DESIGN AND CONSTRUCTION OF A SOLAR COLLECTOR WATER HEATER

A thesis
by

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ABSTRACT

This thesis presents the design and construction of a solar collector water heater system utilizing low-cost materials and passive solar heating principles. The system was developed using homemade heat pipes fabricated from 3/8" copper tubes filled with ethanol and sealed with an oil separator as a condenser unit. These heat pipes were housed inside cleaned fluorescent light tubes to create a simple and effective thermal insulation shell. The heat pipes transfer solar heat to a horizontal HDPE header pipe, which is connected to an insulated plastic tank using 3/8-inch flexible hose pipes. A 12V DC water pump, powered by a 30W solar panel, circulates water through a closed loop whenever sufficient sunlight is available, eliminating the need for external power or controllers. Additionally, a 6-channel temperature monitoring system was developed using Arduino UNO and 104 NTC thermistors, enabling real-time monitoring of system performance at key thermal points, such as the header, tank, and ambient air. All major components, including the heat pipes, tank, header, and control system, were assembled into a single functional unit supported by a custom-built frame oriented for optimal solar exposure. While the current design meets small-scale hot water needs, this paper also proposes future enhancements, including evacuated tubes, automated control, IoT integration, and hybrid heating capabilities. The result is a cost-effective, scalable, and sustainable solution that has the potential to serve as a practical water heating system in rural, off-grid, or educational settings.

CERTIFICATION

This thesis entitled as "Design And Construction Of A Solar Collector Water Heater" submitted by the group as mentioned below has been accepted as satisfactory as a part of the requirements in order to complete the B.Sc. degree at the Department of Mechanical Engineering, Sonargaon University, Bangladesh. This paper embodies the original work done under my super vision.

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Chapter 1
INTRODUCTION

1.1 Background

With the global shift toward renewable energy, solar energy has emerged as one of the most promising and widely accessible sources of clean power. The sun radiates approximately 173,000 terawatts of energy continuously, far exceeding the total energy demand of humanity. Solar thermal technology, in particular, offers a practical means to harness this energy for various applications, such as cooking, electricity generation, and especially water heating. Solar water heating systems use solar energy to raise the temperature of water, reducing the need for conventional fossil fuels or electricity. These systems are especially effective in regions with abundant sunshine. The concept of solar water heating is not new; however, the affordability, efficiency, and ease of fabrication are often limiting factors for wide-scale adoption in developing countries. In this context, heat pipe-based solar water heaters offer a high-efficiency method of capturing and transferring solar heat to water. Heat pipes use the principle of phase change and latent heat transfer to move heat with minimal temperature difference, making them ideal for low-cost and high-performance solar collectors.

1.2 Motivation

Many commercial solar water heaters rely on flat plate collectors or evacuated tubes, which, although effective, can be expensive, fragile, or not readily available in rural and developing areas. Moreover, mass-produced components often require specialized maintenance or replacement parts, which adds to long-term costs and dependency on external suppliers. Our motivation for this project stemmed from the desire to develop a cost-effective, sustainable, and easily repairable solar water heater using locally available materials. By utilizing components such as copper pipes, household oil separators, plastic containers, and basic electronics, we aimed to create a system that could be fabricated through simple, hands-on methods. This approach ensures that the design is accessible and replicable by students, technicians, or individuals with basic fabrication skills. A key objective was to demonstrate the effectiveness of custom-

fabricated heat pipes as a viable alternative to commercially available evacuated tubes. Additionally, we integrated a real-time temperature monitoring system using Arduino and NTC sensors, enhancing the system's educational value while bringing a modern, data-driven aspect to its functionality. This project not only serves practical domestic applications but also encourages innovation and technical learning at the undergraduate level.

1.3 Problem Statement

The primary challenges addressed in this project are outlined as follows:

1. To design an innovative solar water heating system that utilizes heat pipe technology and real-time monitoring, offering improved efficiency over traditional designs.
2. To fabricate the system using locally available and repurposed materials, such as copper pipes, household oil separators, and plastic containers, making it practical and accessible for low-resource settings.
3. To ensure the solution remains cost-effective, minimizing reliance on expensive or imported components while maintaining reliability and ease of maintenance.
4. To compare the performance and practicality of the custom-fabricated heat pipe system with conventional solar collector technologies, highlighting the advantages in design simplicity, thermal response, and repairability.

1.4 Objectives

The primary objective of this thesis is to design and construct a fully functional solar collector water heater that integrates custom-fabricated copper heat pipes filled with ethanol, a solar-powered circulation pump operating in a closed-loop system, and a low-cost temperature monitoring setup built using Arduino and basic electronic components. The system makes use of reused and repurposed materials, including fluorescent light tubes and oil separators sourced from old refrigerators, with a strong emphasis on simplicity, efficiency, and reproducibility. The final design aims to function entirely off-grid, requiring no connection to conventional electricity, while

remaining affordable, easy to maintain, and thoroughly documented so that it can be replicated by students, researchers, or individuals seeking practical and sustainable heating solutions.

1.5 Scope of the Project

The scope of this project is strictly focused on the design and construction of a functional solar water heating system. It includes the selection of materials based on thermal properties and local availability, fabrication of custom heat pipes using standard workshop tools, integration of a header pipe and a solar-powered circulation system, development of an insulated water tank, and the design and implementation of a temperature monitoring system. All components were assembled into a working prototype. However, the project does not cover extensive performance testing, long-term durability evaluation, or cost optimization beyond initial material selection. While these aspects remain outside the current scope, the system has been constructed with them in mind, allowing for potential future enhancements or research extensions.

Chapter 2
Literature Review

Solar water heating is a well-established technology that has been extensively researched for residential, industrial, and institutional applications. Among the numerous technologies, heat pipe-based collectors have shown considerable promise due to their high efficiency, ease of orientation, and thermal reliability. This chapter summarizes previous academic work relevant to heat pipe solar water heaters, working fluids, monitoring systems, and material choices.

Faghri discussed comprehensive theories and applications of heat pipes, explaining their functionality as passive thermal conductors [2]. Shatikian et al. conducted simulations on evacuated tube collectors using heat pipes and found that proper configuration could significantly improve heat transfer and energy retention [3]. Mahendran et al. experimentally compared various working fluids in heat pipes and confirmed ethanol's effectiveness due to its low boiling point and high latent heat [4]. Zhang et al. examined the performance of flat heat pipes and suggested that proper fluid volume and internal structure could significantly affect thermal response, aligning with our own experiments on ethanol volume optimization [5]. Tian and Zhao further supported the use of heat pipes for their high efficiency in thermal storage systems [6]. Kalogirou provided a foundational review of solar thermal systems and collector designs. His work emphasized the evolution from flat-plate to evacuated tube designs, laying the groundwork for modern custom-fabricated collector types [1]. Duffie and Beckman detailed mathematical models and efficiency calculations, essential for any solar system design and useful for benchmarking our own system [7].

Pal and Ghosh developed a cost-effective water heater using local components, similar in spirit to our design philosophy. Their work demonstrates that simplicity and practicality can coexist with performance [9]. Kumar and Prakash also analyzed a heat pipe-based solar water heater and highlighted the importance of fluid choice and collector orientation [8].

