Abstract— Different types of evacuated tube solar thermal collector are used for solar hot water system (SHWS). The characteristics and the performance of these evacuated tube solar collector (ETSC) are different in various weather conditions [1]. In this paper, a comparative analysis has been presented for different types of ETSC. Besides that, the characteristic of a solar hot water system is investigated though out a year. The experimental data have been used to determine the optimum operating temperature for the solar hot water system. Alongside, we also have calculated the payback of the system to determine its feasibility. The result shows that, our system can store the heat energy for 24 hours with a negligible 4% temperature drop in the stored hot water, which is perfectly accurate for the development of automatic solar hot water system. In terms of longevity, annual expenditure and maintenance cost, the solar hot water system is more cost effective than ordinary electric water heater (guizer).

Keywords – microcontroller, solar, evacuated tube, Storage tank

I. INTRODUCTION

Nowadays, solar domestic hot water system is showing tremendous dominance over other hot water systems for its long term performance, inexpensive setup cost and relatively low manufacturing and maintenance cost. Although solar hot water system has widely spread all over the world, little research has been conducted so far on it in Bangladesh. At present, very few solar hot water systems are used in Bangladesh. It has a great demand in developing countries like Bangladesh because of the lack of electricity generation and high electricity charge for hot water system and for unavailability of natural gas connection remote places. This matter motivated this research about the characteristics of solar hot water system in order to decrease the consumption of electricity and limited natural resources like gas and fuel.

In this project, a 150 liters solar collector is used along with a 300 liters storage tank to store the water produced by the solar collector throughout the day. From the system, we have analyzed the optimum temperature [2] of the water to be stored in the storage tank. Alongside, we have done a payback calculation to determine the system’s feasibility in terms of economical advantage. A detailed follow through has been presented in the paper.

The behavior of the solar hot water system varies with region. Therefore, it is necessary to do the required analysis to identify its characteristics in Bangladesh. In this paper, the feasibility study has been made for the optimum operating temperature of the storage tank of solar hot water system by analyzing the temperature of storage water tank. Every day the water is heated up by the 150 liters solar collector and is then transferred to 300 liters storage tank and the loss of temperature in the storage tank is noted in the very next morning. This way, we have collected the energy gained, the amount of hot water that can be produced by our solar hot water system and the operating temperature of our designed automatic solar hot water system.

The operating temperature of the SHWS has been set to 50 degree Celsius. Fig. 1 shows the complete block diagram of our system.

From Fig. 1 we can see that when the solar hot water system will not be able to meet the desired temperature for the user, the electric water heater will serve the user. Here the temperature sensors will detect the temperature and send signals to the microcontroller accordingly to turn the electric water heater on or off.

![Figure 1. Block diagram of the automatic solar water heater](image-url)
II. SOLAR COLLECTORS

A. Type of Solar Collector used in the Project

Basically, there are two types of solar thermal collectors: evacuated tube collector and flat plate collector. A comparative study was previously conducted between different types of evacuated tube collector and flat plate collector [3]. The results confirm that the daily efficiency per unit area of evacuated tube collectors at low temperature can exceed that of flat plate collectors and the difference in performance becomes more significant as the average operating temperature increases. The advantages of evacuated tube solar collector over flat plate solar collector motivated us to use ETSC for our project [4].

After selecting evacuated tube solar collector, which in turns has some sub-types, we have selected one particular type. Among all the types, only all-glass tube and heat pipe tube demonstrate long life under transient outdoor condition [5-8]. Configurations that incorporate glass-to-metal seals are expensive and the seal must be protected from shock loading due to internal thermal transients or physical impact due to hailstorm. System that holds the heat transferring fluid through a glass-to-metal seal is particularly susceptible to damage due to thermal shock when cold fluid enters a hot tube. The glass-to-metal seal in the heat pipe system is partially protected from thermal shock problems, as the cold heat transferring fluid does not pass through the glass-to-metal seal. Alongside its manufacturing and implementation cost is high. The all-glass (water in glass) tube is the simplest and the least expensive type. As the tubes are directly connected with the tank, the heat loss occurs less than heat pipe evacuated tube collector. The area required for water-in-glass evacuated tube solar hot water system is relatively smaller than any other combination because of the tank being mounted on the top of the collectors. Besides, due to thermo siphon process, water-in-glass evacuated tube solar collector water becomes hot in relatively less time.

