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# Studying the Absorption Refrigeration System powered by Thermal Waste and Electricity Conversion from Photovoltaic

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**Abstract:** Currently, buildings are responsible for 32% of the world's energy consumption, with the most massive energy-consuming device in facilities being the refrigeration system. Photovoltaic is an alternative source of energy without causing environmental damage. Solar Refrigeration is an attractive solution because when there is much solar radiation, peak thermal energy is generated, and a lot of cooling capacity is needed. In this research, the amount of PV modules used as the LiBr-H2O Absorption Refrigeration System's primary energy source is investigated. PV modules have a dual function, namely as a producer of electric power and producing thermal waste, both of which can be used as energy sources to drive this refrigeration system. In this thermal waste, two thermal sources, namely thermal convection and thermal radiation, accumulate to activate heat exchange at the LiBr-H2O absorption refrigeration system's generator side. For electrical power from the PV module, it is used to run the air heater to increase the temperature until it reaches the optimum point for hot water supply between 65 to 70 oC. The results are that at least 100 modules of 100Wp Monocrystalline PV Module are needed to drive the LiBr-H2O absorption refrigeration system. Still, it is limited to 15.00, after which the energy source is switched back to electricity from PLN because, after 15.00, many PV modules are required and takes up a large enough space.

**Keywords:** Absorption Refrigeration; Photovoltaic Modules; Thermal Waste; Solar Collector; Electricity Conversion

## 1. INTRODUCTION

Indonesia is the fifth country in energy consumption in ASEAN countries, with a 195 000 KTOE, with electricity consumption per head of 566 TOE per year. However, access to the electricity network in suburban areas is still only 94%, and access to the electricity network in rural areas is only around 32% (Bakhtyar et al; 2003).

Sustainable energy, such as solar energy, has been identified as an excellent point to replace fossil energy dependence. Solar energy can be converted into two types of energy using photovoltaic, which converts solar energy into electrical energy, and uses a solar collector,converting solar energy into thermal energy. The idea to combine PV and Thermal is not new, but in line with the times and the increasing energy demand, PVT has become the focus of world attention. The PVT system converts solar radiation energy into electrical energy and thermal energy. A PVT system is a combination of a flat sheet solar collector and a PV (photovoltaic) module (Chemisana et al., 2011; Li et al., 2011; Zhao et al., 2011).

According to the IEA (International Energy Agency), buildings are responsible for 32% of the world's energy consumption (Roaf et al., 2015). A BIPV/T (Building Integrated Photo Voltaic / Thermal) system uses building

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envelopes to produce electrical and thermal energy. Implementing the BIPV/T system can reduce building energy consumption, utilizing them as an alternative material to replace walls or roofs, increasing the percentage of building replacement components that also function double (Yang et al., 2016).

An installed conventional refrigeration system in the building consumes massive electricity. Therefore, research inthe alternate refrigeration system partially / fully supplied by renewable energy sources is a solar cooling system that uses heat energy from the sun to activate the absorption refrigeration cycle (Monne et al., 2011).

Ferdinand Care first introduced the absorption refrigeration cycle used for Refrigeration in 1896. Absorption refrigeration uses two working fluids as refrigerants, which are referred to as solvent and dissolved. The solvent here uses water ($H_2O$), and the solute here uses Lithium Bromide (LiBr). A refrigeration cycle operates with a condenser, expansion valve, evaporator, and generator (heat collector). First, the absorption refrigeration system absorbs low-pressure vapour (gas) from the evaporator into an absorbing liquid (absorbing liquid) on the absorber side, in the absorber, cold thermal releases. From the absorber, the pressure of the liquid solution rises using a pump to the generator. There is a thermal provision of heat from the generator's environment to activate high-pressure vapour (liquid) from the absorber solution to the condenser. There is a cold thermal discharge in the condenser—conversion from gas to liquid through the expansion valve to the evaporator. In the evaporator, there is a hot thermal reception. The absorption cycle is referred to as the Heat Operated Cycle. In the absorption cycle, work is needed to move the pump;the amount of work is still relatively small (Zainul et el, 2011).