Our use of Arduino-based monitoring is supported by the popularity of microcontroller systems in recent research. The Arduino Uno's compatibility with thermistors, LCDs, SD card modules, and solar-powered circuits has made it a go-to choice for low-cost, modular monitoring systems [10], [11].

Using NTC 104 thermistors and SD card modules, our design draws inspiration from practical guides and aligns with real academic implementations. These systems enhance the educational value and allow real-time observation and data logging of thermal behavior.

Rahman and Khan highlighted the urgent need for localized, renewable energy solutions in developing nations. Their insights support the objective of using recycled and repurposed components such as oil separators, fluorescent tubes, and HDPE containers [13]. Arora also discussed oil separators in refrigeration, supporting their alternate use as passive condensers in heat pipes [12].

Alminderej and Alghamdi presented a solar heater using simple materials and helical coils, reinforcing the feasibility of do-it-yourself approaches [14]. Khan and Islam similarly demonstrated the practicality of designing and constructing local solar collectors for low-cost implementation [15].

The reviewed literature provides strong justification for the selection of ethanol-filled heat pipes, low-cost solar-powered circulation, and Arduino-based monitoring. It also affirms the potential of locally sourced materials to construct efficient and reproducible solar water heating systems, making our project both academically relevant and socially impactful.

Chapter 3
DESIGN AND CONSTRUCTION

3.1 Schematic Design

The solar collector water heater was designed around the concept of heat pipe technology integrated into a simple, closed-loop water circulation system. Each copper heat pipe was fabricated in-house and installed inside a cleaned fluorescent light tube, acting as a protective housing. The condenser ends of the heat pipes were fitted into an HDPE header pipe, which carried the heat to the circulating water.

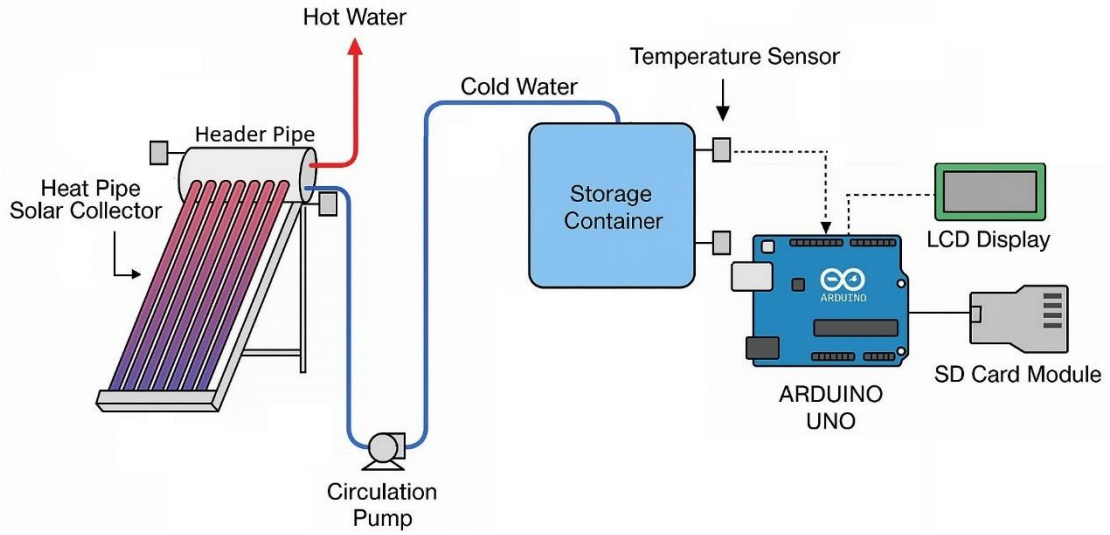


Figure 1: Schematic of the full setup

An insulated plastic tank was used to store water. Water circulated from the tank to the header pipe via a 12V DC pump powered by a solar panel, enabling an entirely off-grid system. A six-channel temperature monitoring system was included to track thermal performance. The layout was optimized to minimize height differences, with the header pipe above the tank and all pipes aligned for efficient thermal conduction and water flow.

3.2 Material Selection

The selection of materials for this project was guided by key factors such as thermal conductivity, mechanical strength, corrosion resistance, ease of fabrication, cost, and

local availability. Each component was carefully chosen to ensure that the overall system remained efficient, durable, and feasible for low-cost replication.

a. HDPE Header Pipe



Figure 2: Completed header pipe

We used a High-Density Polyethylene (HDPE) pipe due to the following reasons:

Sl no	Property	Value / Description
1	Thermal Resistance	Up to ~100°C short-term use
2	Chemical Resistance	High resistance to most chemicals
3	Cost	Low and widely available
4	Ease of Use	Can be drilled, bonded, and sealed easily
5	Flexibility	Reduces risk of cracking under pressure

Pipe Size:

- Outer diameter: 2 inch
- Wall thickness: ~2–3 mm

HDPE was chosen for the header pipe due to its low cost, ease of installation, and chemical resistance. Despite its lower thermal conductivity, its use was justified by its role as a medium, not a heat exchanger.

b. Copper Pipes (3/8 inch)

Copper was used for constructing the heat pipes, as it is one of the best thermal conductors among metals. Its properties make it ideal for transferring heat rapidly from the absorber region to the condenser region.



Figure 3: Copper pipe 3/8 inch

- Thermal Conductivity: ~385 W/m·K — ensures quick transfer of heat.
- Tensile Strength: 210–250 MPa (annealed); provides adequate structural stability.
- Melting Point: 1085°C — can withstand brazing and high thermal loads.
- Corrosion Resistance: Copper resists corrosion in water and ethanol, making it safe and long-lasting.
- Workability: Easily cut, bent, and brazed with standard tools.

c. Ethanol (99.99% Pure)

Used as the working fluid inside the heat pipes, ethanol offers many benefits:
- Boiling Point: 78.37°C — evaporates easily in sunlight, even at relatively low temperatures.
- Latent Heat of Vaporization: ~846 kJ/kg — stores and transfers a significant amount of thermal energy.
- Non-corrosive: Safe for use with copper.
- Availability: Easy to obtain and handle under controlled conditions.

Ethanol volumes from 1 ml to 5 ml were tested, with 1.5 ml providing the most consistent and efficient heat transfer.



Figure 4: bottle of 99.99% pure ethanol

d. Oil Separators (Refrigerator Type)

These are sealed copper containers originally used in refrigeration systems to separate oil from refrigerant. In our design, they function as the condenser section of the heat pipes.



Figure 5: Oil separator

- Material: Copper
- Durability: High-pressure tolerance and long-term sealed performance

Their shape and sealed design allowed safe containment of ethanol vapors while providing adequate surface area for heat rejection to the water flowing through the header.

e. Fluorescent Light Tubes

These glass tubes, originally used for lighting, were cleaned internally and repurposed to house each heat pipe.

