SIMULATION OF DISTRICT COOLING SYSTEM USING SOLAR COOLING WITH LITHIUM BROMIDE – WATER ($LiBr/H_20$) ABSORPTION CHILLER

By

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Dissertation Report submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

JANUARY 2015

Universiti Teknologi PETRONAS
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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved By,

____

(DR. ABRAR INAYAT)

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32610 BANDAR SERI ISKANDAR, PERAK

JANUARY 2015

CERTIFICATION OF ORGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the work contained herein have not been undertaken or done by unspecified sources or persons.

(HU HIN ANG)

ABSTRACT

The worldwide cooling demands is rising drastically. Several causes lead to this scenario such as industrialization, global warming, tropical climate region and etc. This prompts the application of district energy such as gas district cooling (GDC) system to fulfill the demands. Considering the energy sustainability, this project aims to study the feasibility of solar cooling system to produce cooling air (chilled water) which can be scaled up later to function as solar district cooling plant. The conventional usage of vapor compression air-conditioning systems (A/C) causes serious environmental issues such as emission of greenhouse gases due to the coolants (chlorofluorocarbons) used. Hence, the district cooling system will produce chilled water through absorption cooling cycle (lithium bromide-water absorption chiller) which is environmental friendly. Parametric study will conducted by using TRNSYS software to examine the feasibility and potential of solar absorption cooling system. The feasibility of the system is determined when the cooling demand of a particular modelled building has been met (room temperature of the building model is lower after the application of solar cooling system). The typical meteorological year file (TMY 2) containing weather parameter for Malaysia, specifically Kuala Lumpur city is used to simulate the system.

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ABBREVIATIONS AND NOMENCLATURES

RECS	: Residential Energy Consumption Survey
AC	: Air Conditioning
EIA	: U.S. Energy Information Administration
CETDEM	: Center for Environment, Technology and Development
CFCs	: Chlorofluorocarbons
HCFC	: Hydro-fluorocarbon
ODP	: Ozone Depletion Potential
GWP	: Global Warming Potential
GDC	: Gas District Cooling
CHP	: Combined Heat and Power
$LiBr/H_2O$	: Lithium Bromide - Water

CHAPTER 1: INTRODUCTION

This chapter gives a preview about the background of this paper such as the reason solar district cooling is recommended instead of conventional gas district cooling system, a brief description on the applications of sorption cooling system (absorption chiller), overview of integration of solar district cooling system using absorption chillers and the objectives and scope/limitations of this paper.

1.1 Background

The global cooling energy demand is increasing rapidly mainly because of emerging countries with high economic growth and blooming industrialization. The cooling for buildings and industrial process holds a significant proportion of this demand. Countries such as United States, Sweden, and even Malaysia have found to have increases cooling energy consumptions throughout the year. The main reasons are overheating period during summer time (Rydstrand, 2004) for cold countries such as United States and Sweden. Countries such as China and Malaysia have higher annual cooling demands due to the subtropical climate that dominates the regions. Other reasons including growing amount of well insulated buildings, refrigeration requirement, increasing internal heat loads from computers and other office equipment as well as high comfortable indoor temperature standard in the buildings (Lindmark, 2005; Anderson, 2005; Fjärrvärmen,2013). Figure 1 below shows the annual cooling demand in Sweden from year 1996 to year 2011.

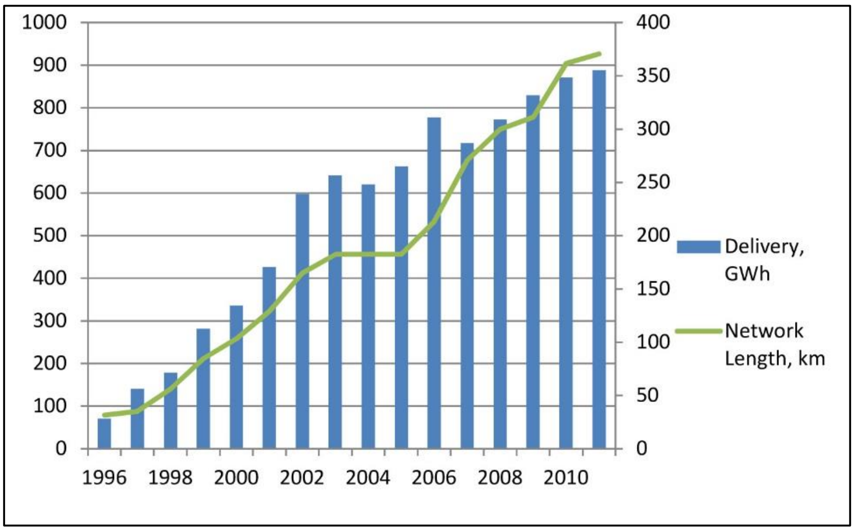


Figure 1 Annual Cooling Demand in Sweden. (Source: Fjärrvärmen, 2011)

From the figure above, it shows that annual cooling demand in Sweden has been increases more than 800%, from less than 100GWh per year in 1996 to almost 900GWh per year in 2011. Besides, latest results from the 2009 United States Residential Energy Consumption Survey (RECS) show that 87% of U.S households are now equipped with air conditioning (AC) system as compared to the year 1993, which only 68% of all occupied housing units had AC. Figure 2 below shows the most recent RECS analysis from U.S Energy Information Administration (EIA) which shows the average household site energy consumption.

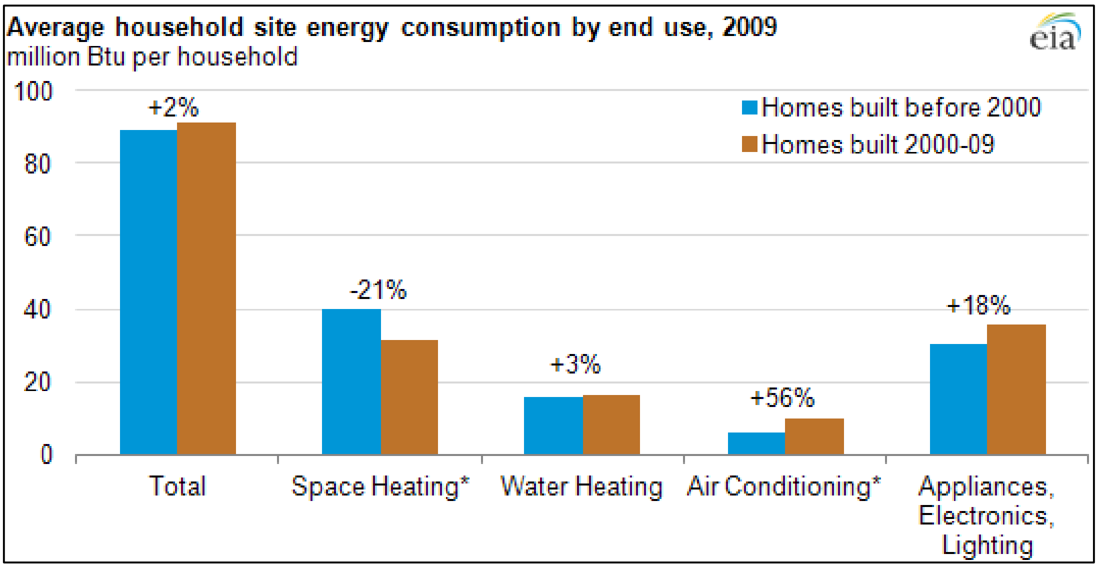


Figure 2 Average Household Site Energy Consumption
(Source: U.S Energy Information Administration, 2009)

From the analysis above, it shows a great increment of 56% in the usage of air condition system for each occupied household unit built from the year 2000 to 2009. In Malaysia, a 2006 study of Household Energy conducted by Center for Environment, Technology and Development (CETDEM), Malaysia has found that nearly 45% of household electricity consumption is taken up by air conditioning.

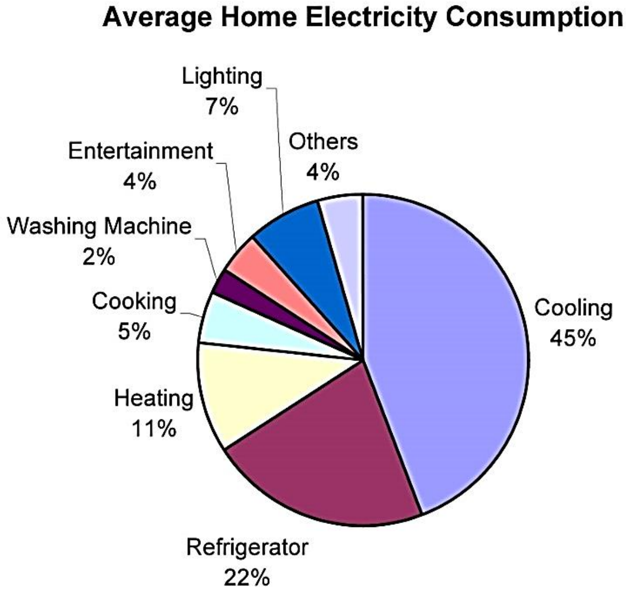


Figure 3 Average Home Electricity Consumption (Source: CETDEM, 2006)

The global trend of conventional cooling method is through the application of vapor-compression air conditioning system. However, this system has some negative effects on the environment, as a result of the usage in the chlorofluorocarbons (CFCs) and the hydro-fluorocarbon (HCFC) refrigerants which induce ozone depletion and the consequent greenhouse effect. In search of sustainable energy utilization technologies, the absorption refrigeration system considerably appears as an alternative way to reduce consumption of electricity and CFCs. Absorption refrigeration system can be powered by fossil fuels, renewable energy resources or waste heat recovered from other thermal systems. Moreover, it uses environment-friendly working fluids such as water, ammonia, lithium bromide and etc. Compared to the conventional compression system, absorption cooling system has high reliability, low maintainability and a silent and vibration free operation. Another important merit of this system is it has zero-ozone depletion potential (ODP) and zero global warming potential (GWP).

When the production ban on chlorofluorocarbons (CFCs) went into effect starting from 1996 (Tabreed, National Central Cooling Co., 2011), replacing conventional compression air conditioning system to absorption cooling system is a costly exercise. The situation would be a lot more different with the existence of district cooling system, for which building owners could have avoided such a large expenditure. Conventional district cooling system, also known as gas district cooling (GDC), as the name suggest utilizes natural gas as its primary fuel source. It supports the cooling requirements using co-generation concept which sometimes known as combined heat and power (CHP) system. CHP system reutilizes energy loss in the form of heat to meet other forms of energy demands.

To increase the energy efficiency measures, renewable energy such as solar energy should be used as the fuel source for district cooling system instead of non-renewable sources such as natural gas or charcoal. The purposes to choose solar energy as the heat source for district cooling system is because solar energy is the most abundant form of energy available (Solarika, 2012). Figure 4 below shows that solar energy is the most abundant energy compared to the other world's used energy.

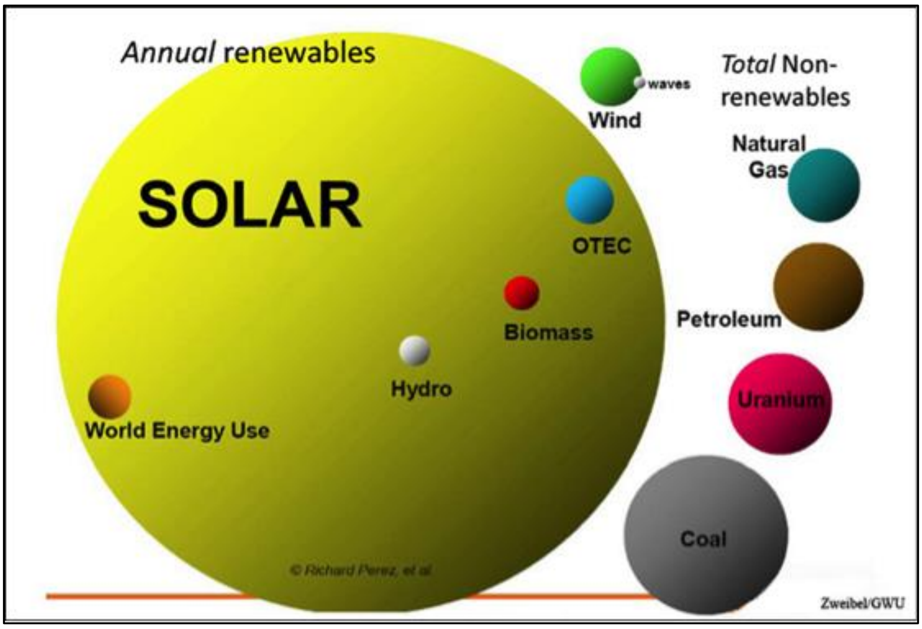


Figure 4 Solar Energy as the Most Abundant Form of Energy. (Source: Solarika, 2012)

Regarding energy efficiency, solar energy has very low running costs where it can be independently installed in remote locations and once installed, the production of energy is almost "free" for the lifetime of the system (high energy efficiency with low running costs). Besides, solar energy can fulfil cooling demands not only for buildings, but also process cooling for industrial applications producing a carbon-neutral and environmentally harmless goods (Henning and Doll, 2012).

Hence, this paper aims to study the feasibility of district cooling system by using solar energy as primary heat source in order to operate absorption cooling system to meet the regional and global cooling demands in the near future.

