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Comparison of Solar PV vs Solar Thermal Hot Water Systems to Provide Energy Solutions for Strata Buildings

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EXECUTIVE SUMMARY

The paper looks at the implementation of solar energy on residential apartment buildings. The aim of the study was to aid Wattblock in providing energy solution for Strata buildings. Reviews of solar photovoltaic (PV) technology, solar thermal energy systems, and a hybrid photovoltaic thermal (PVT) system were conducted. The main objective was to conduct a tech-economic evaluation of solar PV and solar water heater (SWH) systems, and identify the best technology suitable for Strata Residential buildings. Strata buildings have limited roofing space so a case study of one of the building with 200m^2 roof space was used for the study. RETScreen simulating tool was used to design an energy model to enable evaluation of the technical, environmental and economic performance of both PV and SWH.

Technical Results showed that a 35kW PV system will occupy 180m^2 and generate 57MWh electrical energy while a 35kW SWH system will occupying 87m^2 and generate 27MWh thermal energy. The total energy demand of building is 77MWh with 18MWh for water heating.

Environmental results showed a greenhouse gas reduction of 54.2 tCO2 and 25.3 tCO2 for PV and SWH respectively. The economic analyses showed more evidently that PV system is more feasible than SWH. With the same initial cost of $63,360 for both projects, the financial variables of a PV system were: an annual saving of $19,171, $585721 NPV, 29% IRR and a payback period of 3.9years. The SWH system showed the following values: an annual saving of $28,989, $239,558NPV, 14.9%IRR and a payback of 8.4years.

Based on the technical, environmental, and economic analysis, it was concluded that both technologies would be feasible but the solar photovoltaic system should be the ideal project to be considered for most limited roofing space of Strata buildings.

The paper also recommended the consideration of using PV system as the energy source for heating the hot water system of the building and the excess energy fed to load, particular the common areas. The paper also suggested that Wattblock consider Hybrid solar photovoltaic/thermal (PVT) systems as an energy solution for Strata buildings even though it is still at a testing phase.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

Currently, the world faced is with Energy and Environmental issues, with more than 80% of the global energy being produced from fossil fuel. This fossil fuel is a limited source of energy and a major contributor to climate change and global warming. The global action is to find a more efficient and cleaner way of using energy[1].

The Strata system was introduced to Australia in 1961 and its purpose was to handle the legal ownership of portions of residential apartments. Strata residential buildings are mostly high rise buildings with indoor pools and require an alternative to the resident's high power consumption[2]. Strata buildings have limited roofing space and it is important to find the right energy generation technology to suit the space. Wattblock is an Energy Efficient company and is currently focused on finding solutions to aid in the reduction of the energy bills of Strata buildings. Wattblock conducts Energy Audits for the common areas of the buildings which are supplemented with various energy saving proposals and implementations such as renewable energies and lighting solutions.

Solar Energy Systems for domestic as well as for commercial use have extensively increased from a couple of years. Various technological innovations have been carried out in this field to extract the maximum source of energy from the implemented solar system. The main reason behind increased use of solar energy for domestic and commercial purpose is because sun is the renewable energy source and is inexhaustible [3]. Also, the value benefits provided by solar energy are wide in range. Many people are shifting their focus to harness energy from solar and have led to several innovative products available in markets. Australian governments as well have passed various rules and regulations and policies to implement solar energy devices in commercial as well as domestic areas. Statistics acquired as per 2011 show that the solar technology has managed to produce about one tenth of the total global energy demand [4].

Solar energy conversion comes in two dimensions; the first is Photovoltaic, or PV energy conversion, where the sunlight is directly converted to electricity using solar panels. The second is a solar thermal electric generation, which uses concentrators to convert sunlight to heat. This heat runs engines that turn generators to produce electricity. The main application of solar thermal generation in residential buildings is for domestic water heating and 95% of all glazed installed collectors are used for these purposes [5]. To provide evidence on the demands and sustainability of residential buildings, several demonstrations were made in Vienna, Austria, where domestic water and building heating systems are specifically designed to support different sources, namely thermal, photovoltaic, and hybrid solar collectors, as well as long-term ground storage [6]. Solar thermal is applicable everywhere; for example, the Thermosiphon system using natural convection can be used without access to electricity. Solar thermal energy provides cost benefits and stability as compared to other water heating technologies[7]. Just like any other source of energy, even the solar energy has certain disadvantages or pitfalls. Few of its disadvantages are that the solar energy does not work efficiently at night time without any kind of storage device such as battery and also the solar power is sometimes unreliable even during day time (due to cloudy weather conditions). Also technologies associated with solar power are quite expensive when compared to other sources of energy [8].

The presence of Energy Storage Systems is a driver for both self-production and self-consumption of energy but, due to the discontinuity of solar radiance, heat storage has become essential in solar thermal energy based systems. A study of modeling the temperature of a tank and heat loss has been done [9].

The thesis research has a focus to understand and analyze various aspects of two most important and widely adopted solar energy systems (Solar PV and Solar Thermal Water Heating System) and then conduct a comparison of their performance and economic valuation in order to suggest the best solution for residential rooftop applications. Various information was acquired for the thesis research and methodologies in order to arrive at the best possible solution for the Strata residential rooftop applications. Some of the information includes consideration of high-rise buildings located in Queensland, Australia. Some of the other technical / dimensional considerations for the thesis research are defined as follows:

a. Roof space = 200 m^2
b. Number of rooms in a building = 35 to 40 rooms
c. Annual energy consumption = 77 MWh (Mega – Watt hour)

1.1 Research Aims and Objectives

1.1.1 Research aims

To conduct a detailed study on the various types of solar energy systems and develop a methodology to analyse various aspects such as performance and economic valuation to make effective and efficient suggestions for residential rooftop applications in Australia. This project should assist Wattblock in making Energy Efficiency proposals for buildings with limited roofing space.

1.1.2 Research objectives

Following are the thesis research objectives:

1. To conduct an in-depth research and analysis on the background of current trends in solar energy systems
2. To study the theoretical aspects of three important solar energy systems, that are Solar PV, Solar Thermal System, Hybrid Solar Thermal Energy System and their related Storage Systems.
3. Identify an appropriate and efficient methodology to conduct comparison on two most commonly used solar energy systems - Solar PV and Solar Thermal Water Heating System.
4. Conduct an analysis and comparison of the above mentioned solar energy systems on three important factors: technical/performance, environmental and economic/financial valuation
5. Considering the dimensional factors such as roof area, rooms capacity of the building and the annual energy consumption, an appropriate type of solar energy system is to be proposed.

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2 LITERATURE REVIEW

2.1 Global Warming

Human culture has required the exploitation of energy resources. One of the key moment in our evolution is the harnessing of energy in wood made of hydrocarbon molecules to produce fire and then evolution shifted from technologies such as wind and water to fossil fuels [10]. Fossil fuel is formed from decayed plants and animals that have been converted to crude oil, natural gas, and coal by exposure to heat and pressure in the earth's crust over millions of years [11]. The interest of coal in European countries started after World War II with the formation of institutions such as Coal and Steel Community. It was pointed out as a less valuable but very important source of energy [10]. The United States of America is the leading consumer of petroleum and New Eastern Economies like China and India have dramatically risen in the demands for oil more recently [10]. The rapid growth the world's electrical energy demand and this has paralleled the generation and emission of CO_2 into the environment [12].

Comprehensive studies show that the carbon footprint of fossil fuel electrical energy production, distribution, and transmission, varies from 321 g CO2 eq/kWh to 980 g CO2 equivalent /kWh [11]. [13] conducted an investigation to prove long run of equilibrium between relationships of electricity prices and fuel prices in the industry sector. It has become imperative agenda to solve issues associated with fossil fuels because a large amount of carbon dioxide (CO_2) is released into the environment during the combusting process and fossil fuel (CO_2) emissions are a major contributor to global warming and climate change. [1].

The sun's energy is the major driver of earth’s climate and the atmosphere absorbs the solar radiations from it to reduce extreme temperature conditions during the day and night times [1] [14]. The presence of CO_2 or any other greenhouse gas from fossil fuel combustion due to the development and utilizations technologies will reduce this abortion from the sun and this changes the natural other of our climate. Climate change is the change of normal weather pattern,[15]. Australia currently has the highest per capita greenhouse emission in the industrialized world due to being a major producer and consumer of coal [16]. Even with scientific evidence many still doubt fossil fuel and its related greenhouse gases are the cause of global warming but studies have shown it is and research has shown that countries like Australia can reduce its current CO2 emission by the year 2040, using existing and improved Renewable Energy technologies. [16, 17].

Fig 2.1. Below shows the CO_2 emissions in Australia from 1990-2002

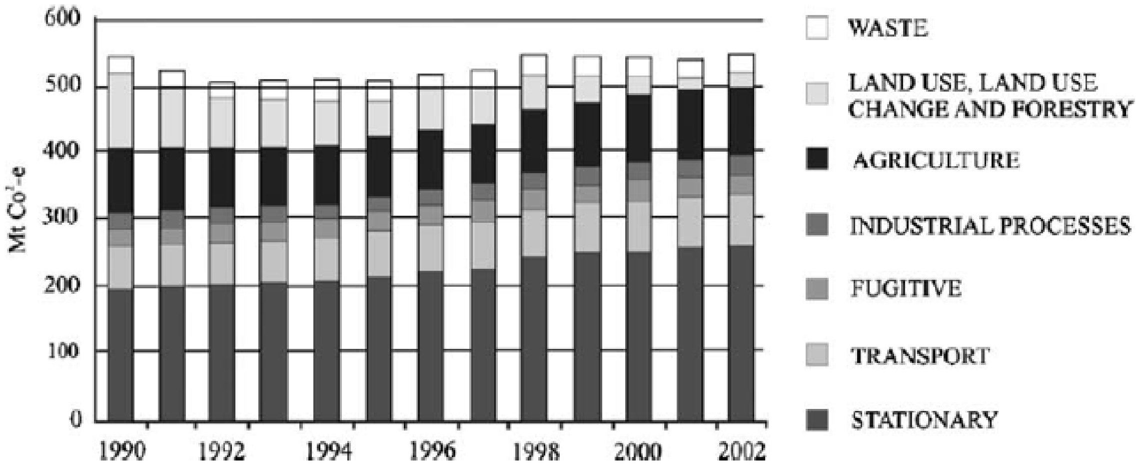

Fig 2.1 Trends in Co2 emission in Australia by different sectors from 1990-2002. [18]

2.2 Renewable Energies

Renewable Energies are the source of energies that are continuously restored by natural processes within a relatively short period of time. All Renewable energies (Hydro, wind, solar, Biofuels, geothermal wave and tidal powers) are in abundant supply and are environmentally clean. [19]. Renewable energies are very important because fossil fuel energy is limited and their application increases the diversity of energy supplies. The security of energy supplies is a major concern to many nations and case study by UN IPCC reported a 50% global energy supply by renewable energy in the year 2050 [14]. The most important energy demand in residential buildings is Electricity and with regards to finding a solution to this problem, International Energy Agency (IEA) estimates about 27% mix scenario renewable energy and 17% solar energy systems would solve global electricity demand in 2050. [20].

Solar electricity generations use PV devices (crystalline or amorphous Si, CdTe and copper indium gallium selenide) that convert sunlight directly into electricity. Another type of solar energy application is solar thermal, where fluid injected through a pipe transfers solar heat and the steam produced runs a turbo-generator like a conventional steam power plant. [14].

Wind energy is another type of renewable energy and an indirect form of solar energy. This is because not all the solar radiation coming from the sun is converted directly to solar energy services required but rather part of it drives the earth wind system and the kinetic energy from the wind is converted to mechanical energy or more commonly this days to our electrical energy through a generator coupled to a variable-speed wind turbine. [21].

Wave Energy explores the energy from the ocean oscillatory motion surface that is induced by the wind and its mechanical energy generated is converted to electrical energy by a wave converter (WEC) [21]. In Geothermal energy, energy is extracted from the thermal energy stored and generated within the earth. Some sources of geothermal energy are hot springs and volcanos [21]. Many countries are now considering solving the problem associated with the negative impacts of fossil fuels on our environment and this has led to lots of research and development of renewable energies systems and the Australian Government has invested 500 and 150 million dollars into Renewable Energy and Energy Innovative Funds $100 million dollar going into Establishing the Australian Solar Institute [22].

2.3 **Solar Energy**

Solar energy is the major renewable energy resource in the world and is the energy obtain from the sun. The sun is an average star that has been burning for more than 4 billion years and expected to remain so another more billion years. It is a giant star and earth revolves around [23]. The earth receives about 3.86 $x10^{20}$ Megawatts of the sun's energy, which is more than billions of times the energy demands of the planet, hence the importance of the adoption of solar energy systems. This energy fills the earth about 1.37 kilowatts per square meter. (KW/m^2) [24]. Unfortunately, not all the arriving sunlight at the top of earth's atmosphere gets down to its surface. Several atmospheric phenomena weaken the radiation coming to the surface and these are (1) Reflection by the atmosphere. (2) Scattering due to molecules and particulate matter (dust and pollutants) in the atmosphere and (3) Absorptions from gases in the atmosphere with major gases such as ozone, water, oxygen, and carbon dioxide[25]. Below is a diagram showing the attenuation of radiant energy to earth.

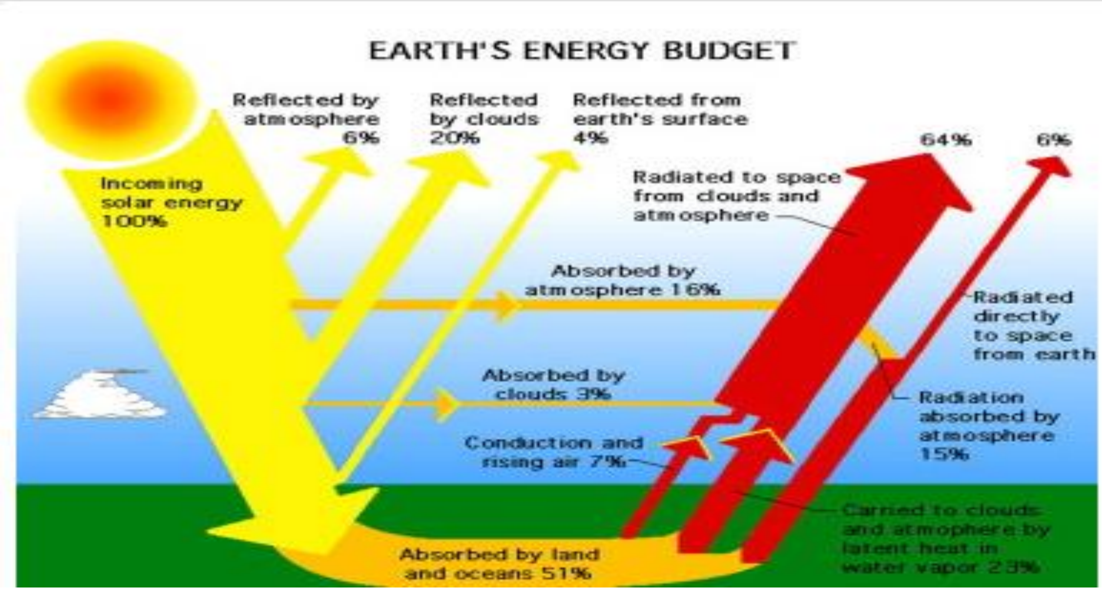

Fig 2.2. Showing attenuations of earth's atmosphere and clouds on the amount of sunlight reaching the surface. Source[26].