- Material: Borosilicate or soda-lime glass
- Length: 4 ft
- Function: Protects the copper pipe and provides a quasi-insulated enclosure
- Preparation: Internal white phosphor coating was removed using dry sand to ensure transparency and avoid contamination



Figure 6: Discarded old Florescent tube lights

Their cylindrical, transparent structure offered a basic greenhouse effect and structural protection for the inner copper pipe.

f. Plastic Water Tank

A transparent plastic storage box was used as the water tank, chosen for its portability and insulation potential. Specification:



Figure 7: 120L Plastic water tank

Sl no	Property	Value / Description
1	Material	High-density Polypropylene (PP)
2	Thermal Conductivity	~0.2 W/m·K (low, good for insulation)
3	Operating Temp Range	-20°C to ~90°C
4	Water Resistance	Excellent
5	Structural Integrity	Durable under medium load & temperature
6	Portability	Foldable & lightweight

3.3 Components

The electrical and electronic components used in this project were selected to ensure full off-grid functionality, affordability, and simplicity in design. The components not only power the system but also monitor its performance. Below are the main subsystems and their specifications:

a. 12V DC Water Pump

We used a 12V DC mini submersible water pump, which is compact, energy-efficient, and well-suited for low-pressure, small-scale water circulation systems like our solar water heater. This pump enables water to move in a closed-loop system — from the insulated tank to the header pipe and back. Pump Specs:



Figure 8: 12V DC Water Pump

Sl no	Parameter	Value / Description
1	Operating Voltage	12V DC
2	Power Source	30W solar panel (Through charge controller)
3	Flow Rate	~5–10 L/min (open flow)
4	Max Lift Height	5 meters
5	Current Draw	1.1 A
6	Body Material	ABS plastic (waterproof)
7	Connection Type	3/8 inch hose barbs

- Functionality: The pump automatically turns on during daylight hours when the solar panel produces sufficient voltage.
- Design Benefit: Keeps the system passive and energy-efficient, relying solely on sunlight to initiate water circulation.
- Sustainability: No grid electricity or backup battery is required.

b. Solar Panel

A 30W monocrystalline solar panel was used to power the water pump. The panel was chosen to match the pump's operating requirements and to avoid the complexity of energy storage systems. It provides consistent power under good sunlight conditions and integrates seamlessly with the system. Solar Panel Specifications:



Figure 9: 30W solar panel

Sl no	Parameter	Value / Description
1	Output Voltage	17–21V (open)
2	Rated Voltage	12V (regulated)
3	Power Output	30W
4	Usage	Directly powers pump (no battery)

- Type: Monocrystalline panel for high efficiency
- Mounting: Positioned at an angle optimized for local latitude to maximize exposure
- Direct Connection: Eliminates the need for charge controllers or batteries
- Environmental Advantage: Fully renewable operation, aligned with sustainability goals

c. Arduino Uno

The Arduino Uno microcontroller acts as the brain of the temperature monitoring system. It reads data from the thermistors, processes the analog signals, and outputs real-time temperatures through serial communication or display.

- Role in System: Reads voltage from NTC sensors using analog pins and calculates temperature values.



Figure 10: Arduino UNO

- Why Chosen: Reliable, easy to program, and supported by a large open-source ecosystem.

- Power: Runs off the 5V power bank circuit.

Specifications:

Sl no	Parameter	Value / Description
1	Microcontroller	ATmega328P
2	Operating Voltage	5V (USB or regulated external supply)
3	Analog Inputs	6 (used for six temperature sensors)
4	Flash Memory	32 KB
5	Clock Speed	16 MHz
6	Communication	USB, UART, I2C, SPI

d. 104 NTC Thermistor

We used six 104 NTC (Negative Temperature Coefficient) thermistors, each with a nominal resistance of 100kΩ at 25°C. These sensors are ideal for simple and low-cost temperature measurement. Specifications:

Sl no	Parameter	Value / Description
1	Nominal Resistance	100kΩ at 25°C
2	Type	NTC (resistance decreases with heat)
3	Temperature Range	-40°C to +125°C
4	Accuracy	±1°C (with calibration)
5	Wiring	2-pin, connected in voltage divider



Figure 11: NTC Thermistor 104

- Placement: Sensors were attached to:
  - Header inlet and outlet
  - Tank Top and bottom

- Data Handling: Thermistor readings were converted to temperature using formula provided by NTC Data sheet given below

$$R_{TH} = R_{25} \times \exp\left\{B\left(\frac{1}{T} - \frac{1}{T_{25}}\right)\right\}$$

e. Micro SD Card Adapter

A Micro SD Card Adapter Module (v1.1) was used to store temperature data logs for future analysis or reference. This module allows the Arduino to write data to a microSD card using the SPI interface. Specifications:

Sl no	Parameter	Value / Description
1	Operating Voltage	3.3V to 5V
2	Interface	SPI
3	Card Support	FAT16/FAT32 formatted microSD (up to 32 GB)
4	Pins	CS, SCK, MOSI, MISO, VCC, GND

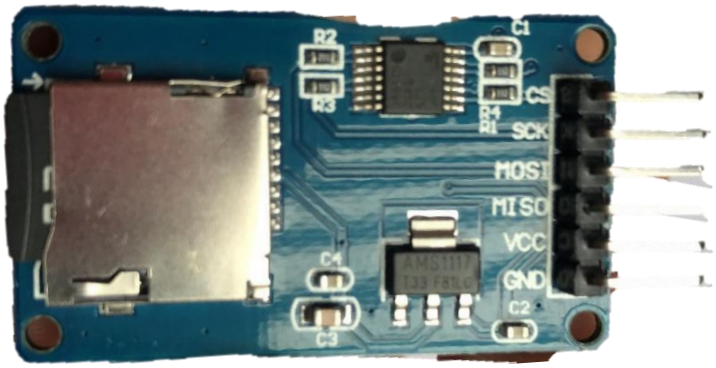


Figure 12: SD Card Module

- Function: Stores temperature data from all six thermistors at regular intervals.
- Benefits: Makes it possible to review historical performance without a constant display or connection.
- Power: Powered via Arduino 5V pin.

f. LCD Display 16x2

We integrated a 16x2 Character LCD Display to show real-time temperature readings from the sensors. It provides immediate visual feedback for users without needing a computer. Specifications:



Figure 13: 16x2 LCD Display

Sl no	Parameter	Value / Description
1	Display Type	Alphanumeric
2	Operating Voltage	5V
3	Interface	Parallel (4-bit or 8-bit)
4	Backlight	LED (white or green)

g. 18650 Battery

To ensure continuous operation of the monitoring system even during low sunlight, we used a 3.7V 18650 Li-ion rechargeable battery.

- Function: Acts as backup power for Arduino and logging/display modules.
- Safety: Used with a protection circuit to prevent over-discharge.

Specifications:

Sl no	Parameter	Value / Description
1	Voltage	3.7V nominal (4.2V full)|
2	Capacity	~2200–3000 mAh
3	Rechargeable	Yes
4	Dimensions	18mm × 650mm



Figure 14: 18650 Li-ion Batteries

h. Boost converter Circuit

A 5V 1A USB Power Bank Circuit was used to boost 3.7V from the battery to 5V, suitable for Arduino and peripherals.



