IRENA
International Renewable Energy Agency

Quality Infrastructure for Renewable Energy Technologies

Solar Water Heaters

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About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
COPANT	Pan American Standards Commission (Comisión Panamericana de Normas Técnicas)
DSIRE	Database of State Incentives for Renewables & Efficiency
EN	European standards
ENAO	Ethiopian National Accreditation Office
ESTIF	European Solar Thermal Industry Federation
EU	European Union
GW_{th}	Gigawatts-thermal
IAPMO	International Association of Plumbing and Mechanical Officials
ICS	Integral collector storage
IEA	International Energy Agency
IEA-SHC	IEA Solar Heating & Cooling Programme
IEC	International Electrotechnical Commission
ILAC	International Laboratory Accreditation Cooperation
Inmetro	National Institute of Metrology, Quality and Technology (Brazil)
INTI	National Institute of Industry Technology (Argentina)
IRAM	National Institute for Standardization (Argentina)
IREC	Interstate Renewable Energy Council
IRENA	International Renewable Energy Agency
ISO	International Organization for Standardization
ISP	Institute for Sustainable Power
ISPQ	Institute for Sustainable Power Quality
JAS-ANZ	Joint Accreditation System of Australia and New Zealand
MENA	Middle East and North Africa
MW	Megawatts
MW_{th}	Megawatts-thermal
NAB	National accreditation body
NABCEP	North American Board of Certified Energy Practitioners
O&M	Operations and maintenance

PROCALSOL	Solar Water Heater Promotion Programme (Mexico)
PTB	German National Metrology Institute (Physikalisch-Technische Bundesanstalt)
PV	Photovoltaic
QA	Quality assurance
QI	Quality infrastructure
R&D	Research and development
RCREEE	Regional Center for Renewable Energy and Energy Efficiency
SABS	South African Bureau of Standards
SANAS	South African National Accreditation System
SDO	Standards developing organisation
SHAMCI	Solar Heating Arab Mark and Certification Initiative
SRCC	Solar Rating & Certification Corporation
SWH	Solar water heating system
USD	United States Dollar

ABOUT THIS REPORT

This report is part of a series prepared by the International Renwable Energy Agency (IRENA) in the field of quality infrastructure (QI) for small-scale renewable energy technologies. The series, *Quality Infrastructure for Renewable Energy Technologies,* has started out with three reports:

Guidelines for Policy Makers. This report explains the essential concepts and elements related to QI, the benefits of developing and implementing QI, and guidelines for policy makers on how to incrementally develop QI in support of national renewable energy technology markets.

The Case of Small Wind Turbines. This report contains an analysis of the key challenges followed by recommendations for developing QI for small wind turbines (SWTs), as well as reviewing the experiences of several countries in developing and implementing QI for SWTs. The report concludes by applying the guidelines to incrementally developed QI for the case of SWT markets.

The Case of Solar Water Heaters. This report contains an analysis of the key challenges followed by recommendations for developing QI for solar water heaters (SWHs), as well as reviewing the experiences of several countries in developing and implementing QI for SWHs. The report concludes by applying the guidelines to incrementally developed QI for the case of SWH markets.

Readers are invited to select the report that is most relevant to their needs in the publications section of IRENA's website. For queries, please contact us at secretariat@irena.org.

EXECUTIVE SUMMARY

Quality Assurance has proven to be indispensable for establishing an enabling environment for a rapid uptake of renewable energy technologies. Quality Assurance consists of standards which are intended to ensure that products and services perform as expected, as well as the mechanisms to verify that such requirements are fulfilled, *e.g.* testing and certification. QA builds the credibility necessary for the creation of healthy, efficient and rapidly growing technology markets and ensures that expectations from investors and end-users for technology performance, durability and safety are met.

Emerging markets need implementing Quality Assurance mechanisms to prevent unsafe, underperforming and failure-prone products from tarnishing perceptions of the technology and poisoning the market. The establishment of QA frameworks requires an institutional infrastructure.

This quality infrastructure (QI) encompasses standards, metrology, testing, certification, inspections, accreditation and quality management systems. QI can be defined as the total institutional network (public and private) and the legal framework that:

- Regulates, formulates, edits and implements standards; and
- Provides evidence of its fulfilment (*i.e.* a relevant mixture of measurements, accreditation, tests, certification and inspections).

QI benefits all stakeholders and market actors involved with the technology, and it provides the following benefits for stakeholder groups:

- **Policy makers:** nurtures emerging markets, enables sound technology promotion and attracts new businesses and jobs.
- **Manufacturers:** reduces regional and international trade barriers, improves product design and improves manufacturing quality.
- **Practitioners:** improves wages and mobility (for professionals involved in the design, installation, operation and maintenance of renewable energy technologies), and attracts new talent.
- **End-users:** builds and maintains end-user trust, enables sound product comparison and increases financial resources.

This report examines QI as it relates to technology for solar water heaters (SWHs), starting with an overview of SWH technology and markets. This is followed by a discussion of established international system and collector testing standards, as well as examples of implementation in selected countries. Market barriers are highlighted and recommendations for developing QI for SWHs are given, focusing on developing markets.

Several steps are crucial to create sufficient QI, and in turn ensure increasingly effective QA, in the renewable energy market. Countries seeking to put in place or strengthen their QI are advised to do the following:

- Base any regional or national standards for SWH testing and certification on existing international standards, including:
  - ISO 9806:2013 “Solar energy – Solar thermal collectors – Test methods”
  - ISO 9459 series “Solar heating – Domestic water heating systems”
- Consider developing QI for SWHs as part of a regional or international network, sharing costs and organisation development and responsibilities among nations.
- In early-stage SWH markets, require testing and certification from approved external organisations for all imports to avoid problems with inferior products while the market is still fragile and before in-country QI is functioning.
- Since proper installation is key to properly functioning systems, it is crucial to develop rigorous training for installers (necessarily local), especially as the market is beginning.
- To keep costs low for manufacturers and suppliers in developing markets, develop QA requirements gradually as the market matures and as local manufacturing develops, starting with durability testing and simpler (albeit less-accurate) means of testing and predicting performance. A QI development sequence is recommended for five market stages.

This publication – part of a set on developing QI for small-scale renewable energy technologies – is meant to provide helpful examples and guidance for anyone involved in planning or promoting SWH solutions, along with energy sustainability in broader terms.

1 INTRODUCTION

The International Renewable Energy Agency (IRENA) supports its members by providing a framework for technology policy aimed at accelerated renewable energy development and deployment. Quality assurance (QA) for renewable energy technologies is an important instrument to achieve this goal, as it plays a key role in strengthening rapidly growing markets and reducing the transaction costs for such technologies. This was shown in the 2013 IRENA publication *International Standardisation in the Field of Renewable Energy,* which examined quality infrastructure (QI) and standards for renewable energy technologies.

This report, which is part of a series of reports in the field of QI for renewable energy technologies, focuses on QI/QA for solar water heating (SWH). It provides clear guidance on a balanced strategy that enables countries to establish QA schemes for SWH while securing the financial feasibility of SWH implementation and overcoming capacity deficits. This study will enrich countries' understanding of the roles of QI and QA in SWH deployment. The study is based on IRENA's previous studies and expertise on standards for renewable energy technologies, and on the primary authors' experience and research.

