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Enhance the performance of cooling systems in small and medium size factories in KSA with the Aid
of Renewable Energy (Solar Energy)

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Abstract

Cooling technologies are varied depending upon the location and the size of the building. The utilization of renewable energy as a source of power to operate a cooling system has a great advantage in term of cost reduction and less environmental impact. The evaporative cooling system is a good alternative which can replace the air-condition based cooling system, because it is affordable, cheap to run, maintain and need less power compared to the air-condition based system. After studying the cost implications of three different cooling's system, it is revealed that a cheapest system could cost up to 39300 USD to cover a demand for a fictional building with a volume of 28000 m³. The mathematical model was studied in order to show how the effectiveness of the system can be improved by studying the thermal parameters of the air when it passes through the pad to be moisturized and make it comfort for inside the building. The research also revealed that the system can work efficiently with a high humidity in the weather when there is a technology of dehumidification deployed with the current evaporative cooling system. This technology uses the heat exchanger to absorb the humidity from the air in order to ensure that the hot air would be dry before it passes to the evaporative pads and get it moisturized. A new technology based on desiccant wheels is recommended to modify the current evaporative cooling system and enhance the performance in such a way that it works with high humidity in the weather during the hot seasons.

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Chapter 1

Introduction

1.1 Back ground of the problem

Many factories including the petrochemical industries are reliant on cooling systems in order to remove heat during different stages of production (Nayantara,2016) as well as refreshing the air inside buildings. One such way of providing this necessity is the use of seawater – mainly thanks to its availability (Anderson, 2004). However the use of untreated seawater comes with its contaminations, the inevitable corrosion, costly transportation and consumption of more energy. Moreover, the current cooling systems do consume high electrical energy to supply the fans and cooling systems. One of the current government policies in King Saudi Arabia is to reduce the dependency on gas and oil in producing electricity as shown in View 2030 (2016).

The use of cleaner energy is becoming largely popular in many countries including the KSA (Hsu et al, 2013). An alternative energy source can be utilized to run the cooling systems that are less costly, more effective, not as harmful and environmentally friendly. The solar energy is considered one of the renewable energy sources and can be a substitute which is widely available today in regions such as Middle East (Vernyuyet al, 2015).

The selection of renewable energy source must then be satisfied by the geographical and climate surroundings. The Middle East is known they have a hot climate where the sun light is rarely hidden. Moreover, hydropower requires close proximity to rivers or seas but power plants providing oil and gas are found closer in land with the named countries. Finally wind energy is not a good source due to the lack of wind in these regions. The best option is then the solar panels which can be used inland where power plants might be located. Utilizing the continuous suns light energy and providing the necessary electrical energy to power the cooling systems.

There are different types of cooling system as shown in the diagram below:

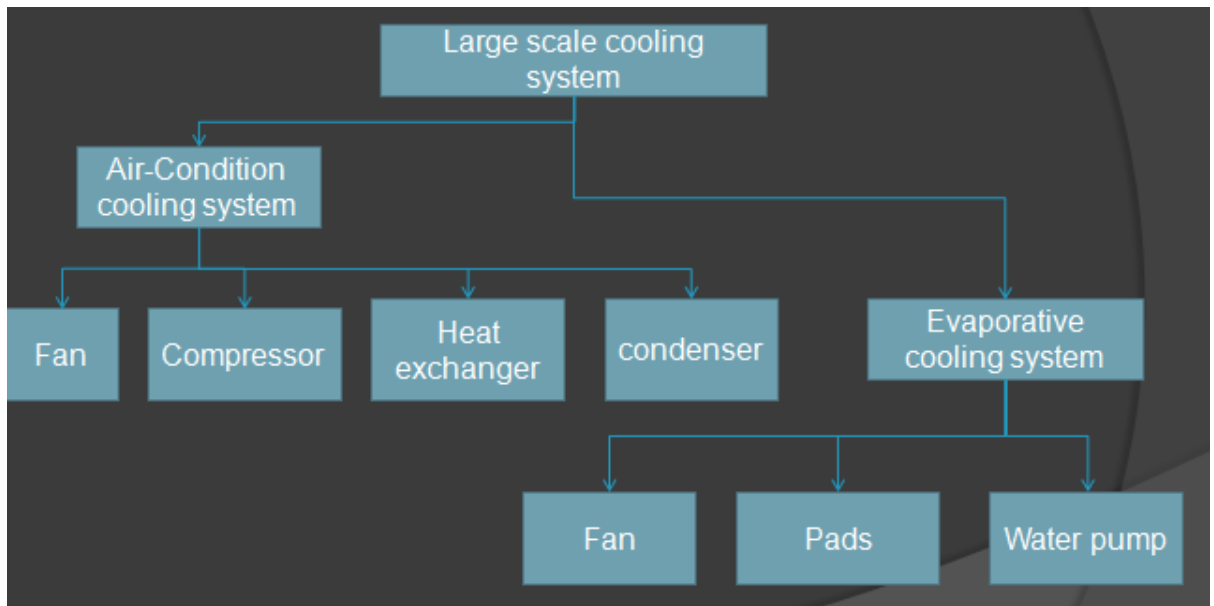


Figure 1 : shows a diagram for different types of cooling systems and their components

Each system has its characteristics and applications. The air-conditioner based system consumes high electricity because it has a compressor, heat-exchanger and a condenser which need high power to operate. Unlike the evaporative cooling system where it has only a fan and water pump, which they consume less power. Depending on the weather condition the type of cooling system is chosen, but the cost implication is essential when a cooling system is aimed to install. In the Middle East where the weather is hot during an average of more than 6 months in a year, both cooling systems are suitable to install, however, the majority of the buildings are using air conditioning system because the region is subjected to high humidity during the Summer season. Furthermore, the evaporative cooling system is used widely in the remote area with desert weather, as there are restrictions with the power supplying and many users are using mobile electrical generators to supply the evaporative cooling system. The overall cost to install and operate the air condition cooling system is relatively high because of the energy cost and the expensive maintenance, unlike the evaporative cooling system which can be run cheap. The technical details related to the cooling system are discussed as a preparation for a suitable mathematical model associated with the evaporative cooling device. Therefore, the effectiveness of the cooling system will be derived from the temperature of the air which usually known as dry bulb temperature T_{DB} and the wet bulb temperature T_{WB} . The dry temperature is the temperature of air in the ambient while the wet temperature is the temperature of the cooled air after leaving the evaporative pads (US Department of Energy, n.d.). If the relative humidity is 100%, then both temperatures are same. Moreover, when the relative humidity decreases, it means the wet bulb temperature

becomes low and this will be known as a depression (Eggie, 2008). This feature can be used with an evaporative cooling system used for food storage.

In this project, a fictitious building will be used to install and evaporative cooling system, as it was difficult to get access to a real building because of the unavailability of the business owner and the long procedure to get permission from the person who is in charge to let the researcher get accessing into the building. The energy source aimed to use is the photovoltaic solar panels or solar based devices. The requirements for installing a complete cooling system will be discussed and the cost implication will be added. At the end of the report, a suggested evaporative cooling system will be made in order to overcome the issue with high humidity.

1.2 Aim and Objectives

The aim of this project is to enhance the performance of cooling systems used in medium and small size factories in KSA using PV solar panels.

To achieve the above aim the following objectives can be considered:

- Ensuring the project is viable by having intensive literature review;
- Choose a sample building in a medium size or small size factory in KSA;
- Determine how many BTU or Joule needed to cool the building;
- Determine specifications of suitable cooling systems to cover the demand;
- Create a sketch using Solid work or other available software tool draw the building and show the positions of the evaporative cooling unites on the roof with an approximate diagram for the ducting system;
- Calculate the demand of electrical energy required to run the cooling systems efficiently;
- Choose suitable PV-solar panels with batteries and invertors to cover the demand.

1.3 Time scale and provisional Timetable

Any project starts with a planning which is an important part when dealing with management. According to Laura (2000), the long time spent on developing a proper project plan could save great time and high cost required to complete project tasks. Furthermore a smoothly running project should be based on a timeframe that set all activities required to complete project tasks within set deadlines. The following table represents this:

Weeks	Tasks
Week 4	Start collecting resources and prepare for Literature review.
Week 6	Prepare the first poster
Week 8	Choose suitable buildings in small or medium size factory in KSA and determine the size and the amount of BTU required for cooling system
Week 10	Prepare the internal exam
Week 12	Determine the number of cooling system required to cover the demand
Week 13	Create a sketch diagram for the mechanical work needed to install the ducts and fans inside the chosen building.
Week 14	Calculate the amount of electricity and the PV solar panels with required batteries and invertors to cover the demand.
Week 16	Evaluate the new energy supply using PV solar panels
Week 17	Start writing up

Table 1 - scheduled time table

1.4 Environmental impact

According to Boyle (2012), any system designed should be investigated whether it has an environmental impact or not. The environmental impact is associated with any issues that have influence on the environment and need to be considered during the design and manufacturing phases. Since the evaporative cooling system need to be used is based on renewable solar energy, there is no significant impact on the environment. However, there is possibility of having a noise pollution from the fans used in the building but this will be on the roof of the building which would not be heard from inside. Furthermore, there is other environmental impact would be faced from manufacturing the materials used to install the cooling system such as the fan, the pads and the PV solar panels used to produce electrical

power. Therefore, it is imperative to consider listing all the possible factors that could cause any environmental issues.

1.5 Mechanical and electrical works

The project included mechanical and electrical works. The mechanical work includes installing the coolers and mounting them on the roof of the building, installing the ducts on the ceiling and mounting the PV solar panels.

The electrical work includes the wiring between the cooler devices to the inverter from one side and the wiring between the solar panels as well as the batteries and the inverter from the other side. To make the system more efficient, an automatic controller will be added into the system so that it will use the power from the national grid in case the PV solar system has a break down or need a major maintenance.

1.6 Project summary

The project is divided into five chapters; the current chapter one is the introduction which includes aim and objectives. The second chapter contains intensive literature review about the subject. The third chapter is the methodology, which explains how the objectives are fulfilled in order to install an evaporative cooling system in a building using renewable energy (PV solar panels). The fourth chapter is the design and installation of the cooling system and finally an efficient discussion chapter will be added into the report and close it with a conclusion and recommendation.

1.7 Project Plan and Gantt chart

Activity	Week No.s from 24/10/2016 to 01/05/2017																											
	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14	w15	w16	w17	w18	w19	w20	w21	w22	w23	w24	w25	w26	w27	w28
Literature review (different cooling system, BTU parameters, ..etc)																												
prepare the first poster																												
choose suitable building, research different types of cooling systems, etc																												
prepare the first intirm viva																												
Christmas and new year holidays																												
Determine the number of cooling system required to cover the demand																												
Create a sketch diagram for the mechanical work needed to install the ducts and fans inside																												
Calculate the amount of electricity and the PV solar panels with required batteries and invertors to cover the demand.																												
prepare the second presentation																												
start writing up and Easter holiday																												
submit the first draft																												
submit the final draft																												
Presentation of the project																												
Finish																												

Chapter 2

Literature review

2.1 Background

Buildings need suitable cooling and heating systems depending on the size and the usability. In Middle East the necessity of cooling system in buildings and factories is essential because of the hot weather. Machines and tools could be damaged if there are no sufficient cooling systems installed in the factory, as the heat produced during the operation reduces the life time of the machine when there is no suitable cooling system installed.

Renewable energy became a promising energy for today and the future, as the dependency upon oil and gas to produce electrical energy is planned to decrease in order to keep the environment friendly and to reduce the cost. There are different types of renewable energy sources which some of them can be listed below

- Wind Energy: The most common method is wind turbines. This type of source is used where wind patterns are high (Dhunny et al, 2016). The turbines are rotated by wind which then works with a shaft generator to the battery. Effectively Turning kinetic energy into electrical energy (Whitburn, 2015).
- Photovoltaic Cells (solar energy): PV cells are panels which make use of the suns light. Directly converting light energy into electrical energy (Knier, 2008). It can then be said that this method is best used where sun light is widely available. There are different types of solar panels available and each provides different efficiencies (Krebs et al, 2013). The selection depends on what the use is for.

Faramarzi, et al (2004) showed the impact of high ambient temperature on the cooling efficiency and hence the amount of electricity required to keep the cooling system operated efficiently. It is obvious that in the chosen research region the demand on electricity is extremely high and the consequence cost is high too, therefore any new ideas based on renewable energy will be highly appreciated.

2.2 Types of PV solar panels

There are different types of PV solar panels which are used to convert sunlight into electrical energy (Notton et al, 2005). The main types of solar panels are listed by Chaniotakis (2001), which are mono-crystalline silicon cell, multi-crystalline silicon, amorphous silicon and thin films. All kinds of PV solar panels are operated on the same principle which can be shown in the following paragraph. Moreover, each type of PV solar panel has advantages and

disadvantages depending upon the applications and the material used in the manufacturing. Furthermore, one panel has multiple solar cells which they convert sunlight into electricity.

