SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Thermosyphon System Potential

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Thermosyphon system potential

Deliverable

Subtask B. Thermosyphon Systems

Report B.1. Report of thermosyphon system potential

This is a report from SHC Task 69: Solar Hot Water for 2030 and work performed in Subtask B: Thermosyphon hot water systems

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1 Executive Summary

One of the main energy consumers in buildings are domestic hot water systems. The share of heat consumption for this purpose in relation to the total energy demand in residential buildings varies around the world and is approximately: 11 % in the United States, 14 % in Europe, 22 % in Canada, 25 % in Australia, 29 % in Mexico, 27 % in China and 32 % in South Africa [1]. In some regions, DHW preparation can amount to more than half of the total household energy use. Driven by rising living standards and increased awareness for hygiene, the hot water demand is anticipated to increase in the coming years. Improvements in building efficiency will likely significantly reduce the space heating demand, making domestic hot water an even more important factor of the energy use in buildings. With a renewable share of ~15 % in the residential sector[2], there is huge potential for decarbonisation as gas and oil-fired boilers and grid-tied electric water heaters are still the predominant technologies for DHW preparation. Techno-economic innovations are necessary for “untapping sustainable and efficient DHW tapping”.

Thermosyphon solar water heating represent opposite poles regarding market status, market dynamics and recent technological advancement. Thermosyphon systems uses natural convection (thermosyphon effect) to circulate water without the need for pumps or electricity, which allows cost-effective, simple system designs without moving parts and low installation and maintenance costs. However, this segment is under pressure from heat pumps and policies towards electrification. Consequently, the global solar heat market declined by 14 % in 2024[3].

This report provides a market analysis of the thermosyphon hot water markets, addressing the status quo, as well as promising opportunities and challenges for the thermosyphon hot water market. One of their key characteristics of the global solar hot water market is its regional diversification in terms of market penetration, deployed technologies, hot water demand, main competitors, etc. The market analysis for thermosyphon systems tries to address this issue by providing in-depth analyses for all relevant market regions, elaborating the regional economic, environmental, technical and political boundary conditions.

The report reveals the high diversity in thermosyphon system applications through in-depth regional analysis. In temperate climates such as Southern Europe, Asia (particularly China and India), Latin America, and the Middle East, thermosyphon systems dominate. Their specific technical configurations—such as direct or indirect systems, and the use of flat-plate or evacuated-tube collectors—are tailored to local freeze protection requirements, water quality, and building types. In contrast, markets in colder winter regions with stringent regulations, such as North America and Northern Europe, are dominated by forced-circulation systems. Meanwhile, in Sub-Saharan Africa, thermosyphon systems are primarily deployed in policy-driven public building projects. In regions like Oceania, their market presence faces significant pressure from competing technologies like heat pumps and photovoltaics.

In terms of technological advancement, the report highlights the trend of enhancing system performance and user experience through intelligent solutions and material innovation. IoT-enabled smart controllers integrate Wi-Fi and mobile apps to deliver remote monitoring, scheduled heating, automatic water replenishment, freeze protection, and pipe circulation functions, effectively addressing pain points in traditional systems. Concurrently, advanced material research exemplified by Austria's SOLPOL project focuses on developing polymer collectors that are resistant to aging, lightweight, and cost-effective, offering new pathways to reduce expenses and increase design flexibility. Furthermore, the report explores future technological directions such as AI-driven predictive heating, phase-change material thermal storage, and multi-energy synergistic control.

In summary, despite the overall downturn in global markets, solar thermal systems retain significant potential in specific regions and markets due to their inherent cost-effectiveness and reliability. Their future development hinges on enhancing competitiveness through smart technology, material innovation, and system integration, while better integrating into the built environment and overall energy systems. This will enable them to play a more pivotal role in advancing the decarbonization of the building sector.

2 Introduction

Domestic hot water (DHW) is already the single largest slice of household energy—about one quarter of all residential demand—and is poised to rise further. Demographers project global population to swell past ten billion by mid-century, while rapid urbanisation and higher living standards are equipping millions of new apartments with showers, washing machines and dishwashers. Post-pandemic hygiene awareness has amplified the trend: Danes now consume roughly fifteen cubic metres of hot water per person each year, up from only ten two decades ago, and they expect it instantly at the tap.

Yet even as envelope insulation, heat pumps and stringent nearly-zero-energy codes slash space-heating loads in both new and retrofitted buildings, the energy required for DHW has remained stubbornly steady. Annual heat consumption expanded by 6% globally over 2018-2024. Renewable energy, excluding traditional uses of biomass, met only half of this increase, with its share in global heat consumption rising to 14% in 2024. [2]—this persistent, growing DHW load represents a prime, still largely untapped opportunity for solar thermal, heat-pump and other low-carbon technologies to accelerate the decarbonisation of the built environment. Within this segment, the thermosyphon configuration—simple, passive, pump-free—dominates Asia, Africa and Latin America because its natural-convection loop slashes both upfront and lifetime costs while remaining immune to grid failures, making it the technology of choice for off-grid and peri-urban communities worldwide.

However, the global solar thermal market is undergoing structural adjustments, and the development of thermosyphon systems faces multiple challenges including regional market fragmentation, intensified technological competition, and the need to enhance user experience. This report aims to provide an in-depth analysis of the current state and regional characteristics of the global thermosyphon market, while systematically examining how cutting-edge technological innovations—such as smart control systems and new material applications—are revitalizing this traditional technology.

As the market dynamics for solar thermosyphons shift from China to Latin America, Africa and Southeast Asia, there is a renewed need for cost-effectiveness and reliability. In addition, modernizing their future development hinges on enhancing competitiveness through smart technology, material innovations, and better integration into the overall built environment energy systems. This will enable them to play a more significant role in advancing the decarbonization of the building sector. To capture these trends in detail, this report first summarizes the status of existing and then categorizes the new technologies and products that are becoming available in the market for solar thermosyphon hot water systems.

3 Application Status of Thermosyphon Systems

3.1 Market Data

Solar hot water systems can be divided into a few main categories: Thermosyphon vs. pumped circulation (as shown in Figure 1 below), and by collector type glazed flat plate vs. evacuated tube. The choice between these options is typically due to climate and the capacity of local manufacturers and retailers, but it can also be heavily influenced by policy settings. Thermosyphon systems often dominate wherever winters are mild or subsidies reward simplicity, whereas pumped systems prevail where Standards/Codes, frost or multi-function demands override cost considerations. In Asia, historically, the passive, close-coupled thermosyphon has served as the default architecture, accounting for 93 % and 82 % respectively of all glazed-water capacity. This pattern is rooted in dense urban roofs, low-cost manufacturing and frost-free or mildly frosty climates. Latin America and Sub-Saharan Africa follow a similar but less extreme profile (with ≈ 60% of installations being thermosyphon systems), driven by single-family housing, institutional projects and moderate solar regimes where simple, self-circulating packages suffice. By contrast, Europe, the United States/Canada and Australia/New Zealand exhibit the inverse. Only 34–46 % of capacity is thermosyphon in these markets, meaning most installed systems are pumped systems mandated by severe freeze risk, water regulations and the prevalence of space-heating integration. The MENA region sits at the cross-over point (with ~55 % of installations being thermosyphon systems), reflecting a split between frost-free coastal zones favouring passive units and inland or high-altitude areas that require pumped freeze protection.

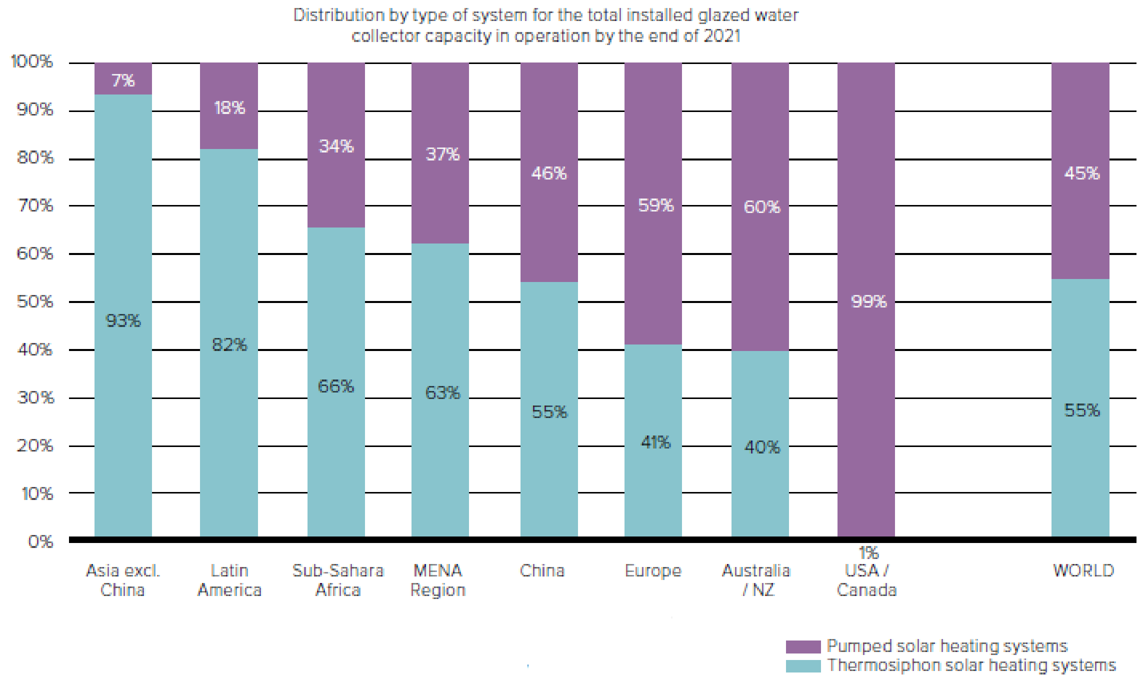

Figure 1: Main technologies per region (Including DIR and Flat etc.).