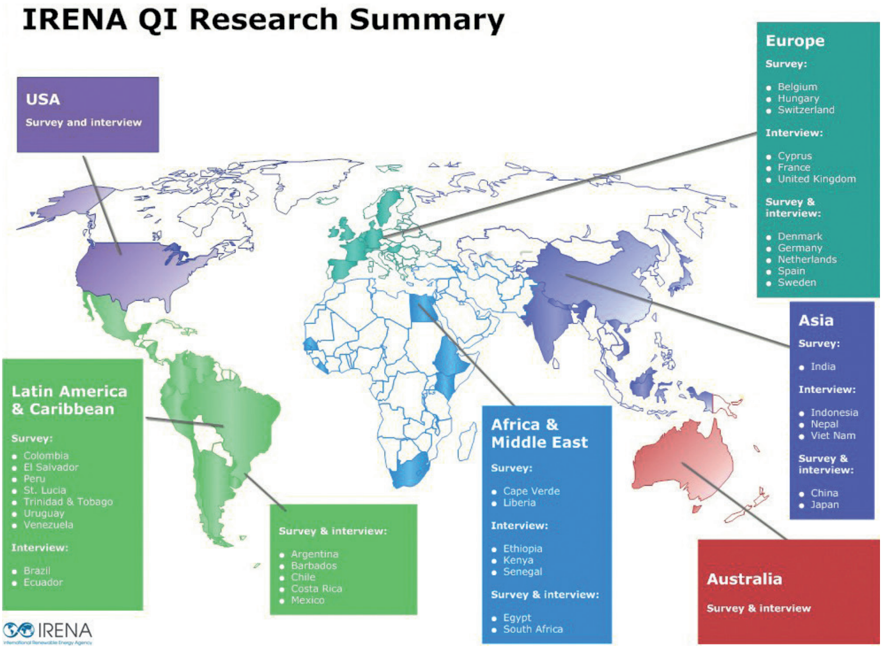
The series of reports *Developing Quality Infrastructure for Small-Scale Renewable Energy Technologies* uses data from 83 survey respondents as well as invaluable feedback from interviews with 34 QI, solar thermal and wind power technology experts.[1] These experts have varied backgrounds and represent countries around the world. Some are directly involved with QI (*e.g* working with metrology institutes, test laboratories and certification bodies), some are directly involved with broader QA frameworks (*e.g.* manufacturing quality, installer quality, etc.) and some are involved in the technology market (*e.g.* as policy makers, manufacturers, project developers, etc.). The report documents experiences and lessons learned from all of these sources. The recommendations and conclusions incorporate a wide variety of perspectives, interests and business strategies gleaned from the survey and interviews. Figure 1 shows the country of the experts that participated in the survey, the interviews or both.

Section 2 of this report discusses SWH specifics, including an overview of the technology and its applications and a summary of the global market.

Section 3 discusses international standards and common practices, global certification and key test equipment used.

1 For the interview summaries, please contact IRENA at secretariat@irena.org.

Figure 1: IRENA quality infrastructure research summary depicting participating countries



Section 4 summarises selected country QI for policy-rich, grid-connected SWH markets.

Section 5 summarises all of the input into key challenges, and section 6 discusses recommendations on how to start QI for different market levels.

2 AN OVERVIEW OF SOLAR WATER HEATING

This section examines SWH technology and markets. Solar water heating is a mature technology that has been in the market for over a century, although it has had a significant presence for only the last 35 years or so. The applications today are primarily for heating domestic hot water in single-family and apartment buildings, although commercial/industrial markets hold significant potential. China and Europe have dominated SWH markets.

2.1 Technology

SWH technologies convert the radiant energy from the sun into heat in water. A backup heat source is always needed with a SWH, due to the inevitability of extended periods of low solar radiation or unusually high hot water demand. Thus, a SWH can be configured in two basic ways: 1) as a *pre-heat system*, providing pre-heated water to a separate conventional auxiliary system (such as an electric or gas storage tank water heater), and 2) as a *complete system*, where electricity or fossil fuel backup is included as part of the solar system.

Pre-heat systems

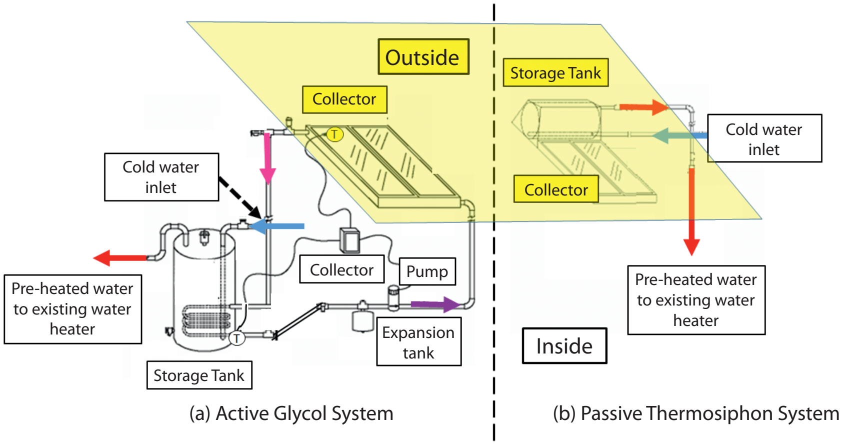
Two pre-heat systems are shown schematically in Figure 2: (a) an *active glycol system*, a system type used where freezing is an issue; and (b) a *thermosiphon passive system*, a system type used most often where freezing is not an issue. A complete system can be made in either case by putting an electric element/controller in the top of the storage tank. The *collector* is the key component of the SWH as it converts the sun's radiant energy to heat. The remaining components are termed the *balance of system*. For the active system, this includes the collector-storage loop, the storage tank, other piping and, depending on the system type,[2] heat exchanger(s), pump(s), auxiliary devices and/or controllers.[3]

Although the focus here is limited to solar heating of domestic hot water, in colder climates it can be cost-effective to upsize the collector/storage and meet both water heating and space heating (a *combi-system*). Depending on the climate, space heating can be much larger than the water heating load. Although the combi-system is more expensive than

2 SWHs were first patented in the late nineteenth century, and literally hundreds of system variations are available. This huge diversity is one of the challenges that QI for SWH must address.

3 For active systems, the balance of system and installation may each cost more than the collector. For passive systems, storage is most often integrated with the collector, and balance of system costs are less.

Figure 2: Two solar water heating systems, configured as retrofit systems: (a) an active glycol system and (b) a passive thermosiphon system. Note the relative simplicity of the passive system.



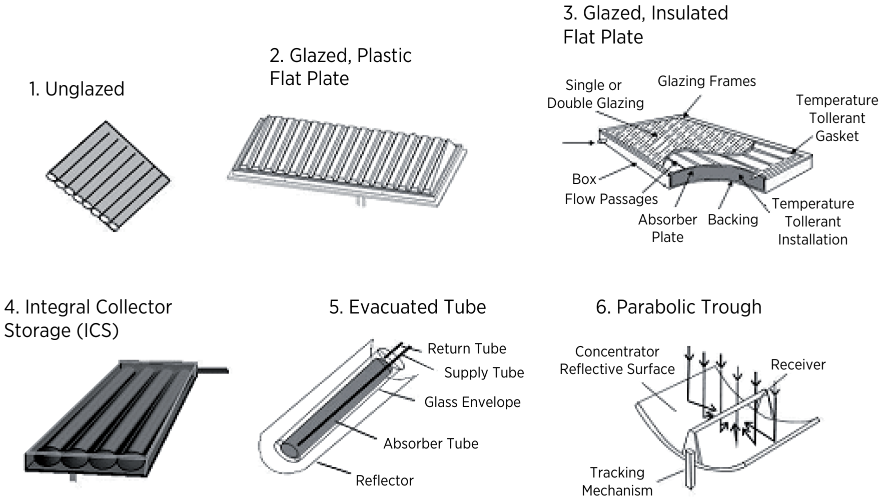
a SWH alone, it meets larger loads, saves potentially much more energy and can be more cost-effective. Combi-systems should be considered in colder climates; they are very common in northern European countries.