Solar radiation can reach the earth surface by direct radiation from the sun but, as can be seen from Fig 2.3 above, some of the sunlight is absorbed and some is scattered by clouds, molecules, and particulates in the atmosphere, hence making global radiation consist of direct radiation and diffuse radiation[27]. As shown from the image above, direct radiations are parallel rays of light coming from the sun; this radiation cast shadows. Diffuse radiations are the radiations with no direction, this is because the radiations are the scattered causing them to arrive at different points and this prevents shadow casting. The proportion of the two radiations is not fixed and it depends on the amount of clouds and dust particles in the atmosphere and the location on the globe [23, 27]. Solar energy provides advantage of reducing transmission lines from grid electricity connections, reclamation of degraded lands, accelerating electricity demands of many rural areas of developing countries, increasing energy independence, and providing diversification and security of energy supply [22].

2.3.1 Solar PV

In 1839, a French physicist discovered a phenomenon responsible for converting light to electricity and this phenomenon was the photoelectric effect. He noticed during an illumination, a voltage appeared on one of his identical electrodes in a weak conduction solution[28]. The study of PVs became popular 19th centuries: first solids such as selenium in the 1870s and then in 1880s selenium photovoltaic cells that were built could convert about 1-2% of light to electricity. The conversion efficiency of Selenium cells was very small, producing relatively small amount of power at relatively high cost, this it was very impractical[29]. The 20th century saw the expansion in the physics of the PV phenomena and 1954 Bell Telephone Laboratories developed the silicon photovoltaic cell which had a conversion efficiency of 4% and over the years increased to 6 % and then 11% efficiencies[29]. This brought a new global era of attention to the power-producing cell such that in 1958 the US Vanguard space satellite used less than one Watt array of solar cells to power its radio. PV cells have been a major contributor to many space missions ever since [28]. Current photovoltaic systems can transform one Kilowatt of solar energy falling on an area of one square meter into about a hundred watt of electricity and mostly this is made from semiconductor materials such as pure silicon [30].

Photovoltaic systems work by converting light energy directly into electricity. This is done by transferring sunlight's photon energy into electrical energy and it takes place in the cells of fabricated semiconductor crystals [22]. The electrical output of a solar photovoltaic system is calculated by multiplying the daily global exposure to the capacity of the photovoltaic system [31].The PV technology has gained widespread acceptance in many communities and many global governmental policies, promoting renewable energy systems, have encouraged its enormous applications [21, 22]. The technology is expected to significantly experience global expansion and an ambitiously IEEE predicts that the energy will supply 11% of global energy demands by the year 2050 [31]. IEE also expects PV power generation systems to generally exceed that of wind electricity power generation. PV systems are commonly made from amorphous thin film silicon and have life span expectancy of 20 years with convention efficiency of 16% [32]. With current global regulations working on solutions to reduce global warming and the global photovoltaic installation is anticipated to exceed 1 terawatt. For example, the United States Department of Energy anticipates that the country should have installed 630GW PV by the year 2050 and China is expected to have 150W installed by 2020 [33]. Rooftop application of solar PV has currently attracted much attention in remote off-rid and grid-connected installation. In the area where cost is not really a concern PV system found to be widely used for space heating application [34]. Recent disasters like the meltdown of the Fukushima Daiichi Nuclear facility in Japan and the country's lack of indigenous energy sources have pushed Japan and other countries to research in Solar PV [21].

Harnessing energy from the sun can be done in various forms but the most popular and widely used method for domestic rooftop electricity generation is the application is the Solar photovoltaic method [31]. Research and development in solar energy started in Australia in the year 1950, with a focus on thermal conversion. Photovoltaic research started later in 1970 with a small of grid system backed by a battery and later it was the technology was applied in residential and commercial buildings. From 1990 to 2013 grid installation in the country expanded from 7MW to 130MW [35]. The table below shows PV installation in Australia (MWh)from 2005-2013

Sub-market	2005	2006	2007	2008	2009	2010	2011	2012	2013
Off-grid residential	20	24	28	33	41	44	55	65	74
Off-grid other	33	37	39	41	43	44	47	53	58
Grid-distributed	7	9	15	30	101	480	1268	2276	3070
Grid-central	0.8	0.8	1	1.3	2.5	4	7	22	24
Total	61	70	82	105	187	571	1377	2415	3225

Table 2.1 Source: [35]

2.3.1.1 Solar Module

Figure 3 shows the typical solar module rated for 20 Volt and 20 Watt. Solar modules are mounted in solar system for providing the energy source to keep the batteries charged completely. The total number of solar modules required for an application depends on the specifics of site such as geographic location in a country, accessibility / availability of the sun and other specific needs of the site such as load demand [36].

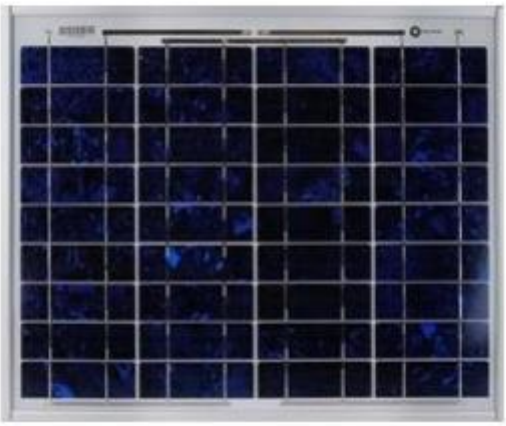

Figure – 2.3. A typical Solar Module [37]

Solar – electric type of modules effectively convert the energy of sun into direct current electricity (DC) which is then converted to AC to be used as by the load [38]. The solar module systems consist of matrix of multi-crystalline or mono-crystalline modules of high performance. The solar modules are attached securely to the pole by making use of adjustable fasteners in order to enable tilt alignment and perfectly match with the latitude at which the installation of module is done and also ensure horizontal adjustments to achieve maximum sun tracking [39]. The transformation of light to electricity by Photovoltaic systems is novel and unique but the efficiency of the modules play vital roles in power generation. Efficiency of commercial PV modules over the last 12 years has increased only about 0.25% and this has led to the conclusion that it the technology will be more efficient if its manufacturing is improved rather than focusing on its module efficiency [33]

The contribution PV provides to climate change is measured by its displacement of non-renewable energy sources during its lifecycle use face compared to the greenhouse gases associated with the manufacturing of the technology. To improve the life cycle of PV, two things should be considered, (1) the efficiency of the PV module must be improved in other to generate more electrical energy during its operation, (2) Reducing the greenhouse gas during the manufacturing of the PV system. The improvement of the life-cycle and economic performance of PVs has been a very important research area in this present days [40]. Improvement on the PV technology system is quantified by GHG payback time and energy pay-back time and [41] Energy pay-back time is the time that PV module takes to generate the amount of energy that is equal to the amount energy utilized in its manufacturing. The ratio of the mass of GHG produced during the production of the amount of electricity generated during the lifetime operation of PV module is the termed GHG [40] [42]. The GHG payback time of a PV module is the time it takes for the module to displace all the mass of GHG produced during its manufacturing at the deployment site [43].

A paper was conducted by [44] in relation to the average number of occupants in residential dwellings in all the states in Australia examining the life cycle cost effectiveness of using photovoltaic technologies at capacity ranges between 1.5Kw to 5kW. Results from the study showed a life cycle cost savings of $273-$53,021 over 15years with the percentage of cost savings were recorded as 0.35% and 123.83% respectively. Studies from [33] provide knowledge on how to quantify the impacts of the life cycle of PV systems and its relation to a time sensitive greenhouse gas emission.

2.3.1.2 Photoelectric effect.

How do photovoltaics work at the cellular level? All matter is made up of atoms consisting of protons, neutrons, and electrons. The protons in the atoms are positively charged, electrons are negatively charged, and the neutrons are electrically neutral. The protons reside in the nucleus of the atom and the electrons revolve around the nucleus. Every atom has a unique number protons and a respective number of electrons. Silicon, which is a very popular material for producing photovoltaic cells has fourteen electrons. Its electrons are arranged such that its outer four electrons can be donated, shared, or can accept other electrons from other cells[45]. When light strikes the silicon crystal some of the light is reflected and some absorbed. If the absorbed light has low energy it creates heat without altering the electrical properties of the material. The incoming lights contain particles called photons; with greater energy, the photons cause changes in the electrical properties of the silicon crystal. The energy from the photon is released into the outer electrons in the silicon material and if it is sufficient, it releases the electron from the attraction of the nucleus and makes the electrons move freely in the silicon material [46]. The electrons move from their natural state, the valence band, to their excited state, the conduction band; this movement leaves behind gaps called holes and the free movement of electrons and holes generate electricity flow in the semiconductor materials and this the core behind PV cells functionality.

Temperature plays a very important role because the higher the temperature the more agitated the electrons and holes and the more they move. In other to produce current for electricity, electrons and holes in semiconductor silicon material must go through a barrier known as the Potential barrier and this barrier is set up with opposite electric charge separated by a line and facing each other. To give the semiconductor materials, like silicon, its electrical properties, impurities are added to it, in a process called Doping [47].

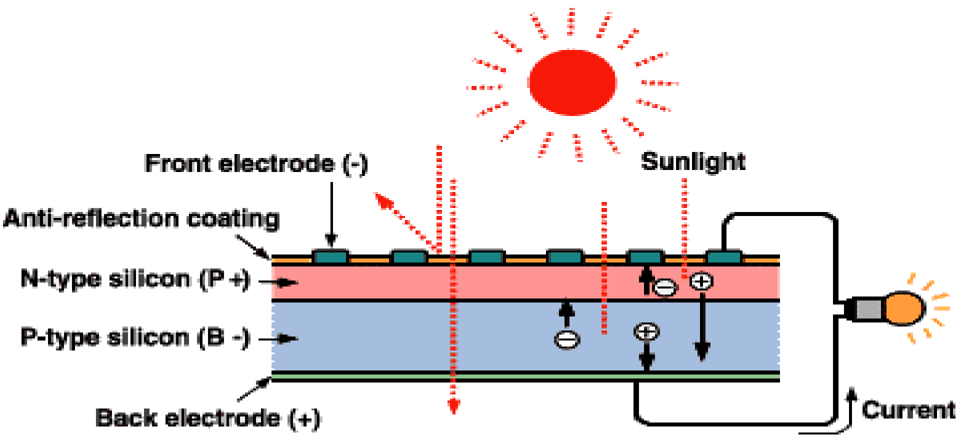

Fig 2.4 Electrical process in a solar cell [45].

Individual solar cells can only produce limited power output so they are connected electrically together to produce the desired output for most applications; in saying that, individual cells can be used to power some devices with smaller demand like toys, watches and hand-held calculators [48]. Several individual cells are joined together to form PV modules and the modules are configured into arrays. These modules and arrays are what we call solar panels. When connecting the individual cells together precautions are taken into consideration because a failure in one cell can lead to a total failure in the assembly of cells[49]. Environmental considerations such as temperature and precipitation are also factored in PV cell arrangement and the waste heat generated by the assembled PV cells. To reduce the environmental impact of the PV system, the cells are encapsulated. The heat is removed from the assembled PV system by convection, conduction, and radiation means and in most cases, the heat is used to produce electricity for commercial purposes and hot water and space heating for domestic buildings[50]. Increasing the power output of PV technology is very important and, from theory, power is the product of voltage and current, therefore; in increasing the power capacity of the PV cells, they are connected in a group by parallel connection (common leads of all positive terminals are tied together and the same is done to the negative leads). This increases the current build-up of the individual cells while the voltage remains the same[51] [52]. After that the group of parallel connected cells are "strung" together in a series (connecting common leads of on cell is joined to the negative lead of the other cell), this leads to an increase in the voltage of the grouped cells [52, 53].Not all cells have the same quality even when under the same condition and illumination and a breakdown of one cell can cause short circuiting throughout all others and block current flow[29]. In solving this issue, an electronic component called a diode is modified into the circuitry of the modules. This diode is a solid-state material that allows electricity to flow in one direction and its placement depends on how it going to be used to protect the module [28]

2.3.2 Solar Thermal Energy

Solar thermal energies operate by concentration solar radiation to thermal energy. The thermal energy can be used as a source to generate electricity or a heat source for many applications such as water heating and space heating in residential applications [54].

Solar thermal electricity is also known as Concentrated Solar Power (CSP) and this involves the concentration of solar radiance to produce steam, which is then used to drive conventional turbine or engines to enable electricity generation. [20]. Utilization of solar energy helps reduce the gap between demand and supply energy and provide a financial benefit for its users by reducing the running cost of appliances. Applying Solar thermal energy as a heating source for water is simple and cheap because solar technologies require a very low capital investment and a closely negligible cost of maintenance [55]. The use of solar thermal energy is free and contributes to the reduction of environmental pollution and keeping and ecological balance. Investigation on cost reduction of solar thermal energy technology was presented by [55] using glazed flat plate collectors to produce hot water. The model of the water heater was carried out automatically by a cell called XOR and the was modes of operation characterized with respect to a solar season and a cold season. A tested prototype was tested and it gave a good yield of 68%.

Residential energy consumption contributed to about 18% of the global energy consumption in 2011. The utilization of solar energy, which is the energy provided by the sun, to heat water (SWH) is currently the most common application of solar energy and it provides a cost-effective solution for house hold water heating. [55]. Solar energy application in water heating technologies (SHW) is easy to design and it is a combination of an array of solar collectors, a medium for energy transfer, a storage tank, and connecting piping for circulation. The solar collectors absorb heat from the sun's radiation which is converted to heat and then the heat is transferred into the anti-freezing fluids that flow through the collector. Heat absorbed is directly used to heat water in an application called Direct Water Heating (Open loop) [56].

