

DESIGN AND CONSTRUCTION OF A HYBRID SOLAR WATER HEATER FOR LOW-COST DOMESTIC WATER HEATING

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Abstract

Domestic water heating is an important household energy demand, particularly during cold seasons and in regions where electricity and natural-gas supply can be interrupted or costly. This study presents the design and construction of a low-cost hybrid solar water heater that combines direct solar thermal heating with an electrically assisted heating stage powered by a solar panel. The prototype uses locally available materials, including a wooden frame, aluminum sheet, aluminum tubing, expanded polystyrene (thermocol) insulation, a transparent cover, rubber connectors, black matte coating, thermometers, and a nickel-chromium resistive heating element. The collector section is designed to expose the aluminum heat-transfer surface and tubing to solar radiation while the transparent cover reduces convective and radiative heat losses. The tubing is bent into a serpentine/U-shaped arrangement to increase the effective heat-transfer path and residence time of water in the collector. A photovoltaic-powered nickel-chromium element is incorporated as a supplementary heating mechanism, producing the hybrid configuration. The thesis reports that the system can warm water primarily through the direct solar collector, with additional heating supplied through the photovoltaic-assisted electrical element. The resulting prototype is intended as an inexpensive and readily repairable alternative to conventional gas- or grid-electric water heaters. Because the original thesis does not provide a complete time-resolved experimental temperature dataset, the present manuscript focuses on the design, construction, operating mechanism, and reported performance claims rather than introducing unmeasured numerical efficiency values. The work provides a practical foundation for subsequent controlled testing under different solar irradiance, flow-rate, ambient-temperature, and photovoltaic operating conditions.

Introduction

Water heating is a routine but energy-intensive domestic service. Conventional electric and gas heaters can provide controllable hot-water supply, but their operation depends on purchased electricity or fuel and can become particularly problematic during supply

interruptions. The thesis identifies electricity and gas load shedding, operating cost, and environmental impacts associated with conventional energy use as important motivations for developing an accessible solar alternative. Solar energy offers an abundant renewable resource that can be converted

directly into useful thermal energy through solar collectors. The submitted thesis specifically targets domestic water heating and proposes a simple passive collector supplemented by a photovoltaic-powered resistive heating element. [17,18,]

Solar water-heating technologies are commonly divided into active and passive systems and include glazed flat-plate and evacuated-tube configurations [19]. For low-temperature domestic applications, a flat collector can provide a relatively simple architecture because the heat-transfer fluid passes through tubing attached to or supported by an absorber surface. In the present design, aluminum is selected for the tubing and absorber sheet because of its low mass and high thermal conductivity, while expanded polystyrene is used as insulation [20,21]. A transparent plastic cover is placed above the collector to permit solar radiation to enter while helping to retain heat within the collector enclosure. These component choices and their intended functions are described directly in the thesis [17,19,].

The novelty of the prototype is not a new solar-thermal principle, but the integration of inexpensive locally obtainable materials with a photovoltaic-assisted electrical heating stage. The thesis describes a system in which water first receives heat from the solar-heated aluminum pipe and absorber, while the photovoltaic supply can energize a nickel-chromium element to provide additional heating. This arrangement is intended to reduce dependence on grid electricity and conventional fuel while maintaining a practical route to higher outlet-water temperatures.

The objective of this work is therefore to design and construct a compact, low-cost hybrid solar water heater and to document its materials, fabrication procedure, thermal management strategy, and operating principle. The work is especially relevant to households seeking simple renewable-energy technologies that can be fabricated, repaired, and operated with commonly available materials.

Background and Related Work

Solar thermal water heating has been investigated as a means of displacing conventional water-heating energy demand. The

thesis literature review notes that solar hot-water systems can reduce reliance on natural gas, oil, and grid electricity and summarizes earlier work on solar thermal collectors, domestic hot-water systems, and hybrid configurations. It also cites studies addressing emissions reduction and the performance of solar domestic hot-water systems. [3,17,]

Previous designs vary considerably in complexity [30]. High-temperature non-tracking collectors can deliver substantially elevated collector temperatures, but their cost and engineering requirements may limit domestic deployment [24,28]. The thesis cites a positive-temperature-coefficient-based design with a reported collector efficiency of 32% and a high-temperature application, while noting its relatively high cost for household use. A separate controller-based approach is described as supplying most hot water from solar heating with an electric heater used as backup [21]. These examples motivate a simpler configuration in which solar thermal heating is combined directly with photovoltaic-assisted resistance heating [10,20,].

