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Renewable Energy Thermoelectric Module Air Conditioning System – Design Factors: A Review

Rupert Gouws

School of Electrical, Electronic and Computer Engineering,
North-West University, Potchefstroom,
South Africa.

Abstract

The conventional air conditioner is fast becoming a noticeable energy user that negatively affects the supplier's ability to supply energy during peak periods when the country's energy need rises. The Clean Development Mechanism (CDM) stipulates that a country committed under the Kyoto Protocol, has to implement emissions-reduction programs in developing countries to help reduce the CO_2 emissions around the world. It is therefore important to invest in renewable energy projects and perform research on air conditioning systems, in order to lower the energy strain on the electricity grid and contribute towards CDM. This paper therefore provides a review on the factors that need to be taken into account and the different technologies that can be used in the design of a renewable energy thermoelectric module (TEM) air conditioning system for South African conditions. The different technologies in the design are compared to each other by means of a unique trade-off study, in order to design the optimal efficient and cost effective renewable energy TEM air conditioning system.

Keywords: Thermoelectric module; air conditioning; renewable energy; cost; availability; functionality.

INTRODUCTION

As climate change takes place in the world, more and more people are using air conditioners for the purpose of cooling as well as heating. The conventional air conditioner is fast becoming a noticeable energy user that negatively affects the supplier's ability to supply energy in peak times as the country's energy need rises [1]. The conventional air conditioner uses chemical gas to cool and the green-house gasses that are emitted into the atmosphere also damage the ozone layer [2].

The Clean Development Mechanism (CDM) stipulates that a country committed under the Kyoto Protocol, has to implement emissions-reduction programs in developing countries to help reduce the CO_2 emissions around the world [2]-[4]. The need therefore exist to investigate other means of air cooling, which can replace the conventional air conditioning system.

As the Cap and Trade Movement is fast growing on an international level, it is becoming more important that a business or country that wants to export goods to other countries, comply with these regulations. Cap and Trade limits a business or country on the amount of carbon emissions that they emit annually. It will be very difficult for countries that do not comply with these standards, to still trade in the future [4]-[6].

As the cost of electricity rises, the need to find other energy sources becomes more important every day. By making use of renewable energy sources, the peak period energy demand that the supplier needs to deliver in order to sustain the country's electricity usage, will also decrease [3], [5].

The primary objective of this paper is to provide a review on the different technologies that can be used and factors that needs to be taken into account in the design of a renewable energy TEM air conditioner system in order to design the optimum efficient and cost-effective renewable energy TEM air conditioning system. In order to do this, the different technologies are compared to each other, by means of a unique trade-off study for South African conditions. This paper also provides a guideline in terms of the available literature on the different technologies that are applicable and available to renewable energy TEM air conditioning systems.

Figure 1 provides the main building blocks in a simplified renewable energy TEM air conditioning system. For this review we focus primarily on the DC power source and the main TEM air conditioner system components. The DC power source is made up of a renewable energy source, a charge controller and a backup power source (or storage system). An alternative to these blocks is a DC power source (like Eskom with an AC-DC inverter). The renewable energy source feeds the charge controller which in turn feeds the backup power source. A control unit receives power from the DC power source and relays this power to the cooling and heating system(s) (TEM), fans and accessories, according to instructions received from a remote control, pre-programmed rules and sensors.

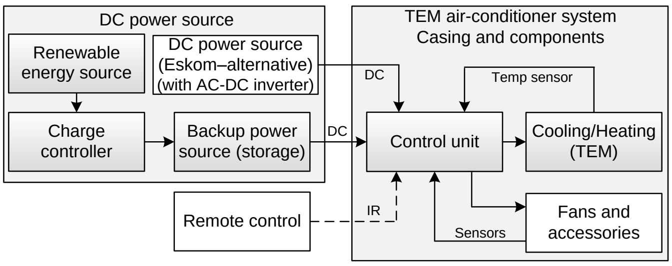

Figure 1: Main building blocks in the renewable energy TEM air conditioning system.

Figure 2 provides an overview block diagram of the different technologies, together with the applicable references for each technology that is discussed in this review. It was decided to limit the different technologies to the building block shown in figure 2, as these blocks are the most applicable. The remote control, fans and accessories are not discussed in this review as these are standard types of technologies.