3.2 Regional Analysis

In Europe, thermosyphon systems represented 56% of new solar water heater installations in 2022, with strong adoption concentrated in Mediterranean countries (Cyprus, Greece, Turkey). These systems are primarily deployed in residential buildings and the tourism sector, with limited public sector use. The dominant technology across the region employs flat plate collectors (often with highly selective coatings), typically configured in 2m² or 4m² sizes paired with 150-300L tanks. Indirect circulation with antifreeze is standard in frost-prone areas, featuring corrosion-resistant tanks (double-enamelled with magnesium anodes) and optimized insulation. Key markets like Greece and Turkey sustain local manufacturing ecosystems (e.g., Calpak, Solimpeks, Bural), supported by regulatory frameworks such as Greece's 30-65% tax deductions for renewable heating investments and mandatory Solar Keymark certification. System performance correlates strongly with solar resource availability, ranging from >2100 kWh/m² in southern Spain/Cyprus/Turkey to 800 kWh/m² in northern UK, enabling 80-90% annual hot water coverage in optimal zones despite varying EU hot water consumption (avg. 72L/person/day at 60°C).

The analysis of the use of thermosyphon systems in Asia primarily focuses on India, Japan, and China as representative cases. The specific details of the case are as follows:

In India, thermosyphon solar water heaters (SWHs) are predominantly applied in single houses within rural areas and multi-storey residential buildings in urban settings. The overwhelming majority of these systems utilize Direct systems with Evacuated Tube Collectors (DIR-ETC), especially in urban and semi-urban areas. In contrast, Indirect systems employing either Flat Plate Collectors (IND-FLAT) or Evacuated Tube Collectors (IND-ETC) are very rarely used. The standard residential configuration is "2 m² collector area + 200 L storage tank", typically priced between USD 250 and USD 500.

In Japan, thermosyphon systems are predominantly applied in detached houses, with minimal adoption in multi-family dwellings. The overwhelming majority (approximately 80%) utilize Indirect systems with Flat-Plate Collectors (IND-PLAT). Direct Flat-Plate systems (DIR-PLAT) represent only 2-3% of the market, while Indirect systems with Evacuated Tube Collectors (IND-ETC) constitute the remainder. The standard IND-PLAT configuration per household is "4 m² collector area + 200 L storage tank", with a total installed cost of approximately ¥350,000 (USD 2,333). Despite a significant market decline from historical peaks (800,000 units/year during the oil crisis) to current levels (~20,000 units/year in 2023), thermosyphon systems are experiencing renewed interest post-2020 due to Japan's Carbon Neutral Declaration, valued for their electricity-free operation, energy savings, CO$_2$ reduction, and lower gas bills. High per-capita hot water demand (~100 L/day at 40°C), driven by daily bathing culture, necessitates this robust system size. Adoption is influenced by regional solar irradiance (higher suitability in Pacific Honshu/Kyushu vs. snow-affected northern regions) and supported by national/local subsidies (e.g., ZEH programs, Tokyo's 50% cost subsidy). Certification requires compliance with JIS 4112 standards under the Solar System Certification System.

In China, thermosyphon systems are primarily deployed in single rural houses and urban multi-story residential buildings. Technology adoption exhibits distinct regional patterns: Direct systems with evacuated tube collectors (DIR-ETC) dominate in rural areas, while urban settings predominantly utilize indirect systems—both flat plate collectors (IND-PLAT) and evacuated tube collectors (IND-ETC)—in multi-story buildings. The standardized residential configuration nationwide is "2 m² collector area + 150 L storage tank", with an average system cost of approximately USD 500. This segmentation aligns with China's four-tier solar resource zoning system and building classifications (GB 50364-2018), where residential hot water demand ranges from 20–70 L/person/day. Recent regulatory mandates (GB 55015-2021) requiring solar installations in new buildings further support adoption, while technical standards (GB 35606-2017) govern system certification.

In Latin America, thermosyphon systems are chiefly household-scale devices that exploit abundant sunshine to produce domestic hot water, but their form and penetration mirror the region’s sharp climatic and socio-economic contrasts. In warm urban zones of Brazil, Mexico and the Caribbean coast, direct flat-plate thermosyphon units dominate, mounted on single-family roofs where freezing is absent and water is soft; here the technology competes mainly with electric showers or bottled LPG. As one moves southward to the colder provinces of Argentina, Chile and southern Brazil, the same passive concept is retained, yet the absorber shifts to evacuated tubes (DIR-ETC) to guard against frost and to secure higher winter yields. In dense mid-rise cities—Bogotá, Lima, Montevideo—where roof space is scarce and water hardness or pressure issues appear, indirect flat-plate thermosyphon banks feeding central storage tanks have become the norm for apartment buildings and small hotels. Industrial or commercial applications remain marginal; only isolated hotels, hospitals and laundries in Brazil and Mexico have upsized the same thermosyphon principle to pre-heat large volumes of water, while process heat beyond 80 °C is still met by conventional boilers. Thus, thermosyphon technology in Latin America is overwhelmingly a residential story, differentiated only by collector type and system configuration to suit local freeze risk, water chemistry and urban density, and its future expansion hinges on replacing inefficient electric resistance heaters and LPG heaters rather than on technological breakthroughs.

In Middle East and North Africa, thermosyphon solar water heaters are predominantly small-scale, roof-mounted packages sized to match household demand—typically 2–4 m² flat-plate collectors coupled with 150–300 L enameled-steel tanks in Morocco, and similar dimensions in Israel—while evacuated-tube imports from China are gaining ground where higher efficiency or frost protection is valued. The systems are overwhelmingly direct thermosyphons in mild climates, but indirect variants appear in the Levant and mountainous zones to cope with water hardness or occasional freezing. Beyond single-family homes, the same modular concept is scaled up for hotels, university dormitories and public bathhouses, yet these non-residential niches remain thin. Israel and the Palestinian Territories still show the highest per-capita penetration, although post-2023 conflict has stalled new sales, while Morocco, Lebanon and Tunisia continue to rely on local assembly lines fed by Greek or Spanish components. Elsewhere—Saudi Arabia, Egypt, Kuwait and Iraq—installations are sporadic, often driven by NGOs seeking resilience against fragile grids rather than by sustained policy. Market momentum is weak because governments privilege photovoltaics, subsidies for bottled gas persist, and trained installers for imported units are scarce; as a result, the once-ambitious Moroccan PROMASOL target of 1.7 million systems by 2020 was missed, and the broader MENA thermosyphon market remains a patchwork of isolated household successes rather than a region-wide transition.

The analysis of the use of thermosyphon systems in North America primarily focuses on United States, Canada, and Puerto Rico as representative cases. The specific details of the case are as follows:

In United States, thermosyphon systems are almost absent because the technology's open-loop, freeze-susceptible design conflicts with the country's widespread winter risk. Instead, the residential and light-commercial segments rely on pumped, indirect, glycol-filled or drain-back packages supplied by roughly a dozen domestic manufacturers concentrated in Florida and California. These forced-circulation systems serve three distinct niches: domestic hot water (retrofit and new-build homes), unglazed polymer collectors for the nation's 3.5 million residential and 240 000 commercial swimming pools, and—to a much lesser extent—space-heating pre-heat for cold-climate houses. High installed costs (USD 2 000–5 000 for a DHW kit), fragmented state incentives and the public's conflation of solar thermal with PV have kept annual sales modest and subsidy-dependent.

In Canada the thermosyphon systems' market is smaller and even more strictly limited to freeze-protected hydraulics. The country's six active manufacturers sell only indirect, closed-loop packages—vacuum-insulated flat-plate or evacuated-tube collectors coupled to twin-coil storage tanks—and the same hardware is redirected to three main applications: seasonal residential pool heating, year-round commercial pool heating, and building-integrated fresh-air pre-heating for offices and schools. Direct thermosyphon units have been discussed for summer-only cottages but remain undeployed; any future uptake would require seasonal drain-down or demountable designs. Recent federal tax credits and the harmonisation of testing standards with U.S. and European norms are intended to revive uptake, yet the market is still overshadowed by the country's booming PV sector.

Puerto Rico sustains one of the most vigorous thermosyphon markets in North America. Four local assemblers (Universal Solar, Tanagua, Sun is Life, MC Green Solutions) import selective-surface flat-plate panels and vitreous-enamel tanks from U.S., European and Chinese suppliers, then fabricate open-loop, direct thermosyphon units of 2 m^2 collector / 200–300 L storage—the canonical Caribbean package. Roughly 10 000–12 000 such systems are installed each year, overwhelmingly on flat residential roofs at 30° tilt. High electricity tariffs (22.67 ¢ kWh^{-1}) and post-hurricane grid fragility have accelerated uptake, reinforced by a USD 550 utility rebate plus the 30 % U.S. federal tax credit. Larger commercial loads are met by cascading multiple residential units rather than by centralized forced-flow designs. The same tropical-thermosyphon template is replicated by Syrius Solar in Guadeloupe and Martinique, confirming that where freeze risk is absent and utility prices are punitive, the passive thermosyphon still dominates North American solar thermal practice.

