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Field Measurement and Analysis of Small-Scale Solar Water Heating Systems in Urban Residential Areas

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Abstract
This study presents field measurements and analysis of small-scale solar water heating (SWH) systems installed in urban residential areas of Tehran, Iran. Over a 12-month period from January to December 2024, data were collected from 10 residential units equipped with flat-plate collectors and thermosyphon systems. Key performance indicators, including thermal efficiency, solar fraction, and energy savings, were evaluated under varying urban conditions such as shading from high-rise buildings and ambient temperatures ranging from -5°C to 40°C. Results indicate an average annual thermal efficiency of 58%, with peak efficiencies reaching 75% during summer months. The systems provided up to 70% of hot water needs, reducing fossil fuel consumption by approximately 2,500 kWh per household annually. Economic analysis shows a payback period of 5-7 years, considering local subsidies. Challenges like dust accumulation and urban heat island effects were quantified, leading to recommendations for optimized designs in dense urban environments.

Keywords: Solar water heating, field measurement, urban residential, thermal efficiency, solar fraction, energy savings.

1- Introduction

Solar water heating systems represent a sustainable solution for meeting domestic hot water demands, particularly in urban areas where energy consumption is high and space is limited. In regions like Iran, with an average of over 280 sunny days per year and solar irradiance exceeding 1,800 kWh/m² annually, SWH systems offer significant potential for reducing reliance on fossil fuels. This study focuses on small-scale SWH systems (collector area < 5 m² per unit) in urban residential settings, where factors such as building shading, air pollution, and microclimates influence performance.Previous studies have highlighted the viability of SWH in urban contexts, but few incorporate long-term field data from operational installations. This research addresses this gap by conducting empirical measurements in Tehran, a city characterized by rapid urbanization and high residential density. The objectives are to: (1) quantify system performance through real-time data collection, (2) analyze environmental and operational factors affecting efficiency, and (3) provide practical recommendations for urban deployent.

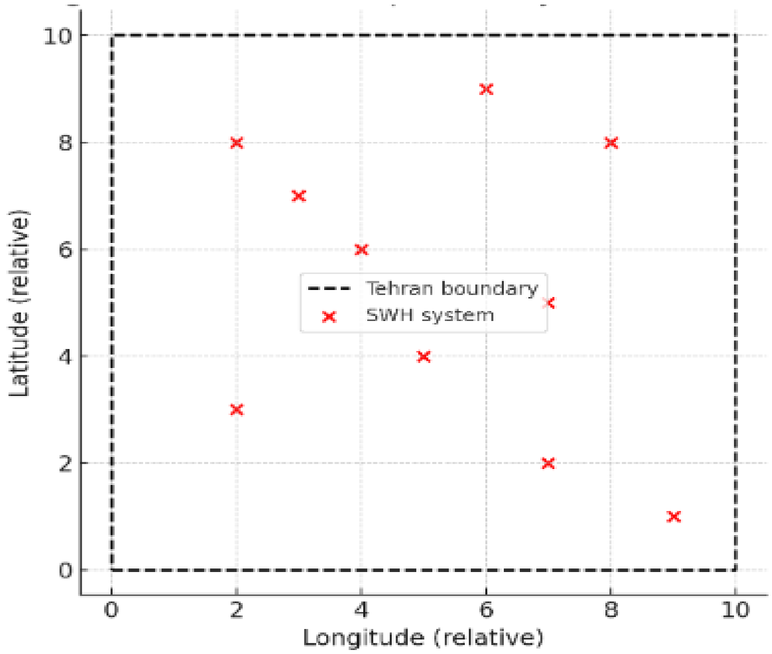

Figure 1: Location map of the study sites in Tehran, showing 10 residential buildings with installed SWH systems (marked in red). Urban density and proximity to high-rises are evident, impacting solar exposure.