Figure 15: Power bank circuit

i. PWM Solar Charge Controller

A 10A PWM Solar Charge Controller was used to safely manage power from the solar panel to the battery. Specifications:

Sl no	Parameter	Value / Description
1	Max Charging Current	10A
2	System Voltage	12V
3	Charging Type	PWM
4	Load Output	12V / 5V



Figure 16: PWM Solar Charge Controller

3.4 Final Assembly

a. Heat Pipe Insertion into Glass Enclosure

The initial step in the final assembly involved enclosing each fabricated copper heat pipe inside a transparent glass tube to protect it from the environment and retain heat. For this, used fluorescent light tubes were repurposed. These tubes were first cleaned from the inside by removing the white phosphorescent coating using dry sand, which was poured into the tube and shaken thoroughly to scrub the interior surface. One end of each tube was intentionally broken open, while the other remained sealed. The copper heat pipe, with its condenser end connected to the oil separator, was carefully

inserted into the cleaned glass tube from the broken end. The assembly was sealed at the broken end using a waterproof and heat-resistant epoxy compound called "M-Seal" to prevent any moisture, dust, or air from entering. The sealed arrangement created a simple yet effective enclosure that mimicked the function of a vacuum tube in commercial solar heaters, allowing efficient heat transfer and protection from weather exposure.

b. Mounting Heat Pipes in an Array

Once enclosed, the heat pipes were arranged in a linear array for uniform solar exposure. A total of ten heat pipes were used. They were mounted on a supporting frame at an angle of approximately 30 to 35 degrees, optimized for the geographic latitude to maximize solar gain throughout the day. Each heat pipe was aligned parallel to ensure consistent heating and minimal shading. The orientation of the pipes was chosen such that the condenser end—fitted with the oil separator and positioned at the bottom—faced downwards, while the evaporator end containing the ethanol was exposed to solar radiation at the top. This setup allowed the ethanol inside each heat pipe to evaporate, rise, condense at the bottom, and then return via gravity, establishing an effective heat transfer cycle.

c. Header Pipe Integration

The condenser ends of the heat pipes were connected to a common horizontal HDPE pipe, which served as the header pipe for water circulation. The HDPE pipe was chosen for its thermal resistance, lightweight nature, and ease of fabrication. It was mounted slightly above the tank water level to facilitate closed-loop circulation. The copper condensers were connected to the header via 3/8-inch flexible hose pipes, which were secured tightly without threads, using sealing clamps techniques. Care was taken to ensure the header pipe was properly aligned and sealed at every connection point to prevent leaks or flow resistance. The header acted as the heat exchanger, receiving thermal energy from the heat pipes and transferring it to the circulating water.

d. Water Tank and Circulation System

A durable plastic cargo storage box, typically used for household purposes, was modified and repurposed as the water storage tank. The box was externally insulated using locally available insulating materials to reduce heat loss. Two hose connections

were made to the tank: one for sending water to the header pipe and another for returning it after heating. Because the header pipe was positioned higher than the water level in the tank, natural convection alone could not maintain circulation. Therefore, a 12V DC water pump was installed to move the water through the loop. The pump was connected directly to a 30W solar panel, allowing it to operate only during daylight hours when solar heating was active. The flow of water was continuous during sunlight, forming a simple closed-loop circulation system that did not require grid electricity or external intervention.

e. Temperature Monitoring System

To enable real-time performance tracking, a custom-built temperature monitoring system was integrated into the design. This system used an Arduino Uno microcontroller as the main processor, interfaced with six 104-type NTC thermistors placed at strategic points in the setup. These points included the water inlet and outlet of the tank, the center of the HDPE header pipe, two separate heat pipe condensers, and the surrounding ambient air to compare thermal gain. The Arduino collected analog data from the sensors and processed it into temperature readings. The readings were displayed on a 16x2 character LCD module for quick visual reference. For data logging purposes, a Micro SD card adapter module was connected to the Arduino via SPI, allowing the system to store timestamped temperature readings for later analysis. The monitoring system was enclosed in a protective casing and installed near the tank for easy access.

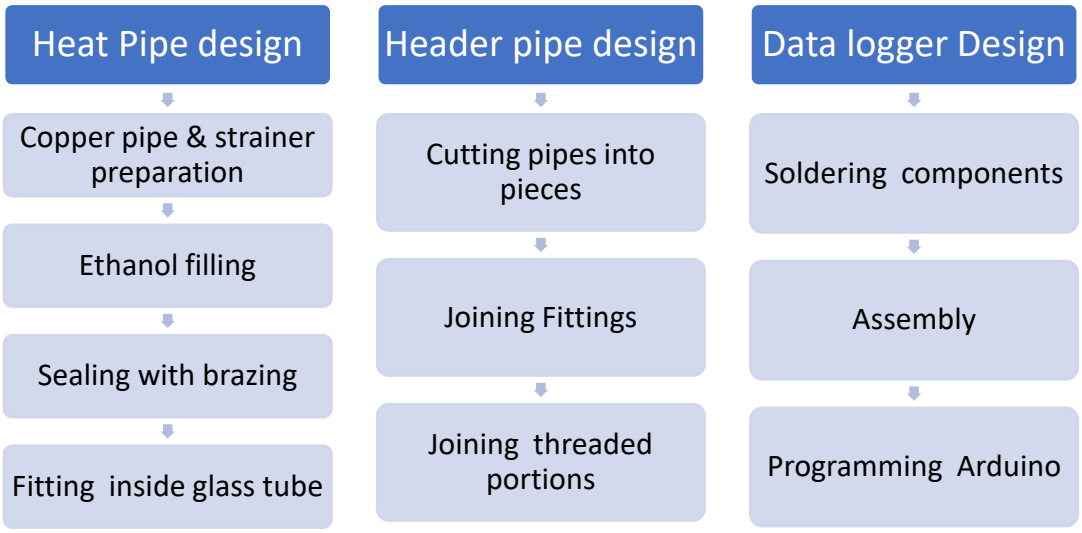
f. Power Supply and Control System

To power the Arduino and monitoring electronics independently from the main pump, a dedicated off-grid power system was built using a rechargeable 18650 lithium-ion battery pack. The battery was connected to a compact power bank circuit that stepped up its voltage to a stable 5V output suitable for Arduino and its peripherals. To manage charging from the same 30W solar panel used for the water pump, a 10A PWM solar charge controller was employed. This controller regulated the voltage and current to safely charge the battery while also offering short-circuit and overcharge protection. The entire power supply system was built to operate autonomously, using only solar energy, ensuring full independence from the electrical grid and seamless integration with the main heater operation.

Chapter 4
METHODOLOGY

4.1 Flow Chart

To clearly visualize the development of the solar water heater system, a structured methodology was followed, beginning from conceptualization and ending with a functional prototype. The flow chart of the entire process includes the following key stages: identifying the need and feasibility of a solar-based water heating system; researching existing technologies and limitations; selecting locally available materials; designing and fabricating custom heat pipes; building the structural frame and enclosure; integrating the circulation and monitoring systems; and finally, testing the complete unit for operational consistency. Each stage of the flow was crucial and built upon the outcomes of the previous one. The chart represents a logical progression from theoretical planning to practical execution, ensuring systematic development and eliminating random trial-and-error approaches.