2.3.2.1 Collectors

The heart of solar thermal energy applications is the collectors used in gathering the sun's energy and the storage component of the technology. For a solar thermal system to work efficiently the solar collectors must have a good optical performance to enable the absorption of much sunlight and heat. On the other hand, the storage system attached to it must have a high-temperature transfer rate a high thermal storage rate and a long-term durability [26]. Primarily, there are different collectors used for solar water heating applications. These collectors are classified as concentrating and non-concentrating collectors according to their concentration ratio. The non-concentrating collectors are unglazed, flat plate, and evacuated tubes while the concentration collectors are Heliostat field collectors, Parabolic dish collectors, Parabolic trough collectors. The concentrated collectors are mostly used for industrial applications for electricity generation [26] [57]. The Figure below shows examples of different collectors.

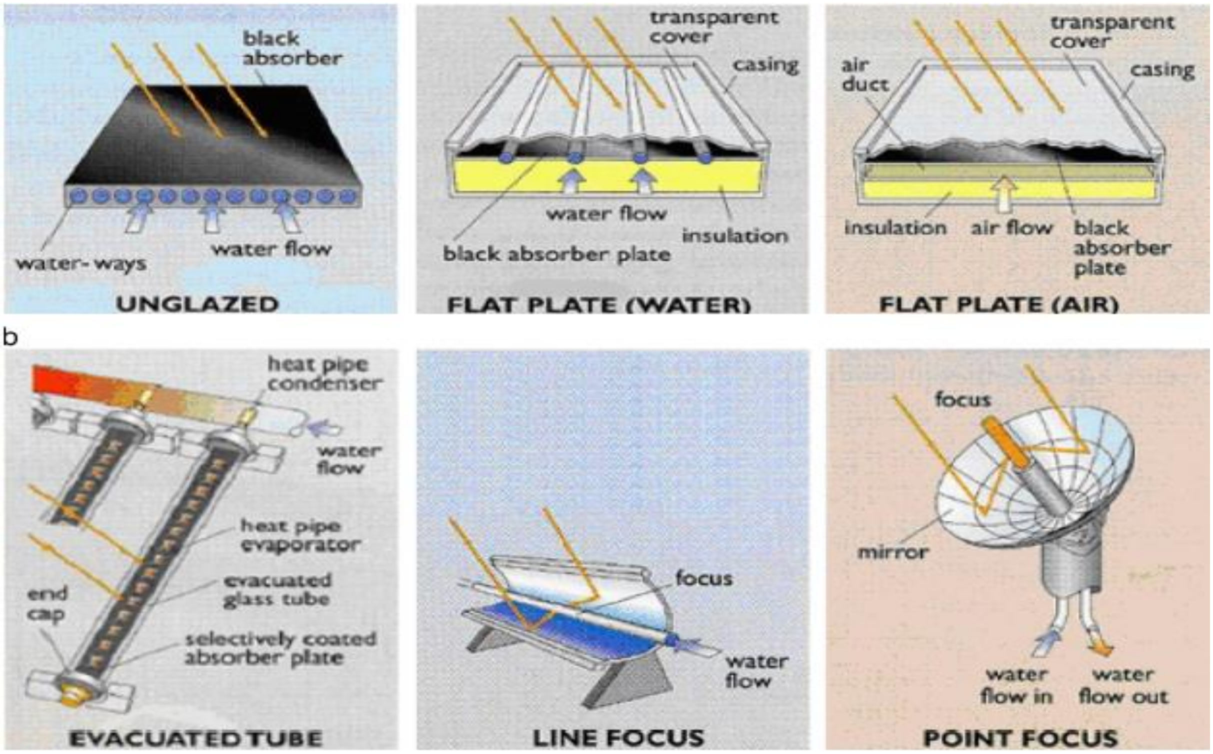

Fig 2.5 Solar thermal collector's illustration [58].

Concentration collectors track and focus the sun's energy on small receiving area which that increases heat flux in fluids and enables thermodynamics process which aids in producing steam to turn turbines. Non-concentrating collectors can be characterized as collectors which use the same area to intercept and absorb the sun's energy. Non-concentration collectors are mostly used for domestic purposes [26]. To develop the residential heating application of solar collectors, [54] investigated different kinds of solar collectors and suggested parabolic trough collectors as the best option.

2.3.2.1.1 Unglazed collectors

The unglazed panel is used for lower temperature applications like heating swimming pools, which mostly requires the heating of the water just a few degrees above ambient temperatures. These collectors have low performance in cold and windy weather and not expensive to purchase [50].

2.3.2.1.2 Flat plate collectors

Flat plate collectors are widely used over the world for domestic, industrial, and commercial purposes because they are relatively inexpensive and are easy and cheap to maintain. They are mostly applicable in a location with a hot climate and low requirement of hot water temperatures. The construction and operation of flat plate collectors are simple and they can be operated in many low-temperature systems applications like water heating and air heating. [57]. Flat plate collectors consist of glazing covers, absorbers plates, insulating layers and an absorber plate all enclosed within on box. The glazing of flat plate collectors is made up of multiple sheets and allows solar radiation to reach the surface of the collector where the radiation is absorbed. The glazing (glass) helps in the reduction of thermal losses due convection and radiation at long wavelength from the absorber plate [50].

2.3.2.1.3 Evacuated tube collectors

Evacuated tubes have been available commercially for over 20 years and are made up of collectors of several series of glass tubes connected and mounted on a together into a manifold box [59]. In this collector system, the absorber plates are sealed within an evacuated glass tube and have an advantage of eliminating conventional loss of other collectors. The absorber plate is a metal plate that is found down the centre of each tube. A special plate pipe is used by the absorber plate to carry the energy collected to the water [50].

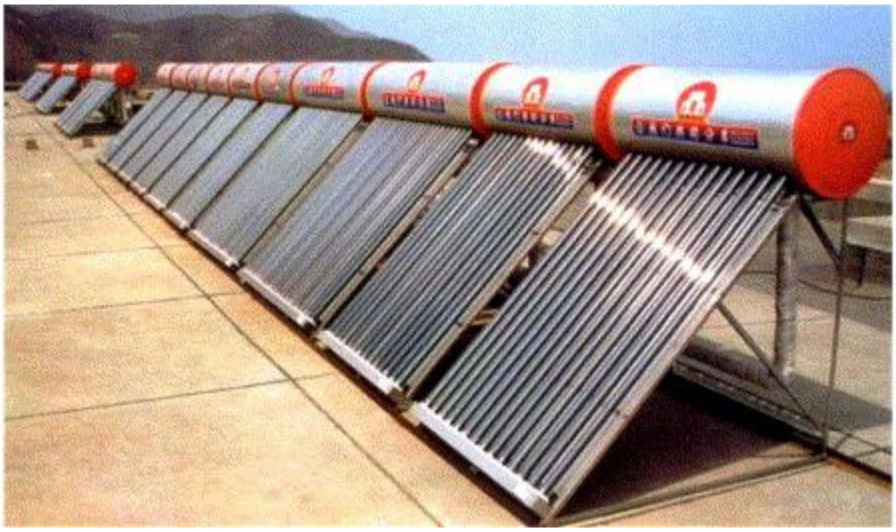

Fig 2.6. Evacuated tube collector Source : [59]

2.3.2.1.4 Hybrid Photovoltaic/Thermal (PVT) Collector

Hybrid photovoltaic/thermal (PVT) is a new type of collector system that is used for both electrical and thermal purposes. This collector is made up of a combination of a thermal absorber and a PV module, with the absorber attached to the back of the PV module. PVT collector system is very efficient and provides a good thermal and electrical performance because the thermal part of the system acts as a cooling compartment for the PV module by reducing its temperature which leads to increased PV module efficiency [60]. The use of hybrid PVT collectors for domestic hot water application is very profitable but dependent on the place of installation and climatic condition. The hybrid solar photovoltaic thermal (PVT) collectors consist of a (1) a transparent cover, (2) photovoltaic cell, (3) an absorber or a heat exchanger, (4) a rear side insulation, and (5) a casing. Collectors, storage tanks, mediums for heat transfers, and interconnection plumbing are the four important basic parts in solar water heating technology application. In their operations, the collectors are used to intercept and absorb sunlight which is then converted to into heat and transferred by antifreeze fluids into the storage tank. The vessel used in this application have expansion properties to accommodate the change in volume of antifreeze fluid due to the heat caused by variations in the sun's radiation [61].

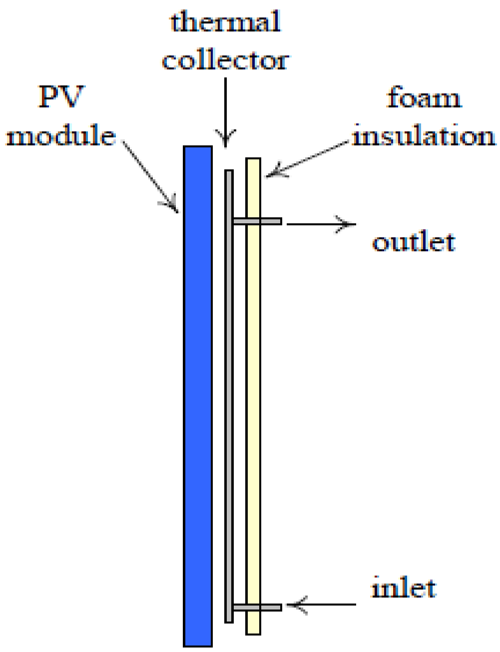

Fig 2.7 Hybrid Photovoltaic / Thermal Collector PVT components [62]

2.3.2.1.5 Concentrating collectors

[54] studied different types of concentrated solar power technologies and explained a solution to its thermal properties by explaining different types of salt properties. The study used a mathematical model to explain how thermal energy can be applied in residential buildings. Concentration collectors are used for large industrial application to achieve higher temperature for working fluids mostly used for electricity generation. This collector mostly has a tracking equipment to follow the direction of the sun and this provides a high thermodynamic efficiency. Some types of concentration collectors are Heliostat field collectors, Parabolic dish collectors and Parabolic trough collectors. [26]

2.3.3 Solar Thermal Energy Applications

2.3.3.1 Domestic Hot Water Heating

A solar domestic hot water system transfers heat to water or another liquid by using the sun's energy it collects through a flat-plate solar collector and when hot water inside is needed in the home, the system then draws from the reservoir or tank. This system then helps reduce your utility bill by complementing an already existing electric or gas hot water system. It helps reduce about 40-70% of the annual household water needs. [63]

There are intermittent issues associated with the irregularity of the sun's radiant energy due to different climatic and weather conditions and this brings a lot of limitation to solar water heating applications and makes it difficult to attain the required water temperature to support the daily life demands. [64].

To find a solution to the problem associated with obtaining hot water at the desired temperature, a control mechanism was designed based on a sensed temperature along with a water flow area of two systems a hot water (primary) source and a cold water (secondary) source. The mechanism proposed a solution by being able to estimate the amount of cold water supplied from the secondary source [55]. Solar hot water heating systems have gained strong governmental supports in recent years and are in the pipeline of becoming the most utilized energy in the future and the healthy contribution of the technology to the environments makes it more advantageous than conventional water heaters. Solar Water heaters (SWH) provide benefits such as reducing the emission of 2 tons of greenhouse gasses (GHG) per year and reducing about 40%-50% of annual water heating costs [65]. A study of the performance of solar hot water systems (SWHS) was conducted in Robat, Morocco by studying the insulation of the transfer circuit. The SWH system was equipped with a forced circulation scale system and was fitted with an automatic subsystem to control the water.

results show 50% efficiency of the solar hot water system and this due to the type of insulation used [56].

An investigation on the potential of solar thermal on technologically fabricated housing blocks was conducted and a calculated method of energy estimation was introduced in the investigation. Results showed that the monthly performance of solar thermal collector's systems depends on the system loses (distribution, circulation, and storage) and the amount heat required for production of the domestic water heating (DWH)[66]. Studies on the performance of using concrete collectors for the domestic water heating system was conducted by [57]. Results of the studies showed in as much as concrete collectors are inefficient they are more cost effective in building integration than normal flat plate collectors using metallic absorbers. [67] Proposes the important role stratified hot water tank heater will play in the heating integrations of many technologies to will operate that operate at different temperatures at a reduced cost of implementation. The studies focused on the assessment of water snake concept of the stratified water tank. [55] proposed the implementation of a hybrid system as a source of reducing energy consumption. By this, solar is used to pre-heat the water and this can help in curtailing the expenses associated with electric water heating.

There are two types of solar water heating systems and they are the active and passive heating systems. In an active system, electrical and mechanical units are used for water circulation by pumping the water (Pumped systems) and a storage tank is used for water storage. The passive system requires no electric or hardware to enable water circulation but relies on natural convection (Thermosiphon systems) and water density to enable circulation of the system [68]. Both systems can be applied in homes, businesses, and industrial sectors. Solar water heaters (SWH) provide 80% more of the water needed to heat water and in cloudy days electric and gas heaters are used as backup systems when efficiencies of collectors are low.

Passive solar water systems are very popular in developing countries with power issues and in non-freezing climatic countries. Figures 2.8 and 2.9 show examples of active and passive hot water heating systems.