Different collector types, encompassing most solar collectors, are shown in Figure 3. Collectors can be classified as *unglazed flat-plate solar collectors* (type 1), *glazed flat-plate solar collectors* (types 2-4), *evacuated tube solar collectors* (type 5) and *concentrating collectors* (type 6). Unglazed flat plates are used mostly for heating swimming pools; glazed flat plates and evacuated tubes are used in domestic water heating, space heating and space cooling; and concentrators and evacuated tubes with or without concentrators are used in space cooling and in industrial processes. Most common for residential SWH are glazed flat plates and evacuated tubes. Most concentrating collectors demand tracking, are used mostly for applications in medium-to-high temperature ranges, and are rarely used in SWH due to their added complexity.[4]

Solar collectors can be classified as *low temperature* (<80°C, types 1-5); *low-medium temperature* (80°C<T<150°C, types 3, 5); *medium temperature* (150-250°C, types 5, 6), *medium-high*

4 An exception is the class of stationary concentrators. They are necessarily low-concentration (<2x) and are useful for applications such as cooling that need temperatures slightly higher than those needed for SWH and space heating.

Figure 3: Six solar water heating collector types



Source: NREL, n.d.

temperature (250-400ºC, type 6) and *high temperature* (>400ºC, type 6 and others). Temperatures above 80ºC are not relevant for residential or commercial building SWH and are not of interest for this report.

The evacuated tube collector provides useful energy at higher temperature differences, but it has the lowest efficiency at small temperature differences, due mainly to the gaps between tubes. Evacuated tubes dominate in China and the East, and glazed flat plates dominate in Europe and elsewhere.

An unglazed collector cannot provide much energy at high temperature differences due to high losses to ambient. They are used most often in swimming pools or in commercial-industrial applications where low temperature differences are acceptable. Unglazed collectors perform acceptably in SWH in warm-to-hot climates, even though unit-area performance is poorer, because they are significantly less expensive and because high temperature differences are not needed.[5]

Glazed and evacuated tube types provide useful energy at SWH operating temperatures in all climates.

5 See Burch *et al.* (2005) for an assessment of unglazed solar water heaters.

Complete Solar water heating systems

There are two main SWH classifications: *active/passive systems* and *direct/indirect systems*.

Active and passive systems

Active systems use a pump plus a controller to circulate a typically freeze-resistant heat fluid between the collector and storage when energy is available. They are dominant in hard-freeze climates. Most active systems are indirect systems, as in Figure 2a, with a heat exchanger between the non-potable, non-freezable heat transfer fluid loop and the potable water storage. This system type is most popular in climates that can have significant freeze episodes. Another type of active system that is popular in cold climates is the drainback system, where water is used in the collector loop and is drained back into a small tank inside conditioned space at night.

Passive systems use no pumps or controls to move heated fluids between the collector and storage and include *thermosiphon* (see Figure 2b) and *integral collector storage* (ICS). Thermosiphons are the most popular system worldwide, with natural convection moving hot water from the collector to the storage tank above and colder water flowing from the tank bottom down to the collector inlet. Passive systems without hard-freeze protection are dominant in warm climates because they are less expensive, perform about the same as active systems, are easier to maintain and do not take additional inside space for components such as the storage tank. However, both ICS and thermosiphon systems add significant weight to the roof, because the storage is also on the roof. Depending on local codes and regulations, the roof structure supports both the collector and storage and may have to be strengthened.

Direct and indirect systems

Direct systems have no collector loop heat exchanger and use potable water directly in the collector loop. Direct systems are subject to catastrophic freeze damage when the ambient temperature falls below approximately 4°C.[6] Direct systems are preferred in hot climates as they are less expensive than indirect systems.[7] They can be used in *mildly* freezing climates if freeze protection is used, such as recirculation of warm tank water under freezing or use of a freeze protection valve, which runs water from the public water network through the collector during freezing conditions. Many freeze failures of direct systems have been reported (especially mass failures

6 Collectors can freeze at air temperatures above 0°C due to sky infrared exchange. The effective sky temperature can be more than 30°C below ambient temperature, bringing the absorber below 0°C at an ambient temperature of approximately 4°C.

7 If record minimum temperature is less than 4°C, direct systems must use some form of freeze protection. Recirculating warm storage water to the collector is common in hot climates, but that wastes some thermal energy.

during locally historic freeze episodes), giving SWH multiple black eyes. One must be *absolutely* certain that the freeze protection will not fail if direct systems are to be promoted in freezing climates.

Indirect systems use a heat exchanger between the collector loop and the storage to separate the collector loop fluid from potable water in the tank, as in Figure 2a. Indirect systems are generally freeze-resistant and are dominant in cold climates. The two dominant indirect systems are: 1) *glycol*, where a freeze-tolerant water-glycol mix is used at a glycol concentration chosen for a worst-case freeze; and 2) *drainback*, where water is used in the collector loop and is "drained back" every evening into a small tank inside conditioned space.

Most SWHs in cold climates with hard freezes are active/indirect systems. Conversely, most SWHs in warm climates are passive/direct systems. When there is a possibility of only occasional mild freezes at worst, direct systems in conjunction with *freeze control valves* have been used successfully. Freeze valves open at approximately 4°C and pass relatively warm water from the public network through the system. Freeze valves can lead to significant water waste if employed in hard-freeze climates.[8]

8 Freeze valve water use is given in Burch and Salasovich (2005).

System reliability issues

Certified systems typically will have limited warranties of 5 to 10 years and lifetimes of 5 to 30 years, depending heavily on maintenance. However, different types of SWHs are suitable for different environments. Users must be careful to choose proper system types to prevent widespread catastrophic system failures. Perhaps the most important reliability issues related to SWH design are overheating and freezing.

- **Overheating** can occur when the heating load is significantly lower than the design load, such as if the user leaves for vacation and there are no draws (called *stagnation)*. The collector and system temperatures rise until they are high enough to reject all the collected heat, reaching a steady state at high temperature. The worst condition is when the sky is clear with high visibility, the sun is roughly normal to the collector and the ambient temperature is warm. Neither stagnation conditions nor temperatures differ greatly between the lower and higher latitudes, whereas this parity is distinctly not true for freezing conditions. Overheating can cause bodily harm due to output of steam or high-temperature water.[9] It can cause parts like gaskets to

9 A *tempering valve* that tempers overheated water with cold water is essential to avoid scalding. It is required by all SWH certification standards.

outgas and fail prematurely and can cause polymeric piping to fail. Most systems have some form of overheat protection.[10] Historically in the United States, some glycol systems did not have any overheat protection, leading in warm climates to glycol deterioration into acid by-products which cause system destruction over time.

- **Freezing** of water in the collector tubes, connecting piping, and some heat pipes for evacuated tube collectors (ESTIF, 2006) will damage the system. Widespread SWH failures can occur at record low temperatures if freeze-resistance is not implemented and maintained to deal with those rare freezing episodes. Only very warm areas in lower latitudes will be totally free from episodes of potentially damaging freeze. The record minimum temperatures for the region should be known, and systems should be chosen accordingly.[11] Glycol or drainback active systems are most common in cold climates.

