Development of hot water storage in hybrid-solar thermal air conditioning system

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Abstract. The utilization of Split AC as a water heater is now initiated but still uses a heater from electricity. Besides that, the use of solar thermal radiation as a source of heating has already made much. In this study discussed if both systems were merged into a hybrid-Solar Thermal Air Conditioner (STAC) system. The STAC system will combine the heat refrigerant on a discharge line compressor with a solar heat collector. This system has been designed in previous studies only limited to the analysis of the achievement of the temperature is 40 °C within 20 minutes. But the obstacles experienced by heat cannot last long because it utilizes peak load time from solar radiation and thin tank insulation. For it developed a hybrid system with the replacement of a hot water tank. The method begins by creating a model for the hybrid system modification, the determination of tank insulation material and heat storage wall thickness so that the water heat loss can be reduced. Then on the solar collector modified by the pipe installation series as well as the 20° collector tilt angle. For circulation flow refrigerant from the discharge line compressor added automatic control, it is expected the performance of the system more maximized. The results can be seen that the water heating time can reach values above 40 oC in 30 minutes, the hybrid system efficiency is 47.9%, and the refrigeration efficiency is 75%.

1. Introduction

Nowadays, air conditioning (air conditioner/AC) has become a primary necessity for most of the population to be was as well as water heater (water heater) has become a common furniture item in urban households. Many air conditioning tools are needed in tropical countries such as Indonesia where air conditions tend to be hot and humid, so it is inconvenient to do so. While the water heater is used for a hot shower as a means of relaxation of the body after its users do a grueling activity throughout the day. Air conditioning generally consumes electrical energy to operate depending on the cooling capacity, while the water heater has a more variable energy source: gas, electricity, and solar. In other conditions, it is necessary to realize that the need for fossil fuels is getting bigger while its availability is depleting, so that if no innovations about alternative energy will threaten the generations to come, and for now The largest consumption is about 42.5% there is on total electricity consumption
[1], while the largest electrical energy needs exist in the use of air conditioning (split AC). And during this water heater obtained separately, such as the utilization of heat exhaust refrigerant on the discharge line pipe compressor split AC with the term ACWH (Air Conditioning Water Heater) [4] or the utilization of solar thermal collector as a water heater with the term SWH (Solar Water Heater)[6], while the combination of system by utilizing a combined system as an energy source is still rarely done research. With this reason, research attention will be analyzed of how much the performance of the combined system of the tool works if combined into a hybrid system-Solar Thermal Air Conditioner (STAC).

The results performed on previous research have only been limited to how much influence the merger of solar thermal collector and Air Conditioner for water heater against efficiency system, but the heated water produced in the tank has not been able to last long because it only utilizes the peak load time of heating of the solar radiation and the thin tank insulation. The use of the hybrid system was previously limited to the analysis of the impact of the hybrid system on the achievement of heating temperature of over 40 °C in about 20 minutes and saving energy is 16% [2]. For that, this research developed a hybrid system with replacement of heat exchanger (APK), as well as hot water storage. The results are expected not only to get the performance and saving energy, but the effectiveness of hot water absorption in the heat storage tank is longer as expected ranging from 40°C-50°C[3], so it can be implemented in the household or commercial sector.

2. Methodology
The research methods used in this study are theoretically and experimentally. Theoretically uses the design calculations of the parameters of the hybrid system, while experimentally done after the system operates well then tested to know the performance analysis of the hybrid system. The stages of research will be conducted (see Figure 1) are as follows:

![Figure 1. Flowchart Research](image-url)
2.1. Preparation Stages (Planning and literature review)

The literature study is conducted to obtain material about the introduction, theoretical review, data or information as a reference material in conducting the test. Planning is done so that there were no mistakes during the manufacturing process.

2.2. Design stages

This is the initial stage of designing the system will be created. In this step, the system is required preliminary design data. Designing ACWH and solar thermal collectors to be made by utilizing the heat of both (see figure 2). After that choose the materials and components to be used.