For the renewable energy source, it was decided for this review to discuss and compare the mono-crystalline PV panel, poly-crystalline PV panel, amorphous silicon PV panel, wind energy and hydro energy. For the charge controller it was decided to discuss and compare the shunt linear controller, shunt interrupting controller, series interrupting controller, series-linear constant voltage controller and maximum power point tracking controller (MPPT).

For the backup power source it was decided to discuss and compare the deep cycle lead-acid batteries, nickel-cadmium batteries, nickel-metal hydride batteries, lithium ion batteries and super-capacitors. For the control unit it was decided to discuss and compare the programmable logic controller, Arduino control board, Panda control board, Raspberry PI control board and dSPACE® control board. For the cooling and heating system it was decided to discuss and compare the TEM, heating elements, oil heating systems, heat pumps and conventional air-conditioner systems. The various technologies are now discussed in the following sections.

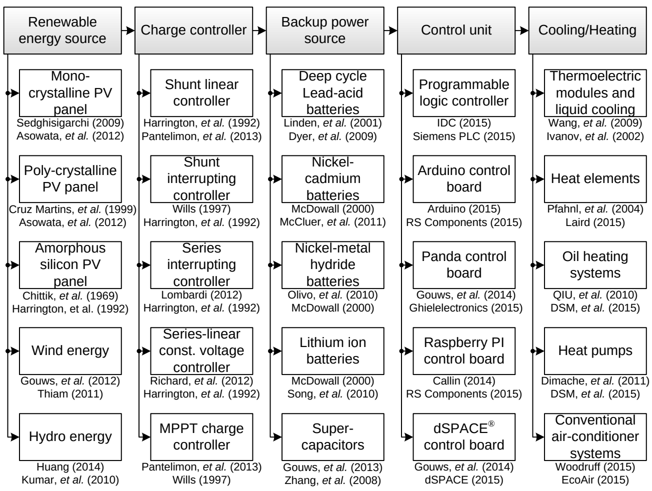

Figure 2: Overview block diagram of the different technologies.

RENEWABLE ENERGY SOURCE

The most common solar energy generation technology used in applications is photovoltaic (PV) panels [7].

PV panels are classified using the rated power output given in watts (W). The expected output power of a PV is determined using one peak hour of sun to produce the power. The geological location of the installation of the PV's is always taken into consideration as the average solar radiation differs from one location to another. PV panels can be connected to form a PV array and this can be done by connecting the PV's in series or in parallel. By connecting PV panels, the rated voltage or rated current of a system can be increased respectively. Series connections will increase the rated voltage of a system while a parallel connection will increase the rated current of a system [8]-[10].

The average solar radiation for most parts of South Africa is in the range of 2100 kWh/m^2 with the average solar radiation spectrum ranging from approximately 1580 kWh/m^2 to 2350 kWh/m^2 [11].

Photovoltaics are becoming more popular in modern day energy applications. The first practical application of this technology was used to power orbiting satellites as well as other space-crafts, but nowadays they are mostly used for grid connected power generation applications. In these types of applications a DC to AC inverter is used to supply power to the electricity grid to help the supplier deliver the electricity demand over peak periods. The use of smaller off-grid applications of photovoltaics are also increasing as the national electricity supplier (Eskom) is struggling to supply the country with the high electricity demand during peak periods. Off-grid applications are also used for remote operations such as roadside emergency telephones and pumps of dams that need to transport water from one point to another [8], [9]. The different types of PV's as well as other renewable energy sources are briefly discussed in this section.

A. Mono-crystalline photovoltaic panel

The cells of mono-crystalline PV panels are cut from a single crystal of silicon. The thickness of the slice is made visible by the smooth texture of the panel. The panels are rigid and must be mounted in a secure frame in order to protect the delicate cells. The main advantage of mono-crystalline cells is their high efficiencies that are in the order of 15%. The manufacturing process that is used to create mono-crystalline cells is complicated and is thus more expensive than other technologies [12]. The mono-crystalline cell of a PV panel with part number ZKX-160D-2 module/160Wp-180Wp has a maximum power output of 160 W at a rated voltage of 34.9 V and a rated current of 5.03 A [7], [12].

B. Poly-crystalline photovoltaic panel

The cells of poly-crystalline PV panels are made from a cut slice from a block of silicon that consists of several crystals. The speckled reflective surface of the panel is responsible for the visibility of the thickness of the slice. The poly-crystalline cells are less efficient than the mono-crystalline cells with an average efficiency of 12% and also cost somewhat less than the mono-crystalline cells. The panels must also be mounted in a secure frame in order to protect the cells. The manufacturing process that is used to create poly-crystalline cells consists of molten silicon that is cast into ingots of poly-crystalline silicon. The ingots are then cut into very thin wafers and assembled to form a complete cell [12].