2.3 Principle of operation of a PV solar panel

PV solar cells have semiconducting material which is sensitive to sunlight. According to Boyle (2012), when photons from sunlight hit the surface of the PV solar panel, the energy absorbed by the electron in the p-n junction and electrons will be excited and moving out of their place leaving holes behind them. The electrons are moving through a channel to the electrode. Similarly the holes will be excited too and will move to the opposite side. The moving is known as an internal electric current which creates a potential difference by accumulating electrons on one side and holes on the other side. When a load is connected externally across the potential terminals, a current will flow through the circuit from the negative side to the positive side.

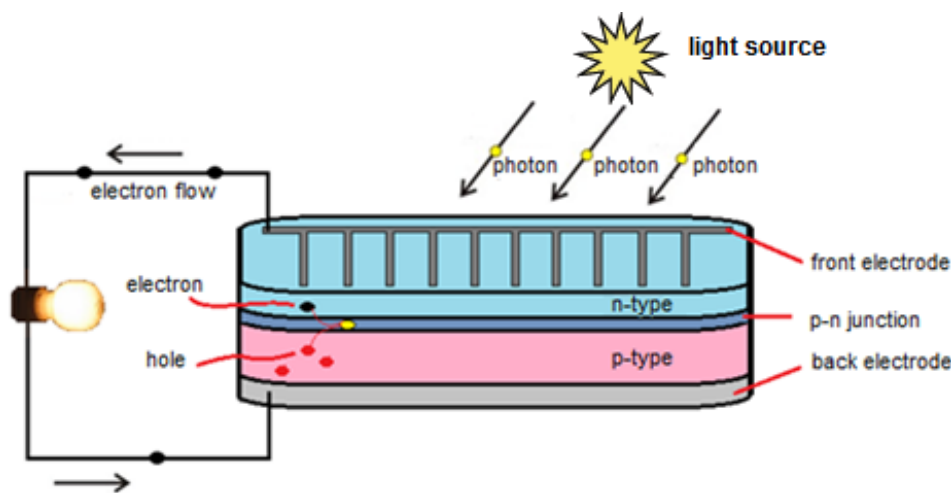


Figure 2: shows the principle of operation of a PV solar panel and the movement of photons between the p-n junction (<https://www.intechopen.com/source/html/39166/media/image8.png>)

2.4 Air-condition based cooling system

Air condition is a cooling device which is used in domestic and commercial as well as in vehicles. The device has multiple stages including fans, compressor and a heat exchanger as well as a control unit (Chadderton, 2014). In an air-conditioning cooling system there are two fans, one is sucking the hot air inside the room and blow it up and other fan blowing dry cooled air inside the room. The compressor has a Freon gas which is circulated through a radiator in order to cool the hot dry air. The heat exchanger is to dehumidify the moisturized hot air and change it into a dry hot air before it passes into radiator. The electrical parts in an air-conditioner cooling system consume high electricity and it needs a regular maintenance, consequently the operating cost for an air-conditioner based cooling system is relatively high, although the output performance and the comfort air produced is high. For commercial and big

building a central cooling system is used. It has a chillier, heat exchanger and multiple fans, see the figure three. The system can be used as a central heating in winter using the solar thermal collector as shown in the same figure three.

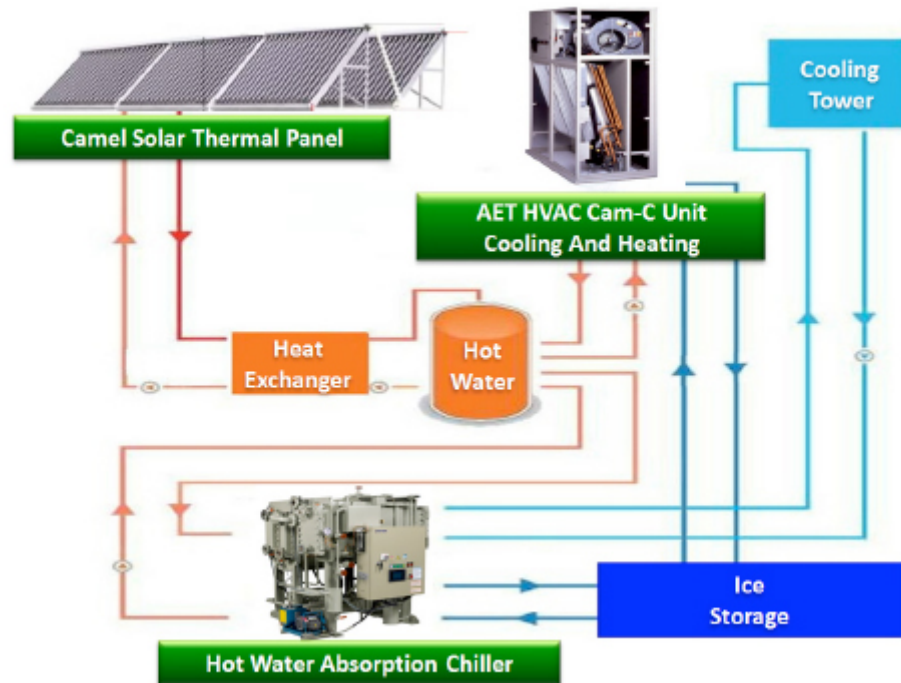


Figure 3: a commercial central cooling system (<http://www.flexiblespace.com/solar-cooling-by-aet/>)

2.5 Evaporative cooling system

It is a cooling device that cooled the outside hot air by using water an evaporative pad and delivers it to inside the building (Jia,2014), see a common evaporative cooling system in Figure (4). The air is fresh and humid which makes the atmosphere inside the building comfortable during the dry hot summer season.

An example of evaporative cooling system was designed and constructed for a place had a volume of 0.6 m^3 which can be used as storage for vegetables/tomato (Abobaker et al, 2016). The relative humidity was designed to be high in order to get the reasonable data. The walls were chosen made of aluminium of thickness of 1 mm while the pads where made of jute and got moisturized from water flow through a perforated pipes. The system had a power supply which was based on a renewable energy. It was operated using a PV solar panel which can supply 18 volts and 0.36Amp. A battery was used for a back up in order to maintain a

continuous cooling during the day and night. The system shows feasibility, as it was cheap to operate while maintaining a reasonable relative humidity during the test.



Figure 4: evaporative cooling system based on solar power
(<http://excelair.gmc.globalmarket.com/products/details/solar-evaporative-cooler-1483036.html>)

2.5.1 Key facts for good performance

In order to maintain a good performance for an evaporative cooling system, the following steps should be followed essentially (Donald et al, 2000):

1. Maintain a good air flow without any obstacles in the air tunnel.
2. Avoid hot air draft from outside the building through windows or doors seals in order to keep the cooled air trapped inside the building.
3. It is essential that pads should be fully moisturized in order to get all incoming air evaporated.
4. Maintain regularly the water pump, nozzles and the pads.
5. The padding area should be large enough in order to have a high operating efficiency.

The next (Table 2) shows a figure for the pads size and the expected system efficiency with the static pressure drop. According to the table, the system is operated efficiently when the pads area are thick and big, as this makes the air pressure drop across the pads high.

Pad type and thickness	Design air velocity through pad	Static pressure drop across pad	Total house static pressure ¹	System efficiency	Total pad area needed	Min. length of 5-ft pad on each side of house
6-in small-flute recirculating	335-350 fpm	0.04"-0.07"	0.06"- 0.09"	72-74%	567-542 sq ft	55 ft
6-in large-flute recirculating ²	335-350 fpm	0.03"-0.04"	0.05"-0.06"	54-62%	567-542 sq ft	55 ft
4-in recirculating	250-300 fpm	0.06"-0.09"	0.08"-0.10"	68-74%	760-633 sq ft	75 ft
2-in spray pad	280-310 fpm	0.03"-0.05"	0.05"- 0.07"	55-66%	679-612 sq ft	70 ft

Table 2: shows the pads types and size compared to the system efficiency (Donald et al, 2000)

2.5.2 Direct evaporative cooling system

In order to maintain an efficient work flow inside a building the climate inside the building should be comfortable during the hot time in a year (Camargo et al, 2003). The evaporative cooling system is an efficient which can be installed without expensive cost. Moreover the fan and water pump inside the cooling system do not need high power, therefore the utilization of a renewable energy such PV solar panels will fulfil the energy demand for operating the electrical devices. The direct evaporative cooling system shown in figure (5) has a fan, water aspersion, evaporative pad and a water tank. The system converts the heat into latent heat and the non-saturated air is cooled by the evaporative pad. The mass heat becomes high because of the movement of the air forced by the fan through the water surface area for evaporation. This process decreases the dry bulb temperature and increases the humidity according to Camargo et al, while the enthalpy of the water is kept ideally constant. The system has other characteristics such that the wet bulb temperature which is the minimum temperature that could be reached during the cooling's process. The effectiveness of the system is measured when there is a difference between T_{DB} and the theoretical real decrease is very low which the case of 100% efficient cooling is. However the area of utilized pads and the type of the pad's material are essential to get an efficient cooling system.

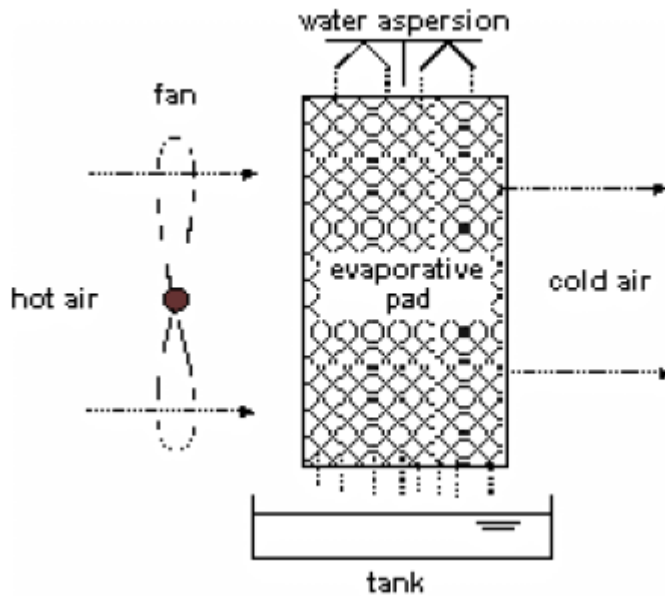


Figure 5: direct evaporative cooler (Camargo et al,2003)

2.5.3 Indirect evaporative cooling system

The utilization of air to air heat exchanger is to remove heat from the main air from the ambient without adding moisture according to (*energy design resource*). A series of horizontal tubes are wetted from outside in order to cool down the air passed through them. A second air stream which is warm and has moisture is blown outside the heat exchanger. This will maintain an effectiveness of 75%. For commercial applications, another type of cooling system is deployed which uses a cross channel heat exchanger that cools gradually the air over multiple stages. The expected effectiveness can reach 85%-100% for this system. Therefore the air pressure increases when it passes through those stages which require a strong fan in order to blow it out inside the building, see figure (4) before.

2.5.4 Indirect-direct evaporative system

It is known as two stages evaporative cooling system see the next Figure (6) (*energy design resources*). The first stage includes passing hot air from outside through a heat exchanger cooled by evaporative which is the principle operation of the indirect evaporative cooling system described before. The cooled air passes through a water soaked pad to add some moisture into the air which is the principle of operation for a direct evaporative cooling system. The moisturized air is blown into the interior room by the fan with a humidity around 50-65% and an effectiveness between 100-115%. Furthermore a DX cooling stage is used with a commercial direct expansion evaporative cooling system to meet cooling requirements during hot and humide weather. A heat recovery is also paired with the system to utilize some

energy lost in the blown out air stream in order to reduce the ventilation cooling load. The system has advantage that it consumes only 0.22 kW/ton unlike an aircondition based cooling system which requires 1 kw/ton . Moreover, when the weather has high humidity, they will be less saving for the electrical energy, as the heat exchanger will work excessively to dry the air before it is moisturized and used for cooling.