![Design Scheme of Hybrid System-Solar Thermal Air Conditioning](image)

**Figure 2.** Design Scheme of Hybrid System-Solar Thermal Air Conditioning

The calculation result of the Solar Water Heater (SWH) can use the equation of the heat energy and the collector efficiency as follows [6]:

2.2.1. Determine the heat transfer rate to heat the water ($Q_{\text{water}}$)

The heat calculations needed to heat the water used equations:

\[
q_{\text{water}} = \dot{m}_c \cdot c_p \cdot (T_o - T_i)
\]  
\[
q_{\text{water}} = 0.01 \frac{kg}{s} \times 4179 \frac{J}{kg\cdot°C} (40°C - 30°C)
\]  
\[
q_{\text{water}} = 417.9 \frac{J}{s} = 417.9 \text{ Watt}
\]

Where:
- $q$ is heat energy of the solar water heater (J/s)
- $\dot{m}_c$ is mass flow rate of the water heater (kg/s)
  \[
  \dot{m}_c = \rho \cdot \frac{V}{t} = 0.01 \text{ kg/s}
  \]
- $\rho$ is a density of water (1000 kg/m$^3$)[8]
- $V$ is a volume of water (30L = 0.03 m$^3$)
- $t$ is a time of hot water reached (45 minute=2700 s)
- $c_p$ is specific heat capacity at a constant pressure of water heater is 4179 J/kg.°C [8]
- $T_0$ is initial water temperature (°C)
- $T_1$ is final water temperature (reached) (°C)

For the equation of the collector efficiency as follows:

$$\eta = \frac{q}{I_s \cdot A_k} \times 100\%$$  \hspace{1cm} (3)

$$\eta = \frac{417.9 \text{ Watt}}{677 \text{ W/m}^2 \times 1 \text{ m}^2} \times 100\%$$

$$\eta = 62\%$$

Where:
- $\eta$ is a collector efficiency (%)
- $q$ is heat energy of the solar water heater (J/s) or (watt)
- $I_s$ is a Solar Radiation (W/m$^2$)
- $A_k$ is a collector area (m$^2$)

Calculation result of the Air Conditioning Water Heater (ACWH)[4] can be use the p-h diagram from refrigerant R32 for determine refrigeration efficiency as follows:

Known:
- Evaporator temperature ($T_e$) = 15 °C = 288 K
- Condenser temperature ($T_c$) = 50 °C = 323 K

![Figure 3. p-h Diagram using R32](image)

The enthalpy value obtained:
- $h_1 = 518$ kJ/kg
- $h_2 = 558$ kJ/kg
- $h_3=h_4 = 302$ kJ/kg

1. Determine the compression work ($q_w$)
The amount of compression work per unit of refrigerant mass can be calculated by the equation:

\[ q_w = h_2 - h_1 = 558 - 518 = 40 \text{ kJ/kg} \]

2. Determine the heat removed (\(q_c\))
The amount of heat refrigerant released in the condenser is expressed in the equation:

\[ q_c = h_2 - h_3 = 558 - 302 = 256 \text{ kJ/kg} \]

3. Determine the refrigeration effect (\(q_e\))
The amount of heat absorbed by the evaporator is expressed in the equation:

\[ q_e = h_1 - h_4 = 518 - 302 = 216 \text{ kJ/kg} \]

4. Determine the refrigeration of the coefficient of performance (\(COP_R\)) divided into:
   4.1 COP of actual cycle
   The amount of actual COP is expressed as a comparison between the refrigerant effect and compression work is:

\[ \text{COP actual} = \frac{q_e}{q_w} = \frac{216}{40} = 5.4 \]

   4.2 COP of Carnot cycle
   The theoretical COP for an air conditioning system is expressed by Carnot’s theorem, reduced to the following equation:

\[ \text{COP carnot} = \frac{T_e}{T_c - T_e} = \frac{288}{323 - 288} = 8.2 \]

5. Determine the refrigeration efficiency (\(\eta_R\))
The efficiency of refrigeration can be described more precisely as a real process about a certain (ideal) reference process by Carnot’s theorem. Referring to the above-mentioned considerations it can be defined [10]:

\[ \eta_R = \frac{\text{COP actual}}{\text{COP Carnot}} \]

\[ \eta_R = \frac{5.4}{8.2} = 68\% \]

6. Determine the heat removed from the coil compressor (\(Q_{coil}\)) (\(\text{discharge line}\))
The heat removed from the coil compressor can be calculated by using the equation follows [2]:

\[ Q_{coil} = \dot{m} \cdot C_p \cdot \Delta T \]

\[ \dot{m} = \frac{\text{compressor power (P)}}{\text{compression work (qw)}} = \frac{0.43\text{kW}}{40 \text{kJ/kg}} = 0.01 \text{ kg/s} \]