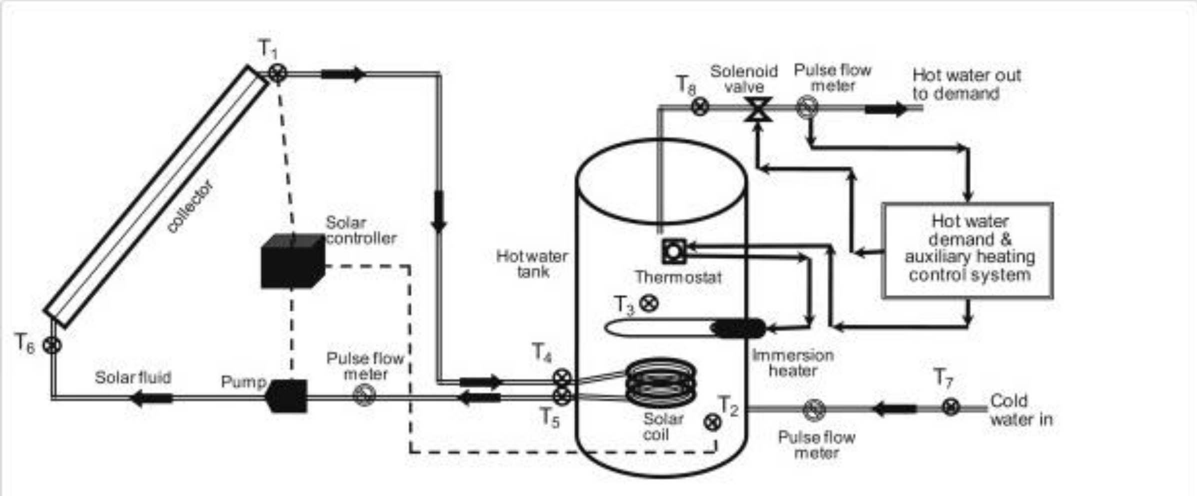

Fig 2.8 Active Pump Circulation Solar Water Heating System source:[69]

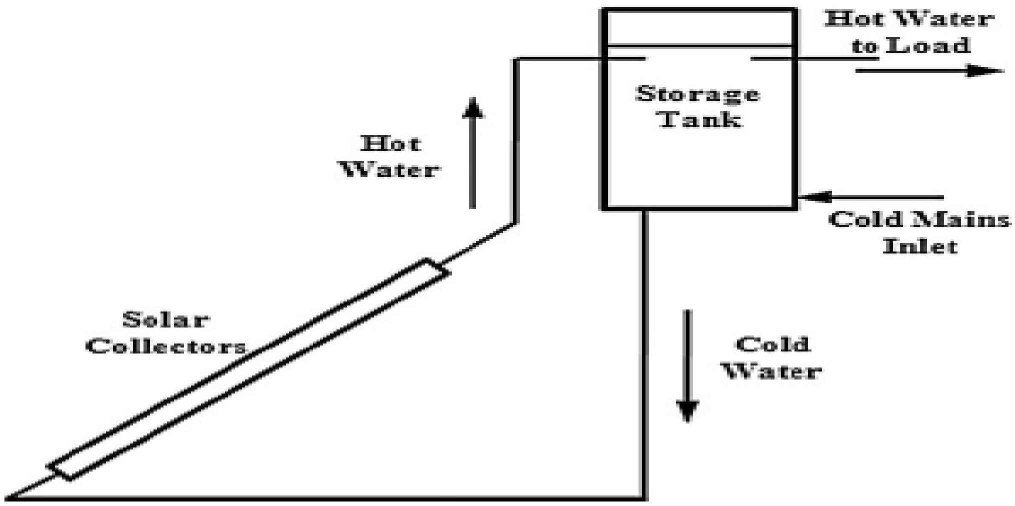

Fig 2.9 Passive natural circulation Thermosyphon solar water heating system [63].

Active systems can be classified into direct and indirect circulation water heating. In the direct solar water heating circulation system, the energy absorbed from the sun by the collectors is used to directly heat water stored in storage tanks. Water from the tank is circulated through channels in the collector to be heated by the sun and once the water gets hot it returns to the tank. Direct water heating is common in rooftop application and can be natural circulation or pumped circulation. In an indirect system, the heating of the water is done by another fluid and mostly an anti-freezing liquid is applied in this process for climate regions. The fluid is circulated in a closed loop through the collector and then goes into the heat exchanger where the heat is transferred into the water in the storage tank. [68].

[64] proposes that by combining solar energy water systems with solar energy air heat pumps, the desired water temperatures can be obtained. In most cases, the solar energy is strong enough and water heating is done but the solar collector but in cases when the heat generated does not meet the demand the air source heat pump is used. The integration of the two heating systems requires a design control system for a reliable operation of the hot water system. [68] proposed the use of an indirect, non-pressurized, closed loop drain-back pipes as a sustainable energy solution to domestic water heating systems. In the studies, it was proposed that driving the drain-back pipe with a photovoltaic power pump will optimize its techno-economic performance, availability, and maximize its environmental performance.

2.3.3.2 Domestic Space Heating

The sun's energy is collected by a solar space heater using a solar collector and this energy is directed into a thermal mass to be stored later when room space is cold. The thermal mass can be anything specifically used to absorb and store energy such as a masonry wall, storage drums, or the floor. Most systems include control devices and a distribution system to help in the circulation of the heat the space to prevent loss from the collector area. It is possible to combine the systems with a solar hot water system and then size them to accommodate both used. Whenever solar space heaters replace electrical heating systems they become more economical [50].

2.3.4 Hybrid solar Photovoltaic Thermal (PV/T) Systems

Renewable energies are best utilized and provide great advantages when used as cogeneration sources, that is classically using the same source to generate electricity and heat. Combined heat and power (CHP) systems are ideal systems for utilizing solar source and effectively meeting multiple end-user energy demands of customers. The two different kinds of CHP systems are the (1) solid line which include solar combinations only, that is a hybrid of a Photovoltaic and solar thermal system (PVT), and (2) dotted line which includes the combination of solar with other renewable energies such as wind and biofuels [19]. Results presented from an investigation to optimize a 2KW small scale ORC for a parabolic trough solar field plant in Brindisi, Italy, showed that in generating both electricity and heat the overall efficiency of the plant increased from 12 % to 30% [19].

Photovoltaic thermal (PV/T) systems is a technology that comprises of the coupling of a normal PV module and a solar thermal collector and mostly the thermal collector is installed at the back of the PV module. They provide both electrical and thermal energy simultaneously using the PV for the electricity generation and the solar thermal collector for heat generation mostly applied as a source for domestic hot water heating, space heating, and air ventilation. [70] [71] [72] [73].

Heat extraction of PV modules in PVT systems, is done by air and water [71] hence the two types of PVT systems (1) Water cooling PV module systems (PVT/water system), technology suitable for water heating and space heating [74] (this technology is made up of thermal contact with a water heat exchanger attached to the rear of a PV module) and (2) the Air-cooled PV modules (PVT/air) systems, which are applicable in roof installations for buildings as part of electrical load for heating and ventilations.

Hybrid photovoltaic/thermal (PV/T) solar systems have a higher conversion rate of the absorbed solar radiation than standard PV modules. Properly designed PVT modules reduce the temperature of PV modules by their heat extraction processes (water and air) and this keeps the electrical efficiency of the module at a satisfactory level [75]. The PVT technology has received a significant amount of research and development work since the 1970s with many innovative systems and products proposals. The motivation of this study is because the efficiency of normal PV modules decreases as its temperature increases, flowing water or air through the cells of PV module will lead temperature reduction and increase the operational efficiencies of the modules, and this system makes use of valuable roof space. [74] [70]. The influence of temperature and the uniform distribution of solar radiance on PV modules are the two most important issues that affect its electrical output.

[76] conducted a test on a hybrid system of photovoltaic modules and thermal collectors (hybrid PV/T). It was observed that as solar radiation increases it increases the temperature of PV modules, thus reducing the electrical efficiency of the system. The electrical efficiency can be kept at a satisfactory level if proper fluid circulation (PV cooling) with low inlet temperatures are maintained. Experiments conducted on temperature of PV modules showed that the temperature of PV module can vary between the range of 300-325 K (27-52) for an ambient temperature of 297.5 K (24.5) and further investigation in the same work noted that the temperature of the module, the packing factor, and the ohmic losses between the solar cells are the reason for electrical efficiencies of PV modules [77]. [78] proposed a detailed physical hybrid photovoltaic/thermal system and also presented a quantitative analysis of its performance using algorithms. The motivation of the work was solar cells acting as good solar collectors and it being used as good selective absorbers. The efficiencies of solar cells were also proposed to increase with the reduction of its cell temperatures and a model of the

proposal was made on the analysis of the conduction, convection, and the radiation of energy flow that can be drawn from modules.

An integration of photovoltaic and thermal solar thermal systems was developed and its energy balance for each temperature of the integrated systems was examined using numerical computations. The results of the simulations predicted a thermal efficiency of 58% which was close to the experimental value of 61.3% proposed by others [79].

An outdoor design and test of an integrated photovoltaic glass-glass thermal system with a capacity of 200L of heated water was conducted in New Delhi. The analytical expression for the characteristics of a flat-plate photovoltaic thermal (PV/T) was then derived for different climatic conditions. The results from the test showed that when a photovoltaic thermal flat plate is covered with PV modules it provides a better thermal and an averagely good cell efficiency [77].

A study of a new PV/T type system was conducted for a system with dual heat extraction method either with water and air and was presented by [71]. This system is suitable for building integration and provides output in all seasons, both water heating for hot water systems and space heating for the buildings. An experiment was then performed for the dual type of PVT and system was arranged to provide a low-cost modification of the two-heat extraction process. After further studying of the dual type of PVT, it was concluded that an improved system could provide an energy advantage to the installation of separate photovoltaic and solar thermal systems especially in areas of limited space and relative energy generation. The University of Patras leads research to improve on the dual heat extraction for PVT modules.

[75] Investigated the performance of passive and active hybrid PVT/T solar system for domestic hot water and this was conducted using with TRNSYS simulations (a transient simulation program). The TRNSYS simulation was made considering the performance of PV/T at different latitudes in Nicosia, Athens, and Madison and considering the domestic thermosyphon systems for flat plate buildings. The results showed that a considerable amount of electricity and heat output can be generated by PVT systems and the technology is economically viable as the technology improves. The simulation also proved that, for domestic buildings, PVT has a greater chance of success when both electricity and water heating are in demand.

Another study was conducted by [80] using TRNSYS to model a hybrid photovoltaic-thermal (PV/T) solar energy system. The simulation comprised a normal PV with an embedded fin heat exchanger at the back and operating at a lower temperature to enhance its efficiency during simultaneous heat and electricity generation. The electricity generation system consisted of PV panels, a battery bank and an inverter, and the Heat generating system of a hot water storage cylinder, a pump, and a differential thermostat. The results showed that the water flow rate of a particular place in Nicosia Cyprus was 25l/h. Using hybrid systems increases the annual efficiency of PV solar PV system from 2.8% to 7.7%. The hybrid system also provides a 49% cover for hot water needs and this increases the mean annual efficiency to 31.7%. The life cycle savings and the payback time after the simulation were found to be Cy£790.00 and 4.6 years respectively.
[81] conducted a study to understand the performance of integrated photovoltaic and thermal solar system (IPVTS) by comparing it with conventional solar water heater with the idea of demonstrating IPVT design. The PV modules used for PV/T collector was a commercial polycrystalline material. Results then show that a corrugated polycarbonate panel attains good thermal efficiencies when used as a solar PV/T collector. The evaluation of primary energy savings efficiency of PVT systems was also conducted. It was observed that the primary energy savings of a PVT system exceed 0.60 which is higher than a that of solar hot water of a normal PV system for electricity generation. The study also proposed that by directly packing the heat-collecting plate, the PV cells, and the glass cover to form a glazed collector, the performance of PV/T system can increase. This will reduce its manufacturing cost of IPVT and make it economically feasible.

An evaluation of the integration of PV modules with air in the climatic region in India was conducted by [82]. The study also considered the PV system producing thermal energy alongside its electricity generation. Using energy balance equations, the overall efficiency was expressed analytically and an experimental validation was carried out on the hybrid photovoltaic/thermal (PV/T) system. The results showed a fair agreement between theoretical land experimental outcomes. It also concluded that the utilization of thermal energy of PV modules increases PVT overall thermal efficiencies.

There are many different types of PV-T technologies and each type has different performances, characteristics, installation costs, and all have different application targets. Hybrid photovoltaic thermal (PV/T) systems are used for air and water heating applications. Water heating systems have two types of com-panels, these being the parallel plate configuration and the tube-in-plate configuration. Of these, the tube-in-plate absorber collector is considered as the most promising design. It has also been concluded that the best thermal and electrical output in terms of photovoltaic thermal applications can be obtained from partial covered power flat plate collectors [77]. Electricity production is the main requirement in PVT system application and it is important that the technology is operated at lower temperatures as this will increase the efficiency of the technology. The low-temperature operation of PVT systems due to electricity generations limits its thermal applications because enough heat is not extracted to enable water heating and space heating. With additional glazing, the thermal loss of PVT system is reduced but it comes with a reduction of the electricity production. [3] Conducted a study to understand the principles of hybrid systems by comparing the techno-economic performance of photovoltaic systems, solar water heating systems and photovoltaic /thermal (PVT) systems. PVT installation systems were compared to separate installations of solar PV and thermal hot water systems for the same allocated space area. A case study generation of 31 kW PVT in the climatic conditions of Cyprus was considered and results showed PVT systems can make use of half the area covered by both PV and SHW systems and generate nearly the same output power with Annual electricity production for PV against PVT being 57,207 kWh/yr against 54,209 kWh and the hot water production of SWH against PVT being 159, 867 kWh/yr against 149,148 kWh/yr. The study then concluded in considering the roofing space to utilized and the power generation that PVT technology is of a greater advantage than PV and SHW.

Other investigations have shown that additional use of glazing to increase the thermal output will improve the performance of a photovoltaic thermal system. Also, the use of booster diffuse reflectors provides flexibility for PV/T systems while increasing its electrical and thermal output [76].

Hybrid systems are easily compatible with domestic and industrial installations water and air heating. Installation of PVT systems is cost effective and can replace separate installation photovoltaic systems and thermal collectors. [73] Presented an industrial application of PV/T technology with water as a heat extraction medium. The work involved the use of TRNSYS software which encompassed a hybrid photovoltaic thermals system producing both electricity and thermal energy occupying a space area of 300m^2 and storage tank of 10 m^3. This was done for three different latitudes: Nicosia, Athens, and Madison and considering a temperature supply load of 60^{o}C and 80^{o}C. The results of the report showed that a non-hybrid PV system produces 25% more electrical energy but it will require more area of operation and a large percentage of thermal energy requirement for its industrial consideration. The Economic viability of PV and the Hybrid system proved that a positive life cycle of the hybrid system can be obtained and savings will increase at high load temperatures applications. The results of the study also discovered that employing polycrystalline solar cells for electrical production is a better output than amorphous ones but its solar thermal contribution is slightly lower than the amorphous solar cells. It also showed that amorphous silicon panels are much less efficient than the polycrystalline ones but have high economic figures due to its slow initial costs, meaning they have better cost/benefit ratio. [83] studied the potential of building integrated photovoltaic thermal (BIPVT) systems being a major renewable source for urban areas. The BIPVT in this study was used as a rooftop application with the idea of generating high electrical energy and producing the necessary thermal energy required for space heating. Using a heat transfer equation, a one-dimensional transit model was developed and examined to select the right BIPVT system that is suitable for climatic conditions in India. Energy performance of the building was also determined and the results show that a system connected in series will give a better performance at a constant mass flow and parallel connection perform better at constant velocity air flow. It also concluded that a $65m^2$ occupying space of BIPVT system will generate 16,209 kW h and 1531 kW h of net electrical and thermal energies with a 53.7% overall thermal efficiency

2.3.5 Solar Storage

2.3.5.1 Photovoltaic

One of the most discussed issues in electricity generation is storage and the cost of storing enough electrical power in batteries to out peak its demand. This practice is problematic and is mostly likely to remain so for a long time. In a situation where electrical energy is used for the thermal process, it is cheap to convert the power to heat rather than stored in batteries [67]. [14] Conducted studies on how electrical energy storage (ECG) can provide services in situations where solar photovoltaic applications are being used for large capacity generation. It proposes that EEG provides the flexibility that allows the PV generation to keep up with its demand and hence should be important for policy makers.[84] Presented a way to calculate the cost-effectiveness of a combined system of a photovoltaic system and an electrical energy storage system for domestic households. In other to access the cost of electricity for the photovoltaic system, it evaluated the electrical demand and compared it with the purchase prices of electricity. The results showed there is profitability in electrical storage but due to its high cost, it reduces the total financial gains of photovoltaic systems.

