building energy rating based on energy efficiency and carbon dioxide emission with Class A1 the most efficient and almost zero carbon dioxide and class G the least efficient

1.2.2 Thermal Insulation of buildings

Thermal insulation of houses is an essential element in enhancing comfort of its occupants. Insulation decreases undesirable heat loss or gain and may reduce the energy needs of heating and cooling systems. In generally, it does not always handle problems of sufficient ventilation. Moreover, insulation may only make reference to the insulation materials used to slow heat reduction, such as for instance cellulose, glass wool, rock wool, polystyrene, foam, timber fiber, plant fiber, recycled cotton, plant hay, animal fiber (sheep's wool), concrete, and earth or soil, Reflective Insulation (also referred to as Glowing Barrier) may include a variety of techniques and methods to handle heat transfer processes - conduction, radiation and convection [37]. The efficiency of mass insulation is typically examined by their R-value, of which there are two - metrics (SI) and US standard, the former being 0.176 times the latter[38]. However, an R-value does not take into consideration the kind of structure or regional environmental factors for every single building. The most effective way of accomplishing a good thermal insulation is by putting the insulation material nearest to the outer lining of heat entry; for example in space heating, insulation must certainly be put near the inner surface of the building envelope while in cooling load principal parts it should be nearer to the external surface The limitations of structural quality of insulation material include low vapor barriers, the attributes and thickness of the insulation material itself.

An efficient way to enhance the energy performance of a building is by increasing the thermal insulation of the envelope. The thickness of insulation in building has improved since the early 1970s, nearly doubling in northern Europe [39]. Also the R and U-values also defines the building insulation property.

1.2.3The R and U-values

In construction, the R-value is the ability of a material's capacity to withstand heat movement from one area to the other. In simple terms, R-values evaluate the effectiveness of insulation and a higher value shows more efficient insulation.

R-values are additive. For example a material with an R-value of 9 connected to some other material with an R-value of 5, both have a combined R-value of 14. Several energy modeling applications and calculations need U-values for analysis. The U-value is the heat transfer coefficient, which merely is the material’s ability to allow the transfer of thermal power across its thickness. The U-value of a construction is the reciprocal of the sum total of R-values.

$$\mathbf{U} = \frac{1}{R1+R2+R3\ldots\ldots} \text{ (W/m2K)} \qquad (1)$$

1.3 Ventilation and Air quality of buildings

From an environmental perception, air means oxygen. Oxygen is a fundamental element of excellent indoor air quality. The improvement of inner air quality of buildings, the conservation of appropriate atmospheric air levels, and the reduction of air pollutant levels have gained immense scientific fascination in recent years. Environmental agencies have set air quality limits, which are generally exceeded inside houses. Again, extensive initiatives have already been exerted to reduce outdoor environmental pollutants. Thus, excellent indoor air quality, wherever people spend most of their times, is imperative.

Appropriately through the scientific research of air movement, the natural ventilation of houses could be managed, and thermal comfort achieved. Moreover, air exchange rates could be enhanced, and indoor quality of air improved. These conditions can lead to improved air concentration levels, which in turn lead to the promotion of good health and pleasant residing atmosphere for the inhabitants. Therefore, the use of high engineering and technical experience during building constructions must be employed to accomplish a conducive indoor air quality [40]

To efficiently make use of the natural ventilation of houses in the architectural design method, analyzing the appropriate scientific areas is essential. The natural ventilation of structures is investigated using computational and lab simulation [41].

1.3.1 Heat recovery ventilation of Buildings

Tight houses produce both moistures and pollutants. The moistures originate from cooking, washing, showers and breathing. At excessive levels, these moistures condense on windows and may lead to structural deterioration. Regions of excessive moisture may also be breeding grounds for mold, fungi, and bacteria [42]. Several attempts have been carried out to achieve a conducive inside air quality of buildings [42]. For instance, an electrostatic filter mounted in a forced-air heating system will certainly reduce airborne contaminants, however it will not help with gaseous pollutants. Also a local exhaust fans may eliminate surplus humidity in the kitchen, shower and washing area but develop negative pressure within the house. As they push air out, the resultant vacuum gradually pulls air into and through the house framework, bringing with it scents, dust and contaminants. An improved whole-house solution is to generate balanced ventilation. In this manner, one fan blows the polluted air out of the house while another replaces it with fresh air. Nonetheless, a little too expensive to warm the replaced fresh air. Therefore the most perfect system for interior quality of air and energy gain is heat recovery ventilation [42].

It is comparable to a balanced ventilation system, except that it extracts the heat of the outgoing air to warm up the incoming the fresh air. It consists of a normal system of two fans—one to take out household air and another to bring in fresh air. What makes Heat Recovery Ventilation distinctive is the heat-exchanger which transfers heat from the outgoing air flow to the incoming stream in exactly the same way that the radiator in a vehicle transfers heat from the engine's coolant to the exterior air [42]. It contains a series of tinny alternating pipes whereby incoming and outgoing air streams flow. As the streams move through, heat is transferred from the hot side to the cold side, but the air streams never mix.

Depending on the design, Heat Recovery Ventilation may retrieve as much as 85 percent of the heat in the outgoing airstream, making these ventilators much easier on financial levels than opening a couple of windows. And, Heat Recovery Ventilation contains filters that hold particles such as pollen or dust from entering the house. A typical Heat Recovery Ventilation installation may run from $2000 to $2500, but expenses will vary generally depending on the particular situation [42].

Even though a heat recovery unit may be effective in summer time, when it will take heat from incoming fresh air outdoors and transfer it to stagnant air-conditioned exhaust, it's most widely used in colder climates throughout the winter. If the temperature falls under about 20° F(-6.7^{o}C), nevertheless, ice may develop within the exchange core [42]. To deal with this, a damper closes off the cold airstream paths. After a few minutes, a timer starts the fresh-air interface and ventilation continues. It is significant to have an excellent air-tightness of the building envelope cover to ensure that the majority of the air replacement goes through the heat exchanger.

In accordance with Estonian building code the heat recovery ventilation was calculated by multiplying the heat loss through ventilation by 0.3. This was calculated for each hour of the year.

1.3.2 Building infiltration

Infiltration is the natural entry of outside air into a building or exit of inner air from a building. It occurs through; mechanical ventilation (induced by fans, blowers etc.), natural ventilation through fenestration (due to wind and buoyancy force) and through cracks and leaks. It also results to indoors pollutions. During building infiltration, particle transmission is dependent upon geometry of air course, pressure difference that drives the movement and particle transfer properties. Even though filters and different cleaning equipment decrease the pollutant levels in structures, various contaminants and reactive gases enter through infiltration. Diesel soot, elements of photochemical smog, commercial particulate emissions, aerosols, airborne pollen, spores and microbial unpredictable natural materials from molds in building envelope are some samples of such metropolitan pollutants [43]. Larger particle levels in the indoor air result in undesirable effects on individual health. These levels rely mostly on the amount of transmission of these particles through the building by infiltration [44]

1.3.3 Factors affecting building infiltration

Infiltration is driven by weather conditions (temperature difference between interior and exterior air and wind movement), building surroundings, building age and building construction characteristics. During indoor heating, air has a tendency to infiltrate into or out of the building through the leaks as result of external weather conditions. The stack effect is also another factor that affects building infiltration rate. It occurs as result of vertical pressure, that is, warm air inside the building is less dense than cooler air outside, and hence escapes from openings high up in the building envelope while cooler denser air enters through the openings lower down. The process continues if the air entering the building is continuously heated. Ignoring the interior airflow resistance, the stack pressure difference is just about 0.02 Pa per meter of building height and degree Celsius of indoor–outdoor temperature difference [45].The operation of ventilation systems and local exhaust fans leads to a net flow of air to the building or from the building, thereby causing a respective increase or decrease of the inner building pressure.

2. Material dimensions and methods

2.1 Building model

A three-dimensional building size was designed using a simulation software (figure1). The dimensions of the building (building size, windows, doors, walls, floor, and roof) were all defined by the software. The modelling structure was a two-story detached house corresponding to the typical detached house defined in accordance with Estonian code of building energy performance. The net floor area of the building was 112.11 m^2 and the structures of the house were made of concrete block wall with thickness of 500mm and no extra insulation required. The base floor was a concrete slab on the ground and the level of thermal insulation of the house ($U_{ext.wall}$ of 0.14 W/m^2 K, U_{roof} of 0.072 W/m^2 K, $U_{basefloor}$ of 0.12 W/m^2 K and $U_{windows}$ of 0.69 W/m^2 K). The building envelope had a volume of 383.3 m3 and each room had defined sizes as shown on the floor plan (figure2). The inner heat gains through walls and windows varied considerable daily. The building cover materials and types are shown in Table3. The room temperature set-point was 21 ° C and winter ambient temperatures were obtained from the Estonian weather service. In this model, the total internal heat gains from the occupants, lighting and devices were not included in the calculations.

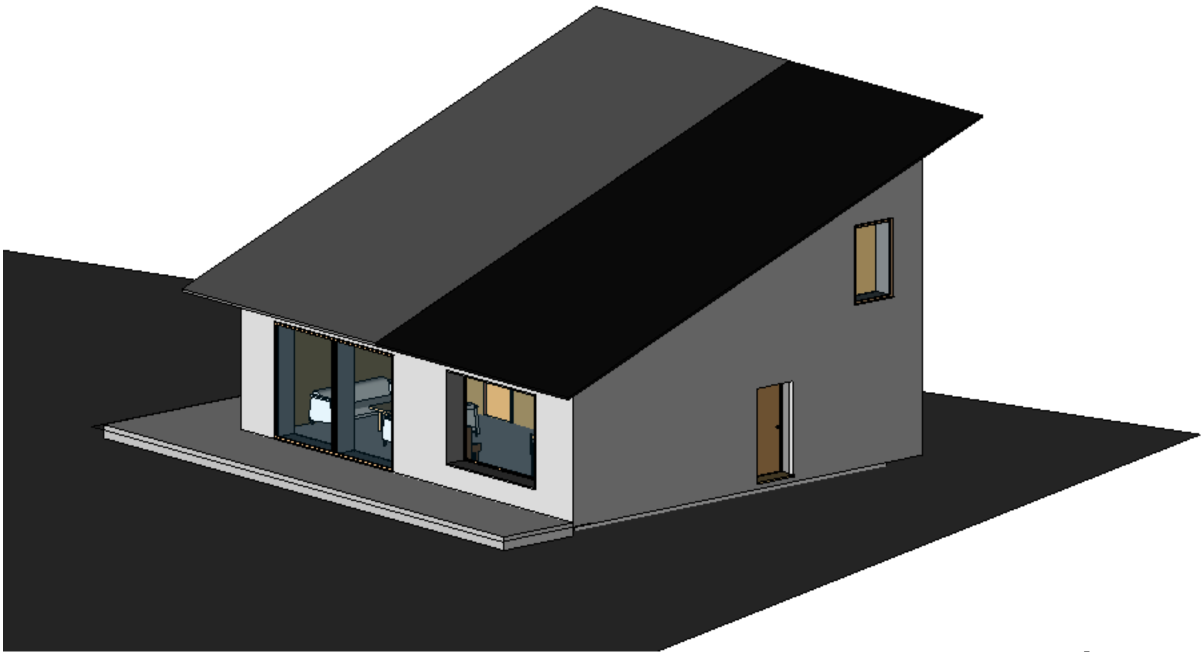

Figure1. 3D view of the simulated building with the black shading showing the 80m^2 surface area of the roof that is occupied by the PV panel.

A building envelope is what separates the indoor and outdoor environments of a building. It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Various components such as walls, fenestration, roof, foundation, thermal insulation, thermal mass, external shading devices etc. make up this important part of any building.