For a low-cost prototype, thermal insulation is critical because useful solar energy can be lost through the rear and sides of the collector. The thesis therefore uses a thermocol layer beneath the absorber. The transparent cover is intended to create a greenhouse-like enclosure and reduce heat losses from the collector surface [25,32]. The absorber and pipe are coated black to increase solar absorption. Together, these features constitute a basic thermal-management strategy that can be implemented without sophisticated manufacturing equipment. [17,19,]

Materials and Methods

Design requirements

The design was guided by three practical requirements: low cost, availability of materials in local markets, and adequate mechanical/thermal performance. The thesis explicitly states that materials were selected to be inexpensive but sufficiently good in quality, readily available for repair, and suitable for constructing a durable model.

Collector structure

The main support is a rectangular wooden frame. The reported frame dimensions are approximately 5 ft in length and 3 ft in width, with 1×2 wooden strips and larger support members used to maintain the geometry. A rigid hard sheet is fitted as a foundation for the collector, followed by a thermocol layer that serves as rear insulation. The absorber/collector surface is formed using an aluminum sheet and aluminum tubing. The thesis reports an aluminum pipe length of approximately 49 ft and a pipe diameter of about 11 mm, with a 5 ft × 3 ft aluminum sheet.

Thermal insulation and transparent cover

The insulation layer is an expanded-polystyrene (EPS) thermocol sheet. The thesis reports a thickness of approximately 41 mm and a 5 ft × 3 ft footprint, with a stated density of 70 and water-absorption value of 0.071% per day under the described exposure. The insulation is positioned beneath the collector to limit conductive heat loss from the heated tubing and absorber toward the supporting structure.

A transparent plastic sheet is installed above the collector. It transmits incident solar radiation

while forming an enclosed space above the absorber. The thesis describes this arrangement as producing a greenhouse effect that assists heat retention. The cover is bonded to the frame using Cementex adhesive so that it remains secured during outdoor operation.

Aluminum tubing and absorber

Aluminum was selected because it combines low density with high thermal conductivity and corrosion resistance. The pipe is bent using a tube bender into a U-shaped/serpentine arrangement. This increases the length of the heat-transfer path available within the collector and allows water to remain in the heated zone for a longer travel distance. Rubber tubing is used to connect the aluminum pipe sections.

The aluminum surface is coated with black matte paint. The thesis uses the black coating to increase solar absorption and reduce reflection. The collector therefore functions as a simple absorber in which incident solar radiation is converted to sensible heat in the metal and subsequently transferred to the water flowing through the tubing.

Table 1. Main materials and reported specifications of the prototype

Component	Material	Reported specification	Function
Collector frame	Wood	Approx. 5 ft × 3 ft; 1 × 2 in strips/support members	Mechanical support and collector enclosure
Absorber sheet	Aluminum	Approx. 5 ft × 3 ft	Absorbs solar radiation and transfers heat
Water tubing	Aluminum	Approx. 49 ft length; 11 mm diameter	Provides water-flow and heat-transfer path
Insulation	Expanded polystyrene (thermocol)	Approx. 41 mm thick; 5 ft × 3 ft footprint	Reduces rearward conductive heat loss
Surface coating	Black matte paint	Applied to absorber/tube region	Increases solar absorption and reduces reflection
Transparent cover	Transparent plastic sheet	Installed above collector	Allows solar radiation in and helps retain heat
Auxiliary heater	Nickel-chromium wire	Approx. 80% Ni / 20% Cr	Provides photovoltaic-assisted resistive heating
Connectors	Rubber tubing	Used at pipe connections	Joins tubing sections and maintains water flow

Table 2. Operating principle and heat-transfer routes of the hybrid system

Heating route	Energy input	Main heat-transfer process	Role in hybrid system
Direct solar-thermal heating	Incident sunlight	Solar radiation is absorbed by the black-coated aluminum absorber and tubing; heat is transferred through the aluminum to flowing water.	Primary heating mechanism
Photovoltaic-assisted heating	Solar electricity from PV panel	Electrical energy is converted to heat by the nickel-chromium resistive element and transferred to the surrounding pipe/water.	Supplementary heating mechanism
Thermal insulation	Heat loss from absorber	Thermocol limits conductive heat loss from the absorber and tubing toward the rear support structure.	Improves heat retention
Transparent-cover enclosure	Solar radiation entering collector	The cover permits solar radiation to enter while helping reduce heat loss from the heated absorber to the surroundings.	Supports thermal retention

Photovoltaic-assisted heating stage

The hybrid component consists of a solar panel connected to a nickel–chromium alloy wire. The wire is routed through the aluminum pipe so that electrical resistance heating can supplement the heat obtained from direct solar absorption. The thesis specifies an approximately 80% nickel/20% chromium alloy composition and reports high electrical resistivity and oxidation resistance as relevant properties. The photovoltaic-assisted stage is therefore intended to provide additional thermal input when direct solar heating alone is insufficient.