In Oceania, only Australia and New Zealand have accessible data on water heating application. In frost-free northern zones the circuit is direct—mains water flows through the collector—whereas southern states add an external heat-exchanger jacket or glycol loop for freeze protection. Roughly 350 000 of these passive units (about 40 % of Australia's 890 000 solar water heaters) serve detached houses, delivering 60–90 % of annual hot-water demand; larger residential or commercial loads have already migrated to pumped systems. Market momentum, however, is ebbing generous PV feed-in tariffs have collapsed, roof space is prioritised for photovoltaic modules and falling heat-pump prices—now favoured by revised building codes in Victoria—are displacing both thermosyphon and pumped solar heaters. In New Zealand the same passive concept is rare; only a few close-coupled units are installed, while the country's 50 000 solar water heaters are mainly pumped, indirect systems. Beyond these two markets, data are scant; in Papua New Guinea and the scattered Pacific islands electricity reaches barely one fifth of households, so thermosyphon technology—where it appears at all—remains a niche import rather than a mass-market solution.

In Sub-Saharan Africa thermosyphon systems have become the work-horse technology for institutional and social-residential hot water, yet their form is dictated more by local policy and climate constraints than by user preference. In Namibia, Zimbabwe and South Africa, cabinet directives oblige public buildings—school hostels, clinics, police stations—to install solar water heaters, and these are almost always indirect, glycol-filled thermosyphon packages:

2–4 m^2 glazed flat-plate or evacuated-tube collectors feeding 200–300 L roof-mounted tanks, protected against both coastal stagnation and inland frost. The same hardware is downsized to 1 m^2/100 L units for low-cost housing estates and old-age homes, while upscale safari lodges chain several identical sets together to meet peak guest demand. Unglazed collectors survive only in a niche role—heating swimming pools in Namibian coastal resorts—whereas do-it-yourself direct thermosyphons have been trialed but remain marginal because local codes now ban direct circuits on quality-of-water and freeze-risk grounds. Consequently, the region’s thermosyphon landscape is a triad of indirect flat-plate systems for policy-driven public projects, indirect evacuated-tube sets for higher-end hospitality, and scattered small direct evacuated-tube units where municipal water is soft and installers are confident; all are imported, increasingly costly, and sized to bridge the gap between escalating hot-water needs and unreliable electricity grids.

3.3 Flaws and Change

The core dilemma facing traditional siphon-type solar water heaters lies in the profound contradiction between their inherent operating mode and modern application requirements. Their reliance on the natural circulation principle of thermal siphoning necessitates installing the water tank above the collector. This not only imposes strict installation space and aesthetic constraints in modern buildings like high-rise apartments but also poses severe reliability and safety challenges due to the system's vulnerability to leaks caused by damaged vacuum tubes. Additionally, the system's passive reliance on sunlight for circulation causes efficiency to plummet during early mornings, evenings, or overcast/rainy conditions. Exposed pipes are highly susceptible to freezing and clogging in severe cold, resulting in inconvenient maintenance, low overall energy efficiency, and an unstable user experience. These structural flaws collectively constrain its survival and development in the current market.

The urgency to advance its technological upgrades stems directly from the user experience and applicability crises triggered by the aforementioned shortcomings. Its conspicuous installation methods clash with architectural aesthetics, directly limiting its adoption in new residential construction. More critically, the system's inherent deficiencies in reliability, freeze protection, and resistance to weather interference fail to meet modern households' core expectations for stable, safe, and convenient hot water supply. As consumers increasingly demand higher living standards, a hot water system prone to freezing, frequent breakdowns, installation constraints, and poor performance on cloudy days can no longer maintain its market competitiveness. Consequently, the inherent limitations of its underlying principles serve as the fundamental driving force propelling the industry toward fundamental transformation.

4 New Technologies and Products for Thermosyphon Systems

Traditional siphon solar water heaters, as a mature technology, are now at a critical turning point in their evolution from functional products to intelligent, integrated systems. With the deep integration of cutting-edge technologies like the Internet of Things and new materials, the industry's trajectory is no longer confined to single-purpose hot water supply. Instead, it is advancing toward enhancing user experience, achieving multi-energy complementarity, and building a home energy management ecosystem. The following discussion will focus on three core areas: innovations in smart controllers, applications of polymer materials, and the prospects for other innovations.

4.1.1 Background

Natural circulation solar water heater has been widely used, especially in China, Mexico, the Middle East and other places, and it is the main application form of domestic solar hot water systems. However, there are some pain points in the actual use of natural circulation solar water heaters, such as the following pain points about the rooftop solar water heating system:

- Working status like temperature and water level of the tank can’t be known without remote monitoring.
- Heating water needs a long time.
- Easy to overheat when the water in the tank is too low and not replenished in time.
- Higher water temperatures are needed in winter.
- Winter frost protection requires manually turning on the heating tape, which has no preventive effect.

Balcony Solar Hot Water System has the following pain points:

- Working status can’t be known without remote monitoring.
- Heating water needs a long time.
- Hot water use needs to wait because of long pipes and cold water.
- Magnesium rods wear out easily and need to be replaced periodically.

These pain points affect the user experience. With the improvement of people's living standards, the demand for reliable hot water is ubiquitous. Therefore, in addition to energy saving of solar water heaters, more attention is paid to the convenience of its intelligent control and manipulation. With the development of Internet of Things technology, more intelligent products are emerging. It not only makes people's lives more comfortable, convenient and instantaneous, but also connects society. Furthermore, the rapid development of information technology and the mature application of Internet of Things technology provide the necessary conditions for the intelligent control of solar water heaters. The time is ripe for the design and application of solar water heater intelligent controller.

4.1.2 Technology of Intelligent Controller

Natural circulation solar water heaters usually need to control water temperature, water level, and anti-freezing / defrosting. The control of the water temperature is mainly to control the opening and closing of the auxiliary electric heating to reach the set temperature. For water level control, it is mainly to control the opening and closing of the solenoid valve according to the signal of the water level sensor in the water tank to ensure that the water tank is filled with water. Balcony natural circulation hot water system does not need water level control. The functions of these controls are relatively simple and can usually be realized with a microcontroller and its programming language. For cost considerations, PLC will not be used. In view of the pain points in use, remote monitoring and mobile APP control controllers are necessary, so the Internet of Things(IoT) platform and WIFI module will be used.

Internet of Things platform: The platform is based on Internet technology and sensor technology and is used to realize the development, management and operation of Internet of Things applications. Through cloud computing, big data analysis and other technical means, it integrates the elements of sensors, devices, networks and applications to realize the interconnection between devices. Data collection and processing IoT platforms are usually based on b/s and c/s remote monitoring. This system is a monitoring system that uses the network as a communication platform and is based on http technology. with the advantages of simplicity and efficiency. Through the IoT platform and its APP, users can use their mobile phones to monitor the operation status of smart products.

Wi-Fi module: Solar water heaters are installed on buildings, and WIFI modules are usually used as transmission units to connect the equipment to the Internet of Things. Its 32-bit microcontroller has built-in Wi-Fi driver and protocol, generally using MCU interfaces like UART, and is suitable for all types of smart homes or smart hardware items. Wi-Fi modules are widely used in smart home, industrial automation, medical equipment, consumer electronics and other fields. For example, in smart homes, Wi-Fi modules can realize wireless connections, and users can control various devices through mobile phone APPs. With the development of smart homes and the application of household appliances, the price of the Wi-Fi module has also decreased significantly, providing opportunities for the application of water heaters.

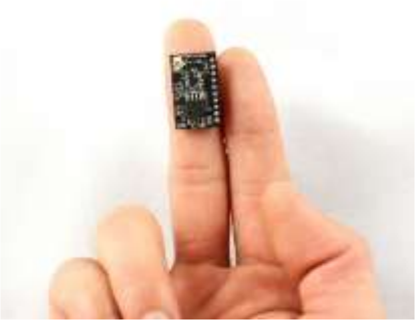

Figure 2: Wi-Fi Module (From Ma Guangbai (QIT)).

4.1.3 Application

Using single-chip microcomputer, embedded WIFI module and Internet of Things platform, we developed intelligent controllers for rooftop natural circulation and balcony natural circulation solar water heaters and realized commercial applications. The rooftop natural circulation solar water heater and its intelligent controller are shown in the figure below.

Figure 3: The Rooftop Natural Circulation Solar Water Heater and Its Intelligent Controller (From Ma Guangbai (QIT)).

Table 1: The Main Function and Application Effect of The Rooftop Solar Water Heater Controller.

MAIN FUNCTION		APPLICATION EFFECT
Monitoring mode	WIFI connection, mobile phone monitoring, screen touch control	Working status can be seen on the mobile phone
Condition display	Temperature and water level display, operating status display	
Heating function	Pre-heating to setting temperature by the phone	Reduces waiting time
Filling water function	Click to refill water on the mobile phone; automatically fills to full water level according to the temperature	Prevent overheating, reduce scale, increase hot water volume
Winter mode	Control to fill only half water level in winter	Get hotter water

Anti-freezing/unfreeze function	Click to unfreeze on the phone; automatically heating to anti-freeze by pipe temperature sensor	Pipeline freezing prevention in winter; unfreeze in advance
Protection function	Lightning, dry burning, electric leakage, anti-freezing protection	Ensure safety

The mobile phone control interface is shown in Figure 4. The water heater operation can be performed in the remote operation area.

Figure 4: The Mobile Phone Control Interface of The Rooftop Solar Water Heater Controller (From Ma Guangbai (QIT)).

The controller of the balcony solar water heater is shown in Figure 5.