Where:
- \(Q_{coil}\) is a heat removed from coil compressor (Watt)
- \(\dot{m}\) is a mass flow rate of refrigerant (kg/s)
- \(C_p\) is specific heat capacity at a constant pressure of the refrigerant is 3,560 J/kg.°C[9]
- \(T\) is the difference temperature between entering coil temperature (\(T_{in}\)) and out coil temperature (\(T_{out}\)) of the refrigerant in coil (discharge line) compressor (K).
\( T_{in} \) is 66 °C (339 K) and \( T_{i} \) is 50 °C (To) (323 K), so obtained \( \Delta T = T_{in} - T_{i} = 339 - 323 = 16 \) K

So, based on equation (4) obtained \( Q_{coi} = 612.3 \) Watt

7. Determine the water heater efficiency (\( \eta \))

To calculate the efficiency in the water heating process can use the following equations [2]:

\[
\eta = \frac{Q_{water}}{Q_{coi}} \times 100% \tag{7}
\]

\[
\eta = \frac{417.9}{612.3} \times 100% 
\]

\( \eta = 68 \% \)

8. Determine the efficiency of the hybrid system (\( \eta \))

To calculate the efficiency in the water heating process can use the following equations:

\[
\eta = \frac{Q_{water}}{(Q_{water}\_collector} + Q_{coi}) \times 100% 
\]

\[
\eta = \frac{417.9}{(417.9 + 612.3)} \times 100% 
\]

\( \eta = 40.6 \% \)

Where:

\begin{align*}
Q_{water} & = 417.9 \text{ Watt} \\
Q_{water\_collector} & = Q_{water} = 417.9 \text{ Watt} \\
Q_{coi} & = 612.3 \text{ Watt}
\end{align*}

2.3. Manufacture and Assembling Stage

After the design is completed, then create a prototype water heater hybrid system called STAC (Solar Thermal Air Conditioning). For AC split it uses an environmentally friendly refrigerant such as R32. For solar thermal collectors use flat plate type. Then add some tools necessary to modify into a prototype hybrid system.
Figure 4. Installation of series type solar collector with tilt angle is 20° (placed on the building)

Figure 5. Air Conditioning Water Heater (ACWH) System Installation: 1. Filler tank; 2. Hot water tank; 3. Condensing unit; 4. Power panel

For the main components of the selected refrigeration system is Split type AC (Air Conditioner) system modified by combining the system such as:
1. Solar Thermal Collector, is a heating element using copper pipes that utilize the heat of the solar radiation where the heat of the element is flowing water so that there is heat transfer to the water[7].
2. The heat exchanger tank (APK) is a tool that is processed occurs heat transfer of fluid is the higher temperature to another fluid that is a lower temperature. The heat transfer process occurs directly or indirectly. Meaning APK directly, the heated fluid will mix directly with the cold fluid (without separation) in the tank. Whereas APK indirectly, that is heat fluid indirect contact process with cold fluid, so the heat transfer using intermediate media such as pipes, plates or other types of equipment. The tank also serves as a water heat storage.

2.4. Testing Stages
In this stage, Testing is conducted to ensure the system operates properly, it will be taken some data using instruments such as digital thermometer, thermocouple, pressure gauge, flow meter, multimeter, and solar power meter. While the data required as follows: Ambient air temperature, temperature and pressure of compressor, temperature and pressure of expansion valve, temperature and pressure of evaporator, temperature and pressure of condenser, entering and out water temperature tank, water temperature on solar collector, water temperature inside the hot water tank, discharge flow reservoir tank, voltage and electric current, solar radiation.

Before the data is obtained from testing, it is necessary to be calculated based on the design data to compare when analyzing the test results.

3. Result and Discussion
As a discussion by comparing the results from previous studies, the results show that the development of hybrid systems is more optimal in collecting data, where a solar radiation measuring instrument is added with use Solar Power Meter to the test, then the flat plate collector has determined the best solar angle of 20°, as well as the APK tank replacement (Heat Exchanger Tank) from heat-resistant material.
using polyurithene so that the temperature of the heat in the tank can last longer ie for 24 hours the temperature condition is still above 40 °C. For this reason, the hybrid system was reconstructed again by calculating the design data with the test results.