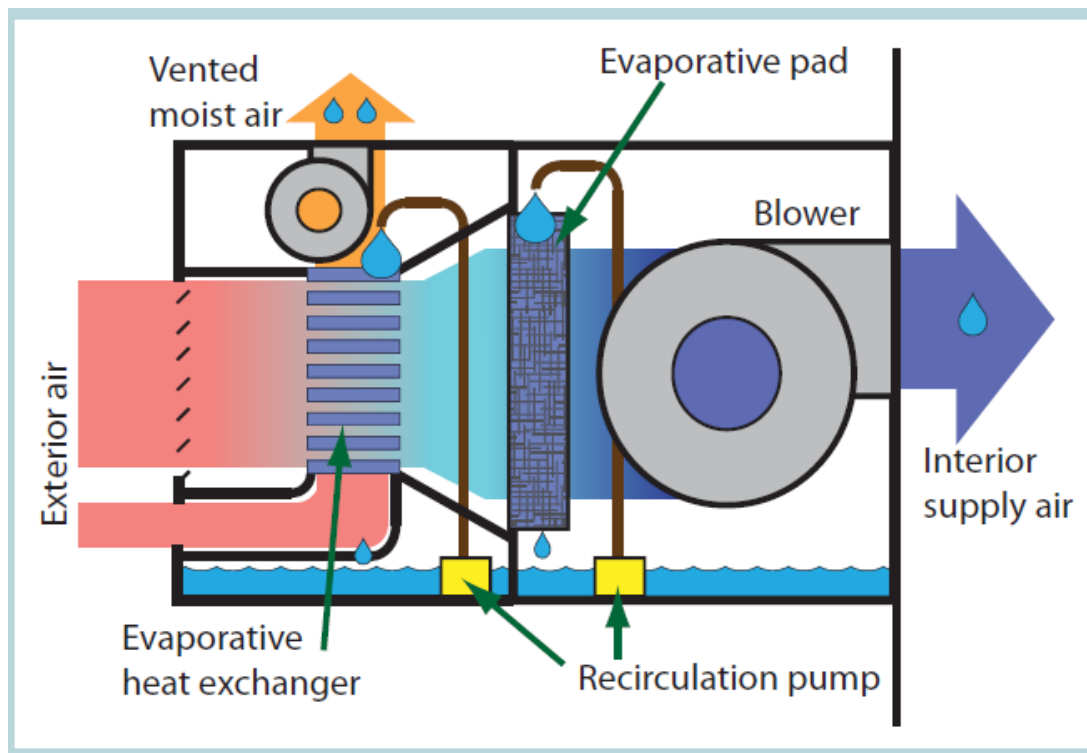


Figure 6: indirect-direct evaporative cooling system (Energy Design Resources)

2.6 Solar chimney and cooling cavity

This technology utilizes the natural ventilation which includes both solar chimney evaporative cooling to reduce the temperature inside a building (Tashtouch, 2013). The system cheap and has no significant environmental impact. The system consists of a solar chimney and a cooling cavity as shown in figure (7). An absorber plate is installed underneath the warm air tunnel which has a glass surface. The solar absorber is directed to the South. When solar radiation is captured by the absorber it allows warm air to draft from inside the building to outside. The cooling cavity is working after spraying a vapour of water into the air coming inside the cavity. The water falls is collected and circulated again using a pump into the water tank on the roof in order to reuse it. The evaporative water is transferred into the air because the partial water pressure is higher than the air pressure inside the room, as there is an association between mass transfer and heat transfer of the evaporative water.

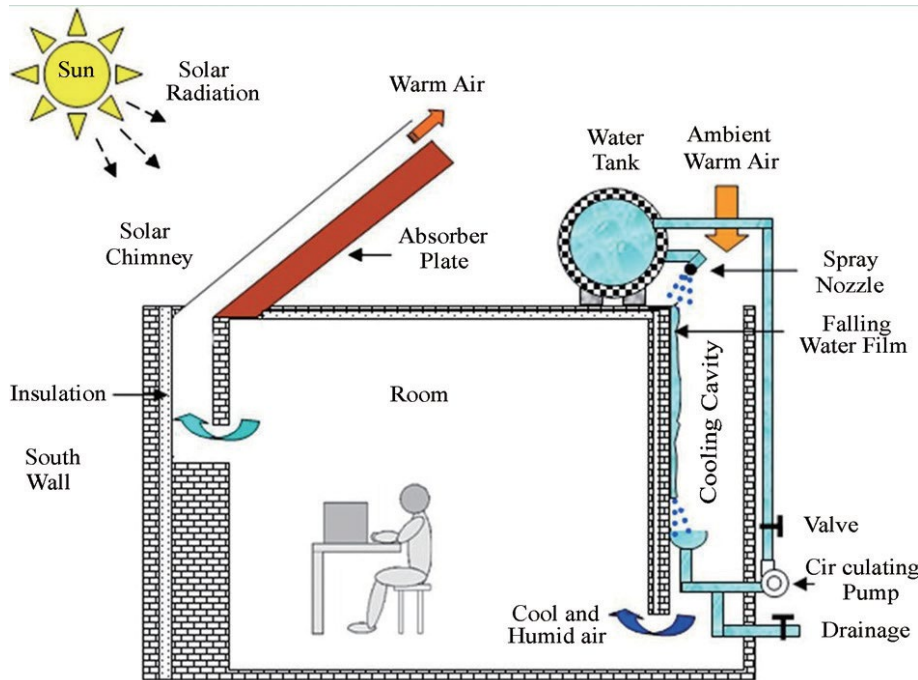


Figure 7: solar chimney and cooling cavity (Tashtoush, et al,2013)

The heat transfer is taken place between the surface of the water and the air; consequently, the system is known a passive evaporative system. The system is able to reduce the room temperature to a comfort level when it operates. However, it is necessary to know the ventilation rate which is almost three times the air change per hour. The system is considered an environmental friendly because it does not produce any kinds of pollution.

2.7 Effectiveness of an Evaporative cooling system

Effectiveness is a measure of how effective is the supply air temperature (SAT) blown out of the evaporative cooling system and how it is close to the wet bulb temperature (*energy device resource*). It is measured using the following equation:

Effect.= $(T_{DB} - SAT)/(T_{DB} - T_{WB})$; where T_{DB} and T_{WB} are the dry bulb and wet bulb outdoor temperature correspondingly. Both the thickness of the pads and the air velocity have influence on the effectiveness. However, the effectiveness reaches 80%-90% especially when the pads have thickness between 8-12 inches. If the weather is hot and dry then the indirect evaporative cooling system is suitable and the wet bulb temperature would reach 20°C or lower.

2.8 Components of cooling loads

The cooling loads for any building contents the following components (Bhatia, n.d.):

- External load

- Internal load

The external load includes the heat transfer through the building walls, roof, floor and windows, while the internal load comes from the light, equipments such as machines and the people occupying the building. Depending upon the type of the building, the ratio between the external loads to the internal load can be changed accordingly. There are also sensible load which is impacted by the dry bulb temperature and latent load which is impacted by the moisture in the outside air. Moreover, building can be classified as externally loaded and internally loaded according to Bhatia.

The external load is highly influenced by the surrounding condition because of the heat transfer. The internal loaded building has near to a constant value because the heat generated from light, occupiers or the machines is almost unchanged which makes the heat transfer between those mentioned factors and the inside of the building is almost constant.

2.8.1 Calculate cooling loads

To calculate the cooling loads, the whole building loads such external and internal loads should be calculated. There are three main ways (Bhatia, n.d.) to calculate it which are the transfer function method, cooling load temperature differential/cooling load factors and total equivalent temperature differential/time averaging. The first method does need a software tool which makes it too complex to achieve data. The second one utilizes tabulated data to get the calculations properly. The results are transferred into a spread sheet in order to do the analysis; however it has a restriction that tabulated data might be not sufficient to make efficient calculations. The third method is simpler than the second one and it needs simple data sheet.

2.9 Greenhouse evaporative cooling system

Franco et al (2014) showed a new technology which could be used to cool greenhouse using evaporative cooling system. The technologies are known as cooling box which was compared to cellulose pads. The utilization of an evaporative cooling box could be an alternative way to cooling a building, as it uses low speed wind tunnel which reduces the air pressure. Moreover, the saturated efficiency for this cooling system is higher than the one uses the cellulose pads which are not influenced by the low pressure also when the water flow increases, see figures (8 and 9). The pads have a cooling capacity which are based upon two factors namely; the air flow and the amount of water passes through the pads from one side and the material geometry (the shape of the pads) from other side. The cool box has a plastic packing inside which is surrounded by four cellulose evaporative pads as seen in figure (10).

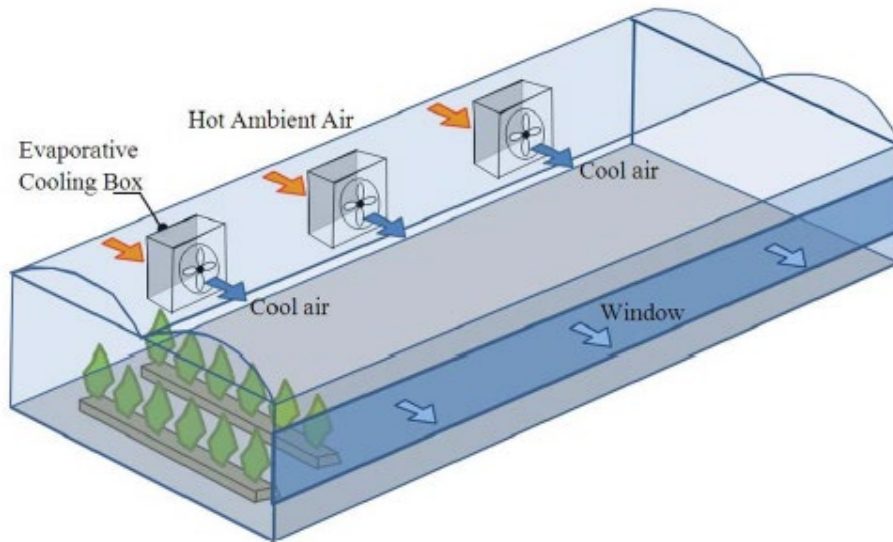


Figure 8: evaporative cooling box suitable for green house (Franco et al,2014)

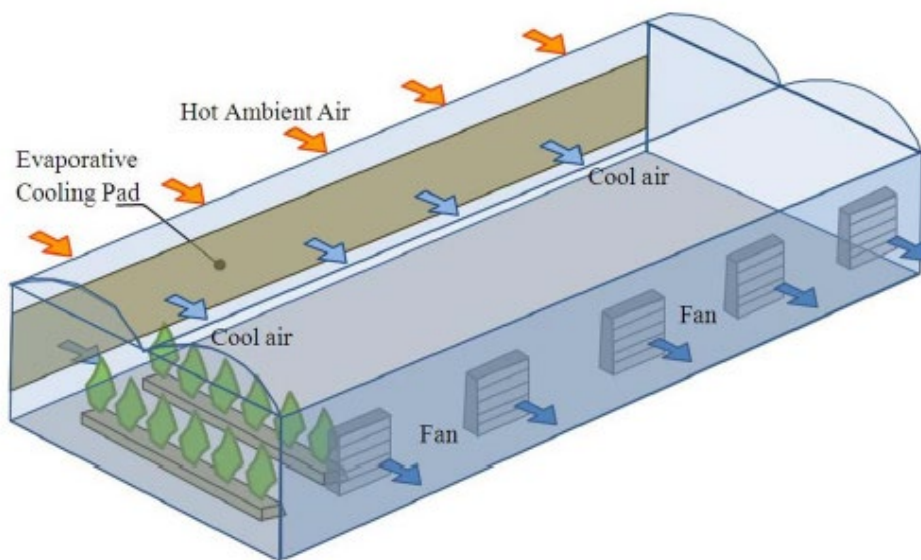


Figure 9: evaporative cooling system using cooling pads (Franco et al, 2014)

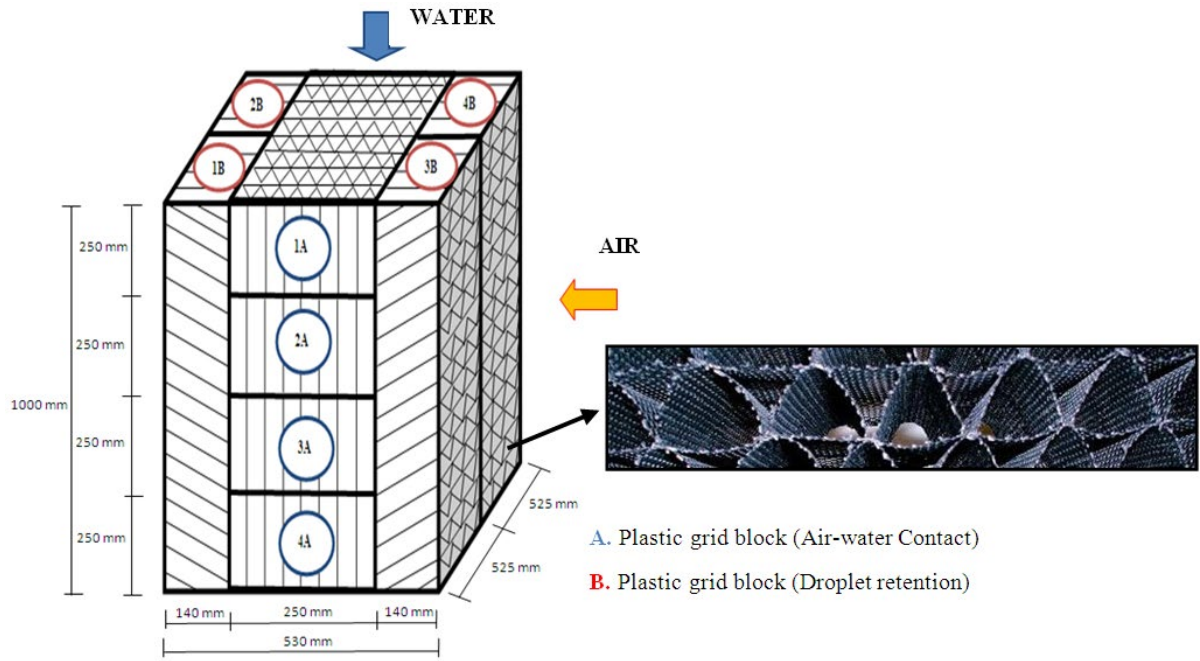


Figure 10: the shape of a cooling box and the inside geometry (Franco et al, 2014).