2.1.1 Floor plan.

Figure2 below is the illustrative view of the floor plan showing the living room, shower, and kitchen. The parallel lines are scaled to the required wall width of $10.1m^2$. Specific dimensions are drawn between the walls to specify room sizes (Techno $9m^2$, office $13m^2$ and living room $47m^2$) and wall length of $11.1m^2$. All doors, windows and built-in elements, such as plumbing fixtures and cabinets, water heaters and furnaces, etc. are also indicated.

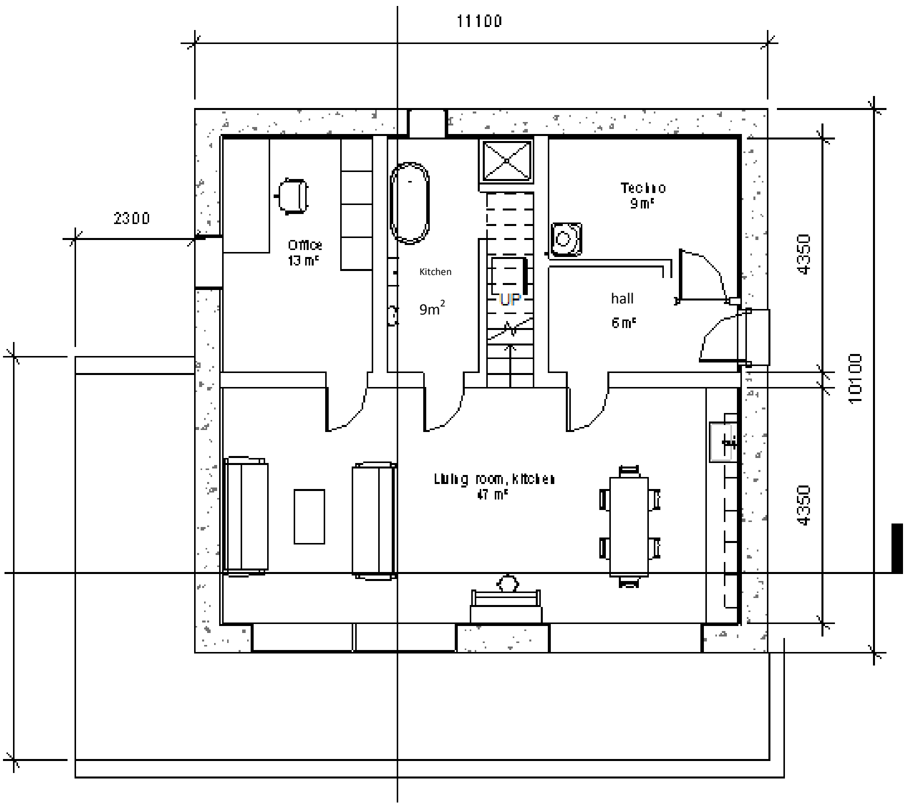

Figure2. Specific dimensions of the floor plan drawn between the walls specify room sizes

2.1.2 External wall

An AEROC ECOTERM with aerated concrete blocks made of a dry density of 300 kg / m³ and compressive strength (fb) of 1.8 N / mm² was used. A class I masonry units that meet up with the masonry harmonized standard and is designed with a CE mark. Its features were a smooth surface rectangular masonry and consisted of a mild wall Massive blocks of a breadth 500 mm allowing the construction of a single-layer warmth envelope without any extra thermal insulation materials needed. This thick massive walls can protect the blazing winter cold and summer heat, ensuring adequate sound insulation performance and excellent protection in the event of fire. The 500mm end of the block are finished with exterior wall thermal conductivity (U) of 0.17 W / (m^2K). Its competitive advantage is its great thermal insulating (λ) ability of 0.072 W / (mK). The Underneath layer of insulation generates an even area for the vapor barrier. Vapor buffer stops moist air from leaking in many layers of insulation. It is confirmed by regular mineral wool during the time of the small architectural activities, such as those that are brought on by the profile account of the sheet material.

The whole wall surface area for this study was 165 m^2.

Figure3: AEROC ECOTERM 500mm exterior block of wall with thermal conductivity (U)of 0.17 W / (m^2K).

Walls are a predominant fraction of a building envelope and are expected to provide thermal and sound comfort within a building, without compromising the art of the building. The thermal resistance (*R*-value) of the wall is crucial as it influences the building energy consumption heavily, especially buildings where the ratio between wall and total envelope area is high. The market available center-of-cavity *R*-values and clear wall *R*-values consider the effect of thermal insulation.

Walls with thermal insulation have a higher chance of surface moisture condensation when the relative humidity of ambient air is greater than 80%, provided the convective and radiative heat transfer coefficients of the exterior wall are small. This problem is more severe during winter months and in colder climatic regions with higher humidity levels .This moisture condensation on building exterior walls promotes undesirable microbial growth which might reduce the wall life and lead to other undesirable conditions in the building. Conventionally, based on the materials used in construction, walls can be classified as wood-based walls, metal-based walls and masonry-based walls. There are other types of advanced building wall designs that are applied to improve the energy efficiency and comfort levels in buildings.

2.1.3 Floor slab

The slab was made of an 85.14 m^2 concrete material on ground floor and 250mm Styrofoam with thermal insulation of 0.036 W/mK. Styrofoam is an extruded polystyrene foam material and is more than an effective thermal insulator. It has a unique combination of physical and chemical characteristics that make it a key component within a wide variety of usage in floor slab. Styrofoam is light weighted, yet exceptionally strong, safe in use and capable of providing adequate insulation.

2.1.4 Windows

A triple glazed, 2x18mm gap and 2x argon filled glass window with thermal conductivity of

0.69 W/m2K.was used

The entire window's dimension was 27.68 m^2 (Two windows on the West with total area of 4.2 m^2, two windows on the South with total area of 11.5 m^2, a North and an East window with respectively 1.4 m^2 and 1.98 m^2). Figure4 shows exact window prescription from Kalesy Company.

Fenestration describes spaces in a building envelope which are mainly windows and doors. The fenestration conducts an essential role in providing thermal comfort and ideal lighting levels in a building. They are also crucial from an architectural point of view; introducing appearance to the building design. Recently; there has been substantial improvements in glazing technologies. These Technologies involve solar control glasses, insulating glass units, minimal emissivity (low-e) coatings.

For passive solar heating applications , windows with minimal U-value and large overall solar energy transmittance (Γ) are preferred. Lightweight spectrometer or solar transmissioon meter can be used to assess the emissivity of fenestration glazing

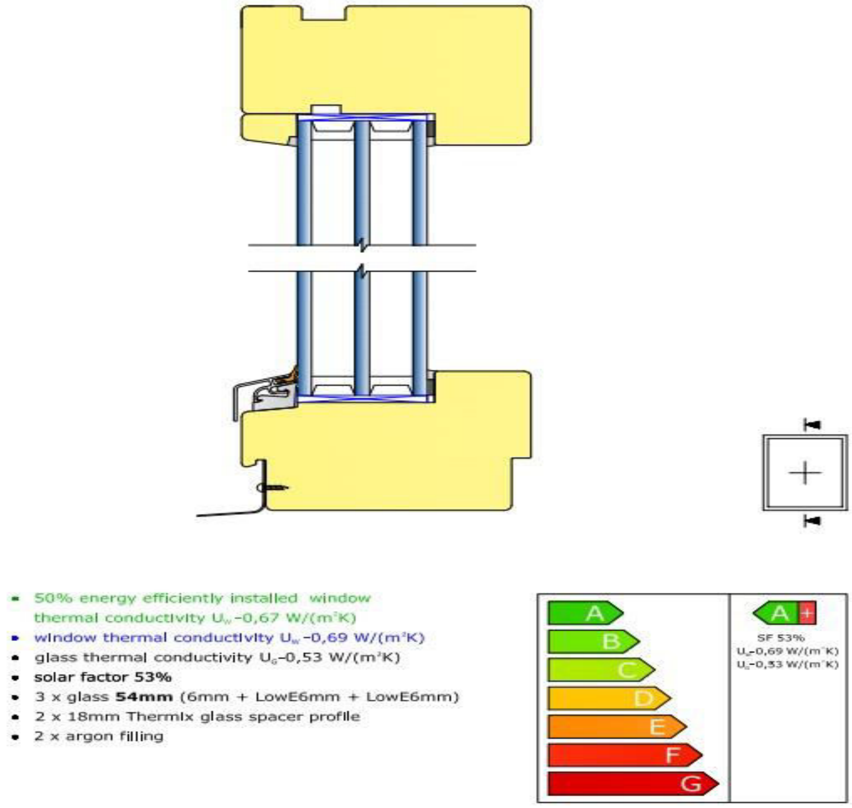

Figure4. A triple glazed, 2x18mm gap and 2x argon filled glass window

2.1.5 Roof

The design was a 500mm Double flat-slab insulated Roof of 0.036 W/mK between and over ceiling joists.

The Underneath layer of insulation generates an even area for the vapor barrier that stops moist air from leaking in many layers of insulation. An insulating layer at the top half of the medium consists of a series of the grooves that form the ventilation of the road network.

Roofs may be categorized into various classes on the basis of the kind of building. The thermal insulation of roofs has been of great significance recently. It has the prospect of preserving equally cooling and heating loads. Polystyrene, fiberglass, rock-wool/mineral-wool are typically applied for roof insulation. The trans missive barrier is usually an expression frequently applied to describe roof thermal insulation. When accompanied by a reflective surface, it is known as radiant-trans missive barrier as it may also reflect infra-red radiation.

2.1.6 Doors

A Triple glazing with 40mm insulated panels door made of solid wood profile and a surface area of 2.52 m^2 was used. Its thermal conductivity was 1W/m2K

2.2Methods

The first part of the study was the simulation of a three dimensional two story residential building. The measurements and structural parameters were defined using an architectural software. Furthermore, the surface materials with defined properties (thermal conductivity, thickness, thermal resistivity etc) were obtained from construction sites (Paroc.ee, aeroc.eu and kalesy.ee). These defined surfaces were; AEROC ECOTERM 500mm aerated concrete block wall, a 50mmSlab on ground floor with 250mm Styrofoam insulation and 0.036 W/mK thermal conductivity, a triple glazed Window of 2x18mm gap and 2x argon filled, a Triple glazing with 40mm insulated panels door made of solid wood profile and a 500mm Double flat-slab insulated Roof of 0.036 W/mK between and over ceiling joists. Two windows each were orientated towards the West and South poles with total areas of 4 and 11.5m^2 respectively. Only one window each was oriented towards the North and East, however system modifications were carried out including windows reduction, different angles of panel inclinations and reduction of wall thickness. The results of these modifications are described in Table 7 and 6

The PV panel used for this study was a commercial mono crystalline Silicon solar cells purchased from Hyundai Solar Module. The dimensions were 983 mm (38.7")(W) × 1,645 mm (64.76")(L) × 35 mm (1.38")(H) and Weight of Approximately 19.0 kg (41.9 Ibs). A Styrofoam box was fabricated to enclose the underneath surface of the panels. The thermal conductivity of Styrofoam used was 0.038W/m K. The panel was mounted on a rooftop over a surface area of 80m^2 at an angle of 55^{o}C degrees so that the panel surface was normal to the irradiation. However angle modifications of 20 and 90 degrees were also used to examine which angle best suits system maximum production. A 2m long pipe through which the inlet cold air enters the system was plunged into the Styrofoam box. 2/3rd m from the air entrance was placed a sensor to detect the level of air intake or wind speed and for measurements. And 1/3rdm away from the air entrance was place a fan to circulate the air behind the PV module. At the other end of the pipe was a 200mm flexible duct attached to an 800mmx300m square-shaped air collection box enclosing the underneath monocrystalline silicon panel. The area of the air channel behind the panel was 30mm x980mm and the distance between the collection layer and the absorbing layer was 1cm. A pyrometer was used to measure and calibrate the solar irradiation. The experimental data was collected with the data acquisition system.