B. Details of Main Components

The main components of evacuated tube solar water heater (non pressurized solar water heater) [10] are the followings:

1. Water in glass evacuated tube
2. Storage tank
3. Mounting frame
4. External water supply source

Fig. 2 shows the illustration of an evacuated tube solar water heater.

Fig. 3 shows the 150 liters tank directly connected to the water-in-glass evacuated tube.

The insulated tank, as shown in Fig. 4, stores the water that come from external water source like the reserve tank. It mainly consists of two tank i.e. inner tank and outer tank. The inner tank is placed inside the outer tank. A gap is maintained between the two tanks, which is filled by high tech insulating material (Rock Wool or mineral wool) in order to reduce the heat losses from the heated water inside the inner.

III. EXPERIMENTAL PROCEDURE

The specification of the solar collector and the storage tank is shown in Table I.

Our experiment mainly included the analysis of water temperature produced by the 150 liters solar collector throughout a year and determining the operating temperature for our system.

The whole system is completely automatic and consists of 5 solenoid valves, which are controlled by microcontrollers. Three of the valves are shown in Fig. 5. Valve 1 is connected between the storage tank and the solar collector. This valve turns on whenever the temperature sensor (Fig. 6) detects that the operating temperature is reached. The temperature sensor consists of LM35 IC inside a copper tube. Valve 2 is connected between the user outlet and the storage tank. Valve 3 opens whenever the water temperature inside the storage tank becomes cold and transfers it back to the reserve tank. Valve
4 provides hot water from the electric water heater to the end user when the storage tank does not have the hot water with the required temperature. As a result valve 2 and 4 will never work at the same time. The last valve, valve 5 is the valve that supplies cold water from the main tank to the 150 liters collector. This valve only opens when the level detector inside the tank detects 150 liters collector’s tank is empty and turns off whenever the tank gets filled. When valve 5 is open, valve 1 is off so that cold water does not mix with the stored water.

Throughout one year, we have studied the characteristics of the whole system. By opening valve 5 while keeping other valves close, we transferred fresh cold water every day to the collector and turning it off when the 150 liter tank get filled to see the temperature rise of the water in every hour. On average, the readings are taken from 0900 hrs to 1700 hrs. At the end of the day, we transferred the heated up water to the 300 liters storage tank through valve 1.

The very next morning, the temperature of the water in the 300 liters storage tank is noted and is emptied by draining the water through valve 3 to the reserve tank. This above procedure is carried out for one whole year (except the transferring of the water to the 300 liter storage tank because of the improper conditions and repeated temperature at the end). From this, we noted the maximum temperature of the water that the 150 liters collector can produce and also the stored temperature and the temperature which had the least drop have been selected as the operating temperature of the system.

### IV. RESULTS AND DISCUSSION

Identification of the maximum and the average temperature was necessary to know the temperature characteristics of evacuated tube solar collector. We have taken the temperature variation of the 150 liters water tank of the whole day for one week. From that one-week data, we have noted the temperature of the hot water tank rose up to (on a full sunny day) 68 degree Celsius and in cloudy days, the maximum temperature was reached up to 56 degree Celsius (Fig. 7). It is obvious that we can store the hot water when it goes its maximum temperature but if we store the hot water like 68 degree Celsius, then the temperature difference between the stored temperature and the ambient temperature will be maximum, leading to a greater loss of temperature over time. This effect is shown in Fig. 8 where it can be observed that whenever the stored water temperature is 50 degree Celsius, the temperature fall of 300 liters storage tank is only 2 degree Celsius, which is the minimum temperature drop among any other stored water temperature. Therefore, 50 degree Celsius temperature has been selected as the operating temperature of our solar hot water system.

