SELF-SUSTAINABLE SERVICE FACILITY

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ABSTRACT

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The objective of this study was to collect and analyze information in producing a self-sustainable service facility. The service facility can be utilized for various reasons, constructed from a shipping/cargo container.

The data researched and analyzed was done by taking into account a rainwater harvesting system and alternative energy options such as solar, wind, and passive energy.

A rainwater harvesting system was found to be a definite viable option, especially in water scarce countries. The system required few skills, little supervision to operate, with minimal maintenance. Another definite viable option was the container modification in a passive solar design for thermal comfort. It is far more available, affordable, and earth friendly than any other traditional energy sources available. A passive solar design can be used throughout the world and can also be implemented to a certain degree according to comfort. On the other hand, energy generating systems such as solar and wind turbine systems were found to be a very expensive investment. Many factors were taken into consideration but these systems are very site specific. Therefore it was inconclusive whether these system would be advisable or not, and other alternative energy forms may be considered.

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Key words: passive; solar; wind; energy; rainwater

CONTENTS

1 INTRODUCTION (CONFIDENTIAL)

2 PASSIVE SOLAR ENERGY

Solar energy is a radiant heat source which can be utilized in a manner to help heat and cool a building through a thorough managed building design. The use of the sun's energy for heating and cooling structures or living spaces is known as passive solar energy. Passive solar energy means that mechanical means are not employed and as a consequence, the basic natural process of heat transfer is exploited. (Sustainable Sources, 2014) Passive solar energy is far more available, affordable, and earth friendly than traditional energy sources, and it can also be used directly or in combination with other energy generating systems. This form of energy can be used for heating, lighting, cooling, etc., thus a properly designed home in a temperate (moderate) climate can use passive solar designs without adding any mechanical assistance. (Findley, D.S., 2010)

2.1. Passive heating and cooling

Passive solar heating is when the sun is used for maximum effect. This happens when sunlight strikes an object and the heat are absorbed (Alternative Energy, 2008.). Passive solar heating can be classified in 3 different approaches; direct gain, indirect gain, and isolated gain. These design approaches utilizes the installation of construction materials which absorbs solar energy easily, then slowly releases the heat throughout the day or night to heat a living space. This is known as thermal mass and will be discussed in more detail in section 2.2.4. (Solar Town, 2009.)

- Direct solar gain is where the sun strikes thermal mass materials such as the floors and walls through a window, and heat is radiated throughout the living space (figure 1). (Sustainable Sources, 2014)
- Indirect solar gain is where the thermal mass material is located between the sun and the living space, thus the thermal mass absorbs thermal heat and conducts it to the living space (figure 2). (Sustainable Sources, 2014).
- Isolated gain designs are where the usage of these heat absorbing materials are remote to the rest of the living space, for example where the sun may warm a sun-room and then naturally funnels the heated air to the living space. Isolated gain is illustrated by figure 3. (Solar Town, 2009.)

Direct and indirect solar gains are important for any site that needs heating, because this is the simplest and least costly way of passively heating a building (Sustainable Workshop, 2011). When heat is inside a building, various techniques can be utilized to spread it and avoid heat loss (Alternative Energy, 2008).
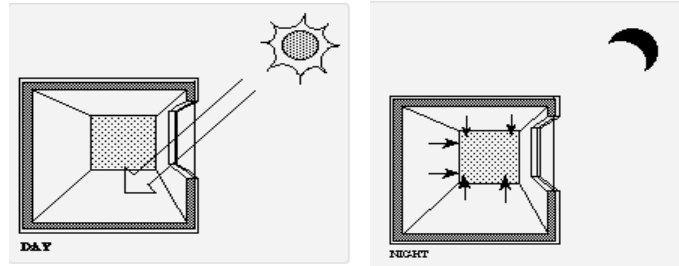
Figure 1: Direct solar gain. During the day the floor of a living space absorbs solar heat directly through a window, and during the night this heat is radiated back to keep the living space warm. (Sustainable Sources, 2014)
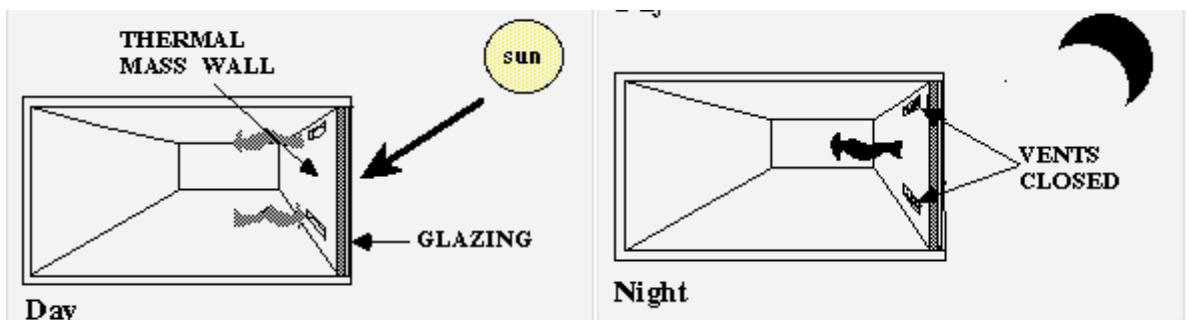
Figure 2: Indirect solar gain. During the day the sun heats the thermal mass wall, the vents are open to let heat in and ventilate the living space. During night time the vents are closed where the heat is then conducted into the living space through the thermal mass wall to keep the living space warm. (Sustainable Sources, 2014)
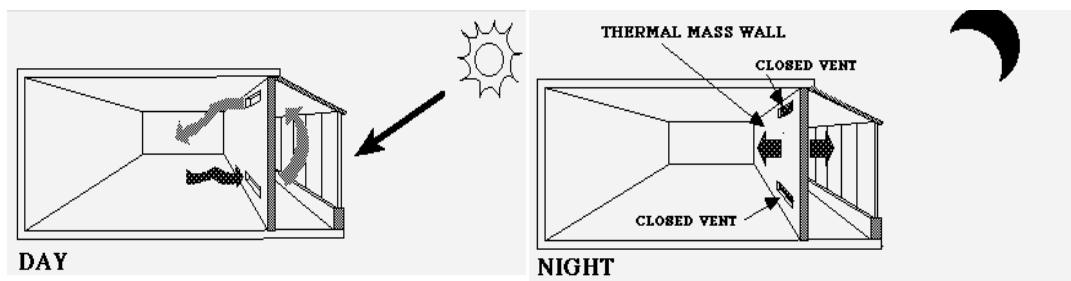
Figure 3: Isolated gain (Sustainable Sources, 2014)

Opposite techniques are applied to passive solar cooling than in passive solar heating (Alternative Energy, 2008). The main objective is to keep the sun out by shading techniques and moving cool air in through ventilation techniques (SEED, 2014). When con-

sidering a building design and ventilation techniques, attention should be paid to cross-ventilation, direction of prevailing winds, and the source of cooling night breezes. Shading devices can be fixed or adjustable to control the amount of solar radiation entering a living space. (Alternative Energy, 2008) Shading is used to prevent as much direct sunlight as possible from reaching walls and floors with thermal mass, so they do not retain heat and can keep the cool air inside. Shading techniques can be in the form of overhangs over windows or on the roof. (SEED, 2014) Buildings can also be shaded by natural vegetation and specialized window glazing. These "shading devices can reduce solar gains by up to 90%, while still admitting a significant amount of indirect light" (Alternative Energy, 2008). It also has to be kept in mind that external solar heat gain can be minimized by good insulation, and reflective materials in the walls and roof for hot sunny climates. (Alternative Energy, 2008)

2.2. Passive solar building design

A building erected with a passive design is practiced throughout the world and has exhibited low energy costs, reduced maintenance, and superior comfort (Sustainable Sources, 2014). Passive solar designs can be used to accommodate average and severe climates. When planning to utilize passive solar energy, the first two considerations that need to be taken into account are the climate and solar elevation (altitude) of the area. The solar elevation (altitude) concerns with angles of the sun as it affects how much light and energy passively enters the home (figure 5 & 6). (Findley, D.S., 2010)

The next consideration to be taken into account in the design approach is the five design elements as illustrated in figure 5. The five elements for a passive solar design are:

- thermal mass is material used to reflect light and collect heat during the day;
- absorber, an absorbing material to hold and store the heat;
- aperture, is an opening to allow the light energy to enter;
- control, to vary the amount of sunlight that is passed; and
- distribution, a method for distributing energy during the evening.

If these elements are present and designed correctly, the building might function without mechanical assistance or intervention (Findley, D.S., 2010).
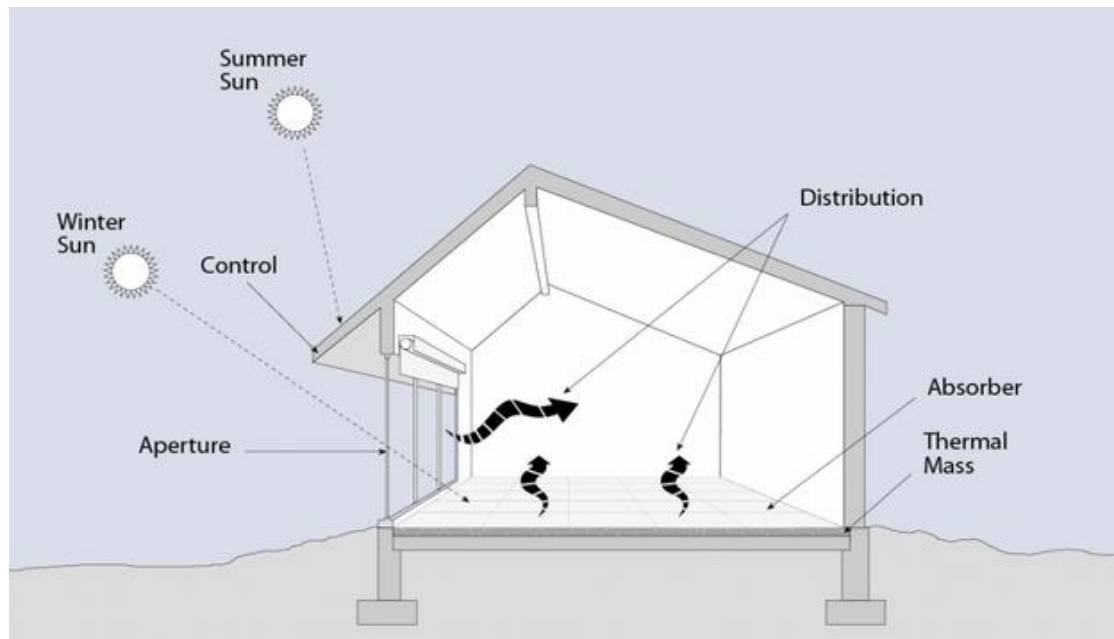
Figure 5: The five elements of a passive solar design and solar altitude
(Findley, D.S., 2010).

In conjunction with these elements, the five major passive design principles should be taken into account. The five major passive design principles are orientation, glazing or shading, ventilation, thermal mass, and insulation. These may include important factors such as, solar exposure, terrain and vegetation, wind patterns, appropriate ventilation and window placement, roof and window overhangs, etc. A passive solar design can take many forms as a design approach where it can be integrated to greater or lesser degrees. (Sustainable Sources, 2014)

Solar elevation calculation

The solar elevation (altitude) angle is the angular height of the sun from the ground surface or horizon. Solstice is an astronomical event that occurs twice a year as the Sun reaches its highest or lowest point in the sky. Throughout the year the path of the sun changes between summer and winter, and therefore the sun is higher in the sky in summer than in winter. (Cairns Regional Council, n.d.) The maximum and minimum elevation angles at solar noon are a function of latitude and the declination angle. The declination angle varies seasonally due to the tilt of the earth on its axis of ration and the rotation of the earth around the sun. (Honsberg, C., and Bowen, S., n.d.) The elevation angles at solar noon can easily be calculated for the solstices and equinoxes as follow:

Equinox = 90° - Latitude

Summer solstice = 90° – Latitude + 23.5° (Declination angle)

$$\text{Winter solstice} = 90° - \text{Latitude} - 23.5° \text{ (Declination angle)}$$

(McGee, C., 2013)
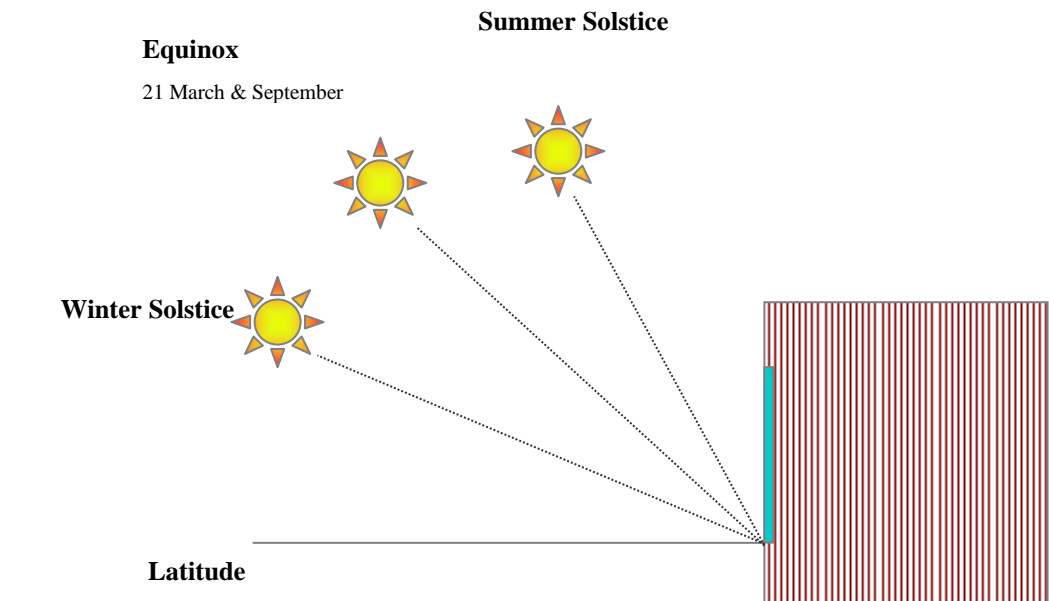
Figure 6: Illustrates the solar elevation variations according to seasons.

Around 21 December the Northern hemisphere of the earth is tilted 23.45 degrees away from the sun. This is the winter solstice for the Northern hemisphere and the summer solstice for the Southern hemisphere. Around 21 June the Southern hemisphere is tilted 23.45 degrees away from the sun. This is the summer solstice for the Northern hemisphere and winter solstice for the Southern hemisphere. Around 21 March and September are the fall and spring equinoxes when the sun is passing directly over the equator and the day and night times are equal in duration. (Gronbeck, C., 2009)

If more elevation angles are required, an online solar elevation calculator can be used to calculate these angles for the specified location according to the respective dates and times, depending on the calculator settings.
Keisan Online Calculator: http://keisan.casio.com/exec/system/1224682277

2.2.1   Orientation

The placement of a structure or building in a right orientation is an important element to consider. Sometimes it is restricted by the aspect of land chosen, but the orientation can reduce or increase heat load of a building. This in turn can reduce the need for costly

artificial cooling or heating and maximize free energy from the sun and wind. (Cairns Regional Council, n.d.)

The sun's path changes throughout the day and due to this phenomenon, advantage can be taken from the most sunlight between 9:00 A.M. And 3:00 P.M. (sun time). This is done by positioning the building with the long axis of the building running on the east-west axes so that the longest wall faces true north or true south (facing the equator). The side of the building facing the equator needs windows to allow solar energy to enter the building. In the Southern Hemisphere the longest wall faces true north to receive the most sunlight (figure 7), and in the Northern Hemisphere the longest wall faces true south. (Cairns Regional Council, n.d.; SEED, 2014)

Figure 7: Orientation of a building in the Southern Hemisphere
(Sustainability Institute, 2009. p.14).

A factor to consider when taking into account a building's orientation is prevailing wind patterns. The orientation of a building can maximize the benefits from cooling breezes in hot weather conditions and shelter from undesirable winds in cold weather. Buildings do not have to face directly into the wind to achieve good cross-ventilation. Internal spaces and structural elements can be designed to channel air through the building. Local site obstructions such as trees and other buildings can obscure prevailing wind directions listed by weather data. "The right strategy depends on the climate." (Sustainable Workshop, 2011)

The orientation of the building should be decided together with building massing early in the design process. Neither can be truly optimized without the other. 'Massing' is taking into account the overall shape and size of the building to maximize the free energy from the sun and wind. (Sustainable Workshop, 2011)

2.2.2 Shading

Shading is a method used to allow solar gain in cold weather conditions and block excess sun in warmer weather conditions. Shading is mainly used to keep a building cool because heat entering through windows is the largest source of unwanted heat gain. (Cairns Regional Council, n.d.) The sun's path changes throughout the year and therefore the sun is higher in the sky during summer than during winter. Shading devices may be:

- eaves such as overhangs illustrated in figure 8,
- louvered, shutters or blinds illustrated in figure 9,
- vegetation-supporting such as deciduous trees or bushes illustrated in figure 10, or
- a combination of these aspects.

Shading devices may also be fixed, operable, and/or removable. Fixed overhangs are durable and low maintenance at the expense of flexibility. Adjustable devices allow the user to fine tune the amount of shade or direct sunlight desired, but these require more maintenance. (InspectApedia, 2014)
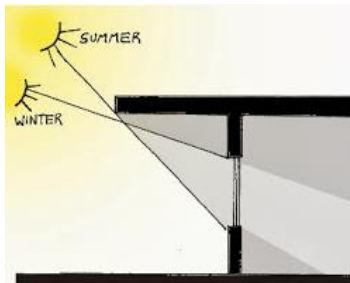

Figure 8: Roof overhang
(Blankenbehler, B., 2013).
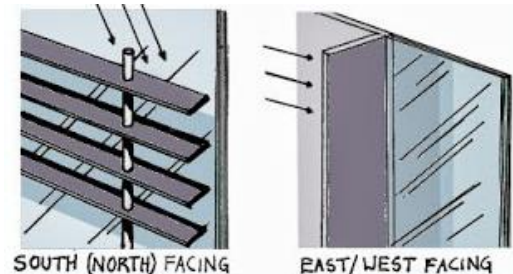
Figure 9: Louvers or blinds
(Blankenbehler, B., 2013).
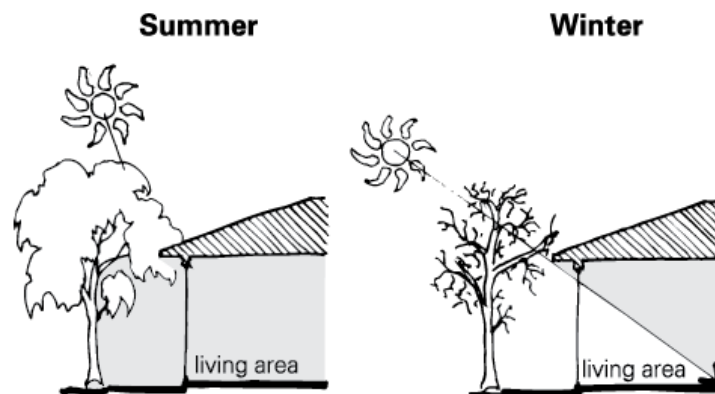
Figure 10: Deciduous trees used to filter sunlight (McGee, C., 2013).

In the form of a window or roof overhang, sunlight can be kept off windows and walls during warm weather when the sun is at a high angle (SEED, 2014). If the building element bears more than about 30º of true south or north, the effectiveness of an overhang (as with any solar feature) begins to decrease. Overheating may occur unless the overhang provides enough shade; therefore the physical dimension of an overhang is important. An overhang that might work well in some locations can be completely inappropriate for other locations. Many variables such as latitude, climate, solar radiation transmittance, illuminance levels, and window size and type need consideration for properly sizing an overhang in a specific location. Since there is not yet a universally simple formula available for sizing overhangs, it is best to have an experienced solar designer or builder to calculate a proper overhang dimension. (InspectApedia, 2014) There are general guidelines and methods that may be useful in estimating a suitable overhang design.

Guidelines

The following guidelines may be useful in overhang design. These guidelines are listed by climate type and solar noon when the sun reaches its maximum altitude for a given day. It has to take into account that solar noon is very rarely the same as noon in local standard time.

- Cold Climates: above 6 000 heating degree days (HDD)* (at base 18ºC (65ºF)) Locate the shadow line at mid-window using the summer solstice sun angle.
- Moderate Climates: below 6 000 heating degree days (HDD)* (at base 18ºC (65ºF)) and below 2 600 cooling degree days (CDD)* (at base 22ºC (75ºF)) Locate shadow line at window sill using the summer solstice sun angle.
- Hot Climates: above 2 600 cooling degree days (CDD)* (base 22ºC (75ºF)) Locate shadow line at window sill using the vernal equinox sun angle.

(HDD and CDD data is available from local weather services) (InspectApedia, 2014)

HDD – Heating Degree Days
CDD – Cooling Degree Days

Solar elevation angles

Roof or window overhangs is useful so that the summer sun is blocked but the lower winter sun is let through. Thus the height of the sun (solar elevation) in summer and winter should be considered for the length of the overhang. (Blankenbehler, B., 2013)

The solar elevation angle estimates were explained in section 2.2, and can be used in a simple sketch to estimate the overhang width.

Overhang rule of thumb

The simplest calculation for a roof overhang with is according to a roof overhang rule of thumb:

$$W = \tfrac{1}{2}\,H$$

where W is the width of the overhang, and H is the height from the window sill of the window to the roof. The equation is illustrated by figure 11 below. (eXtension, 2013)
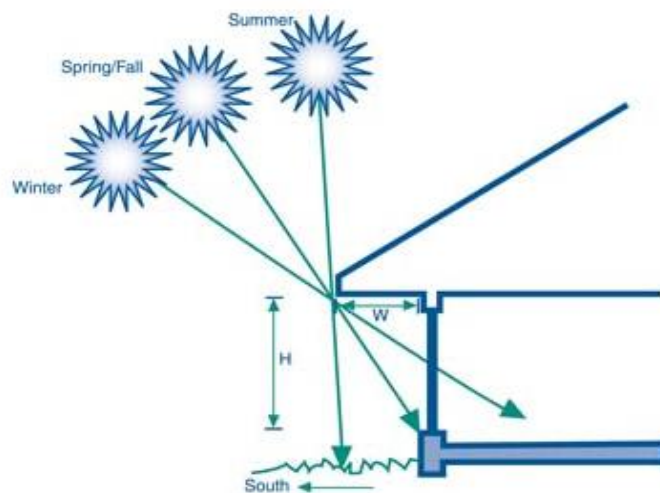
Figure 11: Rule of Thumb: w = ½ H

Eave online calculator

The following is an online calculator to help calculate the required eave depth for ideal passive solar benefit for a North facing (Southern Hemisphere) or South facing (Northern Hemisphere) window. It has to be kept in mind that the values calculated on the website should be taken as a rough guide; it does not take into account other effects such as trees, other buildings, etc.

Website Link: http://www.ecowho.com/tools/passive_solar_eaves_calculator.php

Values required by the online calculator:

- Values for the window – Height in meters.
- Values for the location of the window – Either the latitude or site location such as the country, state and city. (EcoWho, 2014)

2.2.3 Ventilation

An excellent means to naturally cooling a home is by natural ventilation. This is also called passive ventilation which involves the use of natural air movement and pressure differences to both passively cool and ventilate a building. For effective area ventilation, windows should be able to open wide or designed in a way to capture, deflect, or scoop breezes. The opening size of the window or louver can also affect the amount of air and its speed. Pairing a smaller inlet with a larger outlet opening, the cooling effectiveness can be increased (figure 12). As the same amount of air must pass through both the bigger and smaller openings in the same period of time, the air must pass through the smaller opening more quickly and thus the inlet air can have a higher velocity. (Sustainability Workshop, 2011)
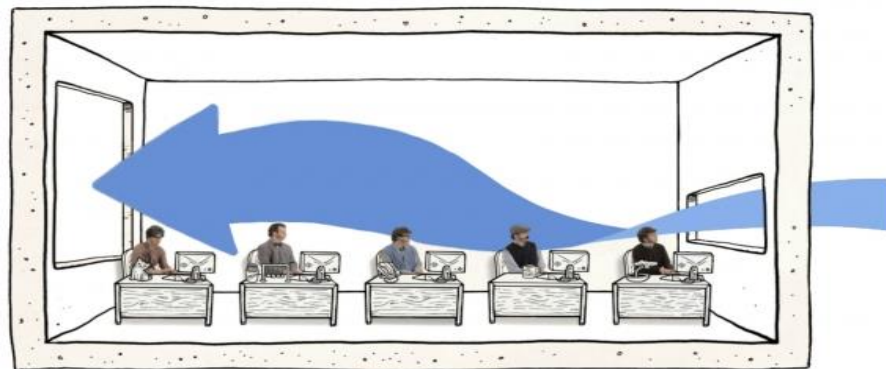
Figure 12: Pairing a smaller inlet with a larger outlet opening increases air velocity (Sustainability Workshop, 2011).