4.2 Steps

The development of the solar collector water heater was carried out in multiple sequential steps, each carefully planned to ensure structural, thermal, and functional integrity. Below is a detailed description of each step involved in the project:

Step 1: Design Planning and System Layout

The project began with designing the complete layout of the system. This included selecting the orientation and number of heat pipes, determining the position of the header pipe, planning the flow of water, and incorporating an electronic temperature monitoring system. Sketches and schematics were prepared to guide the fabrication process.

Step 2: Material Selection and Sourcing

All materials were selected based on their thermal properties, local availability, and cost-effectiveness. Copper pipes, fluorescent light tubes, HDPE pipe, household oil separators, hose pipes, electronic components (Arduino, thermistors, LCD), and other hardware were gathered from local suppliers and repurposed devices.

Step 3: Fabrication of Heat Pipes

Each heat pipe was made from 4-foot-long 3/8-inch copper tubes. The bottom end was fitted with an oil separator and sealed with brazing. Ethanol (1.5 ml) was poured into the pipe through the open end. The ethanol was gently heated to vaporize and displace air and moisture. Once vapor pressure was felt, the top was sealed using a custom end cap and brazing. A total of ten such pipes were fabricated.



Figure 17:1st Short prototype of heat pipe



Figure 18: Preparation of oil separators for the heat pipes



Figure 19: Brazing process of heat pipe construction



Figure 20: Testing heat pipes in the sun



Figure 21: Ready bare heat pipe and header pipes

Step 4: Cleaning and Preparing Glass Enclosures

Fluorescent light tubes were repurposed to act as enclosures for the copper heat pipes. The white powder coating inside was removed using dry sand. One end was broken open, and the cleaned tubes were washed and dried thoroughly.

Step 5: Inserting and Sealing Heat Pipes in Tubes

The fabricated copper heat pipes were inserted into the glass tubes, and the broken ends were sealed using M-Seal epoxy. The condenser (bottom) end of the copper pipe remained outside, while the evaporator (top) part remained exposed inside the glass for solar absorption.



Figure 22: Heat pipes inserted in glass tubes

Step 6: Pipe Mounting Frame

A frame was used to hold all ten heat pipes in a stable, angled position (approx. 30–35°). This ensured uniform solar exposure throughout the day. The pipes were mounted securely in parallel alignment on the frame.

Step 7: Integration of Header Pipe

An HDPE header pipe was positioned horizontally above the tank and connected to the tank 3/8-inch flexible hose pipes. Jubilee clamps were used to ensure leak-proof connections.

Step 8: Preparation of Water Tank

A plastic cargo storage box was chosen as the water tank. The box could be externally insulated using locally available insulating materials like foam or thermal blankets. Two ports were added for inlet and outlet connections.

Step 9: Setting Up the Circulation System

A 12V DC water pump was installed to circulate water from the tank to the header pipe and back in a closed loop. The pump was connected directly to a 30W solar panel so that it only operates in sunlight, syncing water flow with heating hours.

Step 10: Building the Temperature Monitoring System

An Arduino Uno was programmed to read temperature values from six 104 NTC thermistors placed at key positions. The readings were displayed on a 16x2 LCD and logged into a microSD card using a dedicated adapter module.



Figure 23: Temperature monitoring system

Step 11: Assembling the Power System for Electronics

A power bank circuit was built using an 18650 rechargeable battery, regulated via a PWM solar charge controller connected to the same solar panel. This provided a constant 5V supply for the Arduino and sensor modules.

Step 12: Final System Integration and Testing

All components were connected: the heat pipes, header, tank, circulation system, and electronic monitor. The entire system was tested for water flow, sealing, power function, and temperature logging. Adjustments were made wherever necessary to ensure smooth operation.



Figure 24: Installation of the whole system



Figure 25: Complete system left for data collection

4.3 How the System Works

a. Heat Pipe Operation

The primary heat transfer mechanism in this system is the ethanol-filled copper heat pipe. Each pipe absorbs solar radiation on its exposed evaporator section, causing the ethanol inside to vaporize due to its low boiling point. The ethanol vapor then travels upward to the condenser section, which is fitted with an oil separator and remains relatively cooler. As the vapor releases latent heat at the condenser, it condenses back into liquid form and returns to the evaporator via gravity. This cycle repeats

continuously, providing efficient, passive heat transfer with no moving parts or external energy.

b. Heat Exchange through the Header Pipe

The condenser ends of all ten heat pipes are connected to a horizontal HDPE header pipe using unions. As the ethanol vapor condenses inside the heat pipes, heat is transferred to the water flowing inside the header pipe. The header acts as a manifold where water absorbs heat from all heat pipes simultaneously. This indirect heating method ensures even thermal distribution without exposing the water directly to the sun, improving efficiency and reducing water contamination risks.

c. Water Circulation System

It is possible to circulate water between the insulated storage tank and the header pipe in a closed loop. A 12V DC pump can be used to drive the circulation and is powered directly by a 30W solar panel. The pump activates only when sufficient sunlight is available, syncing water flow with solar heating. Water is drawn from the bottom of the tank to the header pipe, absorbs heat, and then returns to the top of the tank. This method maintains a continuous heat exchange cycle without any need for manual control or external electricity. Our current setup uses the pump to deliver the water directly to user after heating.

d. Electronic Monitoring and Data Logging

To monitor system performance, a real-time temperature monitoring setup is integrated using an Arduino Uno microcontroller. Four 104 NTC thermistors are placed at critical points including the water inlet and outlet of the header pipe and Top and bottom of the water tank. The Arduino collects temperature data and displays it on a 16x2 LCD display. Simultaneously, the data is logged onto a microSD card via an adapter module for later analysis. The entire monitoring system is powered independently using an 18650 battery regulated through a boost converter circuit, ensuring continuous operation.

e. Fully Off-Grid, Self-Sustained Operation

The complete system is designed to function without reliance on grid electricity. Solar energy powers both the thermal and electronic subsystems. Water heating, circulation, and monitoring are entirely solar-driven, making the system ideal for rural or off-grid environments. The use of locally available materials and simple construction methods enhances its scalability, maintainability, and educational value.

Chapter 5
RESULTS AND DISCUSSION

5.1 Graphs and Observations

Although this project focused on the design and construction aspects, preliminary observations and temperature trends were recorded using the integrated temperature logging system. The system, equipped with four thermistors, captured real-time temperature readings throughout a typical sunny day.