[84] compared three battery systems: redox flow, lead acid, and lithium ion. It presented redox flow batteries as a profitable technology over lithium ion batteries and more promising than the lead acid battery. The calculation used in the paper could predict the cost-effectiveness of both solar systems and their storage and therefore help in household battery sizing.

[85] presented hybrid battery as a new charging strategic source for both solar photovoltaic panels and grid connection. It stated that in areas with continuous grid supply PV customers will achieve high economic benefits using hybrid batteries. It developed a mathematical model for the strategy of using hybrid batteries and was able to reduce the energy bills local PV customers using the strategy

2.3.5.2 Thermal

Demand management is a major problem faced by strategists in planning the future for electricity generations and the use of renewable energies such as the wind and solar makes the situation worse because of the unpredictability of its energy supply when needed the most [86]. [87] proposes that thermal storage provides balance to the intermittent nature of solar energy systems. Energy storage provides a great advantage to users it allows them to separate from conventional energy loads and couple supply to demand. The most popular storage unit of solar thermal energy is hot water storage because of the low cost of water. Hot water tanks are cylindrical in shaped to reduce losses and contain a heat exchanger for the water. Hot water application requires the use of control systems to aid in the charging and discharging of the thermal energy of the collector and the fluid flowing underneath it is heated by the energy [9].

Solar Energy is intermittent due to weather and climatic condition and energy from the sun is unattainable at night for hot water heating. To solve this the issues of intermittency many research have been conducted on storage tanks and means for storing solar energy.

The application of thermal storages in the fields of solar energy provide the easy dispatch ability of electrical energy generation and space heating requirements for homes. In the application of thermal storages, the fluctuation associated with energy demand during unusual timings of the day can be smoothened [20]. [61] provides the basis for most solar water heating applications; it mentioned expansion vessels used to regulate sunlight variation in volume when fluids are heated. To provide domestic hot water solutions, [88] conducted an experimental investigation on the melting behaviour of phase change material. Results showed that the duration of melting in PCM layers are short at the upper layer than the bottom layer. [9] presented on the use of solar thermal storage as a means of domestic water heating solution in detached housing. It also considered discontinuity of solar energy source and the importance of determining water temperature because heat storage is a dispensable factor in solar thermal based projects. It used Simulink as a model to determine the temperature of storage tanks and temperature of houses.

[20] presented a current summary of the present solar thermal energy storage materials and the storage systems in present days. In the work, it discussed the properties of this solar thermal energy storage material and summarized their dynamic performance.

[86] proposes that stratified hot water can play an important role in the integration of several technologies. It also described the concept of adapting to water snakes as a low-cost concept in stratified hot water tanks.

2.4 Implementation of Solar Power System and considerations

Though the solar energy offers wide range of benefits, consideration of rooftop type of solar power system is not the initial step to save energy and environment. It is very important to analyse and monitor the energy usage and wastage and the efforts to improve the energy-efficiency is the first step in any implementation of a solar power system. A home that is energy efficient significantly reduces the amount of power usage from any source, and thus, a "high-performance" house has the capability to provide various other advantages such as quality, greater comfort, durability, as well as indoor air quality[89].

Making the best investment in upgrading an effective home energy typically produces higher ROI (Return on Investment) and also, enhancing the energy efficiency of a home significantly reduces the size and hence the cost involved in implementation of a solar system that is required to supply power needs. Also, deciding on the type of solar system and technology to be used for the specific application is very important. Hence, one must ensure to understand the implementation basics before deciding on the type of solar system technology to be used in a domestic or a commercial application. As already mentioned, there are various factors that should be considered to make sure the solar system provides high efficiency and performance.

2.4.1 Solar System Placement

The efficiency of overall solar energy system is not only dependent on analysing the energy efficiency of homes and the choice of solar system made, but is also dependent on the precise placement of the solar system in homes[90]. This section of the thesis provides detailed description of the factors that must be taken into consideration while mounting / placing the solar system in rooftop applications. These considerations are as well applicable to the high-rise buildings recommendations made for rooftop applications in Australia.

2.4.1.1 Orientation

Calculations have shown that solar panels provide high efficiency and, therefore, work best when they are oriented towards the South. In certain cases, it is not feasible because of few factors such as aesthetics or roof orientation; facing to about 45 degrees to east or west of south significantly reduces the output of solar system by about 5 percent. If the orientation of a solar panel is such that is faces 90 degrees off a southerly direction, then there is reduction in annual energy output of the solar system by about 10 to 20 percent approximately. So it can be concluded that the roof which faces to the South or even Southwest or Southeast provides good output efficiency and for the roofs facing West or East is nearly acceptable, depending on the users' requirements for the solar system[91].

2.4.1.2 Tilt

The tilt of slope of the solar panels also have significant impact on the overall performance of the solar systems. As per the guidelines followed in United States, the optimal fixed tilt is an angle that is a few degrees lesser than the factor of geographic latitude, but also it is important to note that the exact tilt is not very crucial. About a 15-degree variation (tilt) to make it suitable for the roof's pitch almost makes no significant change in the power output of solar system. While it might not provide conditions most optimal for solar ray capture, most of the rooftop solar panels are placed or mounted parallel to the roof considering the factors of aesthetics and simplicity of the overall system[91].

2.4.1.3 Tracking Arrays

The overall solar system power output can be significantly increased by making the solar system track the sun's rays as the sun moves across sky on a daily basis and also it is quite feasible to adjust the tilt angle of the solar panels according to the seasonal solar path, instead of fixing them in the single orientation. Tracking arrays are normally suitable for solar systems of thermal and hybrid types, and thus, it is not highly recommended for rooftop application because of certain important factors such as increased system complexity, increase in costs in comparison with the energy benefits from the system, and also the maintenance is very difficult[92].

2.4.1.4 Shade

Shade is yet another important factor that has a significant impact on the overall output of the solar system. Depending on the type of solar system implemented in rooftop domestic applications, shade on nearly 25 percent of the solar array can significantly reduce the overall output of the solar system by about 50 percent or in some cases even more. It is very important to examine the shading factor across the path of sun, not only for a day, but for over a year, as the angle of sun is slightly lower in the winter season [93].

2.4.1.5 Mounting

Solar installation comes with some problems because if care is not taken the installation can damage the waterproofing membrane of the roof. Rooftop solar installation is mounted in two forms and that is flash mounting and ballast mounting [94].

2.4.1.5.1 Flash Mount Installation.

Flash mount installation is mostly applicable on tin tile roofs and it is done by making holes in the roof. This type of installation has advantages and disadvantages. The advantage of installing flash mount is that it provides a lighter system by reducing the load bearing on the roof; it also provides installers an opportunity to allow sufficient space underneath the arrays of panels which in turn makes it easy for roof servicing or else the entire solar system would have to be removed in case of any water leakage. The disadvantage of flash mounting is that it can be very challenging to mount and can lead to water leakages on otherwise waterproof roofs. Fig 11. Below shows a typical rooftop flash mount.

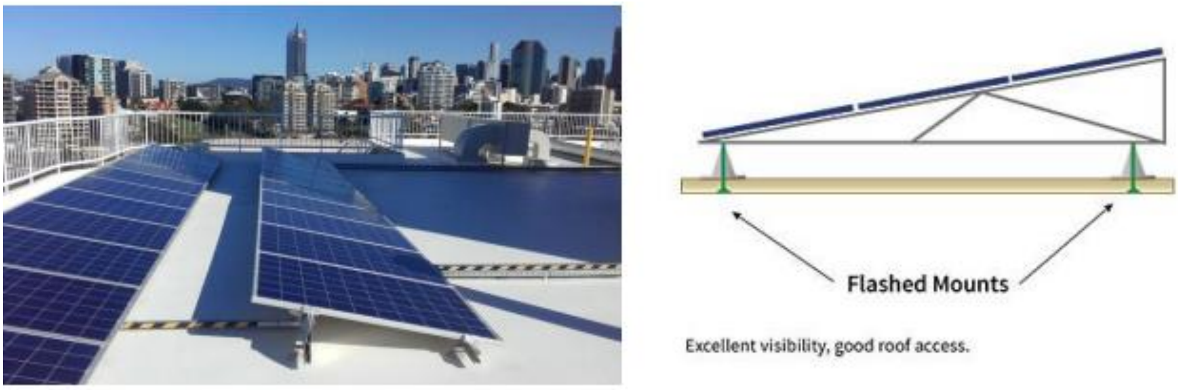

Fig 2.10. Rooftop flash mount (Source Wattblock)

2.4.1.5.2 Ballast Mount Installation

In ballast mounting, no roof penetration is done but rather concrete blocks are placed underneath the array solar system which provides security and prevents wind lifts. Blast mounts are integrated with wind deflectors example shown in Fig 2.11 below.

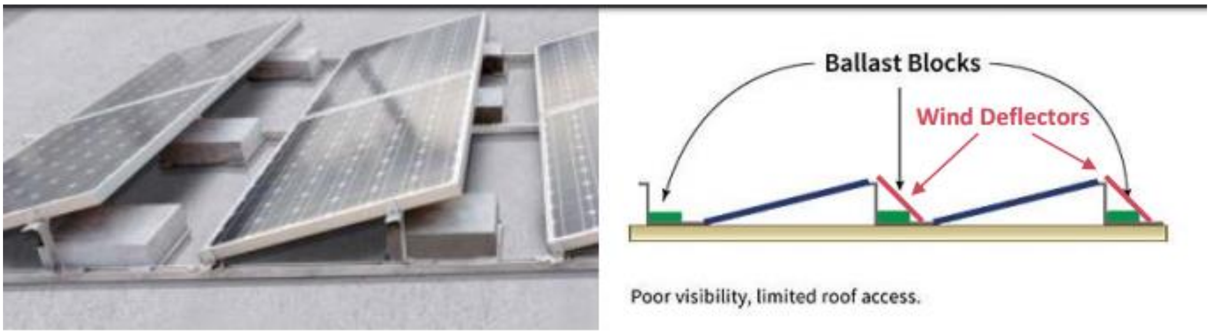

Fig 2.11 Rooftop Ballast mount (Source Watt block)

The disadvantage of installing this kind of systems is that it does not provide space for a roof inspection and servicing because the roof is covered by the concrete blocks. Leaks in this type of mounting take longer periods to repair and mostly leads to structural water intrusion hidden under the ballast array.

2.4.2 Solar Power System Sizing

In order to size the home solar power system, various combinations of factors must be taken into consideration, such as: overall efficiency of the solar system, solar resource (location), availability of the roof space, placement of the solar system, utility rate, electricity usage, and the customer's budget[95]. Thus, the solar power system design is based on consideration of the following factors:

1. Power rating of the solar system – Solar power systems, for example solar PV system is rated with peak direct current (DC) power generating capacity that is measured in watts (W) or even in kilo watts (KW). It is very important to understand the operating capacity of the solar power system, as it will be a little lesser than the rated capacity and in this way, the actual output from the solar system can be predicted[96].
2. Availability of the solar resources – The peak intensity of the sun is not constant at all times in a day, and also, the intensity of solar rays is reduced to a certain extent when the rays strike the solar cells at an angle. In order to estimate the actual output of the solar system, sun peak hours can be used, which gives a measure of number of hours

in which the sun shines at its peak intensity on the unit of solar array. This gives a measure of the radiation amount that was received by the solar array during the day.

3. Electricity Generation – In order to estimate the output production of the solar modules, the operating power capacity (kilowatts) of the solar system that is expected is multiplied with the time. Various software packages are available online that help to calculate the electricity output of a solar system.

2.4.3 Maintenance and Operation of the Solar System

Most of the solar systems today are designed in such a way that they operate automatically, with no or very little user intervention apart from processes involved in cleaning maintenance and inspections. A monitoring system can be used to check the solar system's production on daily, monthly or even on annual basis and modifications to the system can be made to enhance the overall efficiency of the system. Following are some of the internal and external issues faced in maintenance of a typical solar system [97].

3 METHODOLOGY

The paper will evaluate three parameters in relation to rooftop solar energy application. It will contain the technical, economical, and environmental analysis of both Solar Photovoltaic (PV) technology and Solar Water Hot (SHW) technology. The simulation software tool RETScreen was used for this study. RETScreen is an international clean energy project software analysis tool which is used to facilitate the feasibility studies of alternative and clean energy technologies. The software also provides a proven methodology to compare conventional energy sources with alternative clean energy technologies. It provides evaluations like that of energy production, life-cycle costs analysis, and greenhouse gas emission reduction analysis[98]. Renewable energy technology application in residential Strata buildings is key to energy reduction in finances associated with it. Therefore, to provide the best Solar energy solution to Strata, the technical, financial, and environmental parameters stated above will be evaluated and weighted in an ascending order of importance, ranking from, technical to environmental to financial considerations.

3.1 Description of the case study.

The identification and development of the best solar energy system suitable for a high-rise apartment building located in Queensland. The building has 38 apartments and 200-square meter available roofing space for any solar energy application. Data available for the studies are only the monthly and annual electricity consumption of the building. Electricity is the only source of energy for the building, hence is used as a source for water heating in the building. Two solar energy technologies: Solar Photovoltaic (PV) technology and Solar Thermal Water Heater are considered as alternative energy solutions for the building and simulations are made using RETScreen analysis tool. The software tool was studied in the previous semester (semester 2, 2016) by the author of this paper. The study will be concluded by comparing the technical, economic (financial) and environmental analysis for each system and results will identify the best system for this building. Site and technology information are shown in the table (3.1) below.

PROJECT INFORMATION		
	Project 1	Project 2
Project Location	Brisbane QLD	Brisbane QLD
Project Type	Power	Heating
Technology	Photovoltaic	Solar Water Heater
Connection	Central -Grid & internal load	Internal load
Analysis Type	Method 2	Method 2
Heating Value Reference	Higher Heating Reference Value (HHV)	Higher Heating Reference Value (HHV)
Currency	Australian Dollar (AUD)	Australian Dollar (AUD)
Units	Metric	Metric
SITE REFERENCE CONDITION		
Climate Data Location	Queensland	
Latitude	-27.4 ^{o}N	
Longitude	153.1 ^{o}E	
Elevation	10	

Table 3.1. Information of projects.