As the poly-crystalline PV panels are almost as efficient as the mono-crystalline PV panels and are less expensive, poly-crystalline PV's are more commonly used for renewable energy applications. It makes more sense to use poly-crystalline PV's in an array due to the cost than to make use of the mono-crystalline technology [12]. The Sun module SW220 poly-crystalline PV panel has a maximum power output of 220 W at a rated voltage of 29.2 V and a rated current of 7.54 A [3], [12].

C. Amorphous silicon photovoltaic panel

Amorphous silicon (a-Si) was first deposited from a silane discharge by Chittik *et al.* in 1969 [13]. Technological advances over the last few decades are responsible for the development of a-Si solar cell technology. The optoelectronic properties of amorphous silicon PV panels differ over a broad range and plasma deposition conditions can highly influence these properties. Amorphous silicon PV panels are fabricated in a laboratory using a lot of different structures, but p-i-n or n-i-p junctions are mostly utilized for commercial products. Multi-junction cells are being developed to make use of a wider spectrum of the sun's rays in order to obtain maximum efficiency [12]-[14].

Of the three different PV panels that have been mentioned, amorphous silicon PV's are the least expensive to produce, but are also the least efficient. The shapeless characteristic of the thin layer of silicon makes it flexible, and is thus ideal to manufacture flexible PV's. An unfortunate characteristic of the amorphous solar cells is that their power output reduces over time [9], [12].

D. Wind Energy

Another common renewable energy source is wind energy and is mostly used in high wind density areas. These areas mostly include coastal cities. Wind turbines work more effectively on a wind farm, where there are numerous turbines generating electricity, rather than separately for a single application [15], [16]. Wind energy is an effective renewable energy source, but it was decided for this review to focus mainly on solar energy.

E. Hydro Energy

Hydro energy is mostly used within the boundaries of big dams as a lot of water is required to generate the amount of energy that can be seen as substantial enough to cover the installation cost of the turbines. Hydro energy is also an effective renewable energy source, but due to the fact that the turbines that are needed is quite expensive and limit access to large amounts of water are available, this renewable energy source is limited to fixed locations. The cost of this method of energy is quite high, as it usually has to be done on a large scale, and modifications to the available resources, such as adding canals to the river, are necessary [17], [18].

CHARGE CONTROLLER

The primary function of a charge controller that is being used in a stand-alone photovoltaic system is to ensure that the battery does not overcharge or over-discharge and will ultimately help with the overall protection of the battery. Systems that have characteristics such as user intervention, unpredictable loads etc. will need to make use of a charge controller to prevent the shortening of battery lifetime or decreased load availability [9], [19].

The correct operation of a charge controller will help prevent overcharging or over-discharging of the battery despite the system size and seasonal changes that may impact the system. The algorithm of the charge controller will establish the efficiency of charging the battery and the most effective use of the PV system that will ensure that the system meets the load demands [9].

There are two basic methods used by charge controllers namely the shunt controller and the series controller. Shunt controllers regulates the charging of the battery by interrupting the current supplied by the PV by short-circuiting the PV system [20]. This is accomplished with a blocking diode in series between the switching element and the battery. This prevents the battery from shorting when the PV system is shunted. Shunt controllers are used in applications where the PV currents are less than 20 amperes as a result of high-current switching limits. Series controllers make use of some type of control element that is connected in series between the PV system and the battery. There are a few variations of these methods which will be discussed in the following sections [9], [21]-[24].

A. Shunt linear controller

This type of shunt controller uses an algorithm that maintains the battery at a fixed voltage level by making use of a control element that is connected in parallel with the battery [20]. The control element simply turns on or closes if the VR set point is reached and shunts power away from the battery in a linear method and results in a constant voltage level at the battery. This design type that is fairly simply, makes use of a Zener power diode. This limits the power and cost ratings of the charge controller [9], [21].