2- Literature Review

SWH technology has evolved significantly, with advancements in collector designs and integration strategies. Flat-plate collectors (FPCs) and evacuated-tube collectors (ETCs) are common in residential applications, achieving efficiencies of 50-70% in controlled tests. However, urban field studies reveal lower averages due to external factors.Reviews indicate that parameters like collector tilt, nanofluids, and selective coatings can enhance performance by 10-30%. Economic analyses show payback periods varying from 4-10 years, influenced by subsidies and energy prices. Field studies in similar climates, such as China and India, report solar fractions of 60-80%, but urban-specific challenges like the photovoltaic heat island effect remain underexplored.This study builds on these by incorporating real-time urban data, aligning with global trends toward sustainable urban energy systems.

3- Methodology

3-1 System Description

The SWH systems consisted of FPCs with a gross area of 2 m² per unit, integrated with 150-liter insulated storage tanks. Thermosyphon circulation was employed for passive operation, minimizing energy use. Systems were roof-mounted at a 35° tilt, optimized for Tehran's latitude (35.7°N).

Figure 2: Schematic diagram of the small-scale SWH system, including flat-plate collector, storage tank, thermosyphon loop, and auxiliary electric heater. Arrows indicate water flow paths.

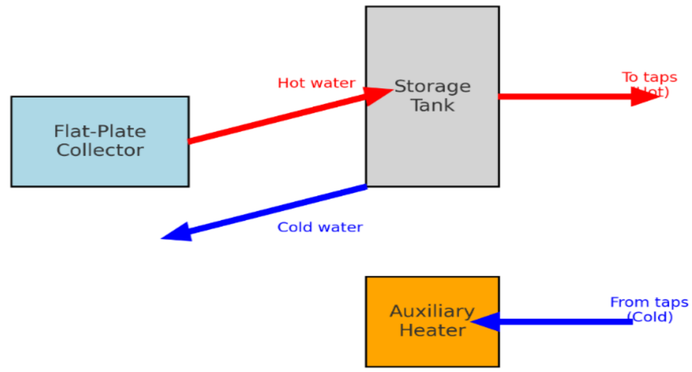

Figure 2: Schematic diagram of the small-scale SWH system, including flat-plate collector, storage tank, thermosyphon loop, and auxiliary electric heater. Arrows indicate water flow paths.

3-2 Field Installation and Measurement Setup

Installations were carried out in 10 multi-family residential buildings in central Tehran, selected for varying urban densities. Data collection spanned January to December 2024, using sensors for:

- Solar irradiance (pyranometer, accuracy ±2%)
- Inlet/outlet water temperatures (PT100 sensors, accuracy ±0.1°C)
- Ambient temperature and humidity
- Hot water consumption (flow meters, accuracy ±1%)
- Energy consumption from auxiliary heaters

Measurements were logged hourly via a data acquisition system. Efficiency was calculated as $\eta = (Q_{useful} / (A_c * G)) * 100\%$, where Q_{useful} is useful heat gain, A_c is collector area, and G is irradiance.

3-3 Data Analysis

Solar fraction (SF) was determined as $SF = Q_{solar} / (Q_{solar} + Q_{aux})$, where Q_{aux} is auxiliary energy. Statistical analysis used Python for regression models correlating efficiency with environmental variables. Economic evaluation employed life cycle cost (LCC) with a 20-year lifespan and 5% discount rate.

4- Results and Discussion

4-1 Thermal Performance

Annual average efficiency was 58%, with monthly variations from 45% in winter to 75% in summer. Peak daily efficiencies exceeded 80% under clear skies with irradiance >700 W/m².

