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System Design of Solar Absorption Cooling : A Case Study in Building of Engineering Physics Department UGM

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Abstract

Air conditioning (AC) is one of the most building's energy consumer, included in building of Engineering Physisc's Departement, Universitas Gadjah Mada (UGM). The declining of fossil fuel reserves and the increasing effects of global warming, forcing the world to switch to renewable energy sources. This paper discusses the design of solar absorption cooling system to replace conventional AC in seven lecture halls of Engineering Physic's Departement, UGM. There are some steps that have been done to design the solar absorption cooling, i.e. do a study of the potential availability of solar energy, calculate the cooling loads, analyze the thermodynamic process of the system, determine the type of collector to be used and calculate area of solar collector needed. The thermal coefficient of performance (COP) of the system designed was about 0.84 which could use some types of flat plate solar collector with each area corresponding to each efficiency values.

Keyword : Air conditioning; global warming; solar absorption cooling; solar collector

Nomenclature

COP	coefficient of performance
η	solar collector efficiency
Q_G	power to generator (kW)
Q_A	power to absorber (kW)
Q_C	power to condenser (kW)
Q_E	power to evaporator/cooling load (kW)
G_T	solar radiation that received by solar collector ($W \cdot m^{-2}$)
A_C	collector area (m^2)
$T\alpha$ and U_L	empiric performance constant for optic and thermal
F_R	heat removal factor
T_{fi}	fluid temperature in collector (^0C)
T_{amb}	environmental temperature (^0C)
$\dot{m}_{(H20)}$	mass flow rate of the refrigerant ($kg \cdot s^{-1}$)
$\dot{m}_{(LiBr)}$	mass flow rate of the absorber ($kg \cdot s^{-1}$)
h_2	enthalpy at point 2 ($kJ \cdot kg^{-1}$)

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h_1	enthalpy at point 1 ($\mathrm{kJ} \cdot \mathrm{kg}^{-1}$)

1. Introduction

Residence and building sector has consumed about 40 % of the world's energy consumption [1]. Nowadays, energy and environmental crisis becomes trending topic due to the unrenewable energy resources has been running low and uncontrolled global warming effects. The biggest contribution of global warming effect is the increase of earth's temperature. Global temperature's average had increased almost 0,74 ^{o}C along the 20th century [2]. The increase of temperature can cause the increase of electricity consumption for building's thermal comfort especially in air conditioning (AC) which consumes the most of building's energy consumption. Moreover, conventional AC usually uses chlorinated fluorocarbons (CFCs) refrigerant and if it's leaking can damage the ozone. The design of solar absorption cooling system [3,4] for university as a role model is the first to be implemented in Indonesia. If this cooling system is applied across universities and other buildings in Indonesia, it certainly could make a big change from the aspect of energy saving and in reducing global warming effects.

2. Materials and methods

There are some steps that have been done to design the solar absorption cooling, i.e. do a study of the potential availability of solar energy, calculate the cooling loads, analyze the thermodynamic process in each component (condenser, evaporator, absorber, and generators), determine the type of collector to be used and calculate area of solar collector needed.

2.1. Study of the potential availability of solar energy

In a year, the average of solar radiation in Engineering Physics' Department is 4.802 $\mathrm{kWh.m^{-2}.day^{-1}}$ [5]. Potential availability of solar energy is obtained from NASA database using Homer by inputting latitude and altitude position of Engineering Physics' Department.

2.2. Calculate the cooling loads

There are seven lecture halls designed to get thermal comfort in temperature range of 24 ^{o}C to 26 ^{o}C. Cooling loads data is obtained from one of Engineering Physics' Department student's final task using data taken from simulated conditions that occurred in 2010 using Autodesk Ecotect software using several assumptions [2]:

- Thermal comfort in temperature range of 24 ^{o}C to 26 ^{o}C, relative humidity 50 %, does not involve evaporation heat load, the activities are assumed to sit sedentary, with the value of room's ACH (Air Change per Hour) is 0.5 ACH.
- Lecture halls operational schedule and air change are made based on the average operational for a year with the establishment of national holiday taken in 2010.
- Interior furniture, stairs, and the building's columns are not modelled and involved in the simulation, only the amount of occupants and other heat sources such as lamps, CPUs, CRT monitors, and viewer are involved as well as the elements of building materials, doors, and windows are modelled and involved in the simulation.