The materials have the dimension indicated in figure (8) and the angle of incident of the air for the four pads are recorded and documented before the tests were carried out in order to investigate the impact of these angles on the efficiency of the system at different water flow rate and different fan speeds. The mathematical model was calculated in order to find out how much water consumed C_w . By using the saturation efficiency, the wet bulb temperature and the temperature difference when water passes through the pads ($T_1 - T_2$) which returns the maximum thermal difference ($T_1 - T_{WB}$). Hence the consumed water is calculated as follows:

$C_w = \frac{m_e}{(T_1 - T_2)Af}$, where m_e is corresponding to the mass flow for water, Af is the exposed surface to the m_e .

The mass flow for water is calculated by using the following relation:

$m_e = h_m A_s \Delta p_v$, where h_m is the coefficient mass transfer (m/s), A_s is contact surface area (m^2) and Δp_v is the water vapour density which can be calculated using the following equation:

$$\Delta p_v = \frac{(p_{v2} - p_{v1})}{\ln(p_{v1} - p_{wb}) / (p_{v2} - p_{wb})}$$

Where p_{v2} , p_{v1} are the water vapour density at the output and the input of the pads and p_{wb} is the saturated water vapour. Therefore the last expression can be rewritten as follows:

$$C_w = \frac{h_m A_s}{(T_1 - T_2)Af} * \frac{(p_{v2} - p_{v1})}{\ln(p_{v1} - p_{wb})}$$

However, this mathematical model cannot be deployed with the cooling system aimed to investigate, as the building is fictile one and no actual measurements were conducted.

2.10 Mathematical model for a direct evaporative cooling system

The model is based upon the idea that a humid air is a mixture of a dry air and water vapour. When a humid air is blown into a wet surface, the heat transfer is occurred only when there is a temperature different between surface temperature T_s and the draft temperature T . Moreover, if the different between the absolute humidity of the air is closed to the surface w_s and the humidity draft w is low, then the mass transfer is occurred. The mathematical representation of the effectiveness can be defined as follows:

$\varepsilon = \frac{T_1 - T_2}{T_1 - T_s}$, where T_1 , T_2 are the first and second bulk temperature correspondingly (Camargo et al, 2003).

$1 - \frac{T_1 - T_2}{T_1 - T_s} = \exp\left(-\frac{h_c A}{m_a C_{pu}}\right)$; where h_c , A , m_a and C_{pu} are the connection heat transfer coefficient, area of the heat transfer surface , air mass flow and the humid specific heat correspondingly. According to Camargo et al, h_c is calculate by using what is known Nusselt number Nu as a function of Reynolds number (Re) and Prandtl number (Pr).

The C_{pu} is calculated as follows:

$C_{pu} = C_{pa} + W_{cpv}$; where C_{pa} is a constant pressure at a specific heat of the air which is usually 1.006 KJ/kg.K during standard environmental condition. C_{pv} is a constant pressure at specific heat of vapour and it is equal to 1.805 KJ/kg.K. Therefore the effectiveness can be rewritten as follows:

$$\varepsilon = 1 - \exp\left(\frac{-h_c A}{m_a C_{pu}}\right).$$

To get an optimal value for effectiveness, the term inside the exponential should reach a minimum value. Moreover, a100% effectiveness means that the air leaves the equipment at a bulb temperature of the entrance. In this case, a large area of the heat transfer and high heat transfer coefficient with a low mass air flow. The effectiveness becomes a constant when m_a is a constant.

Chapter 3

Methodology

3.1 Proposed evaporative cooling system

The proposed evaporative cooling system is a direct evaporative cooling system. The system can be used in commercial and domestic purpose. The device shown in figure 4 before could be a solution as it can be operated by using PV solar panels. It does work with both PV solar and the grid. If there is restriction with supplying electricity from the PV solar panels, the system can switch automatically and operates using the grid. Depending upon the size of the factory, the number of the ventilation systems is calculated. The above evaporative cooling system has specifications shown in appendix A.

3.2 Proposed building

Since there were difficulties to find a real small or a medium size building for a factory to conduct the research, it is agreed with the supervisor of the project to choose a fictional building to complete the research. The difficulties were based on limited relations with business owners who own such buildings and the restrictions to get access to the building characteristics from the construction engineer. Furthermore there were leaks of the knowledge about how imperative to conduct such a research in order to find out an alternative ways to cooling the building using evaporative cooling technologies based on renewable energy. The building will be drawn using either SolidWorks or other software tools to show the positions of the evaporative cooling system on the roof of the building.

The proposed building has the following dimensions; 100 meter length, 40 meter width and 7 meters height and the following characteristic:

- The walls would be built of cement blocks which are typical for a warehouse building.
- There are 10 equal size windows fitted on the walls. Each window is 2 metres length and 1.2 meter width. These windows are divided as follows; 4 windows on each side of the building and 2 windows on the back wall.
- The building has one double main door for accessing to the materials, machines or the machinery and 5 additional small fire protected doors. The main door is 5 meters height and 10 meters width. The small door is 1 meter width and 2 meters height which can be used by the personals working inside the building.
- The roof has a structure made of light steel and concrete to resist the fatigue from the weight of the evaporative cooling devices and to provide a reasonable insulation. Other material could be used for the roof could be metal timber sheet

but they have issues with insulation and are subject to large heat dissipation because of the intensity of the sunlight during the summer season. The timber is light and possibly cannot resist the weight of any object mounted on it.

- The building is used to manufacture hand tools, therefore no consideration would be made to any damages could happen because of the storage before the goods are transported.

See a diagram for the proposed building in figure (11).

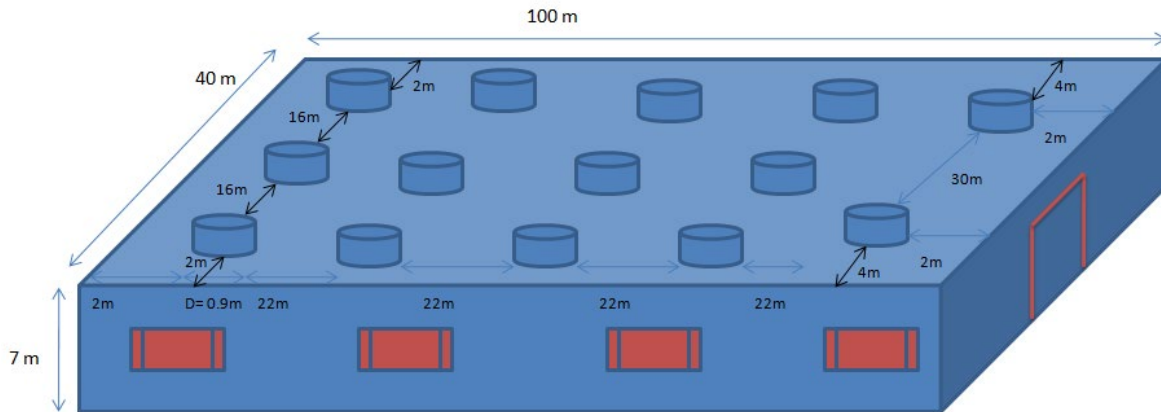


Figure 11: a diagram for the fictional building

3.3 Proposed location

The proposed location chosen for the fictional building is in Riyadh KSA. The city has a geographical coordination of 24.725192, 46.822529 (Latitude, altitude) (<http://maps.cga.harvard.edu/gpf/>). The average weather conditions in the chosen location are shown below:

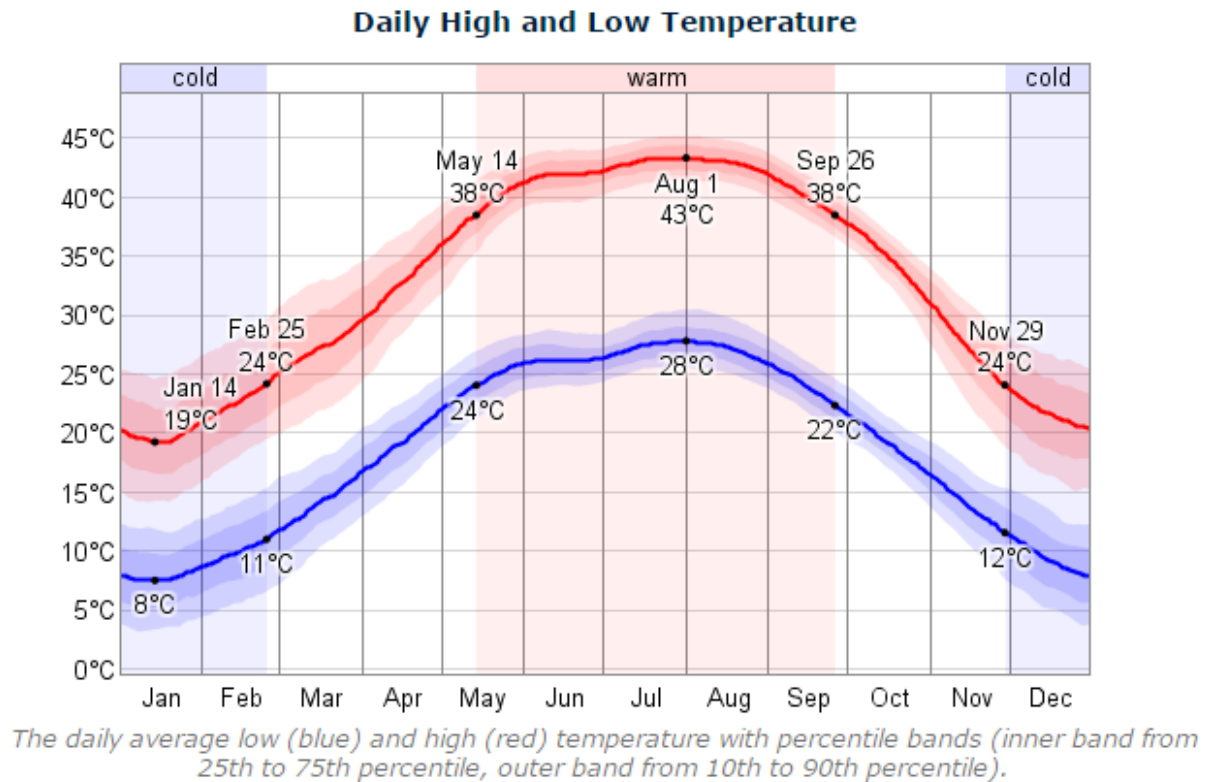


Figure 12: average temperature (<https://weatherspark.com/averages/32777/Riyadh-Saudi-Arabia>)

According to the above figure (12) the temperature is varying between 8° and 43°. This temperature is the dry bulb temperature required to calculate the effectiveness of an evaporative cooling system. The other interested weather's factor which is necessary for the proposed cooling system is the relative humidity as seen in figure (13). According to the figure the highest humidity is between January and February and November to December. This is because of the winter time and the drop in the temperature during the mentioned months as shown in figure (12) again.