Instrumentation and construction sequence

Thermometers are positioned at the inlet and outlet of the aluminum pipe to compare the temperature of water entering the collector with the temperature of water leaving it. The construction sequence consists of: fabrication of the wooden frame; attachment of the rigid base; installation of thermocol insulation; placement of the aluminum absorber sheet; bending and joining of the aluminum tubing; fixing the tubing to the collector; application of black coating; installation of the photovoltaic-powered heating element; placement of temperature measurement points; and final installation of the transparent cover.

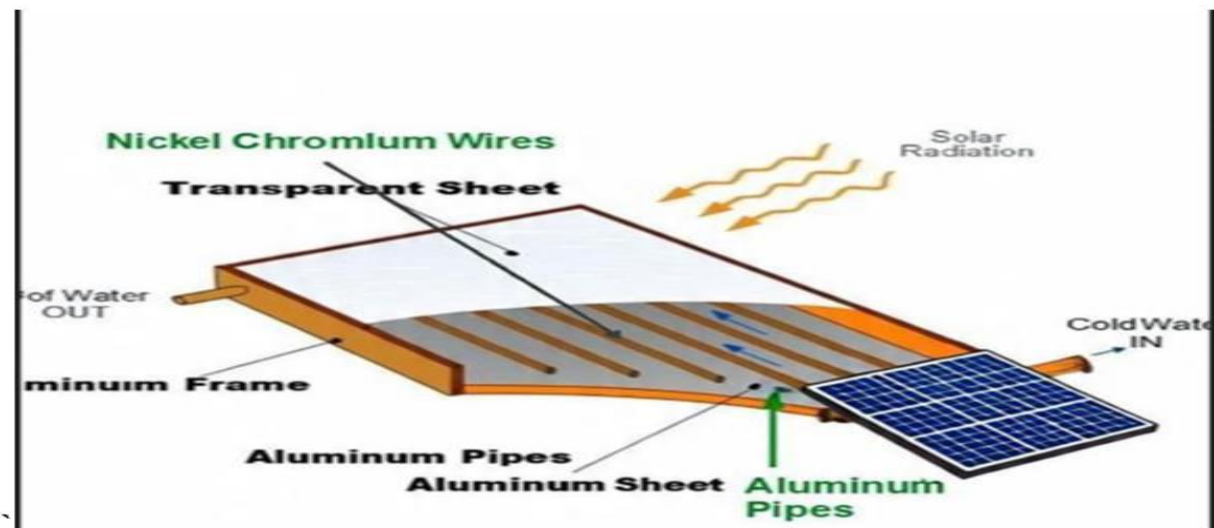


Figure 1. Schematic/working-principle illustration reproduced from the submitted thesis.