The absorption refrigeration system, powered by solar energy, can be a solution.Some intensive research related to absorption refrigeration systems, using either Ammonia-$H_2O$ or $H_2O$-LiBr (Chen et al. 1999) has been done to save electrical energy and reduce environmental disturbances. The single-effect refrigeration system $H_2O$-LiBr is the most suitable solution to use than several other solutions for the combination of solar electric-thermal systems (Kim et al., 2008). The optimum temperature for hot water supply is between 65 to 70 oC for single effect refrigeration systems $H_2O$-LiBr (Asdrubali et el., 2005). In this study, it does not take into account the cost factor and its techno economy. In previous studies, the primary energy source was using only solar collectors, while in this study, using a solar collector integrated with photovoltaic.

## 2. MATERIALS AND METHODS

In this study, the research object was carried out by temperature measurements and the resulting electrical parameters. The thermal radiation and thermal convection calculation and the solar PV module's output power determine the solar PV module's energy output.

### 2.1 Material and Tools

The material used in this research is a PV Module 100Wp Monocrystalline. Measurement of ambient temperature, solar PV module temperature, and voltage and current output from solar PV modules were carried out, with the help of Thermal Gun for thermal spot measurement, Enviro Meter for ambient temperature measurement, and Multimeter (Tang Ampere) for measuring the volt & current flow of electricity.

### 2.2 Equations

Heat exchange convection uses the equation:

$$Q_{conv} = h_{conv} * \mathrm{A} * \Delta T \qquad (1)$$

being,

$$h_{conv} = \frac{Nu * k}{L} \qquad (2)$$

Where hconv [W / (m2K)] is the convection coefficient, and A is the area of the module (m2). ΔT is the temperature difference between the ambient and the module surface. L is the length dimension of the module (m), k is the thermal conductivity of the air in reference temperature [W / (mK)], and Nu is the unified Nusselt numbers.

The following equation is used to find the corresponding parameter for the thermal phenomenon in the PVT system :

$$\mathrm{Pr} = \frac{\upsilon}{\alpha} \qquad (3)$$

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$$Gr = \frac{g*\beta*\triangle T*L}{\upsilon} \quad (4)$$

$$Ra = Gr * Pr = \frac{g*\beta*\triangle T*L^3}{\upsilon*\alpha} \quad (5)$$

$$Re = \frac{u*L}{\upsilon} \quad (6)$$

The Prandtl number (Pr) provides information about the fluid; it also provides information about the thermal boundary layer's thickness and the hydrodynamic boundary layer. Reynold number (Re) provides information regarding the fluid flow, whether inertial or dominant viscous force, to determine whether the flow is laminar or turbulent. The Grashoff number (Gr) is used in the heat and mass transfer planes for natural thermal induction from the surface of a solid object that is inside a liquid/air. The Rayleigh number (Ra) is described as the relationship between momentum diffusivity and thermal diffusivity.Other related parameters include: dynamic viscosity υ ($m^2$ / s), thermal diffusivity α ($m^2$ / s), gravity acceleration g (m / $s^2$).

In calculating the Nusselt number, it is known that there are two components, namely:

$$Nu = \sqrt[3]{\left(Nu_{forced}\right)^3 + (Nu_{natural})^3} \quad (7)$$

And $Nu_{forced}$ :

$$Nu_{forced} = 0.664 * Re^{0.5} * Pr^{1/3} \quad (8)$$

With $Nu_{natural}$ :

$$Nu_{natural} = \left(0.825 + \frac{0387*Ra^{1/6}}{\left[1+\left(\frac{0.492}{Pr}\right)^{9/16}\right]^{8/27}}\right)^2 \quad (9)$$

Heat Exchange Radiation uses the equation:

$$Q_{rad} = h_{rad} * \mathrm{A} * \left({T_1}^4 - {T_2}^4\right) \quad (10)$$

With

$$h_{rad} = \frac{\sigma}{\frac{1-\varepsilon_1}{\varepsilon_1}+\frac{1}{F_{12}}+\frac{1-\varepsilon_2}{\varepsilon_2}} = \frac{\sigma}{\frac{1-\varepsilon_1}{\varepsilon_1}+1+\frac{1-\varepsilon_2}{\varepsilon_2}} \quad (11)$$

$T_1$ is the PV module's temperature's backside, and $T_2$ is the ambient temperature (K). ε1 is the PV module's emissivity's backside, and ε2 is the ground surface's emissivity. σ is the Stephan-Boltzmann constant [5,67 x $10^{-8}$ W/($m^2K^4$)].)].