Cross ventilation is air entering through an inlet and exiting through an outlet to optimize the path air follows through the building. Openings such as windows or vents placed on opposite sides of the building create a funnel effective which aids air movement. Generally it is not recommended to place openings exactly across from each other, as it can cause some parts of the room to be well-cooled and ventilated while other parts are not. Placing openings not directly opposite each other causes the air to mix, better distributing the cooling and fresh air, and also increase cross-ventilation. (Sustainability Workshop, 2011)
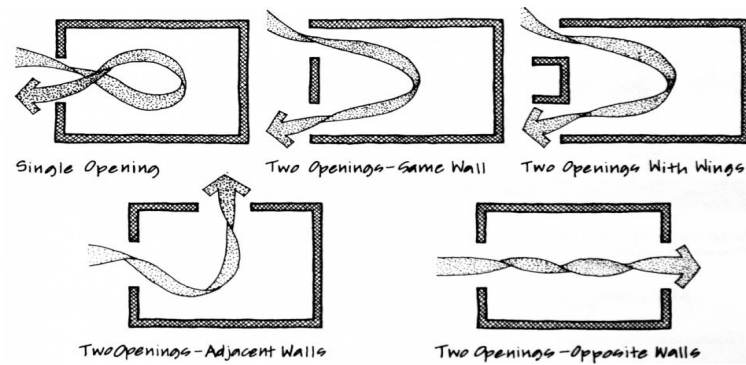
Figure 13: Cross-ventilation. The bottom images are more effective than ventilation that does not pass through the whole space such in the top images. (Sustainability Workshop, 2011)

To cool spaces more effectively, inlets can be placed low in the room and outlets high in the room. These placements of openings leverage the natural convection of air. As a rule of thumb, cooler air sinks while hot air rises. Thus, by locating the opening down low helps push air cooler air through the space, while locating the exhaust up high helps pull warmer air out of the space. (Sustainability Workshop, 2011)
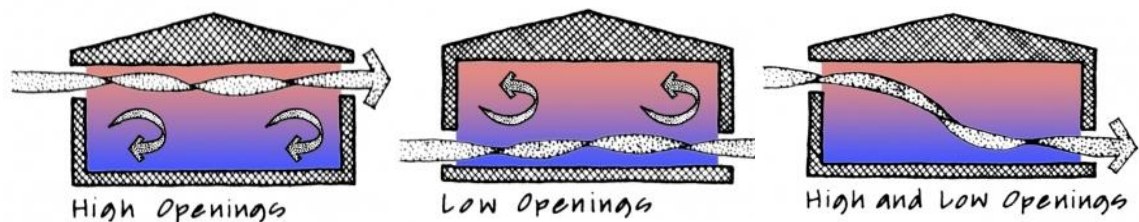
Figure 14: Opening heights affect passive ventilation. (Sustainability Workshop, 2011)

Not all parts of buildings can be oriented for cross-ventilation, but wind can be steered by architectural features. Examples of these architectural features are casement windows, wing walls, fences, or even strategically planted vegetation. These features can scoop the air into a building. (Sustainability Workshop, 2011)
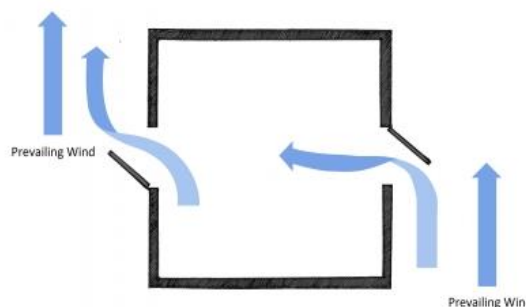
Figure 15: Building structures can redirect prevailing winds to cross-ventilation (Sustainability Workshop, 2011).

Night-purge ventilation is when windows and other passive ventilation openings are kept closed during the day, but open at night. This is to flush the warm air out of the building and to cool thermal mass for the next day. This type of ventilation is especially useful when daytime temperatures are so high that bringing unconditioned air into the building would not be cool enough, but the night time air is cool or cold. (Sustainability Workshop, 2011)
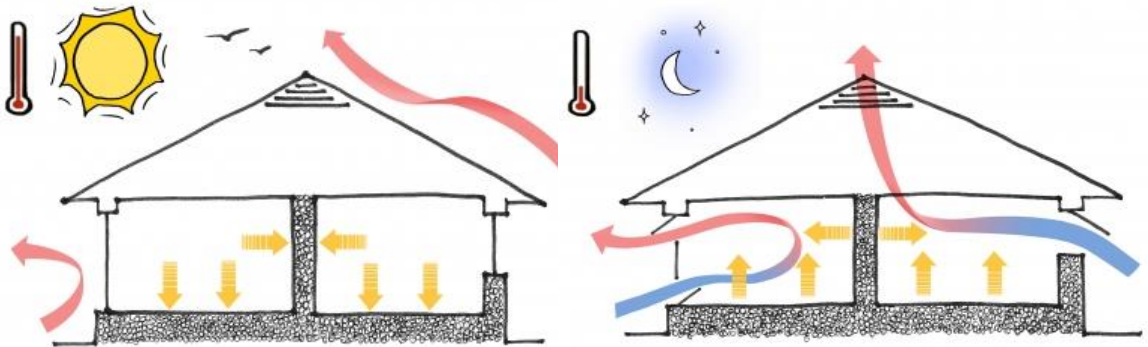
Figure 16: During the day the thermal mass soaks up heat, and at night it is cooled by outside air. (Sustainability Workshop, 2011)

2.2.4 Thermal mass

"Thermal mass refers to the ability of a material to absorb heat energy." Thermal mass is a design principal, but it can also be used to refer to a type of building material. The basic principal is that materials with a high thermal mass act like a battery, which is advantageous in cool climates. (Cairns Regional Council, n.d. Sheet 2) Thermal mass is crucial for thermal comfort and the correct application of thermal mass can moderate internal temperatures by averaging the day/night extremes. It can also exacerbate the worst extremes of the climate when not carefully utilized. For effective thermal comfort, appropriate areas of glazing facing appropriate directions with appropriate levels of shading, insulation, and thermal mass should be incorporated into building design. (Sustainability Institute, 2009) "Correct use of thermal mass can delay heat flow through the building envelope by as much as $10 - 12$ hours, producing a warmer house at night in winter and a cooler house during the summer." (McGee, C., 2013)

High thermal mass materials absorb and retain heat, thus "slowing the rate at which the sun heats the space and the rate at which the space loses heat when the sun is gone." (Sustainability Workshop, 2011) High thermal mass materials are for example bricks, concrete, and masonry which absorbs heat during the day and when the temperature drops, these materials releases the stored heat. (Cairns Regional Council, n.d. Sheet 2) This phenomenon is illustrated in figure 17.

Winter

Thermal mass absorb and store heat form the sun during the day, and re-radiates the heat back into the living space during the night

Summer

Heat absorbed during the day can be flushed out of the house with passive ventilation, and protect thermal mass during the day from excess summer sun with shading and insulation.
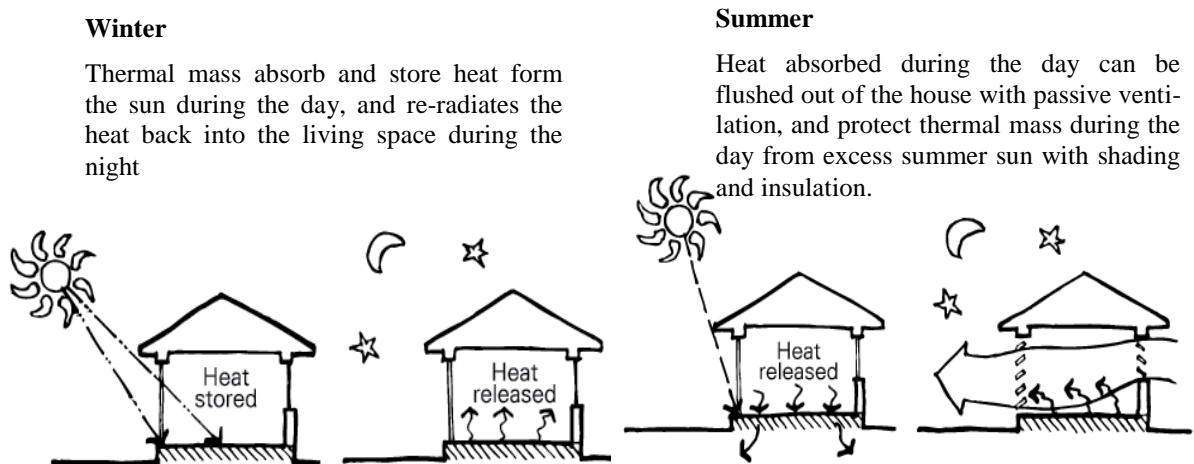
Figure 17: Effect of thermal mass on building inner air temperature. (Sustainability Institute, 2009. p.14)

Low thermal mass materials for the tropics are ideal since these materials reacts well to cooling breezes. Low thermal mass materials do not store heat but react quickly to external conditions. Timber, corrugated iron, and brick veneer are examples of some low thermal mass materials. However, it is possible to couple well insulated and thermal mass (shaded/unshaded) in innovative ways to achieve thermal comfort. "Good integrated design is the key." (Cairns Regional Council, n.d. Sheet 2)

2.2.5 Insulation

Thermal energy travels from hot to cold, therefore heat is lost from inside to outside in winter and cool air is lost in summer as heat tries to move indoors. (RSCP, n.d. 2013) When a passive building is well insulated, warm air is kept inside during the winter and cool air is kept inside during the summer (SEED, 2014). To be fully effective, insulation should be used in conjunction with other passive design techniques. "Insulation is an extremely cost effective measure and can pay itself back within a few years from the

savings on energy bills." (Cairns Regional Council, n.d., Sheet 2) Figure 18 illustrates the typical heat losses during winter and heat gains during summer without insulation in a temperate climate. (Mosher, M., and McGee, C., 2013) Insulation effectiveness is measured by R-values which measure the resistance to heat flow (Cairns Regional Council, n.d., Sheet 2). When choosing insulation, consideration should be given to the R-Value, the price per square meter, and whether it can be installed DIY or it must be done professionally. Some types of insulation should be installed with safety equipment such as masks and protective clothing. The insulation chosen should ensure that it suits the particular application and fits within the space available. The appropriate degree of insulation depends on the climate and building type. (Mosher, M., and McGee, C., 2013)
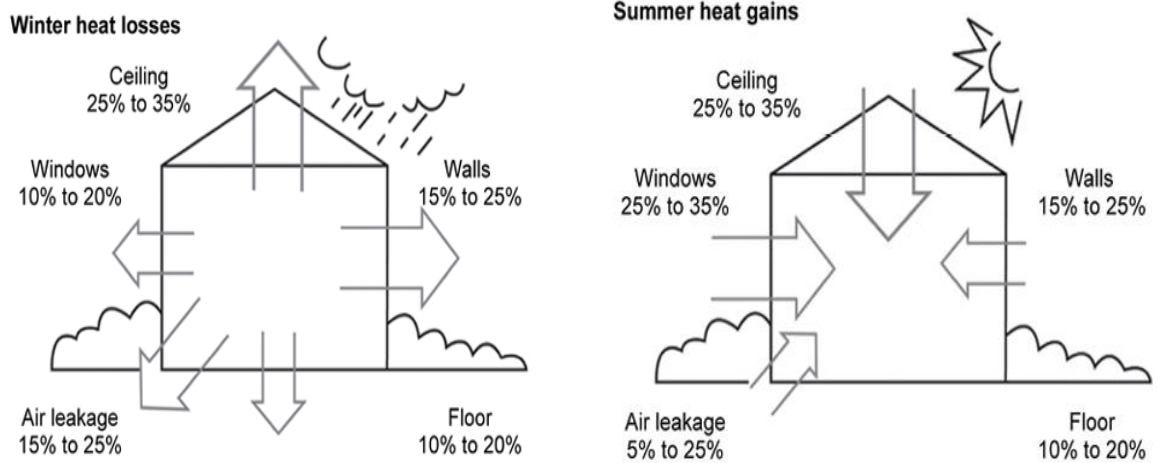
Figure 18: Typical heat losses and gains without insulation.

(Mosher, M., and McGee, C., 2013)

3   ENERGY GENERATING SYSTEMS

Renewable energy sources are obtained from different natural sources, and can be considered as a 'free' energy source with lower carbon emissions. Renewable energy sources such as wind and solar energy are constantly replenished and will never run out. Most renewable energy comes either directly or indirectly from the sun in the form of solar radiation. Solar radiation can be used for heating and lighting homes or buildings (known as passive solar discussed above), and generating electricity. The sun's heat also drives wind, whose energy is captured by wind turbines to generate electricity. The sun radiates a huge amount of energy towards the Earth, thus the sun can provide in about an hour the present energy requirements of the entire human population for a whole year. Renewable energy producing technologies are more effective when it is combined with other factors in an energy efficient structure such as adding passive solar techniques, appropriate insulation, and energy-efficient appliances. (Alternative Energy, 2014; Renewable Energy World, 2014)

The advantages of renewable energy sources are:
- these sources are renewable and easily regenerated, unlike fossil fuels which are perishable once used;
- energy such as solar produce clean energy that does not pollute the environment as no burning is required during energy usage;
- renewable energy are available everywhere throughout the world;
- renewable sources of energy boost economic growth and increase job opportunities.

The disadvantages of renewable energy sources are:
- the technology is costly and some have high maintenance costs;
- most sources are affected by weather and thus reduces their reliability;
- these technologies has difficulty in producing energy quantity that is equivalent to that produced by nonrenewable fuels. (Alternative Energy, 2014; Renewable Energy World, 2014)

3.1. Solar energy system

The sun radiates a huge amount of energy towards the Earth, thus the sun can provide in about an hour the present energy requirements of the entire human population for a whole year (Lynn, P.A., 2010). A PV solar system can be more effective when it is combined with other factors in an energy-efficient structure such as adding passive solar, appropriate insulation, and energy-efficient appliances. Photovoltaic solar systems can be and is used almost everywhere. These systems are stable, reliable, pollution-free, affordable, and it can be profitable in places where the excess power can be sold to a utility company. Solar is a sporadic power source which only functions when the sun is shining. Even with this limitation, PV power can be utilized successfully in cloudy parts of the world. (Findley, D.S., 2010)

3.1.1   Photovoltaic technologies

Photovoltaic (PV) cells or solar cells are the building blocks for a PV system, converting sunlight directly into electricity. PV cells are produced from materials called semiconductors. Semiconductor material is a substance which has electrical conductivity such as silicon. For many years silicon has been and still is the most common used material for solar cells in the PV industry. Silicon is an extremely common component of the Earth's crust but creating the semiconductor layer of the solar cell is expensive. The type of materials used and how these are formed is very important because any impurities will affect performance. (Lynn, P.A., 2010; Findley, D.S., 2010)

The crystallinity of materials indicates how perfectly the atoms in the crystal structure are ordered. Silicon and other semiconductor materials come in these main forms:

- Mono-crystalline or single-crystalline - are crystals that are repeated in a regular pattern from layer to layer. Solar panels produced from mono-crystalline are the most expensive to produce but also offers the highest efficiency, are long lasting, and degrade slowly. (Findley, D.S., 2010)
- Polycrystalline or multi-crystalline – are small crystals that are arranged randomly which is similar to shattered glass. These panels are made from pure molten silicon or silicon offcuts, using a casting process which creates a cell made up of several bits of pure crystal. Polycrystalline panels are slightly less effi-

cient than mono-crystalline panels, as the individual crystals are not necessarily all perfectly aligned together and therefore are losses at the joints between them. Because of the miss-alignment of the individual crystals the cells work better from light at all angels. (C Changes, n.d.) Polycrystalline silicon is utilized in an attempt to cut manufacturing cost; they are not as efficient as single-crystalline silicon but are in performance and degradation. (Findley, D.S., 2010; Toothman, J., and Aldous, S., n.d.)

- Thin-film or amorphous silicon – which is materials in these panels that have no crystalline structure (Findley, D.S., 2010). Thin-film panels can be made flexible and light weight (Wholesale Solar, 2013). This technology does not depend on the long expensive process of creating silicon crystals, it still does depend on silicon which has high levels of impurities and in turn reduces efficiency of the product. Due to the low efficiency more space and mounting hardware is required to produce the same power output as the crystalline silicone cells. (Findley, D.S., 2010)

Mono-crystalline and polycrystalline are the 'traditional' or 'first generation' technologies for solar panels and these are grouped into the category 'crystalline silicon'. Both, mono-crystalline and polycrystalline are the two major types of crystalline silicon solar cells currently in high volume production. (Wholesale Solar, 2013; Lynn, P.A., 2010)
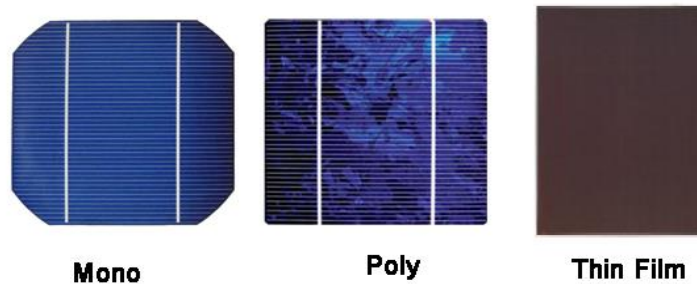
Figure 19: Main forms of solar cell technology (Pak Agro Tech, 2014).
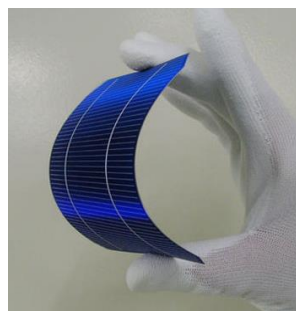
Figure 20: Thin-film PV cell (Electronics Lab, 2014)

The basic element of a PV system is the solar cell. Multiple solar cells are connected to form a module (a panel) where these modules are wired together in series to form strings. Multiple modules are connected to form a solar array (figure 21). (Endecon Engineering, 2001)
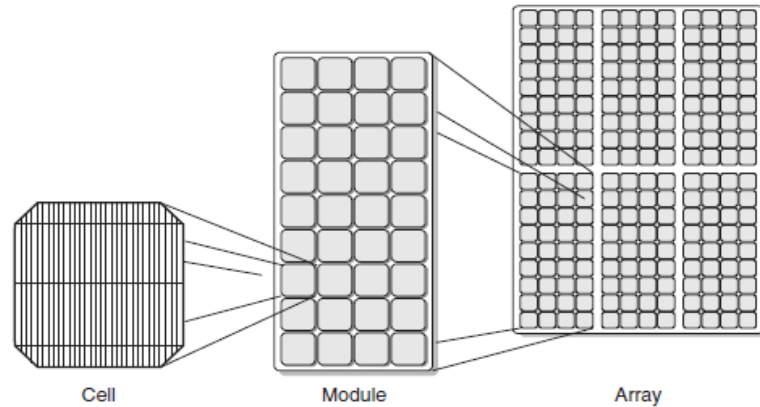
Figure 21: Photovoltaic cells, modules, array (Varkie, C.T., 2013).

The continuous change in module cost and efficiencies due to improved technology and manufacturing methods makes it difficult to provide a general recommendation. Although there are a number of different commercially available solar panel types, they all function in a similar way. The choice of panel to be purchased will depend on how much power is required, where the panels will be mounted, and how much space is available. (Findley, D.S, 2010) In the end it is the efficiency of any solar cell or module (the percentage of solar radiation it converts into electricity) which is considered one of the most important properties. This is especially important when space is limited and additional costs of PV systems such as mounting and fixing module are area related. (Lynn, P.A., 2010) According to Findley, the following numbers are the advertised percentages of efficiency for each of the different types of solar panels: monocrystalline 19%, polycrystalline 15 %, and thin-film 10%.

3.1.2 Mounting structure

PV modules and arrays need a secure mounting whether these are roof pole-mounted, ground-mounted, wall-mounted, or installed as part of a shade structure (Roos, C., 2009). A variety of static mounting structures are available and each has their own pros and cons (Lynn, P.A., 2010). Take for example: roof mount structures typically keep the wire length between the solar array and battery bank or inverter to a minimum but they

may require roof penetrations in multiple locations and expensive ground fault protection devices, ground mounted solar arrays require a fairly precise foundation setup and more susceptible to theft/vandalism and excessive snow accumulation at the bottom, pole mounts are relatively easy to install are a better choice for cold climates because snow slides off easily and it reduces the risk of theft/vandalism. (Wholesale Solar, 2013)

When considering mounting structures, space should be left at the back of the PV modules for air circulation (Lynn, P.A., 2010). To maximize daily energy output, PV panels should face true South in the Northern hemisphere, or true North in the Southern hemisphere. PV panels are also mounted and oriented at an angle for optimum solar collection, as more electricity is produced when the sunlight is more intense and/or strikes the PV panels directly at a perpendicular angle. Solar panels installed at an angle assist in keeping the panels clean by shedding rain or snow. (Roos, C., 2009)

3.1.3   Tilt angle

The angle at which a PV system is installed depends on the latitude of the area. A factor that needs to be taken into account is the season as the sun is in different portions or elevations in the sky throughout the year. (Findley, D.S., 2010) The tilt and orientation does not need to be perfect as PV modules produce 95% of their full power when within 20 degrees of the sun's direction. An optimum tilt of a solar array can achieve yearly maximum output of power. In the winter months an increased tilt favors power output where in the summer months a decreased tilt favors output. (Roos, C., 2009) Tilted PV panels can be fixed or adjustable seasonally. A tracking system can be installed to track the movement of the sun throughout the day but this will increase the cost of a solar system. By adjusting the tilt twice or four times a year can give a meaningful boos in energy as illustrated in table 1. (Landau, C.R., 2014)

Table 1: The effect of adjusting the angle of a solar panel.

	Fixed	Adj. 2 seasons	Adj. 4 seasons	2-axis tracker
% of optimum	71.1%	75.2%	75.7%	100%

(Landau, C.R., 2014)

A tilt angle rule of thumb

A simple tilt angle calculation that can be used for adjusting the tilt angle twice a year is the tilt angle rule of thumb. The rule of thumb is: the latitude of the location, plus 15 degrees in the winter and minus 15 degrees in the summer. It has to be kept in mind that this calculation is only an estimate and the sun angles differs during the year and can affect the output of the solar array. (Landau, C.R., 2014)

Online tilt angle calculator

The tilt angle can also be calculated by an online solar angle calculator. The calculator presents the optimum tilt angle for each month according to the country and city. It also illustrates the optimum tilt angle for winter, summer, and spring/autumn. The figures and values are shown in degrees from a vertical axis. These values can be utilized directly if the solar panels are pole-mounted or mounted on the side of a building. When the tilt angle is needed from a horizontal axis, such as with roof-mount or ground-mounts, a simple formula can be utilized:

Angle from horizontal axis = 90° – Angle from vertical axis

Link: http://solarelectricityhandbook.com/solar-angle-calculator.html

Table 2 below supplies a schedule which indicates when the angle can be adjusted according to season.