Figure 5: The Controller of The Balcony Solar Water Heater (From Ma Guangbai (QIT)).

Table 2: The Main Function and Application Effect of The Balcony Solar Water Heater Controller.

MAIN FUNCTION		APPLICATION EFFECT
Monitoring mode	WIFI connection, mobile phone monitoring; screen touch control	Working status can be seen on the mobile phone

Condition display	Temperature and water level display, operating status display	
Heating function	Pre-heating to setting temperature by the phone	Reduces waiting time
Pipeline hot water circulation	Pump the cold water in pipeline to the tank, let hot water stay in the pipeline	Reduce waiting time with hot water from the pipeline
High temperature sterilization function	Heat to 80℃ realize high temperature sterilization	supply cleaner hot water
Anode protection	Electronic anode protection, no need to replace the magnesium rod	Solve the problem of easy loss of magnesium rod
Heat transfer cycle	Reserve the control interface of the temperature difference heat exchange circulating pump	Long pipeline can be connected to circulating pump

当前温度 25℃

设定温度 51°C

用水循环时间 60S

Figure 6: The Mobile Phone Control Interface of The Balcony Solar Water Heater Controller (From Ma Guangbai (QIT)).

In China, in addition to Linuo Paradigma, other solar brands such as Micoe, Haier, etc., also developed a natural circulating solar water heater controller with remote mobile APP control. These controllers can not only be applied for new sales products but can also be directly replaced with old products that are already in use. They have good application opportunities.

Figure 7: The Solar Water Heater Controller of Micoe (From Ma Guangbai (QIT)).

Figure 8: The Solar Water Heater Controller of Sunrain (From Ma Guangbai (QIT)).

Figure 9: The Solar Water Heater Controller of Haier (From Ma Guangbai (QIT)).

In the future, the intelligent control of solar water heaters can be further expanded and improved in terms of product appearance and texture, simultaneous configuration of Wi-Fi + Bluetooth remote control, voice control, and control of various automatic auxiliary energy forms (electricity, gas, heat pumps).

4.2 Advanced Materials

4.2.1 Background

The SOLPOL research project series SOLPOL 1-6 is a comprehensive Austrian scientific research initiative that started in 2010 and will last until December 2025 with a focus on fundamental materials research and development, development of methodologies and test methods development as well as system integration and market research with regards to the possibilities that polymeric materials offer in the field of solar applications and (thermal) storage technologies. The research project SOLPOL 1-6 has been led by Johannes Kepler University Linz, Institute of Polymeric Materials and Testing. In SOLPOL 1/2 nine scientific partners active in the fields of materials research, polymer processing, energy efficient buildings, industrial design and economics were involved as well as nine company partners in the raw materials as well as polymer processing sector.

4.2.2 Polymeric Materials

Non-technical polymeric materials were analysed for both solar thermal as well as solar photovoltaic systems applications and fundamental research concerning the use of polyolefin polymers with regards to the above-mentioned applications was performed to achieve cost reduction through high prefabrication and optimized functional integration, while still enabling high reliability and long service life. Further objectives included the reduction of collector weight and allowing for simple installation.

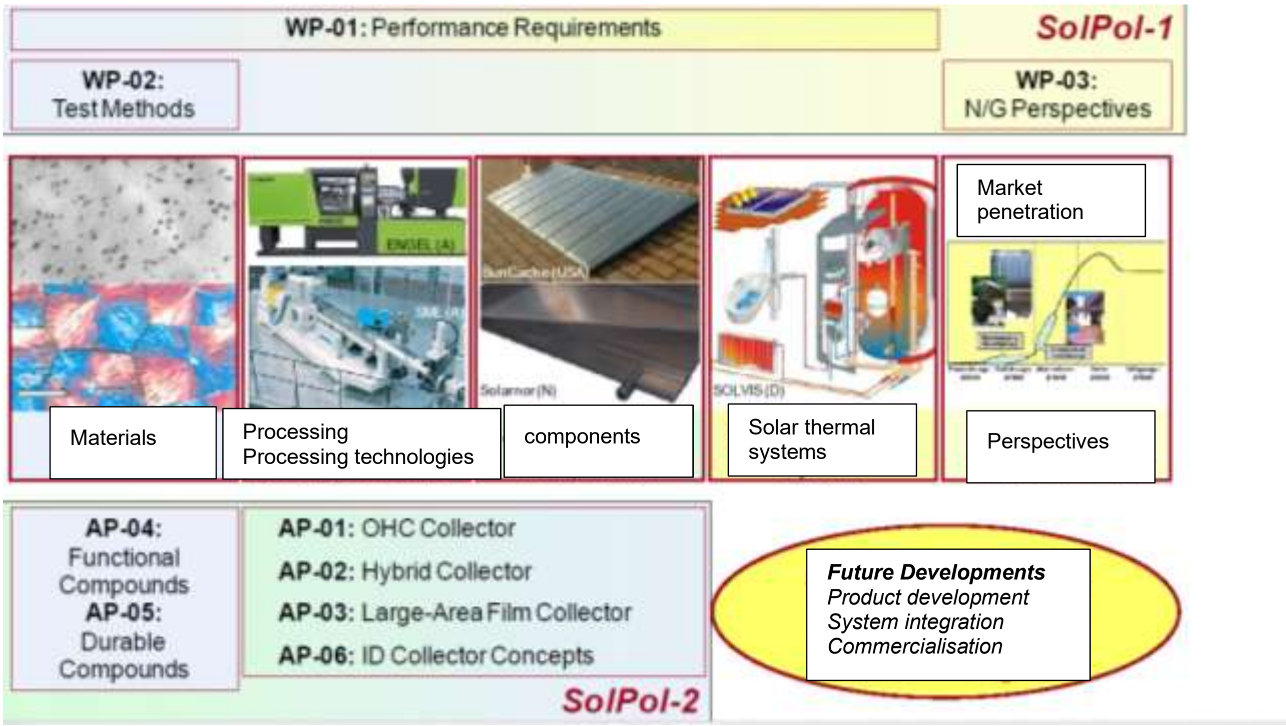

Figure 10: SOLPOL 1/2 Work Stream (Source: JKU).

Fundamental research work on stabilisation and ageing behaviour of polyolefin polymers done in the scope of SOLPOL 1/2 has been published for example in [4],[5],[6],[7],[8]. New antioxidants for polyolefin polymers have been developed and analysed with regards to their thermos-oxidative stability. Further research work was done on the definition of requirements for polymeric materials regarding their use in solar thermal applications that served as a basis for modelling and simulation and components development including hybrid polymeric absorber materials as well as collector testing with overheating protection. Articles about the performance requirements and the OHC overheating protection collector can be found in [9], [10], [11]. Lifetime modelling was done using the Gugumus and Arrhenius approach respectively and the cumulative damage model (Miner's rule) to calculate the failure time. The results largely varied depending on the material used and the location (8 to 34 years). In the following two figures a comparison of different façade collectors with regards to specific solar collector yield and solar fraction as well as the design of a OHC collector and its prototype are shown.

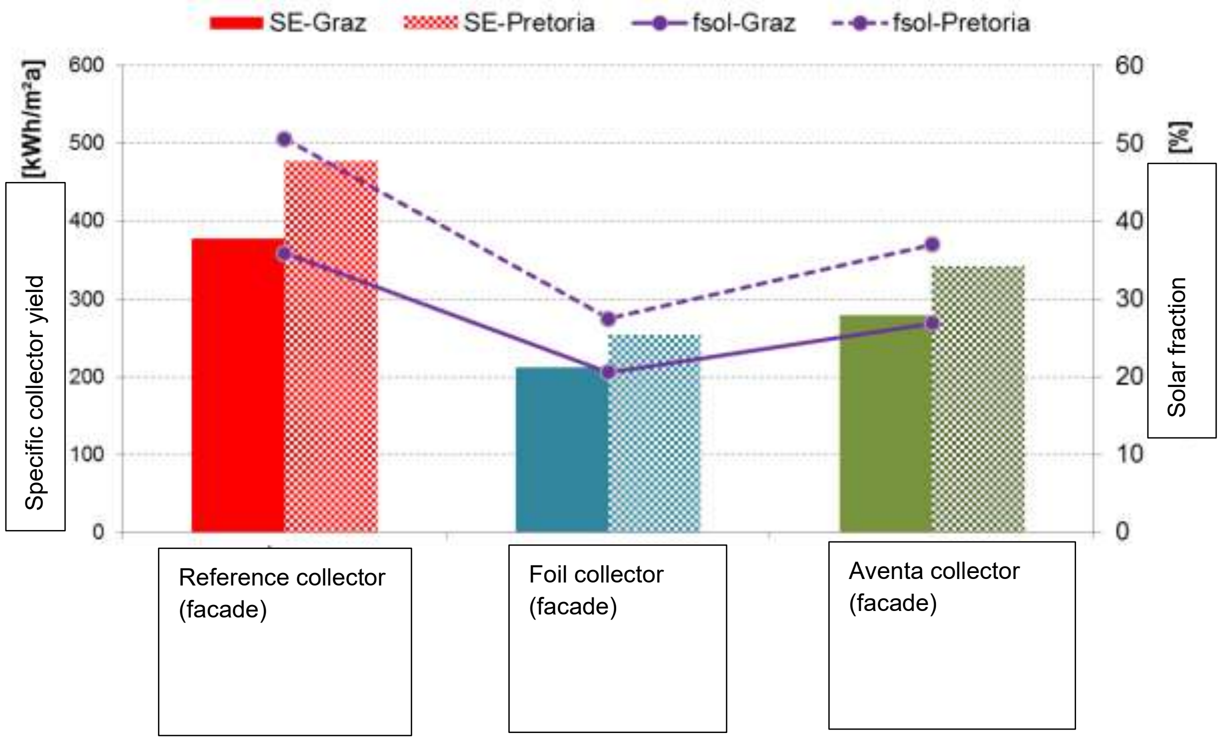

Figure 11: Specific Collector Yield and Solar Fraction for Facade Integrated DHW Systems (Source: SOLPOL 1/2).