B. Shunt interrupting controller

This type of shunt controller uses an algorithm that ensures that the battery charging is terminated when the VR set point is reached by short-circuiting the PV system. The algorithm is called "pulse charging" because of the pulsing effect that occurs as the battery reaches the final charging state. This is not the same as Pulse Width Modulation (PWM). The shunt-linear controllers operate by maintaining a fixed voltage in the battery, while the shunt-interrupting controller merely terminates the charging whenever the battery reaches a set point [9], [22].

C. Series interrupting controller

This type of shunt controller uses an algorithm that ensures that the battery charging is terminated when the VR set point is reached by open-circuiting the PV system. This is accomplished with or without a blocking diode depending on the switching element that was used. There are some of the series controllers that redirect the power supplied by the PV system to a secondary load [9], [23].

D. Series-linear, constant-voltage controller

This type of series controller uses an algorithm that maintains the battery at the fixed VR set point. By making use of a series control element that acts as a variable resistor, keeps the battery at the determined VR set point. The series control element dissipates the power that is not being used to charge the battery. The series element and the voltage drop across the element are responsible for controlling the current. This type of charge controller is suggested for the use of sealed, valve-regulated batteries [9], [24].

E. MPPT charge controller

Maximum power point tracking (MPPT) charge controllers are generally dc-dc converters, inserted between the source of renewable energy and the battery that is to be charged. It has been reported that dc-dc converter type MPPT chargers can deliver more than 30% more energy from solar powered systems, given that the panels are cool and the state of battery charge is low. It was further stated that the MPPT charge controllers have great economic benefits over traditional charge controllers [21], [22].

BACKUP POWER SOURCE

There are two commonly used power storage devices used nowadays. The first being batteries and secondly the use of super capacitors. This section briefly discussed different types of backup power sources.

A. Deep cycle batteries

Deep cycle batteries are often used in solar applications as they can deliver a steady amount of current for a relatively long period without damaging the plates of the battery. Deep cycle batteries can also be discharged to the level of 20% and recharged again without losing battery potential. This is ideal for solar applications as there may be times where there will be no sunlight and the battery will greatly discharge and by making use of charge controllers, damage to the battery can be prevented. Ordinary maintenance free car batteries will be damaged and will not operate long before failing completely [25], [26].

B. Nickel-cadmium batteries

This type of batteries has a relatively long lifetime in stationary applications and is fairly durable and resistant to abuse. One of the downfalls of these batteries is that they are expensive and thus limits the use of these batteries in most applications. In the case of stationary applications, the Ni-Cd batteries are mostly flooded types. The conventional construction makes use of pocket plates of which the active materials are enclosed in a series of perforated pockets of steel that are joint together in order to form a plate [27], [28].

C. Nickel-metal hydride batteries

This type of batteries represents a newer technology that is being widely used in portable (mobile) applications [27]. In the past large amounts of funding was given to support the scaling up of the technology to be used in applications related to electric vehicles. When compared to Ni-Cd batteries, it was seen that the chemical and electrical properties of these batteries are similar. But what makes the NiMH battery superior to the Ni-Cd battery, is the greater energy density of the NiMH battery. This type of batteries is also relatively expensive [27], [29].

D. Lithium ion batteries

The Lithium ion batteries are the latest technology when it comes to batteries and are exceedingly different from other types of batteries. Lithium ion batteries are non-aqueous and chemically it is simply the passing of lithium ions from one electrode to another through the use of an organic electrolyte causing the inserting and reinserting in the electrode’s microstructure. In past years there has also been large amount of funding being given for research to scale up the capacity of the cell, mostly for the use in electric vehicles. There are still development being done on this type of batteries due to the fact that lithium ion batteries are very promising in terms of energy density, cycling capabilities and the long life expectancy in stationary applications. The only disadvantage of this type of battery is the high initial cost of such a battery [27], [30].

E. Super capacitors

Super capacitors have characteristics such as large capacitance, a long life cycle, high energy density, quick charge and discharge when compared to conventional capacitors and can be considered as a new way of storing energy. Super capacitors are very expensive compared to other types of backup power storage, like batteries [31], [32].

CONTROL UNIT

This section provides the different control boards that can be used to control the temperature and flow of air in the air conditioning system.

A. Programmable Logic Controller

A Programmable Logic Controller (PLC) is a commonly used controller that is widely used in various control system applications. The PLC uses logic to control a system. It can be easily programmed with the use of GUI software to deliver the desired controlling of a specific system. PLC’s are preferred by many applications of control systems due to the fact that they can be easily programmed, are reliable and can be reused as desired. They are very robust and can withstand harsh environments that are encountered in the industry [33].