3.2 Technical

The technical phase of the project will take into consideration the construction phase of Solar PV and Solar water heater (SWH) technologies and account for the space each technology will occupy within the limited space available, that is the 200-meter square rooftop availability. The technical phase will also take into consideration the simulation of the energy generation of both systems. In developing the technical performance phase of the two proposed technologies, data from building was collected to enable the use of RETScreen to model the best energy system. Data included monthly energy consumption of the building, Solar radiance of the state in which the buildings is located, and costs associated with the application of both technologies including its balance of system costs. The final results of the technical performance of the two systems under consideration are evaluated and used as a base for the economical and the environmental evaluation in RETScreen [98]. The chat flow used in the simulation tool is shown in the diagram below.

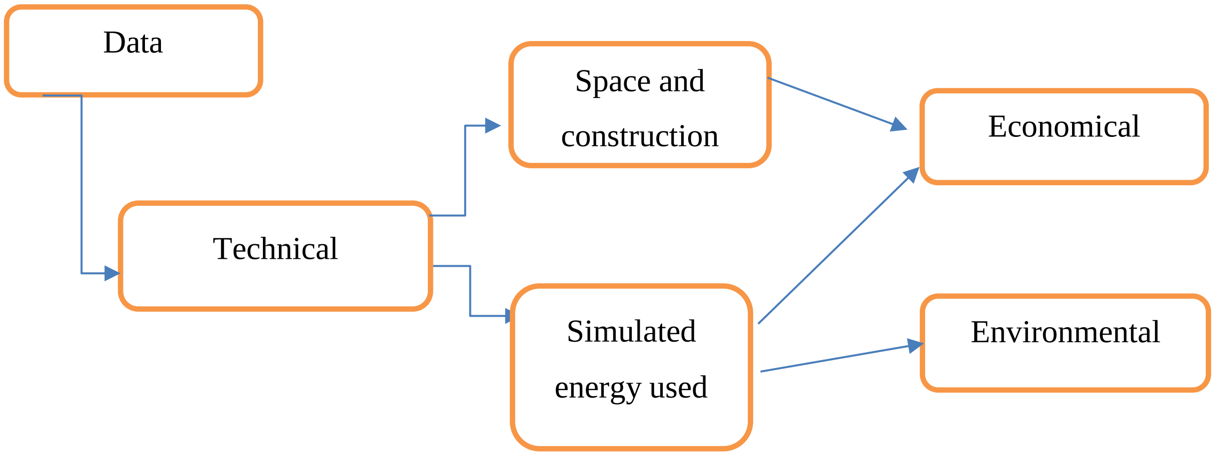

Fig 3.1. RETScreen Technical evaluation structure chats flow [98].

3.2.1 Model Elements

In each step of the simulations, RETScreen uses the manually inputted data (collector type, roof space, number of units and monthly consumption) and meteorological data from the location of the system of construction to calculate the incident solar irradiation of the PV and Thermal collector and subsequently determine they're respective electrical and thermal outputs.

To use RETScreen for the technical evaluation of the PV and the SHW system, research was conducted from relevant material from Wattblock and other relevant papers to enable the acquisition of data [99]. Data collected includes available roof space, annual energy demands of the residence, available system sizes, its lifetime expectancies, efficiencies of technologies, and their power of performance. The technical data inputted into RETScreen was different from each technology and can be seen in the table (3.2) and table (3.3) shown below.

ANNUAL CLIMATE DATA							
Air Temperature	Relative Humidity	Daily Solar Radiation	Atmospheric Pressure	Wind Sped	Earth Temperature	Heating degree-days	Cooling degree-days
°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
20.1	71.2	4.99	101.5	3.7	22.8	270	3,686

Table 3.3 Annual climate data of buildings location RETScreen

Energy Model		
System	Photovoltaic	Solar Water Heater
Type	Mono-SI	Evacuated
Power Capacity	35 kW	35kW
Total Number of Units	110	41
Space Occupied	180m^2	87m^2
Manufacturer	Sunpower	Sunflower Energy
Model	Mono-Si-SPR-320E-WHT	Sunflower Energy SETE-20
Efficiency	19.6%	29%
Miscellaneous Losses	5%	5%

Table 3.4 RETScreen

After all necessary data and information had been collected for the technical phase of the PV and SWH roof top application, an energy simulation was then performed for the building. This was done by comparing the conventional (base) system of the building, which in this case is the building's electricity, to the two alternative energies in this study (PV and SWH). The simulation was performed taking into consideration the total annual energy use of the building and its number of occupants.

3.2.2 Basic data

The monthly consumption of this building is shown in the table and graph below.

`Month	Actual Demand kW	Total Usage kWh	Total annual usage MWh
JAN	26.82	7140.7	7.1407
FEB	26.82	6104.7	6.1047
MAR	26.82	5331.65	5.33165
APR	26.82	5881.47	5.88147
MAY	26.82	6679.38	6.67938
JUN	26.82	5985.49	5.98549
JUL	26.82	5900.5	5.9005
AUG	26.82	5413.07	5.41307
SEP	26.82	6391.51	6.39151
OCT	26.82	7535.14	7.53514
NOV	26.82	7143.96	7.14396
DEC	26.82	7867.64	7.86764
	Sum of annual usage	77375.21	77.37521

Table 3.5 Source :Wattblock

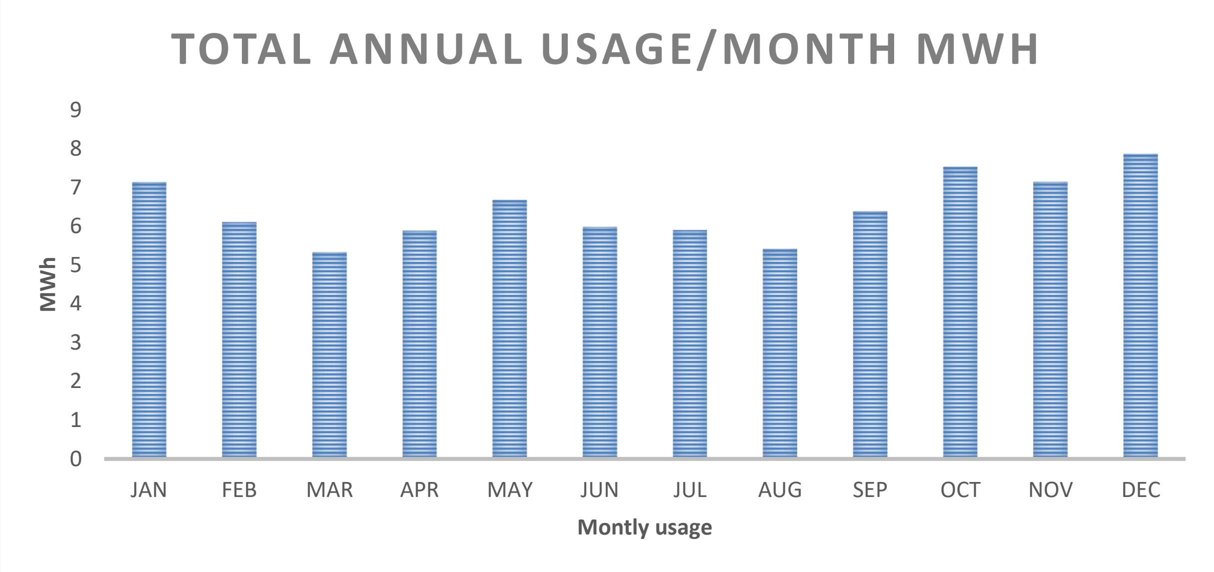

Fig 3.2 Monthly Energy Consumption source: Wattblock

PV Balance of system and miscellaneous	
Inverter	YES
Capacity / Efficiency	30 kW
Capacity Factor	18.2 %
Electricity exported to grid	0
T&D Losses	2%
SHW Balance of system and miscellaneous	
Water Storage	YES
Capacity	200L
Heat exchanger efficiency	90.0%
Miscellaneous losses	1.0%
No Heat pump	Thermosyphon application
Heating System	Electricity
Seasonal efficiency	85%
Solar Fraction	30%

Table 3.6 Data showing outcomes of Technical RETScreen Simulation.

3.2.3 Technical calculations in RETScreen

RETScreen uses the following formulas to come out with energy outputs shown in Table 3.6 above.

The energy delivered by the photovoltaic cells is calculated by RETScreen using the formula below[98].

$$E_P = S\eta_p \bar{H}_t \qquad \text{.. (1)}$$

where,

S = Area of the array.

η_p = Average efficiency

H = monthly average daily solar radiation on a horizontal surface

$$\eta_p = \eta_r \left[1 - \beta_p \left(T_c - T_r\right)\right] \qquad \text{................................. (2)}$$

where

η_r = PV module efficiency at a reference temperature

Tr (= 25°C), and β p is the temperature coefficient of module efficiency.

Tc is related to the mean monthly ambient temperature Ta

The thermal energy produced by the Solar heater collector is done by RETScreen with the formula shown below[98].

$$\dot{Q}_{coll} = F_R\left(\tau\alpha\right)G - F_R U_L\ \Delta T \qquad \text{........................... (3)}$$

where,

Q_{coll} = energy collected per unit collector area per unit time,

F_R = collector's heat removal factor,

τ = transmittance of the cover,

α = shortwave absorptivity of the absorber,

G = global incident solar radiation on the collector,

U_L = overall heat loss coefficient of the collector,

ΔT = temperature differential between the working fluid entering the collectors and outside.

3.3 Economics

The third face of RETScreen takes into consideration the financial factors of the project and this is very important because the outcome of financial calculations aids in the feasibility studies by determining the choice of system to be applied. Calculations were made in the financial stage by considering a profitable way of financing the two projects because the choice of technology and size of the system has an influence on cash flow.

A very important aspect of the financial analysis in most projects is the people involved in the process of construction. This is because higher levels of solar technology installation will require the advice of contractors and energy companies. Our economic evaluation inputs are made in the RETScreen taking into consideration the initial investments cost and operational costs for the two solar technologies. The breakdown of economic structure is shown below. and this is shown in figure 3.3 below.

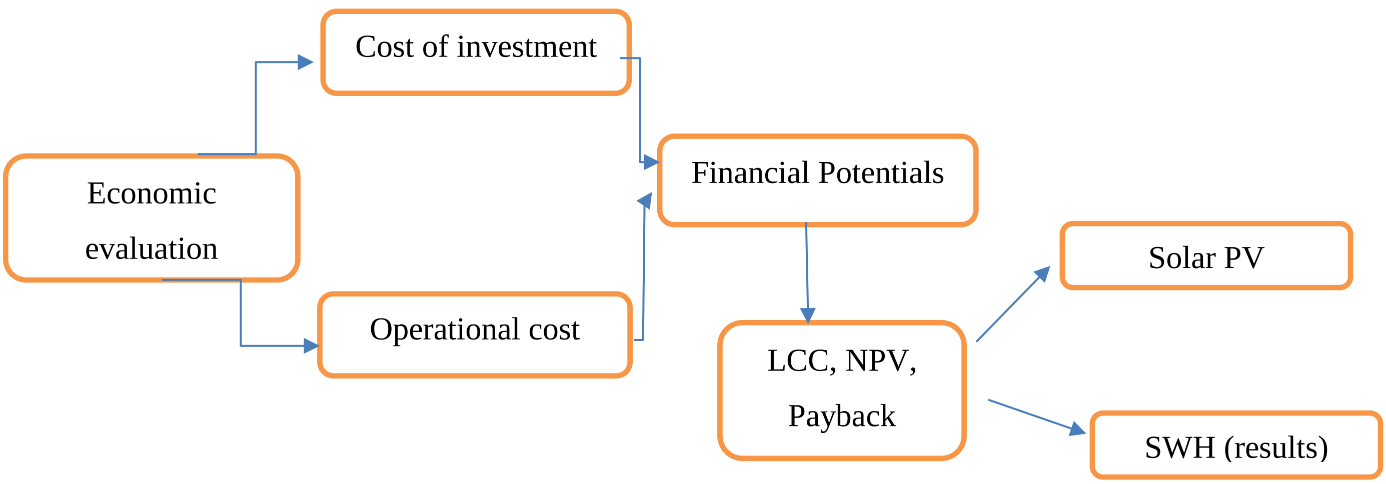

Fig 3.3 RETScreen financial evaluation structure chat flow [98].

Due to the difference in the two proposed technologies that are being simulated, certain consideration had to be made in calculating the financial investment of the two systems. Factors such as the labour cost and maintenance cost, the cost of use of extra pace, prices of local energy suppliers, and the rate of energy exportation were taking into consideration

3.3.1 Financial calculations in RETScreen

RETScreen is then used to evaluate the cost of energy-saving actions associated with the two technologies (PV and SWH) by calculating in different methods, such as the Net Present -

Value(NPV), the Annual cost per KWH (savings), internal rate of return(IRR) and annual life cycle cost (ALCC),

Net Present value method (NPV): In this segment, RETScreen calculates the yearly future expenses and savings that the system will make and converts it into its present value of today. The results of NPV depends on the imputed capital cost of the system, the change in energy precise and finally the duration that the calculations will be made. To determine if the investment of the system is profitable or not RETScreen calculates the capital value which is the present value of future payment – the cost, a value >0 means the investment into the system is profitable. RETScreen uses the formula below for calculation[98].

$$NPV = \sum_{n=0}^{N} \frac{\widetilde{C}_n}{(1+r)^n} \quad \text{……………………………………… (4)}$$

where

r = Discount rate.

C_n = After – tax cash flow

Internal rate of return (IRR): Internal rate of return is used to evaluate the attractiveness of any project or investment and it is defined as the interest rate at which the net present value of all positive and negative cash flows from a project and its investment is equal to zero. Projects are considered profitable when the IRR exceeds the actual cost of capital. Formula for calculating IRR is shown below[98].

$$0 = \sum_{n=0}^{N} \frac{C_n}{(1+IRR)^n} \quad \text{…………………………………......(5)}$$

Where

N is the project life in years

C_n is the cash flow for year n

Annual cost per kWh: This is also called the savings cost and it arrives when the energy cost leads a zero capital cost. The investment in the project can be considered as profitable when its cost is lower than today's energy cost variable[98].

$$0 = \sum_{n=0}^{N} \frac{\widetilde{C}_n}{(1+r)^n}$$ ……………………………………………….……… (6)

Payback Period: This is the length of time that a project will recover from all cost and investment associated with it. This is a very important aspect of the financial analysis it determines whether a project should be undertaken or not because longer payback periods are not desirable by most customers[98].

$$SP = \frac{C - IG}{\left(C_{ener} + C_{capa} + C_{RE} + C_{GHG}\right) - \left(C_{O\&M} + C_{fuel}\right)}$$ ………………………… (7)

Where

C_{ener} = annual energy savings or income

C_{capa} = annual capacity savings and income

C_{RE} = annual Renewable energy production

C_{GHG} = greenhouse gas production income

$C_{O\&M}$ = yearly operation and maintenance cost increased by project

[98]C_{fuel} = annual cost of fuel

Life cycle cost LCC analyses: This method provides a variation of the present-value by minimizing the capital value and including lifetime environmental effects on the project. RETScreen uses the annual life cost saving (ALCS) method all energy savings measures of the two technologies and the one that gives the lowest energy saving cost will be considered the most profitable technology to be undertaken[98].

$$ALCS = \frac{NPV}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right)}$$ ……………………………………… (8)

In the project, it was assumed that all the possible opportunities for financing the project is fixed and will be done by the Strata Cooperation

3.4 Environmental

The larger contributor to environmental influence in alternative energy technologies is the energy use in its daily operations. Therefore, by decreasing the energy use in the operational face of the solar energy technologies the environment is affected positively. Photovoltaic energy source and thermal energy sources are different technologies and therefore their impacts on the environment are different. The difference associated with the environmental impacts of these technologies depends on the heating system used, the efficiency of the system and the source energy chosen for the heating[98]. The later which is the energy source can have impacts on the environment before even being applied to the solar technology and this can take place in the extraction, production and transportation stages.