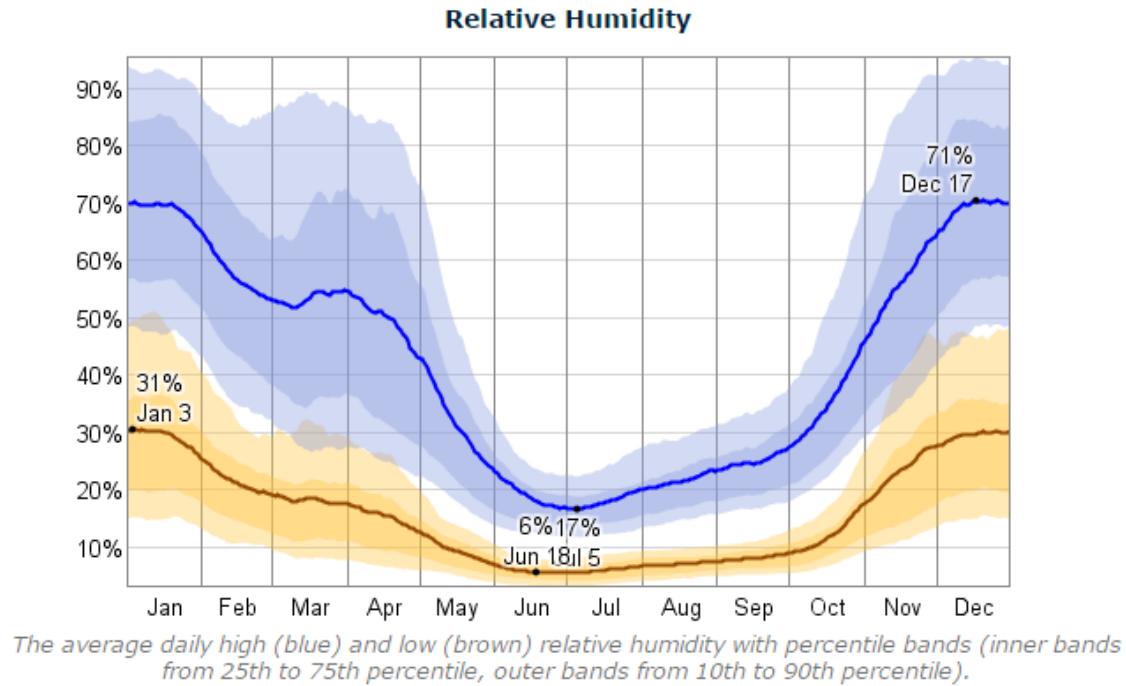


Figure 13: the relative humidity in Riyadh (<https://weatherspark.com/averages/32777/Riyadh-Saudi-Arabia>)

3.4 Alternative solar based cooling system

According to the last resource about the weather details in Riyadh, the number of hours for the day and night times are shown in figure (14). Since the daylight is between 10:35-13.41 hours, the deploying of solar based electricity generator has great advantages, as it will reduce the cost of electricity required to operate the common air-condition based cooling system. Moreover, the earliest time for sunrise and the latest time for sunset during a year are 5:03 AM – 6:47 PM see figure (15), therefore the PV solar panels are working efficiently during the year in the chosen location. The solar based air-condition shown in figure (16) is an alternative technology which can be efficiently used in that location. However, this unit is used mainly in a domestic rather than commercial because it is small in size and is able to supply cooling energy for up to 24000 BTU or 25321.340 kJ. Since the volume of the building is big, the solar based air-condition shown in 16 will not be sufficient and multiple of them will be required to cool down the building, therefore it will be expensive to install and use solar based air-condition and they will be need to get the electricity from the grid in order to operate the air condition to cooling a building.

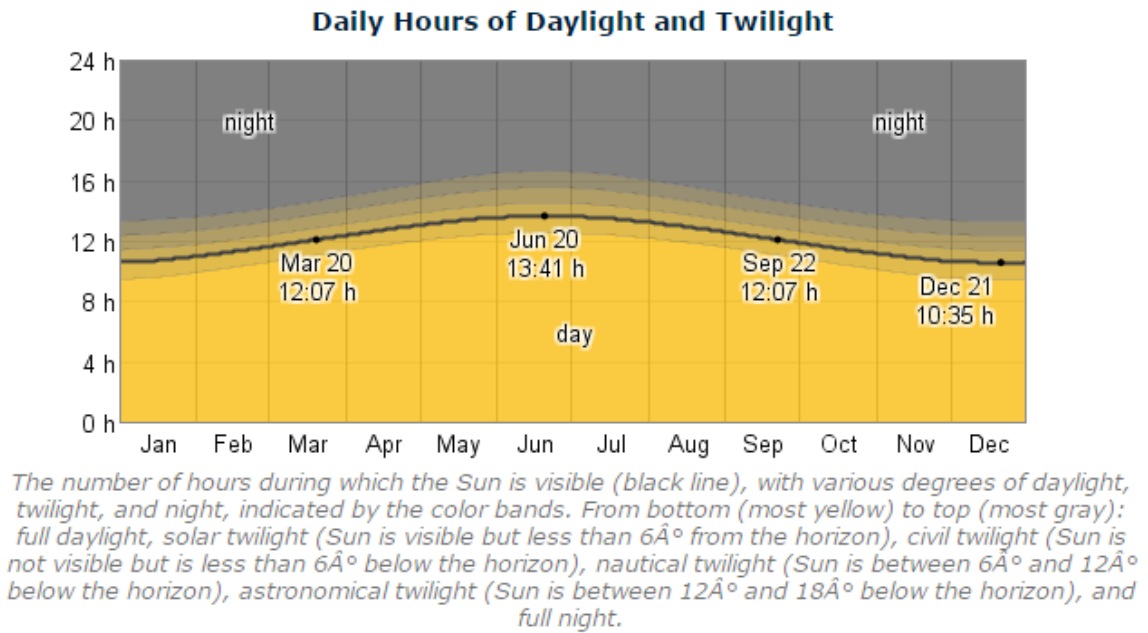


Figure 14: The number of hours during the daylight and twilight (<https://weatherspark.com/averages/32777/Riyadh-Saudi-Arabia>)

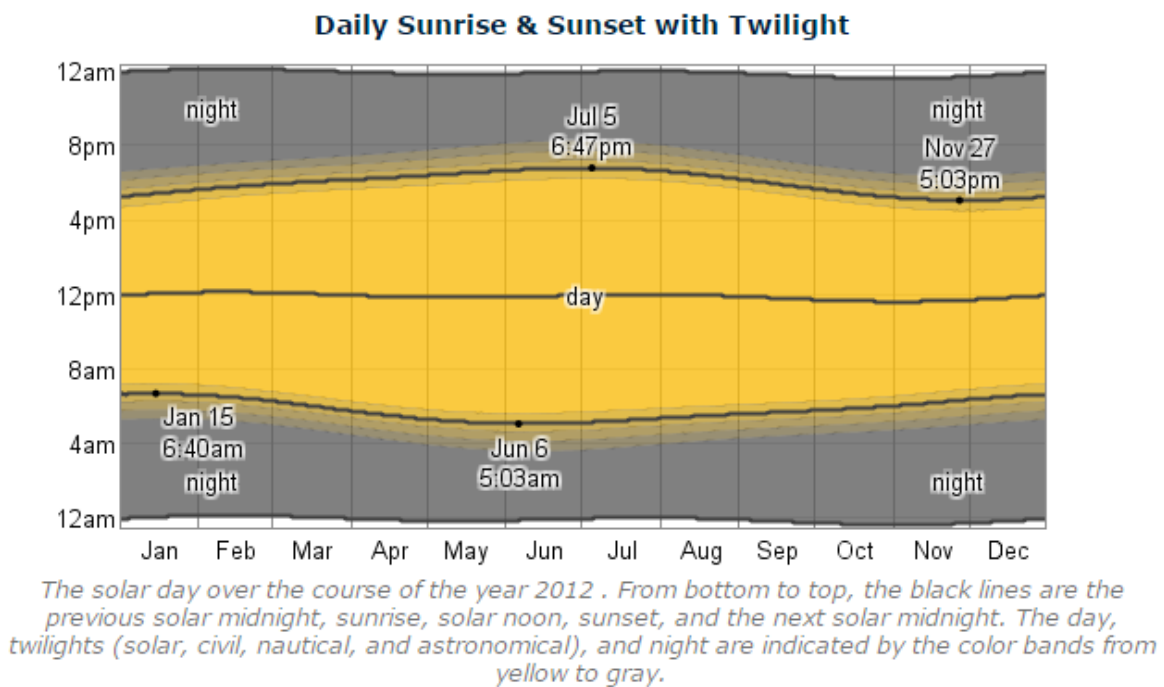


Figure 15: Shows earliest sunrise time and latest sunset time (<https://weatherspark.com/averages32777/Riyadh-Saudi-Arabia>)



Figure 167: solar air condition (<http://sunchisolar.en.made-in-china.com/product/aoqxfXdPfOVb/China-100-DC48V-Solar-Powered-Energy-Air-Conditioning-System.html>)

The evaporative solar cooling system is an alternative solution to cooling a building of small and medium size as shown in figure (4) before. The system can work during the day time using electrical power generated from solar panels while it can work during the night time when there are battery banks which they are charged during the day time and being used as a back during the night time.

3.5 Design and installation system requirements

The evaporative cooling system based on solar technology for the fictional building does need the following requirements:

- The volume of the building which is ($100 * 40 * 7 = 2800 \text{ m}^3$)
- The corresponding BTU which is (1,016,182 BTU/hour or 297,813 watt) (<http://www.calculator.net/btu-calculator.html>). However, it is assumed the insulation condition is poor, and the temperature required to decrease is 22° .
- The type of the evaporative cooling system (Direct, Indirect or Direct/indirect evaporative cooling system).
- The amount of electricity required to operate the current system.
- The number and type of PV solar panels required to fulfil the energy demand.
- The effectiveness of the system as it is a key to study the feasibility of deploying such system.
- The cost implication for all components used in the cooling system.

Chapter 4

Results and analysis

4.1 Building specifications

The fictional building has the following dimensions 100 m length , 40 m width and 7 m height. The volume of the building is 28000 m³. In order to find which ventilation is suitable for this building, the amount of fresh air used inside the building need to be calculated according to (http://www.engineeringtoolbox.com/air-change-rate-room-d_867.html). Therefore the fresh air is calculated by using the following equation:

$$Q = n * V ;$$

Where Q is the amount of fresh air, n is the number of the air change and it varies depending upon the type and nature of business runs inside the building and V is the volume of the building. For an ordinary fictitious factory the number of air change is 2-4, see the last reference. However, this number could go up or down depending when the business type is changed. Hence the amount of fresh air for the researched building is:

$$Q = 4 * 28000 = 112000 \text{ m}^3/\text{h}$$

For an efficient fresh air change, the ventilation should produce fresh air in total 112000 m³/h + 25% = 140000 m³/h

Other specification associated with the building is the location in Riyadh in Saudi Arabia. This location has the characteristics such that the latitude is equal to 24.725192°, the temperature is varying between 8° and 43°.

4.2 Types of ventilation

For the fresh air calculated before, the following ventilation could be used.

The first type of ventilators required could be fourteen Solar WHIZ (SW10000) (<http://www.solair.com.au/commercial--industrial-cooling.php>), see figure (17).

According to the above supplier, each ventilator is able produce a fresh air of 10000 m³/h, hence all fourteen ventilators can produce up to 140000 m³/h.

The ventilator has the other specifications which are shown in appendix B.



Figure 17: Solar WHIZ (SW10000)

An alternative ventilators could be the cool-space cs6-36 VD Avalanche Portable evaporative cooler. This unit is able to produce a fresh air of 32900 m³/h, therefore for the amount of fresh air required for the fictional building; five units will fulfil the demand. The unit is a portable one and can be mounted too on the roof of the building or put on the ground, see figure (18) and appendix C for more technical details about this unit.



Figure 18: Avalanche portable evaporative cooling system (<http://www.wholesaleheaters.co.uk/cool-space-cs6-36-vd-avalanche-50hz-portable-evaporative-cooler/>)

The main issue related to the above evaporative cooling system is the regular maintenance on the pads, water pump and the motor itself as well as the bearing for the fan and the rubber belt, in order to increase the operating efficiency and the life time of the cooling system. The system operates efficiently if there is no hot air draft from outside. Since maintaining a reasonable working's temperature inside the building is the main requirement, it is essential to keep the windows closed during the working time while the cooling system is in operating. However, humidity could be an essential issue here, as the weather is subjected to humidity during certain months in a year as seen in figure (13) in the methodology chapter. As the hot air is moisturized by using pads evaporated by water in order to be cold, the hot air should be dry in order to achieve comfort weather inside the building. In the next chapter a new

technology will be discussed to avoid the high humidity in the weather when the evaporative cooling system is deployed.