## 3. RESULT AND DISCUSSIONS

### 3.1 Data Measurement and Collection

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PV Module 100Wp Monocrystalline has the specification as found in Figure 1.

| PV Module Electricity Performance Parameter | |
|---|---|
| Cell type: | Monocrystalline silicon solar cell |
| Maximum Power( Pmax ) | 100W |
| Voltage at Pmax ( Vmp ) | 18.1V |
| Current at Pmax ( Imp ) | 5.54A |
| Open-circuit voltage ( Voc ) | 22.2V |
| Short circuit current ( Isc ) | 6.00A |
| Max System Voltage: | 700V |
| Temperature Range | -45℃ ~ +80℃ |
| Dimension | 1020x670x30mm |

Figure 1. PV module specification

Measurement of ambient temperature, solar PV module temperature, voltage, and current output from solar PV modules are done within a 1-hour sampling rate. Thereisa difference between temperature in the backside of the PV module, and the Ambient temperature can be found in Table 1.

Table 1. PV module output measurement

| Time | Irradiance ($W/m^2$) | PV Temp (ºC) | Amb Temp (ºC) | PV $V_{mp}$ (V) | PV $I_{mp}$ (A) |
|---|---|---|---|---|---|
| 08:00 | 525.7 | 47.5 | 34.8 | 12.4 | 6.5 |
| 09:00 | 777 | 47.6 | 34.7 | 12.7 | 7.1 |
| 10:00 | 944.5 | 43.9 | 34 | 12.8 | 9.3 |
| 11:00 | 830.5 | 47.9 | 35.7 | 13.2 | 9.1 |
| 12:00 | 765.8 | 47.5 | 38.3 | 13.3 | 8.7 |
| 13:00 | 609.8 | 44.4 | 37.5 | 13.3 | 7.8 |
| 14:00 | 439.5 | 38.9 | 36.8 | 13.3 | 6.3 |
| 15:00 | 276.5 | 35 | 34.8 | 13.2 | 3.5 |
| 16:00 | 288 | 35.2 | 33.8 | 13.13 | 1.9 |

Figure 2 shows the output trends of 100 Wp Monocrystalline PV Module during the daylight. Power output trends of 100 Wp Monocrystalline PV Module during the daylight on Figure 2 shows that start on 10.00 AM, the power rise up and downward until solar set. The PV temperature reaches its lowest value exactly when the power reaches its top value.

Figure 3 describes the energy balance of a solar module exposed to solar radiation. There is waste heat in the photovoltaic process to convert light energy into electrical energy (DC). In terms of the energy balance of the Photovoltaic Modules, there are several things to be assumed, namely:

Clean Energy and Smart Technology
Vol 01, No 01, October 2022
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e-ISSN : 2964-2647

a. The photovoltaic module's solar cell temperature is assumed to be uniform for the module's entire surface.
b. The temperature of the ground (ground) is assumed to be the same as the temperature of the air (ambient)
c. The airflow rate above and below the solar module's surface is assumed to be the same, i.e., close to zero.
d. The emissivity of the solar module's surface (both on the top and bottom surface) is independent of light's temperature and wavelength, as one can find in Table 2.