10 A review of overheat protection methods can be found in Roberts *et al.* (2000).

11 Freeze and overheat are complex topics. Experts should be consulted for setting SWH certification guidelines.

2.2 Market status

Market data in this section are obtained from the IEA Solar Heating & Cooling Programme's (IEA/SHC) publication *Solar Heat Worldwide, Markets and Contribution to the Energy Supply 2013*, 2015 Edition. Figure 4 shows that in 2014, solar thermal had the largest total installed capacity[12] of all non-hydro renewable technologies, slightly more than wind and more than two times greater than PV. As such, SWH is a fairly mature product, although research and development (R&D) still continues in most countries that have substantial markets.[13] Larger market size tends to be correlated with higher levels of QI, with some exceptions.[14]

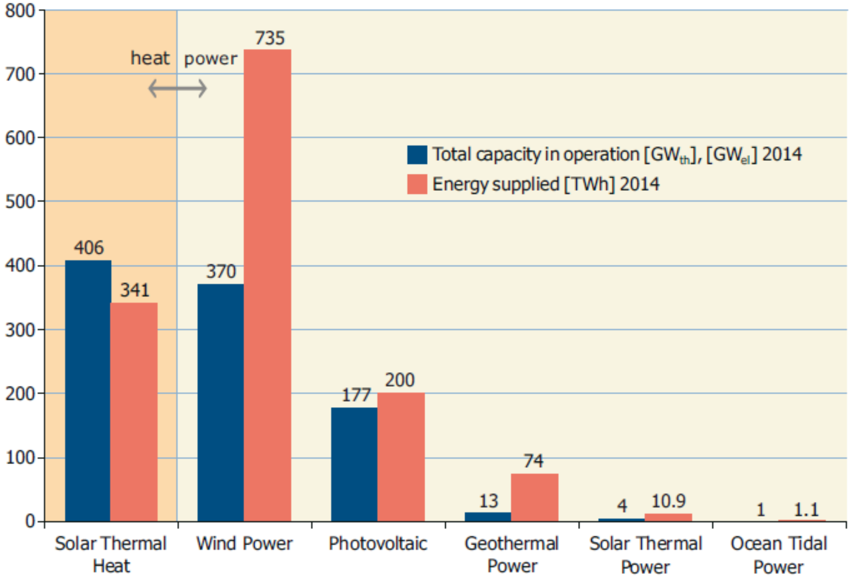
Figure 5 shows the cumulative SWH capacity at the end of 2013, by country. China has dominated the market, in absolute terms, since about 2005. However, *per capita* rates are higher in seven other countries than in China, as shown in Figure 6. It should be noted

12 Capacity is calculated by multiplying the collector area in m^2 by 0.7 kW_{th}/m^2. This corresponds roughly to output of an average collector under a high irradiance of 1,000 W/m^2 and to a low temperature difference of $(T_{coll,avg} - T_{amb}) = 0$.

13 An exception is the United States, where the solar thermal programme was eliminated in 2013.

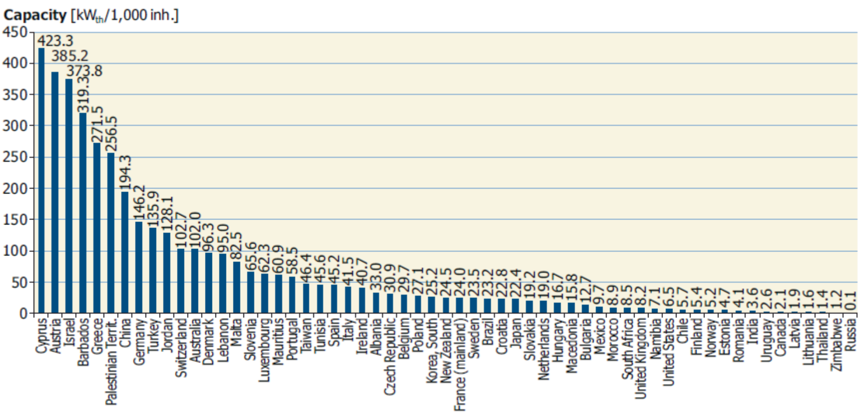
14 Barbados and China are counterexamples. Although China is the largest SWH market and has a well-developed QI framework, the certification body and test laboratory capacity is insufficient, and certification has been in effect unenforceable. Barbados has the third-highest penetration in the world but has historically had no QI (although that is now changing). See the China and Barbados country reports for more details.

Figure 4: Total capacity in operation and energy produced for renewable energy technologies, end-2014 (including glazed and unglazed units)



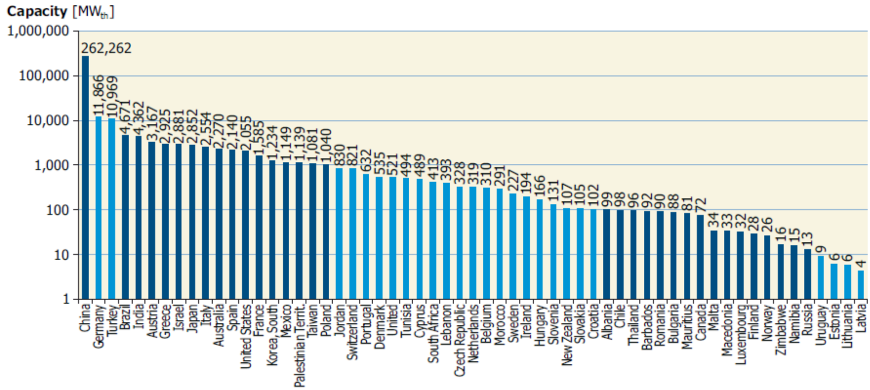
Source: Mauthner et al., 2015

Figure 5: Total installed solar thermal capacity by country, end-2013 (glazed units only; flat plates plus evacuated tubes)



Source: Mauthner et al., 2015

Figure 6: Installed solar thermal capacity per 1,000 inhabitants (glazed and unglazed units), end-2013



Source: Mauthner et al., 2015

that Figure 6 includes both glazed and unglazed collectors. Unglazed collectors are almost always used in pool collectors or other low-temperature change applications, not in the solar domestic hot water systems which are the sole focus in this report.

As shown in table 1, unglazed collectors make up the majority of capacity in the United States and Australia, at 89% and 59% respectively. Worldwide, unglazed collectors are under 10% of the capacity. Thus, the capacity for SWH alone in the United States and Australia can be derived by multiplying the given total for glazed plus unglazed capacity by 0.11 and 0.41, respectively, for the two countries. For other countries, pool heating is not as significant, and such corrections are unnecessary.

Certain shared characteristics explain the higher degree of market penetration in some countries versus others. With the exception of Germany, the high-penetration countries are in regions where:

- Energy cost is high to extremely high (USD 0.20 to 0.60 per kWh$_{th}$),
- Solar irradiance is excellent ($H_{global\text{-}horiz}$ > 4.5 kWh/m^2-day), and
- Government provides support (*e.g.* subsidies to consumers or manufacturers, mandates, technology promotion).