1.2 Problem Statements

To fulfill rapid growth of energy consumptions for global cooling demands, more power has to be generated. Non-renewable sources such as natural gas and charcoal is used to generate power or electricity to operate the conventional compression air conditioning system. This indirectly leads to the greenhouse gases emission which induces global warming and ozone depletion due to the chlorofluorocarbons (CFCs) as the refrigerant. Absorption cooling system is being recommended to replace current application of conventional compression air conditioning system. To develop a system with a low energy demands by energy-efficient measures, solar district cooling system with absorption cooling method has been proposed. The figure below summarized the whole idea of this project:

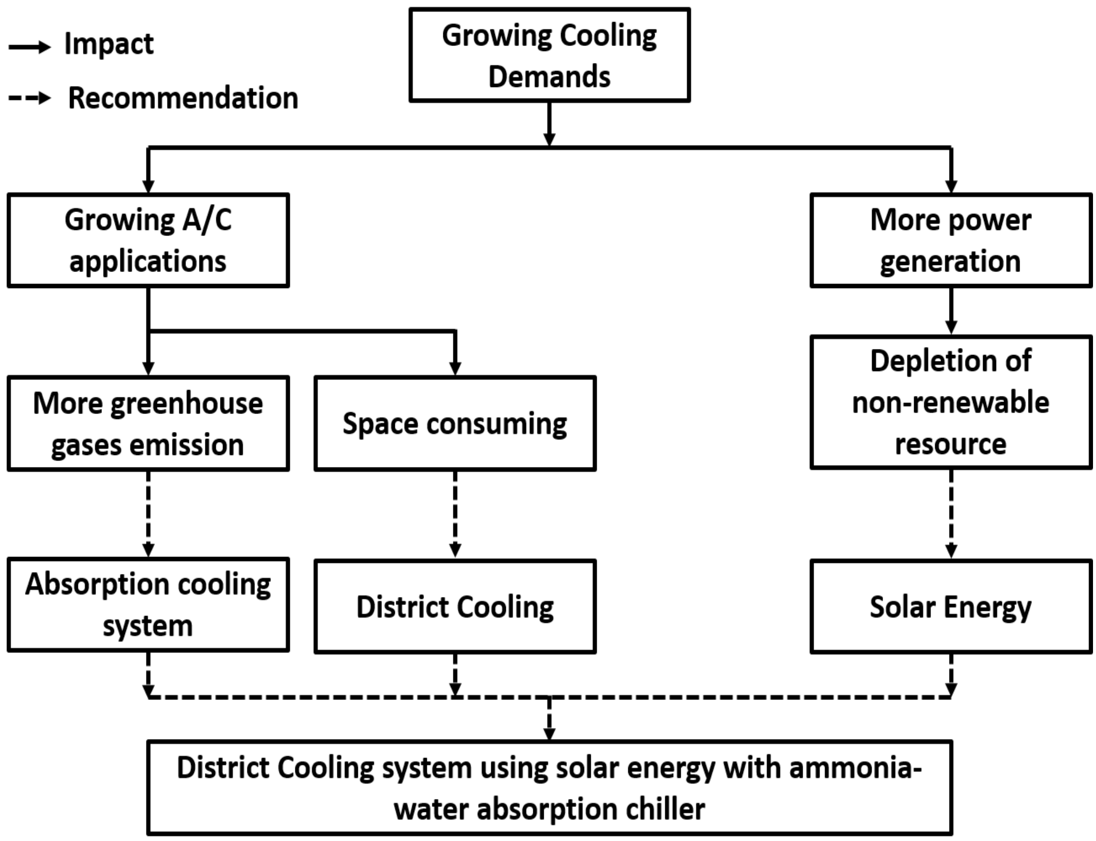


Figure 5 Problem Statement

1.3 Objective

(a) To simulate an energy efficient system using lithium-bromide (LiBr/H20) absorption chiller.

(b) To simulate the system for parametric study to determine the feasibility of the solar cooling system in Malaysia.

1.4 Scopes of Study

(a) To study the feasibility of several parameters which are collector slope angle, collector area and storage tank size.

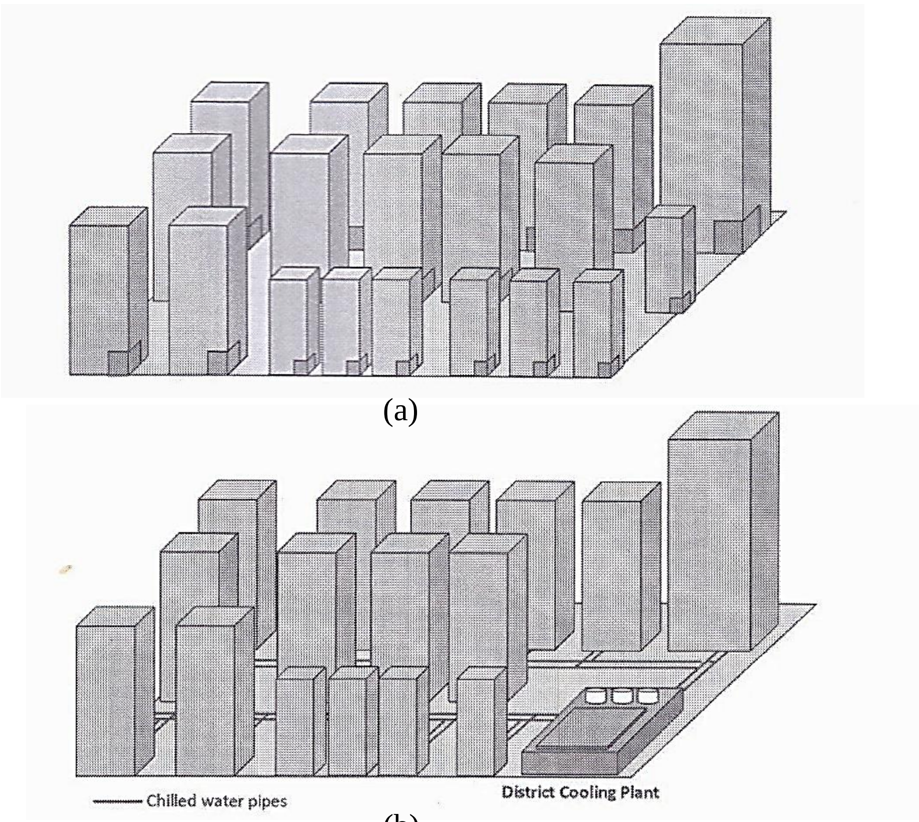
(b) To study the performance of solar heating subsystem.

(c) To study the performance of absorption cooling subsystem.

CHAPTER 2: LITERATURE REVIEW

2.1 Theory of District Cooling

District cooling is perceived as energy saving opportunity and environment friendly solution when it comes to comfort cooling (Umea Energy, 2008; Gas District Cooling in Malaysia, 2011). It operates based on co-generation schemes which utilizes waste heat (Anergy) for the centralized chilled water production. The most significant difference between conventional air-conditioning system and district cooling is no collective independent mechanical chiller plant room for respective buildings instead only a relative smaller area would be required at each building to house in a heat exchanger for chilled water pipe network in district cooling. Besides, district cooling operates on a larger scale and delivers chilled water to many building with only an allocation of district cooling plant within the area. Figures below show the comparisons between conventional air-conditioning system and district cooling.



(a)

(b)

Figure 6 (a) Conventional Air-conditioning System in buildings (b) District Cooling System (Source: Gas District Cooling Malaysia, 2011)

2.1.1 Solar District Cooling vs Conventional Gas District Cooling

Conventional gas district cooling using natural gas as a fuel source (Exergy) for gas turbine as a prime mover for the electrical generator (electrical power generation). Surplus thermal energy from the turbine exhaust gases (also known as waste heat or Anergy) is harnessed (or recovered) to produce steam in a heat recovery steam generator (HRSG). The steam that is produced acts as a source of energy for steam absorption chiller (SAC) for the production of chilled water that cools down the room temperature in a building. Figure below shows the schematic diagram for the conventional gas district cooling system.

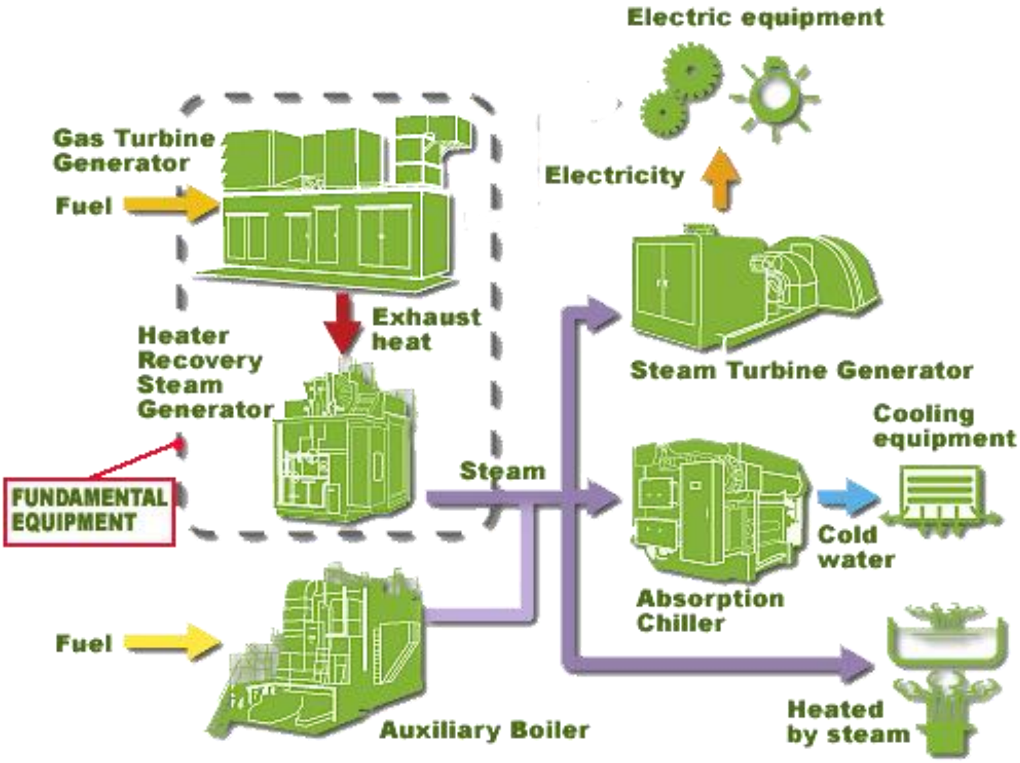


Figure 7 Schematic Diagram for Gas District Cooling System (Source: Whole Building Design Guide, 2014)

This paper aims to focus on the development of a solar district cooling system instead of gas district cooling system. The significant change is the fuel source for this centralized chilled water production plant. As mentioned before, gas district cooling system operates based on natural gas or generally non-renewable sources. The disadvantage of utilizing non-renewable source such as natural gas is the issue regarding its long-terms sustainability. According to US Energy Information Administration in the year 2013, world proved natural gas reserves were enough to last 58 years at 2011 production levels. Figure 7 below shows the ratio of world proved natural gas reserves to production from year 1980 through 2011.

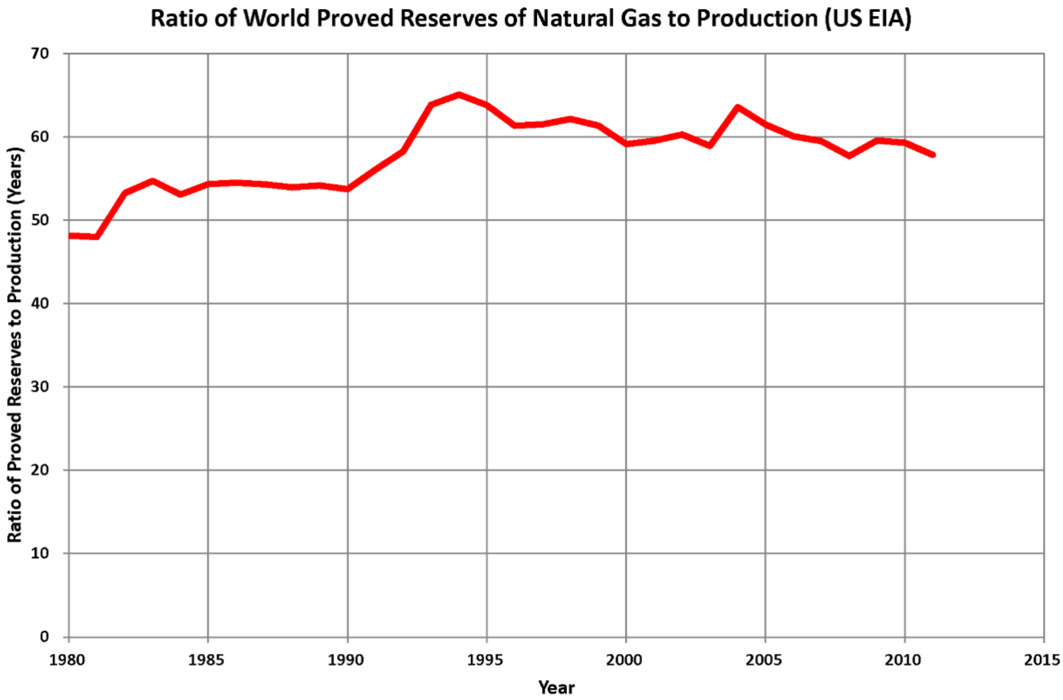


Figure 8 Ratio of World Proved Natural Gas Reserves to Production from year 1980 through 2011 (Source: U.S. Energy Information Administration, 2013)

To maintain the sustainability of energy sources, using renewable energy to meet the rapid energy demand growth is a long-sought goal. Solar energy is one of the most abundant energy source in this world (refer to Introduction section). Therefore, utilization of solar energy is one of the alternative for the long term district cooling operations.