The following trends were observed:

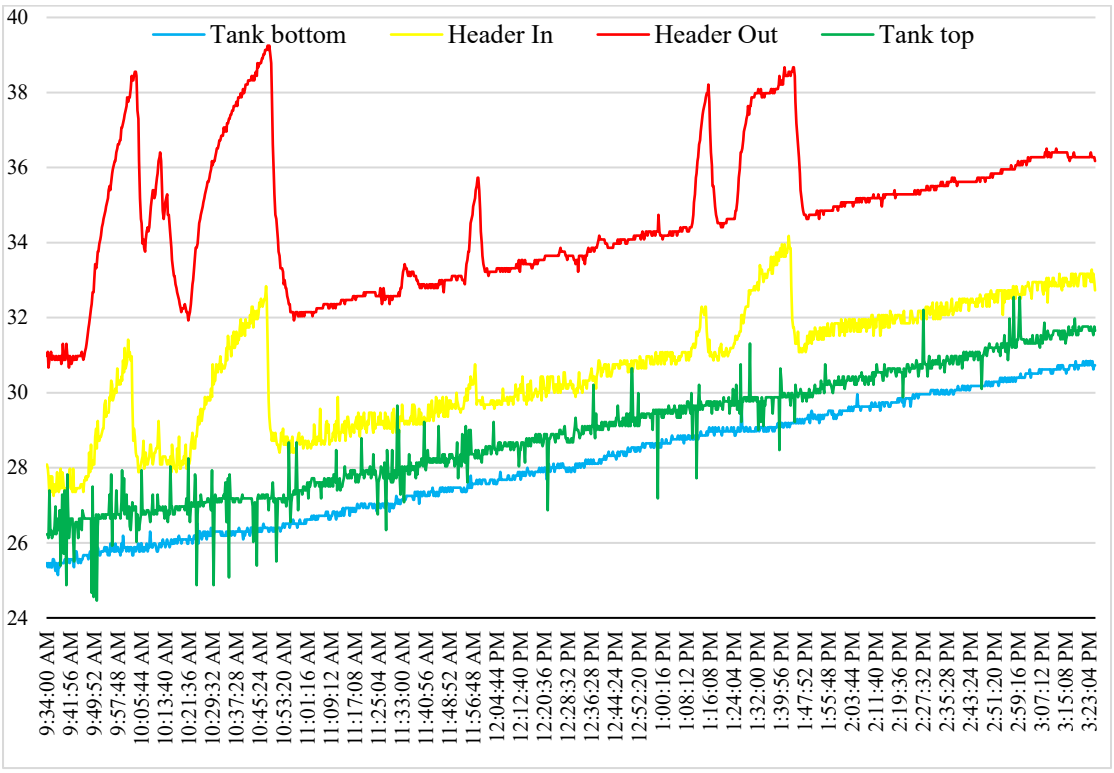
- Heat pipe surface temperatures began rising within 10–15 minutes of solar exposure.
- Header pipe water temperature gradually increased from ambient (~25°C) to around 36–40°C on sunny days.
- The temperature difference between inlet and outlet indicated effective heat exchange.

Data observed from the logger on a random day is given in the table below

Sl No	Time	Tank bottom (°C)	Tank Top (°C)	Header in (°C)	Header out (°C)	Header in-out difference (°C)	Increase in temperature (°C)
1	9:34:00 AM	25.46	26.23	28.09	30.98	2.89	5.52
2	9:41:56 AM	25.56	26.65	27.46	30.88	3.42	5.32
3	9:49:52 AM	25.67	26.65	28.09	33	4.91	7.33
4	9:57:48 AM	25.88	26.76	30.22	36.62	6.4	10.74
5	10:05:44 AM	25.98	27.93	28.19	34.52	6.33	8.54
6	10:13:40 AM	25.88	26.97	28.3	35.07	6.77	9.19
7	10:21:36 AM	26.19	26.97	28.09	32.04	3.95	5.85
8	10:29:32 AM	26.19	26.87	30.76	36.06	5.3	9.87
9	10:37:28 AM	26.3	27.18	31.63	37.75	6.12	11.45
10	10:45:24 AM	26.4	27.18	32.29	38.78	6.49	12.38
11	10:53:20 AM	26.51	27.29	28.62	32.89	4.27	6.38
12	11:01:16 AM	26.62	27.61	28.51	32.15	3.64	5.53
13	11:09:12 AM	26.72	27.61	28.72	32.36	3.64	5.64
14	11:17:08 AM	26.83	27.93	29.15	32.57	3.42	5.74
15	11:25:04 AM	27.04	27.61	29.36	32.57	3.21	5.53
16	11:33:00 AM	27.15	28.04	29.68	33	3.32	5.85
17	11:40:56 AM	27.25	27.93	29.25	32.79	3.54	5.54
18	11:48:52 AM	27.36	28.36	29.57	33	3.43	5.64
19	11:56:48 AM	27.57	28.36	30.22	34.96	4.74	7.39
20	12:04:44 PM	27.57	28.36	29.79	33.32	3.53	5.75
21	12:12:40 PM	27.68	28.47	30.22	33.43	3.21	5.75
22	12:20:36 PM	28	28.9	30.11	33.54	3.43	5.54
23	12:28:32 PM	27.89	28.79	30.11	33.65	3.54	5.76
24	12:36:28 PM	28.11	29.11	30.65	33.86	3.21	5.75

Sl No	Time	Tank bottom (°C)	Tank Top (°C)	Header in (°C)	Header out (°C)	Header in-out difference (°C)	Increase in temperature (°C)
25	12:44:24 PM	28.32	29.11	30.76	33.97	3.21	5.65
26	12:52:20 PM	28.54	29.11	30.65	34.19	3.54	5.65
27	1:00:16 PM	28.65	29.55	31.08	34.08	3	5.43
28	1:08:12 PM	28.76	29.55	30.86	34.41	3.55	5.65
29	1:16:08 PM	28.97	29.66	30.97	37.07	6.1	8.1
30	1:24:04 PM	29.08	29.66	31.3	34.63	3.33	5.55
31	1:32:00 PM	29.08	29.88	32.95	37.98	5.03	8.9
32	1:39:56 PM	29.19	30.32	33.62	38.21	4.59	9.02
33	1:47:52 PM	29.3	29.99	31.3	34.74	3.44	5.44
34	1:55:48 PM	29.52	30.32	31.52	34.85	3.33	5.33
35	2:03:44 PM	29.52	30.43	31.96	35.07	3.11	5.55
36	2:11:40 PM	29.63	30.54	31.74	35.18	3.44	5.55
37	2:19:36 PM	29.85	30.65	32.07	35.29	3.22	5.44
38	2:27:32 PM	29.96	32.21	31.96	35.4	3.44	5.44
39	2:35:28 PM	30.07	30.98	32.4	35.62	3.22	5.55
40	2:43:24 PM	30.18	30.98	32.51	35.62	3.11	5.44
41	2:51:20 PM	30.29	31.2	32.4	35.84	3.44	5.55
42	2:59:16 PM	30.4	31.42	32.62	36.17	3.55	5.77
43	3:07:12 PM	30.62	31.42	32.95	36.28	3.33	5.66
44	3:15:08 PM	30.62	31.31	32.95	36.4	3.45	5.78
45	3:23:04 PM	30.73	31.65	33.06	36.28	3.22	5.55
46	9:34:00 AM	25.46	26.23	28.09	30.98	2.89	5.52

Graph from the temperature profile:



5.2 Cost Breakdown

Sl	Component	Qty	Cost (BDT)	Remarks
1	Copper Pipe (3/8", 4ft)	15 M	4000	
2	Ethanol (99.99%)	100ml	500	
3	Used Fluorescent Tubes	10 pcs	0	
4	Oil Separators	10 pcs	700	
5	HDPE Header Pipe and fittings	As req	4500	
6	Plastic Water Tank	1pc	2200	
7	12V DC Water Pump	1pc	450	
8	30W Solar Panel	1pc	1000	
9	Arduino Uno	1pc	650	
10	Controller	1pc	700	
11	NTC Thermistors	6pcs	100	
12	LCD Display	1pc	200	
13	SD Logger	1pc	60	
14	Battery	4pcs	400	
15	Cables	10 yds	500	
16	Electronics components	As req	1900	
17	Misc items	As req	1900	
18	Other costs	As req	2500	
Total			22260	

5.3 Comparison with Conventional Water Heaters

a. Electric Water Heaters

Electric water heaters are commonly used in households due to their ease of installation and immediate heating capabilities. However, they rely entirely on grid electricity, making them energy-intensive and costly to operate in the long run. In areas with unreliable electricity or high utility costs, these systems become inefficient and impractical. Additionally, they offer no monitoring capabilities and pose safety risks if not maintained properly.

b. Gas-Powered Geysers

Gas geysers are another popular option, particularly in areas where natural gas is readily available. They are typically cheaper to run than electric heaters and heat water quickly. However, they come with their own set of issues, including the risk of gas leaks, carbon monoxide buildup, and the need for proper ventilation. Moreover, like electric heaters, they depend on fossil feul and lack modern monitoring or automation features.

c. Commercial Solar Water Heaters

Conventional solar water heaters—such as flat-plate or evacuated tube systems—offer an energy-efficient and sustainable alternative to electric or gas systems. However, these systems are often expensive, ranging from 18,000 to 25,000+ BDT, which can be a barrier for low-income users. Their pre-fabricated nature limits customization, and repairing them often requires specialized parts or professional assistance. Additionally, most commercial systems do not include any built-in monitoring system, making performance tracking difficult.

d. Our Proposed System

The system developed in this project offers a highly affordable, sustainable, and repairable alternative to all of the above. It is built from reused and locally available materials, such as copper pipes, ethanol, oil separators from refrigerators, and fluorescent light tubes. The system is entirely solar-powered—including both the heater and the water circulation pump—allowing complete independence from the electrical grid. Most importantly, it includes a temperature monitoring and logging system using Arduino, NTC sensors, LCD, and SD card storage, offering users real-time insights into performance. This makes it not only a practical solution but also a powerful educational tool. The design emphasizes simplicity and reproducibility, making it ideal for students, hobbyists, and rural communities seeking low-cost renewable energy solutions.

CHAPTER 6
CONCLUSION AND FUTURE DEVELOPMENT

6.1 Conclusion

This project successfully demonstrates the design and construction of a low-cost, sustainable, and efficient solar collector water heating system using custom-fabricated heat pipes and locally available materials. The system utilizes ethanol-filled copper heat pipes, repurposed fluorescent light tubes as protective enclosures, and oil separators as condensers—all assembled manually using common tools. A simple HDPE header pipe system allows water to circulate through the system in a closed loop, powered by a 12V DC water pump connected directly to a 30W solar panel. To enhance usability and performance insight, a six-channel temperature monitoring system was incorporated using Arduino Uno, NTC thermistors, an SD card module, and an LCD display. This provides real-time data logging, a rare feature in commercial low-cost solar water heaters. The entire system operates off-grid, is energy-efficient, and is easy to replicate or scale based on need. Ultimately, this project highlights how basic components and simple fabrication techniques can produce a functional, reliable, and educational solar water heating solution, making it ideal for rural areas, educational institutions, and sustainable living initiatives.

6.2 Future Development

- Incorporating PCM with the system to store heat
- Applying thermal coating to ensure maximum solar heat absorbance
- Solar tracking for optimum PV panel output.

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APPENDIX

1. Arduino Program:

```
/*
6 Channel analog temperature logger
 */
// include the library code:
#include <LiquidCrystal.h>
#include <SPI.h>
#include <SD.h>
#include <math.h>
// initialize the library with the numbers of the interface pins
// LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
// pins 4, 11, 12 are used by SPI
  LiquidCrystal lcd(9, 8, 5, 7, 3, 2);
String logFileName = "datalog.csv";   // set the File name
String cs = ";";                    // ste the comma separator
const int startButton = 6;          // set up a constant for the pushbutton pin
const int numberOfSensors = 6;      // how many sensors did you hook up?
const int interval = 2000;          // setup cycle Time to measure / update LCD
(default: 1000)
const int logInterval = 5;          // setup logging interval in number of "interval"
(default: 60)
const int chipSelect = 4;
const int numberOfReadings = 1;     // set number of readings for average
calculation
const int numberOfRejects = 0;      // the first readings are rejected
int logCountDown = logInterval;     // reset the downcounter
int logCounter = 0;                 // count number of records
int Vo;
float R1 = 1000;
float logR2, R2, T;
float c1 = 1.009249522e-03, c2 = 2.378405444e-04, c3 = 2.019202697e-07;
```

```
float celsiusValues[numberOfSensors]; // an array to store the celsius values
unsigned long previousTime = 0;       // to store last timestamp
boolean fileDelete = false;           // set true to delete logfile each startup
boolean autoStart = false;            // set true to autostart logger on powerup
/*============= SETUP =============*/
void setup() {
  // set up the Start Button pin as an input
 pinMode(startButton, INPUT);
  // Open serial communications and wait for port to open:
 Serial.begin(9600);
 while (!Serial) {
   ; // wait for serial port to connect. Needed for native USB port only
 }
 // set up the number of columns and rows on the LCD
 lcd.begin(16, 2);
  // initialize SD Card!
 Serial.println("..Initializing SD card..");
 // see if the card is present and can be initialized:
 if (!SD.begin(chipSelect)) {
   Serial.println("Card failed, or not present");
   lcd.clear(); lcd.setCursor(0, 0); lcd.print("SD card failed.");
   lcd.setCursor(0, 1); lcd.print("insert and reset!");
   //if failded, get trapped here
   while (1) { }
 }
 Serial.println("card initialized!");
   // Print a message to the LCD.
 lcd.clear();
 lcd.print("6ch Temp Logger");
 lcd.setCursor(0, 1); lcd.print("Solar Collector monitor");
 Serial.println("SD card ready!");
 delay(2000);
 // option to delete the log file
 if (!fileDelete) {
```

```
  lcd.clear();
  lcd.print("press button to");
  lcd.setCursor(0, 1);
  lcd.print("delete log file");
 }
  //push the button within the time to delete the file
 while (millis()<4000) {
  if (digitalRead(startButton) == HIGH) {
   fileDelete = true;
  }
 }
  if (fileDelete) {
   SD.remove(logFileName);
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("file deleted!");
   Serial.println("Logfile deleted!");
   delay(2000);
   //write table headers if file was deleted
   fileWrite("T1"+cs+"T2"+cs+"T3"+cs+"T4"+cs+"T5"+cs+"T6");
  } else {
   //write zero values to see each restart of the logger
   fileWrite("0"+cs+"0"+cs+"0"+cs+"0"+cs+"0"+cs+"0");
   }
   lcd.clear();
 lcd.print("System ready!");
 lcd.setCursor(0, 1);
 if (autoStart) {
 lcd.print("--starting--");
 Serial.println("--starting--");
 delay(4000);
} else {
 lcd.print("Press start");
 Serial.println("Press start");
```

```
 //wait until somebody presses the button
 while (digitalRead(startButton) == LOW) { }
}
lcd.clear();
}
/*============ BEGIN LOOP ===========*/
void loop() {
  //store current Time
  previousTime = millis();

 // Read each sensor, calculate celsius and fill array
 for (int i = 0; i < numberOfSensors; i++) {
    int totalValue = 0;
    for (int j = 0; j < numberOfReadings; j++) {
      if (j >= numberOfRejects) {
        totalValue += analogRead(i);
      }
      delay(1);
    }
 float Vo = totalValue;
 R2 = R1 * (1023.0 / (float)Vo - 1.0);
 logR2 = log(R2);
 T = (1.0 / (c1 + c2*logR2 + c3*logR2*logR2*logR2));
 T = T - 273.15;
  celsiusValues[i] = T;
  delay (20);
  }
 /*Serial.print(millis());
 Serial.println("<- end of measuring");*/
  //Assemble comma separated string and write to serial
 String dataString = "";
 for (int i = 0; i < numberOfSensors; i++) {
      dataString += String(celsiusValues[i]);
  if (i < (numberOfSensors - 1)) {
```

```
    dataString += cs;
   }
  }
  Serial.println(dataString);
  // if countdown is elapsed, write log to file
  if (logCountDown < 1) {
   fileWrite(dataString);
   logCountDown = logInterval;   // reset the downcounter
   logCounter += 1;              // count the record
  }
   logCountDown -= 1;             // increment one down
  //write data to LCD
  lcd.clear(); //clear the LCD
  lcd.setCursor(0, 0); lcd.print(celsiusValues[0],1);
  lcd.setCursor(4, 0); lcd.print(celsiusValues[1],1);
  lcd.setCursor(8, 0); lcd.print(celsiusValues[2],1);
  lcd.setCursor(0, 1); lcd.print(celsiusValues[3],1);
  lcd.setCursor(4, 1); lcd.print(celsiusValues[4],1);
  lcd.setCursor(8, 1); lcd.print(celsiusValues[5],1);
  lcd.setCursor(13, 0); lcd.print("t-" + String(logCountDown));
  lcd.setCursor(13, 1); lcd.print("n:" + String(logCounter));
  //wait until interval time reached
  while (millis() - previousTime < interval) { }
  /*Serial.print(millis());
  Serial.println("<- loop time elapsed");*/
}
/*============ END LOOP==============*/
void fileWrite(String data) {
   // open the file. note that only one file can be open at a time,
   // so you have to close this one before opening another.
   File dataFile = SD.open(logFileName, FILE_WRITE);
   // if the file is available, write to it:
    if (dataFile) {
     dataFile.println(data);
```

```
    dataFile.close();
  }
  // if the file isn't open, pop up an error:
  else {
    Serial.println("error opening logfile");
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("error opening");
    lcd.setCursor(0, 1);
    lcd.print("logfile");
    while (1) {}
   }
Serial.println(data + " <-- written to file");
}
```