Moreover, the Chinese market has been mostly rural and is characterised by inexpensive SWH, which reflects the substantial government support to consumers and to manufacturers; high

Table 1: Installed solar thermal capacity in selected countries, end-2013 (glazed and unglazed liquid-based collectors)

	United States	Australia	All Countries
	MW$_{th}$		
Glazed	2 055	2 270	330 549
Unglazed	14 635	3 346	23 784
Total	16 690	5 616	354 333
% Unglazed	87.6%	59.6%	6.7%

Source: Mauthner et al., 2015

energy cost relative to income; and highly intermittent or non-existent conventional energy supplies. There are more than 2,000 SWH manufacturers in China, most of them small and rural with no product quality control.

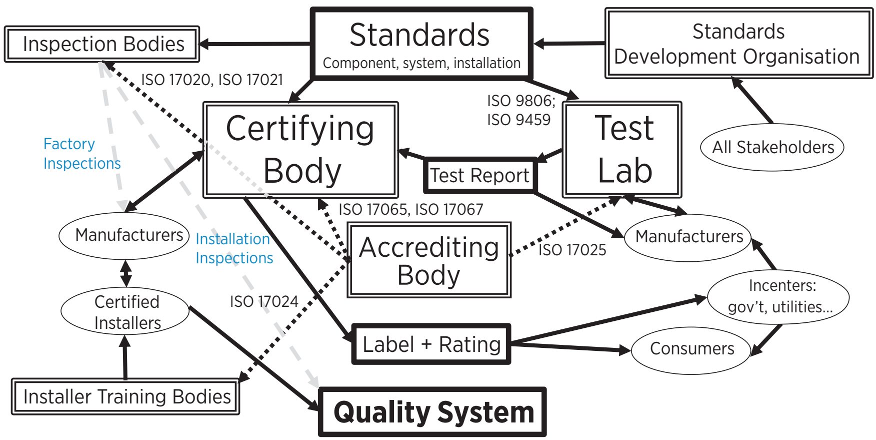
3 DEVELOPING QUALITY INFRASTRUCTURE FOR SOLAR WATER HEATERS

QI requires development of testing laboratories and certification bodies, along with the supporting organisations for accreditation, inspection, installer training and standards development. In this report, we focus on the testing laboratories, highlighting the equipment and related standards.

3.1 International standards and testing for solar water heater equipment

A schematic for a comprehensive QI for SWH is shown in Figure 7, which denotes QI products, organisations, stakeholders and their relationships. Organisations are

Figure 7: Schematic of comprehensive quality infrastructure for solar water heating



shown in double-lined boxes, products (*e.g* standards, reports and the installation itself) are in single-line boxes and stakeholders are in ovals. Accreditation is shown with dotted arrows, and inspections are indicated with light-grey dashed arrows. The relevant standards are noted on the figure. All countries with a SWH market have some level of QI development for SWH. Emerging economies will develop parts of the QI as their market matures. A possible development path that starts low in cost and adopts more comprehensive QI as the market develops is detailed in section 6.

The SWH QI structure is based on standards developed by standards developing organisations (SDOs). This structure varies somewhat by region. In Europe, the SDOs are national bodies, and they are not accredited by the national accreditation body (NAB). In the United States, SDOs are private organisations[15] which are accredited by the American National Standards Institute (ANSI).[16]

National standards for SWH should be developed jointly by all stakeholders. As far as possible, they should follow or be based on the relevant international standards (ISO 9806 for collectors and ISO 9459 for systems). Appendix A discusses lower-cost compromises in testing that deviate from international standards. In this case, the compromises are removed gradually as the market grows and can support more rigorous testing.

The accreditation body testifies that the other organisations are following the relevant standards. The accreditation process includes preparation of documentation and other data from the bodies being accredited, site visits by accreditation body agents, and preparation of reports and other communications. Re-accreditation is required annually. The process is expensive[17] and occurs mainly in mature markets with highly developed QI. Accreditation might be considered as the final key piece of a comprehensive QI for SWH.

The test laboratories conduct two very different types of tests: *performance* and *durability*. Tests are conducted on key elements (*e.g.* collectors) and on whole systems. The collector and system *performance* tests ideally output a general energy performance model that can be extrapolated to unit performance in any climate or under any use conditions. The *durability* tests are performed mostly on the collector and are generally qualitative, with either pass or fail criteria. The

15 The main SDOs for SWH in the United States are the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the International Cold Council and the International Association of Plumbing and Mechanical Officials (IAPMO, which is presently developing SWH standards). To confuse matters, the Solar Rating & Certification Corporation (SRCC) was also an SDO until 2012. See the United States country report for more information.

16 See www.ansi.org.

17 The accreditation cost for SRCC was more than USD 100 000, per J. Huggins, executive director of SRCC, personal communication.

durability tests screen out products that are inferior with regard to the functions targeted by the tests. Ideally, the durability tests would allow a lifetime projection, given relevant operating conditions and maintenance assumptions; however, it is generally problematic to extrapolate the results of necessarily short-term durability testing to a projection of lifetime.

Passing the tests specified in the standards guarantees that the unit will not fail quickly from any of the test mechanisms (such as thermal shock or stagnation), but it does not guarantee that the SWH will have a "long" and "trouble-free" lifetime. The collector durability tests last for only approximately 30 days and stress only a subset of the possible failure mechanisms. As with most products, reliable lifetime statistics must come from field failure data. With SWH, that data is somewhat sporadic, and failure statistics generally are not available.

SWHs are site-assembled systems of some complexity, and a key issue is the quality of the installation. Reliable systems can be rendered useless (or worse) if the practitioner makes errors. Thus, a system of training and certifying practitioners is needed. Section 3.2 offers a discussion of practitioner certification. Training needs to be both general (system types, sizing practice, etc.) and specific to the system at hand (*e.g.* solder the red tube to the red port, etc.). SWH installations are less complex when freeze protection is not required. Implementing a training/testing scheme for practitioners in a country or region with both hot and cold climates is more challenging because criteria for systems appropriate for both freezing and non-freezing climates must be addressed.[18]

Standards

International standards for SWH have been developed under the framework of the International Organization for Standardization (ISO). Table 2 provides an overview of the commonly used ISO standards for collectors and for systems.

Testing

SWH testing is performed on the component level and on the whole-system level. An accepted international standard (ISO 9806) exists for collector testing. Collector durability tests in ISO 9806 subject the collector to extreme conditions, including overheating during stagnation, external/internal thermal shock and high pressures.[19] System testing is more varied and less harmonised than collector testing. As shown in table 2, the ISO system test standard has three methods in common use. No single method dominates. ISO

18 With both non-freeze and freeze climates, the types of systems and their installation criteria/practices that the standard must accommodate is larger. However, there is no fundamental barrier in having all appropriate system types in a single practitioner standard. Climate neutrality is achieved naturally with the ISO/EN SWH *performance* testing standards, as discussed below.