Table 1. Solar Availability in Engineering Physics' Department [5]

Month	Clearness index	Daily radiation ($kWh\cdot m^{-2}\cdot day^{-1}$)
January	0.398	4.280
February	0.414	4.470
March	0.437	4.590
April	0.482	4.720
May	0.529	4.730
June	0.537	4.550
July	0.554	4.800
August	0.559	5.250
September	0.544	5.540
October	0.507	5.390
November	0.440	4.710
December	0.428	4.570
Average	0.428	4.802

Table 2. Characteristics and cooling loads in Engineering Physics' lecture halls [6]

Lecture halls	Floor area (m^2)	Capacity (*the number of occupants*)	Peak load (*kW*)
TN1	103.68	90	2.64
TN2	92.70	70	2.57
TN3	76.32	50	2.50
TN4	76.92	40	1.53
Seminar Room	60.52	27	1.11
TN6	72.75	60	2.22
TN7	129.96	90	3.06
		Total	15.63

2.3. Power balances and thermal COP

Solar absorption cooling system has power balance between its input and output. Input powers in this system are power from generator and evaporator, whereas the output powers of this system are absorber and condenser power [7].

$$Q_G + Q_E = Q_A + Q_C \tag{1}$$

From energy balances of the system, thermal COP (Coefficient of Performance) will be known as ratio between input energy evaporator and input energy in generator [7].

$$COP = \frac{Q_E}{Q_G} \quad (2)$$

2.4. Description of each thermodynamic component

- Condenser
  Condenser function is to condense (transform refrigerant phase from superheated steam to water) refrigerant from generator.
- Evaporator
  Evaporator is a component with vital function in the refrigerant cycle. Its function is to evaporate the refrigerant water within the evaporator.
- Absorber
  Absorber is a tank to keep refrigerant before it pumps up to generator and flow in system again. Absorber has function to absorb water vapour from condenser then mixture it with LiBr to be LiBr-H_2O.
- Generator
  Generator is a component which function to separate water from the absorber (LiBr) by means of evaporation.
- Expansion Valve
  Expansion valve is a component of the machine where refrigeration pressure is reduced to evaporator pressure.
- Pump
  Pump was used to give pressure and flow of fluids in an absorption system. Pump selection must depend on fluid characteristics, its capacity, and its pipeline.
- Throttle valve
  Throttle valve is pressure decreasing valve. Throttle valve will be installed between generator and absorber (in poor refrigerant flows). It will be worked if user compresses it over its pressure capacity, it will be opened.

2.5. Refrigerant phase and the calculation

Refrigerant experienced two phases in the cycle, i.e. liquid and vapour phase. At vapour phase, its quality is an intensive property which can be used in conjunction with other independent intensive properties to specify the thermodynamic state of the working fluid of a thermodynamic system. It has no meaning for substances which are not saturated mixtures (i.e., compressed liquids or superheated fluids).

$$X = \frac{y - y_{(l)}}{y_{(v)} - y_{(l)}} \quad (3)$$

where y is equal to either specific enthalpy, specific entropy, specific volume or specific internal energy, $y(l)$ is the value of the specific property of saturated liquid state and $y(v)$ is the value of the specific property of saturated vapour state.