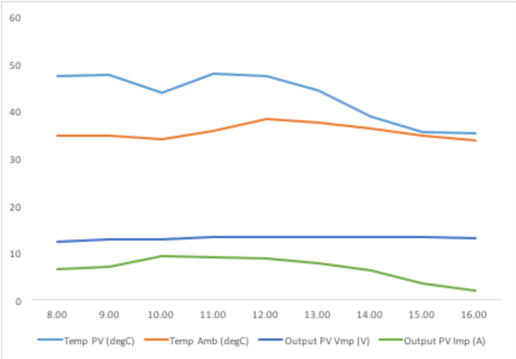


Figure 1 Trend on Temperature and PV Power Measurement

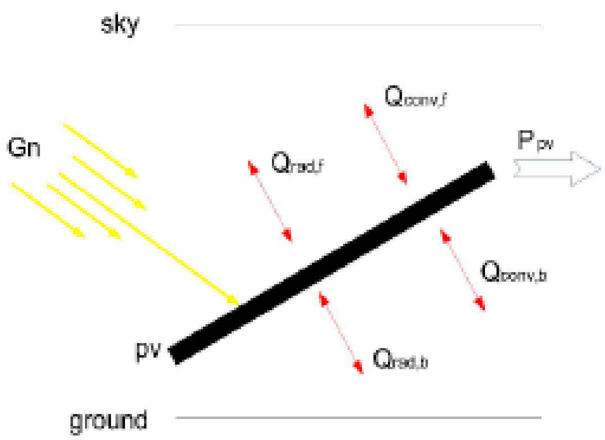


Figure 2 Energy Balance of PV Module (Hammami et al., 2017)

Table 2. Emissivity coefficient

| | ε |
|---|---|
| PV module front surface (glass) *(f)* | 0.91 |
| PV module back surface (backsheet) *(b)* | 0.85 |
| Sky | 0.91 |
| Ground | 0.94 |
| Polished aluminium plates | 0.04 |

Clean Energy and Smart Technology
Vol 01, No 01, October 2022
DOI : https://doi.org/10.58641/cest.v1i1.3
e-ISSN : 2964-2647

There are heat exchange events in the photovoltaic energy balance, namely convection (convective) and radiation (radiative). The solar module dimensions, wind speed, air temperature, and ground temperature are the parameter used in convection thermal energy and radiation thermal energy. Still, in this case, the assumption factors are used as previously described.

The magnitude of the cooling capacity to the absorption refrigeration system here worth 1 TR (tonne refrigerated) or 3.5 kW or 5pK, with the consideration that the volumes of 3.5 kW are still a minimal value, where there is still no vendor that sells the refrigeration system absorption as small as it is (Jakob et al., 2006). Hence, to tolerate losses, the power to drive the absorption refrigeration system is set to 5 kW in the calculation below.

### 3.2 Data Calculation

It takes a temperature delta of about 30 oC to raise the temperature from PV temperature (in Table 1), which is about 40 oC to 70 oC, to heat the water to supply to the LiBr-H2O Absorption Refrigeration cycle. An external heater, powered by DC PV Power, is used to raise the temperature to provide a proper temperature for driving the LiBr-H2O Absorption Refrigeration

Electrical Power generated by PV Module also fluctuates over time, as seen in the following table. The estimated heat loses of the electric heater is 20%.

Table 3. PV Module Quantity based on Electrical Output

| Time | Output PV Vmp (V) | Output PV Imp (A) | Q Elec Conv (W) | Heater Loses (W) | Delta Temperature (ºC) | PV Module Quantity based Elect Output |
|---|---|---|---|---|---|---|
| 08:00 | 12.40 | 6.50 | 80.60 | 16.12 | 27.5 | 77.54 |
| 09:00 | 12.70 | 7.10 | 90.17 | 18.03 | 27.4 | 69.31 |
| 10:00 | 12.80 | 9.30 | 119.04 | 23.81 | 31.1 | 52.50 |
| 11:00 | 13.20 | 9.10 | 120.12 | 24.02 | 27.1 | 52.03 |
| 12:00 | 13.30 | 8.70 | 115.71 | 23.14 | 27.5 | 54.01 |
| 13:00 | 13.30 | 7.80 | 103.74 | 20.75 | 30.6 | 60.25 |
| 14:00 | 13.30 | 6.30 | 83.79 | 16.76 | 36.1 | 74.59 |
| 15:00 | 13.20 | 3.50 | 46.20 | 9.24 | 40 | 135.28 |
| 16:00 | 13.13 | 1.90 | 24.95 | 4.99 | 39.8 | 250.53 |

Table 3 shows that from 15.00 hours onwards, that there are too many PV modules needed, which is more than 100 sheets since it will not be feasible anymore since it will occupy an area more than 70m$^2$.