19 There are no required system *durability* tests in ISO 9459, the only such test is an optional system freeze test.

Table 2: Overview of ISO standards for solar thermal products

ISO standard	Standard title	Status/ Comments
Solar thermal collectors		
ISO 9806:2013	Solar energy – Solar thermal collectors – Test methods	Considers performance and durability
Solar thermal systems		
ISO 9459-1:1993	Solar heating – Domestic water heating systems (Part 1): Performance rating procedure using indoor test methods	
ISO 9459-2:1995	Solar heating – Domestic water heating systems (Part 2): Outdoor test methods for system performance characterisation and yearly performance prediction of solar-only systems	
ISO 9459-4:2013	Solar heating – Domestic water heating systems (Part 4): System performance by means of component tests and computer simulation	Only performance; simplifications discussed in Annex C of the standard
ISO 9459-5:2007	Solar heating – Domestic water heating systems (Part 5): System performance characterisation by means of whole-system tests and computer simulation	Only performance; Dynamic System Test Method

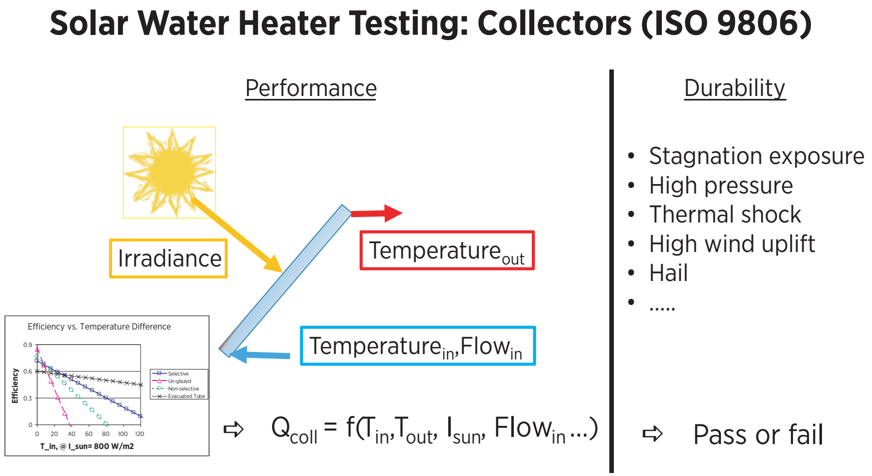
9459-4 requires testing of other key components, including solar storage tanks, heat exchangers, controllers and pumps.

The collector performance test in ISO 9806:2013 provides a general characterisation of the collector-delivered energy in the form of a simple mathematical model (see Figure 8). The model gives delivered energy as a linear or quadratic function of the collector operating parameter, $(T_{coll}-T_{amb})/I_{sun,incident}$, as indicated in Figure 8. This characterisation can be used to calculate the collector energy delivery under any conditions, including *any sets of conditions chosen by a country for country-specific ratings.*[20] The model resulting from the testing will support any reasonable choices for the rating conditions.

Collector durability tests are intended to stress certain mechanisms and to

20 Solar Keymark uses the standard tool Scenocalc to provide uniform, transparent collector ratings based on ISO 9806 results. It is available for download at www.sp.se/en/index/services/solar/ScenoCalc/Sidor/default.aspx.

Figure 8: Schematic testing of collectors, including performance characterisation under normal operating conditions and durability under extreme conditions

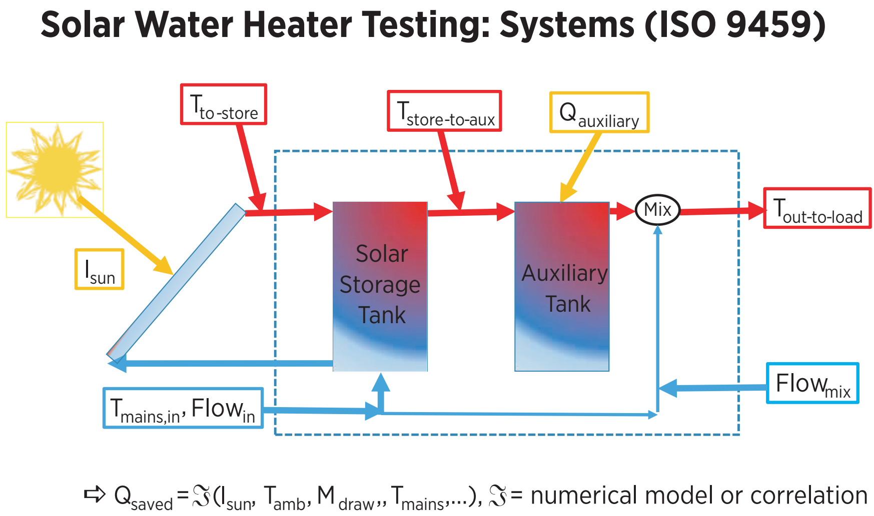


cause failure in inferior collectors. In ISO 9806:2013, durability tests include high-temperature resistance, internal pressure tolerance, 30-plus days of exposure, external and internal thermal shock, rain penetration, wind uplift and impact/hail resistance.

System testing is shown schematically in Figure 9. The entire system is assembled, instrumented and tested, which is relatively expensive. Under ISO 9459-4:2013, the collector, tank, heat exchanger, controller and pump (or some subset of these) are tested, and the component test results are fed into a detailed literal component simulation model that is then validated by system test data.[21] Under ISO 9459-5:2007, the system is tested under a specific protocol designed to elicit the parameters of a simplified SWH system model. *In all of these options, the result is a general model that can be used to estimate the annual savings for the SWH in any climate and for any domestic hot*

21 In the United States and Australia, a variation of ISO 9459-4:2013 is used. Components are tested, but the system need not be tested if the corresponding system simulation model has been validated previously. The cost of system ratings is correspondingly lowered by foregoing an actual system assembly/test. Costs are very low if components already have been tested. Other variations may be useful to generate system ratings with minimal cost at the initial levels of QI, as discussed in appendix B.

Figure 9: Solar water heating system



water use patterns (i.e. volume and timing of draws). An ISO test performed in any one country (*e.g.* Germany) provides a model that can be used to rate systems in another country with a very different climate (*e.g.* Syria) because the model is general and applies in all climates.

3.2 Key equipment required for performance testing

Equipment typically used in collector and system testing is described in table 3. All key equipment must be calibrated at recommended intervals, and calibrations must be traceable to primary standards maintained by the national metrology institute. The key instruments are the solar irradiance devices. There have been several round-robin tests of data acquisition devices; solar irradiance measurement seems to be the main reason that the results from different laboratories do not agree within specified error limits. There is an effort to develop “proficiency tests”, which are rigorous round-robin tests that establish a “truth standard” as the mean result from accredited laboratories and provide an indication of the accuracy of the results from the newly participating laboratories. It may be helpful to consult with outside experts to assist with the test laboratory development. Other countries may have certified testing laboratories which can be used, as emphasised in section 6.