PLC's are specialized computers used to control complex systems consisting of machinery and processes. PLC's have programmable memory which stores functions and instructions such as the switching control, data handling, timing, arithmetic and sequence operations. PLC's are very flexible and can easily be expanded by adding more blocks to provide more inputs and outputs to the control system. PLC's can also be networked to provide network controlling such as data gathering, monitoring of devices, supervisory control as well as the uploading and downloading of programs [33].

PLC's have a fast response time and can be programmed and tested using computer software before it is downloaded to the PLC, ensuring that the system will operate as desired. This is a nice feature of the PLC's as trouble shooting can be done before the physical implementation of the PLC in the control system [33]. PLC's have a lower cost than logic relay system that was used in the past, but are a more expensive than other controllers such as the Arduino controller or the FEZ Panda controller [14].

The Siemens LOGO! basic unit OBA6 PLC controller has a user-interface and a display for communicating important information about the system to the user [34]. This enables easy troubleshooting of a control system if the system operation is interrupted or do not function as desired.

B. Arduino control board

The Arduino controller is a microcontroller that has a large amount of digital input and output pins, analog inputs, hardware serial ports and a crystal oscillator. The Arduino controller also support USB communication and has a power jack that supplies the Arduino controller with power when it is not connected to a computer using the USB connection [35].

The Mega 2560 (or R3) is one of the newest controllers from the Arduino range and replaced the Arduino Mega controller. The Mega 2560 is different from the previous Arduino controllers that used a USB to serial chip, due to the fact that it uses a USB to serial converter instead. The Arduino controller has a recommended input voltage rating of 7-12 V, but has an operating voltage of 5 V. It can handle a DC current of 40 mA on its input and output pins which can be problematic if power electronics are connected directly to the Arduino controller as it will not be able to supply the desired DC current [35].

Thus if power electronics needs to be powered by the Arduino controller, a power electronics circuit will need to be designed and build in order to supply the load with the required voltage and current. Furthermore the Arduino controller will also need to be programmed using computer software that is supplied with the purchase of the Arduino controller board. The controller board does not come standard with a display, but the controller can be expanded by adding a display which is an accessory that can be purchased for the Arduino controller. The Arduino controller is one of the cheapest controller boards available on the market [14], [35].

The Arduino Mega 2560 controller board has a very powerful capability when it comes to electronics and will control most electronic systems if the right extensions are connected to the controller [35].

C. Panda control board

The FEZ Panda II controller board is one of the most powerful controller boards on the market, with the exception of the dSPACE® controllers. The Panda controller is a low costing controller that is relatively small and runs on Microsoft .NET Micro Framework that allows programming using Microsoft's free Visual C# Express software. The programming of the Panda controller is done on the computer and is then transferred to the controller board via the USB connection to the controller [36], [37].

The Panda controller is a microcontroller with 72 MHz, 32-bit ARM7 processor and has 512 KB flash memory and 96 KB RAM. The Panda controller is also compatible with most Arduino shields making the expandability for the Panda controller powerful. It also comes with a built-in Micro SD card socket that allows expanding of the memory of the Panda controller [37].

It has a large number of digital input and output ports, analog inputs and outputs as well as a number of hardware PWM channels. It comes with a built-in Real Time Clock (RTC) with the suitable crystal as well as a whole lot of other features that were not discussed. The Panda controller unlike the Arduino controller has a stackable hardware platform that makes the expansion of this controller quite remarkable. The Panda controller is powered by the USB port in most cases, but can also be powered by an optional power connector, supplying the Panda controller with an operating voltage of 5 V [37], [38].

D. Raspberry PI control board

The Raspberry Pi computer board is the size of a credit card that plugs into a television and a keyboard. It is a miniature ARM-based PC which can be used for numerous applications similar to that of a desktop computer. Applications can include spreadsheets handling, word-processing and running games. It is also able to play high-definition video footage. The device is reported to be less expensive than the PLC, but slightly more expensive than the discussed Arduino [14], [39].

E. dSPACE® Control board

High-tech industries all around the world rely on dSPACE® systems to develop and test electronic control units and mechatronics. These applications include automotive, aerospace, defence, commercial, industrial automation, medical technology and numerous others. dSPACE® solutions gradually reduce development time and costs while increasing productivity. But all of this comes with a price as the dSPACE® controller boards are very expensive [36], [40].