4.3 Working temperature compared to outside temperature

The Typical outside temperature is different than the workplace room's temperature, according to Smith (2010), in the UK the room temperature should be 16°C. If the employees need to do many physical works inside a building, then the desired working temperature workplace temperature should be 13°C. In the Middle East the outside temperature reaches in some days during the summer season 48°C, therefore, the workplace room's temperature should be in the range between 24-28°C. However, for the fictional building aimed to study, and for the number of air changes between 2 and 4 times per hour as mentioned earlier, it is expected that the temperature should be 24°C because some of the employees need to do physical work and because of the thermal energy produced from the machines inside the building.

4.4 Issues with different types of commercial cooling technologies

1. For air-conditioner based cooling system, issues could be:
 - The operating cost (operating staff is required).
 - High cost of Maintenance.
 - High Electricity or fuel required to operate the chillers for large central cooling system.
 - Expensive Lubrication and Freon gas required for the compressor.
2. For evaporative cooling systems, issues could be:
 - Less efficient in case of high humidity.
 - Needs steady water supply and updated pads.
 - Less maintenance is required as there are no expensive consumable parts. Maintenance should be done on the water pump, the fan, the pads and other consumable parts. However this issue is considered to be one of the advantages.
 - Consumes less electrical energy to operate the motor and the water pump; which is considered one of the advantages.

4.5 Usability of PV solar panels in winter time

In the Middle East there is no policy implemented to generate revenue when electricity produced from renewable energy source such PV solar or wind turbine, unlike in the UK where a Feed In Tariff was introduced by the government in order to encourage home owners, companies and business owners to install PV solar panels on the roof of their buildings and encouraging building onshore and off shore wind turbines farms to generate electricity and the more energy produced and not used is feed back into the national grid against certain charge paid back by the government to them

(<https://www.ofgem.gov.uk/environmental-programmes/fit>). Therefore, in winter there is no demand on an efficient cooling system like in summer and other seasons in a year but there is still a need for the fresh air discussed before to maintain the comfort inside the building. Furthermore,

4.6 Cost analysis

As seen in the previous paragraphs, there are three different design suggestions; the first one is by using fourteen units from model SW10000 fans, the second one is when fourteen units from model EX767-SO evaporative cooling system are used and the last one is when cool-space cs6-36 VD Avalanche Portable evaporative cooler would be used.

For the first option, the following cost implications which are made in USD should be considered;

- 1- The cost of the PV solar energy fans which is already taken from the chosen product SW10000 and mounted on the roof of the building is **30800 USD**.
- 2- Depending upon the type and the strength of the evaporative cooling systems, a duct system will be required in order to circulate the whole fresh air inside the whole building, consequently, the following cost will be considered to install the ducting system:
 - Cost of the installation which is in the range between 20 – 30 % of the total price for the complete system. It is usually (6160 – 9240 USD) for a 1000 square foot circa 93 m² (*How Much Does A HVAC System Cost?*), where the cost will include materials and labours. The area of the fictional building is 400 m², hence the cost of the ducting system is 30% of the cost of the units, which is **9240 USD**.
 - The cost of the pads which is usually depending upon the quality of the material used is varied between 40 – 80 USD. For sustainability, it is recommended to use rigid sheet pads. They are made of corrugated material that is stacked tightly together. This type of pads has a long life time up to six years if the water used for evaporation has no contaminations and the cost **\$50 to \$80** per pad (*Evaporative cooling cost*). However in total the cost of all evaporative pads used with all units will be **1120 USD**.

For the second type of evaporative cooling system, the following cost implication should be considered:

- 1- The cooler uses hybrid power of solar energy and the power from the grid. It means it starts using the power from the grid and then it runs using the solar PV panels come with each unit.
- 2- There is a need for a 14 unites to cover the demand. Each unit cost in average 2635 USD, hence the total cost for all units of cooling system is **36890 USD**, (*How Much Does A HVAC System Cost?*).
- 3- The ducting system is as described before and the cost is equal 30% of the total cost which yields **11000 USD**.

For the third type of the evaporative cooling system the model cool-space cs6-36 VD Avalanche Portable evaporative cooler is suggested. The cost implication of this system is shown as follows:

- 1- The cost of each unit according to the market price is 3400 USD. As discussed earlier, five unites will be needed in order to cool the whole building, therefore the total price for all unites without VAT is **17000 USD**.
- 2- The cost of the PV solar panels system and the batteries need is calculated according to the demand for the electricity needed to operate the evaporative cooling systems.
- 3- Each unit consumes up to 1.419 kWh for maximum fan speed, hence the total power consumed by the 5 unites is 7.095 kWh.
- 4- The PV solar panels should produce up to 7.095 kWh plus 25% losses, therefore the total output power produced by PV solar panels is 8.869 kWh according to (*Leonics*). The output power of any PV solar panel is calculated by watt peak Wp , therefore the total output power of the PV solar panels should be $8.869k/3.43$ and it is equal to 2.586 kWp .
- 5- If one PV solar of 270 Wp is used see appendix D, we need the following solar panels: $2.83k/270 = 9.58$, which means the needing is for up to 10 PV solar panels to cover the demand from all chosen evaporative cooling system.
- 6- The cost of one PV solar panel is approximately equal to 300 USD (market price, see appendix D), hence the total cost of all PV solar panels is **3000 USD**.
- 7- The PV solar module needs an inverter in order to convert the dc power generated by the PV solar panels into an AC power. The system is a stand-alone one and it should have the capacity to supply ac power that is needed to cover the whole demand by all evaporative cooling systems when they are operated at the same time. Moreover, the size of the inverter should be 25-30% higher than the power consumed by all cooling

units. For a unit with a compressor or high speed motor the inverter size should be three times the power consumed by the same unit in order to ensure operating smoothly especially during the start up to handle the surge current (*Leonics*). Hence the inverter size should be $7.095\text{kWh} * 3 = 21.3 \text{ kWh}$. The cost of one inverter model SMA sunny Tri power STP is equal to **3420 USD**, see appendix E.

- 8- In order to use the system efficiently, bank of batteries will be added into the proposed system in order to be used as a backup during the night time, in case of the emergency break down or shut down during the maintenance. The battery size is measured as Ah and can be calculated according the demand too. For the aimed cooling system need to be designed, the battery size is calculated by using the following equation (*Leonics*):

$$\text{Capacity Ah} = \frac{(\text{total power of all units} - \text{no. hours battery is used})}{(0.85 * 0.6 * \text{voltage of the battery})} \\ * \text{days used without charging the battery}$$

The total power of all units is 8.869 kWh; the number of hours the batteries are used is 12 hours; the days where batteries are used without charging is 3 days of autonomy (*Leonics*) and the output voltage of the battery is 12 volts. By substituting all variable in the battery capacity equation above, the following capacity will be achieved:

$$\text{Capacity Ah} = \frac{8869 - 12}{0.85 * 0.6 * 12} * 3 = 4341.66\text{Ah}$$

Therefore the number of batteries needed to cover the whole demand is depending upon the type of the battery. The chosen battery is ABS L230, 230 Ah, see appendix F. The cost of one battery is roughly \$200. Therefore the number of batteries required for the proposed cooling system is:

$$\text{Number of Batteries} = \frac{4341.66}{230} = 19 \text{ batteries}$$

And the cost of all batteries is $19 * 200 = \mathbf{3800 \text{ USD}}$

4.7 Cabling cost

The cost of cabling should be taken into the consideration when the total cost of the project is calculated. If 14 units are used, each unit is connected to the inverter hence a cable's length of 20 meters maximum could be used to connect one unit to the inverter. Therefore the total cable length used to connect all units to the inverter 280 meters. Moreover, to connect all PV solar panels to the inverter, the following cable length will be required:

The 10 PV solar panels should be mounted over an area determined according to a single area for one PV solar panel which is 1.63 m^2 . Therefore 10 PV solar panels should be mounted

over an area of $1.63 * 10 + 10\% = 179.3 \text{ m}^2$ which is reasonable for the area of the roof for the fictional building. The 10% is added into the area in order to avoid shading between the PV solar panels. Each PV solar panel will require a cable of 20 m to connect to the inverter and the batteries. Therefore the 10 PV solar panels will require up to 200 meters and it can be from same manufacturer in order to consider only one type of cable power lost.

Hence the total cable length required is: $280 + 200 = 480 \text{ m}$ and the cost of cables is equal to **960 USD**, model USE-2 10 AWG wire 500 ft spool (*SPS Solar Panel Store*), see appendix G.

4.8 Summary of the cost

Type of the cooling system	Cost of the units	Cost of the duct system	Cost of the pads	Cost of the PV solar panels	Cost of the inverter	Cost of the batteries	Cost of the cabling	Sub Total in USD	Total = Subtotal +10%(market price variations)
SW10000	30800	9240	1120			3800		45600	49456
EX767-SO	36890	11000				3800	960	52650	57915
CS6-36-VD	17000	11000		3000	3420	3800	960	35760	39336

Table 3: shows the summary of the cost implication for three different kinds of cooling system which can be used with the fictional building.

According to the last table the best system which can be installed is **CS6-36-VD** because it has low cost implication and can work efficiently. Furthermore the ducting system plays a role as it will ensure that the whole building will have fresh air during the operating time. The fictional building with all cooling units chosen, the PV solar panels, the batteries and inverter are shown in the drawing below.

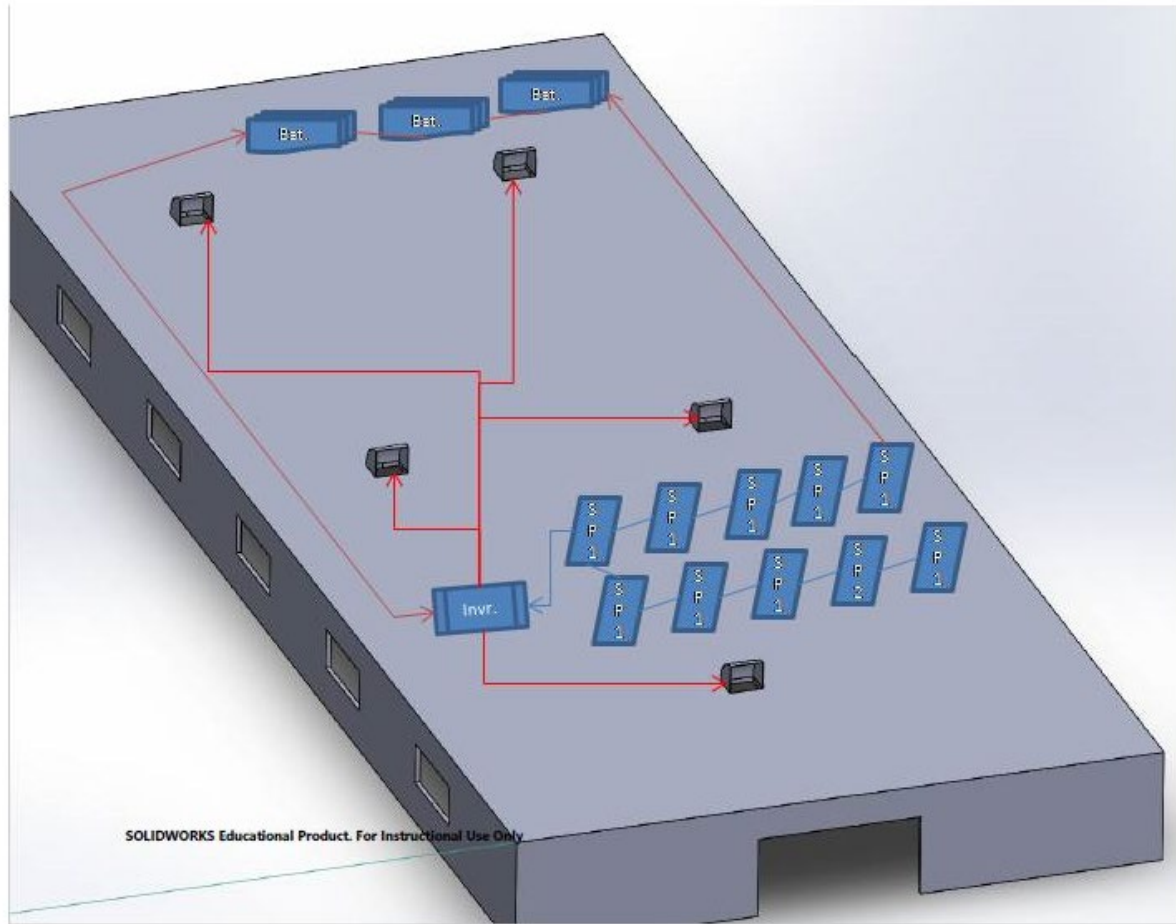


Figure 19: the fictional building with all evaporative cooling units, PV solar panels, batteries and inverter

4.9 System maintenance

The chosen evaporative cooling system will require a minor maintenance for the evaporative pads, the fan, water's pump and the PV solar panels.