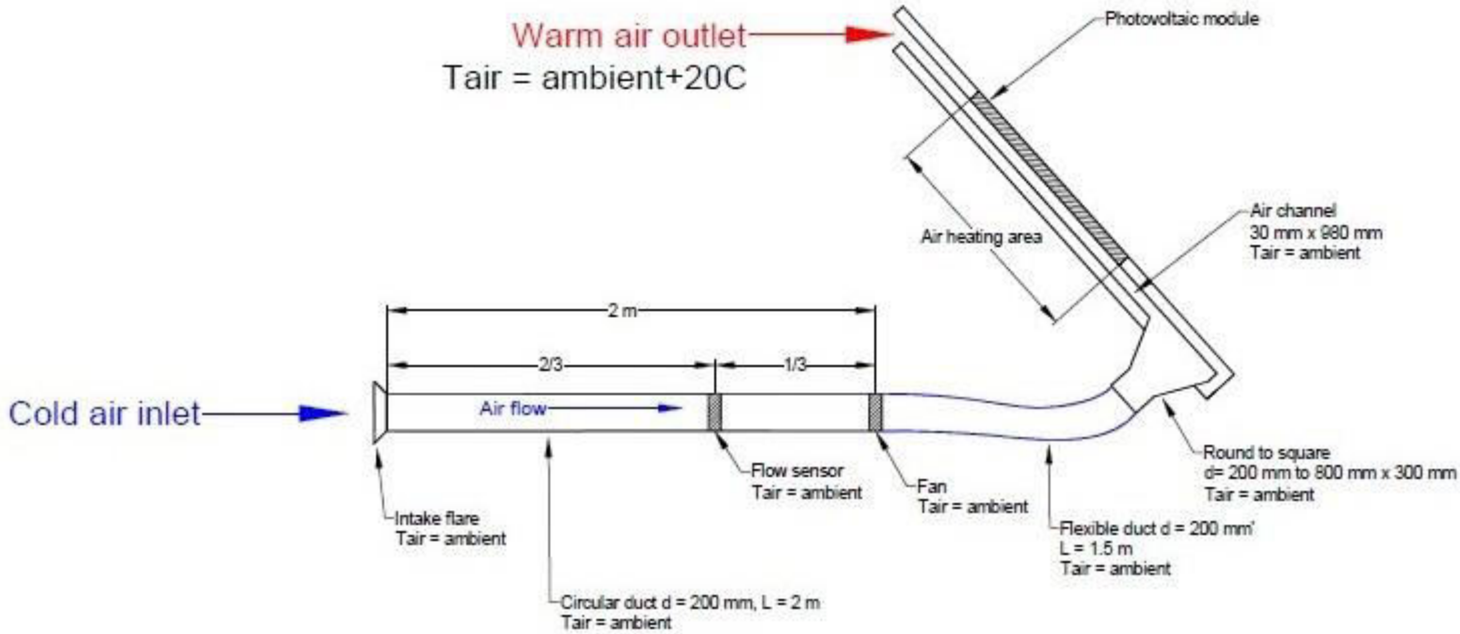

Figure 5. A 2m tube through which the inlet cold air enters the system to extract heat

It is important to note that Pure Al powder, high density polyethylene (HDPE) and polyvinylchloride (PVC) could also be used to fabricate a functional graded material layer through which pipes are embedded to trap heat. Again Thermal couples could also be attached on the solar panel to evaluate the temperature distribution.

2.2.1 The Advantage of using air over water

The advantage of using air was that when water (or an aqueous propylene glycol solution) is used for a Photovoltaics thermal systems the financial status are much higher compared to when air is used. This is as a result of the required plumbing, more complex façade and greater weight. Nevertheless studies have shown that the cost of a PVT systems water as a collector can be lowered by reducing PV module manufacturing costs, installation costs, operation and maintenance costs and by improving PV and other component efficiencies.

3. Calculations and Equations

The evaluation of building energy is usually time dependent because the exterior surrounding temperatuure ,wind velocity and solar radiation differ with time. Also, the heat gains as a result of occupants, equipment, illumination, and solar radiation transmission through fenestration, besides the ventilation and infiltration of the exterior air will need to be accounted for. Nevertheless in this study heat gain from occupants and equipment were not taken into account. Numerous techniques with various levels of simplification occur for building energy calculations.

The architecture soft used defined all the dimensions (Length, width, Area, volumes) of the building parts (walls, windows, doors, floor, roof,). By using this professional software the floor diagram drawn are therefore considered to be rigid. A module was form using an excel sheet and the following calculations were done.

3.1 Input data

The temperature difference between the inside of the building and the outside of the building was calculated for each hour of the year. The thermal conductance of each part of the building were also calculated by multiplying their respective areas by their thermal conductivities.

Heat losses by Ventilation, infiltration and through walls, doors, windows, floors and roofs were calculated by multiplying each respective thermal conductance AU (W/K) by the temperature difference for each hour for one year.

3.1.1Heat loss through walls

Heat transfer through the brick or concrete wall is acquired by calculating the conductive, convective and radiative heat movement through each cavity. Building parts are subjected to humidity level differences just as much as temperature differences, between the interior of the concrete and the exterior.

$$H_w = AU\,(T_{insde} - T_{outside}) \qquad (2)$$

.where H_w is Heat loss through walls (W), A is area of the walls minus areas occupied by windows (m^2) U is thermal conductivity (W/m^2K) and (T_{insde}- $T_{outside}$) is temperature difference

3.1.2Heat loss through windows

Heat transmission loss from windows with poor glazing patterns with regards to energy performance constitutes a large percentage of the entire transmission loss.

This heat loss may be considerably decreased by changing the windows to those with minimal emissive glazing. The following calculations were performed

$$H_w = A\ U\ (T_{insde} - T_{outside})$$
(3)

Where H_w is Heat loss through windows (W), A is Area occupied by windows (m^2), U is thermal conductivity (W/m^2K) and (T_{insde}- $T_{outside}$) is temperature difference

Heat loss through doors, floors and roofs were calculated using the same formula above in which case their respective areas and U-values were used.

However the heat loss through floor was constant as the floor temperature was estimated to 6^oCin accordance with the Estonian housing regulation. Thus its calculation was as follows

$$H_f = A\ U\ (T_{insde} - T_{outside})$$
(4)

Where H_f is Heat loss through floor, (T_{insde}- $T_{outside}$) is temperature difference, A is area of floor and U is thermal conductance.

3.1.3 Heat loss through Ventilation

The thermal conductance through Ventilation was calculated by dividing the entire building volume by two.

That is; Volume/2 in cubic meters.

As shown in figure below.

The heat loss for one year was obtained by multiplying the value obtained by temperature difference;

3.1.4 Heat loss by infiltration

Heat loss through air leakages of building are merely determined based on the temperature difference between inside and external air.

It was calculated using the formula below.

$$H_i = c_p \rho\ n\ V\ (T_{insde} - T_{outside}) \qquad (5)$$

The infiltration air flow rate q*i* (l/s) or n is calculated in accordance with Estonian code of building energy performance using the formula:

$$q_i = \frac{q_{50}}{3{,}6 \cdot x} A, \qquad (6)$$

Where H_i is heat loss by infiltration (W) ,$c_p$is specific heat capacity of air (J/kg/K), ρ is density of air (kg/m^3) and n or q*i* is air flow rate in accordance with Estonian building regulations,

q50 is the average air leakage rate in $m^3/(h \cdot m^2)$ of the building envelope, obtained from air leakage standard in accordance with Estonian code of building energy performance (table6 below)

A is the area(m^2 of the building envelope (including floors) ;

x is the factor which is 35 in the case of a single-story building, 24 in the case of a two-storey building, 20 in the case of a three or four-story building and 15 in the case of a five-storey or higher building, the height of a story being 3 metres in our own case which was 24;

3,6 is the conversion factor of airflow rate unit from m3/h to l/s.

3.1.5Air leakage of buildings

When the building's air leakage rate is not measured or proven in any other manner, the values of air leakage shown in the table 6 are used for the energy calculation. If the design air leakage obtained is greater than the base value in Table 1, the design air leakage value is used. When air leakage is obtained according to the standard EVS-EN 13829 or has been proven by the supplier of the house, the measured or proven value is used in the energy calculation.

Table 1. Base values of air leakage of buildings per square meter of building envelope for Estonia

Purpose of use	Base value of air leakage $m^3/(hm^2)$	
	New building, major renovation	Renovation, existing building
Detached houses	6	9
Other buildings	3	

3.2 Solar gains

The amount of solar energy gained through windows or walls from sun light. To calculate this, the data for solar irradiance were also obtained from the Estonian weather service. The following calculations were conducted

$$\text{Solar gains} = A\ (\text{Transmission})\ (\text{Insolation}) \quad (7)$$

Where A is area of windows, Transmission is fraction of incident solar radiation transmitted to interior (0.53 EU standards) and Insolation is solar radiation incident on window surface.

3.3 Heat demand and production

The daily heat demand of the building as well as the daily heat production of the system were calculated by summing the hourly heat demand and production each day for one year. This analysis was also done for a difference of three days in both cases.

3.3.1Useful energy

The useful energy production from the system was calculated using the MIN excel function between daily heat demand and daily heat production. This implies getting the amount of heat energy demand the can be covered by our system

3.3.2. System energy demand ratio

The sum total of the useful annual heat production by the system was divided by the sum total of the annual energy demand. The result was multiplied by a hundred to obtain the system performance ratio.

PV electric efficiency was also defined by,

$$\eta pv = Epv/Ein = [(P\text{max})(A)]/(Pin)(A) \quad (8)$$

where *P*max is the maximum output electrical power based on the output I–V curve of the solar cell and *Pin* is the solar irradiation, for example 1000W/m2, and *A* is the area of the solar panel.

The results of the above calculations are analyzed in the following section;

4. Results and Discussions

The thermal conductance (AU) of the building surface like walls, floor, windows, roof and doors were calculated as above and the results shown in the (Table 2).The table shows the building surfaces that determined the heat demand of the 500mm block wall building used. The U values were calculated by dividing the thermal conductivity of each surfaces with their respective thickness. However some of the U-values were defined by the individual companies of respective material surface production. AU values of the table is thermal conductance and obtained by multiplying the U-values by their respective surface areas.

Table2. Building surfaces that determined the heat demand of the 500mm block wall building with their respective thermal conductance.

Surfaces	length	width	Height	Area(A)	U values	AxU
	m	m	m	m^2	W/m2K	W/K
AEROC ECOTERM 500mm aerated concrete block wall			4.5	155.9	0.1	21.8
A 50mmSlab on ground floor with 250mm Styrofoam insulation 0.036 W/mK	9.9	8.6		85.1	0.12	10.2
Window1 triple glazed, 2x18mm gap, 2x argon filled West	2	1.2		2.4	0.7	1.7
Window2 triple glazed,2x18mm gap, 2x argon filled WEST	1.8	1		1.8	0.7	1.2
Window triple glazed,2x18mm gap, 2x argon filled EAST	1.8	1.1		2	0.7	1.4
Window1 triple glazed,2x18mm gap, 2x argon filled SOUTH	2.6	2		5.2	0.7	3.6
Window2 triple glazed,2x18mm gap, 2x argon filled SOUTH	2.1	3		6.3	0.7	4.3
Window1 triple glazed,2x18mm gap, 2x argon filled NORTH	2	0.7		1.4	0.69	1
Triple glazing with 40mm insulated panels door made of solid wood profile	1.8	0.7		2.52	1	2.5
500mm Double T-slab insulated Roof of 0.036 W/mK between and over ceiling joists				164	0.07	11.8
Total						65.5

- The results of the thermal conductance by infiltration and ventilations are also shown as follows:

  Thermal conductance by ventilation

  The entire volume of the building was calculated to be 383.1cubic meters. Therefore,

  Thermal conductance = 383.1/2

  =191.1W/K

- The result of that total heat loss through ventilation for one year is shown in table 7.