COOLING AND HEATING

This section provides details on the applicable cooling and heating technologies.

A. Thermoelectric modules

Thermoelectric modules (TEM) consist of a number of n-type and p-type semiconductors that are connected electrically in series and thermally in parallel [41]. These semiconductors are typically placed between two ceramic plates which hold the semiconductor structure mechanically firmly together whilst insulating the individual semiconductors from external mounted surfaces like heat sinks etc.

By applying a DC voltage to the TEM will result in a heat transfer from the one side of the TEM to the other. One side of the TEM will generate heat whilst the other side will be cooled [42], [43]. The TEM can therefore be used for cooling as well as heating.

Thermoelectric coolers with a simple structure are capable of supplying active cooling and are very important for the thermal problem to be solved. Comparing thermoelectric cooling to conventional air conditioners that uses refrigerant for cooling, thermoelectric cooling systems have the benefit of being very compact, robust, simple and quiet. Taking the consideration of the environment into account, thermoelectric systems do not leak or produce any harmful gases that can contribute to global warming or the damaging of the ozone layer [44], [45].

Assuming constant temperatures T_c (the temperature at the cold side shunt) and T_h (the temperature at the hot side shunt), constant material properties and negligible interfacing losses will result in the heat that is being absorbed at the cold side of the TEM to be given by [44]:

$$Q_C = \alpha T_C I - 0.5 I^2 R - K\Delta T \quad (1)$$

where α is the combined Seeback coefficient of the N-type and P-type semiconductors, I is the current, R is the electrical resistance, K is the thermal conductance and ΔT is the difference between the temperatures at the hot and cold side shunts.

The heat that is generated at the hot side of the TEM is given by [44]:

$$Q_C = \alpha T_H I - 0.5 I^2 R - K\Delta T \quad (2)$$

The input power is given by [44]:

$$Q_{IN} = \alpha I \Delta T + I^2 R \quad (3)$$

The cooling of the TEM is defined by the coefficient of performance (COP) and given by [44]:

$$COP = \frac{Q_C}{Q_{IN}} \quad (4)$$

Using equations (1) – (4), the maximum COP can be derived and is given by [44]:

$$COP_{max} = \frac{T_C}{\Delta T}\left[\frac{M-1-\frac{\Delta T}{T_C}}{M+1}\right] \quad (5)$$

where $M = (1 + ZT_{average})^{0.5}$, $T_{average} = 0.5(T_h + T_c)$, $Z = \frac{\alpha^2}{\lambda\rho}$, λ is the thermal conductivity and ρ is the electrical resistivity. Z is the figure of merit, a measure that indicates the performance of thermoelectric materials.

These equations are used to calculate the different parameters that are needed to determine the size of the TEM [46], [47]. This will help ensure that the right TEM is used for the design of a project. This is crucial because the size of the TEM will influence the size of the PV system and battery system that need to be used in a project. TECMs also have a liquid cooling option [36].

B. Heat element

A heat element is a robust resistor that when connected to a power source, is able to dissipate heat as it becomes warmer and warmer. This enables the heat element to become a heat source and the heat is transferred to the air surrounding the element [48], [49].

C. Oil heating

Oil heating is almost the same as liquid cooling as the oil is heated by using a source of some type, the oil is then circulated within a closed loop and the heat energy is transferred to the ambient temperature leaving the oil a little bit cooler than before [1], [2].

D. Heat pumps

The basic operation of a heat pump is to transfer heat from one place to another, causing the area where heat was removed to be cooler, and the area to where it is being transferred to, to be heated. A heat pump is generally used to transport heat to an area, but by applying the process in reverse, the same device can be used to cool down an area. The heat is disposed of elsewhere, or can even be used for another application [2], [32], [50].

A study involving the operation of a heat pump as a cooling device by making use of renewable energy sources confirmed that this operation is possible. The study made use of various energy sources, investigating the use of solar-, wind-, geothermal, and bio-mass energy. The study mentions that bio-mass energy is not really a sustainable source, and that it would not be a reliable source [51], [52].

E. Conventional air conditioning systems

The compressor, evaporator coil, condensing coil and expansion valve are common components to both heat pumps and air conditioners. The heat pump extracts heat from the ambient air outside the house to inside the house for heating purposes, by means of a reversing valve, during the heating cycle. During the cooling cycle, the air conditioner and heat pump functions in the same way, by using the refrigerant to transfer heat from inside the house to outside the house [53].