2.2 Chilled Water Production Techniques

The chilled water can be produced through three main techniques:

(a) **Free cooling** – Free cooling utilizes the surrounding nature's cooling such as using water from lakes and oceans. The cold water is pumped into the plant to cool the district cooling water through a heat exchanger. The cooled water or known as chilled water is distributed to the respective users or customers based on demands.

(b) **Absorption chiller** – Absorption chiller produces cooling energy using waster heat that is released from the industries or process. Absorption chiller is much more environmental friendly as it operates using working fluid such as lithium bromide, water, ammonia and etc. instead of chlorofluorocarbons (CFCs). The two most commonly employed working solutions are either Lithium

Bromide –Water solution (LiBr-H_2O) or Ammonia-Water Solution (NH_3-H_2O).

(c) **Cooling from heat pumps** – Heat pumps can produce cooling energy with the integration of compressor which can be described as cooling using a large refrigerator.

As proposed by the title of this paper, absorption chiller technique will be the focus for the solar district cooling simulation.

2.2.1 Absorption Chiller System

The absorption process is founded by two fundamental circumstances,

(a) Absorbent solutions ability to absorb the refrigerant vapor.

(b) Refrigerant boils at a very low temperature during high pressure.

The absorption cycle works based on the strong affinity of the working fluids available in the system. The whole absorption cycle has four main components: generator, condenser, evaporator and absorber. Other components are electrical pumps for keeping the refrigerant an absorbent circulating inside the cycle and a heat exchanger to increase the efficiency of the cycle by helping to cool down the concentrated solution and heat up the weak solution (York International, 2008). Figure below shows the schematic sketch over the absorption cycle process.

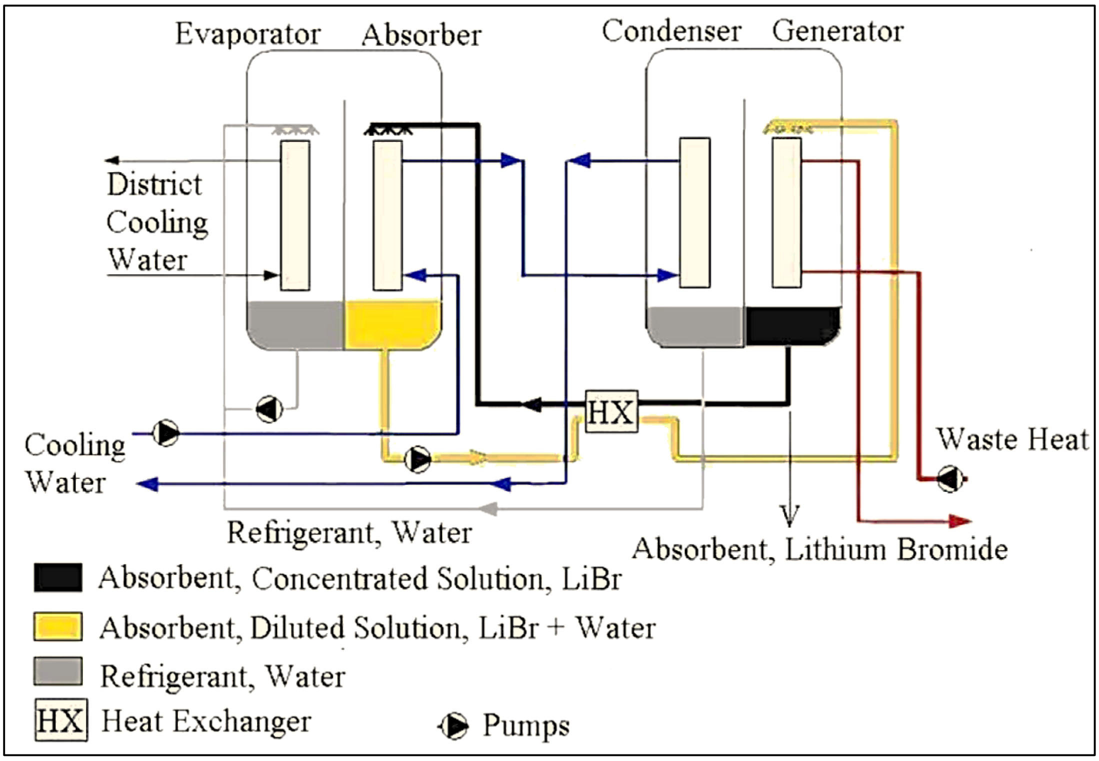


Figure 9 Schematic sketch over the Absorption Cycle Process (Source: Rydstrand et al., 2004)

The working mechanism for the absorption cycle is explained by employing Lithium bromide -Water as the working fluid. The cooling energy to the district cooling water is produced in the evaporator, where refrigerant (Ammonia) is sprayed out at low pressure and absorbs the heat energy from the incoming district cooling water. This process vaporizes the refrigerant and the vapor is the transported to the absorber (York International, 2008).

In the absorber, the concentrated absorbent solution (lithium bromide) is sprayed out and absorbs the refrigerant vapor (water). Thermal energy is released by this absorption process and the mixture of these two is then condensed by the incoming cooling water to a diluted solution LiBr-H2O. (York International, 2008).

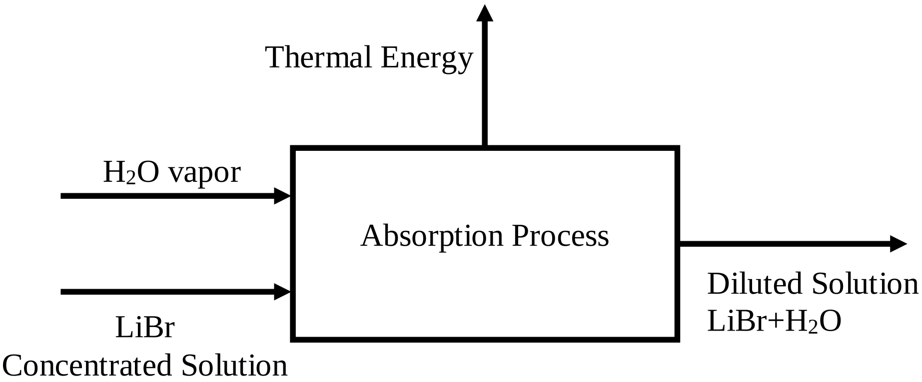


Figure 10 Absorption Process (Source: Herold et al., 1996)

The diluted solution is then pumped through the heat exchanger to the generator where heat is added by the waste heat. The added thermal energy makes the solution vaporize, which means a desorption process occurs. The process separates the refrigerant and the absorbent into a concentrated solution and refrigerant vapor. The solution is then pumped back to the absorber through the heat exchanger, while the vapor is transferred to the condenser to be cooled and liquefied. (York International, 2008).

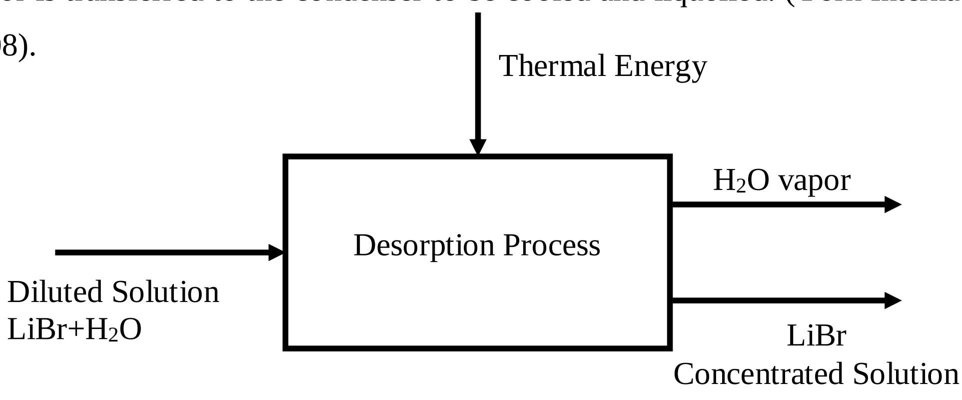


Figure 11 Desorption Process (Source: Herold et al., 1996)

The refrigerant vapor from the generator is then condensed by the cooling water. The condensed refrigerant is then transferred back to the evaporator. With that entire absorption cycle is closed (York International, 2008).

2.2.2 Working Fluids

There are many combinations of working fluids that have been considered for absorption machines such as water/sulfuric acid, ammonia/water, water/lithium bromide and water/sodium. The most common and conventional absorption fluids are ammonia water and water/lithium bromide. One of the key criteria to choose the working fluids is the high affinity (chemical attraction force between different substances). To find a mixture that meets all the criteria for the desirable properties is not possible, some compromises have to be made (Herold et al., 1996). Table below shows the comparisons between two most conventional combinations of working fluids.

Table 1 Compilation of the property criteria's for the most Conventioanl Absorption Working Fluids (Source: Herold et al., 1996)

<table>
<tr><th></th><th>Refrigerant/Absorbent Property</th><th>Ammonia/Water</th><th>Water/Lithium Bromide</th></tr>
<tr><td rowspan="4">Refrigerant</td><td>High Latent Heat</td><td>Good</td><td>Excellent</td></tr>
<tr><td>Moderate Vapor Pressure</td><td>Too high</td><td>Too Low</td></tr>
<tr><td>Low Freezing Temperature</td><td>Excellent</td><td>Limited Application</td></tr>
<tr><td>Low Viscosity</td><td>Good</td><td>Good</td></tr>
<tr><td rowspan="2">Absorbent</td><td>Low Vapor Pressure</td><td>Poor</td><td>Excellent</td></tr>
<tr><td>Low Viscosity</td><td>Good</td><td>Good</td></tr>
<tr><td rowspan="3">Mixture</td><td>No Solid Phase</td><td>Excellent</td><td>Limited application</td></tr>
<tr><td>Low Toxicity</td><td>Poor</td><td>Good</td></tr>
<tr><td>High Affinity between Refrigerant and Absorbent</td><td>Good</td><td>Good</td></tr>
</table>

2.3 Literature Review

Publications on solar district cooling by using absorption chiller are scarce. Most of the papers are either focusing on the simulation or experimental performance for solar cooling. The difference between solar cooling and solar district cooling is the production capacity of the cooling energy by the heat collected from the solar collectors. In this case, solar district cooling has larger cooling capacity compared to normal solar cooling. Despite of the insufficient data and publications on solar district cooling, data and results for the solar cooling still can be referred for the development of solar district cooling system. The following gives a brief review of recent important literature related to this issue.

In the paper published by Weber et al. (2014) describes that the main technical drawbacks of solar cooling systems such as low efficiency of commonly used single effect absorption chillers and large collector areas needed to produce the thermal energy are referring to flat plate collectors and evacuated tube collectors. This issues can be overcome by improvising concentrating solar system. Concentrating solar system is described can improve the energy efficiency of solar cooling system when high driving temperatures above 120℃ are required. It offers lower thermal losses and thus higher thermal temperature of the fluid, high ground usage and adequate recycling of component materials. A solar cooling system with concentrated solar system has been installed to monitor the performance for the two units of Robur NH_3-H_2O absorption chiller for cooling temperatures between -10℃ and 0℃. With the optimized system control on both the collector and chilled water circuit, good efficiency and performance values were achieved. They conclude that solar cooling is a viable solution to provide cooling supply in a sustainable way. Further development also look at bigger centralized system solutions like solar district cooling.

An overview on solar cooling installations utilizing concentrating collectors was elaborated by Ayadi et al. (2012). They state that for higher primary energy savings, double and triple effect absorption chillers are required. Therefore, higher driving temperature are required which can only be provided by concentrating collectors with a reasonable efficiency. They conclude that in the future developments, it is essential to decrease the parasitic consumption of the solar cooling installation, especially for the heating-up phase and chiller operation. Feasible potential are, variable speed control of solar pumps, advanced design of the generator heat exchanger and direct steam generation for industrial applications.

To further increase economical balance and the system efficiency and in order to ensure an environmentally friendly technology, the Life Cycle Assessment (LCA) approach is being applied to help decision makers to evaluate energy and environmental advantages of a given technology in a specific climate. This approach takes into account resource use (raw materials and energy) and environmental burdens related to the full life cycle of a technology (Beccali et al., 2012). A LCA study is applied to investigate two different configurations of solar heating and cooling plants (SHC) in two localities: Palermo (Southern Italy) and Zurich (Switzerland). Overall Primary Energy (PE) consumption varied from about 460 GJ (plant installed in Palermo) to about 1475 GJ (plant installed in Zurich). The total PE consumed during the use phase was 70-90%. The PE consumptions was related to the production of the solar collectors and the absorption chiller. The performance of the system was compared to the performance of a conventional plant with vapor compression and a gas boiler. The innovative plant had a lower environmental impact than the conventional plant.