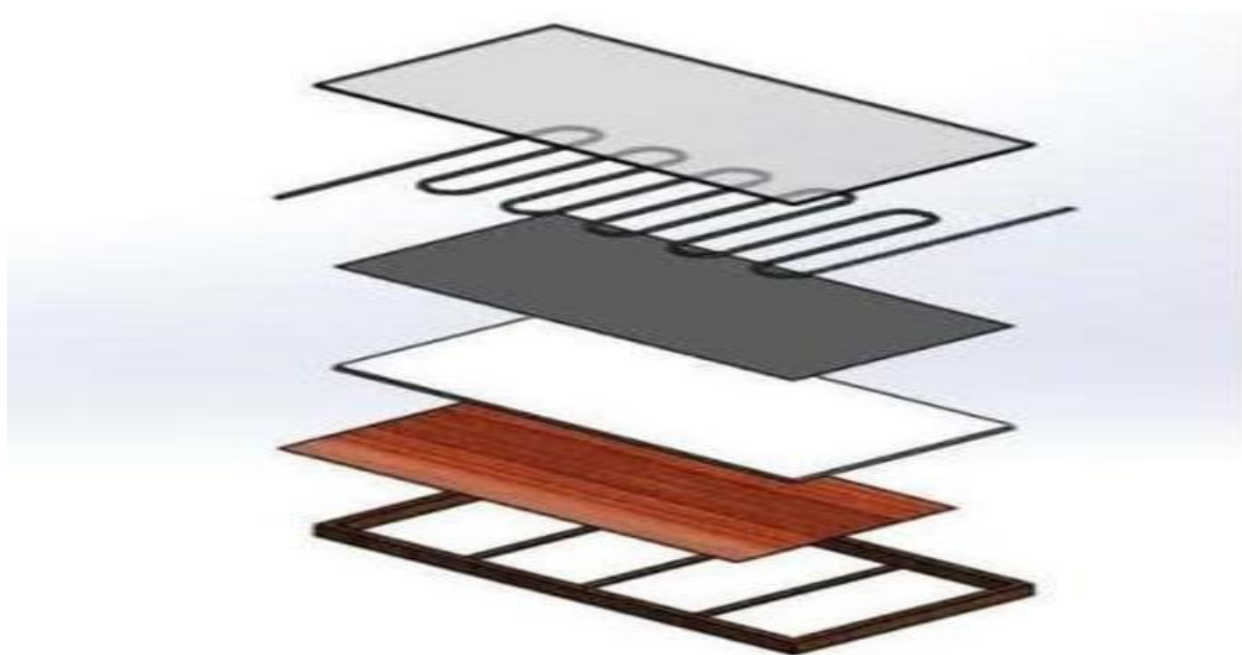


Figure 2. Final prototype framework shown in the submitted thesis

Operating Principle

The prototype operates through two complementary heat-transfer routes. In the first route, incident sunlight passes through the transparent cover and is absorbed by the black-coated aluminum absorber and tubing. Heat is conducted through the aluminum wall and transferred by convection to the water flowing inside the pipe. The insulated backing reduces rearward heat loss, while the transparent cover

helps retain heat above the absorber. The thesis describes this as the primary direct-solar heating mechanism.

In the second route, photovoltaic electricity is supplied to the nickel-chromium resistive element. Electrical energy is converted into heat through Joule heating, and that heat is transferred to the surrounding aluminum pipe and water. The two routes operate together in the hybrid configuration. The intended benefit

is that the solar-thermal collector provides the main heat input while the photovoltaic-assisted element can raise the water temperature further. The heat balance of the collector can be expressed conceptually as $Q_{\text{useful}} = Q_{\text{solar}} + Q_{\text{PV}} - Q_{\text{loss}}$, where Q_{solar} is the absorbed solar heat, Q_{PV} is the electrical heat generated by the resistive element, and Q_{loss} represents combined convective, conductive, and radiative losses. For water flowing through the collector, the useful thermal gain can also be related to the inlet and outlet temperatures by $Q_{\text{water}} = \dot{m} c_p (T_{\text{out}} - T_{\text{in}})$. These relations provide a suitable framework for future quantitative characterization, although the submitted thesis does not provide sufficient time-resolved measurements to calculate a defensible experimental efficiency curve.

Prototype Construction

The construction begins with a rectangular wooden frame that provides mechanical support

and establishes the collector angle. A rigid sheet is attached to the frame, followed by the thermocol insulation layer. The aluminum sheet is then positioned over the insulation to act as the absorber surface. Aluminum tubing is bent into the required shape and fixed to the collector using metal wire. Rubber connectors join the separate pipe sections, producing a continuous water path.

After mechanical assembly, the absorber/tube region is coated with black matte paint. The photovoltaic-assisted heating element is then connected to the solar panel and positioned through the aluminum pipe. Temperature measurement devices are installed at the inlet and outlet. Finally, the transparent plastic cover is attached and sealed to the frame. This sequence creates an enclosed collector in which solar radiation enters through the cover and heat is retained around the absorber.