Table 2: Estimated time-line for adjusting the tilt angle accordingly.

	Northern hemisphere	Southern hemisphere
Adjust to summer angle on	April 18	October 18
Adjust to autumn angle on	August 24	February 23
Adjust to winter angle on	October 7	April 8
Adjust to spring angle on	March 5	September 4

(Landau, C.R., 2014)

3.1.4 Factors affecting the output of a solar system

The output of PV panel is rated and tested at the factory under Standard Testing Conditions (STC). These conditions are easily recreated in a factory but do not include factors such as ambient and cell temperature and irradiance that affect the output of modules in the real world. Actual conditions will rarely match rated conditions and thus actual power output will almost always be less. STC ratings provide a basis for comparisons of products. The STC conditions are: solar cell temperature = 25ºC; solar irradiance (intensity) = 1 000 W/m²; and solar spectrum as filtered by passing through 1.5 thickness of atmosphere. The output of a PV panel is also affected by battery efficiency, inverter efficiency, and wiring losses due to resistance. Module mismatch also affects the output and is due to slight inconsistencies in performance from one module to the next. (Roos, C., 2009; Davidson, J., and Orner, F., 2008.)

Photovoltaic panels are affected by shading, thus a well-designed system needs clear and unobstructed access to the sun. According to Roos, C., 2009, even a small shadow can reduce the power output of a solar module. A shadowed cell still carry string current as it is part of a series with all the other operating sell, but without internally generated voltage, the shadowed cell cannot produce power (acts as a load instead) and the remaining cells in the string must work at a higher voltage to make up for the loss (Patel, M.R., 2006). It also has to be kept in mind that an area may be unshaded during one part of the day may be shaded at another part of the day, and a site that is unshaded during summer time may be shaded in the winter due to longer winter shadows. (Ross, C., 2009)

Another factor to consider is the temperature of a solar panel. It is ironic but the hotter the panels gets, less energy can be produced. When a solar panel temperature increases, its output current increases exponentially, the voltage output in turn reduced linearly as power is equal to voltage times current. In some cases the heat factor can reduce output by 10 – 25% depending on the location. Not all solar panels are affected by heat equally as the power loss due to temperature is also dependent on the type of solar panel being used. The recommended operating use is 25ºC. When acquiring a solar panel, the manufacturer's data sheet should display the 'temperature coefficient Pmax'. This means that for each degree over 25ºC, the maximum power of the panel is reduced by that value. (Solar facts and advice, 2013)

Dirt and dust that accumulate on solar array surface can block some of the sunlight. Certain airborne particles may be abrasive and scratch the surface of the solar modules which can cause permanent damage when not removed. Other organic deposits can become wet and cause potential corrosion. Allowing build-up can lead to overheating inside solar modules, called hot spots. Hot spots cause the same effects as shading. Although dirt and dust is cleaned off during the rainy season, rainfall alone does not suffice to properly clean and maintain solar modules. In addition, rain may itself leave mineral deposits on solar models after evaporation. Thus solar panels should be cleaned frequently, but the frequency by which it should be cleaned depends on the location and environment in which they are placed. (Sol Clean, 2011; Endecon Engineering, 2001)

3.1.5 Site evaluation

Solar is universal and will work virtually anywhere, but some areas are more suitable for solar panels than others. Irradiance is a measure of the sun's power available at the surface of the earth (peaks at 1000 w/m²), and insolation is a measure of the available energy from the sun which is expressed in terms of 'full sun hours'. Take for example, 4 full sun hours equals 4 hours of sunlight at an irradiance level of 1000 w/m². Different parts of the world receive more 'full sun hours' per day than others. By utilizing a solar insolation zone map (figure 22) will give a general idea of the 'full sun hours' per day at a location. (Wholesale Solar, 2013)
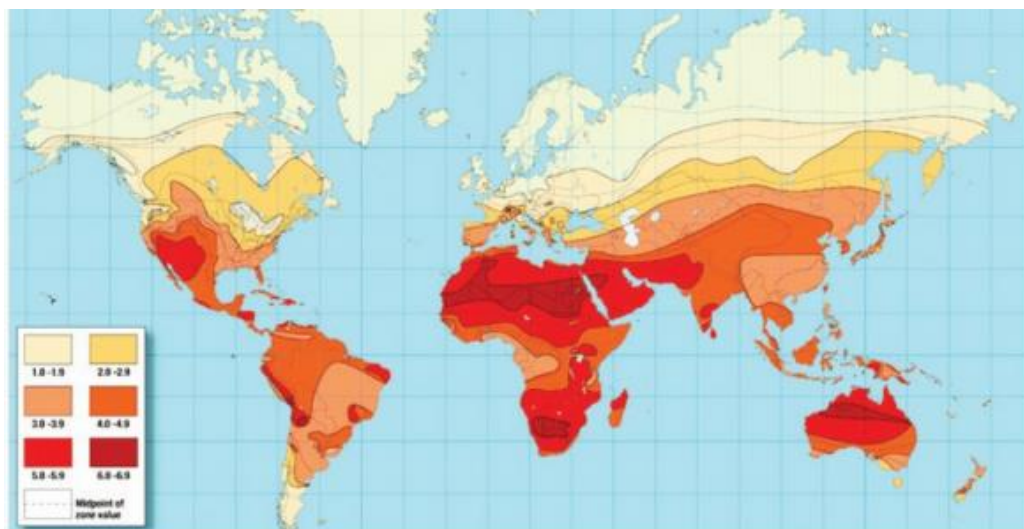
Figure 22: Solar insolation map - The amount of solar radiation throughout the world with color-tone shading. (Ember LED, n.d.)

Even though the sun is up for 12 hours a day at certain locations, all these hours are not considered as full sun hours. Early morning and late afternoon sunlight shines through more atmosphere than at midday and also the angle of the sun is too sharp relative to the surface of the solar panels. (Roos, C., 2009; Wholesale Solar, 2013) It has to be noted, a solar module can produce up to 80% of its full sun power on partly cloudy days, and even with heavy clouds on an extremely overcast day it can produce about 30% power. (Roos, C., 2009)

The online links supplied below can be used to find peak sun hour charts for more accurate data according to a specific location:

World Climate and Temperatures - http://www.climatemps.com/

World Weather and Climate Information - http://www.weather-and-climate.com

Solar Irradiance Calculator - http://solarelectricityhandbook.com/solar-irradiance.html

3.2. Wind energy system

The terms 'wind energy' or 'wind power' describes the process by which natural wind in the atmosphere is captured and converts the wind's kinetic energy into mechanical/rotational energy and then electricity (Wind Energy Development, n.d.). Wind turbines are mounted on a tower to take advantage of faster and less turbulent wind and capture the most energy. When the wind blows past a turbine it catches the wind's energy with its propeller-like blades and rotates. There are usually two or three blades mounted on a shaft to form a rotor. As the wind blows, a pocket of low-pressure air is formed on the downwind side of the blade, the low-pressure air pocket pulls the blade toward it which causes the rotor to turn, and this is called lift. The force of the lift is much stronger than the wind's force against the front side of the blade, called drag. Thus the combination of lift and drag causes the rotor to spin like a propeller (figure 23). The rotation triggers an internal shaft to spin, connected to a gearbox, connected to a generator that ultimately produces electricity. Wind energy has become the least expensive source of new electric power that is also compatible with environment preservation programs (Patel, M.R., 2006). But since wind energy is affordable the greatest disadvantage is that is not accessible everywhere. (American Wind Energy Association, 2013; Renewable Energy World, 2014; Sautter, E., n.d)
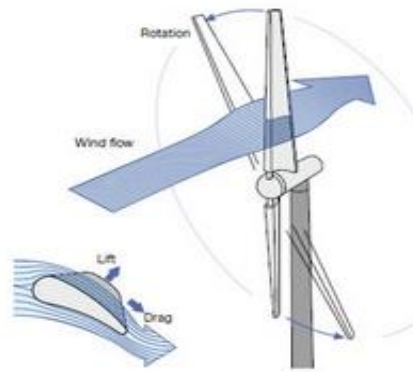
Figure 23: Pressure difference (Clean Energy Brands, 2014).

3.2.1 Wind turbine technologies

Wind turbines are available in an assortment of types and sizes. Basically small home-sized or distributed wind turbines are used to directly power a home, farm, or small business as its primary use. Small home-sized turbines have rotors between 2,5 and 8 meters in diameter, can stand 9 meters tall, and are 50 kilowatts or smaller. (American Wind Energy Association, 2013; Wind Energy Development, n.d.) Wind turbines can further be classified according to their type of design. There are various small-scale wind turbine types in operation today. They all operate on similar principles but fall into two basic groups; horizontal-axis turbines and vertical-axis turbines (figure 24):

- Horizontal-axis turbines - are the most common turbine used today and most of these are two-or three-bladed. The blades are typically made of fiberglass, glass polypropylene, or some other composite material. The turbine consists of a tall tower, rotor, generator, controller, and other components. These turbines utilizes a fan-like rotor that faces into or away from the wind and are placed high atop a tower to take advantage of stronger and less turbulent wind The amount of power these turbines will produce is determined by the diameter of the rotor, in other words, the 'swept' are or the quantity of wind intercepted by the turbine.
- Vertical-axis turbines have blades that go from top to bottom. These turbines make up only a very small share of the wind turbines today. Vertical-axis turbines are available in two types, Savonius and Darrieus. (Wagner, HJ. & Mathur, J., 2009; U.S. Department of Energy, 2013)
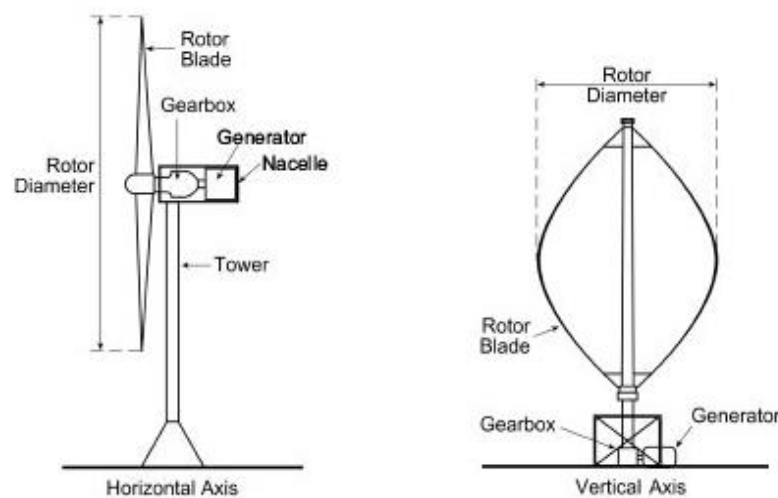
Figure 24: Horizontal-axis and Vertical-axis wind turbines
(The Scottish Government, 2006).

The basic theoretical advantages of a vertical-axis turbine are that the generator, gear-box, etc. can be placed on the ground and that a yaw mechanism is not needed to turn the rotor against the wind. But the basic disadvantages of vertical-axis turbine are:

- the need of a tower is eliminated, but the wind speed will be very low on the lower part of the rotor;
- the overall efficiency of the vertical-axis turbine is less than that of a horizontal-axis turbine;
- it is not self-starting. For example a Darrieus machine will need a 'push' before it starts. When the turbine is grid connected this is only a minor inconvenience since the generator may be used as a motor drawing current from the grid to start the machine
- the machine may need guy wires to hold it up (Wagner, H.J. & Mathur, J., 2009).

3.2.2 Mounting structure

There are two types of domestic-sized or home-sized wind turbines:

- Pole mounted/mast-mounted/free-standing – these turbines are free standing and are erected in a suitable exposed position.
- Building-mounted/roof-mounted – these turbines are smaller than mast-mounted systems which can be installed on the roof. Often these types are around 1kW to 2kW in size. (Energy Savings Trust, 2014)

It should be noted that wind turbines mounted to structures vibrate and transmit vibrations to the structures. This can lead to noise disturbances within the building. When a wind turbine is roof-mounted, it is an area of increased turbulence which can shorten the life of the turbine and reduce energy production. Additional costs to mitigate these concerns can lead to increased total cost of the installation. (OpenEI, 2013)

There are two types of towers; self-supporting (free-standing) and guyed (anchored) towers (figure 25). Most home wind power systems use guy towers. Guyed towers are less expensive than self-supporting towers and they are easier to install. These towers consist of lattice sections, pipes, or tubing (depending on the design); support guy wires; and the foundation. Guyed towers require space to accommodate them because the radi-

us must be one-half to three-quarters of the tower height. There are also tilt-down towers available but these are more expensive. They offer an easy way to perform maintenance and it is useful during hurricanes and other hazardous weather conditions when it necessary to lower the turbine. A lot of manufacturers provide wind energy system packages that include a range of tower options. (OpenEI, 2013; U.S. Department of Energy, 2012)
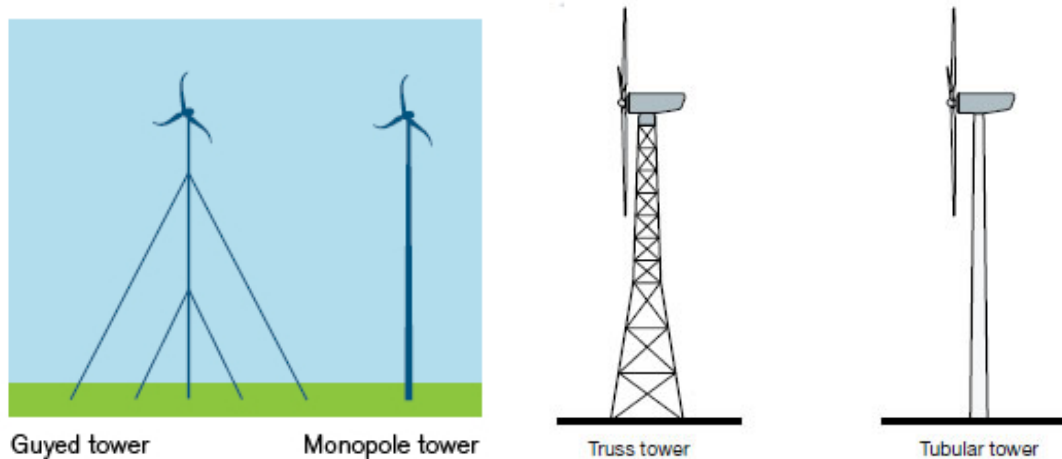
Figure 25: Types of towers (Wind Power Systems, n.d.; Clean Energy Brands, 2014).

The tower needs to be as tall as possible as the wind speed increases with height (OpenEI, 2013). When siting the wind turbine, it should also be erected as far away from local turbulence causing obstructions such as large trees, buildings, and hills. Extreme turbulence or 'bad winds' can cause fatigue damage and can shorten the turbine's working life. If erecting the wind turbine far away from obstructions is not possible, the other option is to use a taller tower to ensure that the turbine is well above these obstructions which gives the turbine access to cleaner and stronger wind resource. Therefore it is advisable to erect the turbine as high as the zoning laws and the initial investment allow. Since taller towers increases the cost of a wind turbine system, it is best to evaluate the overall energy and cost payback before investing in taller towers. (Energy Matters, 2012)

3.2.3   Minimum tower height consideration

It is recommended to site the wind turbine at least 6 m (20 feet) above any surrounding obstacles such as trees or buildings in a 76 m (250 feet) radius (illustrated by figure 26).

Trees and taller structures can be down-wind from the wind generator. The result is an entry level tower height that should be considered and not seen as the optimal height. This gives an indication of the minimum tower height that might be needed to overcome the effect of obstacles and the turbulence they create. (Energy Matters, 2012)
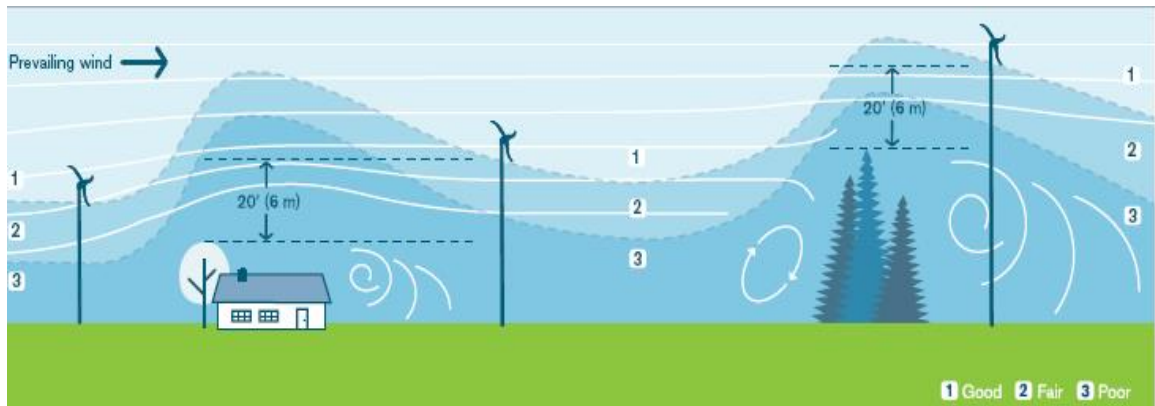
Figure 26: Siting wind turbine (Energy Matters, 2012)

Take into consideration a few invariable complications. The following situations include:

- The largest obstacles that usually pose a problem are trees. Not just the current height of the surrounding trees needs to be known, but also the mature height for these trees. Or the growth of these trees over the 20 – 30 year life of the wind turbines system.

- If the specific are has a prevailing tree line or the area consists of 50% tree cover, the tree line becomes the effective ground level for the tower and should be sized accordingly.

- The strongest seasonal winds in most locations come from one to several prevailing wind directions. The wind turbine can be sited upwind of obstacles towards the prevailing wind directions. This may compromise occasional winds from other directions, but it reduces the effect of turbulence from trees and buildings. (Sagrillo, M., 2009) Tower height always is "site specific."

Velocity at different height estimation

Wind resources are measured at certain height and the measured height might not be at the same height as where the wind turbine is going to be located. Wind is strongly affected by obstacles on the ground and the surface roughness. Higher above the ground the wind is no longer influenced by the surface, approximately 5 km above ground.

Wind speed changes between these two extremes and this phenomenon is called vertical wind shear. (The Swiss Wind Power Data Website, n.d.)

The formula below can be used to estimate the velocity at different heights and by estimating the wind velocity at a different height, the power output at that height can be estimated. Since a taller tower will increase the productivity of any wind turbine by giving it access to higher wind speeds as shown in the Wind Speeds increase with Height graph. Estimating the power outputs at different heights, such as the minimum tower height rule of thumb, a bit taller or a bit shorter, can give some indication on the tower height which will fit the bank.

$$v_2 = v_1 \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)}$$

where v_2 is the wind speed at a certain height (h_2), and v_1 is the wind speed at a measured height (h_1). Z_0 is the roughness length that can be selected according to a roughness class supplied in the table 3 below. (The Swiss Wind Power Data Website, n.d.)

Table 3: Roughness Classes and Lengths

Roughness class	Roughness length (Z_0)	Land cover types
0	0.0002 m	Water surfaces: seas and lakes
0.5	0.0024 m	Open terrain with smooth surfaces, e.g. concrete, airport runways, mown grass, etc.
1	0.03 m	Open agricultural land without fences and hedges; maybe some far apart buildings and very gentle hills.
1.5	0.055 m	Agricultural land with a few buildings and 8 m high hedges separated by more than 1 km.
2	0.1 m	Agricultural land with a few buildings and 8 m high hedges separated by approx. 500 m.
2.5	0.2 m	Agricultural land with many trees, bushes and plants, or 8 m high hedges separated by approx. 250 m.
3	0.4 m	Towns, villages, agricultural land with many or high hedges, forests and very rough and uneven terrain.
3.5	0.6 m	Large towns with high buildings.
4	1.6 m	Large cities with high buildings and skyscrapers.

(The Swiss Wind Power Data Website, n.d.)

Wind Profile Calculator - http://wind-data.ch/tools/profile.php?lng=en

3.2.4 Factors affecting the output of a wind turbine

The earth's surface roughness and obstacles slow winds down and therefore decrease wind energy efficiency. The earth surface roughness affects wind speed due to the friction against the surface of the earth. Obstacles affect wind speed due to the occurrence of turbulence and also impose more wear and tear on the wind turbine. The slowdown effect on wind from an obstacle increases with the height and length of the obstacle. Generally the slowdown effect is more pronounced close to the obstacle and close to the ground. This is why towers for wind turbines are usually made tall enough to avoid turbulence. (Wagner, HJ. & Mathur, J., 2009)

There is also the difference in wind directions near the surface. Sea breezes, mountain breezes and 'tunnel effects' influence the flow of wind patterns close to the surface of the earth. A tunnel effect occurs when air becomes compressed on the windy side of buildings or mountains, and the speed increases considerably between the obstacles to the wind. By placing a wind turbine in such a tunnel is one way of obtaining higher wind speeds than in the surrounding areas. But to obtain a good tunnel effect the tunnel should be 'softly' embedded in the landscape, as turbulence may negate the wind speed advantage completely. (Wagner, HJ. & Mathur, J., 2009)

The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed. The figure below illustrates a formula showing the variables that determine the power in the wind going into the wind turbine.

$$\text{POWER IN THE WIND} = (\text{DENSITY OF AIR}) \times \left(\text{TURBINE BLADE DIAMETER}\right)^2 \times \left(\text{VELOCITY OF WIND}\right)^3 \times (\text{A CONSTANT})$$

$$\text{POWER IN THE WIND} = d \times D^2 \times V^3 \times C$$

Figure 27: Variables determining the power in the wind (Watson, D., 2010).

Density of air

Air density changes slightly with air temperature and elevation. Air density increases the colder it gets and it decreases the warmer it gets, thus the denser or 'heavier' the air, the more energy is received by the turbine. (Wagner, HJ. & Mathur, J., 2009) Ratings for wind turbines are based on standard conditions of 15°C at sea level and a density

correction can be made. According to the International Standard Atmosphere (ISA), air has a density of approximately 1.225 kg/m³ at sea level and at 15°C.