The calculated energy collected by the collector for the whole one year from July 2009 to June 2010 has been shown in Table II. In the table, we see that the collector’s area is multiplied by the isolation energy [11] (kWh/sq.m/day) to get the energy collected throughout month. This total energy is graphically presented in Fig. 9. As the amount of isolated energy from the sun is increased, the amount of energy that

### TABLE I. SPECIFICATION OF THE 150 LITRES COLLECTOR AND THE STORAGE TANK

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of the collector (Length)</td>
<td>5 ft. 6 inch</td>
</tr>
<tr>
<td>Size of the collector (Width)</td>
<td>70. 9 inch</td>
</tr>
<tr>
<td>Capacity of the Solar Water Heater</td>
<td>150 Liter</td>
</tr>
<tr>
<td>Capacity of the Storage Tank</td>
<td>300 Liter</td>
</tr>
<tr>
<td>Number of the collector for 150L storage tank.</td>
<td>15 tubes</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.045 meter</td>
</tr>
<tr>
<td>Length</td>
<td>1.8775 meter</td>
</tr>
<tr>
<td>Total area for 15 collector</td>
<td>1.99 sq. meter</td>
</tr>
</tbody>
</table>
system for monthly basis by using the following equation [12]:

\[ Q = M \int_{t_1}^{t_2} C_{pdT} = \int_{t_1}^{t_2} \rho C_{pdT} \]  

Where,

- \( M \) is the mass (kg).
- \( C_p \) is the specific heat of water (J/kg \( ^\circ \)C)
- \( \rho \) is the density (kg/m\(^3\))

Figure 7. The maximum temperature of solar hot water system

In the calculation of total energy absorbed by the solar hot water system and the amount of hot water produced, we have considered the number of days of every month. It is known that 1kg of water is approximately 1 liter and 1 Wh is 3600J.

The total hot water and energy are produced throughout the year is calculated to be 117126.4 liter and 2.51E+07 watt-hour (Wh) respectively.

Different rise in temperature is needed in different months because of the varying room temperature due to the weather condition. Fig. 10 shows a straight line at 50 degree Celsius which is the operating temperature. In May to June, the room temperature is the maximum and the temperature difference from the operating point temperature to that temperature is the minimum and thus requires less energy from the collectors. On the other hand, during December-January period, the room temperature is low, leading to a greater difference between the operating and the room temperature. Thus, high energy is needed to achieve the operating temperature.

V. COST ANALYSIS

We have calculated the total cost of our system and compared the expenses with electric water heater. The Total cost of the developed system is Bangladeshi Taka, BDT 1,00,000 considering every components of our automatic solar hot water system.

To calculate the electricity bill for an electric heater, the average electricity bill is collected from a water heater retailer named “Jamil and Co.” in Dhaka, Bangladesh. According to the retailer, per month electricity bill for an average family consuming hot water is approximately BDT 700.

Therefore, per year electricity cost = BDT 700 x 12 = BDT 8,400.

Other Charges which should be included in the electricity bill is:

- Demand charge=3.43 per BDT 100
- VAT=5.24 per BDT 100
- Service charge = per month BDT 6

Total other charge per month= BDT 14.67
Total other charge per year= BDT 176.04

According to the power development board of Bangladesh (PDB) per unit electricity charge is BDT is mentioned below:

- 0 to 100 units = BDT 2.60
- 101 to 400 units = BDT 3.30
- 401 and above = BDT 5.65

Therefore, per year cost = BDT 8400+176.67 = BDT 8576.67

From the above charge rate, it can be concluded that electric heater per month charge is in the 101 to 400 units.

Therefore, we have calculated BDT 260 for first 100 units and then we have subtracted from BDT 700 and got BDT 440. For this BDT 440, the unit range has to be 101 to 400.
So units used per month by the guizer = 100 units + 133 units = 233 units = 233 kWh/month = 233 x 12 = 2769 kWh/year.

Amount of energy we get from the collectors per year (from the isolation data) = 3395.2584 kWh/year.

So, we can conclude that our collector is producing more hot water than the required amount.