An assessment of solar cooling technologies based on cost and performance parameters as well as boundary conditions of weather and cooling demands was presented by Mokhtar et al. (2010). 25 solar cooling systems with concentrating collector technologies and PV cells are simulated and their results showed that on a smaller scale the Fresnel collector option is the most economical one. The two most influencing parameters on the cost economy were the investment costs of the collector and the chiller performance that is again influenced by the heat rejection technology.

Al-Aili et al. (2012b) studied the performance, economic and environmental benefits of a 10 kWc NH_3/H_2O absorption chiller under Abu Dhabi's weather conditions. The solar air conditioning system had a specific collector area of 6 m^2 kW_c^{-1} and a specific tank volume of 0.1 m^3 kW_c^{-1} . The system was found to consume 47% less electrical energy than the widely spread vapor compression cycles of the same cooling capacity. The economic analysis showed that the collector area was the key parameter in reducing the payback period of the initial investment.

Hidalgo et al. (2008) experimentally investigated the performance of a single effect H_2O/LiBr absorption cycle driven by 50 m^2 surface area of flat plate collectors. The absorption cycle was able to produce 6-10kW of cooling under Spain summer weather conditions. The system performance, economic savings and environmental impact were compared to those of a vapor compression cycle using R407C having a seasonal coefficient of performance of 2.4. The energy cost savings and the CO_2 emission savings were found to be 62% and 36% respectively.

Florides et al. modeled a complete system, comprised of a solar collector, a storage tank, a boiler and a LiBr-water absorption chiller, which can cover a typical house load for the whole year. Computer simulation of thermal systems presents many advantages. The most important are the elimination of the expense of building prototypes, estimation of the amount of energy delivered from the system, the optimization of the system components and prediction of temperature variations of the system. By using TRNSYS program, this paper will focus on study the feasibility of the solar cooling system by considering several parameters such as collector slope, collector area and storage tank size. The system will then considered as a feasible system to be scaled up as district cooling system when the cooling demand of a building is met.

CHAPTER 3: METHODOLOGY

This section will present an overview or a proposed applicable method corresponding to this project. Specific procedures and techniques will be described in flowchart to identify, select, and analyze information applied to understanding the research problem. Section 3.1 will explain the flow of this project. Section 3.2 defined the timeline and progress for every part of this project. Section 3.3 presented the simulation methodology or specific procedures that should be carried to achieve the objective of this project.

3.1 Process Flow Chart

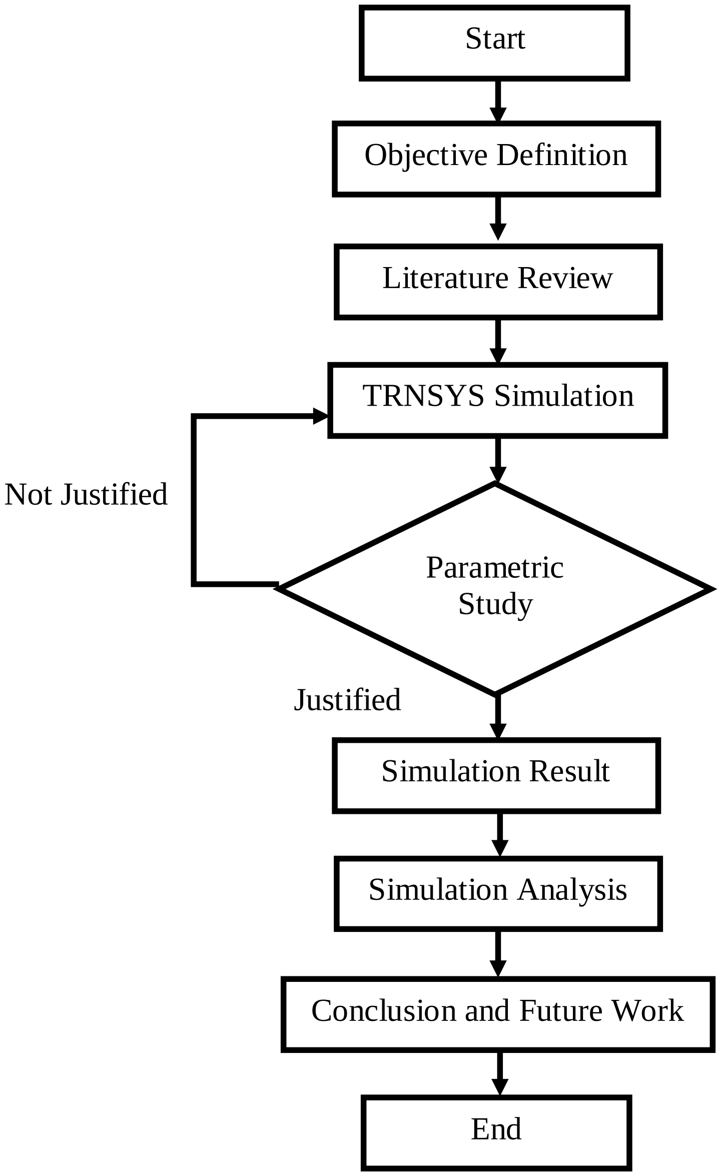


Figure 12 Process Flow Chart

3.2 Solar Cooling System Description

Schematic diagram for the solar cooling system will be shown in the Figure 13.

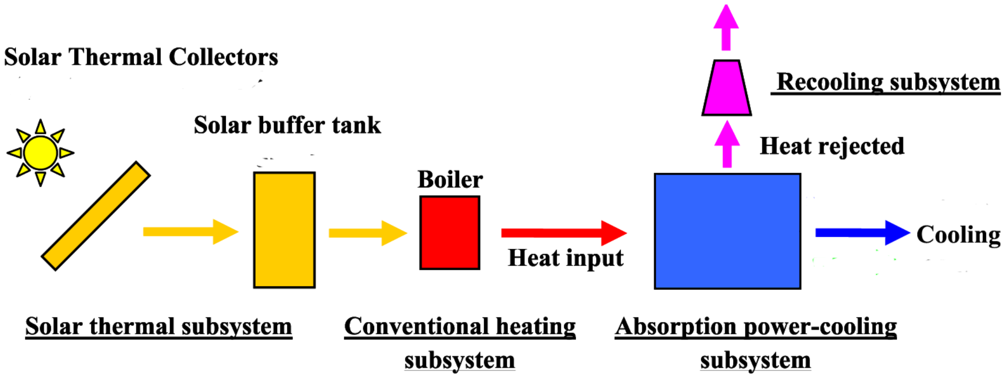


Figure 13 Schematic Diagram of Solar Cooling System

The flat plate solar collector is used to receive solar energy from sunlight. The energy collected is transferred to the hot water storage tank/solar buffer tank for the heat energy storage. This will increase the efficiency of the system and allow the system to operate when there is no sunshine but heat is available in the storage tank. Auxiliary heater is used to supply additional heat (especially during cloudy and rainy weather) when the hot water temperature is not sufficient to act as operating temperature for cooling process in absorption chiller. The operating temperature for lithium bromide – water absorption chiller is ranged from 70 ℃ - 95 ℃ (Kalogirou S. A., 2004). Hot water from the solar heating subsystem is used to heat up the refrigerant in the generator. Cold water from the cooling tower flow through the condenser and absorber to remove the rejected heat from the system and dissipate it to the environment. Evaporator produces chilled water which will be distributed to heat exchangers installed at the respective buildings for cooling effect. The hot water will goes back to the hot water storage tank and the whole cycle will be repeated.

3.3 TRNSYS Simulation Description

TRNSYS (Transient Systems Simulation Program) 16 was used for the solar cooling system modeling and simulation. The model simulated consists of two main parts that are solar heating subsystem and absorption cooling subsystem. This model consists of many subroutines, called Types which model various sub-system components. Once all the selected components are identified, they are linked together to form the system model. Every components' parameters are defined by the user to decide on the information transferred from one component to the other. Therefore, a detailed information flow diagram for the system should be constructed once all the components (Types) are identified. Initially, the metrological weather data for the proposed site are created, then the suitable components are set-up in the deck file. This is followed by the determination of the parameters, inputs and variables and the execution of the program. Subsequently, the results are analyzed based on charts and diagrams produced by the program, thus the feasible parameters and inputs may be identified.

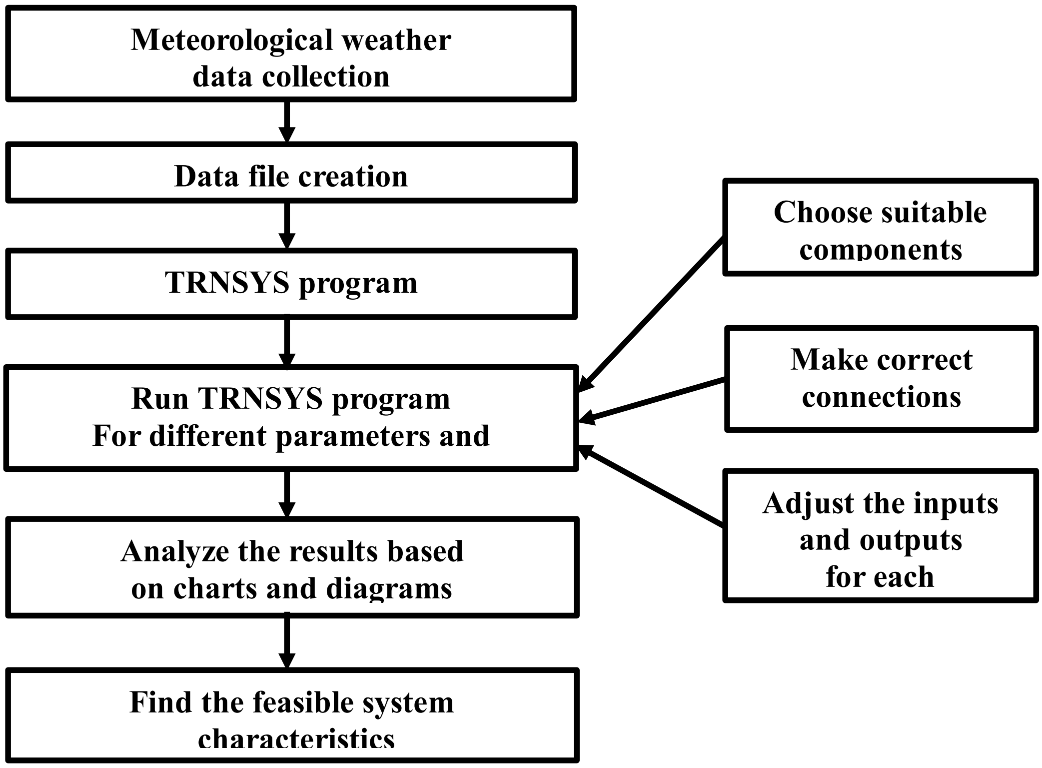


Figure 14 TRNSYS Simulation Flow Chart

To model the system, a number of assumptions are required. The assumptions are based on empirical and experimental results taken from published works on solar cooling and are necessary to create an integrated system for computer simulation. (Assilzadeh et al., 2005)

(a) The solar fraction is taken to be the part of the generator load that can be covered by the solar system.
(b) Power consumption by other equipment (circulating pump and controllers) is excluded.
(c) Since the daily average ambient temperature is higher than the indoor temperature, the storage tank is kept outdoors, thus the energy loss from the storage tank is minimized.

(d) There is no need to use antifreeze solution or a heat exchanger between the collector water loop and storage tank.

(e) The circulation pump in the collector water loop operates when the temperature difference between the collector outlet water and the top layer temperature of the storage tank exceeds 3°C, and stop when this difference becomes lower than 0.5°C.

The information flow diagram for the whole system is also created as shown in the diagram below.