Initial installation cost of a heat pump is much more than that of a conventional air conditioner system or a conventional electrical heater, but heat pumps have a better payback period, due to the better (lower) running cost [54].

Since the heat moves from one area to another, rather than manufacturing heat, the heat pump is a much more efficient process, especially during the heating cycle [53]. Heat pumps basically use the electricity required to operate a 1-bar heater, but provides the heat of a 4-bar heater. The running cost of a heat pump is therefore a lot lower than that of a gas or traditional electrical heater [54].

TRADE-OFFS

In this section the different components that were discussed in the previous sections will be compared by means of a unique trade-off study for South African conditions, in order to design the optimal efficient and cost effective renewable energy TEM air conditioning system. Marks will be allocated to each component in each of the three categories. The three different categories are cost, availability and functionality. A mark out of 5 is given to each component where 1 is very poor and 5 are excellent.

A. Renewable energy sources for South African conditions

In table 1, the different types of renewable energy sources for South African conditions are listed and compared. The three chosen types of renewable energy sources are solar, wind and hydro energy. The cost of implementing wind and hydro energy sources is very high and the availability is also not that good as compared to solar energy sources. Solar energy is fast becoming a frontier in renewable energy applications as South Africa is a country with a lot of solar radiation. Solar energy therefore shows the greatest potential for a project like this. Solar energy will have a higher score for the inland areas, where wind energy will have a higher score for the coastal areas.

Table 1: Unique renewable energy source trade-off for South African conditions.

	Cost	Availability	Functionality	Total
Solar energy	3	5	5	13
Wind energy	2	4	5	11
Hydro energy	1	1	1	3

Table 2 provides the three chosen PV panel types for South African conditions. The three chosen types of PV panels are mono-crystalline, poly-crystalline and amorphous silicon. Mono-crystalline is a bit more expensive than the other two, but has the highest efficiency at 15%. Poly-crystalline has an efficiency of about 12% and amorphous silicon has the lowest efficiency, but also has the lowest price. Amorphous solar cells have a disadvantage that the power output reduces over time.

Table 2: Unique PV panel trade-off for South African conditions.

	Cost	Availability	Functionality	Total
Mono-crystalline	2	3	5	10
Poly-crystalline	3	3	4	10
Amorphous silicon	4	3	3	10

B. Charge controllers for South African conditions

In table 3, the different types of charge controllers for South African conditions are listed and compared. The five chosen types of charge controllers are shunt linear, shunt interrupting, series interrupting, series linear constant voltage and MPPT controllers. It was seen that the shunt linear, shunt interrupting and series interrupting controllers are all relatively on the same level when it comes to cost, availability and functionality. The functionality was seen to be relatively equal and each having a different application.

The MPPT charge controller was seen to be a bit more expensive, but the functionality within a solar energy system was a lot better. The MPPT charge controller is 30% more efficient than the ordinary charge controllers. Taking into account the losses within the solar energy system and compensating for these losses, a smaller system can be implemented by using a MPPT charge controller. These expenses compared to each other, it was seen that the additional cost of a MPPT charge controller will be meaningful.

Table 3: Unique charge controller trade-off for South African conditions.

	Cost	Availability	Functionality	Total
MPPT Charge Controller	3	4	5	12
Shunt Linear Controller	4	4	3	11
Shunt Interrupting Controller	4	4	3	11
Series Interrupting Controller	4	4	3	11
Series Linear constant voltage	4	4	3	11

C. Backup power sources for South African conditions

In table 4, the different types of backup power sources for South African conditions are listed and compared. The five chosen types of backup power sources are the deep cycle battery, the Nickel-Cadmium battery, the Nickel-metal hydride battery, the Lithium ion battery and the super-capacitors. It was seen that the cost of the different types of batteries varied significantly with the Lithium Ion battery and super-capacitors being the most expensive of the backup power sources being discussed. The Nickel-Cadmium battery was also relatively expensive when compared to the deep cycle battery. The availability of the batteries are not that far apart, but it is seen that the Lithium Ion battery and super-capacitors due to its cost are a bit more difficult to acquire.

The deep cycle battery is mostly used in solar application due to its versatility and availability. The deep cycle battery also has a greater lifespan as discussed previously. The deep cycle battery comes in a lead acid variant as well as a gel cell variant for applications that require the battery to be positioned upside down or on its side.