Testing data retrieval is conducted to determine the achievement of the design temperature (40 °C) of the hybrid system of the water heater according to the design. Data retrieval is done when the system operates. Here are the data of the results in the graph form as follows:

![Graph of Water Temperature in APK against Time](image)

**Figure 6. Graph of Water Temperature in APK against Time**

Data retrieval is conducted for 3 hours by operating two ACWH and SWH systems. The graph above explains in the initial 5 minutes of water temperature reaches 36.7 °C and for 30 minutes the temperature of the water reaches above 40 °C. The following data retrieval results in each system in one of the same operations:

3.1. **The test result of the solar water heater (SWH)**

Data retrieval is conducted for 3 hours at 11:00 – 14:00 WIB. The following data retrieval results in graphic form:

![Graph of Water Temperature Collector against Time](image)

**Figure 7. Graph of Water Temperature collector against Time**
From the graph above can be seen the temperature of incoming water at 11:10 that reaches the temperature of 38 °C when experiencing the process of heating by solar energy collectors, the temperature of the water has an increase in temperature regularly. So the collector output water temperature reaches the design temperature at 11:30, which is 42 °C with a length of 30 minutes of heating. Then the hottest temperature collector output for 3 hours at 14:00 is 55 °C.

3.2. *The test result of the Air Conditioning Water Heater (ACWH)*

Data retrieval is conducted for 3 hours at the same time on SWH. Following data retrieval in graphic form:

![Graph of Refrigerant Temperature of The APK against Time](image)

*Figure 8. Graph of Refrigerant Temperature of The APK against Time*

From graph above explains the increase and decrease in refrigerant temperature in APK and out APK through the water in hot water tank for 3 hours by using 1/4 inch pipe of helical type [5]. So the temperature of the design water reached at 20 minutes is 40.2 °C with the in refrigerant temperature of APK is 67 °C, where the difference in the temperature transfer of the refrigerant heat to water is 26.8 °C due to the heat transfer to a lower temperature. The highest water temperature for 3 hours is 55 °C.

For test results obtained from the actual data using the equations of the design calculations so that it can be a known comparison of the results of both as in this table 1 and 2 below.

**Table 1.** Comparison of design calculations and test results of solar collectors

| Variable                     | Design Calculation | Test Result  |
|------------------------------|--------------------|--------------|
| Qwater (Watt)                | 417.9              | 1002.96      |
| Hot water time is reached    | 45                 | 30           |
| (minute)                     |                    |              |
| Water temperature in a tank (°C) | 40                 | 42           |
| Solar radiation (W/m²)       | 677 W/m²           | 1213 W/m²    |
| Collector efficiency (%)     | 62%                | 82%          |

In table 1 above it is known that the efficiency of the collector is higher in value than the design data of 20%, and the heat time is 15 minutes faster, this is influenced by the intensity of sunlight absorbed by the collector is large enough so that the water entering the exchange tank The heat (APK) is higher.
Table 2. Comparison of design calculations and test results of the hybrid system

| Variable                                | Design Calculation | Test Result  |
|-----------------------------------------|--------------------|--------------|
| Qcoil (Watt)                            | 612.3              | 1002.96      |
| Qwater (Watt)                           | 417.9              | 1044.75      |
| Hot water time is reached (minute)      |                    |              |
| Water temperature in tank (°C)          |                    |              |
| Refrigeration efficiency (%)            | 68                 | 75           |
| ACWH Efficiency (%)                     | 68                 | 95           |
| The efficiency of the hybrid system (%) | 40.6               | 47.9         |

From table 2 above it can be seen the comparison between the test result and design calculation on the hybrid system. Where the heating efficiency of the test result is higher in value than the design calculation, this is influenced by the water heating in the tank which is quite high and also the faster heating time. While the refrigeration efficiency in the test result is also higher in value than the design calculation, this is influenced by the power needed to drive the compressor smaller when the heat is used for heating the water, so that it will increase the value of the actual COP (Coefficient of Performance). And then, it can be known that the efficiency of the hybrid system in both results is small, but the value of the test result is higher than the design calculation. The results of the small efficiency values are both influenced by the utilization of water heater that is too small compared to the heat of the water collector and the heat of water from ACWH.

4. Conclusion
Based on the results of the test and analysis, can be concluded as follows:
1. The use of a Hybrid Water Heater System from combining two systems can heat water more 40°C for 30 minutes with a water capacity of 30 liters;
2. From the comparison of hybrid system efficiency it can be seen that the value of the test result is higher than the design calculation of 47.9%, this is because the heat obtained from the hot water collector and the water from the discharge line coil on the test results is greater in value, and time achieving shorter heat periods;
3. As a future research development, a hybrid system needs to be added to a storage tank as a heat sink from a collector with a good insulator, and a control system for the distribution of water flow in and out of the water heater tank, as well as the use of alternative energy to reduce the use of electricity from National Electricity Company.

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