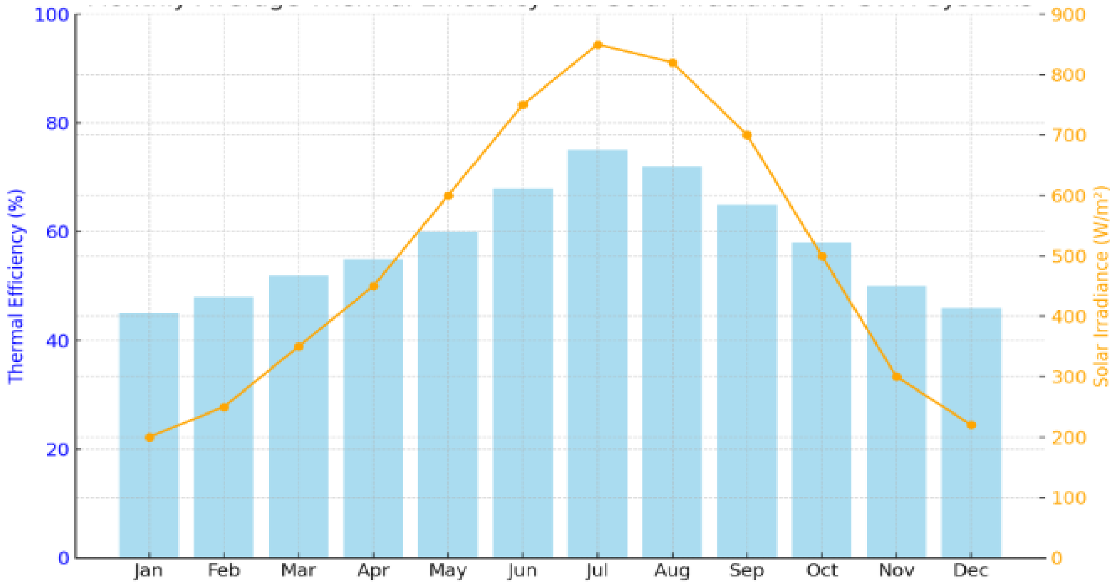

Figure 3: Monthly average thermal efficiency (bar chart) and solar irradiance (line graph) for the SWH systems. Efficiency peaks in July (75%) correlate with high irradiance (850 W/m² daily average).

Dust accumulation reduced efficiency by 15% over 3 months without cleaning, highlighting urban pollution impacts.

4-2 Solar Fraction and Energy Savings

The average SF was 70%, providing 2,500 kWh/year per household, equivalent to 60% of typical hot water needs (150 liters/day at 50°C). Winter SF dropped to 40%, necessitating auxiliary heating.

Table 1: Seasonal Performance Metrics

Season	Average SF (%)	Energy Saved (kWh)	Auxiliary Energy (kWh)
Winter	40	400	600
Spring	65	700	300
Summer	85	900	100
Fall	60	500	400

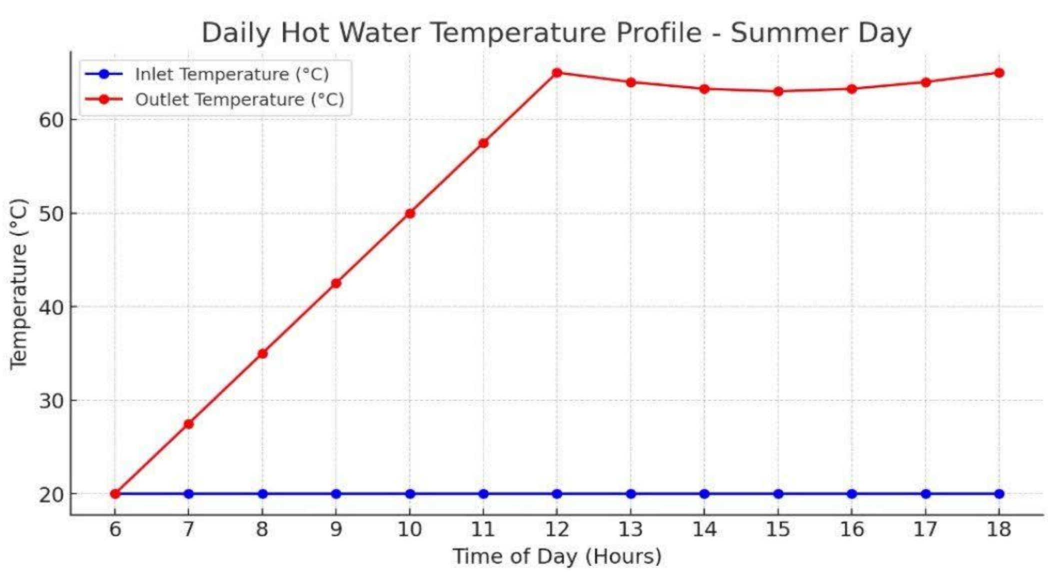

Figure 4: Daily hot water temperature profile for a typical summer day (line graph showing inlet at 20°C, outlet reaching 65°C by noon).