Based on the Ts diagram, the value of the refrigerant mass flow, power from condenser, and power from absorber is determined by the Eq. 4, Eq. 5, and Eq. 6 respectively.

$$\dot{m}_{(H20)} = \frac{Q_C}{h_2 - h_1} \quad (4)$$

$$\dot{Q}_C = \dot{m}_{(H20)}\left(h_{C(v)} - h_{5(l)}\right) \quad (5)$$

$$\dot{Q}_A = \dot{m}_{(H20)}\left(h_{2(v)} - h_{E(l)}\right) + \dot{m}_{(LiBr)}\, C_b\, \Delta T \quad (6)$$

2.6. Solar collector

Solar collector is one of instrument to absorb solar radiation energy to be usable heat. In general terms, solar collector contains three main parts: absorber area, aperture area, and gross area. Absorber area was connected to conductive pipe, so where solar collector gets some heats, heat will be transferred immediately to those pipes so fluids in pipe will receive those heats. Eq. 4 explains about efficiency of solar collector.

$$\eta = \frac{Q_G}{G_T\ A_C} = F_R.(\tau\alpha) - F_R.U_L\,\frac{(T_{fi} - T_{amb})}{G_T} \quad (7)$$

Solar collector efficiency was influenced by some factors, they are type of collector and operational temperature $(T_{fi} - T_{amb})$. Type of collector will give value of $F_R.(\tau\alpha)$ and $F_R.U_L$, and each type have different value. Fig 1 explain its graphic efficiency of one of collector.

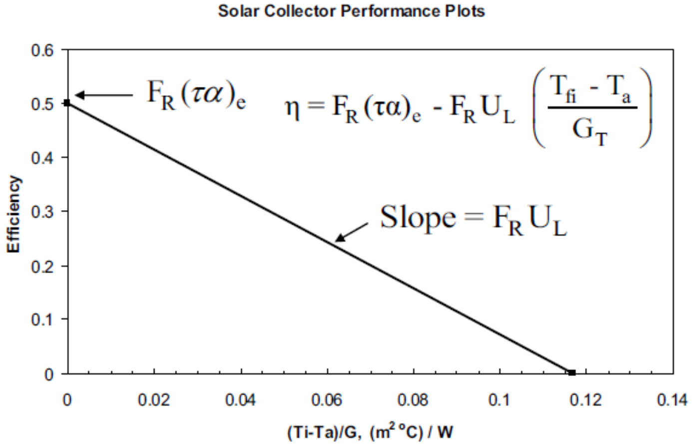

Fig. 1. Efficiency solar collector calculation [8]

3. Result and discussion

3.1. Analysis of thermodynamic process in each component

Thermodynamic processes that occur in the absorption refrigeration system designed to refer to water and steam properties, the schematic design and T-s diagrams.

Table 3. Water and steam properties for solar absorption cooling designed

Parameter	Condensation	Evaporation
Saturation Temperature desain	T_C = 38. 112 °C	T_E = 7.926 °C
Pressure desain	P_C = 6.666 kPa	P_E = 1.067 kPa
Entalphy in liquid phase	$h_{C(l)} = 159.53\ \mathrm{kJ \cdot kg^{-1}}$	$h_{E(l)} = 33.225\ \mathrm{kJ \cdot kg^{-1}}$
Entalphy in vapor phase	$h_{C(v)} = 2{,}569.9\ \mathrm{kJ \cdot kg^{-1}}$	$h_{E(v)} = 2{,}515.0\ \mathrm{kJ \cdot kg^{-1}}$
Entrophy in liquid phase	$s_{C(l)} = 0.5468\ \mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$	$s_{E(l)} = 0.1197\ \mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$
Entrophy in vapor phase	$s_{C(v)} = 8.2926\ \mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$	$s_{E(v)} = 8.9514\ \mathrm{kJ \cdot kg^{-1} \cdot K^{-1}}$

- Condenser

In the condenser, there is a transfer of heat from the cooling water pumped from the cooling tower with water vapour refrigerant that previously had been heated in the generator. Refrigerant in the form of water vapour coming from the generator enters the condenser at design pressure of 6.666 kPa that turns into a liquid phase at a temperature of 38.116 °C. At the time of the condensation process, usually there will be events sub cooling, where the condensation temperature will drop slightly from the saturation temperature. In this design it is expected sub cooling temperature at a temperature of about 35 °C. Referring to the T-s diagram, the value of the enthalpy at point 5 (see Fig. 3) is 146.47 $\mathrm{kJ \cdot kg^{-1}}$, which represents the difference between the enthalpy at point 4 (see Fig. 3) with the enthalpy due to a decrease in sub cooling temperature.