Table 3: Key equipment required for solar water heater performance testing

Test	Data/Equipment	Description
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Global solar irradiance/ Pyranometer	Device that measures the total short-wave solar radiation (0.3μ to 3.0μ) incident on the absorber plane from any direction (usually stationary).
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Normal beam irradiance*/ Pyrheliometer	Device that measures the short-wave solar radiation (0.3μ to 3.0μ) within a narrow 10 mrad field of view (tracks the sun).
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Global diffuse irradiance pyranometer with beam shading	Device that measures the short-wave *diffuse* solar radiation, using a shadow-band or tracking shadow-ball to block out the beam.
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Global far infrared net irradiance/Pyrgeometer	Device that measures the long-wave radiation (4.0μ to 20μ) incident on the absorber plane from any direction (optional for glazed collectors).
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Fluid temperature/ thermocouple, RTD or other temperature transducer	Sensor that measures the temperature of the fluids entering and leaving the system, which must be mounted in the fluid stream.
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Air temperature/ shielded temperature transducer	Device that measures the relative humidity, dew point or wet bulb temperature of the ambient air (optional for glazed collector/system testing).
ISO 9806:2013 and ISO 9459-4:2013	Ambient air moisture humidity sensor, dewpoint sensor, or other	Device that measures the relative humidity, dew point, or wet bulb temperature of the ambient air (optional for glazed collector/system testing)
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Fluid flow rate/ turbine meter, positive displace-ment meter, bucket + scale or other	Device that measures the volumetric or mass flow rate of the fluids entering and leaving the system.
ISO 9806:2013 and ISO 9459-4:2013	Wind velocity/ vane anemometer, ultrasound Doppler or other	Device that measures the velocity of wind, typi-cally over the collector plane (optional for glazed collectors).
ISO 9806:2013 and ISO 9459-4:2013, ISO 9459-5:2007	Electric power/ electric power meter	Device that measures the electrical energy going to SWH components driven by electricity, including pumps/controls and auxiliary electrical elements (needed for system testing only).
ISO 9806:2013	Rainwater penetration/ spraying device	Device that uniformly exposes the collector to driving rain.
ISO 9806:2013	Pressure/ pressure gauge	Device that indicates fluid pressure.
ISO 9806:2013	Wind uplift/ suction cup device or other	Device that subjects the collector glazing to uplift forces and tests strength of glazing, collector and roof mounting.
ISO 9806:2013	Impact resistance/ice ball launcher, steel ball pendulum or other	Device that subjects the collector glazing to impacts.

* *Note that any two of the data {normal beam, total on horizontal, diffuse on horizontal} are sufficient; the third value can always be derived from the other two, as $I_{total\text{-}horiz} = I_{normal\text{-}beam\text{-}horiz} + I_{diffuse\text{-}horiz}$. The beam or diffuse device can be eliminated, although it is better to have all three as a data accuracy check.*

For testing collectors efficiently, it may be desirable to use two-dimensional tracking to keep the insolation on the collector at mostly normal incidence and to maximise the incident radiation. The trackers will speed up the testing of collectors considerably.[22]

The test laboratories in small markets may not have enough testing work to support the laboratory. In these circumstances, it is practical either to use a regional laboratory or to associate the test laboratory with a university or other educational institute so that the faculty and students can use the facility for research and training when SWH tests on products are not conducted.

3.3 Standards and certification for solar water heating practitioners

SWHs are small-scale renewable energy systems that require a fairly complex installation process that (usually) interfaces with an existing water heater. An SWH is NOT a "plug-and-play" device like a refrigerator that can be installed easily by homeowners, even if they have significant practical skills in plumbing, mechanical and electrical work. The best system can be rendered useless (or worse) by a poor installation, as the SWH industry has experienced over and over again.

22 The dynamic collector test option in ISO 9806 also speeds up testing relative to steady-state testing, allowing much wider ranges on insolation and temperature variances during testing.

Background survey results

The survey found in the report *Developing Quality Infrastructure for Small-Scale Renewable Energy Technologies: Guidelines for Policy Makers* showed that most of the respondents involved in SWH markets indicated that installer credentials do not exist in their countries. Some installers may be quite competent, but there is no formal QI structure to assure that this is true. Without an accreditation scheme, it is likely that unskilled installers are working and making mistakes in installations. Respondents stated that poor quality in the installation and operation and maintenance (O&M) of SWH systems has a higher negative impact in the market than quality issues related to the product hardware.

Another problem is maintenance over the system lifetime. All systems have multiple components that can fail over time, and periodic inspection and maintenance are necessary. It is not common practice to set up a maintenance contract at the time of installation, and maintenance usually is not done until the system owner notices a problem.[23] Problems which can destroy systems (such as glycol breakdown) need to be corrected before any extensive damage is done.

23 Homeowners in Europe and the United States do not routinely inspect their systems for problems, which thus can go undetected for a long time. Some controllers now alert homeowners when a fault is detected.

Relevance of training and training certification for practitioners

When discussing issues related to a well-developed QI, it is important to remember that a successful renewable energy system is the combination of good products, a sound installation and proper O&M over the system's lifetime. The latter two elements are the province of practitioners. Having top-quality components improperly installed or maintained can result in a shortened equipment lifetime, lowered performance and even safety issues for end-users.

As renewable energy technologies mature, the quality of the hardware tends to improve. The number of failures due to poor equipment quality is reduced, as was shown for the solar PV sector. At the same time, the number of failures due to poor installation and O&M of equipment is increasing (TÜV Rheinland, 2013). Even moderate failure rates can damage the public's trust of the technology. Training and certification of practitioners offer the public a high degree of confidence because practitioners need to document extensive experience and/or training and to pass an exam to qualify for certification. They also offer practitioners a way to distinguish themselves from their competition.

A number of the experts interviewed in this study consider training and certification of practitioners to be more important than the testing and certification of the equipment, particularly in small emerging markets, and they believe that this should be the first QI aspect developed. One rationale for this position is that emerging markets may start by importing equipment rather than producing it locally, making it important to focus on installation quality more than on production quality. In addition, product quality can be handled by implementing regulations requiring adequate equipment certification from the country of origin, which effectively provides equipment QA at essentially no cost. Nonetheless, most countries with emerging markets do not focus on practitioner certification; in practice, this tends to happen too late in the QI development process.

The need for practitioner training early in the market development is emphasised again in section 6.

International and national expertise

International trainer accreditation

The Institute for Sustainable Power (ISP) developed an international standard (ISPQ #01022) that provides metrics for training administration, appropriate facilities, training hardware, training staff experience and competencies, and quality standards. The six accreditation and certification recognitions are: Accredited Training Program, Accredited Continuing Education Provider, Certified Affiliated Master Trainer, Certified Independent Master Trainer, Certified

Affiliated Instructor and Certified Independent Instructor. Each clean energy technology developed a task analysis that in some tiers must correspond to the course contents of the training institution. The standard was initially licensed and used by entities in various countries.

The standard was used widely in the United States, and the US Department of Energy required it for the accreditation of energy efficiency training institutions. Standards for online classes exist as well. ISP provided the standard for a comprehensive framework for developing an accreditation programme for training institutions and a certification programme for trainers. During the past three years, ISP transferred the rights to ISPQ #01022 to the Interstate Renewable Energy Council (IREC). IREC continued to use the standard to promote consistent and quality workforce standards and recently updated it and developed IREC Standard 01023:2013, General Requirements for Renewable Energy, Energy Efficiency, and Distributed Generation Training.

Europe: training organisations for SWH practitioners

Intelligent Energy Europe has supported InstallRES, an organisation offering training for a wide variety of renewable energy installer services. InstallRES offers training courses for practitioners of small-scale renewable energy systems (solar PV, solar thermal, heat pumps and biomass systems) that are now available in Bulgaria, Greece, Italy, Poland and Slovenia. A recent study concluded that there were no real barriers to regional training and certification for solar PV (a technology similar to SWH) (PVTRIN, 2013). Other organisations involved in SWH training include QualiCert, SUNTRAIN and QualiSol (Diaz, 2014).

Most countries in the Solar Keymark scheme have some level of programmes for training SWH practitioners. There are significant differences in training content between countries as the climatic stresses and the types of systems used vary significantly across the European Union. It makes little sense for practitioners in non-freezing climates (where thermosiphon systems dominate) to train for installing the more complex, active indirect SWH or combi-systems that dominate cold climates. This diversity makes writing a single standard more difficult. The Fraunhofer Institute for Systems and Innovation Research completed a study in 2004 on implementing solar thermal training certification (Fraunhofer ISI, 2004).[24] Skill sets were defined, exams were produced and pilot programmes were set up in Germany, Greece, Spain and the United Kingdom. However, there is no active work on developing a single practitioner certification for Solar Keymark.