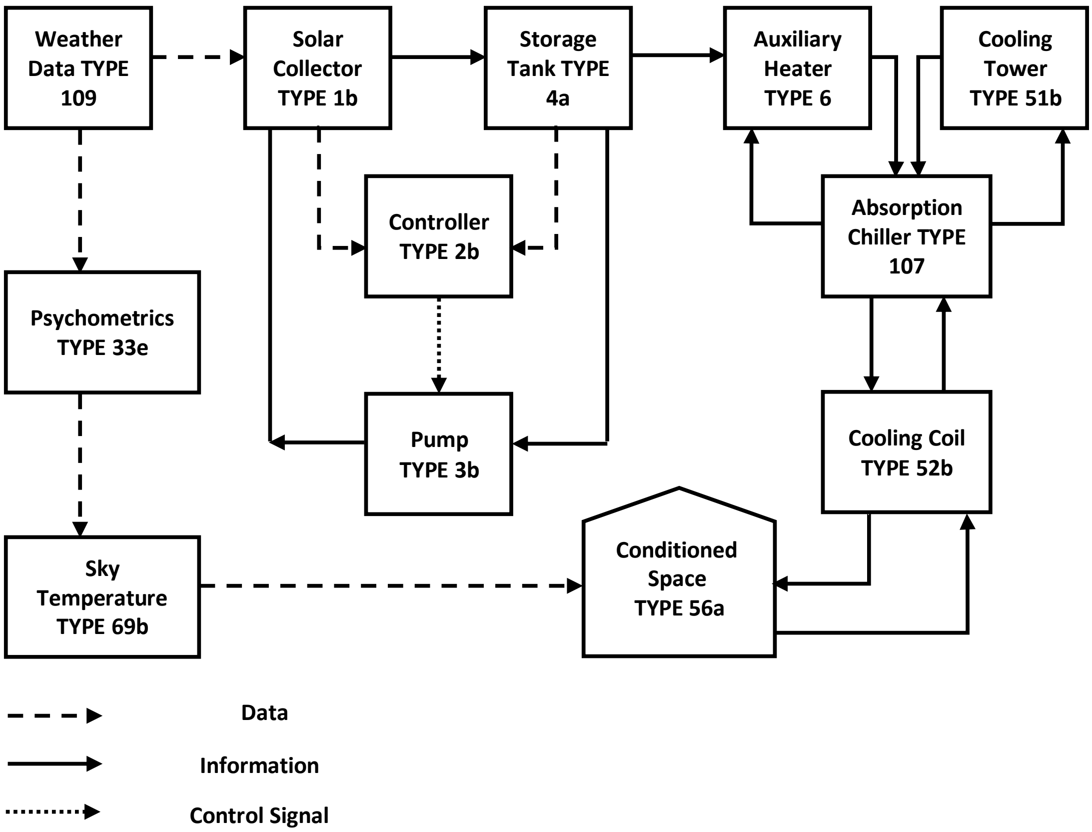


Figure 15 Information Flow Diagram

CHAPTER 4: RESULTS AND DISCUSSION

4.1 TRNSYS Solar Cooling Simulation

The solar cooling system modelled using TRNSYS is shown in the figure below. Details for each component's parameters and inputs are attached in the Appendix A.

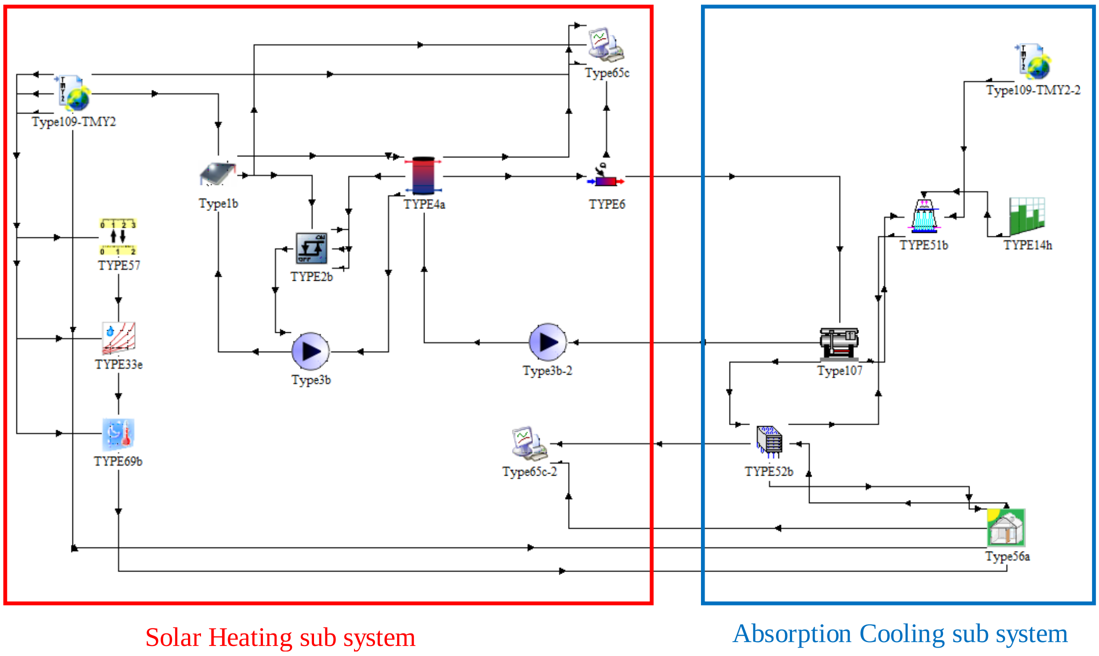


Figure 16 TRNSYS Solar Cooling Simulation

The system is used to generate the monthly average variation of dry bulb temperature for Kuala Lumpur, Malaysia.

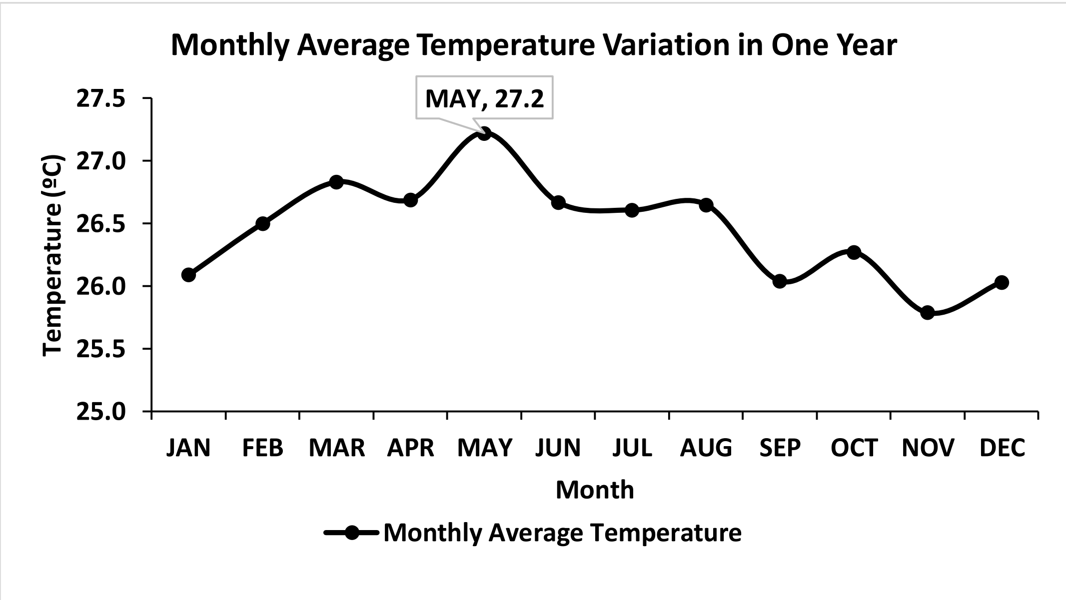


Figure 17 Monthly Average Temperature during 1 Year

From the graph above, May has the highest average dry bulb temperature which is 27.2 ℃ (highest solar radiation with good sunshine and no clouds). Hence, 28th of May is chosen based on the hourly solar radiation which is shown in the graph below. From the graph, it is clearly shows that 28th of May is a typical day with good sunshine and no clouds. From the graph, it indicates that from time ranged from 1000 – 1300, it is the peak hour for the highest solar radiation (7816.40 kJ/hr – 11011.52 kJ/hr). It also means that the heat energy collected (solar energy gain) will be at the maximum.

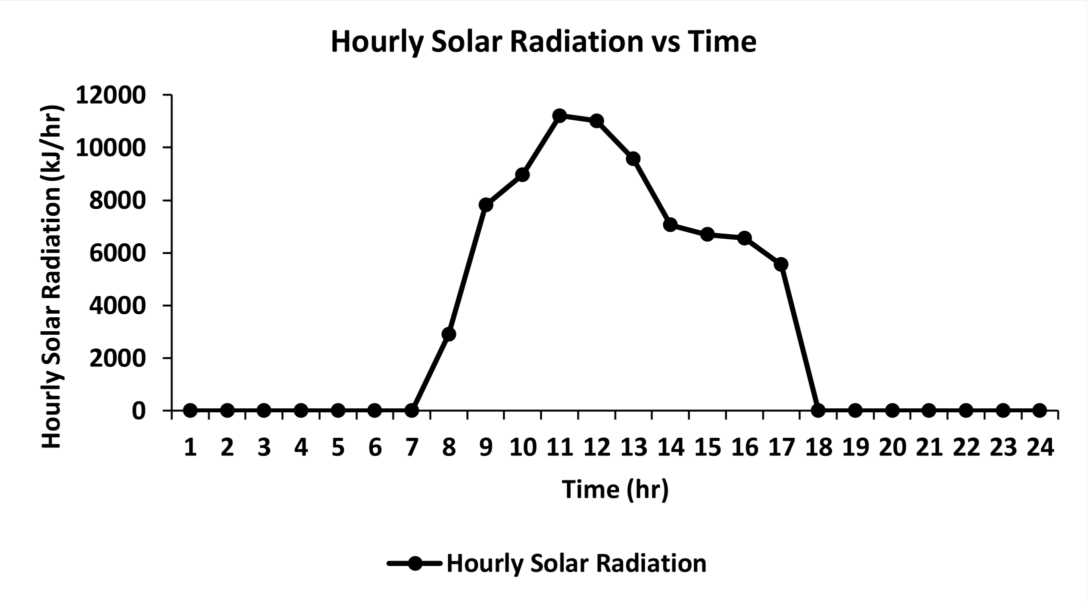


Figure 18 Hourly Solar Radiation for 28th of May

4.2 Parametric Study

A series of run have been carried involving a few parameters in order to study the feasibility of the system. The parameters involved are as below:

(a) The Collector Slope Angle
(b) Storage Tank Size
(c) Collector Area

4.2.1 Collector Slope Angle

The feasible collector slope angle is determined with the default collector area set at 15m^2. The feasible angle in the Malaysia environment is 5 ° for the flat plate solar collector as it gives the highest solar heat gain (102657.50 kJ/hr).

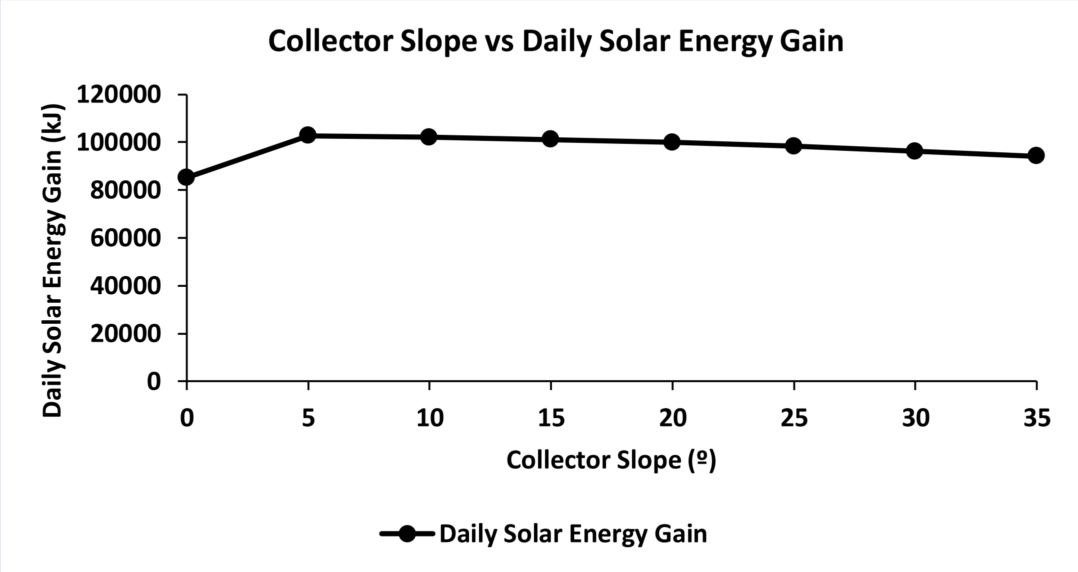


Figure 19 Collector Slope Angle

4.2.2 Storage Tank Size

It is an important factor to determine the auxiliary heater heat required for different storage volume. The storage tank size is feasible when the auxiliary heater need to supply the less heat to the system. As observed in the figure below, the feasible size for storage tank is 0.8 m^3.

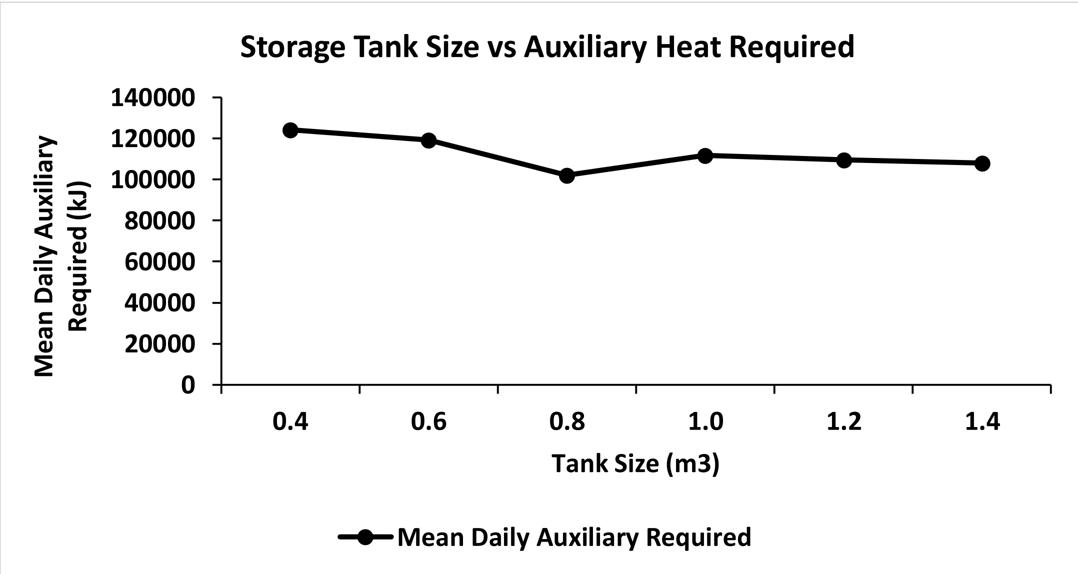


Figure 20 Storage Tank Size

4.2.3 Collector Area

The feasible collector area is studied against the boiler heat required. As expected, the larger the collector area, the more the collected heat energy (102657.50 kJ/hr), the less auxiliary heat is needed (115649.6 kJ/hr). Therefore, the feasible value needs to be decided by conducting an economic analysis, which is this paper, no economic analysis is performed. Hence, 15m^2 is considered as the feasible collector area based on literature review (Assilzadeh F. et al., 2005).