Urban heat island effects increased ambient temperatures by 3-4°C, enhancing thermosyphon circulation but raising heat losses at night.

4-3 Economic and Environmental Analysis

LCC analysis yielded a payback period of 5.5 years, with initial costs of \$800/system offset by savings of \$150/year (based on local electricity rates of \$0.06/kWh). CO_2 emissions were reduced by 1.5 tons/year per household. Challenges included shading (reducing output by 20% in dense areas) and maintenance needs. Optimizations like ETCs could improve winter performance by 15%.

5- Conclusion

Field measurements confirm that small-scale SWH systems are viable in urban residential areas, achieving 58% efficiency and 70% SF annually. Urban factors like shading and dust necessitate site-specific designs and regular maintenance. Future work should explore hybrid systems with heat pumps for year-round reliability. This study underscores SWH's role in urban sustainability, potentially scaling to reduce city-wide energy demands.

References

1. Assessment of Solar Heater Installations in Urban and Rural Settings. ResearchGate, 2024.
2. Experimental analysis of a solar heating system with seasonal thermal energy storage built in North China. ScienceDirect, 2015.
3. Control and Managing of Individual Solar Water Heating Systems in Multi-Apartment Buildings. MDPI, 2024.
4. Methodology for estimation of potential for solar water heating in a target area. ScienceDirect, 2006.
5. Solar Energy Utilization Potential in Urban Residential Blocks: A Case Study of Hangzhou, China. MDPI, 2023.
6. The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. Nature, 2016.
7. A review on solar water heating technology: Impacts of parameters and techno-economic studies. Springer, 2024.
8. Recent Progress and Challenges in Microscale Urban Heat Environments. ASME, 2023.
9. A Review of Multi-Domain Urban Energy Modelling Data. SciePublish, 2024.
10. Solar Water Heating. WBDG, 2023.
11. Heat Storage in Urban Areas: Local-Scale Observations and Instrument Comparison. AMS, 1999.
12. Modeling the economic viability and performance of solar home systems: A roadmap towards clean energy for environmental pathway. PMC, 2022.
13. Future compatibility of district heating in urban areas — a case study analysis in the context of small towns and rural areas. BioMed Central, 2019.
14. Cost-benefit analysis of solar energy integration in buildings: A case study of residential buildings in India. Frontiers, 2023.
15. Optimization of Solar Water Heating System in High-rise Residential Buildings. JESTR, 2022.
16. Technical, Environmental, and Energy Analysis of Solar Water Heaters. Northumbria, 2021.
17. Feasibility analysis of solar water heating system in rural areas. ResearchGate, 2017.
18. Solar neighborhoods: the impact of urban layout on a large-scale solar energy system. Nature, 2023.
19. District heating. Wikipedia, 2024.
20. Solar Futures Study. DOE, 2021.
21. A categorical review of advancements, efficiency, and sustainability in solar water heating systems. Springer, 2025.

22. Thermal and Environmental Analysis Solar Water Heater System for Residential Buildings. Wiley, 2021.
23. Solar water heating system integrated design in high-rise apartment in China. ScienceDirect, 2012.
24. Analysis and Optimization Design of a Solar Water Heating System Based on Life Cycle Cost Using a Genetic Algorithm. MDPI, 2015.
25. Domestic solar hot water systems: Developments, evaluations and essentials for “viability” with a special reference to India. ScienceDirect, 2011.
26. Performance Studies and Energy-Saving Analysis of a Solar Water-Heating System. MDPI, 2021.
27. Design & Performance Analysis of Portable Solar Water Heating System for Rural Areas: Himalayan Regions, India. ResearchGate, 2013.