The chosen evaporative material has a long life up to 5-6 years as discussed earlier hence checking that they are getting moisturized efficiently can be done through the maintenance. The fans can be lubricated and cleaned and similarly the water pump and the nozzles when the water used is not treated very well. The PV solar panels should be cleaned regularly in order to increase the operating performance, as dust or dirtiness accumulated on the surface

of the panel will increase the surface temperature which has an impact on the output power of the PV solar panels (Chandrakar and Tiwari, 2013)

Chapter 5

Discussion

5.1 Evaluate a mathematical model

The mathematical model is associated with the cooling pads. The heat transfer process is shown in figure (20) below which is used to evaluate the mathematical module.

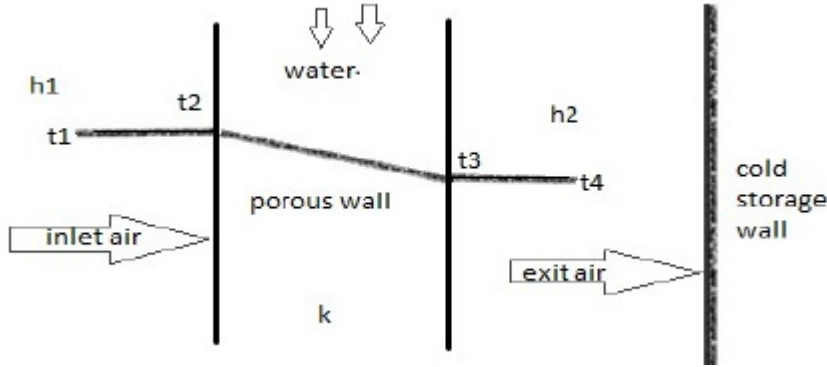


Figure 20: A diagram shows how the heat transfer process across the porous evaporative cooling pad (Ndukwu et al, 2013)

The following equation is used to explain the process about how the heat is changing when the hot air passes through porous wall of the evaporative pads. It explains how the heat flux is changing because of the thermal heat changes in the pads according to (Ndukwu et al, 2013).

$$d_q = h_1(T_1 - T_2)dA$$

$$d_q = \frac{(T_2 - T_3)}{\frac{X_{23}}{K_{23}}} \cdot dA$$

$$d_q = h_2A(T_3 - T_4)dA$$

Where h_1 and h_2 are the convective heat transfer, A is area of the pad, X is thickness of the pad, K is the thermal conductivity and A is the area of the pad. After solving the last three equations, the heat balance is:

$$d_q = \left(\frac{T_1 - T_4}{\frac{1}{h_1} + \frac{X_{23}}{K_{23}} + \frac{1}{h_2}} \right) \cdot dA$$

The thermal flux is represented in term of the mass air flow m_a and the humid specific heat C_{pu} in such a way that (Ndukwu et al, 2013):

$$d_q = m_a C_{pu} dA$$

After solving the derivative, the cooling efficiency will be used to evaluate the module as follows:

$$\eta = \frac{T_{dB} - T_s}{T_{dB} - T_{WB}}$$

Where T_s is the dry bulb temperature of the cold air which is equivalent to T_3 and T_{WB} is wet bulb temperature of the ambient air which is equivalent to T_4 . The above equation can be used to calculate the effectiveness of the cooling system during one day operation from 07:00 AM till 05:00 PM, see figure (21). Real measurements for the dry bulb hot temperature, dry bulb cold temperature and the wet bulb temperature were taken from a building factory in Riyadh named Maeen factory for water packaging in order to measure the effectiveness, see appendix H.

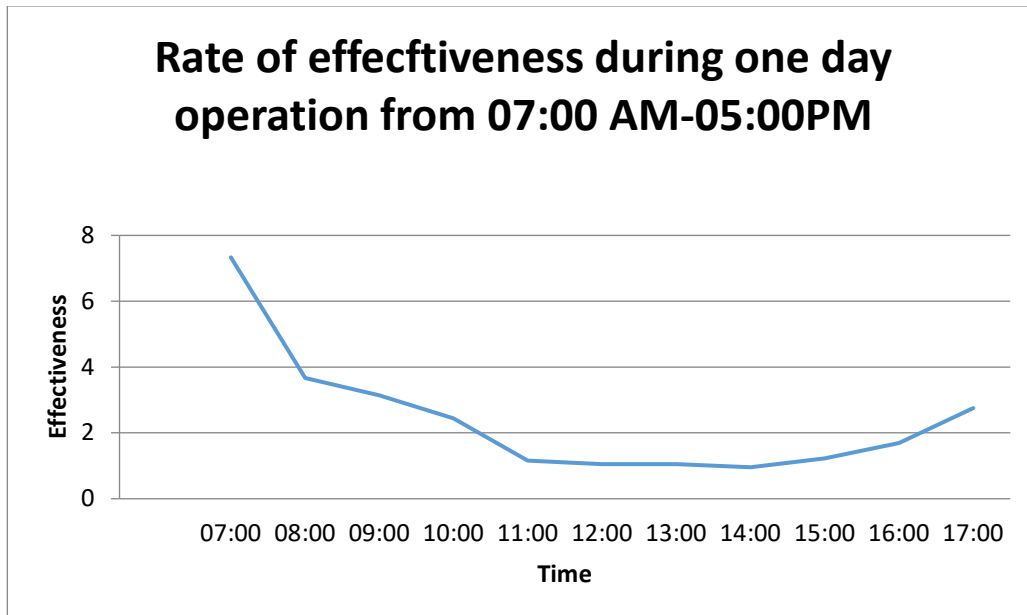


Figure 21: show the rate of effectiveness during a day operation between 07:00 AM-05:00PM

According to figure (21), the effectiveness is getting low between midday until 2:00 PM then it started increasing again because the dry bulb cold temperature reduced again after the 2:00PM. This is because during the midday the weather temperature reaches the highest values which are corresponding to a less efficient of the cooling system during this time.

For the model shown in figure (22), the evaluation parameters of the mathematical module are as follows.

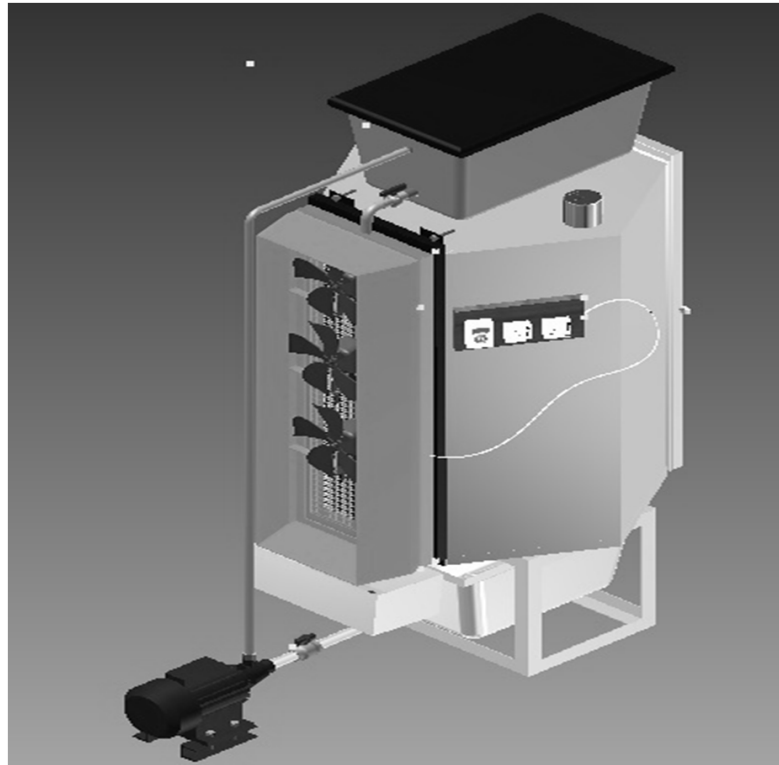


Figure 22: An active evaporative cooling system used to evaluate the model (Ndukwu et al,2013)

Evaluation Parameters								
day one			day two			day three		
Time(hr)	ΔH	ΔT	Time(hr)	ΔH	ΔT	Time(hr)	ΔH	ΔT
10	2.05	4	10	2.9	6	9	1.54	2.9
12	0.4	6.5	11	6.58	6.7	11	2.37	4.8
14	5.05	9.7	12	4.99	8.2	13	2.04	7.4
16	0.18	8.2	13	5.08	9	15	2.12	9.7
18	4.51	7.7	16	3.42	10	17	6.74	8.7
			18	7.5	8.3			

Table 4: shows evaluated parameters for direct evaporative cooling system (Ndukwu et al,2013)

According to the model, the thermal conductivity and the thickness of the pads are considered to determine how accurate the evaluation is. However the accuracy achieved was between 92-99% which was very close to the real values.

5.2 Calculate system size

To calculate the size of an evaporative cooling system, it is important to apply the heat balance equation on the system which can be abbreviated by the following equation:

Solar heat + all heat produced by equipments/machine/people = heat removed by the cooling system (Palmer, 2002).

The right hand side of the equation depends upon the type of the evaporative system such as rigid media or Aspen media. Furthermore, the rigid media is more efficient than the Aspen which is a more efficient. Hence the discharge temperature will be lower and the airflow is less. However, the size is designed depending upon the dry and wet bulb temperature as well as the BTU or Joule value for the building in such a way that the effectiveness should as much high as possible as seen in chapter too. The effectiveness depends upon the velocity of the air passing through the evaporative pads which is varying between 400 to 700 feet per minute according to Palmer.

5.3 Options for evaporative cooling system features

When an evaporative cooling system is designed the following options should be taken into consideration:

- Choosing the suitable type of the system with the highest effectiveness.
- Choose the most suitable features for the components of the evaporative cooling system. These features could be warranties on the units, resistance against corrosion, the suitable fan power and bearing and rump size.
- Choose suitable configuration such as the type of the discharge, damper configuration and the filters.
- Choose the capacity of the system by calculating the cooling load and choosing a suitable ducting system.
- Choose a suitable control for the fan speed, the temperature and the water pump.
- Choose suitable thermostat to control the turning on/off the system depending upon the room temperature. The thermostat could be a mechanical or electronic one depending upon the cooling system itself.
- Choose a suitable damper for energy economic or energy saving.

5.4 Optimization of the evaporative cooling system

The evaporative cooling system can be optimized in such a way that it works better and supply efficient cooling during the hot season. One of the important factors which need to consider is the way the pads are installed so that the air flow stays efficient and the heat transfer process is successfully done, see figure (23). According to MD. Mahmoud et al (2012), if the water evaporative is made in the air flow duct, it will decrease the temperature and increases the cooling air. This method is known as the induced process which combines both heat and mass transfer. If moisture is added into the air, the relative humidity becomes slow and better cooling effect is achieved. There is other factor which increases the performance

through maintaining the cooling's fan which makes it spin smoothly without disturbance. Moreover, mists, spray or pads can be used as medium to evaporate air in order to reduce the temperature in the air tunnel. The humidification and heat exchanger are used to reduce the relative humidity. Moreover the cost is significant low, as most of the components except the motor are not expensive.



Figure 23: shows different layout for the fins used as evaporative pads (MD.Mahmoud et al,2012)

5.5 Solar dehumidification cooling system

The solar cooling system is an effective system which can replace the current expensive air conditioning system because it is cheap to run and is considered as environmental friendly. The system has an issue with the humidity especially in the hot region where they have been impacted by a high humidity (Rafique et al, 2016). The evaporative cooling system works efficiently when there is low humidity, but in case of high humidity the system can be operated in conjunction with desiccant dehumidifiers to control the amount of humidity and improve the air quality inside the building according to Rafique et al. The coefficient performance was studied for different locations in KSA using the last mentioned system in order to find out where the system can be deployed efficiently.

5.5.1 Desiccant evaporative cooling system

The system has a significant advantage that it consumes less electrical energy and can operate longer time supplying comfortable air. According to figure (24), the system uses ventilation cycle and psychometric process for cooling the air using evaporation.