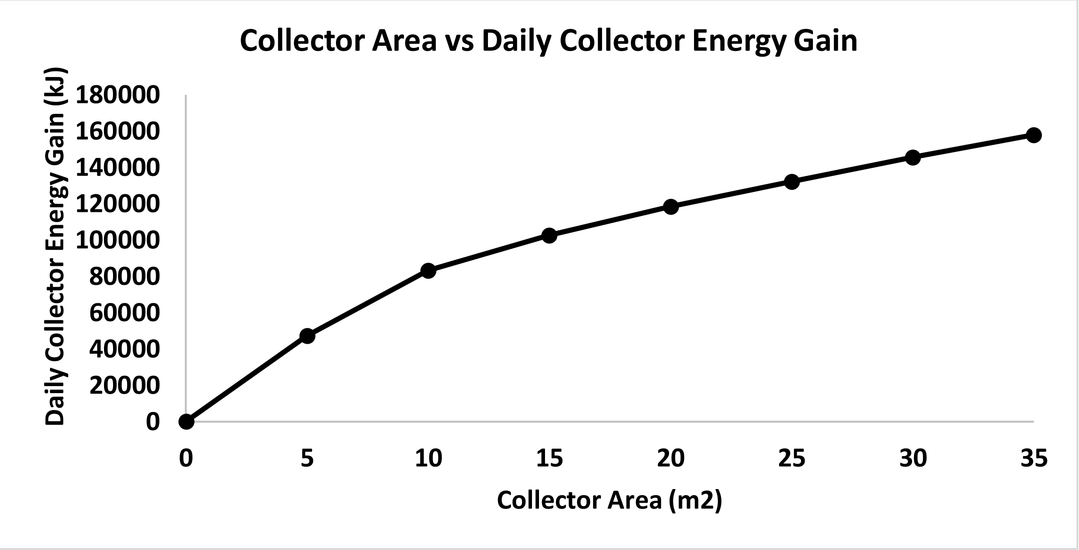


Figure 21 Collector Area vs Daily Collector Energy Gain

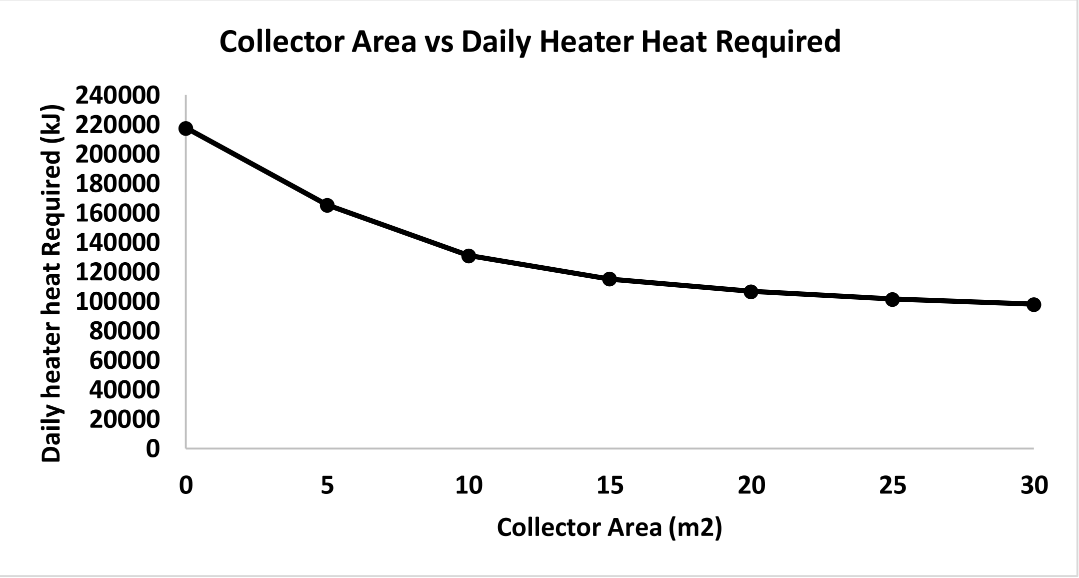


Figure 22 Collector Area vs Daily Heater Heat Required

4.3 Performance Study

4.3.1 Storage Tank vs Auxiliary Heater

From Figure 18, it shows that the highest amount of heat energy collected occurs at noon. Hence, the heat energy transfer from the hot water storage tank should be in phase with the water. The heat transfer rate from the auxiliary heater is inversely proportional to the storage tank. From the figure below, it proves that heat energy transfer rate from storage tank is in phase with the weather (5567.40 kJ/hr) while auxiliary heater has the minimum heat energy transfer rate (2767 kJ/hr) during the peak hour.

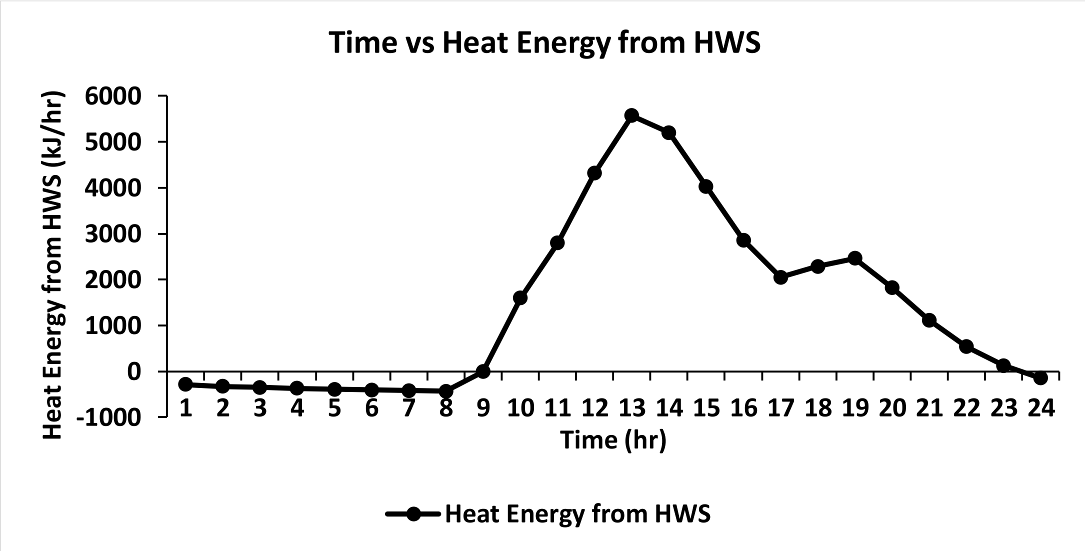


Figure 23 Time vs Heat Energy Transfer Rate from HWS

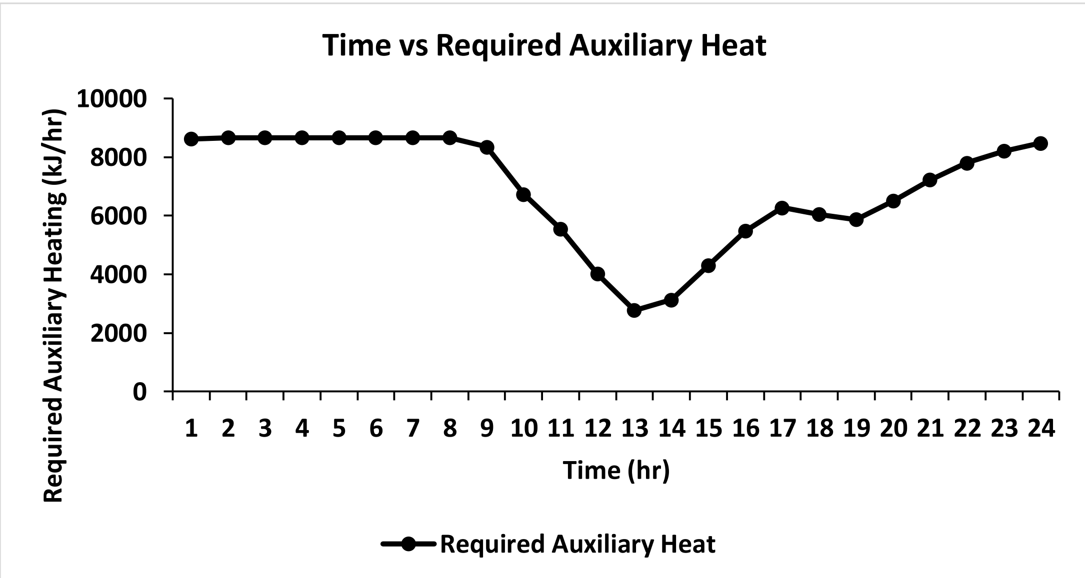


Figure 24 Time vs Heat Transfer Rate from Auxiliary Heater

4.3.2 Absorption Cooling System

The cooling demand is the energy required to remove heat from a particular space. Cooling rate is the rate of the heat energy being removed from a space. Cooling demand is obtained from the building modelled while the cooling rate is determined from the absorption chiller. Both cooling rate (3532.07 kJ/hr) and cooling demand (3442.24 kJ/hr) is directly proportional to each other and they are maximum during the peak hour. From the figure below, cooling demand is met when cooling rate is higher than the demand.