Thermal conductance by infiltration

Table 3: show building and conversion factor for calculating air leakage rate in accordance with Estonian building code

q50 =	6	$m^3/(hm$
A(area) =	343.9	m^2
X (building factor) =	24	
conversion factor =	3.6	
air density =	1.2	kg/m^3
Specific heat capacity of air=	1000	kg/J.K

The infiltration flow rate was calculated from using Eqn (6) above and results were as follows

$$q_i = 6/(3.6)(24)\ \ (343.9)m^2$$

$$= 23.9L/s$$

And to get the thermal conductance by infiltration eqn(5) was used and the results shown as follows

$$I_c = (23.9)(1.2)(100)(3.6)/3600$$

$$= 28.7W/K$$

Note 3.6 was used to convert L/s to m/s and the value obtained was divided by 3600 to obtain the thermal conductance in one hour.

4.1 Amount of energy gain from solar gains

Table4 shows the conventional ways of obtaining solar gains. (A)(transmission) are the values obtained by multiplying the total individual areas of West, East and South windows by European standard solar transmission value(0.5).

Table 4. Window orientations that are can transmit solar irradiation to the building

Total Area for West windows	12.8	m^2
Total Area for South windows	11.5	m^2
Area of East window	1.98	m^2
A x transmission-West =	6.784	m^2
A x transmission-South =	6.095	m^2
A x transmission-East =	1.0494	m^2

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4.2Annual heat loss through building surfaces, ventilations and infiltration.

The heat losses through windows, doors, floor, roof, walls, ventilation and infiltration for each month were summed. The summarized annual heat loss through these parameters are presented in Table 5 below. These were the total energy loss through the building parameters without taking into account the solar gains. The negative value in the month of July indicates heat gain, that is, the temperature difference between the inside of the building and outside was negative or outside of the building was warmer than the inside as a result heat flew from the outside to the inside of the building. The last column of the table shows total heat loss through all the parameters (windows, doors, floor, roof, walls, ventilation and infiltration) for each month and the last row indicates heat loss through individual parameters.

Table5. How much Monthly and annual heat is lost through building surfaces, ventilation and infiltration when solar gains are not taken into account

Monthly	Infiltration(kWh)	Ventilation(kWh)	walls(kWh)	windows(kWh)	roof(kWh)	doors(kWh)	Totals(kWh)
Jan	**719.04**	**432.18**	**578.74**	**177.13**	**295.83**	**63.14**	**2266.06**
Feb	**529.99**	**318.55**	**426.58**	**130.56**	**218.06**	**46.54**	**1670.28**
Mar	**454.15**	**272.97**	**365.54**	**111.88**	**186.85**	**39.88**	**1431.27**
Apr	**280.77**	**168.76**	**225.99**	**69.17**	**115.52**	**24.65**	**884.86**
May	**153.44**	**92.22**	**123.5**	**37.80**	**63.13**	**13.47**	**483.56**
Jun	**103.78**	**62.38**	**83.53**	**25.56**	**42.70**	**9.11**	**327.06**
Jul	**-60.65**	**-36.45**	**-48.81**	**-14.94**	**-24.95**	**-5.33**	**-191.13**
Aug	**48**	**28.85**	**38.63**	**11.82**	**19.75**	**4.21**	**151.26**
Sep	**180.71**	**108.62**	**145.45**	**44.52**	**74.35**	**15.87**	**569.52**
Oct	**327.92**	**197.1**	**263.94**	**80.78**	**134.92**	**28.79**	**1033.45**
Nov	**406.47**	**244.31**	**327.16**	**100.13**	**167.23**	**35.69**	**1280.99**
Dec	**597.52**	**359.14**	**480.93**	**147.19**	**245.84**	**52.46**	**1883.08**
Totals	**3741.15**	**2248.6**	**3011.17**	**921.6**	**1539.22**	**328.49**	**11790.26**

4.2.1Overall energy loss

The total heat loss was calculated only for winter time when the outside temperature is lower than the inside of the building. This was done by summing the overall heat losses during winter periods after subtracting the solar gains. The sum total for the winter periods in Estonian January to 15th May and from 15th October to December were analyzed and the results shown in the table 6. Also the heat gain was analyzed for summer months June, July, August and September however, this is not shown in Table6 because the purpose of this study was to examine how much of this energy demand can be covered by our system.

Table6. Overall monthly and annual energy loss when the solar gains of the building are taken into account

Annual energy loss (winter periods)	
Months	**Energy loss(kWh)**
Jan	**3119.6**
Feb	**2285.0**
Mar	**1524**
Apr	**456.6**
Sep	**299.6**
Oct	**1008.8**
Nov	**1796.3**
Dec	**2814.3**
Totals	**13304**

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4.2.2Daily heat demand and production

The daily heat demand of the building as well as the daily heat production of the system were analyzed for each hour of each day for one year. This analysis was also done for a difference of three days in both cases and represented in figure 6 and 8below. The graph shows ratio of heat energy produced by the PVT system over the heat demand of the building. On the X-axis lies heat demand and on the Y- axis energy production. The slope of the curve shows that the photovoltaics thermal system is only useful when there is high energy demand by the building. Lower energy demand indicates maximum energy production which is not used by the building and as the energy demand of the system start increasing the useful energy produced by the system starts falling until levels off.

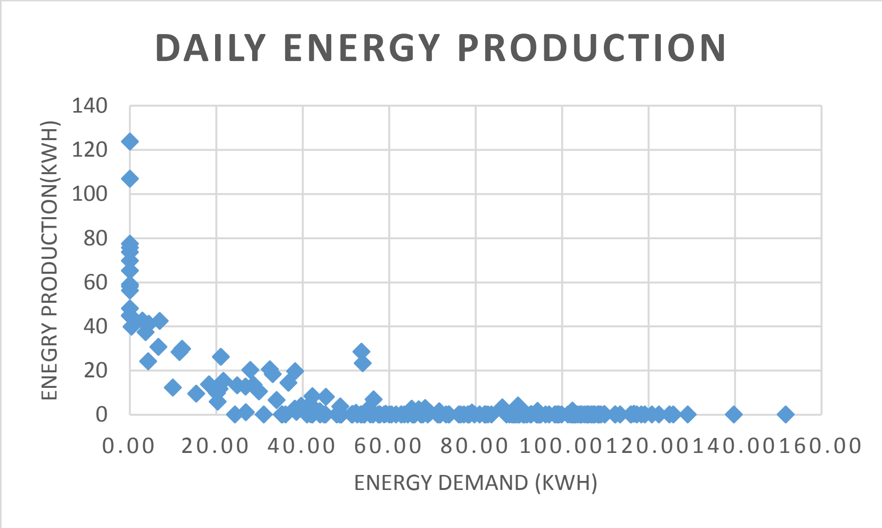

Figure6. The relationship between energy demand and production as shown by the slope indicates that the productivity of the system decreases at high energy demand

The heat demand ratio were calculted as follows

Annual heat demand of the system= 13670 (kWh)

Annual useful heat production =408 (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system)(100)

= (13670)(408) (100)

=2.98%

We tried to handle the issue of high energy production on low energy demand days of the building by analysng the data after three days. The main idea was to save energy within three days interval to balance up the energy demand state of the building. That is, to take advantage of the heat capacity of the building. Precisely heat production for three days were summed as well as the heat demand, therefore the amount of heat needed by the building within this interval was already determined by comparing these values. In other words the system could produce energy and the building temperature was already lets say 21^{o}C so to save this energy we still heat the house with heat from the system up to about 25^{o}C which is still normal. This energy is saved in the building fabrics and redistributed within other days as temperatues fall. Summing heat energy demand and production for three days will already determine how much will be needed or redistributed within ths interval. By this way we had saved energy without using any storage dervice. The results of this procedure were fascinating and the heat demand ratio of the system was imrpoved from 2.98% to 4.79%

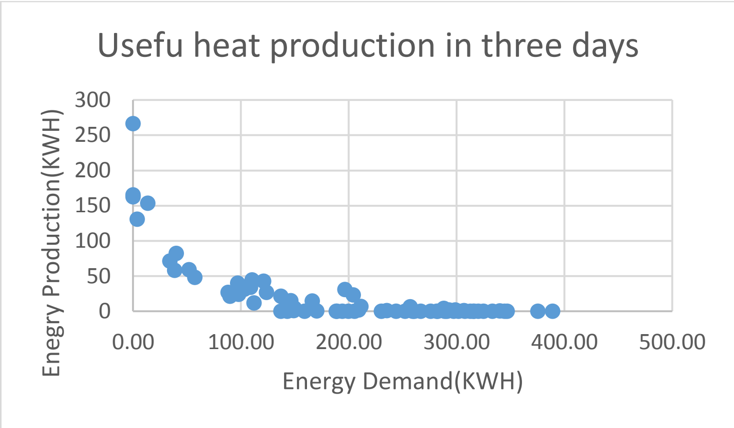

Figure7. An increase in energy production from 407.9 to 651.7 as a result of a difference in three days interval.

The heat demand ratio were calculted as follows

Annual heat demand of the system= 13592(kWh)

Annual useful heat production =651.7 (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system)(100)

= (13592)(651.69) (100)

=4.8%

4.2.3Results showing the efffect of the system on the electrical effeciancy

In addition the electrical output was estimated. The solar panel surface average temperatures and PV cell efficiency were assess. At room temperature (21 °C), the PV cell efficiencies was 13.7% and under the irradiations of 1000W/m2. Without air flow, the efficiencies decrease as the temperature increases. The highest average temperatures recorded for the PV cell was 55 to 60°C with the irradiations of 1000 W/m2. At these temperatures, the PV electric energy production decrease from 76kWh to 74kWh. When air flow was introduced, the PV elements were rapidly cooled to a stabilized temperature of 32 °C to 38 °C and the PV cell efficiencies was recovered. These results are very encouraging and demonstrate that PV efficiency can be increased by employing the design's air-cooled cogeneration panel system.

4.3 System modifications

4.3.1 Effect of change in angle of inclination.

In order to select which angle was best for our system performance, the system was inclined at 20, 55, and 90 degrees. The energy production at these orientation were evaluated and presented on the Figure 8 below.