Figure 12: Design of Roof-Integrated Polymeric Collector with Overheating Protection OHC (left), Collector with Overheating Protection (OHC) on Testing Facility at University of Innsbruck, Austria.

The OHC performed very well in comparison with a high-performance flat plate collector (see

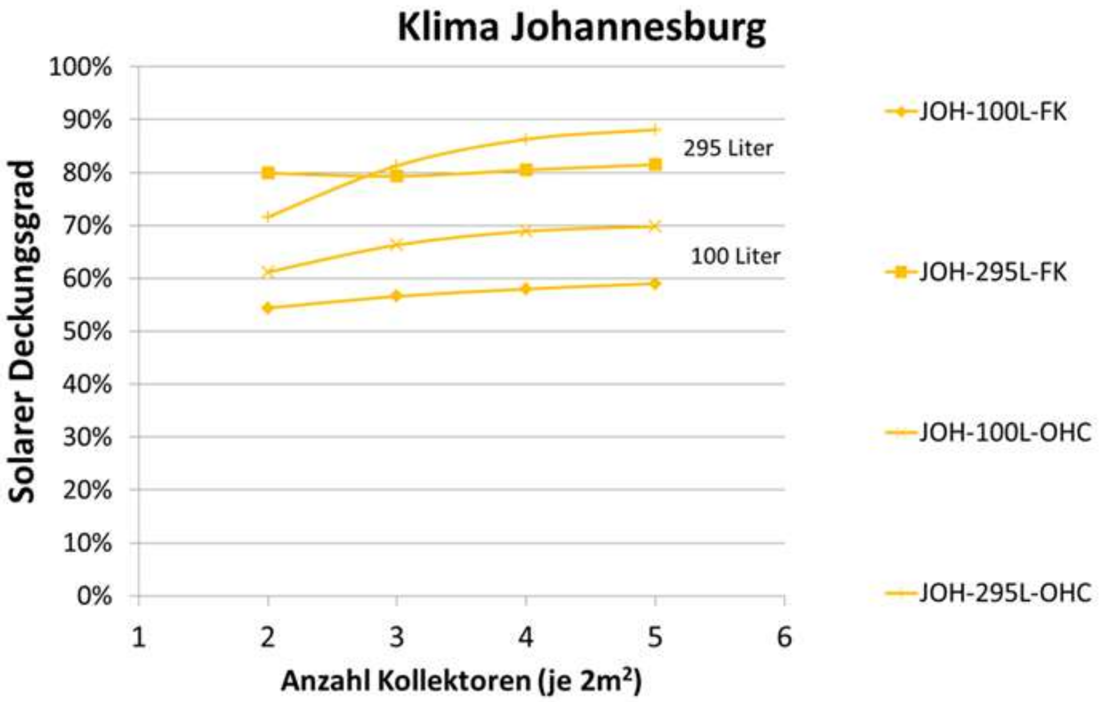

Figure)

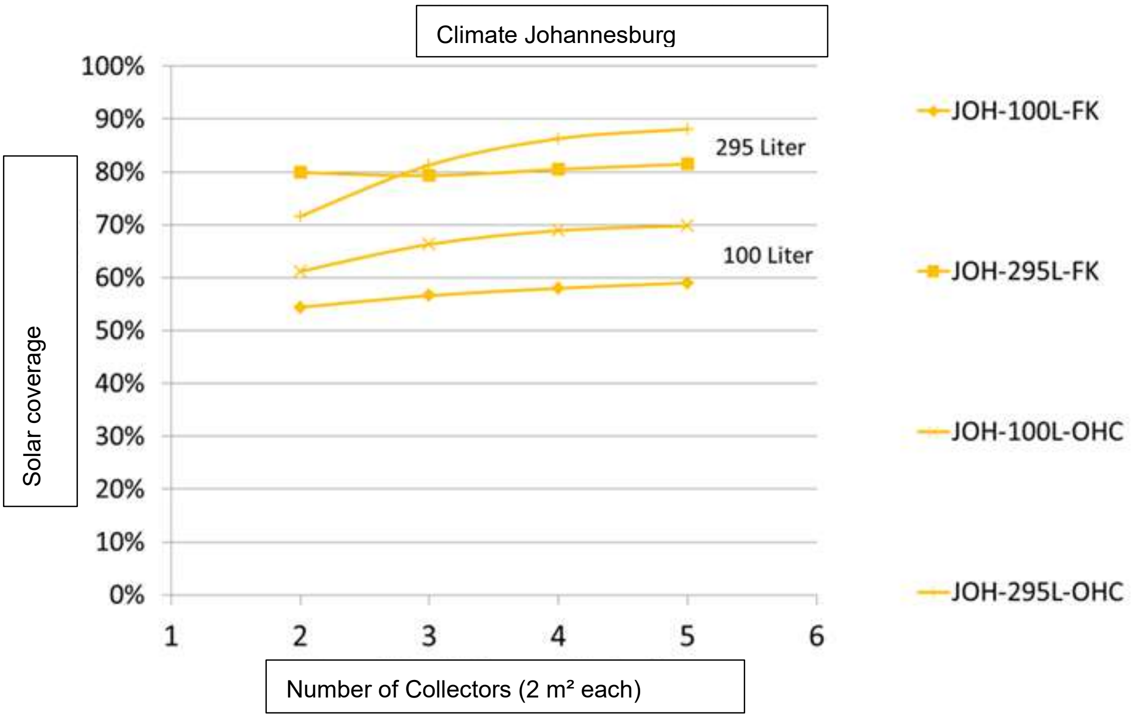

Figure 13: Simulation Results on A Yearly Basis for OHC (Overheating Protection) Collector (OHC; η0=0,77, a1=6,1; a2=0,007) Compared with A High-Performance Flat Plate Collector (FK; η0=0,8, a1=3,0; a2=0,01) (Climate Johannesburg).

Figure 14: Design Studies with Regards to Polymeric Collector Concepts (Source: SOLPOL 1/2).

4.2.3 Design and Test

The SolPol-4/5 projects aimed at significantly reducing the costs and improving the performance of solar thermal systems by leveraging polymer-based materials and high levels of system prefabrication. The project recognized that most current pumped systems are overly complex and costly due to on-site assembly using non-standardized components. SolPol-4/5 promoted standardization, prefabrication, and plug-and-function installation to simplify assembly, reduce errors, and cut costs. The project has successfully advanced the large-scale application of polymers in solar thermal systems, achieving substantial progress particularly in non-pumped integrated thermal storage systems.

During the project SOLPOL 4/5- WP-02, high-quality non-pumped systems have been analysed. The work includes an analysis of single-loop integrated storage collector systems, an analysis of dual-loop systems with integrated sensible heat storage, addresses dual-loop systems with integrated storage based on thermoformed components, and considers economic and ecological perspectives.

An existing single-loop integrated storage collector system was analyzed using practical and theoretical research methods. Solutions for critical components were worked out and further elaborated. It was possible to determine material-specific requirements necessary for further research.

Based on the preliminary results of the EU-funded project SCOOP, a theoretical storage collector model was matched with the simulation program (Polysun 6.2). Annual simulations for the worst-case scenario (no domestic hot water demand) were calculated and expanded with the expected surface temperatures. For this purpose, the relation between the temperature gradient between the medium and the surface of the side of the metal pipe facing the sun and the irradiation was calculated and validated using measured data. Using the hourly data of the medium temperatures (from Polysun 6.2) for the storage collector as a basis, this was expanded with the temperature gradient according to the climate conditions (irradiation on the inclined collector area). In a next step, the occurring temperatures were analyzed and the frequencies for one simulation year were calculated for five reference locations (see Figure 15).