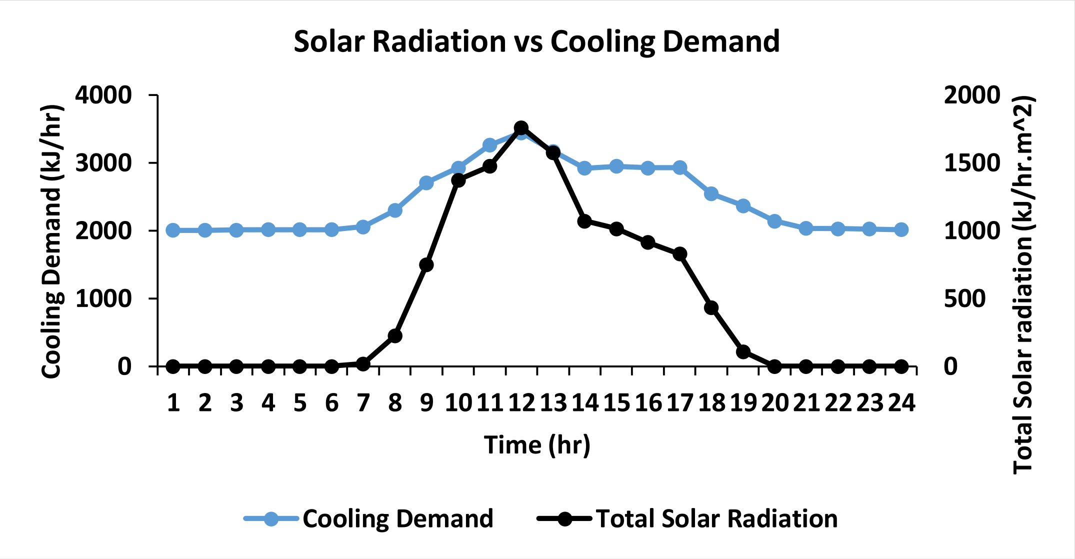


Figure 25 Solar Radiation vs Cooling Demand

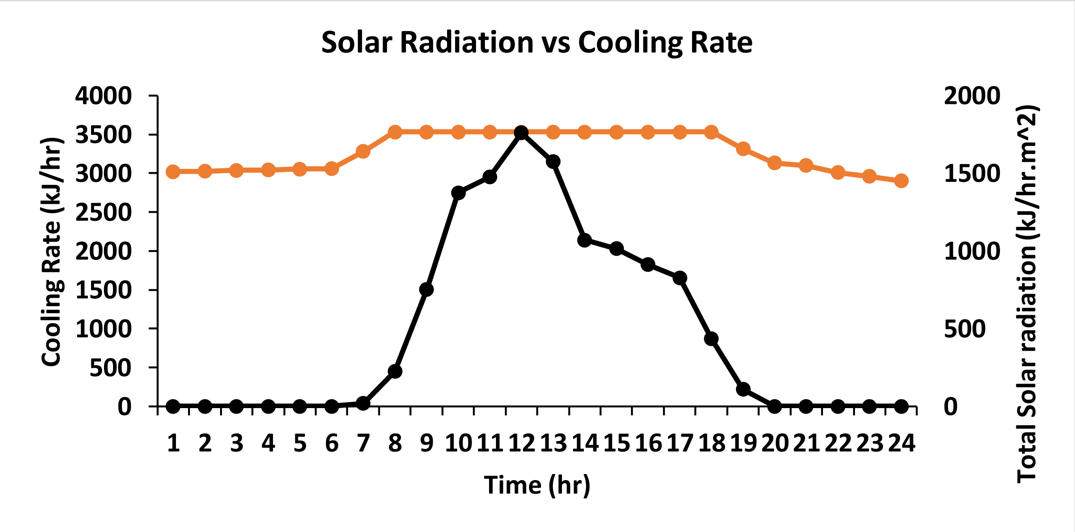


Figure 26 Solar Radiation vs Cooling Rate

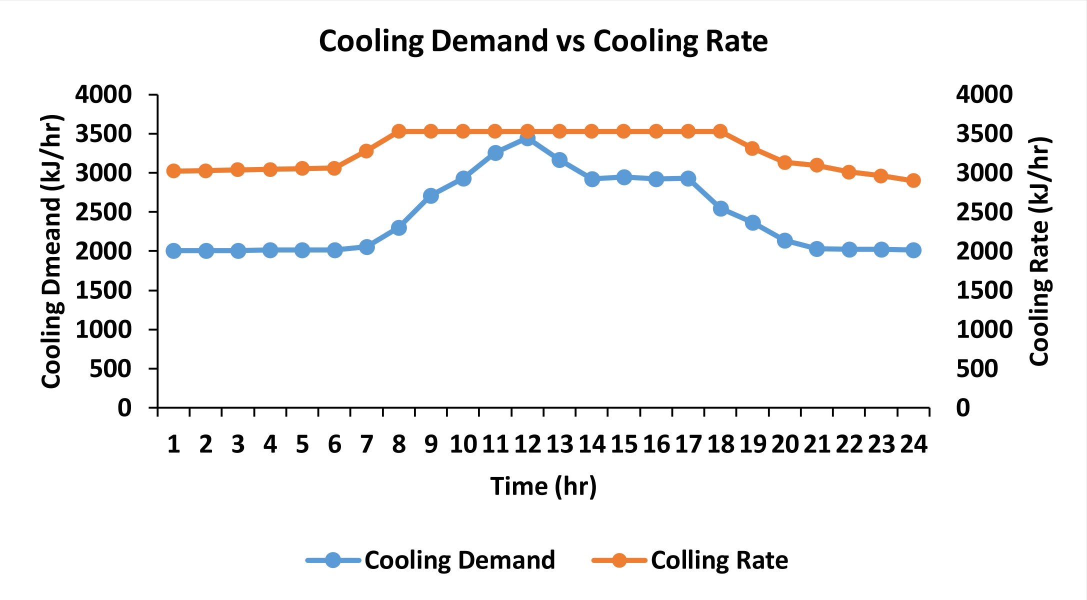


Figure 27 Cooling Demand vs Cooling Rate

Another graph is constructed to compare initial ambient temperature of the modelled building and the ambient temperature after being cooled by the chilled water. From the graph, the highest ambient temperature studied is 31.39 ℃ and the lowest temperature recorded is 18.06 ℃. Hence, it proves that the system is feasible to produce cooling effect by meeting the cooling demand of the buildings (the building is managed to be cooled down).

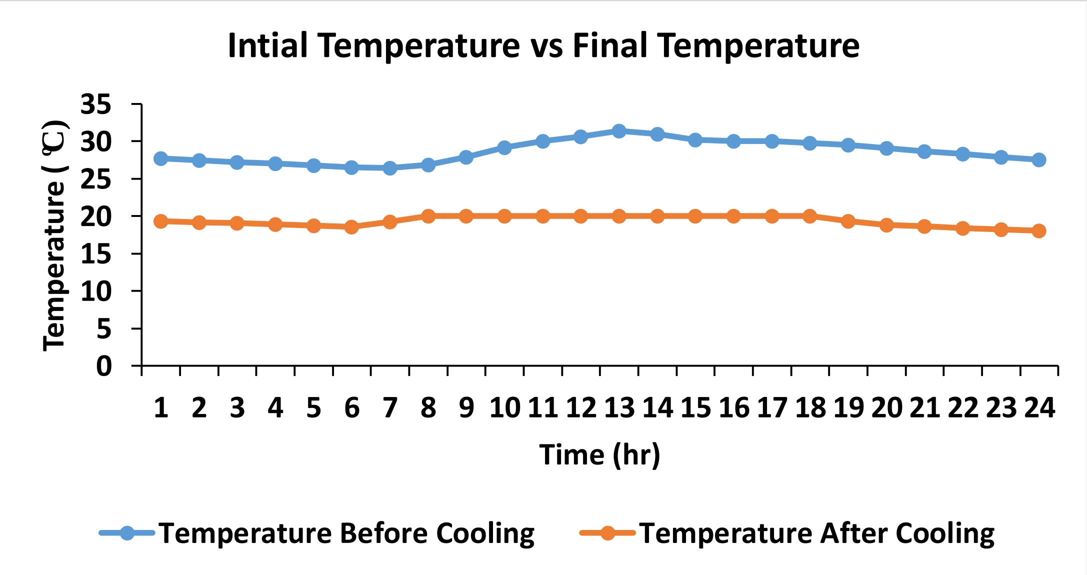


Figure 28 Initial Temperature vs Final Temperature

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

By considering the problem of pollution of the planet due to the burning of fossil fuels the adoption of solar energy to power absorption chillers should not be underestimated. The greatest advantage of solar-powered air-conditioning when compared to other power sources is that the system is in phase with the daily solar radiation, i.e. the greater the sunshine and thus the cooling demand, the larger the cooling effect achieved by the solar refrigerating system. However, solar district cooling will focus on centralized chilled water production while utilized the advantages of solar-powered absorption chiller. In order to achieve continuous operation of the generator and increase the reliability of the system, a hot water storage tank is essential for high quality performance. From the simulation, the feasible parameters using flat plate collector are 5 ºof collector slope, 15 m^2 collector area and 0.8m^2 storage tank size. It proved that the feasibility of the system when the cooling demand is being met and the initial ambient temperature of the building is cooled. The feasibility of the system is studied. Hence, the solar cooling system can be scaled up and simulated as district cooling system.

5.2 Recommendations

(a) A detailed economic analysis should be performed to study the optimum collector area for the solar heating subsystem. Two parameters can be studied in determining the economic feasibility which are energy cost incurred and energy saving. Both approaches are identical and differ in the sense that the former has to be minimized and the latter has to be maximized.

(b) The performance of the difference type of solar collector should be studied such as mean daily heat gain and etc. to determine the most suitable collector used in different regions and climates.

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APPENDIX: Parameters and Inputs of the Simulation

(a) <u>Weather Data Reading and Processing (TYPE 109 – TMY 2)</u>

- The weather values of a typical meteorological year 2 (TMY 2) file for Kuala Lumpur, Malaysia is used for the system simulation.

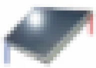
Table 2 Parameters and Inputs for Type 109-TMY 2

TYPE 109 – TMY 2 : Weather Data Reading and Processing			
Parameters			
No.	Parameter	Unit	Value
1.	Data Reader Mode	-	2
2.	Logical Unit	-	30
3.	Sky Model for Diffuse Radiation	-	4
4.	Tracking Mode	-	2
Inputs			
1.	Ground Reflectance	-	0.2
2.	Slope of Surface – 1	Degrees	90
3.	Azimuth of Surface – 1	Degrees	180
4.	Slope of Surface – 2	Degrees	90
5.	Azimuth of Surface – 2	Degrees	0
6.	Slope of Surface – 3	Degrees	90
7.	Azimuth of Surface – 3	Degrees	-90
8.	Slope of Surface – 4	Degrees	90
9.	Azimuth of Surface – 4	Degrees	90

(b) <u>Solar Collector: Quadratic Efficiency, 2nd Order Incidence Angle Modifiers (TYPE 1b)</u>

- This component models the thermal performance of a flat-plate solar collector where the user must provide results/value for solar collector efficiency versus a ratio of fluid temperature minus ambient temperature to solar radiation.

Table 3 Parameters and Inputs for Type 1b



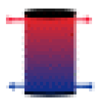
TYPE 1b : Second Order Incidence angle Modifiers			
Parameters			
No.	Parameter	Unit	Value
1.	Number in series	-	1
2.	Collector area	m^2	15
3.	Fluid Specific Heat	kJ/kg.K	4.190
4.	Efficiency Mode	-	2
5.	Tested flowrate	-	70

6.	Intercept Efficiency	-	0.734
7.	Efficiency Slope	-	5.504
8.	Efficiency Curvature	-	0.05976
9.	Optical Mode 2	-	2
10.	1st-order IAM	-	0.2
11.	2nd-order IAM	-	0.0
Inputs			
1.	Inlet Temperature	C	25
2.	Inlet Flowrate	kg/hr	100
3.	Ambient Temperature	C	25
4.	Incident Radiation	kJ/hr.m^2	0.0
5.	Total Horizontal Radiation	kJ/hr.m^2	0.0
6.	Horizontal Diffuse Radiation	kJ/hr.m^2	0.0
7.	Ground Reflectance	-	0.2
8.	Incidence Angle	Degrees	45.0
9.	Collector Slope	Degrees	20.0

(c) <u>Hot Water Storage Tank : Fixed Inlets – Uniform Losses (TYPE 4a)</u>

- The function of the tank is to store heat energy that is collected from the solar collector for space cooling. Water is used as the heat storage medium as it has a high specific heat capacity compared to other mediums. With the installation of hot water storage tank, the space cooling can be carried out either daytimes or during the night continuously to meet the cooling demands. In this simulation, the tank has fixed inlet position defined within the code. Hot fluid entering the hot side of the tank at the top of the tank node while cold fluid entering the tank through the bottom node.

Table 4 Parameters and Inputs for Type 4a

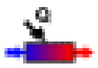
 TYPE 4a : Fixed Inlets – Uniform Losses Storage Tank			
Parameters			
No.	Parameter	Unit	Value
1.	Fixed Inlet Positions	-	1
2.	Tank Volume	m^3	0.8
3.	Fluid Specific Heat	kJ/kg.K	4.190
4.	Fluid Density	kg/m^3	1000
5.	Tank Loss Coefficient	kJ/hr.m^2.K	3.0
6.	Height of Node – 1	m	0.3
7.	Height of Node – 2	m	0.3
8.	Height of Node – 3	m	0.3
9.	Height of Node – 4	m	0.3
10.	Height of Node – 5	m	0.3

11.	Height of Node – 6	m	0.3
12.	Auxiliary Heater Mode	-	1
13.	Node Containing Heating Element 1	-	1
14.	Node Containing Thermostat 1	-	1
15.	Set Point Temperature for Element 1	C	55.0
16.	Dead band for Heating Element 1	deltaC	5.0
17.	Maximum Heating Rate of Element 1	kJ/hr	16200.0
18.	Node Containing Heating Element 2	-	1
19.	Node Containing Thermostat 2	-	1
20.	Set Point Temperature for Element 2	C	55.0
21.	Dead band for Heating Element 2	deltaC	5.0
22.	Maximum Heating Rate of Element 2	kJ/hr	16200
23.	Not Used (Flue UA)	W/K	0.0
24.	Not Used (Tflue)	C	20.0
25.	Boiling Point	C	100.0
Inputs			
1.	Hot-side Temperature	C	85.0
2.	Hot-side Flowrate	kg/hr	100.0
3.	Cold-side Temperature	C	20.0
4.	Cold-side Flowrate	kg/hr	100.0
5.	Environment Temperature	C	25
6.	Control Signal for Element – 1	-	0.0
7.	Control Signal for Element – 2	-	0.0

(d) Auxiliary Heater (TYPE 6)

- Auxiliary heater is used to elevate the temperature of a flowstream. The heater is designed to add heat to the flowstream at a user-designated rate (Qmax). This is to maintain an outlet temperature of Tset. By providing a control function of zero or one from a thermostat or controller, this routine will perform like a furnace adding heat at a rate of Qmax but not exceeding an outlet temperature of Tset.

Table 5 Parameters and Inputs for Type 6



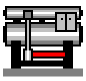
TYPE 6 : Auxiliary Heaters			
Parameters			
No.	Parameter	Unit	Value

1.	Maximum Heating Rate	kJ/hr	65000
2.	Specific Heat of Fluid	kJ/kg.K	4.19
3.	Overall loss coefficient for heater during operation	kJ/kg.K	0.0
4.	Efficiency of auxiliary Heater	-	1.0
Inputs			
1.	Inlet Fluid Temperature	C	25
2.	Fluid Mass Flowrate	kg/hr	100
3.	Control Function	-	1
4.	Set Point Temperature	C	86
5.	Temperature of Surroundings	C	25

(e) <u>Hot Water-Fired Single-Effect Absorption Chiller (Type 107)</u>

- In the gas district cooling operation, steam absorption chiller is used to produce chilled water. However, in this solar cooling system, heat energy from the hot-water stream supplied from auxiliary heater is used as a heat source to run the absorption chiller in order to produce chilled water. The working fluid used in the absorption chiller is Lithium Bromide – water (LiBr-H2O). The operating temperature in the generator for absorption chiller is around 85-93℃. The manufacturer data of YAZAKI water –fired LiBr/H2O absorption chiller is used in this simulation.