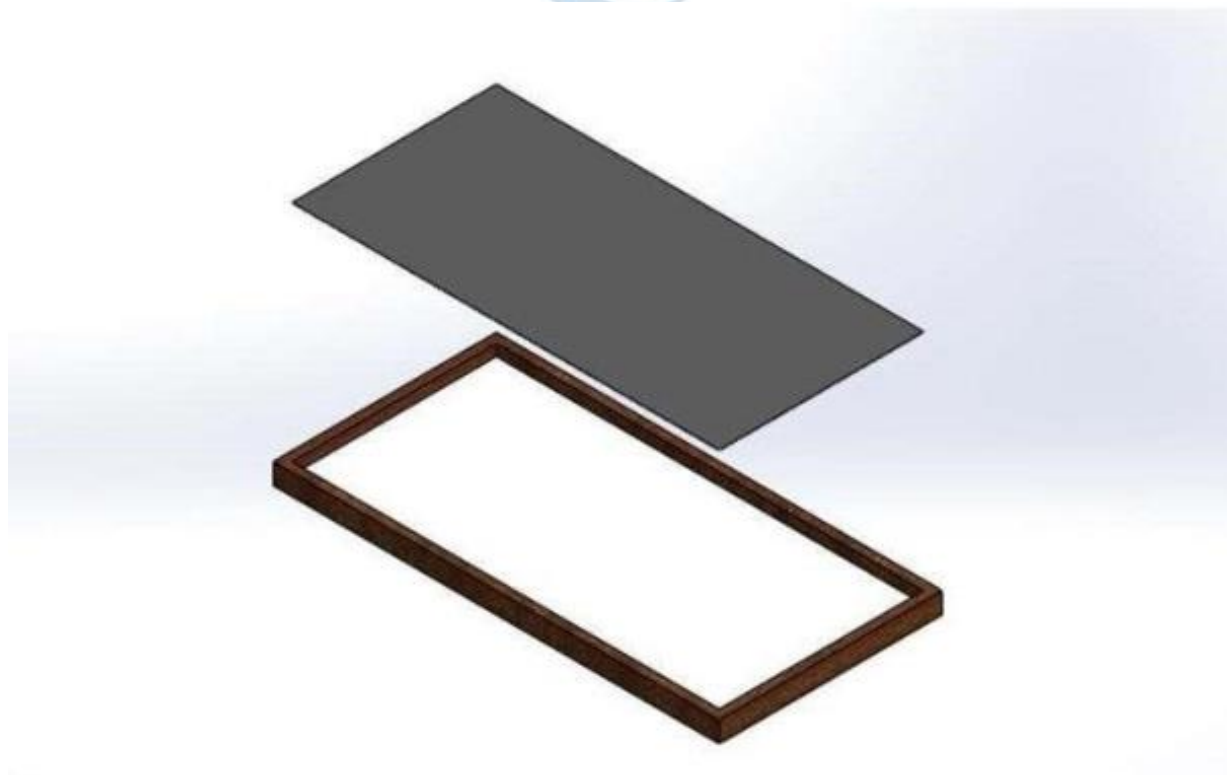


Figure 3. Aluminum pipe/collector assembly during construction.

Results and Discussion

The completed prototype demonstrates the feasibility of integrating a direct solar-thermal collector with a photovoltaic-assisted electrical

heating stage using inexpensive materials. The reported design combines an aluminum absorber and tubing, thermal insulation, a transparent cover, and an auxiliary resistive

heater. From a system perspective, the design addresses several common losses: thermocol limits heat conduction to the rear structure; the transparent cover reduces direct exposure of the hot absorber to ambient air; and the black coating increases absorption of incident solar radiation. These features are consistent with the intended heat-transfer pathway described in the thesis.

The thesis reports that approximately 80% of the warming is achieved directly through the aluminum pipe and sheet using solar energy, with further warming provided by electrical energy generated through the solar panel. This statement should be interpreted as a reported project outcome rather than as a fully quantified thermal efficiency because the thesis does not provide the irradiance, water flow rate, inlet/outlet temperature time series, collector area, photovoltaic electrical output, or uncertainty analysis required to independently reproduce a percentage performance metric.

The hybrid architecture nevertheless has a clear operational rationale. Direct solar heating is passive and can provide useful heat without converting sunlight first to electricity. The photovoltaic-resistance branch provides a controllable secondary heat source without requiring grid electricity, which is particularly relevant when conventional electricity supply is interrupted. The trade-off is that the photovoltaic-to-electric-to-heat pathway introduces conversion losses compared with direct solar thermal absorption. Future testing should therefore determine the operating conditions under which the auxiliary heater provides a meaningful increase in outlet temperature relative to its electrical energy input.

A further advantage is maintainability. The principal structural components—wood, aluminum sheet, aluminum tubing, insulation, transparent sheet, connectors, fasteners, and paint—are commonly obtainable. The thesis emphasizes that the system was designed around low cost and accessible replacement materials. Such design choices are valuable for small-scale applications where sophisticated evacuated-tube collectors or high-temperature concentrating systems may be difficult to purchase or maintain.