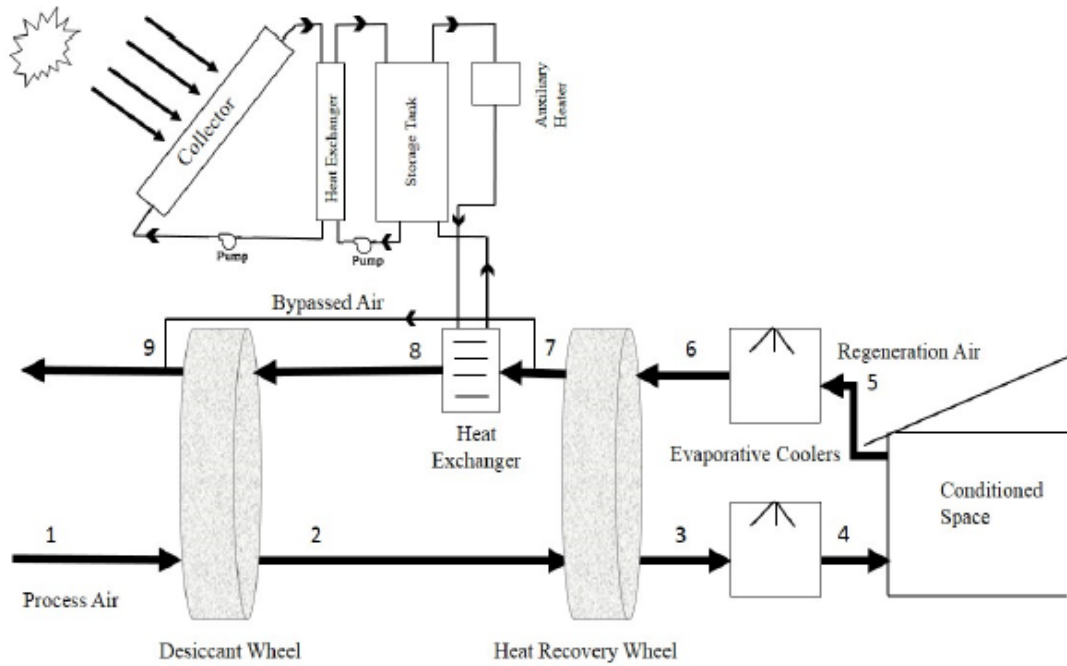


Figure 24: Desiccant evaporative cooling system (Rafique et al,2016)

The desiccant wheel is structured with absorbed material such as silica gel or titanium dioxide (Rafique et al, 2016). When the wheel spins slowly, it filters the moisture from the air circulated around it. After the air leaves the desiccant wheel, the dehumidifier reduces to suitable supply condition required for the evaporative cooling system. In this case the air reaches the evaporative pads will have low humidity which makes the weather inside the building more comfortable. The system is subjected to a reheating to the designed regeneration in order to remove moisture from the desiccant wheel. Therefore two desiccant wheels were used to complete this process. According to the above figure the second wheel cooled the air by using a heat recovery process and then it passes through evaporative cooling system to make the air more convenient. The returned air is cooled the heat regeneration then it passes through the heat recovery wheel in order to remove moistures. A solar collector was used in order to produce the required heat for the heat exchanger and the output hot air passes through the desiccant wheel to reuse it. The system can be added into the current evaporative cooling system in such a way that it can be operated only when there is high humidity in the weather. Moreover, the model can be built up in a box and the box has an evaporative system mounted inside. The solar collector is added into the model in order to heat the water for the heat exchanger which is used to dry the air with the humidity before it is regenerated and passed through the desiccant wheel which is spinning because of the air tunnel created by the evaporative cooling system fan. The new modified evaporative system has the ability to operate in different hot weather conditions when there is humidity or not and it has a significant low cost compare to the air condition based cooling system, see the suggest model in figure

Where m_c , h_B and h_A are the tem mass air flow (kg/s), specific enthalpy (kJ/kg) before and after the desiccant wheel correspondingly. The specific enthalpy is determined using the temperature of the air before and after the desiccant wheel.

$$Q_r = m_r(h_{HXA} - h_{HXB})$$

Where m_r , h_{HXA} and h_{HXB} are the mass air flow of the regenerated air (kg/s), the specific enthalpy (kJ/kg) after heat exchanger and before heat exchanger correspondingly.

The total volume of moisture removed from the air is equal to the moisture absorbed from the air passes through the desiccant wheel.

$$m_{removed} = m_p(\omega_B - \omega_A)$$

Where m_p , ω_B and ω_A are the mass flow of the moisture, humidity ratio (g/kg) before and after the desiccant wheel. The last equation gives an indication about the amount of moisture need to remove in order to maintain an efficient cooling system during a year.

Chapter 6

Conclusion and Recommendation

6.1 Conclusion

Buildings cooling technologies are varied according to the size, location and the purpose the buildings are occupied for in order to maintain comfort working place temperature. In the hot regions such as the Middle East cooling technology is high demandable and the working temperature should be between 24°C - 26°C. The current air conditioned based cooling system is dominated in the market because it works efficiently with different weather conditions but it is expensive to operate and maintain. The evaporative cooling system is an alternative cooling system which works efficiently during the hot dry weather. It is cheap to operate and does not need major maintenance. In this report three different evaporative cooling systems were studied in terms of the cost and when they are used with PV solar panels. The selection of PV solar panels as one of the renewable energy sources is to drop the operating cost. It was obvious that a best choice was for the model CS6-36-VD evaporative cooling system which would cost 39300 USD. This system can cool the whole fictional building chosen.

Different technologies were discussed to show how to improve the performance of the system by changing the pads material and the position in such a way that the effectiveness is increased. Furthermore, a mathematical model is investigated in order to show which parameter has influence on the effectiveness. The mass air flow, the enthalpy and the heat transfer are based on the dry bulb and wet bulb temperatures. These temperatures control the effectiveness and the performance, as they indicate what is the air temperature before entering the evaporative pads and after leaving them to be used in cooling the building. Many features for the evaporative cooling system were studied in order to show what needs to be done such that the cooling system is aimed to install.

6.2 Recommendation

It is highly recommended to use the chosen evaporative cooling system with a desiccant wheels which act as dehumidifier in order to ensure the efficient working of the system when the humidity is high in the weather as seen in the last chapter. Moreover, it is recommended to apply the chosen cooling system to real buildings of different size after studying the demands and the purpose the building is used for. This will ensure how feasible is the system as it is used with a renewable energy source.

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Appendices

Appendix A

The Specification of EX767-SO:

	Airflow (m ³ /h)	1st Speed	2nd Speed	3rd Speed
		6,400	7,300	8,100
		4th Speed	5th Speed	6th Speed
		9,000	9,800	10,500
Performance	Maximum Airflow	10,500 m ³ /h		
	Evap. Efficiency	~92%		
	Water Capacity	15 L		
	Power Supply	220 V 50 Hz		
	Power Consumption	170~550 W		
Program	Airflow Adjustment	6 Segments		
	Programmed On/Off	6 Stages		
	Filter Washing	Auto/Manual		
	Water Sterilizing System	Auto		
	Auto Drain	Auto		
Dimensions	Size of Dropper Duct	668 *668 mm		
	Make-up Water Inlet	1/2"		
	Drain Water Outlet	40 mm		
	Installed Dimension	1040*1040*1105 mm		
	Shipping Dimension	1040*1040*1230 mm		
Weight	Operating Weight	95 KG		
	Shipping Weight	88 KG		

<http://excelair.gmc.globalmarket.com/products/details/solar-evaporative-cooler-1483036.html>

Appendix B

SW10000 Specifications

Model	SW1000 specs	
Models Available	SW10000	
Capacity	10000 m3/h	
PV panel Polycrystalline.High-impact resistant panel	Adjustable angle 0-80 degrees (mounted externally) - 100 Watt	No Gable SW10000 Available
Fan motor	26 (24?) Volt DC brushless motor with double shielded ball bearings	
Fan Decibels	<80 dBA	
Fan blade (SW1000)	3 blade design	
Fan cap	Aluminium alloy for maximum durability	
Body	Corrosion resistant steel (superior corrosion resistance suitable for coastal installations)	
Flashing (SW 10000)	Aluminium 915 x 915 x 0.9mm	
Coating	Electro Static UV resistant spray cured in high temperature drying process	
Hardware	Cold sheet steel brackets, stainless steel fasteners and screen	
Dimensions	SW10000 – 900 (diameter) 305 (height) 75W Panel – 815 x 725 x 40 100W Panel – 1260 x 700 x 40	
Packing Size	SW10000 – 920 x 920 x 340 75W Panel – 770 x 840 x 70 100W Panel – 1010 x 725 x 70	
Packing Weight	SW10000 – 8kg 75W Panel – 12kg 100W Panel – 15kg	
Colour	Black Powder Coating	
Options	Thermostatic control: Fixed temperature 30°C or adjustable 10-30°C Eave Vents,& Ceiling Vents Night operation	

<http://www.solarwhiz.com.au/wp-content/uploads/2013/12/SW10000-Specifications.pdf>

Appendix C

AVALANCHE

Portable Evaporative Cooler

Specification Sheet CS6-36-VD-50Hz (or 60Hz)

Housing: Constructed of roto-moulded, corrosion free, UV rated polyethylene

Cooling Media: 20 cm thick high efficiency-cross corrugated, angle fluted, specially formulated cellulose material treated with a thermosetting resin and edge coating for additional strength and to prevent growth of algae.

Fan: 90 cm industrial duty plastic, three-blade propeller for quieter operation

Fan Motor: High efficiency, totally enclosed.
560W /230V/50Hz (or 60Hz)

Variable Speed:
High: 16,500 m³/h @ 37 Pa ESP
Low: 10,860 m³/h @ 37 Pa ESP

Variable Speed Direct Drive: 560W/230V/1ph/50Hz (or 60Hz)

Amps: High: 6.3 A / Low: 1.8 A

Circulation Pump: Submersible, high efficiency, self-priming and maintenance free with internal low water shut-off
120W/230V/1ph/50Hz (or 60Hz) /0.75A

Water Supply: Garden hose connection or portable supply tank. Water level regulated by a float valve. Maximum pressure 8 bar

Electrical Requirements: 230V/1ph/15A minimum branch circuit

Electrical: All wire connections are enclosed in a water tight junction box

Castors: 100 mm 2 swivel, 2 stationary

Water Reservoir: Internal 174 L capacity

Cooling Coverage Area: Approx. 350 m²

Dimensions (mm): 1575 wide x 762 deep x 1780 high

<http://www.wholesaleheaters.co.uk/cool-space-cs6-36-vd-avalanche-50hz-portable-evaporative-cooler/>

Appendix D



Viridian

270Wp Clearline Mono Solar Module - 60 Cell - Black
Roof Integrated

IN STOCK

£238.97 £286.76 inc VAT



TECHNICAL SPECIFICATION

Country of Manufacture	United Kingdom
Dimensions (mm)	1640 x 992 x 69
Frame Colour	Black
Material	Monocrystalline
SKU	VIR-PV16/270
Weight (kgs)	21

(<https://www.cclcomponents.com/viridian-270wp-clearline-mono-solar-module-60-cell-black-roof-integrated?gclid=CMP1gunIsNICFSEL0wodwa4J5A>)

Appendix E



SMA Sunny Tripower STP 25000TL-30 Solar inverter without Display

\$3417.88

Solar inverter for grid feed-in Pac,r/Sac,max
25000 W/ 25000 VA, three-phase einspeisend, 98,4%
Maximum efficiency, with reactive power supply,
transformerless, rotary switch for country settings,
Multi-String function, DC connection SUNCLIX, integrated
DC-switch disconnectors

SMA Sunny Tripower STP 25000TL-30 Solar inverter without
Display

SMA-part number: STP25000TL-30

(<https://www.solar-pur.com/products/sma-sunny-tripower-stp-25000tl-30-solar-wechselrichter-ohne-display?variant=34588212110&ls=en&qclid=CJ7dwvuZttlCFfEy0woduzULgg>)

Appendix F

SALE!



ABS L230 230AH LEISURE BATTERY

In stock



Length	518mm	Width	276mm
Capacity	230 Ah	Height	240mm
Weight	55 kg		

~~£299.00~~
£180.00
inc. VAT

VIEW PRODUCT

ADD TO BASKET 

(<https://advancedbatterysupplies.co.uk/product/abs-230ah-ampere/>)

Appendix G

Item		Extended	
USE-2 10 AWG Wire 500 Ft Spool			
Our Part Num: COLO-00678			
Qty.		Each	
6	Edit Delete	\$160.00	\$960.00
Subtotal:			\$960.00
Alabama ▼		select	
Total:			
			Checkout

http://www.solarpanelstore.com/index.php?app=process_buy_form&buy_product_id=678&min_order_quantity=1&count=6

Appendix H

Time	Temp.DB	Temp.S	Temp.WB	effectiveness
7:00	29	7	26	7.333333333
8:00	32	10	26	3.666666667
9:00	33	11	26	3.142857143
10:00	35	13	26	2.444444444
11:00	45	23	26	1.157894737
12:00	47	25	26	1.047619048
13:00	47	25	26	1.047619048
14:00	49	27	26	0.956521739
15:00	44	22	26	1.222222222
16:00	39	17	26	1.692307692
17:00	34	12	26	2.75