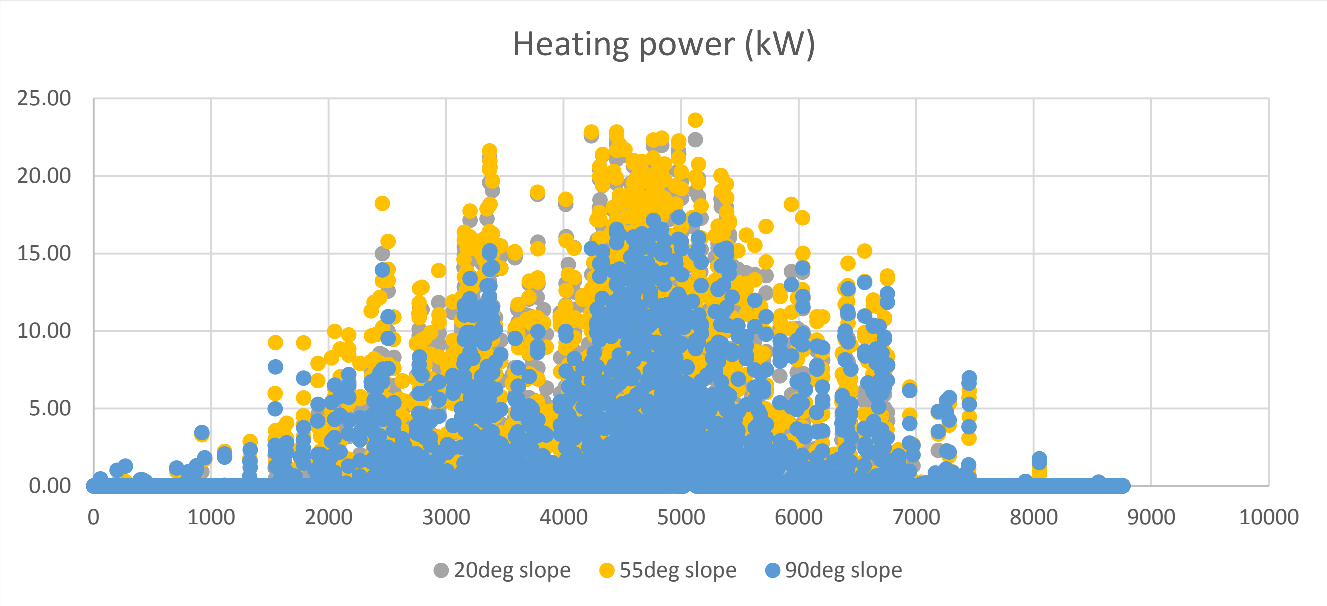

Figure8. Effect of change in angle of inclination on energy production with 55 degree indicting the best angle to be used (see yellow dots). Slope at angle 20degree shows poor power production (grey dots).

As shown in the graph the x- axis represent time in hours and the y- axis heat production. The grey dots are for 20degree sloping while yellow and blue are for 55 and 90degrees respectively. At the beginning of the year in January which are heating demand periods, the system slopping at 90degree is prominent. However as the days continue ahead, heat production of the system are more if the angle is inclined at 55 degrees this is shown on the graph above by the yellow dots. This high levels of production at this angle continues throughout the whole year hence the reason why this research was designed at this angle. Low energy production throughout the year were observed for 20 degree slope as shown by the grey dots.

4.3.2 AEROC ECOTERM 375mm aerated concrete block wall

The wall thickness were modified to 375mm with thermal conductivity of 0.19W/m2K.

The same calculations as done for the 500mm wall thickness were carried out. The results showed that there was an improvement in the heat demand ratio. Because 375mm means the thermal insulation is smaller than that of 500mm wall hence more heat is lost from the building or in other words the heating demand of the building is high. And because our system works in respect to the heating demand of the building, this increases the energy production of the system. The X- axis remains the heat demand and the Y-axis energy production. The slope also decrease as energy demand increases until levels off as in figure 6 and 7 above. The results are shown for daily energy production and three days difference in figure 9 and 10 respectively

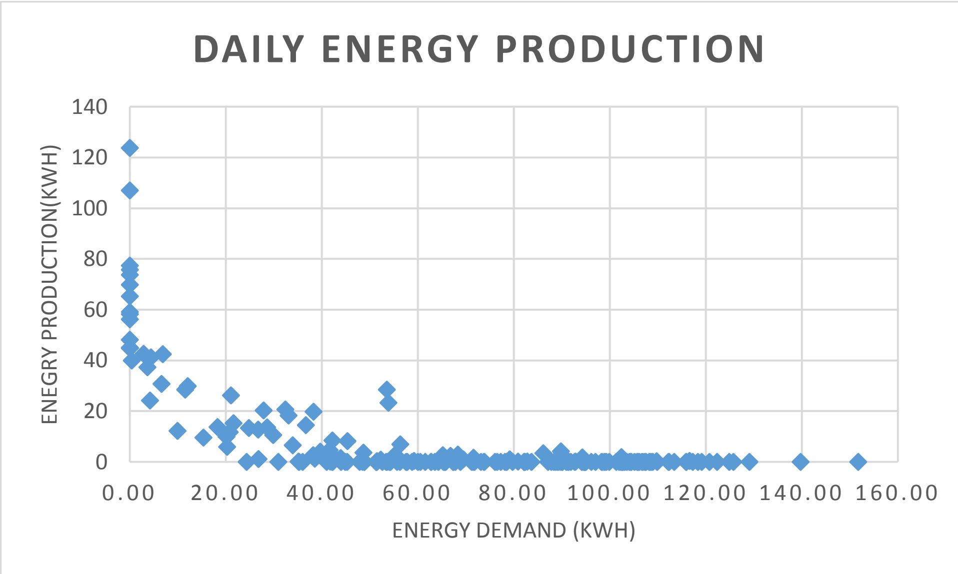

Figure9. Increase in energy prodution as a result of wall thickness modification to 375mm. The trend of energy production remains the same as in figure6 above that is as energy demand gets higher the slope of the curve starts to drop.

The heat demand ratio :

Annual heat demand of the system= 14586 (kWh)

Annual useful heat production =438. (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system) . 100

= (14586).(438) .100

=3%

The change in heat demand ratio was not very significant because of high annual heat demand as compare to 500mm block wall version(13670kWh).

The same system improvement occurs when a difference of three days were considered (Figure 10). However with varied energy demands and production as compared to daily system analysis.

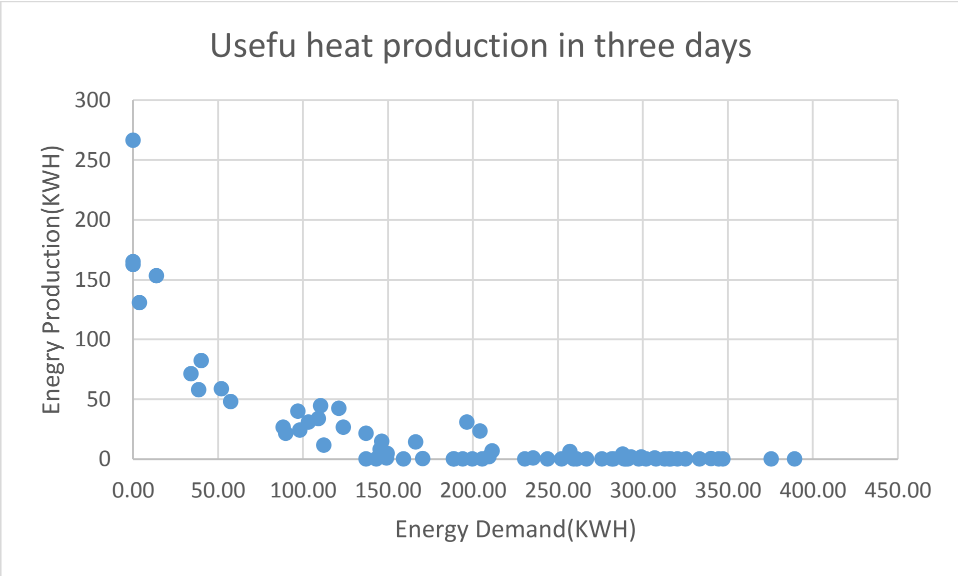

Figure10. Improved heat demand ration after three days interval for 375mm modified version of the building.

The heat demand ratio :

Annual heat demand of the system= 14515 (kWh)

Annual useful heat production =695.96 (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system) (100)

= (14515)(695.96)(100)

=4.79%

4.3.3 The reduction of windows by half, a quarter and by zero in the South

The windows were reduced in size and number by the half, a quarter and zero in the south orientation. And for every reduction there was an increase in system performance base on the same reason as thus. Decreasing window sizes leads to a reduction in the solar gains by the building, and a reduction in solar gains results in high increased heat demand of the building which relatively enhances the system production.

Reducing the numbers/size of windows in the south orientation by half improved the energy production from 651.69 to 877.97kWh.

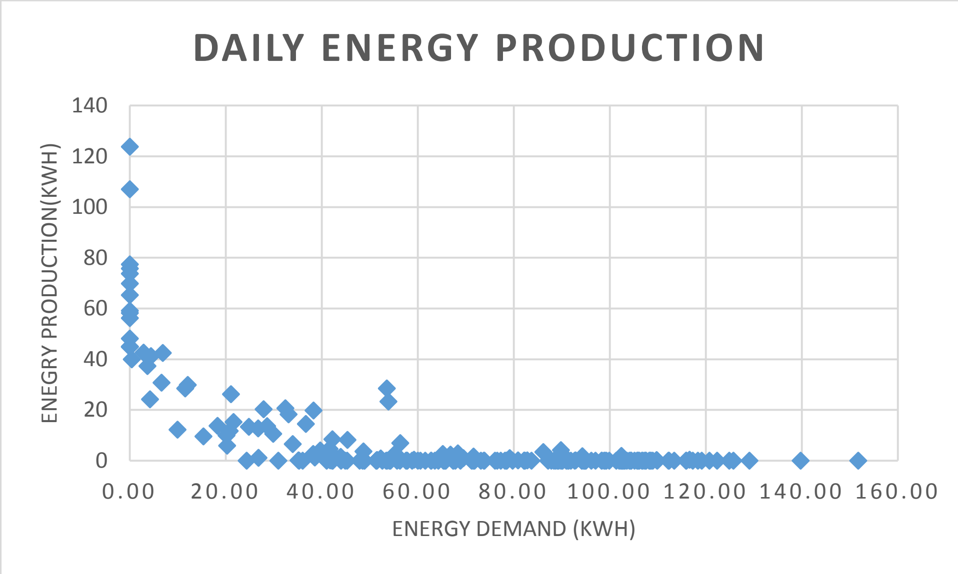

Figure 11. Increase in heat demand ration of the 500mm block wall when the south windows are halved.

The heat demand ratio :

Annual heat demand of the system= 14442 (kWh)

Annual useful heat production =628.17 (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system) (100)

= (14442)(628.17)(100)

=4.35%

And for the three days the production was significant.

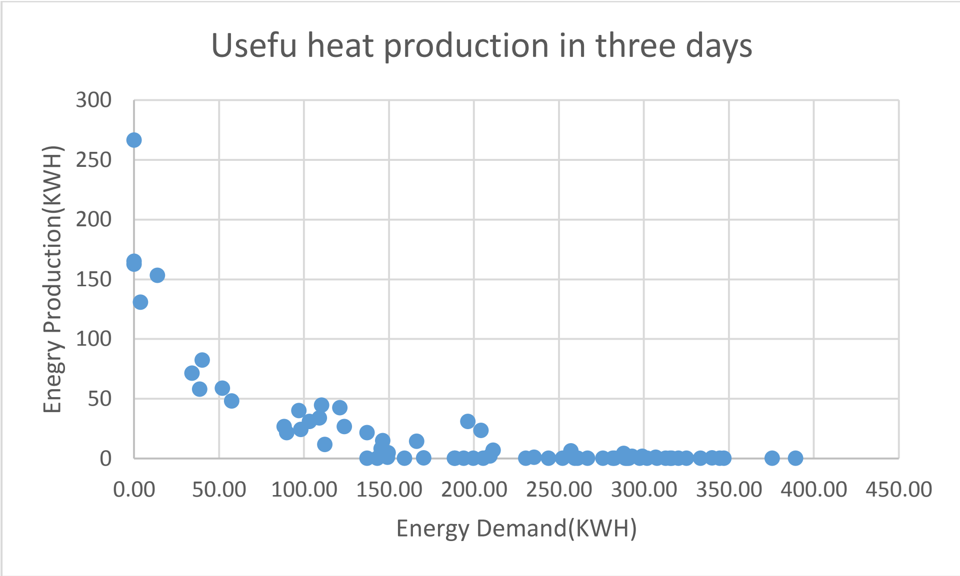

Figure 12. The energy production after three days increases from 628.17 (kWh) to 877.35 (kWh) when the south windows are halved

The heat demand ratio :

Annual heat demand of the system= 144420 (kWh)

Annual useful heat production =877.35 (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system)(100)

= (144420)(877.35)(100)

=6.09%

The results of this analysis for 500mm block show that even a more decrease of window size and number by a factor of 1/2 to a factor 1/4 leads to higher system performance as shown in figure 13.