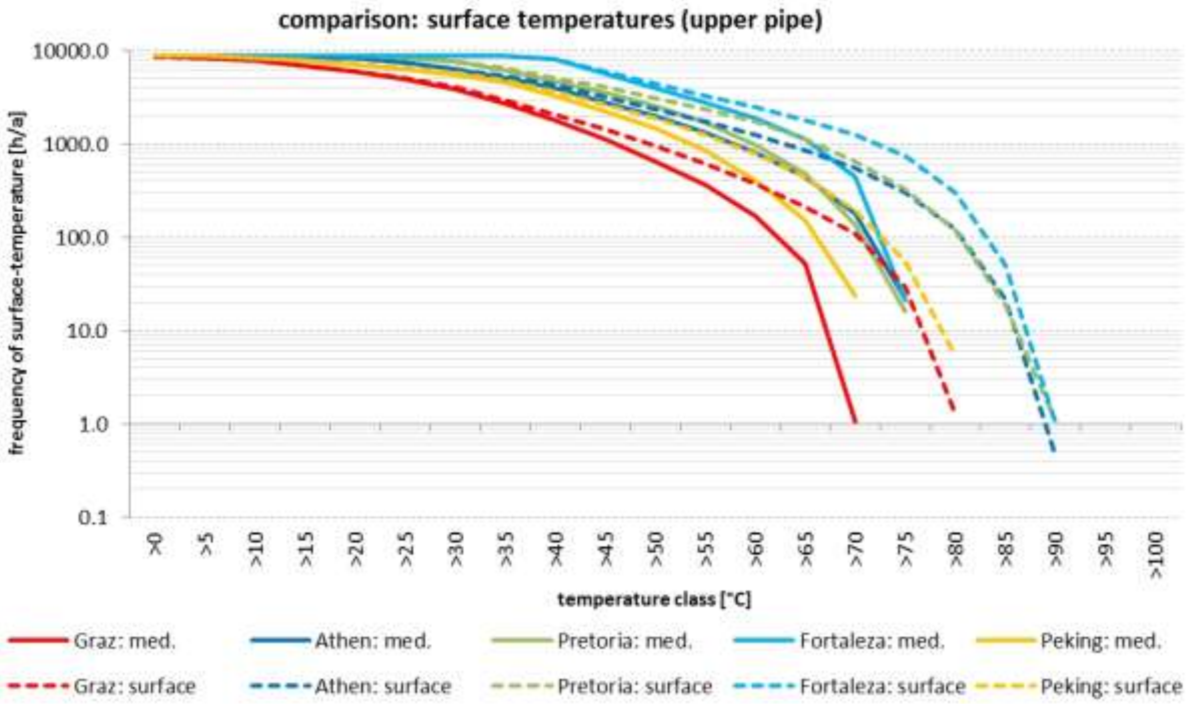

Figure 15: Cumulative Frequency of The Medium and Surface Temperature of The Storage Collector without Domestic Hot Water Demand (Worst-Case Scenario) for Five Different Locations. Source: Reinhold W. Lang, Gernot M. Wallner, Jörg Fischer et al. (2019); Solar-thermal Systems Based on Polymeric Materials: Novel Pumped and Non-Pumped Collector-Systems, SolPol-4/5, Final Report, Climate and Energy Fund, Austria 2019.

Concerning the double-loop systems, various designs were assessed with functional models and numerical simulations: the selected configuration is a direct hot water draw-off from storage (no hot water heat exchanger) and includes harp design for storage pipes connection. Overheating control (via a back cooler) was shown to offer great potential to use low-cost polymeric materials in thermosyphon systems. A design has been carried out, achieving a thermosyphon system with high-share polymer content. Its lightweight and potentially low cost are attractive. Nevertheless, the manufacturing processes are not yet clear and may need further assessment and optimization.

Substituting the metal components with polymer components opens a great potential for cost reductions with simultaneous performance improvements. A thermosyphon system with a high proportion of polymeric components has been designed (see Figure 16). All components are designed in such a way that they can be produced in different plastics processing technologies.

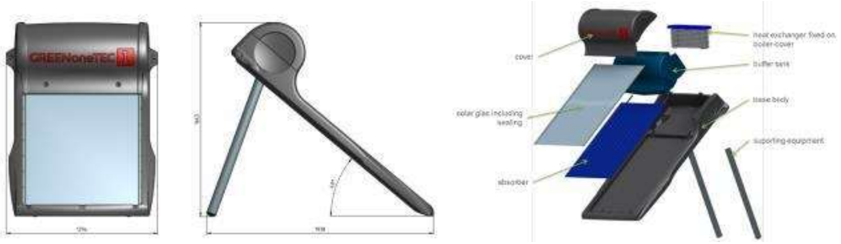

Figure 16: Design Study of a Polymer Thermosyphon Systems Done by GREENoneTEC (Source: SolPol-4/5, Final Report, Climate and Energy Fund, Austria 2019).

Manufacturing costs for individual components (base body, cover, buffer tank) and investment costs for the tools required were estimated for rotation-molding (see Figure 17).

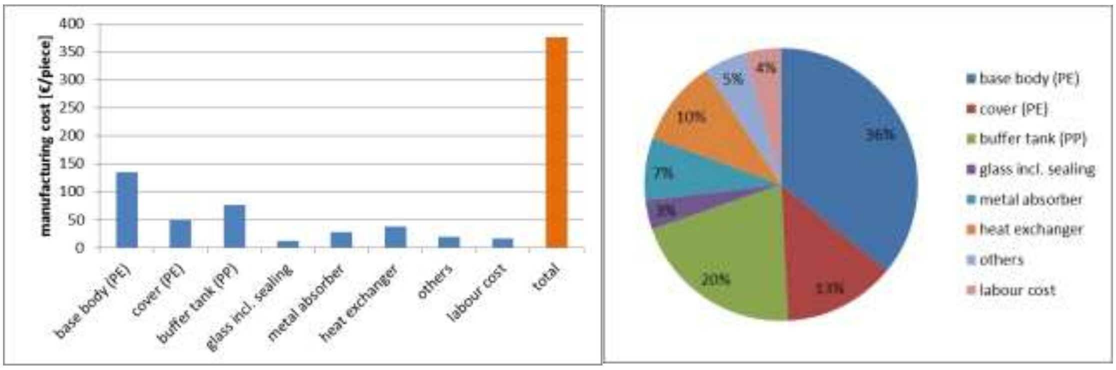

Figure 17: Polymer Thermosyphon System: Cost Estimation (left) and Share of Costs (right) Done by GREENoneTEC. (Source: SolPol-4/5, Final Report, Climate and Energy Fund, Austria 2019).

An essential step forward in developing the integrated storage collectors has been achieved especially in the design of the polymer-based pressurized storage. Based on a theoretical analysis and on outdoor performance tests, an optimized storage design for the use in the single-loop as well as in the double-loop systems has been identified (Figure 18). The elaborated design combines the attributes of improved draw-off profiles for the single- and double-loop systems and an efficient and effective stratification during storage charging via a PV pump. The multifunctional design leads to a cost-optimized component, based on the LFT manufacturing process, which can fulfil highest system efficiency and comfort requirements in different climate zones. Furthermore, based on results of the previous studies, auxiliary collector components and materials have been selected involving the entire consortia value chain.

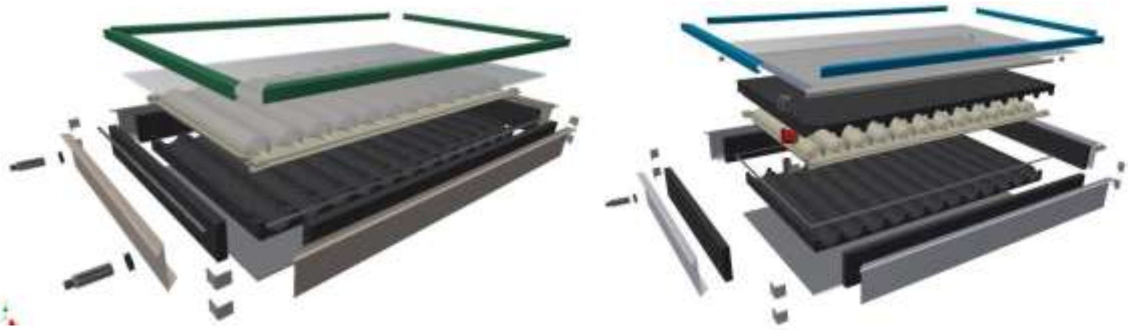

Figure 18: 3D Model of The Single-Loop (left) and Double-Loop (right) Integrated Storage Collector, with The Multifunctional Pressurized Storage (Source: SolPol-4/5, Final Report, Climate and Energy Fund, Austria 2019).

The thermosyphon system, manufactured with high share of polymer materials, has been tested in outdoor conditions. The heat exchanger immersed in the pressure-less storage is satisfying, limiting the temperature hub from storage to hot water to 10 K. The need for over-heating control in case of stagnation has been observed, as the pressure-less storage should not reach 100 °C to avoid evaporation. Subsequently, a temperature-controlled back-ventilation, based on work from Task 1.3, has been implemented and tested.

Compared to thermosyphon systems with vacuum tubes the costs of the developed polymeric integrated storage collector system are still somewhat higher, hence further concepts were conceived and assessed as to their potential for further cost reductions (polymeric ISC with expanded PP (foam) frame; 100 $ system for extremely low-income regions). The latter work was performed to replace the originally envisaged work on the market potential and economic effects of polymeric collector systems.

4.2.4 Key Achievements

Based on all developments in WP-02, a full-scale functional model of a single loop Integrated Storage Collector (ISC) system has been manufactured (Figure 19). It is composed of two glued polymer half-shells shaping 12 pipes connected vertically in parallel. The 12 vertical absorber-storage pipes are obtained from assembling 6 molded elements made of 2 pipes each. The pipes are made of two molded half-shells glued together. The half shells are obtained through long-fibre reinforced thermoplastics (LFT) manufacturing process. In the functional model, all storage pipes are connected with a copper pipe screwed on the inlet connection at the bottom and on the outlet connection at the top.

The storage pipes are insulated at the back and covered with a twin-wall polycarbonate sheet on the front side. This full-scale functional model has been successfully tested in outdoor conditions. The results of this polymer-based ISC system indicate similar cool-down at night, a slightly lower efficiency than the metal-based Solcrafte, but similar efficiency to common thermosyphon systems. Most of all, the polymer-based collector resists much better to corrosion which makes it very suitable for regions with high chloride concentration in water and in the atmosphere (esp. in coastal areas).

Figure 19: Left: Detailed Construction of The Single Loop System. Right: Full-scale Functional Model Out of Plastic Absorber-Storage Pipes. (Source: SolPol-4/5, Final Report, Climate and Energy Fund, Austria 2019).