The thermal waste via convection and radiation of the sun, resulting in the calculation can be seenin Table 4. In this study, heat exchange is translated as thermal waste, considering that the primary purpose of using PV modules is to generate electricity. In contrast, the thermal variable that occurs is a side product that is unavoidable to happen (Zhao et al., 2011).

Based on table 4, there is a fluctuation in the value of thermal waste, which decreases in line with the time function. Table 5 shows a calculation of the PV module's quantity as the primary source of Solar Refrigeration Absorber with the Heat loss of heat exchanger estimated at 10%.

Table 4. Heat Calculation on PV module

| Time | Q Heat Radiation (W) | Q Heat Convection (W) | Q Total (Q Rad + Q Conv) (W) |
|---|---|---|---|
| 08:00 | 51.64 | 31.56 | 83.20 |
| 09:00 | 52.45 | 32.06 | 84.51 |
| 10:00 | 39.41 | 24.60 | 64.01 |
| 11:00 | 49.91 | 30.32 | 80.23 |
| 12:00 | 38.03 | 22.86 | 60.89 |
| 13:00 | 28.00 | 17.15 | 45.14 |
| 14:00 | 10.21 | 6.46 | 16.67 |
| 15:00 | 2.69 | 1.74 | 4.42 |
| 16:00 | 5.34 | 3.48 | 8.82 |

Since each PV module produces a thermal waste of that amount in the table, to meet a value of 5kW, the abundant PV module's thermal accumulation is required with that amount in the module. But it seems from 14.00 hours onwards, that there are too many PV modules needed, which is over 100 sheets.

The idea of combining the power from PV Power and Thermal waste of PV to provide sufficient power to drive Absorption Refrigeration is to minimize the quantity of PV module. Table 5 shows a combination of thermal waste & DC PV Power, indicating the amount of PV modules becomes lesser.

Table 5. PV Module Quantity based on a Combination of Thermal Waste and DC PV Power

| Time | Delta Q Thermal Waste (W) | Delta Q DC PV Power (W) | Q Total (Thermal Waste+DC PV Power) (W) | PV Module Quantity |
|---|---|---|---|---|
| 08:00 | 78.04 | 64.48 | 142.52 | 35.08 |
| 09:00 | 79.26 | 72.14 | 151.40 | 33.02 |
| 10:00 | 60.07 | 95.23 | 155.30 | 32.20 |
| 11:00 | 75.24 | 96.10 | 171.34 | 29.18 |
| 12:00 | 57.09 | 92.57 | 149.66 | 33.41 |
| 13:00 | 42.34 | 82.99 | 125.33 | 39.89 |
| 14:00 | 15.65 | 67.03 | 82.69 | 60.47 |
| 15:00 | 4.16 | 36.96 | 41.12 | 121.61 |
| 16:00 | 8.28 | 19.96 | 28.24 | 177.06 |

Table 5 shows that even though there are a hybrid power, utilizing thermal waste and DC PV Power, still after 15.00 hours onwards, requires PV module more than 100 sheets. It's not feasible anymore since it will occupy an area more than 70m2 for only 1 TR.

## 4. CONCLUSION

In this study, it can be concluded that photovoltaic can be the primary energy source for LiBr-H2O Absorption Refrigeration System, both by using thermal waste and its electrical conversion. However, the Absorption Refrigeration System of 1 TR's cooling capacity requires the number of PV Module monocrystalline of close to 100 sheets, which requires a large enough land, which is about 70m2.

However, starting from 15.00 onward, it takes an enormous amount of PV Module, indicating that need for

**Clean Energy and Smart Technology**
Vol 01, No 01, October 2022
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PLN intervention as the primary source of Absorption Refrigeration. The use of renewable energy and sustainable energy for building cooling needs emphasing reducing greenhouse gases (GHG). Further study may be conducted to reduce the quantity of PV module by implying an alternate research method.

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