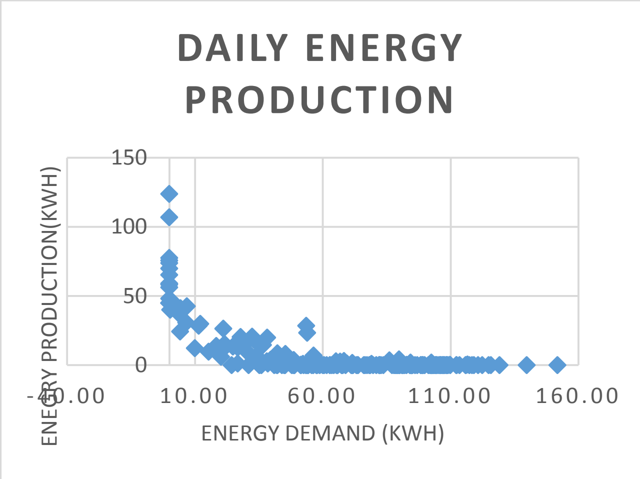

Figure 13. Improved system performance as when the south windows reduced by a quarter

The heat demand ratio :

Annual heat demand of the system= 14865 (KWh)

Annual useful heat production =764.22 (KWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system) X 100

= (14865) (764.22) .100

=5.15%

Decreasing the windows by a quarter led to an increased in system perfromance and the data are analyzed after three days the heat demand ratio increased from 5.14 to 6.65% as shown in figure 14.

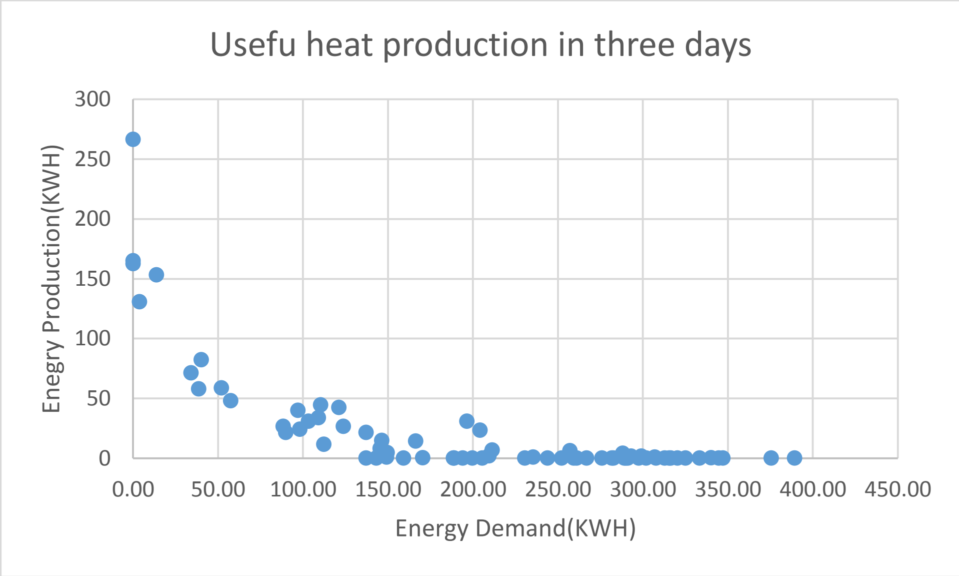

Figure 14. An increase in energy production after three days when the south windows are reduced by a quarter

The heat demand ratio :

Annual heat demand of the system= 14853(kWh)

Annual useful heat production =988.35 (kWh)

Percentage of heat demand covered by the system = (Annual useful heat production)/ (Annual heat demand of the system)(100)

= (14853)(988.35)(100)

=6.65%

4.3.4Maximum system production

Maximum system performance was attained at totaly zero windows in all directions(South, East, West and the North). This was to set the design variable based on the econimics for future model (Figure15,). A maximum value of 1110.89kWh was obtained

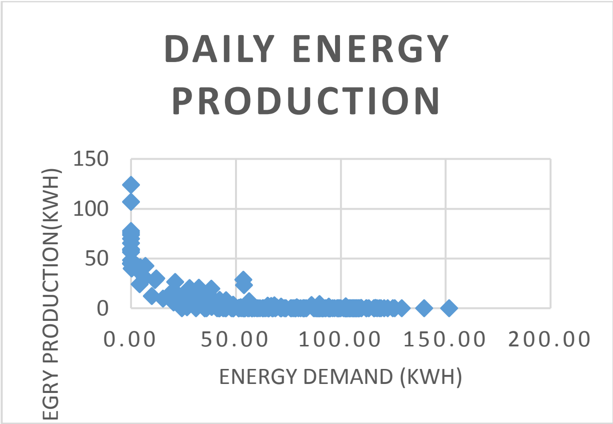

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Figure 15. Increase in energy production when there are absolutely no windows in all direction

And for the three days difference the results were as follows;

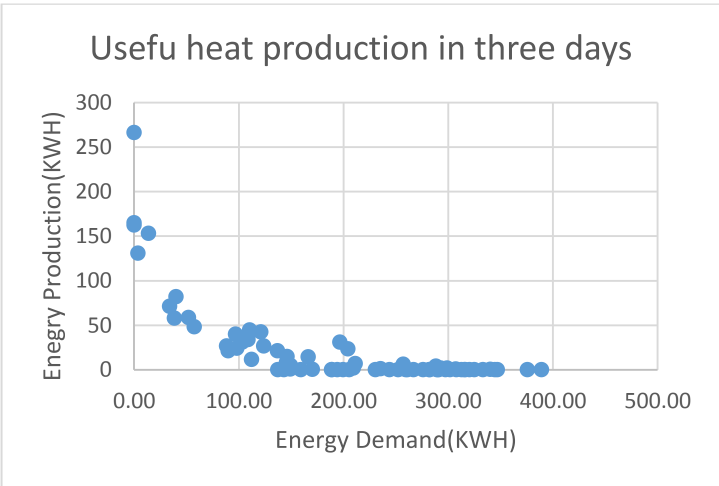

Figure 16. Maximum energy production at absolute zero windows in all direction

4.3.5 System dependence on solar gains

The effect of solar gains were asses by reducing the window sizes of the south orientation by half, a quarter and by zero for the 500mm block and 375mm block wall building version. The results showed that the production of energy by the system increases with decreasing solar gains as result of reduced window sizes. This implies that the bigger the size of South windows the more solar irradiation transmitted into the building and hence the building passively heated. Therefore little or no dependence on the system for energy demand. The maximum energy production was achieved at totally zero windows in all direction. The results and summary of these analysis are presented in the Table6 below.

Table6. A decrease in energy production as a result of an increase in on solar gains

Building version	Energy demand	Energy production	Solar gains	Efficiency
kwh	kWh	kWh	kWh	%
500mm wall thickness	13670	408	7678.1	2.9
500mm wall thickness half windows	14442	628.2	4895.7	4.4
500mm wall thickness a quarter windows	14865	764.2	3497.7	5.1
500mm wall thickness zero windows in the south	15286	881.9	2109.1	5.8
Total zero windows	**15472**	**1047**	**0**	**6.8**
375mm wall thickness	14586	438	7678.1	3.0
375mm wall thickness half windows	15410	672.8	4895.7	4.4
375mm wall thickness a quarter windows	15226	803.9	3497.7	5.3
375mm wall thickness zero window to the south	16288	917.3	2109.1	5.6
Total zero windows	**16704**	**1077.4**	**0**	**6.5**

At full windows in the south for 500mm block wall version , the percentage of heat demand covered by our system was 2.9% and when the windows were reduced by half, a quarter and zero in the south, the heat demand ratios increased to 4.4, 5.1 and 5.8% respectively showing an inverse relationship with solar gains. Therefore thermal photovoltaics system is only useful at low solar gains as a result best for winter periods. This inverse relationship is shown graphically in the Figure17 below.

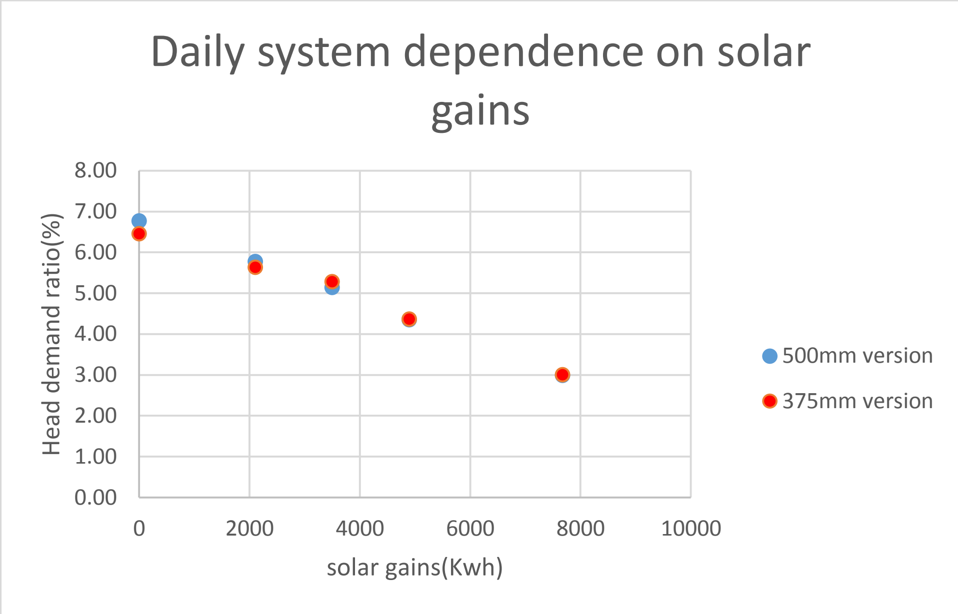

Figure17. Linear decrease in heat demand ratio of the system with respect to increase in solar gains.

Modifying the system for an interval of three days showed the same results; an inverse dependence of the system on solar gains. However with a small reduction as energy production and energy demand ratio of the system in three days intervals are higher compare to daily production.

Table7. The amount of energy production increases after three days but still decreases will increasing solar gains.

Building version	Energy demand	Energy production	Solar gains	Efficiency
kwh	kwh	kwh	kwh	%
500mm wall thickness	13592	651.69	7678.05	4.79
500mm wall thickness half windows	14420	877.97	4895.7	6.09
500mm wall thickness a quarter windows	14853	988.35	3497.67	6.65
500mm wall thickness zero windows in the south	15281	1081	2109.06	7.07
Total zero windows	15470	1221	0	7.89
375mm wall thickness	14515	695.96	7678.05	4.79
375mm wall thickness half windows	1539	919.51	4895.7	5.97
375mm wall thickness a quarter windows	15247	912.49	3497.67	5.98
375mm wall thickness zero window to the south	16284	1110.89	2109.06	6.82
Total zero windows	16702	1253	0	7.50

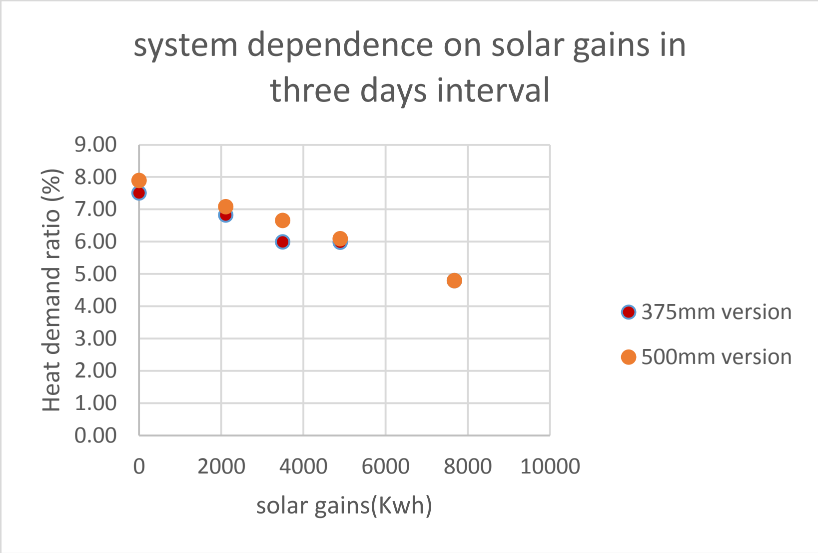

Figure 18. Linear decrease in heat demand ratio of the system with respect to increase in solar gains is higher after three days.