4.3 Solar Energy Meter

4.3.1 Background

Solar meters are a vital component of solar energy systems. With ongoing technological advancements and evolving demands, these devices have evolved from basic display and control units into integrated household energy management hubs that combine safety, energy efficiency, and intelligent control. Looking ahead, as the Internet of Things, big data, and ecosystem interconnection technologies become deeply integrated, solar meters will transcend their role in hot water management alone, emerging as a key gateway to smart homes and sustainable living.

4.3.2 Core Functionality

Currently, mainstream solar water heater control instruments have achieved a highly integrated and intelligent functional system, primarily comprising the following core modules.

（1）The Cornerstone of Safety Protection：

- **Comprehensive Self-Diagnostics and Fault Early Warning:** Performs a power-on safety self-test, continuously monitors system status, and displays faults in code format.
- **Electrical Safety:** Equipped with leakage protection, overload protection, and lightning protection (Level 3), fundamentally ensuring user safety.
- **System Protection:** Multiple safeguards protect the water heater itself, including: - Anti-explosion tube (prohibits water supply during high-temperature water shortage) - Anti-dry heating (disables electric heating at low water levels) - Anti-leakage (intelligently detects pipe or vacuum tube rupture)

（2）Smart Water Management:

- **Precision Monitoring:** Real-time display of water temperature (0-99°C) and water level (25%, 50%, 75%, 100%).
- **Flexible Water Supply Strategy:** Supports multiple modes including manual watering, scheduled watering, low-water-level watering, and temperature-controlled watering.
- **Complex Operating Conditions Management:** Features emergency functions including low water pressure protection (intermittent water supply) and forced water supply (in case of sensor failure).

（3）High-efficiency energy-saving operation:

- **Multi-mode selection:** Offers three core modes—Energy Saving, Timer, and Winter—to accommodate different seasons and user preferences.

  Energy-saving Mode: Prioritizes solar energy utilization with manual auxiliary electric heating to achieve maximum solar thermal efficiency.

  Scheduled Mode: Supports user-defined timed water filling and heating cycles to meet personalized needs.

  Winter Mode: Integrates pipe freeze protection (intermittent electric heating strip operation) and tank freeze protection functions to ensure normal operation during severe cold weather.

- **Automatic Pressure Boosting:** In areas with low water pressure, the system can activate the water pump to assist with water supply, enhancing user experience.

（4）Personalized Settings and Adaptive Adjustments:

- Users can customize the temperature at which heating stops, the target water level for filling, and scheduled timers.
- Features adjustable water level sensitivity to accommodate variations in water quality across different regions.

The current control instruments have addressed most of the pain points in solar water heater usage, achieving a leap from “functional” to “user-friendly,” and laying a solid functional foundation for future development.

The dashboard's functional display is shown in Figure 20.

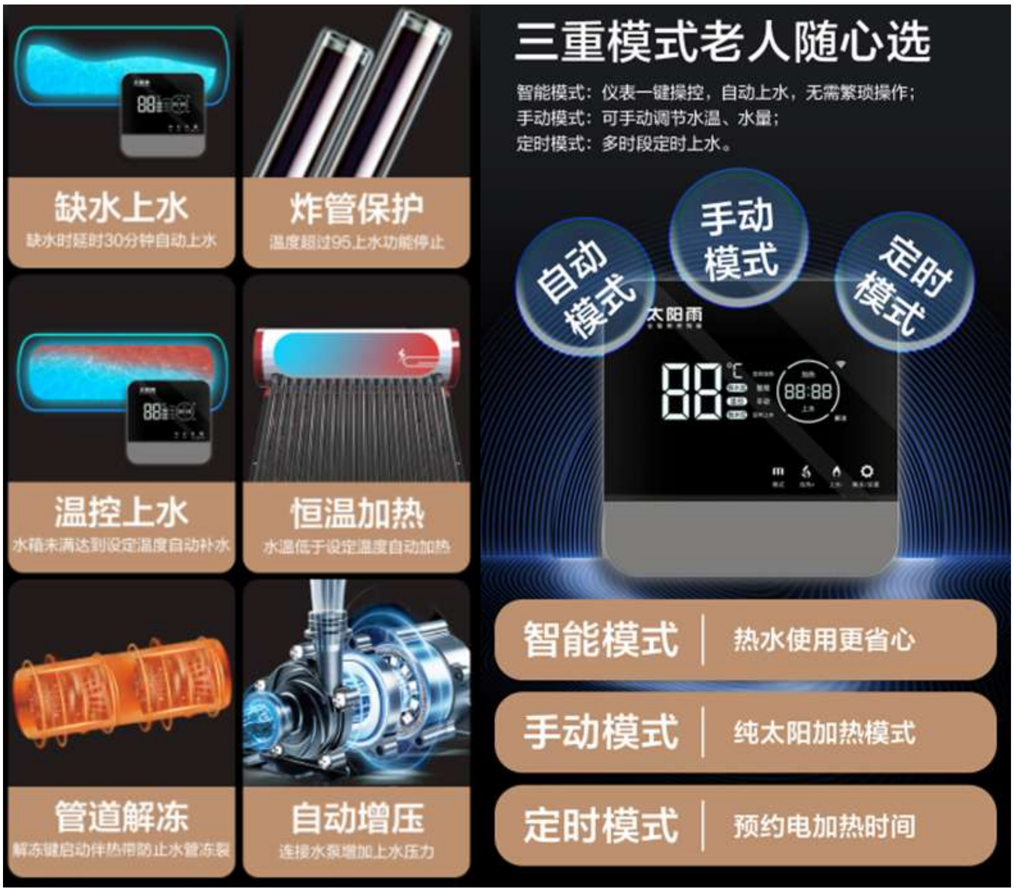

Figure 20: Functional Demonstration of Solar Energy Meters (From Li Kaichun (SunRain)).

4.3.3 Technological Development

The industry is actively evolving from “standalone intelligence” to “connected intelligence,” with key technological directions focused on:

IoT Integration and Remote Control: Connect the meter to a cloud platform via its built-in Wi-Fi module. Develop a companion mobile app enabling users to remotely monitor water temperature and level, manually start/stop water supply/heating, switch modes, and set scheduled tasks anytime, anywhere—eliminating spatial and temporal constraints.

Multi-Energy System Integration: Enables intelligent coordination between solar water heaters, electric water heaters, and gas water heaters. During periods of insufficient sunlight or high-water demand, the system automatically activates backup energy sources to ensure continuous, stable hot water supply, forming a highly efficient, complementary household hot water center solution.

The development and application of technological advancements are shown in the Figure 21.

Figure 21: The development and application of technological advancements (From Li Kaichun (SunRain)).

4.3.4 Outlook for Smart Solar Energy Meters

Future solar meters will no longer be isolated controllers but key nodes in home energy management and green living. Their future functions will revolve around “data-driven,” “visual,” and “eco-friendly” capabilities.

At the data level, the system will evolve beyond simple temperature monitoring into a sophisticated home energy calculation unit. By collecting real-time key parameters such as water tank temperature rise and volume, the platform can precisely calculate daily solar heat gains and automatically convert them into quantifiable metrics: standard coal savings and reduced carbon dioxide emissions. This provides a robust, credible data foundation for every green contribution, making environmental value measurable and traceable.

At the visualization level, these dry data points will be transformed into intuitive, vivid charts on user terminals through formats like “personal carbon statements.” Users can clearly see their daily and monthly contributions to reducing the Earth's environmental burden, turning abstract environmental concepts into tangible achievements and motivation for participation. This significantly enhances user experience and encourages sustained engagement.

At the ecological level, the system's value will transcend the equipment itself, integrating into broader digital lifestyles. By connecting with corporate platforms like Alibaba's “Green Energy,” individual carbon reduction actions gain social value and can be redeemed for incentives such as virtual tree planting.

Simultaneously, electric or gas water heaters with integrated solar preheating functions are being introduced. These products simplify installation, reduce reliance on traditional large solar water tanks, and are better suited for scenarios with limited installation space, such as urban apartments, thereby promoting the widespread adoption of solar thermal utilization. Integrated Platform as shown in Figure 22.

Figure 22: Integrated Platform (From Li Kaichun (SunRain)).

The solar water heater control instrument industry is at a pivotal turning point. Its development path is clearly visible:

- Currently, we possess comprehensive, safe, and reliable "smart controllers."
- In the medium term, we will welcome interconnected, multi-energy complementary "home hot water brains."
- In the future, we will advance toward a "Energy and Environmental Service Platform" that is data-driven and integrated into green lifestyles.

Ultimately, the value of solar meters will transcend the hardware itself. By building a smart ecosystem connecting users, devices, and the environment, it will not only deliver an exceptionally convenient hot water experience but also pioneer a tangible, quantifiable green and low-carbon lifestyle. This will contribute solid momentum toward society's overall "dual carbon" goals.

4.4 Other

In addition to the above, the following innovative technologies and products are still emerging in solar thermosyphon water heating systems:

AI-Predictive Heating: In siphon-type solar water heating systems, the integration of AI predictive heating technology significantly enhances user experience and energy efficiency. This system collects real-time weather forecast data for the coming days and combines it with historical parameters such as solar radiation intensity, temperature, wind speed, and cloud cover to accurately predict the collector's heat gain efficiency. Simultaneously, by learning household hot water usage patterns—such as peak consumption times and water volume—the AI model intelligently identifies heating gaps. When anticipating insufficient sunlight or potential water demand shortfalls, the system proactively activates the electric auxiliary heating device to gradually preheat the storage tank, rather than passively waiting until water temperatures drop before responding. This proactive intervention strategy effectively overcomes the limitations of traditional siphon-based systems that rely entirely on weather conditions. It significantly reduces user wait times for hot water, delivering a stable and comfortable "instant hot water" experience. Simultaneously, by implementing off-peak heat storage and demand-based auxiliary heating, it minimizes idle energy consumption, achieving dual optimization in both energy efficiency and convenience.