Turbine blade diameter / Rotor swept area

The rotor area determines how much energy a wind turbine is able to harvest from the wind. If the swept area is doubled, the power it produces is also doubled. Thus the basic idea is when the rotor area increases it might increase the energy output. (Carbon Trust, 2008; Wagner, HJ. & Mathur, J., 2009)

Velocity of wind / Wind speed

Wind speed is always fluctuating and due to this phenomenon the energy content of the wind is always changing, in other words, the energy output from a wind turbine varies as the wind vary. The wind speed is illustrated as a function to the power of 3, thus if the wind speed doubles the power is increased eightfold ($2^3=8$). This demonstrates how sensitive power is to wind speed and why it is of utmost importance to understand the wind conditions in the site location when considering wind turbines. (Carbon Trust, 2008; Wagner, HJ. & Mathur, J., 2009)

A constant (Betz limit) / Efficiency

Wind energy is generated by the flow of air over the blades and through the rotor area. The wind turbine extracts the kinetic energy in the wind by slowing it down. If a wind turbine was 100% efficient by converting all the wind's kinetic energy to mechanical energy, the velocity leaving the turbine would be zero. In other words there is no kinetic energy left in the wind and there is no wind. Therefore a wind turbine would not work. The theoretical maximum amount of energy that a wind turbine can collect from the wind is approximately 59%, otherwise known as the Betz limit. (EnergyBible, 2012; Watson, D., 2010)

The collection efficiency of a turbine in practice is not as high as 59%. A specific wind turbine has a 'design point'. It is the peak efficiency at a wind speed for which the system is designed. The efficiency is the same or less at wind speeds above and below the design speed. At all other wind speeds the efficiency will be worse. Generally wind turbines operate at lower than best efficiency, as wind speeds are never constant or average. The efficiency decreases even more when taking into account the energy losses in a complete wind energy system. (EnergyBible, 2012; Watson, D., 2010) The system

components has less than perfect efficiencies and according to the Carbon Trust, anecdotal evidence suggests that the capacity factor for a small-scale wind turbine generally ranges between 12 – 20% or less than 25%. (Carbon Trust, 2008)

3.2.5 Site evaluation

Wind turbines can be an effective source of renewable power in many areas across the world. Before considering a small wind turbine system for a specific site, the following conditions should be determined beforehand: there is at least a 4.5 m/s average wind speed (best at 5.4 m/s or more), the property is unobstructed from tall buildings and trees, the property has enough space for erecting the tower, and the local zoning allows a structure that is at least 12 m tall. A proper site for a small wind turbine system is critical to its performance and longevity. (Energy Matters, 2012)

Determining the wind resource can be done by utilizing Meteorology data. Ideally in terms of a wind rose which was calculated over 20 – 25 years would probably be the best guide, but care should be taken when using meteorology data. The wind data collected by meteorologists is for weather forecasts and aviation, where this information is often used to assess the general wind conditions for wind energy in a specific location. Therefore it is difficult to estimate wind conditions at a nearby site and should be used as an indication of what the wind resource is at the specific location. According to Wagner and Mathur, in most cases using meteorology data directly underestimate the true wind energy potential in an area. (Wagner, H.J. & Mathur, J., 2009)

Wind resource data can also be obtained from local weather stations or universities. It is recommended not to use airport data as a source, since airports are generally located in lower wind areas such as valleys and their measurement techniques do not produce good data. Another method that can be used collectively with wind maps or local data is by looking around and observing the deformation of vegetation and trees on and around the specific site. The Griggs-Puttnam Index was a scientific study, where the wind resource at a particular site can be determined by looking at how wind deforms the vegetation (figure 28). Conducting an actual wind resource assessment at the specific site would by far be the most accurate strategy, but it is also the most expensive and time consuming (hiring someone or DIY). (Energy Matters, 2012)
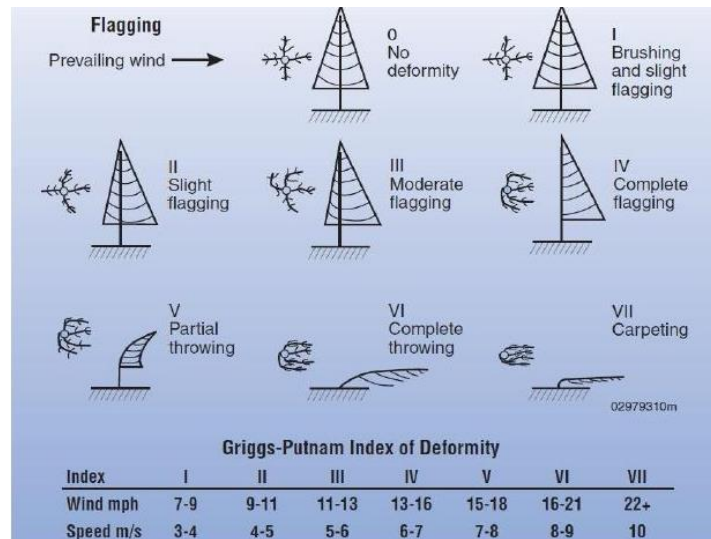
Figure 28: The Griggs-Puttnam Index deformity chart
(Silverford Renewable Blog, 2012)

A wind turbine should be erected in the most optimum place. The ideal position would be (figure 29):

- a flat open space with good wind from at least one direction known as the prevailing wind direction. Winds running off a cliff may be very turbulent, causing wind shears, therefore it is very important to site the generator far enough from a cliff to avoid turbulent wind;

- a coastline, typically very strong prevailing winds blow from the ocean and for this reason it is important to install the wind turbine as close to the coastline as possible; or

- a smooth hill top with an open area in the prevailing wind. Near the top of a hill, the wind compresses as it blow over the top and the wind speeds up significantly. With proper placement the air flow should be reasonably smooth and free from excessive turbulence and a shorter tower can be used. (Energy Matters, 2012)
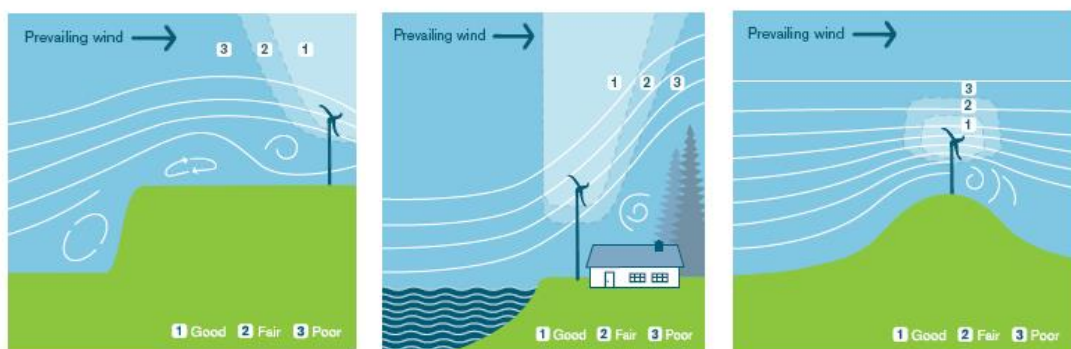
Figure 29: Three typical siting considerations (Energy Matters, 2012).

3.3. System connection

The electricity generated by solar panels or wind turbines can be stored, used directly, fed back into the grid line, or combine with other electricity generators. Energy generating systems includes different components (explained in section 3.4), that should be selected according to the system type, location, and application. (Roos, C., 2009) These systems can generally be divided into two major categories: grid-connected and stand-alone systems. A grid-connected system is interfaced to an electricity grid and a stand-alone system is self-contained. (Lynn, P.A., 2010)

The grid-connected or grid-tied systems are the most common type of PV and wind turbine systems (figure 30). The PV or wind turbine system and the grid acts in harmony and there is an automatic, seamless back and forth flow of electricity according to sunlight/wind conditions and the electricity demand. With this type of system connection the PV array or wind turbine does not need to produce 100% of the electricity demand and allows users to utilize energy from the electricity grid when required. The excess output from these renewable sources can be fed into the grid when it is not required. (Lynn, P.A., 2010) Thus a net metering agreement with the utility company can be completed where this agreement allows utility customers to receive credit for their excess energy generated. Net metering policies and agreements are different for each country and utility. (Roos, C., 2009)
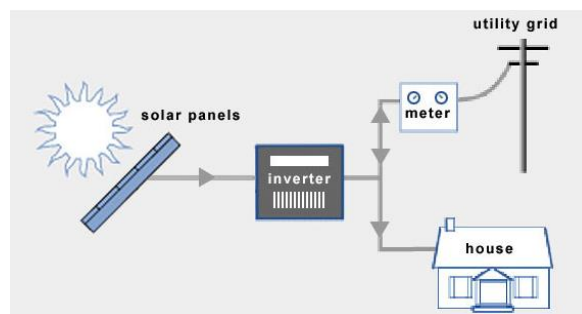
Figure 30: A grid-connected solar system (Wholesale Solar, n.d.)

Grid-tied systems without battery backup are the simplest, most reliable, and least expensive configuration. But this type of system will shut down when a utility power outage occurs, where on the other hand, a system with battery back-up can maintain power to some or all of the electric equipment. Adding batteries to a system comes with several disadvantages such as: batteries consume energy during charging and discharging which reduce the efficiency and output of the system; batteries increases the complexity

of the system and the cost; batteries require maintenance; and batteries will usually need to be replaced before other parts of the system. For this reason the disadvantages must be weighed against the advantage of power back-up. (Roos, C., 2009)

Stand-alone systems (figure 31) can be more cost-effective in remote locations than extending a power line to the electricity grid, but can also be used to obtain independence from the power provider or demonstrate a commitment to non-polluting energy sources.
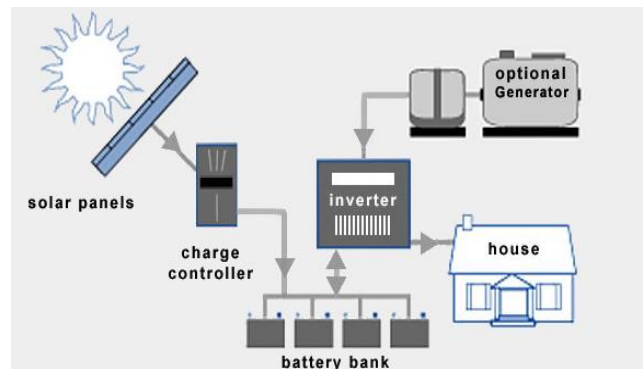
Figure 31: Stand-alone solar system (Wholesale Solar, n.d.).

Another type of stand-alone system is known as a hybrid system (figure 32). The main purpose of a hybrid power system is to combine multiple electricity generating sources to generate 100% of the electricity demand. PV and wind turbine systems can be connected with each other, or it can be connected with another source of power, and are more likely to produce power when required. When neither the PV and wind turbine produce electricity, power can be provided through batteries and/or an engine-generator powered by fossil-fuel like diesel. Adding an engine generator makes the system more complex. Modern electronic controller can operate these systems automatically and adding an engine generator can also reduce the size of the other components needed. Hybrid systems can also be connected to the utility grid. (Wagner, HJ. & Mathur, J., 2009)
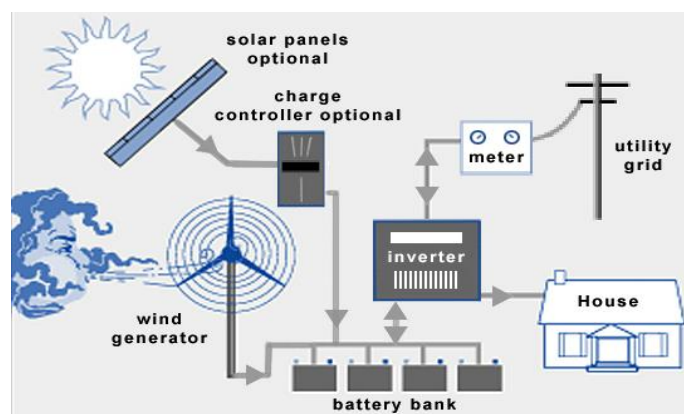
Figure 32: Hybrid system, grid-tied with a battery bank (Wholesale Solar, n.d.).

3.4. System components

As mentioned before, energy generating system includes different components that should be selected according to the system type. Additional items are required to complete a system which is essential to a properly engineered installation. These are generally referred to as Balance-OF-System (BOS) equipment. The BOS equipment can include an inverter, charge controller, batteries, etc.). BOS equipment are also the additional costs to the energy generating equipment and mounting structures, including parts and labor which will depend on the specific application. Some manufacturers do supply system packages that include all the parts necessary for specific applications.
 (Lynn, P.A., 2010)

3.4.1   Inverter

Inverts are used to convert direct current (DC) to alternative current (AC). PV modules, some wind turbines, and batteries produce DC power, where appliances use AC power. For this reason, an inverter is one of the most important equipment in a system connection. Inverters used in a grid-connected system are not suitable for stand-alone systems. Stand-alone system inverters are not as constrained as grid-connected inverters, for the basic reason that the inverter receives power from the battery bank which has more or less constant DC voltage. Grid-connected inverters are designed to connect to the utility grid. Thus grid-connected inverters can also be divided into two types, inverters designed to be used with batteries and inverters designed for a system without batteries. (Lynn, P.A., 2010)

Grid-tied inverters receive energy from the utility grid, receives energy from the renewable energy sources or a battery bank, and it can also feed the excess energy generated back into the utility grid. Grid-tied inverters not only convert DC to AC, but also generate AC at precisely the right frequency and phase to match the grid supply and for the use in appliances. These types of inverters must be able to handle a wide range of energy output from PV modules and/or wind turbines, in other words, fluctuating power output according to the sunlight and wind conditions. This is done by using maximum power point tracking (MPPT) to optimize the energy yield.(Lynn, P.A., 2010) The MPPT automatically adjust the system voltage and when selecting an inverter the

MPPT capability should be considered. Sizing and selecting grid-tied inverters entail different considerations, but it is easier since the system does not have to provide 100% of the energy demand and peak energy demand and surge capacity does not need to be taken into account. (Roos, C., 2009)

Micro inverters are also available which is directly attached to the individual panels in a PV array making each module its own AC power source. Micro-inverters have several advantages over conventional central inverters. The main advantage of micro-inverters is that it can be used to get the most power from a PV system. Shading, debris, snow lines, or malfunctions from one panel will not affect the output of the entire PV array. Thus each inverter harvest its optimum power by performing MPPT for its individual connected panel. Another advantage is that instead of sizing an inverter to a specific number and overall wattage of solar panels, the size of the solar electric system can be increased and panels of different wattages and manufacturers can be added. Since a micro-inverter is installed on each solar panel, the total cost for these micro-inverters can be more than for a central inverter. Another disadvantage can be life reduction due to high temperatures when a PV array is installed on the roof. (AMECO Solar, 2014)

3.4.2 Batteries

Stand-alone systems need a battery bank to provide power at night and cloudy or windless days. If a system is grid-connected, a battery bank is not necessary unless it is used as a back-up emergency power. Batteries is an electrical storage device and come in many shapes and sizes, but they all have one thing in common, they store direct current energy for later use. (Davidson, J. & Orner, F., 2008) This energy storage comes at a cost, it reduces the efficiency output (about 10%), it increases the complexity of the system, and it also increases the cost. In general, battery backup in grid-tied systems can be smaller since it is only used when there is a power outage. The types of batteries used are:

- Lead-acid batteries
  - Flooded or liquid vented (FLA), unsealed with liquid electrolyte
  - Sealed or valve-regulated lead acid
  - Absorbent Glass Mat (AGM), sealed with electrolyte held captive by glass mat

o Gel cell (VRLA), sealed with gel electrolyte
- Alkaline batteries
    - o Nickel-cadmium
    - o Nickel-iron

Each type of battery has its own benefits, drawbacks and requirements. The most common batteries used in the systems in general are lead-acid batteries. The comparisons between the three different lead acid batteries are summarized in table 4. (Solar Town, 2012; Roos, C., 2009)

Table 4: Comparison Chart – Lead acid batteries

	Lifespan (if well cared for)	Minimal Gassing	Spill Proof Rating	Flexibility in Mounting	Charging Voltage Sensitivity	Maintenance	Price
Flooded	3	1	1	1	3	1	3
Gelled	2	3	3	2	1	3	2
AGM	2	3	3	2	2	3	1

Rating: 1 – Poor; 2 – Good; 3 - Excellent

(Solar Town, 2012)

Alkaline batteries are more expensive, but they are only recommended in extremely cold temperatures (-45°C or less) or for certain commercial or industrial applications. Their advantages over lead-acid batteries include tolerance of freezing or high temperatures, low maintenance requirements, and the ability to be fully discharged or overcharged without harm. (Roos, C., 2009)

High-quality lead-acid batteries should be utilized for stand-alone systems. These batteries must have long working lives under frequent conditions of charge and discharge. During long cloudy periods or winter months, the batteries must also display low self-discharge rates and high efficiency. A rule of thumb, the faster the discharge the lower the capacity. The most energy derived form a battery is by discharging it as slowly as possible. The capacity of a battery also depends on the temperature, where the rated capacity normally applies to 20°C and reduces by about 1% for every degree drop in temperature. (Lynn, P.A., 2010)

When sizing a battery bank for an off-the-grid system, it is usually sized for one to three cloudy days. In the other hand, battery bank sizing for grid-connected systems, it is for relatively short periods of time such as 8 hours being typical. Depending on the particular needs of a facility and the length of power outages expected, sizing may vary. In a PV system the solar array must have a higher voltage than the battery bank in order to fully charge the batteries. Another consideration is the wiring distance between the modules, the charge controller and the battery bank, since higher voltages may be required for long wiring distances. (Roos, C., 2009)

An ideal battery storage area has the following characteristics:

- good ventilation, even in a plastic storage box,
- not near any open flames,
- no possibility for electrical sparks,
- easy to maintain and inspect,
- tidy and easy to clean, kept at 15,5 to 21.1ºC,
- out of reach of non-authorized personnel, and
- has an up-to-date fire extinguisher handy. (Davidson, J., and Orner, F., 2008)

3.4.3   Charge controller

A charge controller is also sometimes referred to as regulators or a battery charger. A charge controller is only necessary in a system with battery back-up as it protects batteries from damage and prolongs its working life. The primary function of a charge controller is to prevent the overcharging batteries when the electricity supply exceeds demand, and over discharging when demand exceeds supply. Charge controllers also prevent charge from draining back to solar modules and wind turbine when these components do not produce electricity. Depending on the price and sophistication of the charge controller, various subsidiary control and display functions are included to protect the batteries and ensure an operating regime that maximizes the performance and length of life. Since batteries are an expensive part of a system, especially in stand-alone systems, the modest cost of a good charge controller is money well spent. (Lynn, P.A., 2010; Roos, C., 2009)

There are four types of charge controllers: shunt, series, pulse, and maximum power point tracking.

- A shunt controller is a solid-state device with a transistor in parallel to the array. It directs the excess current produced to an earth ground, a power dissipating heat sink, or another load. Shunt controllers are simple, inexpensive, and are only designed for very small systems (Roos, C., 2009).

- Series controllers usually have a relay or switch transistor in series between the PV array and the battery. This device switches array current on and off.

- Pulse controllers also connect in series like the series controller but this device rapidly switch or pulse the array current on and off.

- Maximum power point tracking (MPPT) controllers are also connected in series. But these controllers use a microprocessor-based algorithm to repeatedly find the highest solar array voltage and current output. MPPT controllers are most effective in cold weather. According to Davidson and Orner, manufacturers claim that their devices increase power production up to 25% but, the typical annual increase is 15% or less. Davidson and Orner also state that with this production increase, it is enough to justify the two- to four-times higher price of a MPPT charge controller. MPPT controllers should not be confused with solar array trackers that physically move the the array to follow the sun, and most grid-tie inverters have MPPT electronics but these inverters do not regulate the charge from to a battery bank. (Davidson, J., and Orner, F., 2008)

Charge controllers selected for off-grid systems, their default setting may not be appropriate for grid-connected systems. A charge controller should not interfere with proper operation of the inverter when it is set up, and the controller must be set up so that the charging of batteries from the PV array takes precedence over charging from the grid. Also, the charge controller must be selected to deliver the charging current appropriate for the type of batteries used in the system. (Roos, C., 2009)

3.4.4 Other BOS equipment

Grounding equipment

This equipment provides a well-defined, low resistance path from the system to the ground. It protects the system from current surges from lightning strikes or equipment

malfunctions, it also stabilizes voltages and provides a common reference point. Equipment grounding provides protection from shock caused by a ground fault which occurs when a current-carrying conductor comes into contact with the frame or chassis of an appliance or electrical box. Any exposed metal and all system components should be grounded. (Roos, C., 2009)

Meters and instruments

Installing a PV or wind turbine system, it might be required to install a new electrical meter. The meter allows for a measurement of net energy consumptions in both entering and leaving the system. (Findley, D.S., 2010) Essentially there are two types of meters used in the systems, a utility kilowatt-hour meter and a system meter. A utility kilowatt-hour meter measures energy delivered to or from the grid, where a system meter measures and displays system performance and status. (Roos, C., 2009)

Disconnects

A disconnect is needed for each source of power or energy storage device in a system. Automatic and manual safety disconnects protect the wiring and components from power surges and other equipment malfunctions where they also ensure safe system shut down and removal of components for maintenance and repair. When a system is grid-connected, the safety disconnects ensure that the generating equipment is isolated from the grid as it is very important for the safety of utility personnel. It is not always necessary to provide a separate disconnect, but before omitting a separate disconnect, a result for unsafe conditions in performing maintenance on any component should be considered. Another consideration is the convenience of the disconnect location, where an inconveniently located disconnect may lead to the tendency to leave the power on during maintenance which can result in a safety hazard. (Roos, C., 2009)

3.5. Energy generating system sizing

3.5.1   Estimating the energy consumption demand

To calculate the daily energy consumption of each appliance, the following formula can be used:

Watt-hours per day consumption = Quantity x Rated watts x Hours used per day

Add up all the watt-hours per day consumption for each appliance to calculate the total energy consumption demand. The estimated power consumption demand per day calculation can easily be calculated by utilizing the power consumption demand worksheet below.

Total Power Consumption Demand Worksheet

Appliance	Qty		Watts (volts x amps)		Total Watts		Hours per day used		Average Watt-hours per day
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
		X		=		X		=	
Total Watt consumption at one time		=							
Total Watt-hours consumed per day								=	

(Wagner, HJ. & Mathur, J., 2009)

3.5.2 Solar array sizing

Sizing the solar array needed to produce the total watt-hours needed per day depends mostly on energy consumption demand. The amount of solar panels needed in the array also depends on: the derating factors, weather the system includes a battery bank or not, the peak sun hours, and the module wattage rating. The solar array size needed can easily be calculated by utilizing the following formula:

Number of Modules =Total Watt-hours per day ÷ Derating Factors ÷ Peak Sun Hours ÷ Module Wattage Rating (STC)

The derating factors

The derating factors take into account the efficiency losses. The derating factors are supplied in table format below.

Table 5: Typical Derating and Efficiency Factors

Derate Factor	Derate Range	Typical Deratings
Temperature	0.95 – 0.80	0.90 for single-crystal Si 0.88 for polycrystalline Si 0.95 for amorphous Si
Dust and Dirt	0.98 – 0.90	Keep array clean for less than 5% loss
Module Mismatch	0.98 – 0.96	0.98 to 0.96 (2% to 4%)
DC Wire Loss	0.99 – 0.97	0.98 (2% or less)
Battery Conversion Efficiency	0.90 – 0.80	0.90 (90% coulombic efficiency)
Inverter Efficiency	0.90 – 0.80	0.90 for batteryless type 0.85 for battery type or manufacturer's rating at 75% load
AC Wire Loss	0.99 – 0.98	0.995 (1.5% or less) Keep total DC + AC wire loss below 3%

(Davidson, J., and Orner, F., 2008.)

This table can be used to calculate the efficiency loss for each system components separately or an alternative method for an approximate calculation is to divide the amount of electricity demand by an overall efficiency of a PV system:

- 65% for a system with batteries or
- 75% for a system without batteries

Assuming the PV array is placed in the correct orientation and tilt angles according to the specific location for optimum energy output. PV Array Azimuth Derating Factor and PV Array Tilt Derating Factor = 1. (Wagner, HJ. & Mathur, J., 2009)

Peak sun hours

The actual watt-hours demand from the PV array is calculated by taking into account the solar insolation, irradiance or peak sun hours of a specific location. Solar insolation or peak sun hours can be found or calculated by utilizing an insolation map, peak sun hour charts, or the solar irradiance calculator as explained in the site evaluation in section 3.1.5. The value chosen as the peak sun hours should be the lowest winter value, as not to size the solar array too small. (Wagner, HJ. & Mathur, J., 2009)

Module wattage ratings

There are different PV modules and sizes available and each will produce different amount of power. The result from this calculation is the minimum number of PV panels, if more models are installed, the system will perform better and battery life will improve. The total power needed per day from the PV array is divided by the rated output Watt-peak of the PV modules available. The result should be rounded off the next highest full number. This will be the number of PV modules required. (Leonics, 2013)

- For 24-volt DC systems using 12-volt modules round up to the nearest number divisible by two.
- For 48-volt DC system using 12-volt modules round up to the nearest number divisible by four. (Wagner, HJ. & Mathur, J., 2009)

3.5.3 Wind turbine sizing

There is no universal formula to size a wind turbine, but the energy that a wind turbine needs to produce depends mostly on energy consumption demand from the appliances or devices at one time. This value gives an idea of the size wind turbine that is needed and it is advisable to acquire a bit bigger turbine to take into account efficiency losses. It is also recommended that if appliances are used with inductive motors which require more power to start, a wind turbine at least 3 times bigger should be considered.