Now, considering that the electric heater and the controller consume 20% of the electricity bill (approx.), the amount we are saving:

\[ \text{BDT 8,567.67 x 80% = BDT 6,854.136} \]

So, the payback would be in \( \frac{1,00,000}{6854.136} = 14.6 \) years.

Our solar hot water system lifetime is 30 years where the electric water heater lifetime is not more than 5 years. Hence, after 5 years a new electric water heater will bear more cost. The maintenance cost of electric heater is about BDT 1000 to 2000 whereas there is no requirement for maintenance of solar water heater.

### VI. CONCLUSION

Throughout this paper, the operating temperature of automatic solar water heater is determined to be 50 degree Celsius. Since most of the users use hot water for their domestic purpose where the requirement is about 50 degree Celsius, this point has been considered as the second reason of the operating temperature as 50 degree Celsius for our solar hot water system. Beside this, the cost analysis shows us that using solar water heater instead of electric water heater is more beneficial for the users for its cost effectiveness.

### REFERENCES

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### TABLE II. AMOUNT OF HOT WATER AND ENERGY COLLECTED BY THE AUTOMATIC SOLAR HOT WATER SYSTEM

<table>
<thead>
<tr>
<th>Month</th>
<th>Isolation kWh/sq.m/day</th>
<th>Total hr/day hrs</th>
<th>Total energy from the sun kWh/day</th>
<th>Area of collector sq. m</th>
<th>Days per month</th>
<th>Energy gained per month in Wh</th>
<th>Energy gain per month in Joule</th>
<th>Amount of hot water produced Liters</th>
<th>Amount of hot water per day Liters</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>4.09</td>
<td>13</td>
<td>8.1391</td>
<td>1.99</td>
<td>31</td>
<td>2.49E+06</td>
<td>8.97E+09</td>
<td>9623.661961</td>
<td>310.4407084</td>
</tr>
<tr>
<td>August</td>
<td>4.2</td>
<td>12</td>
<td>8.358</td>
<td>1.99</td>
<td>31</td>
<td>2.49E+06</td>
<td>8.97E+09</td>
<td>9891.250127</td>
<td>319.0725847</td>
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<td>September</td>
<td>3.95</td>
<td>12</td>
<td>7.8605</td>
<td>1.99</td>
<td>30</td>
<td>2.49E+06</td>
<td>9E+09</td>
<td>8705.283256</td>
<td>290.1761085</td>
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<td>October</td>
<td>4.43</td>
<td>11</td>
<td>8.8157</td>
<td>1.99</td>
<td>31</td>
<td>2.51E+06</td>
<td>9.05E+09</td>
<td>9395.896966</td>
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<tr>
<td>November</td>
<td>4.37</td>
<td>10</td>
<td>8.6963</td>
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<td>30</td>
<td>2.54E+06</td>
<td>9.15E+09</td>
<td>7970.546868</td>
<td>265.6841562</td>
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<tr>
<td>December</td>
<td>4.07</td>
<td>10</td>
<td>8.0993</td>
<td>1.99</td>
<td>31</td>
<td>2.56E+06</td>
<td>9.23E+10</td>
<td>7025.330871</td>
<td>226.6235765</td>
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<tr>
<td>January</td>
<td>4.29</td>
<td>10</td>
<td>8.5371</td>
<td>1.99</td>
<td>31</td>
<td>2.26E+06</td>
<td>9.24E+09</td>
<td>7261.176037</td>
<td>234.2314851</td>
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<tr>
<td>February</td>
<td>5.18</td>
<td>11</td>
<td>10.3082</td>
<td>1.99</td>
<td>28</td>
<td>2.54E+06</td>
<td>9.15E+09</td>
<td>8818.038906</td>
<td>314.9296609</td>
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<tr>
<td>March</td>
<td>5.96</td>
<td>12</td>
<td>11.8604</td>
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<td>31</td>
<td>2.50E+06</td>
<td>9.03E+09</td>
<td>13025.73655</td>
<td>420.185050</td>
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<tr>
<td>April</td>
<td>5.83</td>
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<td>427.186607</td>
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<tr>
<td>May</td>
<td>5.28</td>
<td>13</td>
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<tr>
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<td>344.6171713</td>
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