RETScreen environmental flow chart is shown below.

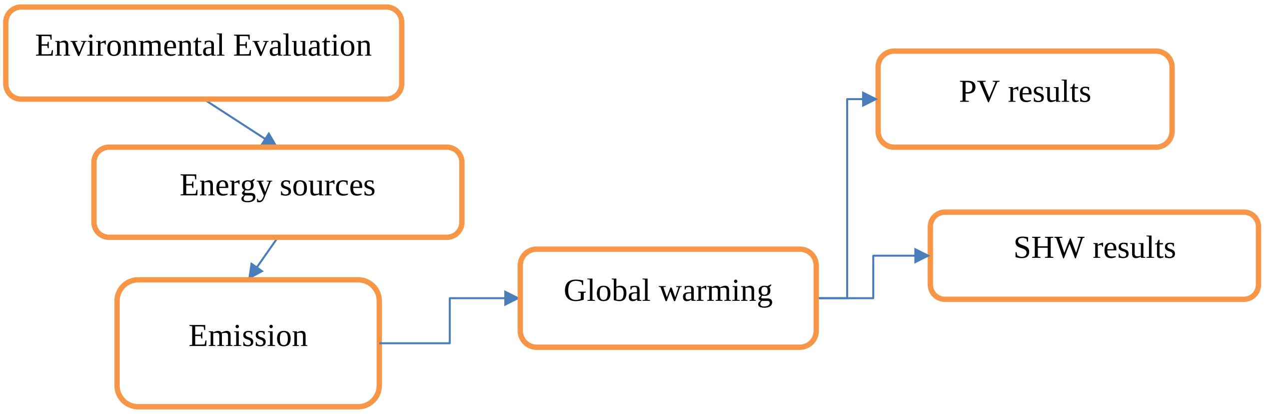

Fig3. RETScreen Environmental evaluation structure chat flow [98].

3.4.1 Environmental calculations in RETScreen

RETScreen estimates the annual GHG emission reduction of electricity with the formula[98]:

$\Delta_{GHG} = (e_{base} - e_{prop})\, E_{prop}\, (1- \lambda_{prop})\, (1- e_{cr})$

Where,

e_{base} = base case GHG emission factor,

e_{prop} = proposed case GHG emission factor,

E_{prop} = proposed case annual electricity produced,

λ_{prop} = fraction of electricity lost in transmission and distribution (T&D) for the proposed case,

e_{cr} the GHG emission reduction credit transaction fee.

RETScreen estimates the annual GHG emission reduction of heating with the formula[98].

$\Delta_{GHG,\ heat} = (e_{base,\ heat} - e_{prop,\ heat})\, E_{prop,\ heat}$

Where

$\Delta_{GHG\ heat}$ = annual GHG emission reductions from heating

$E_{prop\ heat}$ = is the proposed case end-use annual heating energy delivered

$e_{base\ heat}$ = base case GHG emission factors for heating

$e_{prop,\ heat}$ = the proposed case GHG emission factors for heating

4 RESULTS AND DISCUSSION

To effectively facilitate identification of the best solar energy technology for the defined case study (Stata building) the simulation software tool RETScreen was used. The two alternative energy technologies used: Solar photovoltaic (PV) technology and the solar thermal water heater (SWH) are different in terms of power consumption and generation. Solar Photovoltaic technologies generate energy (electrical) and solar water heater (SWH) generate thermal energy. In other to make a possible comparative analysis for both system, RETScreen permits an input of different parameters of data for both cases[98].

Photovoltaic (PV) analysis RETScreen

- Available roof space
- Type of PV module and capacity
- Electricity export rate
- Inverters

Solar Hot Water, SWH RETScreen

- Type of solar collector and capacity
- Number of Apartment Units
- Daily Hot water demand
- Storage
- Heat exchanger
- Heating System

Results from the technical, economical, and environmental analyses are identified and showed in figures, graphs, and tables. The result is then compared to the conventional energy source of the building. Further discussion and suggestion are also considered on how to best utilize the chosen system in roof application to enhance an efficient energy system.

4.1 Technical Analysis

The technical analysis of a solar PV and solar water heater energy system is based on a performance of Photovoltaic and Solar Hot Water systems in terms of energy generation. Electrical generation output per unit area of a PV module and the thermal output per unit collector area of the solar collector are the most important aspect of solar energy application in electricity and heat generation. This output can vary from system to system due to the amount of solar radiation received and the size of collector area of by the modules. Secondly, another important aspect of technical analysis is the module efficiency of the PV system and the Thermal system. For solar PV, this efficiency is described as the amount of sunlight falling on the surface of the module as compared to the amount converted to electrical energy and for SWH it is described as the amount thermal energy produced by collector relative to the amount of solar energy falling on it [70]. A vital factor in the calculation for the energy produced by the photovoltaic technology was made possible due to the space allocated for the implementation of the project in RETScreen. Due to the availability of only 200m^2 roofing space, the RETScreen was allocated 180m^2 space for a 35kWh Sunpower Mono-Si-SPR-320-WHT PV module. It was assumed during simulation that due to low or no maintenance of a PV systems after installation most of the space will be utilized for electrical energy generation with a few square meters' space of left for movements if maintenance is required.

Similarly, in the thermal energy calculations of the solar water heater system, RETScreen permits only the data entry of the number of occupants, the type of collector and the space it will occupy. To have a base of comparative analysis a 35kWh evacuated tube collector was used for as the solar thermal water heater system. The table below shows the results of cell efficiencies, cell/collector capacities, annual energy production and space occupied by both PV and SHW systems respectively after simulations. The table also compares the energy produced by the two technology as compared to conventional electricity currently in used.

System	Energy delivered to load (MWh)	Efficiency of cell/collector %	Space Occupied m^2
Photovoltaic	57	19.6	180
Solar Water Heater	27	29	87
Electricity (Conventional)	77	Assumed 95	

Table 4.1 Energy output by conventional energy source and proposed energy source.

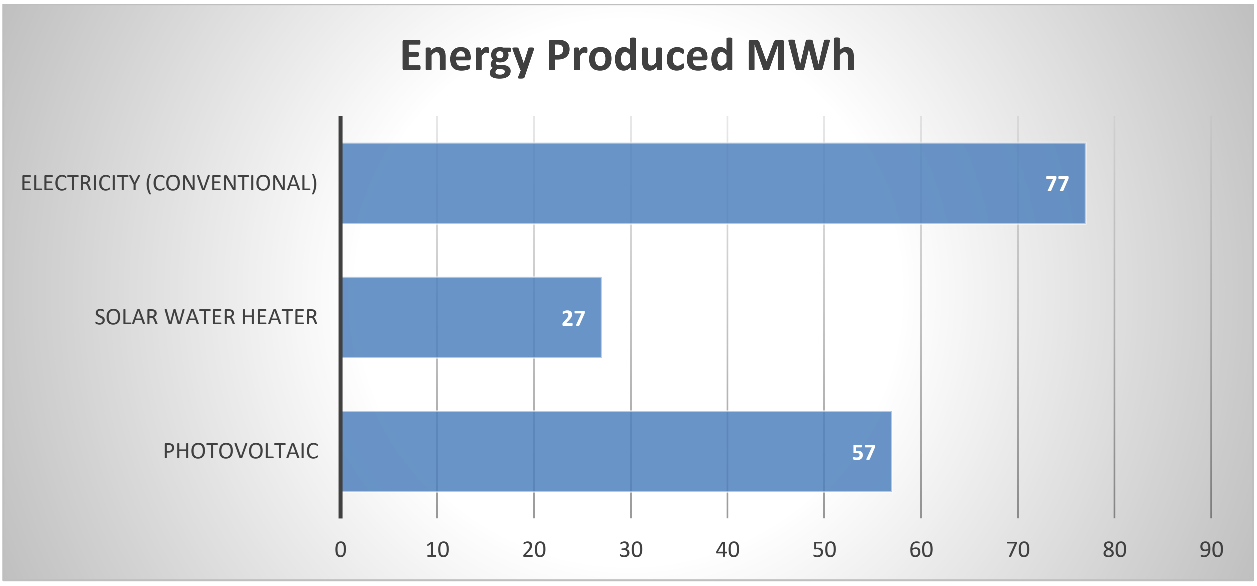

Fig 4.1 Energy production by base case and alternative energy system (PV, SHW)

Wattblock conducted a case study for Strata Community Australia and proposed the sizing of community systems that is the combination of common area electricity consumption and internal apartment loads on Strata Residential buildings. The case study illustrated an averagely split energy consumption of residential building usage for typical Strata Buildings (fig4) below. The figure shows that strata buildings use about 23% annual energy in hot water heating, hence this percentage will be the base for determining the advantage of installing the solar water heater in this case study.

With this percentage, it will mean the building in this exercise will require an approximate 18MWh out of the 77MWh annual energy for hot water heating. This energy can be met by both photovoltaic and solar hot water installation on the building. Based on technical results for the limited space available, a stand-alone PV system cannot generate enough energy to match up the total energy demand building. It will require an additional 12MWh support from the grid.

Fig 4.2 Breakdown of residential energy usage (Wattblock)

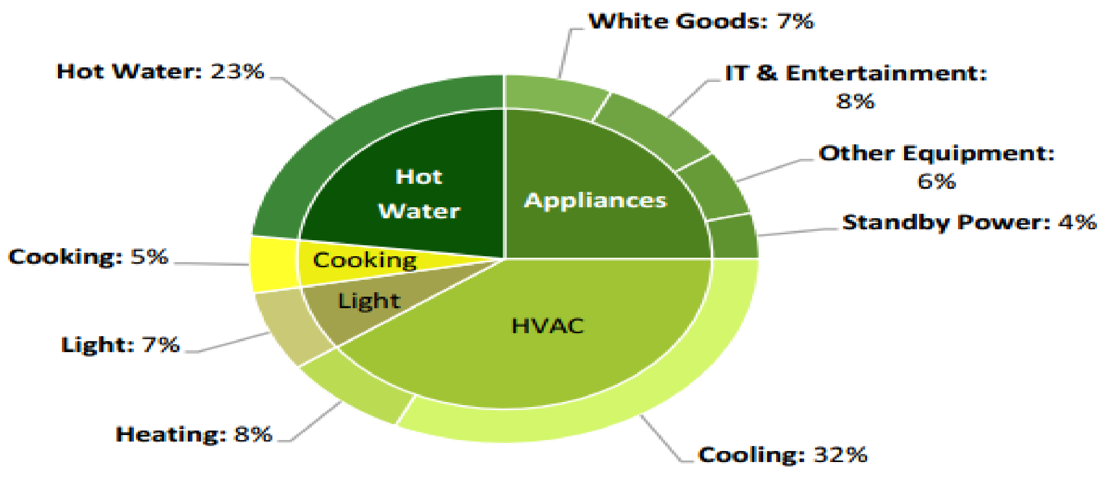

Fig 4.2 Breakdown of residential energy usage (Wattblock)

4.2 Environmental Analysis

The main reason for global acceptance and introduction of renewable energy systems is to solve issues associated with greenhouse gases that lead to global warming; this makes an environmental evaluation of solar energy technology very important. The greenhouse gas emission of both solar PV and solar water heater application in our case study is estimated according to the full operational life of each technology from its manufacturing phase to its operational phase. Table 4.2 below shows the emission reduction of both solar technologies compared to the conventional system, while table 4.3 and 4.4 display the emission of associated with the two proposed systems, PV and SWH.

Proposed case (PV)			
Fuel type	Fuel mix	Fuel Consumption MWh of building	GHG emission tCO2
solar	82.20%	57	0
Electricity	17.80%	12	10.3
Total	100%	69	10.3

Table 4.2

Proposed case (SWH)			
Fuel type	Fuel mix	Fuel Consumption MWh building	GHG emission tCO2
Solar	26.40%	26	0
Electricity	73.60%	71	60
Total	100%	97	60

Table 4.3

EMISSION ANALYSIS			
System	Base case GHG emission tco2	Proposed case GHG emission t/co2	Net annual GHG emission reduction tco2
Solar PV	64.5	10.3	54.2
Solar Water Heater	85.3	60	25.3

Table 4.4

Tables 4.2 and 4.3 show the percentage of fuel mix and the energy consumption rate of two proposed systems. As shown in the tables and mentioned in the technical phase of the project, the proposed solar PV system will require additional 12MWh electricity from the grid in a fuel mix ratio of 82.2% solar and 17.8% grid electricity. The solar PV will emit zero greenhouse gas but the additional support from the electricity will emit of 10.3t/CO_2.

In Table 4.3, it is also noticed that due to intermittency of solar energy due weather conditions and lack of sunlight during night times the SWH will require an additional fuel support from the electrical grid in a fuel ratio of 26.4% solar and 73.60% grid electricity. For thermal energy required, the solar part of the system will generate zero greenhouse gas but the electrical part will generate a 60 tCO_2

The results from table 4.4 show that in application of the two solar energy systems. The solar PV will contribute to a higher annual greenhouse gas reduction than the solar water heater when compared to their respective conventional energy system needed to generate same amount of electrical and thermal energy. The results also go to prove the literature review, that greenhouse gases are reduced when solar technologies are implemented

4.3 Economics

4.3.1 Project Costs

COST ANALYSIS		
System	Total initial costs	Total annual cost

PV	$63,360	$3,068
SHW	$63,360	$17,839

Table 4.5

The cost of installing solar energy in this case study includes an estimated sum for feasibility studies, project engineering, operation and management, crane cost and balance of system cost of both the power system and the heating system. Results shown in the table below give the initial cost of installation of 35kWh PV at $63,360 and that of 35kWh Solar hot water at $63,000 [99]. The total annual cost of the proposed energy systems is the yearly cost that will be incurred during the operation (fuel cost) and maintenance of the systems and the fuel cost.