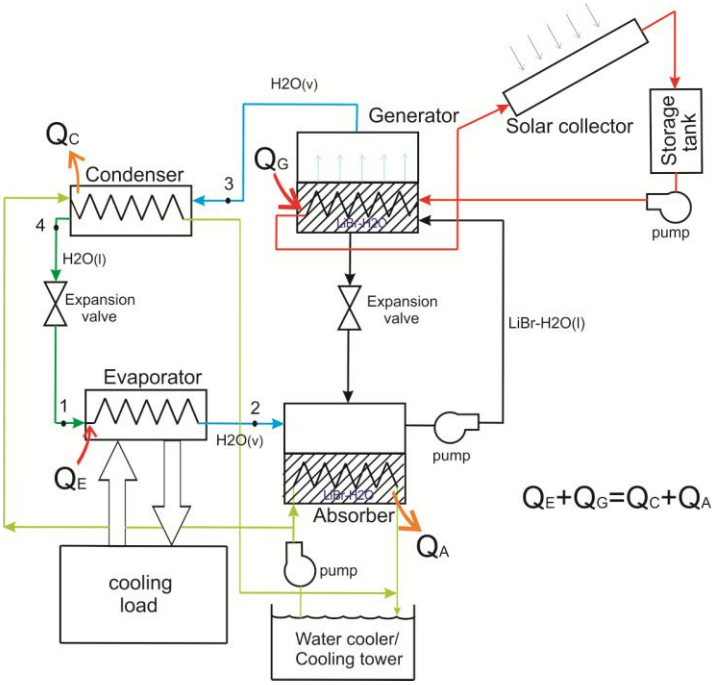

Fig. 2. Schematic design of the system

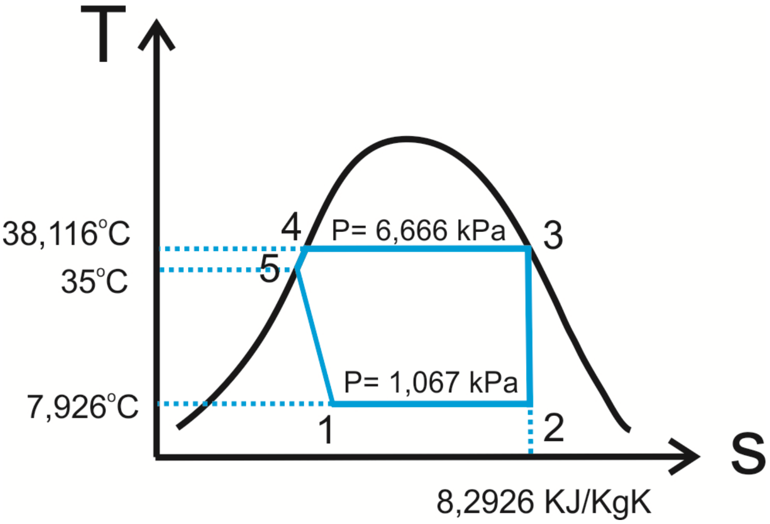

Fig 3. T-s Diagram of the system

- Evaporator

In the evaporator, the refrigerant in the form of water in the liquid phase gets the heat transfer from the heat load of the room to be cooled. When the refrigerant enters the evaporator, pressure of 1,067 kPa is designed to obtain the refrigerant evaporation temperature of 7.926 ^{o}C. The pressure is obtained with the expansion valve that connects the condenser to the evaporator. Value of enthalpy at the evaporator is shown in point 2 T-s diagram, obtained by manipulating the Eq. 3. Enthalpy value at point 2 in the vapour phase is 2329.86 $kJ \cdot kg^{-1}$. Refer to Eq. 4, the design of mass flow rate obtained or refrigerant expansion of water is 7.159 x 10^{-3} $kg \cdot s^{-1}$. The transfer of heat from the room air to the refrigerant, resulting the indoor air temperature circulated back into the room to be reduced.