A recommended minimum wind speed of at a site for a wind turbine is 5 m/s. It is gen-
erally accepted that wind speed measurements are based on readings at 10 m above
ground (Energy Savings Trust, 2014), but the wind resource should rather be measured
at the top of the tower where the wind turbine will be living and working. (Energy Mat-
ters, 2012)

The power output of a wind turbine can be estimated according to a selected wind tur-
bine power curve. The turbine manufacturer should be able to supply the power curve
and some common terms associated with wind speed are explained below:

- Start-up Speed – The speed at which rotor and blade assembly begins to rotate.
- Cut-in Speed – Is the minimum wind speed at which the wind turbine will gen-
  erate usable power. Usually between 3 – 4.5 m/s (7 – 10 mph) for most turbines.
- Rated Speed – Is the minimum wind speed at which the wind turbine will gener-
  ate its designated power. Usually between 11 – 15.5 m/s (25 – 35 mph) for most
  machines. A wind turbine power output increases as the wind increases. The
  power output according to wind speed can be seen in the 'power curve', supplied
  by most manufacturers for the specific wind turbine.
- Cut-out Speed -Is the wind speed where the turbine cease power generation and
  shut down due to very high wind speeds. This is a safety feature which protects
  the wind turbine from damage. (EnergyBible, 2012)

In addition to wind speed terms mentioned above, the relationship between wind speed
and power for a wind turbine can be considered. This can be presented as a power
curve, presented in figure 33. A site's wind characteristics and a turbine's power curve
can be used in conjunction to determine how much energy the selected turbine will gen-
erate. (Carbon Trust, 2008)
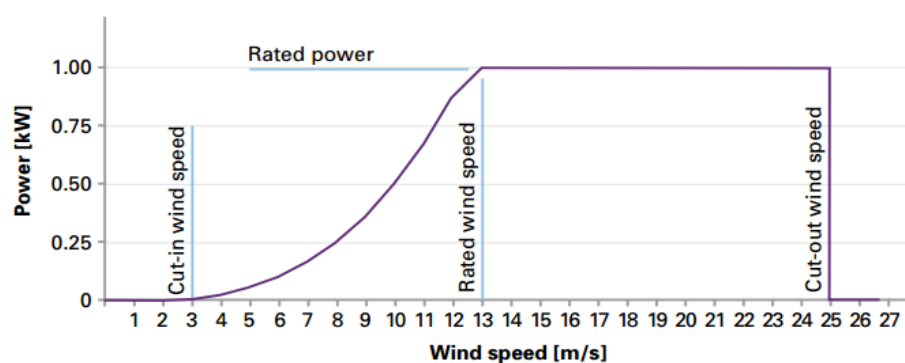
*Figure 33: Wind turbine power curve. (an illustrative example, not a particular make
and model) (Carbon Trust, 2008).*

OR

In theory it is possible to estimate the maximum power a wind turbine can extract in a free stream. This is due to the wind power (P) governed by the relationship: $P \sim v^3 A \rho$. The the following formula can be used to calculate the maximum power that can be extracted from a free stream:

Maximum power in a free stream = (16/27) ($v^3 A \rho \div 2$)

where:

- 16/27 is a constant known as the Bertz limit,
- v is the wind speed (m/s),
- A is the swept area (m²) calculated: $A = \pi r^2$, and
- ρ is the density in air (kg/m³). (Carbon Trust, 2008)

3.5.4   BOS equipment sizing

Batteries

Batteries should be large enough to store efficient energy to operate appliances when energy is not generated by the energy generating equipment. The following is used to calculate the size of batteries:

i.   **The watt-hours of storage needed:**

Watt-Hours of Storage Needed = Total Watt-hours per day

x Autonomy Multiplier

x Battery Temperature Correction Factor (Table 6)

÷ 0.5 (correction for 50% depth of discharge)

Where:

- the autonomy multiplier for battery storage is the number of days needed to operate a system when there is no power production. Usually a standard of 3 days are used, but this value can also be found for certain countries from a battery storage requirements map.
- a battery temperature correction factor table is supplied below. (Commonly select the correction factor that corresponds to the average winter time ambient temperature that the battery bank will experience)

- the 50% depth of discharge for the battery provides a safety factor so that over-discharging the battery bank can be avoided.

ii. **The battery watt-hours for chosen batteries** (The ampere-hour is the battery's rated storage capacity)

Battery Watt-Hours = Battery Ampere-Hours x Battery Voltage

iii. **The number of batteries needed**

Number of Batteries Needed = Watt-hours of storage Needed / Battery Watt-hours

*Round up to the nearest even number of batteries in series string to equal the system voltage. (Wagner, HJ. & Mathur, J., 2009)

Table 6: Battery Temperature Correction Factor for Vented Lead-Acid Cells

Electrolyte temperature		Cell size correction factor	Electrolyte temperature		Cell size correction factor
(° F)	(° C)		(° F)	(° C)	
25	−3.9	1.520	78	25.6	0.994
30	−1.1	1.430	79	26.1	0.987
35	1.7	1.350	80	26.7	0.980
40	4.4	1.300	81	27.2	0.976
45	7.2	1.250	82	27.8	0.972
50	10.0	1.190	83	28.3	0.968
55	12.8	1.150	84	28.9	0.964
60	15.6	1.110	85	29.4	0.960
65	18.3	1.080	86	30.0	0.956
66	18.9	1.072	87	30.6	0.952
67	19.4	1.064	88	31.1	0.948
68	20.0	1.056	89	31.6	0.944
69	20.6	1.048	90	32.2	0.940
70	21.1	1.040	95	35.0	0.930
71	21.7	1.034	100	37.8	0.910
72	22.2	1.029	105	40.6	0.890
73	22.8	1.023	110	43.3	0.880
74	23.4	1.017	115	46.1	0.870
75	23.9	1.011	120	48.9	0.860
76	24.5	1.006	125	51.7	0.850
77	25.0	1.000			

(Integrated Publishing Inc., 2010)

Charge controller

Charge controllers are rated and sized depending on the current and voltage. "Ampere ratings can be between 1 – 100 amps and voltage ratings from 6 – 60 volts." (King Solar, 2009) It is important to make sure the charge controller has enough capacity to handle the current (amps) from the PV array or wind turbine feeding into the controller (Leonics, 2013). An additional 25%-30% needs to be factored in due to factors that cause a sporadic increase in current levels. It can be advantageous if a higher amps charge controller is acquired, as it can be used if there are plans to increase the size of the energy system in the future. (King Solar, 2009)

Charge controller rating (A) = (Input Wattage ÷ Battery Voltage) x 1.3

where:

- the input wattage is the total watts produced by the energy generating equipment,
- the battery voltage is the battery voltage of the battery bank. (Most systems today are 24 or 48 VDC and most grid-connected systems operate at 48 volts or higher (Wholesale Solar, n.d.).), and
- 1.3 is an additional 30% factored in due to factors that can cause a sporadic increase in current levels.

Sizing a charge controller for a solar system depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (*series or parallel configuration)." (Leonics, 2013) Thus the following equation can be utilized:

Charge controller rating (A) = Total short circuit current (Isc) x 1.3

MPPT (Maximum Power Point Tracking) charge controller: commonly used when the voltage differs from the battery bank's voltage (the lower voltage). This charge controller also works well with systems that have panels with odd voltage ratings. MPPT charge controllers automatically and efficiently convert higher voltage to lower voltage. (King Solar, 2009)

Inverter

The inverter input rating should never be lower than the total watt of the appliances. It should also have the same nominal voltage of the battery if a battery is acquired. When it is a stand-alone system, the inverter must be large enough to handle the total amount of watts used at one time. The best is to use an inverter size 25%-30% bigger than the total watts of the appliances. Another factor to take into account is when an appliance type is a motor or compressor. The inverter size should be minimum 3 times the capacity of these appliances because a surge current during starting must be added to the inverter capacity. When the system is grid-connected, the input rating of the inverter should be the same as the PV array or wind turbine rating to allow for safe and efficient operation. (Leonics, 2013)

Inverter rated power (W) = Total watts of the appliances x 1.3

where:

- the total watts of the appliances is the total watts consumed at one time, and

1.3 is an additional 30% factored in due to factors that can cause a sporadic increase in current levels.

3.6. General system estimation

Considering an energy generating system require planning to determine if there is enough sun/wind resources on a consistent basis in the specified area, if there is enough space, if zoning codes or covenants allow the systems in the area, and if the system will be economical with all of the elements taken into consideration including installation and maintenance considerations (Energy.Gov,2012). To help determine the suitability and the size for an alternative electric system, the following factors need to be taken into account.

Estimate the resources available

This can be done by a site evaluation and to take into account the factors affecting the output of the renewable energy system. Estimating the resources available can vary significantly over an area. (Energy.Gov,2012)

System sizing

The size of the system required for energy production will depend on energy consumption demand according to the appliances that needs to be powered. Estimating the size of a system involves taking into account the energy generating equipment such as the solar panels or wind turbine, including the balance-of-system equipment. This will also depend on whether the system is grid-connected, stand-alone, or a hybrid system. (Energy.Gov,2012)

Investment and space required by the system and additions

When a general idea of the systems size and the required equipment is known, the cost of the system and space available for all the equipment needed should be taken into consideration. The investment and space needed for the respective renewable energy system need to take into account the following:

- Solar system – Solar array, mounting racks and hardware, wiring, and the BOS equipment.
- Wind generating system – Wind turbine, tower and foundation, wiring, and the BOS equipment. (Energy.Gov,2012)

Zoning codes, permits and other considerations

Zoning regulations, codes, and permits vary dramatically across states, countries, and municipalities. Before investing in a renewable energy system, it is advisable to acquire information on the zoning regulations, codes, or permits needed. (Energy.Gov,2012)

Deciding to invest in a renewable energy system, a professional installer should be contacted for a more accurate estimation. A credible installer may also be able to provide additional information on all these considerations. (Energy.Gov,2012)

4   RAINWATER HARVESTING

Harvesting rainwater is a method used to capture and use rainwater. Rainwater harvesting is especially useful locations where water is a scarce resource and water supply is limited. It can reduce the need and demand for water transport systems which threatens the health of the water cycle and the environment. Even areas with low rainfall still have an enormous potential for harvesting rainwater. There are many potential sources for harvesting rainwater, but for the purpose of this paper, roof harvesting and their necessary components will be reviewed. (Greywater Action, n.d.) Rainwater harvesting can also provide water needed for fire protection in regions where water is either scarce or not connected to a municipal water supply.

The following are the pros and cons of harvesting rainwater.
Pros:

- Most useful in arid and semi-arid areas where other sources of water are scarce.
- Provides a source of water at the point where it is needed and it is owner operated and managed.
- It is an essential reserve in times of emergency and/or breakdowns of public water supply systems.
- Construction of a rooftop harvesting system is simple, and local people can easily be trained to build one which minimizes cost.
- The technology is flexible as the system can be built to meet almost any requirements.
- The properties, physical and chemical, of rainwater may be superior to groundwater or surface water that may have been subject to pollution, especially from unknown sources.
- The running costs are low.
- The construction, operation, and maintenance are not labour intensive.

Cons:

- It is not a dependable water source in times of dry weather or prolong drought. The success of rainwater harvesting depends on the frequency and amount of rainfall.

- Low storage capacities limit rainwater harvesting. The system may not be able to provide water in a low rainfall period. Increased storage capacities add to construction and operating costs.

- Possible contamination of water from animal wastes and vegetable matter.

- The system increases construction cost. (Organization of American States, n.d.)

4.1. A roof rainwater harvesting system

A roof rainwater harvesting system is simple and can store water for later use. A basic rainwater harvesting system consists of three elements: a collection or catchments area, a conveyance system, and a storage tank.

Catchment area

The catchment area is the surface which directly receives the rainfall. This would be the roof area of the shipping container. The roof material is not as important as the contaminants that may be on the roof. Since the container is a metal roof, it can easily shed contaminants. The slope of the roof affects how quickly water will runoff, and a steep roof will shed runoff quickly and more easily cleaning the roof of contamination. A less-steep or flatter roof will cause the water to move more slowly which raise the potential for contamination to remain on the catchments surface. The size of the catchment area will determine how much rainwater can be harvested. (AgricLife Extension, n.d.)

Conveyance

The conveyance system consists of the gutters and/or pipes that is attached to the building to deliver rainwater from the roof to the storage tanks. Gutters attached to the edge of a roof gathers water from the catchment area and are connected to a downspout which transports the rainwater to a covered storage tank. Gutters can be semi-circular or rectangular. Using locally available material such as plain galvanized iron sheet, folded to the required shape, a rectangular gutter can be produced. A semi-circular PVC gutters can be prepared by cutting PVC pipes into two equal semi-circular channels. The size of the gutter should be according to the flow during the highest intensity rain and over-sized by 10-15%. Gutters need to support the load when filled with water, thus they need to be supported so they do not sag or fall off. It is possible to fix iron or timber brackets into the walls for gutter support. Downspouts can be of any material like pol-

yvinyl chloride (PVC), galvanized iron (GI) or fiberglass, materials that are commonly available.

- A 'first flush device' can be connected to direct the first rain of the year away from the tank and the subsequent water continues to flow to the tank (figure 34). The 'first flush system' is utilized because the first rain of the year is the most dirty as it cleans the roof and due to pollutants.

- Screens such as coarse mesh are attached over the downspout connected to the gutter or to the inlet of the storage tank. This is utilized to remove leaves and debris from the rainwater collected on the roof. (Greywater Action, n.d.; Center for Science and Environment, n.d.)
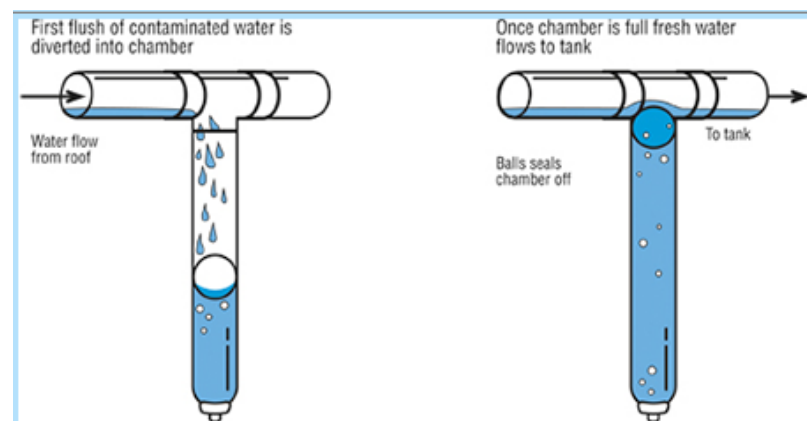
Figure 34: First-flush device (Aquabarrel, 2014)

Storage tank

The storage tank can be located next to the building, leveled, and on a raised platform. Each tank should have an excess water overflow system. More than one storage tank can be connected to the same system if one storage tank is not sufficient. The storage tank can be dark which prevent algae from growing, and covered to prevent leaves, debris, and mosquitoes from entering. Large storage tanks can be made from plastic, Ferro cement, metal or fiberglass, available in a range of sizes. Rain barrels are a popular choice for rainwater harvesting as they are low in cost and can be installed along buildings. (Greywater Action, n.d.; Center for Science and Environment, n.d.)

4.2. Rainwater collected

A rainwater harvesting system require few skills and a little supervision to operate, but the major concern is the prevention of contamination during construction and while it is replenished. Contamination with certain materials such as oil can be avoided by the use of proper materials during the construction phase. (Organization of American States, n.d.) Rainwater is naturally very clean, having been naturally distilled by the sun and its heating action causing evaporation from the surface of the earth and water sources. But rainwater collects pollutants through the atmosphere and is usually slightly acidic in nature. It also dissolves or physically carries dirt, debris, insects, and bird and animal droppings on the roof surface down to the gutters. Thus, the end result is that a large collection of organic and fecal material on the roof finds its way into the rainwater collection system. The best strategy is to remove as much of this contaminating material as possible, by physically cleaning the roof surface and drains during the year. Screens and a first flush system can also be put in place to eliminate some contaminating material. Screens and first flush devices have a very large sieve size and are not capable of removing small bacteria, viruses, and parasites. For this reason the water should not be used as drinking water, unless it is properly filtered or disinfected by other means such as boiling. (One House Green, 2014)

4.3. Estimating the size of a system

Estimated rainwater resource available

The estimated amount of rainwater (net runoff) that can be harvested can be calculated by the following formula:

Net Runoff (liters) = Catchment area x Rainfall x 0.95

where:

- the catchment area is the roof area measured in square meters (m²),
- the rainfall measured in millimeters or liters per square meter (1 mm = 1 L/m²), and
- 0.95 is the runoff coefficient for a pitched metal roof.

(Lancaster, B., 2006)

Collection capacity needed

The collection capacity needed (size of the storage tank) can be estimated by using the same equation as above but the rainfall in the equation can be according to a large storm event:

Capacity needed (liters) = Catchment area x Rainfall expected in a local high volume storm x 0.95

This is a rough estimate of the tank size that will be needed to capture the roof runoff for this size storm. It will reduce the water loss to overflow from the tank and extend the availability of a lot of rainfall long after the rain event. (Lancaster, B., 2006)

Estimated pipe size

If too small pipes are utilized in the system, it will restrict the water flowing through the system fast enough. A rule of thumb that can be utilized is: 1 cm² of gutter cross section per 1 m² of roof area. To calculate the pipe diameter, the equation used to calculate the area of a circle can be converted to the following equation:

$$Diameter = 2 \times \sqrt{\frac{Area}{2}}$$

(Appropedia, 2012)

Table 7 can be used if the rainfall intensity can be found. The following table supplies some indication of the diameter pipe required for draining out water based on rainfall intensity and roof area

Table 7: Sizing of rainwater pipe for roof drainage.

Diameter Of pipe (mm)	Average rate of rainfall in mm/h					
	50	75	100	125	150	200
50	13.4	8.9	6.6	5.3	4.4	3.3
65	24.1	16.0	12.0	9.6	8.0	6.0
75	40.8	27.0	20.4	16.3	13.6	10.2
100	85.4	57.0	42.7	34.2	28.5	21.3
125	-	-	80.5	64.3	53.5	40.0
150	-	-	-	-	83.6	62.7

(Appropedia, 2012)

5 SUSTAINABLE SERVICE FACILITY CASE STUDY: JOHANNESBURG, SOUTH AFRICA

The methods or modifications that can be used to construct a self-sustainable service facility were applied, evaluated, and discussed. Each method was applied hypothetically if a self-sustainable service facility would be constructed at a specified location. Passive solar energy, energy generating systems, and rainwater harvesting system all has one thing in common, they all are 'site specific'. Therefore all values calculated, information examined, and discussed were based on the consideration of a service facility constructed in Johannesburg, South Africa.

5.1. Passive solar energy

The passive solar design discussed below is an illustrative example if a service facility would be placed on a site in Johannesburg, South Africa. First the climate, wind direction, and solar altitude of the location were considered.

Climate

Johannesburg has a mild temperate climate with dry winters and warm summers (climatemps, 2014). According to Reardon, C. (2013), the main characteristics for a mild temperate climate zone is:

- Low day–night temperature range near coast, high range inland
- Four distinct seasons: summer and winter exceed human comfort range; spring and autumn are ideal for human comfort
- Mild to cool winters with low humidity
- Hot to very hot summers, moderate humidity. (Reardon, C., 2013)

The temperature averages were illustrated in table 8. Temperature averages can be found by various sources on the internet. Some internet sources that can be utilized were supplied in appendix 3.

Table 8: Temperatures in Johannesburg, South Africa

Temperature	Max	Avg	Min
Max Temperature	31ºC	22ºC	11ºC
Mean Temperature	24ºC	16ºC	5ºC
Min Temperature	19ºC	10ºC	-2ºC

(Weather Underground, 2014)

Wind directions

Figures 35 and 36 illustrate the wind directions over the year in Johannesburg, South Africa. The figure shows that most often the wind blows from the north and North-West.
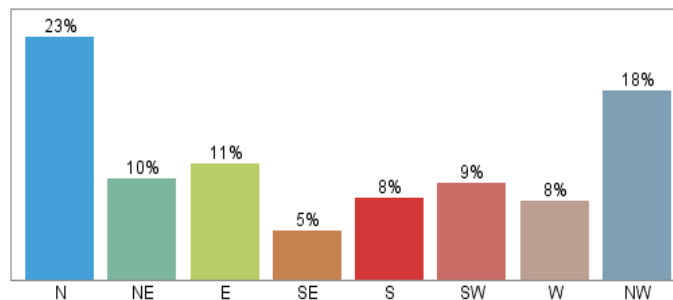
Figure 35: Wind direction percentage over a year (WeatherSpark, n.d.).
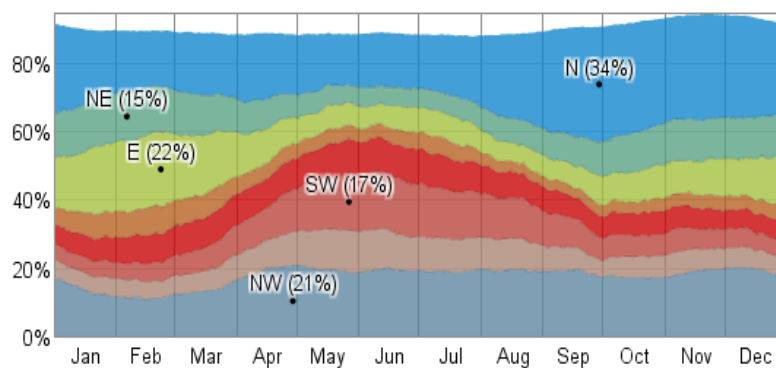
Figure 36: Monthly wind directions over a year (WeatherSpark, n.d.).

* "The fraction of time spent with the wind blowing from the various directions over the entire year. Values do not sum to 100% because the wind direction is undefined when the wind speed is zero" (WeatherSpark, n.d.)

Solar elevation

The solar elevation angles were calculated as explained previously. The latitude for Johannesburg, South Africa is 26º10'S (Maps of the World, 2014).

- Equinox = 90 degrees – Latitude

$$= 90º – 26.10º$$

$$= 63.9°$$

- Summer solstice = 90 degrees – Latitude + 23.5 degrees

$$= 90º – 26.10º + 23.5º$$

$$= 87.40º$$

- Winter solstice = 90 degrees – Latitude – 23.5 degrees

$$= 90º – 26.10º – 23.5º$$

$$= 40.40º$$

To confirm these values, an online link which calculates the elevation angle for a location according to its respective dates and times were utilized (figure 37).

11:30	83.12
11:45	86.03
12:00	87.30
12:15	85.31
12:30	82.27

11:30	39.56
11:45	40.12
12:00	40.43
12:15	40.47
12:30	40.24

Figure 37: The summer and winter solstice for Johannesburg, South Africa
(Keisan, 2014; modified).

After the climate, wind direction, and solar elevation were known, the passive solar design elements were considered in conjunction with the passive design principals. Thus some design considerations that were taken into account for a mild temperate climate with dry winters and warm summers while designing a passive service facility was:

- Individual site analysis and location within the region determine whether heating or cooling is the predominant need.
- Minimize external wall areas (especially east and west-facing).
- Passive solar heating is essential when heat is needed and simply achieved where solar access is available. (Solar access require north-facing with the majority of glazing.)
- Reducing heat gain though appropriate use of window shading and glazing (size, location and type) as it is a critical design consideration.