The prototype also reveals several engineering considerations. First, the use of thermocol provides insulation but requires protection because EPS is combustible and non-biodegradable. The thesis itself recognizes these limitations and recommends careful handling. Second, the transparent plastic cover must remain optically clear and mechanically sealed; degradation or leakage can reduce thermal performance. Third, the aluminum tubing must be adequately supported to prevent deformation and leakage. Finally, the photovoltaic-assisted element requires electrical isolation and appropriate current/voltage control to ensure safe operation.

7. Performance Evaluation Framework

For a journal-quality experimental study, the prototype should be evaluated using a controlled measurement protocol. At minimum, the inlet-water temperature, outlet-water temperature, ambient temperature, solar irradiance, water flow rate, photovoltaic voltage, and photovoltaic current should be recorded at regular time intervals. The useful thermal power can then be calculated from $\dot{m}_c p \Delta T$, while collector thermal efficiency can be estimated as $\eta_{th} = \dot{m}_c p (T_{out} - T_{in}) / (G A_c)$, where G is solar irradiance and A_c is collector aperture/absorber area.

The hybrid system should be tested in at least three modes: (i) solar-thermal collector only, (ii) photovoltaic-assisted heating only, and (iii) combined hybrid operation. Comparison of these modes would establish the incremental contribution of each subsystem. Testing should preferably be performed under similar weather conditions or normalized using measured irradiance. Repeated measurements would permit uncertainty estimates and strengthen the evidence for any performance claim.

The current thesis provides the construction details and qualitative performance conclusions but not a complete dataset suitable for generating a rigorous temperature-versus-time graph. Accordingly, this paper does not invent numerical temperature curves or efficiency values. The reported 80% direct-heating statement is retained as a thesis-reported outcome, while the recommended quantitative

evaluation is presented as a framework for future experimental work.

Practical significance

The prototype demonstrates how basic thermal-engineering concepts can be combined with renewable electricity generation to construct a domestic hot-water device from accessible materials. Its strongest contribution is practical rather than theoretical: the design provides a simple platform that can be experimentally optimized through changes in absorber geometry, insulation thickness, transparent-cover material, flow rate, collector tilt, and photovoltaic heating power.

Future Development

The thesis recommends improving portability, reducing system size, selecting improved materials, and using better photovoltaic technology to reduce the impact of cloudy conditions. It also proposes exploring materials or solar technologies capable of recovering thermal radiation for nighttime heating.

Future work should additionally include a properly instrumented experimental campaign. A thermocouple array could measure absorber, tube-wall, inlet, outlet, and ambient temperatures simultaneously. A pyranometer or calibrated irradiance sensor would allow thermal performance to be normalized against incident solar energy. A flow meter would permit calculation of useful thermal power. Electrical measurements on the photovoltaic branch would allow the auxiliary heating contribution to be compared directly with solar electrical input. These additions would transform the present proof-of-concept into a quantitatively validated solar water-heating study.

Design optimization could focus on absorber geometry, tube spacing, number of passes, hydraulic resistance, insulation thickness, glazing material, and collector inclination. A selective solar absorber coating could potentially reduce thermal losses relative to ordinary black paint, while a more durable glazing could improve long-term outdoor performance. A thermostatic controller could also switch the auxiliary heating stage on only when the outlet temperature falls below a specified set point, reducing unnecessary electrical consumption.

Conclusions

A low-cost hybrid solar water heater was designed and constructed using a wooden support frame, aluminum absorber and tubing, thermocol insulation, a transparent cover, black matte coating, and a photovoltaic-powered nickel-chromium heating element. The design combines direct solar thermal heating with photovoltaic-assisted resistance heating in a single domestic hot-water system. The aluminum tubing provides the water-flow path and heat-transfer interface, while the absorber, insulation, and transparent cover are arranged to increase useful solar heat retention. The prototype therefore provides a practical and accessible approach to renewable water heating. The thesis reports that the majority of heating is obtained directly through the aluminum collector and that additional heating can be supplied through the photovoltaic-assisted stage. The reported design is intended to reduce reliance on conventional electricity and gas while remaining inexpensive and repairable. However, quantitative performance claims should be strengthened through controlled measurements of irradiance, flow rate, inlet/outlet temperatures, photovoltaic power, and uncertainty. The prototype is consequently best regarded as a promising low-cost proof-of-concept that provides a clear basis for future experimental optimization.

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