4.3.6 Energy demand dependence on global horizontal irradiance

Solar energy production is directly correlated to the amount of radiation received at a project location. Like all weather-driven renewable resources, solar radiation varies rapidly over time and space and understanding this variability is crucial in determining the financial viability of a solar energy project. The three components of irradiance most critical for determining solar installation production values are Global Horizontal Irradiance, Direct Normal Irradiance, and Diffuse Irradiance. Fixed panel photovoltaic installations are dependent on Global Horizontal Irradiance or the total amount of radiation received by a horizontal surface. For this reason we investigated the relationship between energy demand of the building and the global horizontal irradiance. The results showed that at lower Global Horizontal Irradiance, the heat demand of the building is high and falls as the Global Horizontal Irradiance increases. This is true as an increase in horizontal irradiance results to enough illumination of the building through solar gains hence it does not require extra heating. This dependency was carried out on daily basis and for three days as shown in Figure 20.

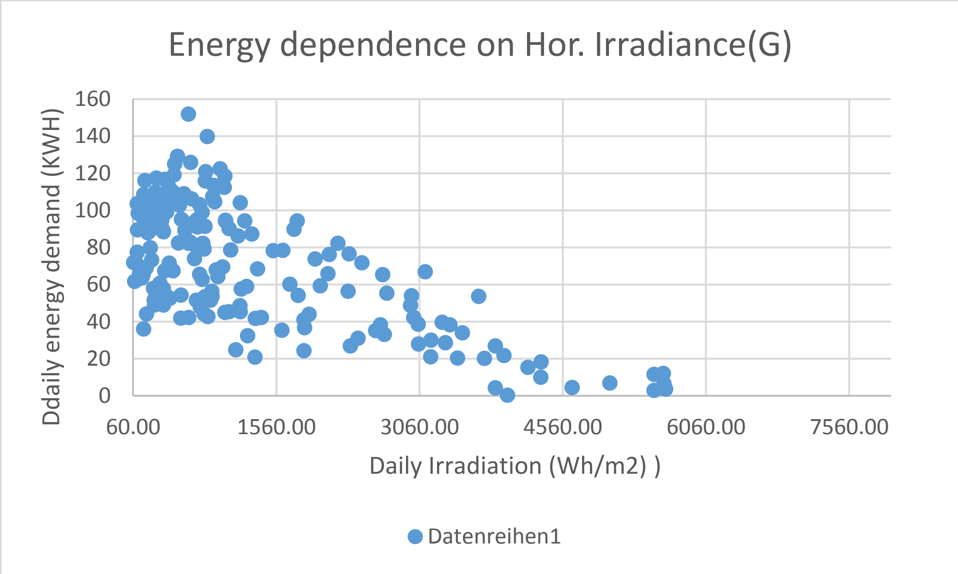

Figure 19. The decrease in Energy demand as global horizontal irradiance increases.

After three days the effect of Global Horizontal Irradiance on energy demand increases comparatively. That is heat demand is much lower at a significantly very little increase in Global Horizontal Irradiance.

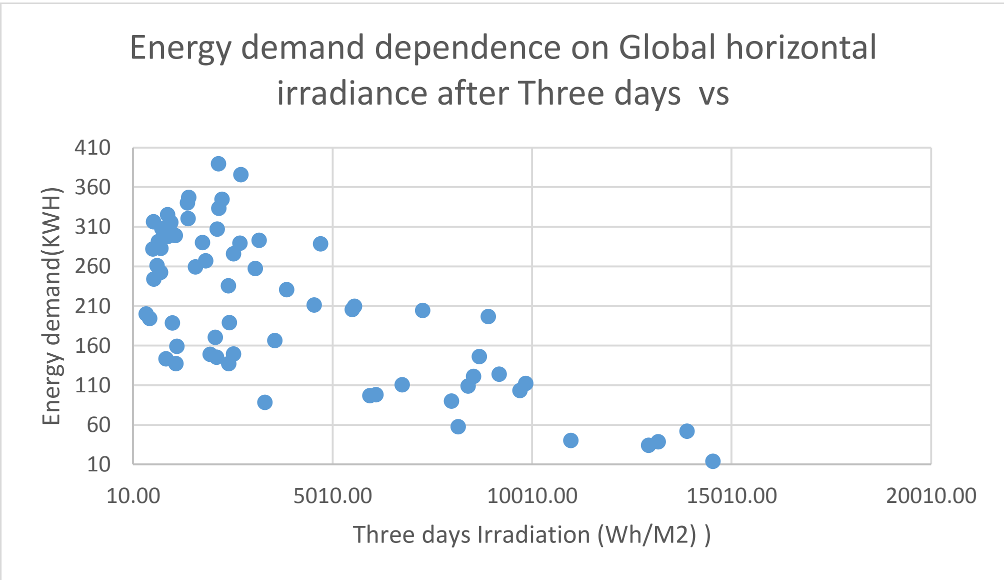

Figure 20.The decrease in Energy demand is high as global horizontal irradiance increases after three days.

4.4 Discussions.

The building used was simulated with defined parameters in accordance with the Estonian Code of building energy performance. This was so that all the statistical data analyzed could be referred to in the future if someone is interested in this kind of system. The energy transmissions or losses of the building were also calculated on the basis of Estonian weather and climate to get the exact analysis for such a system in Estonia. The results of the system performance and amount of energy production were analyzed for a period of one year during the winter periods when heat is required. The system was tested with different building version based on insulation capacities (500mm and 375mm block wall) and there was in increase in amount of energy production by the system from 407.94kWh to 438kWh. This explains, that photovoltaic thermal system is only useful when there is energy demand. That is summer times or high solar gains illuminate the building enough and no extra heating is needed. Furthermore the energy production in three days interval for both block wall thickness (500mm and 375mm thickness), was analyzed and the percentage of heating demand that can be covered by the system increased from 4.5% to 6.1%. The main idea was to explore the internal specific heat capacity of the building. That is, energy could be saved in the building globe and redistributed within the other days. Therefore the sum of energy production and energy demand for these three days will determine the energy usage within this interval. The system dependence on solar gains were also analyzed and proven that the system depends significantly on solar irradiance; when the solar gains are high the building is already heated enough through the structural fabrics like walls and windows, hence does not need heat energy from the photovoltaic thermal system and the reverse occurs when solar gains are low. To prove this we calculated the energy productions by reducing windows sizes by half, a quarter and zero in the south orientation for all the building versions. At totally zero windows in all directions, the maximum energy production was attained and the define economics for future use will be based on this value. However the change in energy demand ratio when the wall size was modified was not very significant compared to the change when the window sizes were reduced. This shows that the system performance is much more dependent on solar gains than wall thickness. Analysis for modified window size in the South direction for 375mm block wall was also carried out and again the results showed an increase in energy production implying the system function depends on the amount of solar gains see Appendix1, 2 and 3.

5. Conclusions

In line with addressing the use of sustainable energy and efficient building energy performance, a designed photovoltaic thermal system can extract the waste heat released by photovoltaic modules which can be used for space heating or even hot water systems in Estonia. The maximum annual energy production realized for this study was 1110.89kWh. If the electrical analysis of this were to be taken into account, these combined outputs from a single system would enhance the total Photovoltaic system performance which was the main goal of this study. The electric production on a particular day was observed to be 74kWh without air flowing behind and when air was allowed to pass behind to extract heat within a short time period, it increased to 76kWh. This imples that the flow of air reduces the operating temperature of the module and hence improves electric productivity. Enhancing the electrical production of the module by producing another form of energy on the other hand brings about a double advantage of the system, which satisfies entirely the main objectives for this study.

This implies an improved efficiency will result to a decrease in the pay back time of the whole installation which is relative to cost. There are however an adequate quantity of beneficial recommendations for more study. Photovoltaic thermal systems require significant extra real-world screening to maximize awarenes about the market. Furthermore, there is an importance for more financial analyses of PV cogeneneration systems. This will likely be necessarily complicated since there are multiple form of energy being produced**.**

Also, optimized instruments that will combine the benefits of PVT alongside thermodynamic evaluation will undoubtedly be needed to assist in process. In addition, the change of the shape of the plat form of the panel (vertical or horizontal orientation) without changing the surface area and the distance between the collector and the panel layer should also be taken into consideration. Finally, study in PV cogeneration techniques may turned out to be optimistic if conversations between specialists from the solar thermal and solar electrical fields are feasible. These experts do not generally coordinate their initiatives. To ensure any large-market scale of solar power systems, there will have to be extended discussions between these parties.

Abstract

A photovoltaic (PV) system generates heat that is typically wasted and leads to energy inefficiency of the systems. The extraction of this energy using heat exchangers (air) could provide a solution to his problem, hence a form of cogeneration system. However the ability to respond rapidly to the growth of this type of technology with respect to quality and efficiency is still an issue to be addressed. The main goal of this study was to investigate how much heat energy can be extracted for a period of one year from a photovoltaics system using different modified techniques. Heat flow from the modules can be achieved through radiation, conduction, or convection. These processes were explored using heat collector (air), measuring the annual energy production by the system and quantifying the building energy demand in relation to this annual production. It was found that up to 1110.89 kWh heat energy could be harnessed by extracting this energy using airflow behind photovoltaics cells. These findings offer an awareness into the energy savings which are possible with a well-designed building integrated photovoltaic (BIPV) system. The benefits of employing heat exchangers to utilize the thermal energy generated by the photovoltaic modules can be useful in many residential buildings.

Furthermore, eliminating the high temperature from the PV cells also decreases thermal stresses as well as improves the electric productivity of the PV system.