Table 4: Unique backup power source trade-off for South African conditions.

	Cost	Availability	Functionality	Total
Deep cycle battery	4	4	4	12
Nickel-Cadmium battery	3	3	4	10
Nickel-metal hydride	3	2	4	9
Lithium ion battery	3	2	4	9
Super-capacitors	2	2	4	8

D. Control units for South African conditions

In table 5, the different types of control units for South African conditions are listed and compared. The five chosen types of control units are the PLC, Arduino controller, Panda controller, Raspberry PI and dSPACE® controller. The cost of the Panda controller and PLC was seen to be more or less the same depending on the specific model of the PLC that will be used. The Arduino controller was seen to be the least expensive controller that can be used. Looking at availability it was seen that the PLC and the Arduino controller are more or less equal with the Panda controller being a bit less acquirable. The factor that sets these controllers apart from one another is the functionality of the controllers. Although the Arduino and Panda controllers as very powerful controllers with USB interfaces etc., these controllers are mostly used in electronic design situations where small currents flow within the circuitry. The PLC on the other hand, is very versatile and robust. The PLC units vary and have different features.

Table 5: Unique control unit trade-off for South African conditions.

	Cost	Availability	Functionality	Total
Programmable Logic Controller	4	5	5	14
Arduino control board	5	4	4	13
Raspberry PI	5	4	4	13
Panda control board	3	4	4	11
dSPACE®	1	4	4	9

E. Cooling and heating components for South African conditions

In table 6, the different types of the cooling and heating components for South African conditions are listed and compared. The five chosen types of cooling and heating components are the TEM, heat element, heat pumps, conventional air conditioners and oil-heating. It was seen that the oil-heater is relatively expensive to implement, that its availability is somewhat low and that its functionality is also not that great. The heat element was seen to be the cheapest option in terms of heating when compared to the other components. The availability of the heat element is very good and the functionality is also relatively good. The TEM was seen to be a bit more expensive when an assembly is considered, but relatively cheap when the TEM is bought as a standalone component. The availability is also good due to the fact that a lot of companies are supplying these Peltier devices. TEM are becoming a very popular technology in cooling applications due to the fact that the entire compressor concept can be discarded and because the TEM is so effective. The heat pump and conventional air conditioner have relatively the same cost and availability, but heat pumps score a bit higher, since they make use of environmental conditions.

Table 6: Unique cooling and heating components trade-off for South African conditions.

	Cost	Availability	Functionality	Total
Thermoelectric Module	3	4	5	12
Heat element	5	5	2	12
Heat pump	4	4	3	11
Conventional air conditioner	4	5	1	10
Oil-heating	3	4	2	9

CONCLUSION

This paper provided a review on the design factors that must be taken into account when developing a renewable energy TEM air condition system for South African conditions. A unique trade-off study is provided, in order to design the optimal efficient and cost effective renewable energy TEM air conditioning system. It is important to note that the cost, availability and functionality of components are unique for South African conditions and that this trade-off might be different for other areas and other countries, and might change drastically over time as the cost changes, components become more available and functionally improves with the introduction of new technologies into the market.

The chosen technologies according the trade-offs are as follow: solar energy – mono-crystalline or poly-crystalline PV panels, charge controller – MPPT controller, backup power source – deep cycle batteries, control unit – PLC controller, cooling and heating – TEM. The remaining components like the air conditioning casing, fans, remote control, sensors and smaller components are not discussed in this review, as they are normally standard technologies with very little trade-off between them. By choosing a renewable energy source it was seen that a project like this can greatly benefit the environment as well as help the national electricity supplier to reduce the daily peak time energy demand of South Africa. By taking some of the air conditioners of the near future off the national electricity grid will help reduce the CO_2 emissions of a business or country and will ultimately contribute to the Cap and Trade Movement.

The initial cost of a solar TEM air conditioning system will be relatively higher than the installation of a conventional air conditioner, but such a project will qualify as a renewable energy project that helps relieve the immense pressure that the national electricity supplier is facing to supply South Africa with the desired peak time energy. CDM stipulates that a country committed under the Kyoto Protocol, has to implement emissions-reduction programs in developing countries to help reduce the CO_2 emissions around the world [2]-[4]. Although South Africa is not committed under the Kyoto Protocol, it will be good practice to comply with the movement as the decay of the ozone layer will eventually affect us all.

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