Table 6 Parameters and Inputs for Absorption Chiller

 TYPE 107: Absorption Chiller			
Parameters			
No.	Parameter	Unit	Value
1.	Rated Capacity	kJ/hr	17.6
2.	Rated C.O.P	-	0.74
3.	Logical Unit for S1 Data File	-	33
4.	Number of HW Temperatures in S1 Data File	-	5
5.	Number of CW Steps in S1 Data File	-	3
6.	Number of CHW set points in S1 Data File	-	7
7.	Number of Load Fractions in S1 Data File	-	11
8.	HW Fluid Specific Heat	kJ/hr	4.190
9.	CHW Fluid Specific Heat	kJ/kg.K	4.190
10.	CW Fluid Specific Heat	kJ/kg.K	4.190
11.	Auxiliary Electrical Power	kJ/hr	48
Inputs			

1.	Chilled Water Inlet Temperature	C	12.5
2.	Chilled Water Flowrate	kg/hr	2750
3.	Cooling Water Inlet Temperature	C	31
4.	Cooling Water Flow Rate	kg/hr	9180
5.	Hot Water Inlet Temperature	C	86
6.	Hot Water Flow Rate	kg/hr	4320
7.	CHW Set Point	C	6.667
8.	Chiller Control Signal	-	1.0

(f) <u>Cooling Tower (Type 51b)</u>

- Cooling tower functions to remove process waste heat through evaporation of water. In this model, process heat is being removed in the generator and absorber of the absorption chiller. This is to ensure the working fluid cycle in the absorption chiller is continuous through heat gain and heat removal.

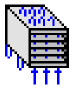
Table 7 Parameters and Inputs for Type 51B Cooling Tower

 TYPE 51b : Cooling Tower			
Parameters			
No.	Parameter	Unit	Value
1.	Calculation Mode	-	1
2.	Flow Geometry	-	1
3.	Number of Tower Cells	-	1
4.	Maximum Cell Flow Rate	m^3/hr	106681
5.	Fan Power at Maximum Flow	kW	7.457
6.	Minimum Cell Flow Rate	m^3/hr	10.0
7.	Sump Volume	m^3	1
8.	Initial Sump Temperature	C	15
9.	Mass Transfer Constant	-	2.3
10.	Mass Transfer Exponent	-	-0.72
11.	Print Performance Results?	-	1
Inputs			
1.	Water Inlet Temperature	C	20.0
2.	Inlet Water Flowrate	kg/hr	100.0
3.	Dry Bulb Temperature	C	15.0
4.	Wet Bulb Temperature	C	12.0
5.	Sump Make-up Temperature	C	15
6.	Relative Fan Speed for Cell	-	1

(g) <u>Cooling Coil (TYPE 52b)</u>

- Cooling coils is used to carry out heat transfer between chilled water and air duct. This model does not account for ice formation on the coils.

Table 8 Parameters and Inputs for Type 52b Cooling Coils



TYPE 52b : Cooling Coil			
Parameters			
No.	Parameter	Unit	Value
1.	Calculation Mode	-	2
2.	Number of Rows	-	7
3.	Number of Tubes	-	4
4.	Duct Heght	m	1
5.	Duct Width	m	1
6.	Outside Tube Diameter	m	0.025
7.	Inside Tube Diameter	m	0.02
8.	Tube Thermal Conductivity	kJ/hr.m.K	500
9.	Fin Thickness	m	0.01
10.	Fin Spacing	m	0.1
11.	Number of Fins	-	25
12.	Fin Thermal Conductivity	kJ/hr.m.K	700
13.	Fin Mode	-	1
14.	Center to center distance	m	0.35
15.	Tube Spacing	m	0.35
Inputs			
1.	Water Inlet Temperature	C	20.0
2.	Inlet Water Flowrate	kg/hr	100.0
3.	Dry Bulb Temperature	C	15.0
4.	Wet Bulb Temperature	C	12.0
5.	Sump Make-up Temperature	C	15

(h) Multi-zone Building (TYPE 56a)

- This components models the thermal behavior of a building. It can be generated and edited based on the supplied information by running the preprocessor program called TRNBuild. For instance, this component is able to generate its own set of monthly and hourly summary output files. The building model consists of two zones 9a back-zones and a sun-zone) separated by a common interior wall. The total zone volume modelled is 170.1 m^3. The back-zone is a rectangular single zone (8m wide x 6m long x 2.7 m high) which has lightweight construction with characteristics as described in the table below. The sun-zone is 2m deep by 8m wide by 2.7m high. The back (north) wall of the sun-zone is the common wall. The south wall of the sun-zone contains two 6m^2 windows and are raised to a level of 0.5m above the ground.

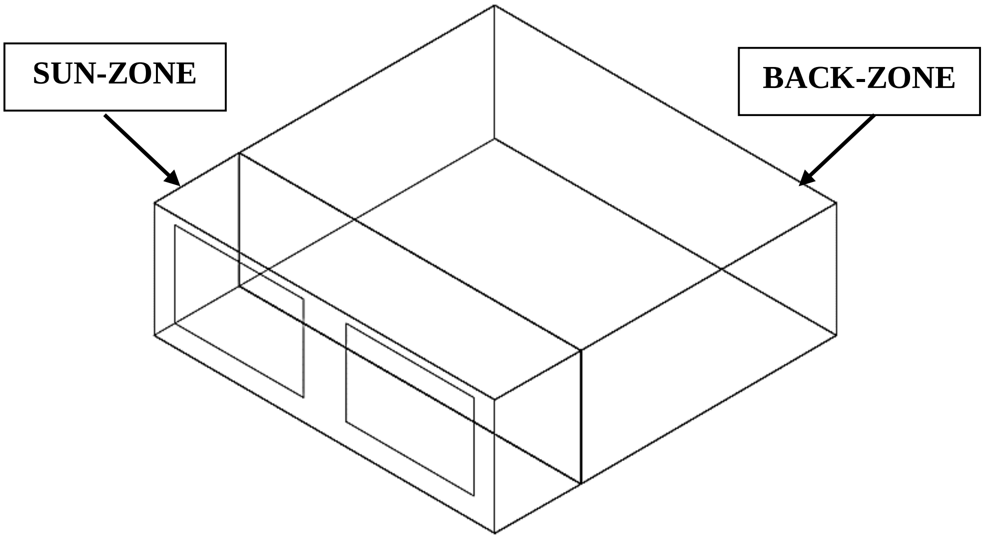


Figure 33 Isometric View of Sunspace Building with Back-Zone and Sun-Zone

Figure 34 Isometric View of Sunspace Building with Back-Zone and Sun-Zone

Bac

Figure 35 Isometric View of Sunspace Building with Back-Zone and Sun-Zone

Wa

No. K)

Figure 36 Isometric View of Sunspace Building with Back-Zone and Sun-Zone

1. 3

2.	Fiberglass Insulation	0.040	0.066	0.606
3.	Wood Siding	0.140	0.009	15.556
Roof Construction (light weight mass)				
1.	Plasterboard	0.160	0.010	16.000
2.	Fiberglass Quilt	0.040	0.1118	0.358
3.	Roof Deck	0.140	0.019	7.368
Floor Construction (light weight mass)				
1.	Timber Flooring	0.140	0.025	5.600
2.	Insulation	0.040	1.003	0.040

(K-value = thermal conductivity; U-value = thermal transmittance)

TYPE 56a : Multi-zone Building

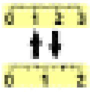
Sun-Zone				
Wall Construction (heavy weight mass)				
No.	Element	k (W/m.K)	Thickness (m)	U ($W/m^2.K$)
1.	Concrete Block	0.510	0.100	5.100
2.	Foam Insulation	0.040	0.0615	0.651
3.	Wood Siding	0.140	0.009	15.556

4.	Common Wall	0.510	0.200	2.55
Roof Construction (light weight mass)				
1.	Plasterboard	0.160	0.010	16.000
2.	Fiberglass Quilt	0.040	0.1118	0.358
3.	Roof Deck	0.140	0.019	7.368
Floor Construction (heavy weight mass)				
1.	Concrete Slab	1.130	0.080	14.125
2.	Insulation	0.040	1.007	0.040

(i) Unit Conversion Routine (TYPE 57)

- The unit conversion routine component checks the input to make sure it is of the correct variable type and providing the new output type which will become the input of another components. In this solar cooling model, type 57 components convert unit of atmospheric pressure from Pa to atm.

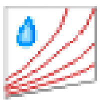
Table 10 Parameters and Inputs of Unit Conversion Routine

 TYPE 57 : Unit Conversion Routine			
Parameters			
No.	Parameter	Unit	Value
1.	Table Nb. for input	-	10
2.	ID number from table for input	-	3
3.	ID number from table for output	-	4
Inputs			
1.	Water Inlet Temperature	-	0

(j) Psychometrics: Dry Bulb and Relative humidity Known (TYPE 33e)

- This component takes as input the dry bulb temperature and relative humidity of moist air. It reads the input from the weather data reader and radiation processor.

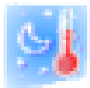
Table 11Parameters and Inputs for Psychometrics (TYPE 33e)

 TYPE 33e : Psychometrics			
Parameters			
No.	Parameter	Unit	Value
1.	Psychometrics Mode	-	2
2.	Wet Bulb Mode	-	1
3.	Error Mode	-	2
Inputs			
1.	Dry Bulb Temp.	C	22
2.	Percent Relative Humidity	-	60
3.	Pressure	atm	1

(k) <u>Effective Sky Temperature for Long-wave Radiation Exchange (TYPE 69b)</u>

- Type 69b determines an effective sky temperature, which is used to calculate the cloudiness factor of the sky. The cloudiness factor is determined and calculated based on the dry bulb and dew point temperatures.

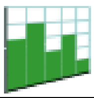
Table 12 Parameters and Inputs for TYPE 69b

 TYPE 69b : Effective Sky Temperature			
Parameters			
No.	Parameter	Unit	Value
1.	Mode for Cloudiness Factor	-	0
2.	Height Over Sea Level	m	0
Inputs			
1.	Ambient Temperature	C	0
2.	Dew Point Temperature at Ambient conditions	C	0
3.	Beam Radiation On The Horizontal	kJ/hr.m^2	20
4.	Diffuse Radiation On The Horizontal	kJ/hr.m^2	0

(l) <u>Time Dependent Forcing Function (TYPE 14h)</u>

- Type 14h component make convenient for a system that has a behavior characterized by a repeated pattern. The pattern o the forcing function is established by a set of discrete data points indicating the value of the function at various times throughout one cycle.

Table 13 Parameters for Type 14h

 TYPE 14h : Time Dependent Forcing Function			
Parameters			
No.	Parameter	Unit	Value
1.	Initial Value of Time	hr	0
2.	Initial value of Function	any	0.5
3.	Time at Point – 1	hr	1
4.	Value at Point – 1	any	0.85
5.	Time at Point – 2	hr	12
6.	Value at Point – 2	any	0.9
7.	Time at Point – 3	hr	14
8.	Value at Point – 3	any	0.9
9.	Time at Point – 4	hr	18
10.	Value at Point – 4	any	1

11.	Time at Point – 5	hr	24
12.	Value at Point – 5	any	0.5

(m)<u>ON/OFF Differential Controller (TYPE 2b)</u>

- The on/off differential controller generates a control function which can have a value of 1 or 0 which is normally used with input control signal connected to the output control signal. In this simulation, this controller is used to control the temperature of water in the hot water storage tank by manipulating the heat transfer from solar collector.

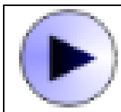
Table 14 Parameters and Inputs for Type 2b

TYPE 2b : ON/OFF Differential Controller			
Parameters			
No.	Parameter	Unit	Value
1.	No. of Oscillations	-	5
2.	High Limit Cut-Out	C	100
Inputs			
1.	Upper Input Temperature Th	C	93
2.	Lower Input Temperature TI	C	25
3.	Monitoring Temperature Tin	C	85
4.	Input Control Function	-	0
5.	Upper Dead Band dT	Temp. Difference	10
6.	Lower Dead Band dT	Temp. Difference	2

(n) <u>Pump (TYPE 3b)</u>

- Two pumps have been used in the solar cooling simulation which are named Type 3b and Type 3b-2 respectively. Pump Type 3b is used to control the flowrate of recycled water back to the solar collector. Pump Type 3b-2 is used to control the flowrate the hot water from the absorption chiller back to the hot water storage tank. Both having the same parameters and inputs as described in the Table 15 below.

Table 15 Parameters and Input for Type 3b



TYPE 3b : Pump			
Parameters			
No.	Parameter	Unit	Value
1.	Maximum Flow rate	kg/hr	100
2.	Fluid Specific Heat	kJ/kg.K	4.190
3.	Maximum Power	kJ/hr	60
4.	Conversion Coefficient	-	0.05

5.	Power Coefficient	-	0.5
Inputs			
1.	Inlet Fluid Temperature	C	25
2.	Inlet Mass Flow Rate	kg/hr	100
3.	Control Signal	-	1