- Cooling comfort is simply achieved with adequate cross-ventilation and minimizing solar and ambient heat gains with shading and insulation.
- Use convective ventilation and heat circulation.
- Lower thermal mass requirements allow for low embodied energy solutions. (Reardon, C., 2013)

5.1.1 Orientation

SA is located in the Southern Hemisphere of the world and according to the shape and window placement of the container; the container should be oriented with its long axis on the East-West axes with the window facing true North. Facing the window North allows solar energy to enter the container. Solar gain through the window will be very beneficial during the winter as the low temperature can range between 19 to -2°C. At this point the wind directions were also taken into consideration, since the window is specifically placed where the rod rack will be stacked in the container and the container doors can either face East or West. As mentioned above, the wind direction is most often from the North and North-West and due to this phenomenon; the container doors should face to the west side to take advantage of the north-west winds. Generally the optimum orientation would be that the shorter axis align with prevailing winds to provide the most ventilation (Sustainable Workshop, 2011), but structures such as the container doors and window can be used to direct winds. Figure 38 below illustrates the orientation of the shipping container as discussed above.
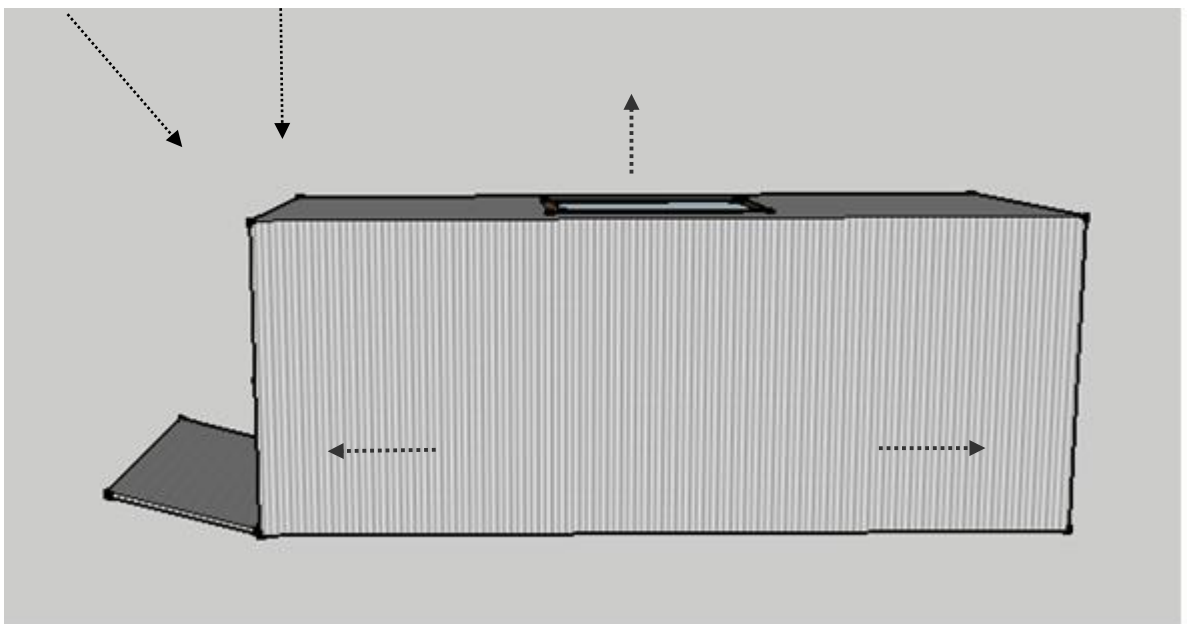
Figure 38: Container orientation

5.1.2 Shading

Shading can be used to regulate the solar heat gain in container. The basic idea of the shading structures are to keep the sun out in the summer and let the sun through in the winter. The container can either be shaded with a window overhang to shade the window or a roof overhang to shade the window and the wall facing the sun. The choice will depend on the customer and the degree of thermal comfort he/she is comfortable with. The roof and window overhang were utilized in the example.

South Africa has a moderate climate and according to the weather history (see table 9 below), Johannesburg has HDD below 6 000 and CDD below 2 600. According to the guidelines for overhang design provided by InspectApedia, the shadow line should be located at the window sill using the summer solstice sun angle.

Table 9: Degree days in Johannesburg, South Africa

Degree Days	Max	Avg	Sum
Heating Degree Days	24	6	1 744
Cooling Degree Days	10	1	375

(Weather Underground, 2014)

By utilizing the guideline and the solar elevation angles calculated above, a sketch was drawn according to scale (1 m = 50 mm) to estimate the width of the overhang (roof or window). This principle was illustrated in figure 39 below. As seen from the sketch, the width can be drawn and estimated to any length for a comfortable fit. Since summer, the beginning of autumn, and the end of spring can get very hot, the overhang was drawn through the summer solstice elevation angle line to the equinox elevation angle line. The roof overhang was measured and estimated to be 0.97 − 1.0 m wide, where it is supposed to shade the wall during the whole summer and only half of the time during spring and autumn. The window overhang was measured and estimated to be 0.6 m wide, where it is supposed to shade the window during the whole summer and half of the time during spring and autumn. The same principle can be used to estimate the roof overhang to shade the whole wall during summer. The only difference is that the solar elevation angles should be measured from the ground surface and not the bottom of the window sill.
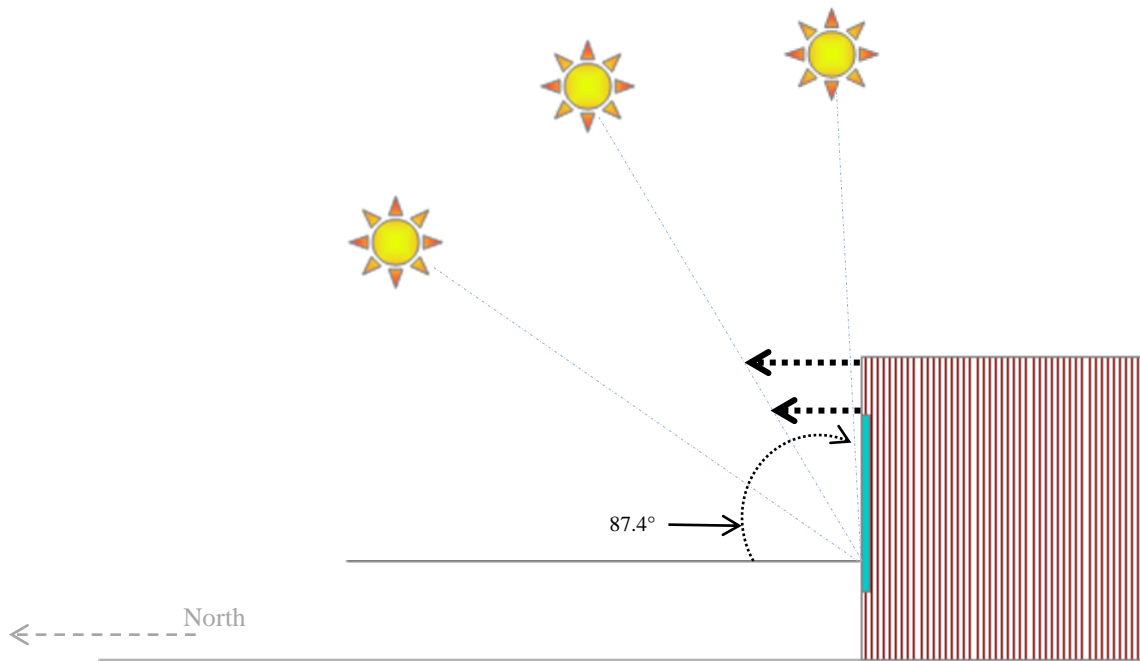
Figure 39: Roof and window overhang according to solar elevation.

The roof overhang rule of thumb and the window eave online calculator were also utilized to estimate the roof and window overhang for the container. These methods were also used to confirm the values estimated above, since there is no universal formula to easily calculate the roof and window overhang.

The roof overhang rule of thumb: W = ½ H

The total height of the shipping container = 2.896 m

The window height = 1.2 m

Height from the ground to the window sill = 0.9 m

Thus the height from the window sill to the roof top was calculated as follow:

H = Total height of the shipping container - Height from the ground to the window sill

= 2.896 m - 0.9 m

= 1.996 m

By utilizing the rule of thumb formula:

W = ½H

= 0.5 (1.996 m)

= 0.998 m

According to this method the roof overhang should be 0.9 – 1.0 m wide. The rule of thumb was illustrated by the figure below.
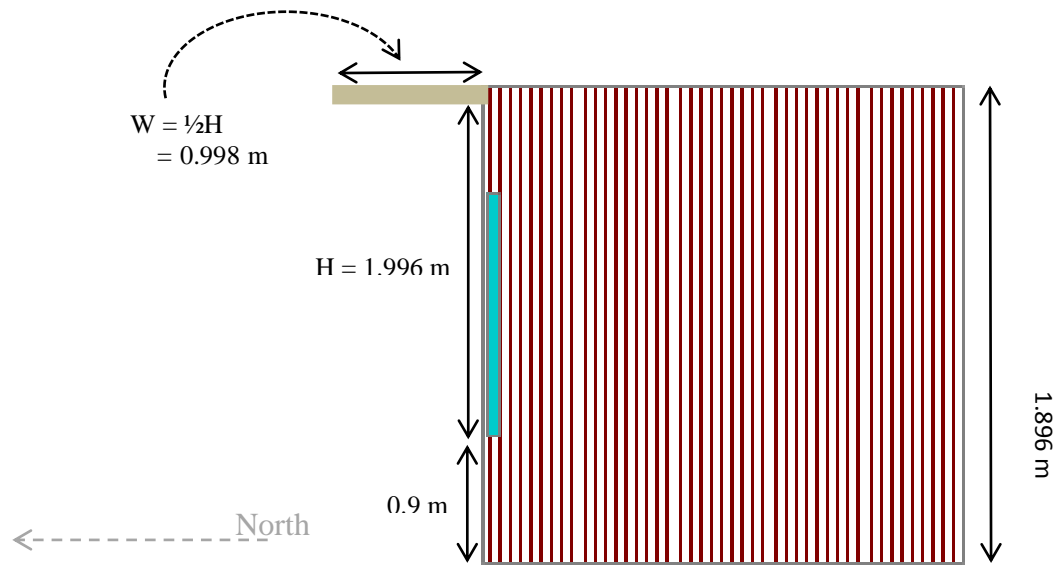
Figure 40: Overhang rule of thumb illustrated.

Window overhang online calculator

According to the online calculator, the window overhang width should be 0.53 m and the overhang would produce a 0.33 m top window winter shade if the overhang would be placed right above the window. The online calculator also supplied information such as:

- The width includes everything that contributes to shade across the window (i.e. gutters).
- The top window winter shade is the space at the top of the window to the over-hang itself which will always be in shade throughout the year.
- The algorithm works on the principal that complete summer sun shade during the hottest part of the day during the whole of summer is wanted. (Eco Who, 2014)

The figure below illustrates the results generated by the online calculator according to the values supplied.

Latitude:	27° 48'S
Window Height:	1.20m
Ideal Eave Depth (from top of window to edge of Eave)	0.53m
Top Window Winter Shade (from top of window down)	0.33m
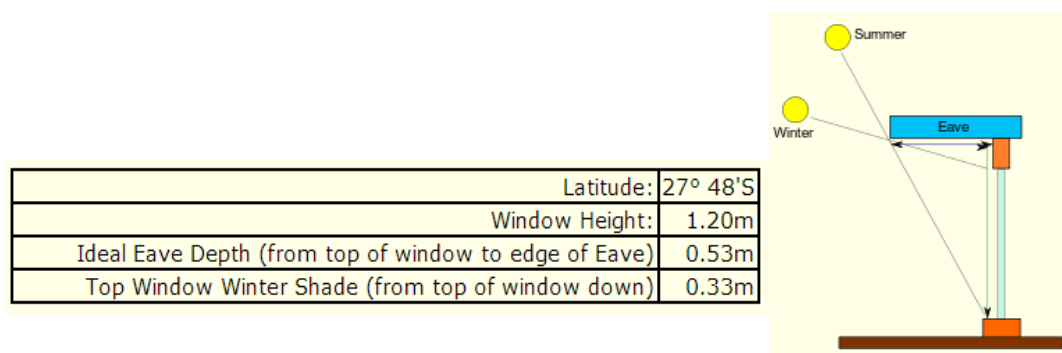
Figure 41: Results from online calculator (EcoWho, 2014; Modified).

As seen from the two methods used above, the rule of thumb and online calculator, the values calculated for a roof and window overhang is quite accurate when using the solar elevation sketch. The only difference (and advantage) between the solar elevation sketch method and the other two methods, are that the sketch can be used to estimate the overhang width according to the solar gain wanted during the equinox (spring and autumn).

The window can also be installed with adjustable blinds or fixed horizontal louvers to shade the window. Adjustable shading can be very beneficial during spring and autumn to allow viable solar access. Adjustable shading also makes it easier to control heat gain according to comfort. Window efficiency can also be considered, as the window choice will affect the heat gain and the light transfer. The basic consideration for a temperate climate would be a window with a high SHGC and low U-value glazing. (Reardon, C., 2013) Other considerations would be deciduous trees or bushes, but these should already be available at the right place and size to function as an effective shading method/device.

5.1.3 Ventilation

The container can be ventilated passively by utilizing the window and container doors to direct the wind from the different wind directions. Since most of the wind comes from the North, the North facing window should be able to open to let the wind pass through. The container door can also be opened at an angle to direct the Northern wind to enter the container. The second highest wind direction is from the North-West which can let the wind through by the west facing doors and a window opening that opens to

the east to direct the wind inside (figure 42). The same principle but opposite openings can be used to deflect the wind when it is unwanted in the winter or cooler days.

North
North-West
Winds
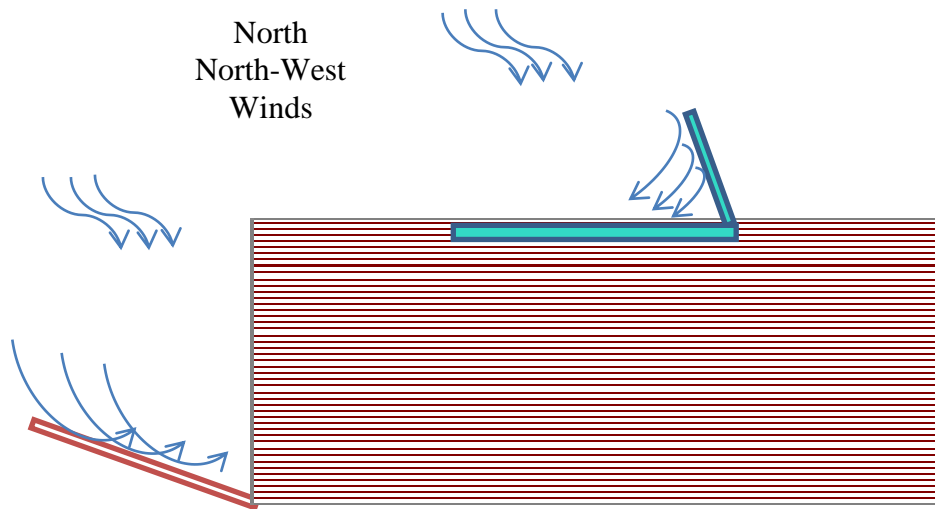
Figure 42: Door and window openings used to scoop the wind inside.

These are just simple examples that can be used to scoop or deflect the wind to or from the inside of the container. If blinds and louvers were to be used for shading, it should not hinder the opening of the window since not all parts of the building can be oriented for effective cross-ventilation. Using the door and window opening, which is adjacent from each other, creates a funnel effect which aids the air movement and increases the cross-ventilation. A vent can also be cut from the east side wall of the container. The vent should be placed high in the wall, which can be used as an outlet for hot air as hot air rises. The vent should also be adjustable since the heat needs to be kept inside during the winter and therefore the vent will be closed. Figure 43 illustrates the cross-ventilation created by the window and door openings, where figure 44 illustrates the cross-ventilation created by the door and a vent opening.
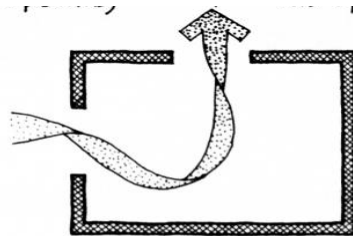
Figure 43: Two openings – Adjacent
(Sustainability Workshop, 2011)
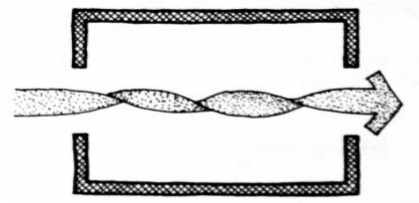
Figure 44: Two openings – Opposite
(Sustainability Workshop, 2011)

5.1.4   Thermal Mass

The container is constructed out of corrugated iron which is a low thermal mass material. This kind of material reacts quickly to external conditions, which means it will heighten the climate extremes. This can be avoided by the insulating options discussed below. The amount of sunlight absorbed by building material also depends on its color. The container would be spray-painted white which is beneficial for reflecting the sun and keeping the inside cool. Adding an overhang to the container can either be constructed out of wood or corrugated iron. This is due to the fact that lower thermal mass requirements allow for low embodied energy.

Taking thermal mass into consideration, care should be taken when choosing a window. It was noticed that metal equipment will be stacked by the window. This means that when the sun strikes these equipment, the metal would heat up and radiate heat into the container. Letting the sun through the window and heating the metal equipment will be beneficial in the winter, but it must be shaded during the summer. Blinds can be used to control the solar gain to the metal equipment, but it has to be kept in mind that blinds will also radiate heat from the sun to the inside of the container. Therefore it might be more beneficial if a roof or window overhang is utilized to shade the window during the summer. If there is some unwanted solar gain through the window during the winter, adjustable blinds can be used to protect the metal equipment from heating up.

5.1.5   Insulation

There are several different ways to insulate the interior of a shipping container and there are more coatings on the market that offer insulation qualities. Although the more commonly used materials are fiberglass, rigid polystyrene foam panels and closed cell spray foam (figure 45). (Gregorio, R., 2012)

Fiberglass insulation has a standard thickness of about 90 mm and provides an insulating value of R-13. Sections are cut and fitted inside of a wood framed interior. Since the walls of a storage container are corrugated there will be gaps between the insulation and the outside corrugation. Depending on where the storage container is going to be placed,

it might be advisable to consider a moisture barrier between the container wall and the insulation. (Gregorio, R., 2012)

Rigid polystyrene foam panels are available in varying thickness as well as size. These panels are also available in varying densities. The application of the container will dictate the type of panel utilized. An approximated insulating value of R-5 per inch is provided by foam panels. A major benefit in using foam panels instead of fiberglass is interior space can be saved. Space is saved because foam panels do not need wood frames as in fiberglass insulation, thus saving several inches on the sidewalls and ceilings. Foam panels can either be glued directly to the wall or it can be screwed into flat bar mounted to the walls. (It is recommended that the flat bar method should be utilized opposed to gluing the panels to the wall. Since the container walls are corrugated, the panels do not come in constant contact with the walls.) (Gregorio, R., 2012)

Closed cell spray foam is of the opinion that it is the most efficient insulation. It can offer the highest insulation value of approximately R-6 per inch. The spray foam completely covers the surface of the corrugated shipping container wall, thus there are no gaps between the insulation and the container wall. There is also much less risk of condensation or moisture developing with closed cell spray foam, there is no need to frame out the interior as the spray foam adheres directly to the walls and ceiling, it can be sprayed as thick as necessary to achieve the required insulating value. The major disadvantage of this type of insulation is its cost. (Gregorio, R., 2012)

Any of these methods are very effective and it is recommended that a wall covering, such as plywood, installed over the insulation to finish out the interior. (Gregorio, R., 2012)

Figure 45: Fiberglass, rigid polystyrene foam panels, and closed cell spray foam respectively (Gregorio, R., 2012).

5.2. Energy generating systems

A solar system and wind turbine system were sized and evaluated according to different system connection options. The energy generating systems were sized and evaluated accordingly, if these systems were to be used in a service facility placed in Johannesburg, South Africa. First the major components to complete an energy generating system were sized and discussed separately. After the size of these components needed were known, the different system connection options were compiled and discussed as a whole.

During the course of sizing the major components to complete an energy generating system, tables were compiled to illustrate the price and equipment specifications. The information compiled in these tables was derived from two South African online eco stores which produces equipment specifications and their prices freely. The tables were used as a basis for evaluation and discussion purposes, but it has to be kept in mind that there would be a lot more choices available in the market from different manufacturers at different ratings and at different prices. Each component's specifications supplied according to the component being sized and discussed were as follow:

- Solar module specifications (table 13),
- Wind turbine specifications (table 15),
- Battery specifications (table 18),
- Charge controller specifications (table 22), and
- Inverter specifications (table 25)

(Sustainable.co.za, 2014 & Alternagy.co.za, n.d.)

5.2.1 Estimating the power consumption demand

The power consumption demand was calculated by using the total power consumption demand worksheet. First the appliances that need to be powered in the service facility (as specified) were listed and their respective values used to complete the worksheet were explained below.

The appliances in this instance that need to be powered are:

- Grinding machine, compressor, lights, laptop, room air conditioner (optional)

The power each appliance consume were estimated values as approximate values for these devices were not supplied, except for the grinding machine. The approximate values should be used that is supplied on the appliance label, or specified by the manufacturer as this will give a more realistic estimation on the total power consumption demand. The values used in the power consumption estimation were explained by appliance:

Grinding machine: 2 400 W

$$Watts = Amps \; x \; Volts$$
$$= 10 \; Amps \; x \; 240 \; Volts$$
$$= 2 \; 400 \; Watts$$

Information according to the grinding machine specs supplied in appendix 2.

Compressor (8 – 10 bar): 2 000 Watt

This value is an estimate for an 8 to 10 bar compressor according to some compressor specifications. The energy consumption will depend on which type of compressor is utilized such as an oil less, lubricated, silent, etc. compressor. The torque power (starting power) consumed should also be taken into account, as this power consumption can be three times more than the running consumption. The starting and running power consumption information can be supplied by the compressor manufacturer. A 2 000 W value for simplicity sake was used, but when determining the amount of power consumption for a system, it is advisable to use the values supplied by the manufacturer according to the specific compressor utilized.

Laptop: 60 W

The power consumption of a laptop depends on the screen size. Typically the power consumption for a laptop when running off the battery is as low as 20 watts, but can go up to 100 watts. When charging a laptop battery, the power consumption will increase 10% - 20%, thus it is estimated that 60 watts is the average power consumption for a 14 – 15 inch laptop when plugged in. (Energy Use Calculator, 2014)

Lights (CFL 60W): 14 W (CFL light bulbs were chosen for the calculations.)

	LED	CFL	Incandescent
Watts per bulb (equiv. 60 watts)	10	14	60
Light bulb projected lifespan	50 000 hours	10 000 hours	1 200 hours
Cost per bulb	$ 35.95	$ 3.95	$ 1.25

(Eartheasy, 2012)

Room air conditioner (optional): 1 000W

Single room air conditioners come in different sizes and can use from 500 W to 1 500 W per hour. (Energy Use Calculator, 2014)

Next the time each device can be used per day were estimated and explained:

Device/Appliance (Qty)   Hours used per day

Grinding machine (1)   4 hours in the morning and 4 hours in the evening

Compressor (1)   4 hours in the morning and 4 hours in the evening

Laptop (1)   8 hours during day and 8 hours during night

Lights* (3)   12 hours

Air Conditioner* (1)   8 hours

The estimated hours used for these devices are including day shift (6:00 − 15:00) and night shift (20:00 − 5:00). When estimating the times used for each device or appliance, the maximum value were used to avoid sizing the system too small.

*Lights − Johannesburg (South Africa) receives a minimum of 10:30 hours of daylight during mid-winter. Thus the lights might be used one or two hours extra in the winter during the day, 3 hours for day shift + 9 hours for night shift.

*Air Conditioner - The temperatures in Johannesburg (South Africa) were already supplied in table 8.

Thus assuming the service facility is not passively designed, the summer will have day extremes and the winter will have night extremes. For this reason an 8 hour air conditioning use were estimated, for the day extremes during summer and night extremes during the winter.

System sizing scenario 1: Day and night shift including an air conditioning unit

Appliance	Qty		Watts (volts x amps)		Total Watts		Hours per day used		Average Watt-hours/day
Grinding machine	1	x	2 400	=	2 400	x	8	=	19 200
Compressor	1	x	2 000	=	2 000	x	8	=	16 000
Laptop	1	x	60	=	60	x	16	=	960
Lights	3	x	14	=	36	x	12	=	504
Air Conditioner	1	x	1 000	=	1 000	x	8	=	8 000
Total Watts at one time				**= 5 502 W**					
Total Watt-hours per day								=	**44 664 W**

The total watts and total watt-hours per day consumption demand value calculated above is a rough estimate. The actual power consumption demand may vary substantially depending on the location of the service facility, type of devices or appliances used, and the hours used per day. For this reason, each customer need to supply values that is as exact as possible according to their situation for a more accurate estimate of their power consumption demand. To illustrate the importance for exact values used, two more scenarios were taken into account and therefore two more system sizing worksheets were supplied. Worksheet 2 is where the service station is located, modified, and designed to utilize passive solar energy and no air conditioning unit is needed. Worksheet 3 is where the service station is only used during the day shift.