Modular Thermal Storage Units: The introduction of modular thermal storage units in siphon-type solar water heaters represents a key technological innovation that overcomes their dependence on sunlight. The core of this device lies in encapsulating phase change materials (PCM) into standardized, flexibly expandable energy storage modules that are integrated into or form part of the water storage tank. During periods of abundant sunlight, not all solar-collected heat is directly used to heat the water; instead, a significant portion is absorbed and stored by the PCM modules. During the PCM's phase change (e.g., melting from solid to liquid), it sequesters a large amount of thermal energy. During periods when collectors cannot operate—such as cloudy days, rainy weather, or nighttime—ambient temperatures drop. The PCM then triggers a reverse phase change (solidifying from liquid to solid), steadily and continuously releasing its stored latent heat into the surrounding circulating water. This process functions like a "thermal battery" within the water heater, effectively compensating for interrupted solar heating. It significantly extends the system's ability to sustainably provide hot water—from the traditional few hours to over 24 hours—greatly enhancing water supply reliability during cloudy or rainy days and improving the overall energy efficiency of the system.

Blockchain Carbon Credit System: In the application of siphon-type solar water heaters, the introduction of a blockchain-based carbon credit system aims to quantify users' environmental contributions and convert them into tangible benefits. By integrating smart monitoring modules into the equipment, the system precisely measures the actual substitution of solar energy for traditional electricity and gas sources, automatically calculating the resulting carbon dioxide emissions reductions. This critical data is recorded immutably on the blockchain. Its decentralized, transparent, and traceable nature ensures the authenticity and uniqueness of each emission reduction unit. After verification by authoritative algorithms, this data automatically generates corresponding personalized “carbon reduction certificates” (e.g., carbon credit tokens). These digital certificates can be directly sold in regional or global carbon trading markets, delivering immediate economic returns to users. This mechanism ingeniously transforms individual households' green energy-saving behaviors into tangible assets. It not only provides users with sustained economic incentives but also significantly boosts their motivation to install and utilize solar water heaters. At a deeper level, it propels the widespread adoption of distributed renewable energy and advances the realization of carbon neutrality goals.

Cross-Energy Coordination Control: The introduction of cross-energy coordination control in siphon-type solar water heating systems aims to establish a highly autonomous “photovoltaic-electricity-thermal” energy microgrid. This system integrates rooftop photovoltaic power generation units, high-efficiency air-source heat pumps, and traditional solar water heaters into a smart integrated system. Its core control unit continuously monitors the power output of the photovoltaic system and intelligently schedules operations according to the principle of “local consumption and green electricity priority.” During daylight hours with ample sunlight, the system automatically prioritizes using green electricity generated by PV to drive the heat pump. Acting as a powerful auxiliary heat source, the heat pump injects heat into the storage tank at an efficiency several times higher than traditional electric heating. This significantly accelerates hot water preparation and overcomes the limitations of siphon systems during cloudy/rainy weather and nighttime. This synergistic model maximizes the comprehensive utilization efficiency of solar energy, directly converting free solar energy into thermal energy or efficiently storing and utilizing it via electricity as an intermediate form. This significantly reduces dependence on the public grid and household energy costs, achieving an upgrade in smart energy management from “passive collection” to “active coordination and efficient conversion.”

5 Summary and Outlook

This report systematically examines the current state, regional characteristics, technical challenges, and innovation directions of the global thermosiphon solar water heating system market. The report indicates that domestic hot water (DHW) has become one of the largest energy consumption categories in residential buildings, accounting for 11% to 32% of total global residential energy use. Demand for DHW will continue to grow as living standards rise and hygiene awareness increases. Despite advances in building energy efficiency technologies and a gradual decline in space heating energy consumption, hot water energy use remains persistently high. This presents significant development opportunities for solar thermal technologies, particularly thermosiphon systems, which offer simple structures and low costs. However, the global solar thermal market is experiencing overall contraction, with a projected 14% decline in 2024. Thermosiphon systems face increasing pressure from competing technologies like heat pumps and photovoltaics, making technological upgrades and system integration essential to enhance competitiveness.

From a global regional market perspective, the application of thermosiphon systems exhibits significant diversity and regional dependence. In sun-drenched regions with mild winters—such as Southern Europe, Asia (China, India), Latin America, and the Middle East—thermosiphon systems dominate. Their configurations (direct/indirect, flat-plate/vacuum tube) are highly adapted to local frost protection requirements, water quality conditions, and building types. Conversely, in regions with harsh winters and stringent regulations—like North America and Northern Europe—forced-circulation systems prevail. Sub-Saharan Africa is primarily policy-driven, deploying indirect thermosiphon systems in public buildings. The Oceania market faces pressure from strong competition from heat pumps and photovoltaics. These regional differences reflect the resilience of thermosiphon systems and their cost-effectiveness and reliability advantages in specific contexts, while also indicating that future development must be closely integrated with localized energy policies, building codes, and user habits.

In terms of technological innovation, the report highlights how intelligent systems and materials science are revolutionizing thermosiphon systems. IoT-based smart controllers integrate Wi-Fi and mobile applications to enable remote monitoring, scheduled heating, automatic water replenishment, freeze protection, and pipe circulation—effectively addressing pain points such as poor user experience and maintenance challenges in traditional systems. Concurrently, advanced materials research exemplified by Austria's SOLPOL project focuses on developing anti-aging, lightweight, and low-cost polymer collectors and system components, opening new avenues for reducing system costs and enhancing design flexibility. The report also prospectively explores cutting-edge directions such as AI-based predictive heating, phase change material (PCM) thermal storage, blockchain-based carbon assets, and integrated control of photovoltaic-heat pump-solar thermal systems. These developments signal the evolution of thermosiphon systems from single-function devices toward comprehensive energy management systems.

In summary, despite the overall challenges facing the global solar thermal market, thermosiphon systems retain irreplaceable potential in specific regions and markets due to their inherent economic viability, reliability, and passive operation characteristics. Their future survival and development hinge on continuously enhancing user experience and system efficiency through intelligent empowerment, material innovation, and deep integration with other energy systems, thereby better integrating into the built environment and overall energy structure. Only through such approaches can thermosiphon systems continue to play a vital role in the decarbonization of the building sector, achieving a transformative upgrade from “functional products” to “intelligent energy nodes.”

6 Appendix

6.1 Abbreviations

IoT	Internet of Things
DHW	Domestic hot water
AI	Artificial Intelligence
SWHs	Solar water heaters
DIR-ETC	Direct systems with Evacuated Tube Collectors
IND-FLAT	Indirect systems employing Flat Plate Collectors
IND-ETC	Indirect systems employing Evacuated Tube Collectors
LPG	Liquefied petroleum gas
PLC	Programmable Logic Controller
APP	Application
UART	Universal Asynchronous Receiver/Transmitter
MCU	Microcontroller Unit
OHC	Overheating protection collector
PCM	Phase change materials
LFT	Long-Fibre reinforced Thermoplastics
ISC	Integrated Storage Collector

6.2 List of Figures

6.3 List of Tables

6.4 References

[1] O. Ibrahim et al. Review of water-heating systems: General selection approach based on energy and environmental aspects, Building and Environment (2014).

[2] IEA, Renewables 2025, 2025

[3] The IEA Solar Heating and Cooling, Solar Heat Worldwide Press Release, 2025.

[4] Kurzböck M., Wallner G. M., Lang R. W. (2012): Black-pigmented polypropylene materials for solar absorbers, Energy Procedia, 30, 438-445 (2012) Polypropylene materials development for has been published in.

[5] Povacz M., Wallner G. M., Kaiser A., Fink C., Hausner R., Ramschak T., Lang R. W. (2014d): Lifetime modelling of polypropylene solar thermal absorber materials using Miner's rule, Solar Energy, eingereicht (2014).

[6] Beer S., Brueggemann O (2013a): Antioxidant immobilization via the polymerization of fatty acid basedmonomers", EPF2013, Pisa, I (2013).

[7] Beer S., Brueggemann O (2013b): Synthesis and characterization of macromolecular antioxidants for the long-term stabilization of polyolefins, 3rd Biennial Bayreuth Polymer Symposium, Bayreuth, D (2013).

[8] Grabmayer K., Wallner G. M., Schobermayr H., Lang R. W. (2012): Accelerated Aging Testing of Heat Storage Liner Materials Using Micro-Sized Specimens, in: MoDeSt 2012 Abstract Book, Series Proceedings MoDeSt (2012).

[9] Kaiser A., Fink C., Hausner R., Ramschak T., Streicher W.(2013a): Leistungsanforderungen an Polymermaterialien in solarthermsichen Systemen, Erneuerbare Energie, ee 1-13, 12-17 (2013) (in German).

[10] Hintringer C., Thür A., Streicher W. (2013): Entwicklung eines eigentemperatursicheren Kunststoffkollektors, in: 23. Symposium Thermische Solarenergie (2013) (in German).

[11] Hintringer C., Thür A., Streicher W. (2014): Ein Beitrag zur Simulation und Messung eines Kunststoffkollektors mit integriertem Überhitzungsschutz, in: 24. Symposium Thermische Solarenergie (2014) (in German).