Résumé.
Suur osa päikesekiirgusest, mis neeldub päikesepaneeli struktuuris, läheb paneeli soojendamiseks, mis omakorda vähendab süsteemi efektiivsust. Kasutades ära päikesepaneelide jääksoojust saame suurendada päikeseelektri süsteemi efektiivsust ning vähendada süsteemi tasuvusaega. Käesoleva magistritöö eesmärk oli uurida kuidas saaks ehitisintegreeritud päikesepaneelide abil koos toota nii elektri- kui ka soojusenergiat õhk tüüpi soojusülekande abil, kasutades ära päikesepaneelide jääksoojust. Töö raames viisime läbi simulatsiooni, mille tulemusena selgitasime välja, kui palju ehitisintegreeritud päikesepaneelide poolt toodetud soojusenergiast saaks kasutada eramu kütteks ühe aastase perioodi jooksul Eesti kliimas. Simulatsiooni tulemused näitasid, et õhkjahutusega 11kW päikeseelektri süsteemi abil saab toota ca. 1110 kWh soojusenergiat, mida saaks kasutada otseseks eluruumide kütmiseks kütteperioodil. Simulatsioonis kasutatud testhoone puhul moodustab see kuni 8% vajaminevast soojusenergiast. Jääksoojuse kasutamisega alanes päikesepaneelide temperatuur, mis omakorda suurendas süsteemi elektrilist efektiivsust

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APPENDIX 1

Energy production at absolutely zero windows for 375mm wall

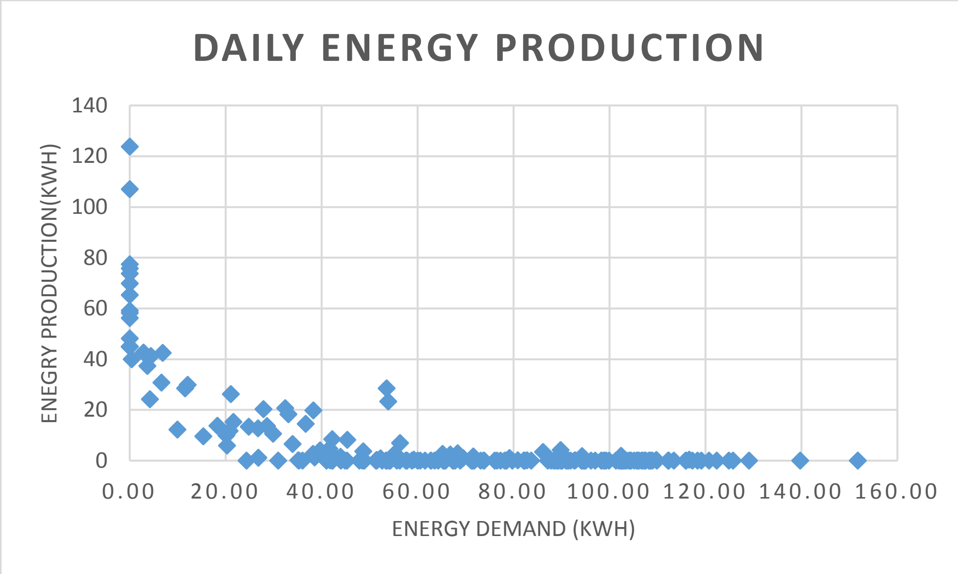

Figure1. Absolute Zero window in the for 375mm block wall version of the building

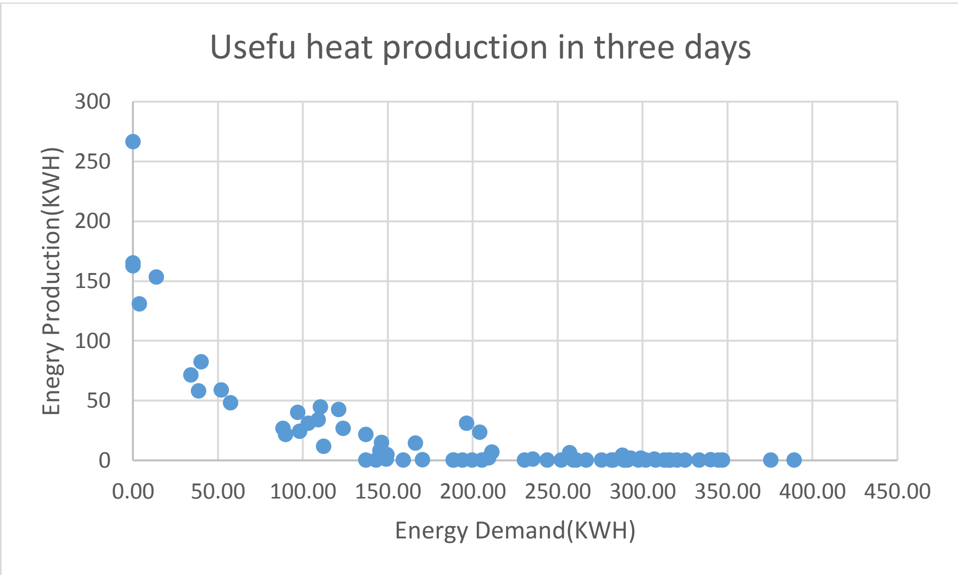

Figure2. After three days the amount of energy production increases.

APPENDIX 2

Energy production when the windows are reduced to a quarter for 375mm block wall

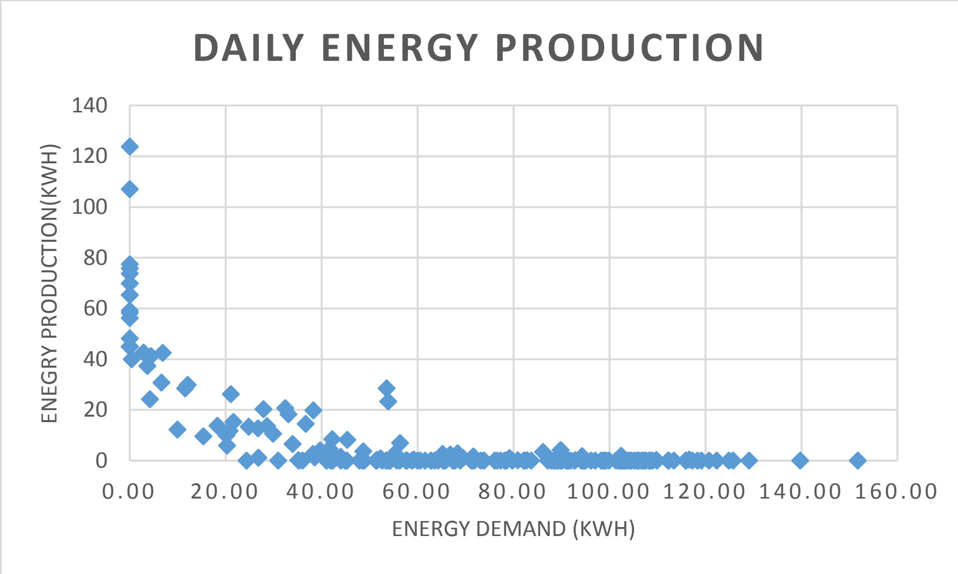

Figure3. Daily energy production when the windows of 375mm wall are reduced to a quarter.

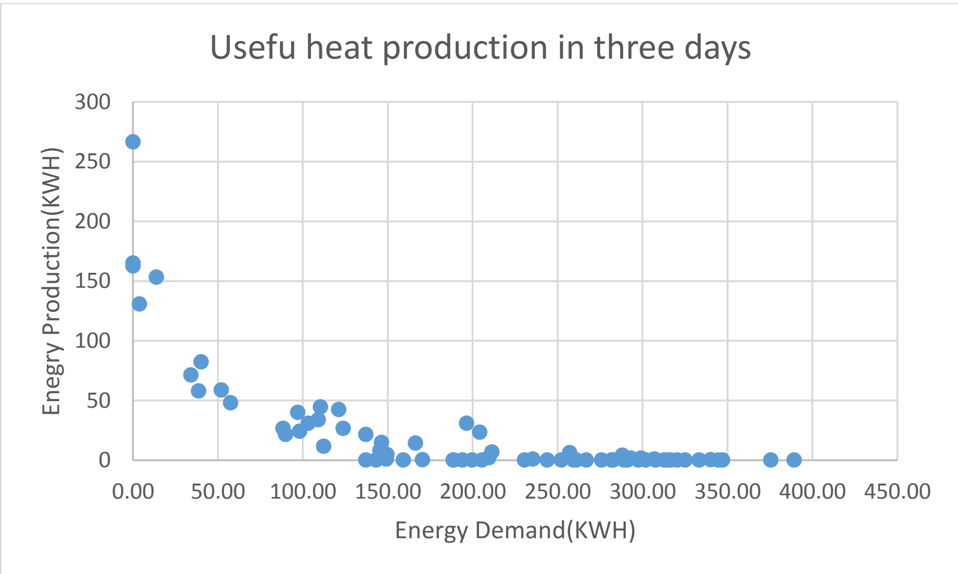

Figure 4. The system production also increases as in other cases when energy production are analyzed for three days interval

APPENDIX 3

Energy production when the windows are reduced to half for 375mm block wall

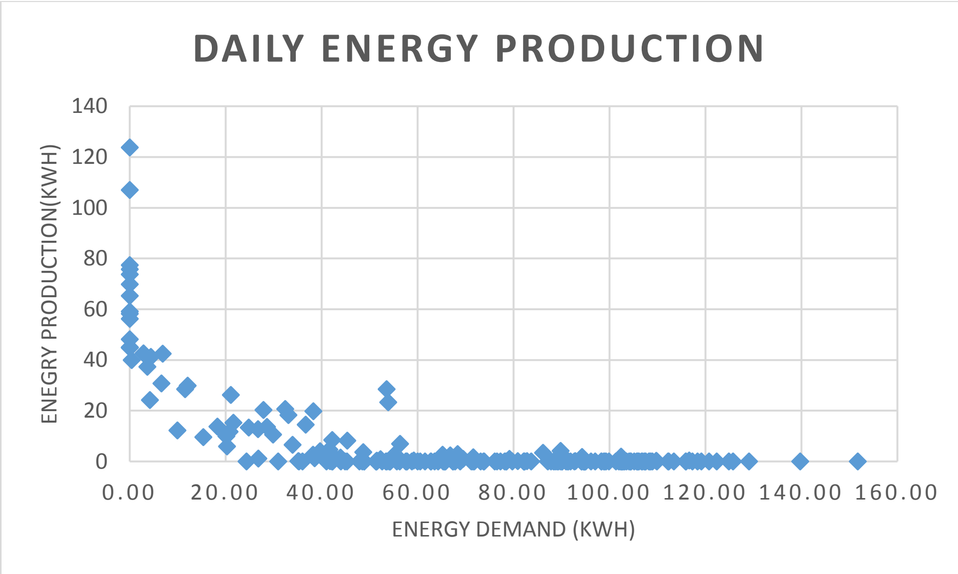

Figure 5. Daily energy production when the South windows of 375mm wall thickness building are halved.

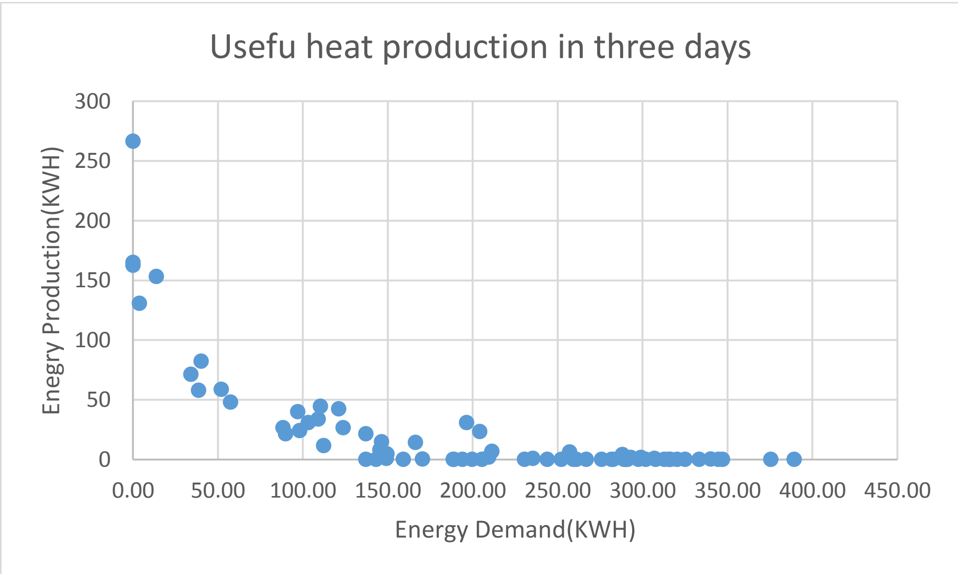

Figure 6. Energy production after three days for halved South windows