System sizing scenario 2: Day and night shift excluding air conditioning unit

Appliance	Qty		Watts (volts x amps)		Total Watts		Hours per day used		Average Watt-hours/day
Grinding machine	1	x	2 400	=	2 400	x	8	=	19 200
Compressor	1	x	2 000	=	2 000	x	8	=	16 000
Laptop	1	x	60	=	60	x	16	=	960
Lights	3	x	14	=	36	x	12	=	504
Total Watts at one time				**= 4 502 W**					
Total Watt-hours per day								=	**34 664 W**

System sizing scenario 3: Only day shift including air conditioning unit

Appliance	Qty		Watts (volts x amps)		Total Watts		Hours per day used		Average Watt-hours/day
Grinding machine	1	x	2 400	=	2 400	x	4	=	9 600
Compressor	1	x	2 000	=	2 000	x	4	=	8 000
Laptop	1	x	60	=	60	x	8	=	480
Lights	3	x	14	=	36	x	3	=	42
Air Conditioner	1	x	1 000	=	1 000	x	8	=	8 000
Total Watts at one time				**= 5 502 W**					
Total Watt-hours per day								**=**	**26 122 W**

The table blow illustrates the results from the estimated power consumption demand calculated according to three scenarios. The three scenarios were taken into account for comparison purposes and to illustrate the importance for utilizing accurate values.

Table 10: Results of the total watt consumption at one time and the total watt-hour consumption per day according to their different scenarios.

	Scenario 1	Scenario 2	Scenario 3
Total Watts at one time	5 502 W	4 502 W	5 502 W
	~ 5 500 W	~ 4 500 W	~ 5 500 W
Total Watt-hours per day	44 664 Wh	36 664 Wh	26 122 Wh
	~ 45 000 Wh	~ 37 000 Wh	~ 26 000 Wh

It can already be seen from table 10 that by eliminating an air-conditioning unit lowers the power demand with 1 kW, as scenario 1 and scenario 2 were calculated using the exact same values but eliminating the air-conditioning unit from scenario 2. Power consumption demand also differs in the time each appliance is used per day. This was illustrated in the difference between scenario 1 and scenario 3. All the values used were the same, except that the appliances were used less per day in scenario 3 than in scenario 1. All the values used in the calculation were estimated values and not approximate values.

5.2.2   Solar array sizing

The estimate solar array size was calculated by using the following formula:

Number of Modules =Total Watt-hours per day ÷ Derating Factors ÷ Peak Sun Hours ÷
Module Wattage Rating (STC)

Thus the estimated number of modules needed according to scenario 1 (table 10) for a system with batteries and using a 300 W module was calculated as follow:

Number of Modules =44 664 Wh ÷ 0.65 ÷ 3.96 hours ÷ 300 W

= 57.84 ≈ 58 modules

where:

- the total watt-hours per day used was 44 664 Wh supplied in table 5,
- the derating factors used were the alternative method for an approximate calculation of a system with batteries (65%),
- the peak sun hours used were according to the solar irradiance calculator (figure 41), and
- module wattage rating used were a 300W solar module.
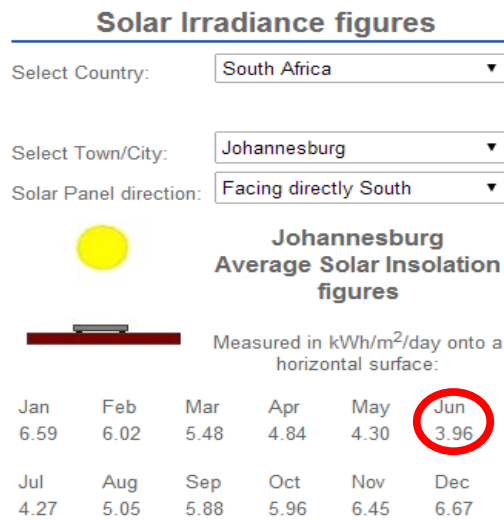
Figure 41: Result from the solar irradiance calculator
(Solar Electricity Handbook, 2014; modified).

The solar irradiance calculator measures the average solar insolation in kWh/m2 per day. As seen in June the average solar insolation is 3.96 kWh/m2/day, thus Johannesburg receives 3.96 peak sun hours per day during June. This value was used during the calculations as the rule of thumb is to apply the lowest winter value of sun hours.

Table 11 was compiled to illustrate the total number of modules needed according to the different total watt-hours per day (supplied in table 10). The table also illustrates the difference in the total number of modules needed for a system with batteries and a system without batteries. The only difference in the calculation for a system without batteries was the derating factor, which was 75% according to the alternative method for an approximate calculation.

Table 11: The total number of modules needed in a solar array

	System with batteries			System without batteries		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Total Watt-hours (Wh) per day	45 000	37 000	26 000	45 000	37 000	26 000
Overall efficiency adjustment	÷ 0.65			÷ 0.75		
Peak Sun Hours (h)	÷ 3.96			÷ 3.96		
Module Wattage Rating (W)	÷ 300 W			÷ 300 W		
Number of Modules	**58**	**48**	**34**	**51**	**41**	**30**

Solar is universal and will work virtually anywhere, but some areas are more suitable for solar panels than others as it depends on the solar irradiance available at the surface of the earth (Wholesale Solar, 2013). Two different cities in their respective countries were chosen to illustrate the effect solar irradiance has on the solar array size in these cities. The two cities chosen were Tampere, Finland and Kitwe, Zambia. Their peak sun hours were calculated using the solar irradiance calculator (figure 47). The results were compiled in table 12.

Table 12: Solar array needed in different cities

	System with batteries			System without batteries		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Johannesburg, SA Peak sun hours: 3.96 Number of Modules	58	48	34	51	41	30
Tampere, Finland Peak sun hours: 0.14	1 637	1 336	957	1 418	1 158	830

Number of Modules						
Kitwe, Zambia Peak sun hours: 4.91 Number of Modules	47	39	28	41	33	24
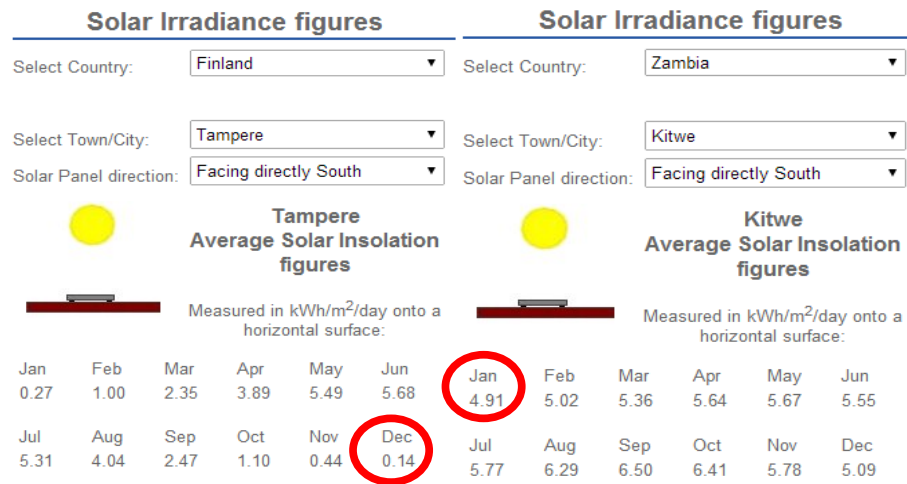
Figure 47: Result from the solar irradiance calculator for Tampere and Kitwe (Solar Electricity Handbook, 2014; modified).

As seen from the values calculated above, the number of modules needed in a system depends on how much sun hours is available in a location, the power the array should provide and whether the system includes a battery bank or not. These dependent factors have a huge impact on array investment and space needed to mount the array. The alternative derating factor method was used to calculate the array size, but this value is not an exact value of the efficiency loss that can occur. By utilizing specific derating factors as supplied in the derating factor table or efficiency values supplied by the manufacturer specifications for each component used in the system, the array size needed to produce the power demand might be smaller as calculated above. This in turn will also have an impact on the investment and space needed for the array size.

Table 13: Solar module specifications

Manufacturer	Module Power Rating	Cell type	Price	Area (m²) L x W	Weight (kg)	Short circuit current (Isc = A)
ReneSola	300 W	Poly-Crystalline	R3 300 (€ 230)	1.94	29	7.02
Tenesol	300 W	Mono-Crystalline	R4140.00 (€ 290)	1.96	22.5	8.7

Solaire	250 W	Poly-Crystalline	R2990 (€ 210)	1.64	19	9.03
Tenesol	250 W	Mono-Crystalline	R3450 (€ 240)	1.63	19	8.8

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

Table 14 illustrates the total cost and space required for the total number of modules needed in a solar array calculated in table 11. During the table compilation, different modules were evaluated for comparison purposes to illustrate the solar array investment difference. These values were as follow:

- A 300 W poly-crystalline solar module – R 3 299/module and 1.94 m²/module (ReneSola).
- A 300 W mono-crystalline solar module – R 4 140/module and 1.96 m²/module (Tenesol).
- A 250 W poly-crystalline solar module – R 2 990/module and 1.64 m²/module (Solaire).

Table 14: Solar array investment difference

	System with batteries			System without batteries		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
300W Poly-crystalline Number of Modules	58	48	34	51	41	30
Total space required	113 m²	93 m²	66 m²	99 m²	80 m²	58 m²
Total Cost	R 191 340	R 158 350	R 112 170	R 168 250	R 135 260	R 98 970
	€ 13 340	€ 11 030	€ 7 820	€ 11 730	€ 9 430	€ 6 900
Total weight	1 680 kg	1 390 kg	990 kg	1 480 kg	1 190 kg	870 kg
300W Mono-crystalline Number of Modules	58	48	34	51	41	30
Total space required	113 m²	94 m²	66 m²	100 m²	80 m²	59 m²
Total Cost	R 240 120	R 198 720	R 140 760	R 211 140	R 169 740	R 124 200
	€ 16 750	€ 13 860	€ 9 820	€ 14 730	€ 11 840	€ 8 660
Total weight	1 310 kg	1 080 kg	770 kg	1 150 kg	920 kg	680 kg
250W Poly-crystalline Number of Modules	68	56	40	60	49	35
Total space required	112 m²	92 m²	66 m²	98 m²	80 m²	57 m²
Total Cost	R 203 490	R 167 580	R119 700	R179 550	R146 630	R 104 740
	€ 14 190	€ 11 690	€ 8 350	€ 12 520	€ 10 230	€ 7 300
Total weight	1 290 kg	1 060 kg	760 kg	1 140 kg	930 kg	670 kg

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

Table 14 specifically illustrates the difference between the total cost and space needed for different power rated modules and different type of modules. The solar array size for a mono-crystalline and poly-crystalline with a 300 W power rating was the same, but a factor that was not taken into account is that a mono-crystalline module has a higher efficiency value than poly-crystalline modules. This in turn can decrease the number of modules needed in an array and since the efficiency values of these modules were not supplied, the solar array size for the respective module types could not be calculated. Assuming the array size is the same, the cost for a mono-crystalline module or array is more expensive and more space is needed compared to poly-crystalline modules.

The difference between the power ratings of the same type of module was also analyzed. As seen in table 14, a higher number of modules are needed for a smaller power rating module (250 W). And as expected, even though the smaller power rating module cost less per module, the total cost for the array size needed is more expensive than using the higher power rated modules. The space needed for these different modules does not have a big difference, thus the deciding factor would be the total cost for an array. Therefore, the 300W ReneSola poly-crystalline solar module was used for the rest of the evaluation and calculations.

The roof area of the container was calculated as follow:

$$A = L \ x \ B = 6 \ m \ x \ 2.33 \ m$$
$$= 13.98 \ m²$$

The number of 300W ReneSola solar modules that will fit on the roof of the container was calculated as follow:

$$13.98 \ m² ÷ 1.96 \ m² = 7.13$$

Thus only seven 300W solar modules would be able to fit on the roof of the container. The rest of the panels or all of the panels can either be ground – or pole-mounted.

5.2.3   Wind turbine sizing

There is no universal formula to size a wind turbine, thus the choice of turbine depends on the energy a wind turbine needs to produce for energy consumed by the appliances or at one time. The power consumption at one time was already calculated and supplied in table 10. These values gave an indication of the size wind turbine that was needed to

produce the power requirement. A bit bigger turbine was considered to take into account efficiency losses.

Table 15: Wind turbine specifications

Manufacturer	Rated Power Output (W)	Price	Cut -in Speed (m/s)	Rated Speed (m/s)	Tower Height (m)	Rotor Diameter (m)	Weight (kg)
Earth Power 10KW	15 000 (Max) 10 000 (Rated)	R138 150 (€ 9 630)	3 – 25	11	15	7	1 250
Earth Power 5KW	8 000 (Max) 5 000 (Rated)	R72 840 (€ 5 080)	3 - 35	12	12	5	357

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The wind resource available and the recommended tower height entry level were evaluated as follow:

- **Wind resource**

The figure below illustrates the wind resource available in Johannesburg, SA. The average daily minimum is marked by the red band, the maximum wind speed by the green band, and the average wind speed with the black band. The figure also illustrates the value and date of the highest and lowest wind speed according to the maximum and average colored bands. Thus over the course of the year, the typical wind speeds vary from 3 m/s to 7 m/s. The highest average wind speed of 5 m/s occurs around 16 October. At this time the average daily maximum wind speed is 7 m/s. The lowest average wind speed of 3 m/s occurs around 17 May. At this time the average daily maximum wind speed is 5 m/s.
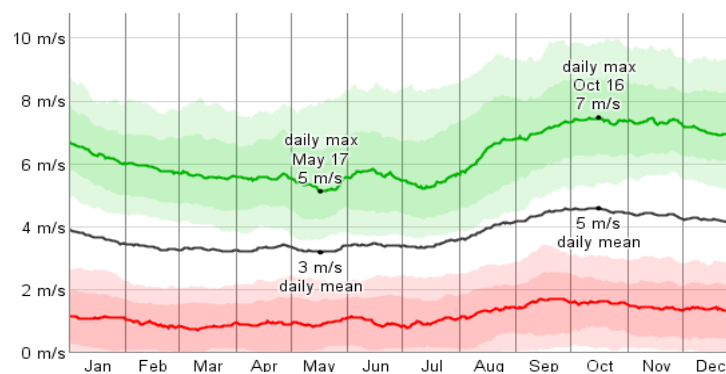

Figure 48: Wind Speed in Johannesburg, SA (WeatherSpark, 2014).

- **Tower height**

It is recommended to site a wind turbine at least 6 m above any surrounding obstacles in a 76 m radius (Energy Matters, 2012). Assuming the container would be the only obstacle in a 76 m radius from the wind turbine, the turbine recommended entry level tower height should be around 10 m.

$$Recommended\ entry\ level = Container\ height + 6\ m$$
$$= 2.896\ m + 6\ m$$
$$= 8.896\ m \approx 9\ m$$

Since the recommended entry level was assumed to be 9 m and it is generally accepted that wind speed measurements are based on readings at 10 m above ground, both wind turbine sizes (10 kW and 5 kW) would not be able to produce the power requirements needed. Mentioned above, the typical wind speeds vary from 3 m/s to 7 m/s over the course of the year, but these turbines need wind speeds of 11 to 12 m/s to generate their rated power. Johannesburg receives on average wind speeds of 3 to 5 m/s, and thus it can be assumed that these turbines will generate the minimum usable power as these wind speeds only reach the cut-in wind speed. Even though the highest maximum wind speed during the year is 7 m/s, not enough power is extracted by the 10 kW wind turbine to supply the energy demand the whole year through (in all three scenarios).

A wind energy system might not be a suitable option in Johannesburg, S.A. as the wind turbines are unlikely to provide a cost-effective way of producing electricity. It has to be kept in mind that the evaluation was made for the resource available at a height of 10 m. Increasing the tower height exposes a wind turbine to higher and cleaner wind speeds. Therefore it is crucial to measure the power a wind turbine can provide at different heights with different wind speeds before installing a wind turbine system.

In theory the maximum power that a wind turbine can extract from a free steam can be calculated by using the equation below:

$$Maximum\ power\ in\ a\ free\ stream = (16/27)\ (v^3 A \rho \div 2)$$

Thus the estimated maximum power that can be extracted by the Earth Power 10 kW wind turbine (information available in table 15) was calculated as follow:

Maximum power in a free stream = (0.59) ((5 m/s)³(38.485 m²)(1.225 kg/m³) ÷ 2)

= 1 738.544 kgm²/s³

= 1 738.44 W

Where:

- 16/27 is a constant known as the Bertz limit,

- v is the wind speed which was used at 5 m/s,

- A is the swept area which was calculated to be 38.485 m² (calculated: A = π(3.5 m)²), and

- ρ is the air density which equals 1.225 kg/m³ according to the International Standard Atmosphere (ISA).

Table 16 was compiled to illustrate the theoretical maximum power that can be extracted by the Earth Power 10 kW and 5 kW wind turbines according to different wind speeds. The table was compiled to illustrate the increased power that can be extracted with higher wind speeds and different size rotor swept area.

Table 16: The estimated maximum power extraction by the respective wind turbines.

Wind speed	Earth Power 10kW (Rotor diameter = 7 m) Rotor Swept Area = 38.485 m²	Earth Power 5kW (Rotor diameter = 5 m) Rotor Swept Area = 19.635 m²
3 m/s	380 W	190 W
5 m/s	1 740 W	890 W
7 m/s	4 770 W	2 430 W
9 m/s	10 140 W	5 170 W
11 m/s	18 510 W	9 440 W

As seen from table 16 above, in theory the power these wind turbines can extract form the wind increases dramatically when the wind speed increase and also when the rotor diameter increases. But it has to be kept in mind that these power outputs are only estimated values for illustration purposes and that the actual amount of electricity produced may be drastically lower than calculated. The lower than calculated values are due to the fact that the Bertz limit of only 59% was taken into account, where according to the Carbon Trust, anecdotal evidence suggests that the capacity factor for a small-scale

wind turbine generally ranges between 12 – 20% or less than 25% (Carbon Trust, 2008). Thus to make sure a wind energy system will be financially worthwhile, it is advisable to contact a professional before installing a wind energy system.

As mentioned before, a wind energy system might not be a suitable option in Johannesburg, S.A. as the wind turbines are unlikely to provide a cost-effective way of producing electricity. This does not mean that a wind turbine system cannot be utilized in other cities and countries where a service facility can be located. The Earth Power 10 kW wind turbine was chosen to complete further evaluation of a wind turbine system, assuming that this type of wind turbine is able to generate enough power for the power consumption demand in all three scenarios if given optimal wind resources.

5.2.4   Battery sizing

The formulas to calculate the battery size were as follow:
- The watt-hours of storage needed:

Watt-Hours of Storage Needed = Total Watt-hours per day

x Autonomy Multiplier

x Battery Temperature Correction Factor (table 6)

÷ 0.5 (correction for 50% depth of discharge)

- The battery watt-hours:

Battery Watt-Hours = Battery Ampere-Hours x Battery Voltage

- The number of batteries needed:

Number of Batteries Needed = Watt-hours of storage needed ÷ Battery Watt-hours

Thus the watt-hours of storage needed were calculated as follow for scenario 1 (table 10):

Watt-Hours of Storage Needed = 44 664 Wh/day x 3 days x 1.190 ÷ 0.5

= 318 900 Wh

Where:
- the total watt-hours per day used was 44 664 Wh/day,
- the autonomy multiplier value used was 3 days,

- battery temperature correction factor used was 1.190 as the average low temperature reaches 10ºC (table 6), and
- the correction for a 50% depth of discharge.

Table 17 was compiled to illustrate the watt-hours of storage needed according to the different total watt-hours per day (supplied in table 5).

Table 17: Watt-hours of storage needed

	System with batteries		
	Scenario 1	**Scenario 2**	**Scenario 3**
Total Watt-hours (Wh) per day	44 664	36 664	26 122
Autonomy Number	x 3 days		
Battery Correction factor	x 1.190		
Depth of discharge	÷ 0.5		
Watt-Hours of Storage Needed	**318 900 ~ 319 000**	**261 780 ~ 262 000**	**186 511 ~ 187 000**

The battery watt-hours were calculated as follow for the Trojan J185H-AC lead acid battery:

$$Battery\ Watt\text{-}Hours = 225\ Ah\ x\ 12V$$

$$= 2\ 700\ Wh$$

where:

- the battery ampere-hour was 225 Ah,
- and the battery voltage was 12 V (as supplied in table 18)

Thus the battery watt-hours were calculated and included in the battery specification table below.

Table 18: Battery specifications

Manufacturer	Type	Price (R)	Ampere-hour (Ah)	Volts (V)	Battery Watt-hours (Wh)	Weight (kg)	Dimension L x W x H (mm)
Trojan J185H-AC	Lead Acid	4 210 (€ 290)	225	12	2 700	58	381 x 178 x 371
M-Solar C100	Lead Acid	11 750 (€ 820)	900	6	5 400	133	585 x 262 x 460

U.S. Solar	Lead Acid	2 800 (€ 200)	130	12	1 560		330 x 171 x 248
Trojan T145	Lead Acid	2 890 (€ 200)	260	6	1560	33	264 x 181 x 295
Victorian Energy	AGM	5 920 (€ 410)	220	12	2 640	65	522 x 238 x 240

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

As seen from the battery specification, the higher the watt-hours of a battery, the more expensive, heavier and bigger the dimension of the battery. The AGM battery is an exception which will be discussed below.

The number of batteries needed was calculated as follow for scenario 1:

$$Number\ of\ Batteries\ Needed = 318\ 900\ Wh \div 2\ 700\ Wh$$

$$= 119\ Batteries$$

where:

the battery storage needed were calculated supplied in table 17, and

the battery watt-hours were calculated and supplied in table 18.

Table 19 below was compiled for comparison purpose taking into account the different battery watt-hours and the different battery storage needed. The table results illustrates the number of batteries needed, including the total cost, the space required, and the total weight for the battery bank. The different batteries compared and their respective watt-hours were:

- Trojan J185H-AC lead acid battery (2 700 Wh),
- M-Solar C100 lead acid battery (5 400 Wh),
- US Solar lead acid battery (1 560 Wh),
- Trojan T145 lead acid battery (1 560 Wh), and
- Victorian AGM battery (2 640 Wh)

Table 19: Comparison table according to different batteries

	System with batteries		
	Scenario 1	Scenario 2	Scenario 3
Watt-Hours of Storage Needed	**318 900**	**261 780**	**186 510**
Trojan J185H-AC (12V) Number of batteries	119	97	70

Total Cost	R 500 990	R 408 370	R 294 700
	€ 34 930	€ 28480	€ 20 550
Space Needed	2.99 m³	2.44 m³	1.76 m³
Total Weight	6 902 kg	5 630 kg	4 060 kg
M-Solar C100 (6V)			
Number of batteries	60	49	35
Total Cost	R 705 240	R 575 950	R 411 390
	€ 49 180	€ 40 170	€ 28 690
Space Needed	4.23 m³	3.45 m³	2.47 m³
Total Weight	6 780 kg	5 540 kg	3 960 kg
US Solar (12V)			
Number of batteries	205	167	120
Total Cost	R 574 000	R 467 600	R 336 000
	€ 40 030	€ 32 610	€ 23 430
Space Needed	2.87 m³	2.34 m³	1.68 m³
Trojan (6V)			
Number of batteries	205	167	120
Total Cost	R 592 450	R 482 630	R 346 800
	€ 41320	€ 33 660	€ 24 190
Space Needed	2.89 m³	2.35 m³	1.69 m³
Total Weight	6 770 kg	5 510 kg	3 960 kg
Victorian AGM (12V)			
Number of batteries	121	99	71
Total Cost	R 716 320	R 586 080	R 420 320
	€ 49 960	€ 40 870	€ 29 310
Space Needed	3.61 m³	2.95 m³	2.12 m³
Total Weight	7 870 kg	6 440 kg	4 620 kg

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The number of batteries needed in a battery bank to supply the battery storage needed depends mainly on the watt-hours a battery can provide. The higher the watt-hour (size) per battery, fewer batteries is needed in the battery bank. The less batteries needed in a battery bank does not necessarily mean the battery bank would be less expensive.