- Absorber

In the absorber, the refrigerant vapour from the evaporator turns into a liquid phase and mixed with a solution of $LiBr\text{-}H_2O$. The temperature of the solution dropped from the design temperature of 48 ^{o}C to 38 ^{o}C and accompanied by a decrease in concentration from 60 % to 55 %. Through the calculation of the solution's concentration, obtained LiBr mass flow rate of $78{,}75 x 10^{-3}$ $kg \cdot s^{-1}$.

- Generator

$LiBr\text{-}H_2O$ solution is then pumped from the absorber to the generator to get the heat energy from the solar collector working fluid, so that the equilibrium temperature rise from 72 ^{o}C to 82 ^{o}C and causes evaporation of water vapour in the solution because of differences in boiling point. Evaporation of water into the condenser, causing $LiBr\text{-}H_2O$ solution concentration increased from 55 % to 60 % period. The strong solution of $LiBr\text{-}H_2O$ then flows into the absorber to conduct cooling process by the absorption of water vapour coming from the condenser.

3.2. Balance of the power system equilibrium

Cooling loads in Engineering Physics' lecture halls (the value of heat flow rate from the evaporator) is 15.63 kW. By referring to Eq. 5 and Eq. 6, the value of heat flow rate from the condenser is 17.349 kW and from the absorber is 16.91 kW, respectively. From the Eq. 1 about the equilibrium balance of power, the value of power needs to be supplied to the generator is 18.629 kW. Thermal COP values obtained with refer to Eq. 2, is 0.84.

3.3. Power system planning

In the designed system, the solar collector used to supply heat to the generator must be able to produce a working fluid with a temperature greater than 82 °C in order to evaporate the refrigerant from the solution of LiBr-H_2O. The temperature of the working fluid from the solar collector is required ranged from 85 °C to 99 °C. With reference to Eq. 7 and graphic characteristics of solar collector which is similar to Figure 6, as well as average G_T is 4.802 $kWh\cdot m^{-2}\cdot day^{-1}$, where it is assumed that the effectiveness of solar radiation per day starting at 8 a.m until 4 p.m (8 hours), so 4.802 $kWh\cdot m^{-2}\cdot day^{-1}$ = 4.802 / 8 = 0.6 $kW\cdot m^{-2}$), obtained some type of solar collectors that can be installed in the Department of Engineering Physics, the value of efficiency, as well as the total area of solar collector required in accordance with the cooling load at seven lecture halls, as represented in the Table 4.

Table 4. Characteristic of collcetor types used

Collector type	Efficiency	Total area needed (m^2)
Double glazed, flat plate, flat black paint	25 %	104
Antireflective double glazed, flat plate, black chrome selective surface	37 %	70.27
Single glazed, flat plate, black chrome selective surface	39 %	66.60
Single glazed, evacuated tube, concentricselective absorber, no rear reflector	48 %	54.16

4. Conclusion

In designing the solar absorption system, steps that are required i.e. study the potential of solar energy availability, calculate the desired cooling load, analyse the thermodynamic processes in each component of the system (condenser, evaporator, absorber, and generator), determines the type of collector to be used, and calculate the area of the collector to meet the required heat energy supply. For study case in seven lecture halls at Department of Engineering Physics Universitas Gadjah Mada, a thermal COP of the system designed was about 0.84 which could use some types of flat plate solar collector with each area corresponding to each efficiency values.

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