Due to the size of the systems being installed, research from [99] proves that the system will require low maintenance once installed so the maintenance cost of both systems will be zero in this studies. This leaves the cost related to fuel consumption which is shown as $3,068 and $17,839 respectively for PV and SWH. These values are due to the fuel mix ratio shown the environmental analysis section of this work.

4.3.2 Financial variables

FINANCIAL VIABILITY				
System	SPV		SWH	
IRR-equity	29 %		14.9%	
IRR-assets	29 %		14.9%	
Simple payback	3.9yr		8.4yr	
Equity payback	3.6.7r		7.3yr	
Net Present Value(NPV)	$ 585,721		$ 239,588	
Annual life cycle savings	$23,429 per year		$ 9,584 per year	
Benefit-cost (B-C) ratio	10.24		4.78	
GHG reduction cost	432	AUD/tCO2	379	AUD/tCO2
Annual Savings	19.171	AUD	28,986	AUD

Table 4.6

The Net Present Value is used to compare the present value of all cash outflows with the present value of all cash inflows of the project over the it's lifespan. NPV value helps to identify which of the projects if profitable to invest in[98]. If the value is positive then it profitable to invest. The of PV and SWH are $585,721 and $239,588. These values show that over the operational period of 25 years, investing in PV is more profitable.

A higher internal rate of return (IRR) of a project means it is very profitable to invest in. The internal rate of return for the solar PV after simulation 29% and Solar Water Heater was 14.9%. Rate of returns are very important when investing and thus drives decision making for most business. Therefore, with these values investing in PV is more attractive to investing in SWH.

The simple payback value of a project is the question everyone is interested in when investing money because this is the time estimated for the system to pay for itself. A short payback period has a great influence in decision making. The payback for both PV and SWH are 3.9 years and 8.4 years respectively.

In other make quantitative and qualitative analyses, most businesses use the Benefit-cost ratio (BC) which allows them to determine the ratio of the net benefit of the project to the cost of the project. A high value means the project is profitable. BC ratio of the PV system and the SWH systems arec10.24 and 4.78 respectively. This shows that investing in PV will have more benefits.

The annual life cycle savings (ALCS) of the project is also calculated by RETScreen. This is like the NPV value but in this situation not only the initial cost is taken into consideration but also the annual cost associated with future operating and management the project over its entire lifespan[98]. The ALCS values of PV and SWH are $23,429 and $9,584.

The GHG Emission reduction cost represents the levelised nominal cost to be incurred for each tonne of GHG avoided[98]. The results of both systems, 432 AUD/tCO2 for the PV system and 379 AUD/tCO2 for SWH.

RETScreen also compares the annual savings and income of each project compared to the conventional method after implementation of the projec[98]t. When both PV and SWH are compared to the conventional base system (grid-electricity), the annual savings and income of PV and SWH is $19.171 and $28,986 respectively. This value is relative to the conventional system generation the same amount electrical and thermal energy respectively.
The cash flow of the proposed system is shown in Fig 4.3 and 4.4 below.

PV CASH FLOW

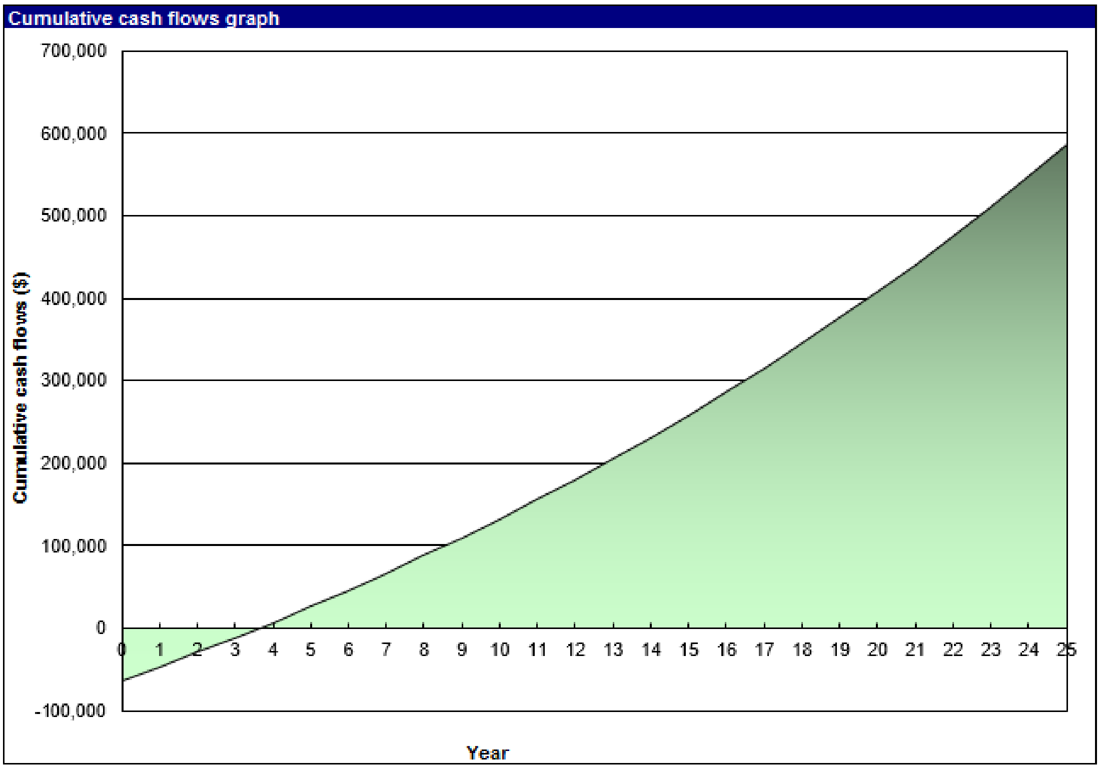

Fig 4.3

SHW CASH FLOW

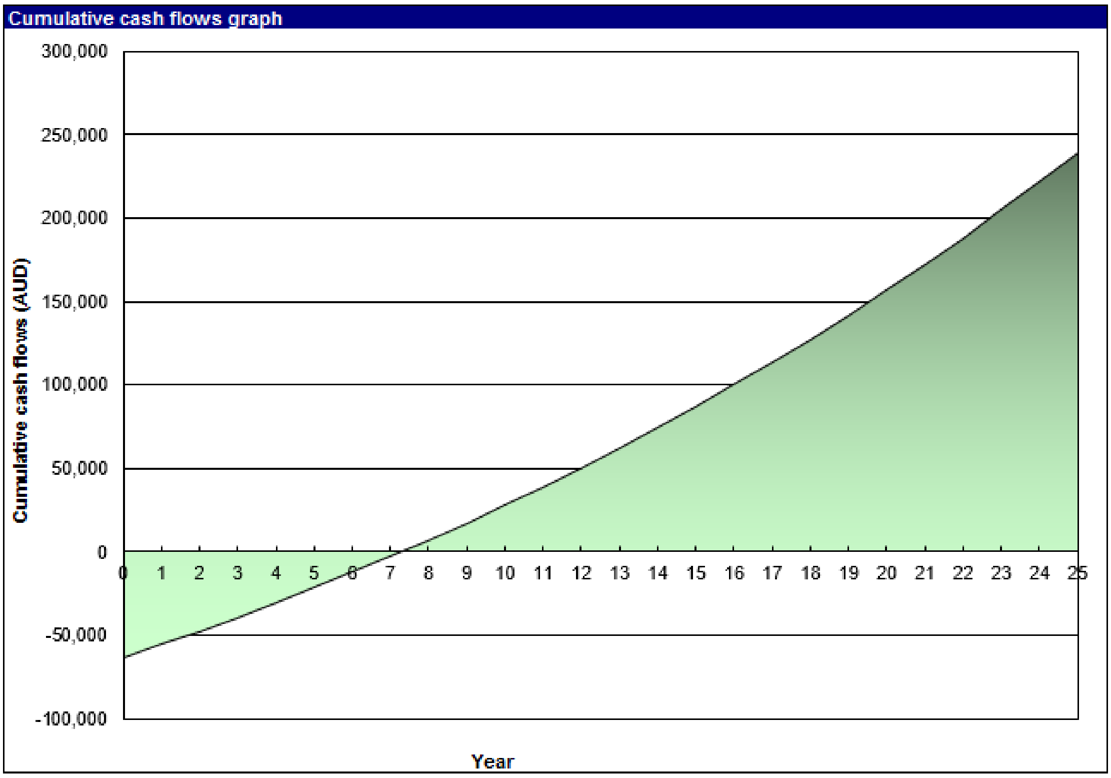

Fig 4.4

4.4 Limitations and Assumptions

The first step in sizing a community solar system is to build a load profile of the common areas and internal apartments combined showing average daily energy usage patterns. However, during the this study the load profile was unattainable and information on heat demand was also unattainable hence it was appropriate to use demands estimated by RETScreen for the case study building as a point for the studies. Therefore, the percentage of 23% proposed by Wattblock on a different but similar building was taken as a base for calculating the water demand in this case study.

4.5 Summary of analysis

All available roofing space for Strata buildings are fixed and this brings limitations in the application of renewable energies. The technologies considered in this work compete in terms of the space required for their installation, energy generation, finances involved is system application and the impacts each have on the environment. The annual energy consumption of the case study building is 77 MWh of which 18 MWh is used for annually water for the building. There are different advantages and disadvantages in using both system and this can be seen in the table summarized below.

	Technical Analysis		Environmental Analysis		Financial Analysis		
Technology	Space Occupied m^2	Energy Production MWh	Net annual GHG Reduction tCO_2	Total Annual Cost $	Annual Savings $	Payback years	NPV
Solar PV	180	57	54.2	3,068	19,171	3.9	$585,721
Solar Water Heater	87	27	25.3	17,839	28,989	8.4	$239,588

4.5.1 Proposed Solar Photovoltaic PV system

Given limited roofing space, only 180m^2 roof space was allocated for the implementation of 35Kw PV system. These systems consist of 110 panels and will generate 57MWh of electricity annually. This energy is not enough to match the annual demand of 77MWh therefore a grid connection of 12MWh would be connected.

The proposed solar PV system will generate 10.3 tCO_2 and this is due to the electricity supplement from the grid. The solar technology itself will produce zero greenhouse gas. When the proposed system is compared to the conventional system it reduces 54.2 tCO_2 and this means a proposed solar PV system with 12MWh connection from the grid is environmentally friendly.

For many corporate bodies like Strata, financing is capital budgeted; therefore, it is very vital for the cooperation to identify and value the best project to invest. For such cooperation, the amount the capital available for projects is limited and the organization pursues projects that enhance the values of the cooperate body. One way the cooperate body financially evaluate a project is the simple pay back, IRR and NPV values of proposed projects. The payback, IRR and NPV are 3.9years, 29 % and $585,721 respectively.

4.5.2 Proposed Solar Water Heater system.

For the proposed Solar water heater of this case study, a thermosyphon water heating system was implemented. The SWH installation for the building consist 41 panels occupying $81m^2$ and producing 27 MWh of thermal energy annually. The annual energy produced by the proposed system is more than the 18 MWh demand required by the building. It is assumed that, with little losses in the storage unit, the extra energy should provide enough heating temperature in the storage system during intermittency of solar energy.

During night times and cloudy weather conditions, an electrical supplement will be needed to heat the water. The proposed solar water heater system, which includes an additional electric heater, will emit 60 tCO_2 but the solar part of the system will generate zero greenhouse gas. Application of the proposed solar water heater system will reduce 25.3 tCO_2 annually if compared with conventional system of generating that exact thermal energy. This proves that solar thermal water heating is environmentally friendly.

The financial results of SWH are also attractive and provides a high amount of annual savings of $28,986 when compared to the conventional system. The payback, NPV and IRR of a SWH system are 8.4years, $239,588, and 14.9% respectively.

From all the values above, looking at technical, environmental, and financial parameters of both projects, installing of solar photovoltaic systems has an advantage in all three parameters compared to solar thermal water heater (SWH), hence it will the best technology that should be considered in solar energy implementation in this case study.

4.6 Recommendation.

From the technical analyses, it looks appropriate to use the solar PV system as a source of power to heat the domestic hot water of the case study building since it produces more energy in MWh than the solar water heater system and the excess energy can be fed the load particularly the common area load

From the literature review of this paper, it can be noted that hybrid solar photovoltaic/ thermal (PVT) systems are a new upcoming technology in its prototype stages. Research's PVT field of study proves that the system can use half the space occupied by both PV and solar water heater (SWH) system and able to increase the electrical and thermal outputs of both system respectively [3]. This PVT technology is an area that Wattblock should consider in making energy proposal for Strata Buildings.

5 CONCLUSIONS

As part of an industrial working experience for Griffith IAP programs, this project was conducted for the Energy company Wattblock. The purpose of the project was to compare two solar energy systems for rooftop application and suggest the best one that can be implemented to aid in energy efficiency in measures for Strata buildings. The two solar energy systems analysed were solar photovoltaic (PV) system and a Solar water heater (SWH) system. These two solar systems are currently the most widely used solar technologies on residential and domestic buildings hence important to find the right technology that can be implemented for Strata high rise buildings.

Principles behind the two solar energy technologies and research ongoing in their fields were introduced in the literature review. A high-rise Strata building located in Queensland with a roof space of 200 square meters was chosen as a case study of this project. The simulation software tool RETScreen was used to conduct the feasibility study for solar energy implementation of this building. Data acquired from this building was the annual energy consumption and the size of roof space available. The operational lifespan for both projects was predicted to be 25years.

The feasibility studies of the solar technologies were done in three phases: technical, environmental and financial. The annual electricity usage of this building is 77MWh by the conventional system (Electricity) with an approximately 18MWh for water heating.

Technically PV system generated 57MWh of electrical energy occupying 180m^2 roofing space while SWH system generated 27MWh thermal energy and occupied 87m2 roof space.

Environmentally PV system reduce 54.2 tCO_2 and SWH reduces 25.3 tCO_2. Finally, the financial results showed $585,721NPV, 29 %IRR, 3.9years of payback and $19,171annual savings for the PV system and $239,588NPV, 14.9 IRR, 8.4years of payback, $28,989 annual savings for the SWH system. The annual life cycle of PV and SWH was $23,429 and $9,584 respectively.

The deduction from the results proves that implementation of both PV and SWH heater on Strata residential buildings are technical, economically, and environmentally feasible. However solar PV provides better advantages than solar water heater and hence it should be the technology to be considered in limited roof residential buildings.

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