Comparing the two highest watt-hour batteries, the Trojan 12V and M-Solar 6V batteries. The M-Solar 6 V battery produces the highest watt-hour per battery of all the batteries, thus fewer batteries are needed in the battery bank. The number of M-Solar 6V batteries needed is almost half compared to Trojan 12V batteries needed in the battery bank. But taking into account the total cost for the M-Solar 6V battery bank, it is more expensive to invest in this kind of battery and more space is needed to mount the battery bank.

Comparing the two batteries which has the same watt-hour (1 560) per battery, the U.S Solar 12V and Trojan 6V batteries. The number of batteries needed in the battery bank would be the same for both types of batteries. The total cost and space needed for these batteries would be different as the cost and dimension for these individual batteries differ. This might be because a 6 volt battery is more expensive than a 12 volt battery or due to the fact that these batteries are produced by different manufacturers. But a general conclusion that can be made is that batteries should not be chosen for a battery bank for its high rated ampere-hour or watt-hour, but should be looked at as a whole. Thus, the total cost, the total space needed, its total weight, and other specific criteria.

Take for example the AGM battery which costs more, needs more space, and weighs a lot more compared to all the other batteries (even batteries with higher watt-hours). But AGM lead acid batteries are non-hazardous, resistant to cold temperature, not inclined to heat up, able to hold a static charge for a long time, and has a higher discharge rate than the others batteries (Roos, C., 2009). Therefore the choice of battery will depend on the investor. For further evaluation and calculation purpose, the Trojan J185H-AC (12V) battery was used as it produced the lowest total cost, space needed, and weight for a battery bank according to the battery bank sizing.

Table 20 shows the difference in battery bank size when a different autonomy number is utilized to size the battery bank. The same battery (Trojan J185H-AC (12V)) was used in all the calculations for the evaluation for the number of batteries needed. The table results also illustrates the number of batteries needed, including the total cost, the space required, and the total weight for the battery bank.

Table 20: Comparison of a battery bank according to lower autonomy number

	System with batteries		
	Scenario 1	Scenario 2	Scenario 3
Autonomy Number 3			
Watt-hours of Storage needed	318 900	261 780	186 510
Number of batteries needed	119	97	70
Total Cost	R 500 990	R 408 370	R 294 700
	€ 34 940	€ 28 480	€ 20 550
Space Needed	2.99 m³	2.44 m³	1.76 m³
Total Weight	6 900 kg	5 630 kg	4 060 kg
Autonomy Number 1			
Watt-hours of Storage needed	106 250	86 740	62 170
Number of batteries needed	40	33	24

Total Cost	R 168 400	R 138 930	R 101 040
	€ 11 740	€ 9 690	€ 7 050
Space Needed	1.01 m³	0.83 m³	0.60 m³
Total Weight	2 320 kg	1910 kg	1 390 kg

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The autonomy number used depends on the facility need and the system connection. An autonomy number of 3 were used for a stand-alone system with a battery bank, and the autonomy number of 1 was used for a grid-connected system with a battery bank. As seen from above, the autonomy number used to size a battery bank has a dynamic effect on the batteries needed, the total cost, space needed, and weight of a battery bank.

The autonomy number is the number of days estimated for which the battery bank is sized to produce power when the energy generating component, the solar array or wind turbine, cannot produce the power needed. Usually a battery bank is sized for 1 to 3 day in a stand-alone system, but when the system is grid-connected less backup time is necessary. Grid-connected system only uses a battery bank to anticipate for power outages or according to investors' choice. Therefore a grid-connected system with a battery bank is usually sized for 8 hours, but this value depends on the particular needs or the length of the expected power outages.

5.2.5 Charge controller sizing

The formula used to size the charge controller was:

Charge controller rating (A) = (Input Wattage ÷ Battery Voltage) x 1.3

Thus the charge controller rating was calculated for the total solar array wattage output according to scenario 1 (table 11) for a system with batteries:

Charge controller rating (A) = (17 400 W ÷ 48 V) x 1.3

= 471.25 A

where:

- the input wattage was the total watts produced by the solar array as this value would be the input wattage for the charge controller – 300 W x 58 solar modules = 17 400 W, and

- the battery voltage was assumed to be 48 V. (Most systems today are 24 or 48 VDC and most grid-connected systems operate at 48 volts or higher (Wholesale Solar, 2014).), and

- 1.3 was an additional 30% factored in due to factors that can cause a sporadic increase in current levels.

Table 21 illustrates the charge controller size that would be needed according to the solar array size that was calculated in table 6 for a system with batteries.

Table 21: Charge controller for a 300 W poly-crystalline solar array

Solar System with batteries			
	Scenario 1	**Scenario 2**	**Scenario 3**
Number of modules	58	48	34
Input Wattage	17 400 W	14 400	10 200
Charge controller rating	**472 A**	**390 A**	**277 A**

A charge controller rating was calculated for a wind turbine according to a specific wind turbine chosen. Charge controller for the Earth Power 10 kW rated wind turbine:

$$Charge\ controller\ rating\ (A) = (10\ 000\ W \div 48\ V)\ x\ 1.3$$

$$= 271\ A$$

where:

- the input wattage was the total watts produced by the wind turbine as this value would be the input wattage for the charge controller – even though the wind turbine can produce 15 000 W, it was assumed that the wind turbine would not be able to produce the maximum power rating as the wind resource does not exceed the rated power and can only produce the rated power which is 10 000 W, and

- the battery voltage was assumed to be 48 V, and

- 1.3 was an additional 30% factored in due to factors that can cause a sporadic increase in current levels.

Table 22: Charge controller specifications

Manufacturer	Current Rating	Price	Voltage	Type
Steca Tarom - 440	40 A	R 4 730 € 330	48 V	Hybrid
Microcare : 100 Amp	100 A	R 11 020	12 – 48 V	Solar MPPT

		€ 770		Limit − 150 V
*Kestrel: 300I	60 A Max Current	R 3 160 € 220		Wind Turbine

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The choice of the charge controller will depend on the charge controller rating, energy generating system, and the system connection. Therefore the highest charge controller rating was chosen for each energy generating equipment found on the online eco stores illustrated in table 22 above. It has to be kept in mind that there would be a lot more choices available in the market from different manufacturers at different ratings and prices. These charge controllers were chosen as their price and specifications were freely available. The total costs of the charge controller for each system were calculated using the charge controller specifications above and the results compiled below (table 23).

Table 23: Charge controller cost by type of system

Solar System with batteries			
	Scenario 1	**Scenario 2**	**Scenario 3**
Charge controller rating	472 A	390 A	277 A
Microcare : 100 Amp (Charge controllers needed) Total cost	(4.72 ≈ 5) R 55 120 € 3 840	(3.9 ≈ 4) R 44 090 € 3 080	(2.7 ≈ 3) R 33 070 € 2 310

Wind turbine System with batteries			
	Worksheet 1	**Worksheet 2**	**Worksheet 3**
Charge controller rating	271 A	271 A	271 A
Krestel : 60 Amp (Charge controllers needed) Total cost	(4.52 ≈ 5) R 15 790 € 1 100	(4.52 ≈ 5) R 15 790 € 1 100	(4.52 ≈ 5) R 15 790 € 1 100

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The charge controller for a solar system depends on the solar array size and the total watts the array produce. Therefore the results in table 21 were used to calculate the total cost for the charge controller according to the charge controller rating. The total cost of the charge controller for a wind turbine system was calculated to be the same value. This is due to the fact that the charge controller is sized according to the wattage rating

for the specific turbine chosen. The wind turbine charge controller were sized according to its rated power as explained (10 000 W), when wind resources are available higher than the rated wind speed, the maximum power output (15 000 W) should be used to size the charge controller.

5.2.6 Inverter sizing

The formula used to size the inverter was:

Inverter rated power (W) = Total watts of the appliances or devices x 1.3

Thus the inverter rating was calculated for the total watts consumed at one time according to scenario 1 (table 10):

Inverter rated power (W) = 5 502 W x 1.3

= 7 150 W

where:

- the total watt consumption of all the appliances at once were calculated in table 10, and
- 1.3 was an additional 30% factored in due to factors that can cause a sporadic increase in current levels.

Table 24 shows the results of the inverter rated power calculated for the total watts the appliances can consume at one time.

Table 24: Inverter rated power

	Scenario 1	Scenario 2	Scenario 3
Total Watts at one time	5 502 W	4 502 W	5 502 W
Inverter Rated Power	7 150 W	5 850 W	7150 W

Table 25: Inverter specifications

Manufacturer	Rated Power	Price	Type
Microcare	10 000 W	R 43 878 (€ 3 060)	Bi-Directional (Grid-connected incl. Battery bank)
*SMA : Sunny Tripower 10000TL	10 000 W	R 68 257 (€ 4 760)	Grid Tie (Grid-connected excl. Battery bank)

MLT Drives : Oasis 6048 Pure Sine Wave	6 000 W	R 33 781 (€ 2 360)	Off Grid (Stand-alone incl. Battery Bank)

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The choice of the inverter will depend on the inverter rated power, and the system connection. Therefore the highest inverter rating was chosen for each system connection found on the online eco stores illustrated in table 25 above. It has to be kept in mind that there would be a lot more choices available in the market from different manufacturers at different ratings and prices. These inverters were chosen as their price and specifications were freely available. A bi-directional inverter is used when a system is grid-connected with a battery bank. This type of inverter converts not only DC to AC, but can also convert AC to DC. The total cost of the inverter for each system connection were used directly from the table above, as the inverter choice are not defined by the type of system used but the system connection type.

5.2.7 System connection types

The system connection types that were taken into account to produce a energy generating system for a service facility were as follow:

- Solar system
  - ◦ Stand-alone system with a battery bank
  - ◦ Grid-connected system with a battery bank
  - ◦ Grid-connected system without a battery bank
- Wind turbine system
  - ◦ Stand-alone system with a battery bank
  - ◦ Grid-connected system with a battery bank
  - ◦ Grid-connected system without a battery bank

Different components were needed to complete a specific system connection. The different system connection types and their components needed were as follow:

- Stand-alone system with a battery bank - energy generating equipment + battery bank + charge controller + inverter
- Grid-connected system with a battery bank - energy generating equipment + battery bank + charge controller + inverter

- Grid-connected system without a battery bank – energy generating equipment + inverter

Table 26 below was compiled to illustrate the difference in the estimated cost for complete systems. The total cost of the systems calculated below does not include mounting structures, wiring, installation (labor) cost, and safety and metering equipment. The costs were calculated to supply a general estimate on how much a system's major components would cost and for comparison purposes. Comparisons such as the cost difference between the system connection types, the cost difference between the system sizes according to the power consumption demand, and the cost difference between the system types. The following major components sized above were specifically used in the table compilation which also indicates where the values were derived from:

- Solar array - 300W Poly-crystalline solar panel (calculated in table 14)
- Wind turbine – 10 kW Earth Power wind turbine (supplied in table 15)
- Battery bank – 12V Trojan J185H-AC battery (calculated in table 20)
- Autonomy number 3 for a stand-alone system, and
- Autonomy number 1 for a grid-connected system
- Charge controller – (calculated in table 23)
- Inverter – (calculated in table 25)

Table 26: Total estimated system cost

Solar System			
System connection type	**Scenario 1**	**Scenario 2**	**Scenario 3**
Stand-alone incl. Battery bank • Solar Array • Battery Bank (Autonomy 3) • Charge Controller • Inverter	R 781 140 € 54 480	R 644 600 € 44 950	R 473 720 € 33 040
Grid-connected incl. Battery bank • Solar Array • Battery Bank (Autonomy 1) • Charge Controller • Inverter	R 458 740 € 31 990	R 358 250 € 24 980	R 290 150 €20 240
Grid-connected excl. Battery bank • Solar Array • Inverter	R 236 510 € 16 490	R 203 520 € 14 190	R 167 230 € 11 670
Wind turbine System			
System connection type	**Scenario 1**	**Scenario 2**	**Scenario 3**
Stand-alone incl. Battery bank • Wind Turbine • Battery Bank (Autonomy 3) • Charge Controller • Inverter	R 688 620 € 48 020	R 596 090 € 41 570	R 482 420 € 33 640
Grid-connected incl. Battery bank • Wind Turbine • Battery Bank (Autonomy 1) • Charge Controller • Inverter	R 366 220 € 25 540	R 336 750 € 23 480	R 298 860 € 20 840
Grid-connected excl. Battery bank • Wind Turbine • Inverter	R 206 410 € 14 400	R 206 410 € 14 400	R 206 410 € 14 400

(€ 1 = R 14.36 @ 25 September 2014) (xe.com, 2014)

The table above shows that a stand-alone system is the most expensive compared to a grid-connected system with and without a battery bank. This is due to the big battery bank that is needed. A grid-connected system with a battery bank is not as expensive as a stand-alone system. A grid-connected system does not need to produce 100% of the power demand and are only sized to anticipate for power outages, where stand-alone system needs to produce 100% of the power demand and a larger battery bank is needed to anticipate for cloudy or non-windy days. Thus the initial investment for system con-

nection types including a battery bank increases the initial investment in general, but the investment will depend on the autonomy number used.

The total cost from worksheet 1 to 3 can vary dramatically, take for example a stand-alone (solar and wind turbine) system, the difference in the initial investment is about R 100 000. The reason for these differences is due to the fact that the system components are sized according to the power it needs to provide, the estimated power consumption demand. Therefore the table shows the importance of using approximate values to estimate the power consumption demand as it has an effect on the initial cost for the system.

The cost difference between a solar and wind turbines system also relies on the estimated power consumption demand. When sizing a solar system, the solar array is dependent on power demand, thus the higher the power demand, the bigger the solar array, the more expensive the system. Where on the other hand, a wind turbine does take the power consumption demand into account, but it is sized according to its rated power it can generate according to the wind resource available. Therefore one big enough wind turbine was used compared to a solar array that needs a number of solar panels to produce a specific amount of power. This is clearly indicated in the grid-connected systems excluding a battery bank. The type of system does not affect the battery bank size since a battery bank is sized according to the power consumption demand and the autonomy number.

The table below is an illustrative example of the total space and weight that would be needed in a solar system according to the system size and system connection types. The example only takes into account the estimated solar array and battery bank. The space is a very important factor to consider; especially where space is limited and a personal micro solar plant might not be allowed on a location. Weight is important as it can increase the total cost due to transportation cost. Therefore it will have an effect on a decision to purchase these components locally or from abroad.

Table 22: Space and Weight

Solar System			
System connection type	**Scenario 1**	**Scenario 2**	**Scenario 3**
Stand-alone incl. Battery bank			
Solar array space needed	112.52 m²	93.12 m²	65.96 m²
Battery bank space needed	2.99 m³	2.44 m³	1.76 m³
Solar array and battery weight	8 584 kg	7 018 kg	5 055 kg
Grid-connected incl. Battery bank			
Solar array space needed	112.52 m²	93.12 m²	65.96 m²
Battery bank space needed	1.01 m³	0.83 m³	0.60 m³
Solar array and battery weight	4 002 kg	3 306 kg	2 378 kg
Grid-connected excl. Battery bank			
Solar array space needed	98.94 m²	79.54 m²	58.20 m²
Solar array weight	1 479 kg	1 189 kg	870 kg
Wind turbine System		1 250 kg	

5.3. Rainwater harvesting system

Johannesburg receives on average 543 mm of rainfall per year, or average 45.3 mm per month. July is perceived as the driest month of the year when an average of 4 mm of rainfall occurs, and January is perceived as the wettest month with an average of 125 mm. (Climatemps, 2014) According to weather underground, high volume thunderstorms has a precipitation value between 14 – 18.03 mm per storm event. There were 2 higher values but they were treated as outliers since those values were extraordinarily high. (Weather Underground, 2014) By taking into account these average values, the water resource available and storage capacity needed were calculated.

Water resource available

The rainwater resource that can be harvested was estimated by the following formula:

Net Runoff = Catchment area x Rainfall x 0.95

Thus the annual net runoff that can be harvested by a rainwater harvesting system was calculated as follow:

Annual Net Runoff = Catchment area x Average Rainfall per year x 0.95

= 13.98 m² x 543 L/m² x 0.95

= 7 211.58 L

where:

- the catchment area was the roof area of container measured to be 13.98 m²,
- the rainfall measured was an average of 543 mm per year (or 543 L/m²), and
- 0.95 is the runoff coefficient for a pitched metal roof.

The average net rainfall was calculated for the following events by utilizing the same equation as above:

- Monthly (45.3 mm) = 602 L
- Wettest month (125 mm) = 1 660 L
- Driest month (4 mm) = 53 L

Collection capacity needed

The collection capacity for a high volume storm was estimated by utilizing the same formula as above. The measure indicates the size of the storage tank that can be ac-

quired to reduce water loss due to overflow in a storm. The capacity was calculated as follow:

Capacity needed = Catchment area x Rainfall expected in a local high volume storm x 0.95

$$= 13.98 \ m^2 \ x \ 18.03 \ L/m^2 \ x \ 0.95$$

$$= 239.46 \ L$$

The estimated water need was calculated per month. Since the re-grinding machine's water tank (20 L) will be changed at least once a week, the estimated minimum water need was calculated to be:

20 L x 4 times a month = 80 L/month

Estimated pipe size

The pipe size was estimated by utilizing the rule of thumb - 1 cm² of gutter cross section per 1 m² of roof area, thus the estimated minimum pipe size = 14 cm² cross section. The pipe diameter was calculated by using the equation to calculating the area circle and converting it to diameter.

$$Area = 2 \ x \ (Diameter \div 2)^2$$

$$Diameter = 2 \ x \ \sqrt{\frac{Area}{2}}$$

$$= 5.3 \ cm$$

Sizing a rainwater harvesting system involves estimating the resources available, the storage capacity needed, and the pipe size. The estimated resource availability values calculated above were (on average) 7 212 liters collected yearly, 602 liters collected monthly, 1 660 liters collected on the wettest month, and 53 liters collected on the driest month. The estimated storage capacity needed can either be 80 liters which is the minimum amount needed to replace the regrinding water once a week, or 240 liters which is the amount of water that can be collected in a high volume storm event. The pipe size was estimated to be a minimum of 5.3 cm in diameter. The minimum pipe size is to allow water flowing fast and freely through the system.

A volume of 80 liters water is needed per month to replace the water in the grinding machine storage tank once a week, thus the minimum volume for rainwater storage capacity needed is 80 liters. By taking into account the minimum storage capacity needed and the estimated resource available during the driest month (53 liters), July would not

be able to produce the required minimum water needed for the month. Therefore it might be advisable to invest in a bigger storage capacity to plan for dry months such as in July. Since Johannesburg receives an average monthly net rainfall of 602 liters that can be collected, a bigger storage capacity of 80 liters can definitely be invested in.

6 CONCLUSION

A rainwater harvesting system can be applied anywhere in the world if needed. Therefore a rainwater harvesting systems would especially be beneficial in locations where water is scarce and/or not connected to a municipal water supply. The system require few skills, little supervision to operate, with minimal maintenance such as keeping the roof, gutters, and filters clean. The system can also be connected to the grinding machine's filtration system to filter out unwanted impurities collected in the water through its course to the storage tank before the water is replaced. With a bit of initiative and UV protected supplies the system can easily be installed DIY. A rainwater harvesting system takes up minimum space, depending on the storage capacity needed.

The storage capacity needed depends on how many times the water in the grinding machine is going to be replaced. Taking into account the estimated resource available during the driest month(s) of the year, the storage capacity can be estimated to collect the required minimum water needed per month. The storage capacity does not necessarily have to be for the required monthly volume needed, but can be according to any desired volume. Individual storage tanks can always be added later if more storage capacity would be needed or desired.

A passive solar design is the easiest method to start transforming the service facility into a sustainable service facility. This method does not need to be implemented just to decrease energy use, but can be implemented to increase the thermal comfort in the service station. The design elements, principles, and considerations that need to be taken into account can easily be applied and implemented to the service facility as the container is limited in size.

Basically the orientation depends if the location is in the northern or southern hemisphere and weather the side of the doors should face east or west. The heating and cooling depends on the climate and controlling the heat gain and natural ventilation in the service facility. There are various different techniques discussed which can easily be applied and modified in controlling heat gain and natural ventilation to suit a specific climate/location. The most important principle that needs to be considered in the service facility is insulation. As mentioned above, the container is constructed out of corrugat-

ed iron (a low thermal mass material) which reacts quickly to external conditions. For this reason it is of utmost importance that the container is insulated and insulating the container would cater for seasonal as well as daily variations in temperature.

Thermal mass should be taken into account in each step of the designing process. This principle can sometimes not be considered on its own. Take for example a design principle that needs consideration, it does not matter on the location, the choice in window and shading the window. According to the container specified layout, metal equipment will be stacked by the window. This means that sunlight that strikes on these equipment will heat the metal and in turn radiate the heat into the container space. This can be very beneficial during cold temperatures, but will cause uncomfortable temperatures during warm temperatures. Due to this phenomenon, extra care should be taken when considering a passive design.

Well coupled insulated and thermal mass with innovative shaded or unshaded ways can achieve efficient thermal comfort. A passive solar design can be utilized anywhere across the world and can also be implemented to a certain degree according to comfort and investment.

Renewable energy is also available everywhere throughout the world, but these technologies are expensive, need a lot of space and it has to be remembered that they are not maintenance free. These technologies also rely and are affected by the weather which reduces their reliability. It is inconclusive whether a renewable energy system would be a suitable choice for the service facility as it is not black and white. There are too many depending factors that need consideration at a location due to the fact that these systems are site specific. Wind turbine system would only be a viable option if the wind resources are optimal for a wind turbine at the location. Solar systems can be erected throughout the world but the size of the solar array dependent on the solar irradiance (peak sun hours) at that location. For some places it would just be too expensive to install a solar system. Other depending factors would be space, devices that needs power, the weight of transport, permits and regulations, and funds available.

Globally, each country differs, not just in their regulations but also in resources available. Therefore another depending factor that needs consideration is whether the location already has usable power available or not on the site. In my opinion if power is not

available a system can be sized and the cost compared to the cost of laying power lines. Also when power is provided but not freely available, a system can be sized accordingly and invested in to reduce the power cost or other renewable technologies can be researched.

During the course of sizing these systems different sources supplied different methods to size a system's major components. The manner in sizing these components were basically the same as explained above but other values such as, the derating factors or using ampere instead of watts, were used to size these components. These methods were utilized for interest sake and it was found that the results were different from the results explained above. Therefore it is crucial to utilize approximate values from the start, values pertaining specifically to the location and situation, and the method above should only be used as an estimate. The estimated size can also be compared with other methods before deciding to invest in an energy generating system. When a decision is made and before installing a system, a professional should be contacted to get a complete project quote.

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APPENDICES

Appendix 1. Service facility specifications (CONFIDENTIAL)

Appendix 2. Grinding machine specifications (CONFICENTIAL)

Appendix 3. Online Links

Climate:

Weather Underground: http://www.wunderground.com/

World Climate and Temperatures: http://www.climatemps.com/

World Weather and Climate Information: http://www.weather-and-climate.com/

WeatherSpark : http://weatherspark.com/

Latitude:

World Climate and Temperatures: http://www.climatemps.com/

Maps of the World: http://www.mapsofworld.com/lat_long/

Solar Elevation Calculator:

Keisan Online Calculator: http://keisan.casio.com/exec/system/1224682277

Overhang Calculator:

EcoWho: http://www.ecowho.com/tools/passive_solar_eaves_calculator.php

Solar Irradiance Calculator:

Solar electricity handbook: http://solarelectricityhandbook.com/solar-irradiance.html

Tilt Angle Calculator:

Solar electricity handbook: http://solarelectricityhandbook.com/solar-angle-calculator.html

Wind speed at a different height:

Wind Profile Calculator: http://wind-data.ch/tools/profile.php?lng=en