2. Tables of properties:

Sl no	Property	Value / Description
1	Thermal Resistance	Up to ~100°C short-term use
2	Chemical Resistance	High resistance to most chemicals
3	Cost	Low and widely available
4	Ease of Use	Can be drilled, bonded, and sealed easily
5	Flexibility	Reduces risk of cracking under pressure

Table 1: properties of HDPE pipe and fittings

Sl no	Property	Value / Description
1	Material	High-density Polypropylene (PP)
2	Thermal Conductivity	~0.2 W/m·K (low, good for insulation)
3	Operating Temp Range	-20°C to ~90°C
4	Water Resistance	Excellent
5	Structural Integrity	Durable under medium load & temperature
6	Portability	Foldable & lightweight

Table 2: properties of PP water tank

Sl no	Parameter	Value / Description
1	Operating Voltage	12V DC
2	Power Source	30W solar panel (direct)
3	Flow Rate	~5–10 L/min (open flow)
4	Max Lift Height	~1.2 meters
5	Current Draw	~0.5–0.8 A
6	Body Material	ABS plastic (waterproof)
7	Connection Type	3/8 inch hose barbs

Table 3: properties of DC water pump

Sl no	Parameter	Value / Description
1	Output Voltage	17–21V (open)
2	Rated Voltage	12V (regulated)
3	Power Output	30W
4	Usage	Directly powers pump (no battery)

Table 4: properties of 30w solar panel

Sl no	Parameter	Value / Description
1	Microcontroller	ATmega328P
2	Operating Voltage	5V (USB or regulated external supply)
3	Analog Inputs	6 (used for six temperature sensors)
4	Flash Memory	32 KB
5	Clock Speed	16 MHz
6	Communication	USB, UART, I2C, SPI

Table 5: properties of Arduino UNO

Sl no	Parameter	Value / Description
1	Nominal Resistance	100kΩ at 25°C
2	Type	NTC (resistance decreases with heat)
3	Temperature Range	-40°C to +125°C
4	Accuracy	±1°C (with calibration)
5	Wiring	2-pin, connected in voltage divider

Table 6: properties of NTC Thermistor

Sl no	Parameter	Value / Description
1	Operating Voltage	3.3V to 5V
2	Interface	SPI
3	Card Support	FAT16/FAT32 formatted microSD
4	Pins	CS, SCK, MOSI, MISO, VCC, GND

Table 7: properties of SD card module

Sl no	Parameter	Value / Description
1	Display Type	Alphanumeric
2	Operating Voltage	5V
3	Interface	Parallel (4-bit or 8-bit)
4	Backlight	LED (white or green)

Table 8: properties of LCD module

Sl no	Parameter	Value / Description
1	Voltage	3.7V nominal (4.2V full)
2	Capacity	~2200–3000 mAh
3	Rechargeable	Yes
4	Dimensions	18mm × 650mm

Table 9: properties of 18650 Li-ion Batteries

Sl no	Parameter	Value / Description
1	Max Charging Current	10A
2	System Voltage	12V
3	Charging Type	PWM
4	Load Output	12V / 5V

Table 10: properties of PWM solar charge controller

Sl	Component	Qty	Cost (BDT)	Remarks
1	Copper Pipe (3/8", 4ft)	15 M	4000	
2	Ethanol (99.99%)	100ml	500	
3	Used Fluorescent Tubes	10 pcs	0	
4	Oil Separators	10 pcs	700	
5	HDPE Header Pipe and fittings	As req	4500	
6	Plastic Water Tank	1pc	2200	
7	12V DC Water Pump	1pc	450	
8	30W Solar Panel	1pc	1000	
9	Arduino Uno	1pc	650	
10	Controller	1pc	700	
11	NTC Thermistors	6pcs	100	
12	LCD Display	1pc	200	
13	SD Logger	1pc	60	
14	Battery	4pcs	400	
15	Cables	10 yds	500	
16	Electronics components	As req	1900	
17	Misc items	As req	1900	
18	Other costs	As req	2500	
Total			22260	

Table 11: Approximate cost breakdown