United States

The main credentialing organisation for renewable energy practitioners in the United States is the North American Board of Certified Energy Practitioners

24 For more information, see Horizon 2020 (n.d.).

(NABCEP).[25] NABCEP was formed in 2002 and launched certification for solar PV installers in 2003, for SWH installers in 2006 and for small wind turbine installers in 2010. NABCEP has been formally accredited according to ISO/IEC 17024:2012 "Conformity assessment – General requirements for bodies operating certification systems of persons".[26] NABCEP certification is intended to be a voluntary credential. However, many state renewable energy incentive programs require NABCEP installer certification before a project can qualify for an incentive[27]. Installer certification in such circumstances is essentially mandatory.

Developing a certification programme is a complex and time-consuming process requiring up-front funding (which has to be provided until the programme is functioning for a few years), a strong commitment from volunteers from all stakeholder groups, and creation of an administrative organisation to maintain oversight and quality. The job task analysis and resource guides for SWH are available (NABCEP, 2011; NABCEP, 2013).

NABCEP solar water heating practitioners

Certification requires that the practitioner meet prerequisites of related experience and/or education and successfully pass a rigorous written exam. To maintain certification, the practitioner must complete continuing education and installation requirements within the re-certification time frame. There are eight experience categories to qualify for the exam, allowing different mixes of previous training courses and experience. A list of recommended training sources is maintained. The exam consists of 60 questions, selected from a pool of about 180 questions developed by a group of expert and experienced volunteers. The question list is updated every year. Certified applicants are allowed to use a NABCEP logo (see Figure 10).

Entry-level programme

In addition to the practitioner certification, NABCEP offers an entry-level programme demonstrating basic knowledge. Passing the entry-level requirements exam

Figure 10: North American Board of Certified Energy Practitioners' certified solar heating installer logo for use by certified practitioners

NABCEP
CERTIFIED
Solar Heating Installer
John Doe
CERT #SH0101-1234

Source: NABCEP, 2014

25 Others include Underwriters Laboratories and ETA International.

26 See www.iso.org/iso/home.

27 See Database on State Incentives for Renewables & Efficiency (DSIRE), www.dsireusa.org.

demonstrates to firms seeking installers that the person has basic knowledge and is ready for further on-the-job training. The exam tests for knowledge of site analysis, safety, standards, codes, system types for different climates and applications, installation methods and maintenance. To qualify for taking the certification exam, the practitioner must complete a training course from one of 32 approved training organisations (NABCEP, 2015b). The resource guide referenced above provides a good introduction to the installation issues.

State licensing

In the United States, each state may pass laws requiring contractors to meet licensing requirements. Like certification, licensing protects the industry's reputation and protects the consumers from safety risks due to improper installation.

Licensing and certification have different advantages and disadvantages. A voluntary national certification results in lower costs, more consumer choices and more geographic mobility versus the state or local licence. However, licensing has an advantage over certification in that it typically provides more consumer protection from safety hazards and is enforceable by law.

Although most states do not explicitly define licensing requirements for solar installers, those that do either rely on plumbing contractor licensing or require licensing specifically for solar thermal installations, either as a specialty under the plumbing licence or as a separate licence. A search of the DSIRE database revealed that in the United States, 12 states and Puerto Rico have solar contractor licensing requirements (NCSU, n.d.).

Major challenges for practitioner certification

From discussions with interviewed experts, the following barriers to practitioner certification were identified:

- Finding industry partners in the country that are willing to help develop practitioner QI
- Finding dedicated volunteers or organisations willing to commit time and money to start the process and create the administrative structure
- Finding an organisation willing and dedicated to hosting the certification effort for the long haul
- Finding an initial funding stream for the first three to five years
- Identifying the subject-matter experts and individuals from various related fields who are willing to participate on various committees
- Attaining buy-in from the key stakeholders
- Attracting enough business to be self-sustaining without government support.

4 QUALITY INFRASTRUCTURE FOR SOLAR WATER HEATERS IN SELECTED COUNTRIES AND REGIONS

The main source of the data and other information in this section is the interviews conducted with country experts.[28] Unreferenced data refer to interview data. Countries for which the interview and other data were considered of high quality are presented first, in alphabetical order. Data from other countries are presented in section 4.8. Section 4.9 discusses regional certification in Europe and in the Middle East and North Africa (MENA), and section 4.10 discusses global certification for collectors. Some of the details of QI structures in the countries described in this section are summarised in appendix B. The summary includes standards used, the names of the national metrology institutes, test laboratories, certification bodies and accreditation bodies.

4.1 Argentina

Argentina has a small SWH market and currently has no national QI specifically for SWH. An updated national standard, IRAM 210.002, exists for evaluating the performance of collectors. Other national standards date to the 1980s and are undergoing technical revision at the National Institute for Standardization (IRAM) based on ISO standards. There are no accredited test laboratories or certification bodies; however, the National Institute of Industry Technology (INTI) does testing for energy performance and durability, following ISO standards. Some local universities also test the performance of collectors.

Governmental support is more focused on other technologies, and there are no national-level incentives for SWH deployment. There are only a few local efforts. The province of Santa Fe, for example, implemented in 2014 a financial support scheme for SWH via soft loans (Gobierno de Santa Fe, n.d.). An interesting recent development is the plan from the INTI to build up a certification system for SWH installers, following the standard ISO 17024, expected to be operational by 2016.

Challenges

Experts interviewed stated that the fundamental barrier for the SWH market is the highly subsidised price of natural

28 The opinions expressed may not represent the views of all stakeholders.

gas, which costs less than USD 0.05 per m^3 in cities. The low fuel cost limits the savings from a SWH. Depending on the access to the gas network and the fuel price, savings might be in the range of USD 10-300 per year. Additionally, without a QI structure, poor-quality local and imported products have tarnished the technology reputation, resulting in low levels of consumer confidence. Aware of this situation, the INTI and four SWH manufacturers jointly have invested close to USD 100 000 in setting up laboratories for testing SWH under ISO standards, as well as giving monetary support to the industry to improve its manufacturing processes.

Possible scenarios for building quality infrastructure

Argentina is interested in an evolving regional collector and system labelling programme and has been working with the Pan American Standards Commission (COPANT) and the German Metrology Institute (PTB) in developing a regional collector and system labelling programme. Work is needed on a regional labelling and rating standard that accommodates the wide range of climates in Argentina.

It is difficult to simultaneously develop the market and QI. The foundation for any SWH market is a QI system to eliminate poor systems and provide unbiased performance feedback, so the ideal first step would be for the government to set up a certification system for products as well as for installers based on international standards to help nurture the market. With a QI, there is a structure for confident use of obligations and subsidies to promote a healthy market.

4.2 Australia

Australia has had a strong SWH market: cumulative installations of water-based collectors is 4.6 gigawatts-thermal (GW_{th}), of which 2.7 GW_{th} was unglazed (59%). Under Australia's Renewable Energy Target subsidy scheme, SWHs receive subsidies averaging approximately EUR 700 per system.

The two governing standards are AS/NZS2712 and AUS/NZ 4324. AS/NZS2712 is a durability and reliability standard that includes similar tests to ISO 9806:2013, but it is not equivalent to the standard. The system test standard AS/NZ 4324 is similar to ISO 9459-4. These standards are mandatory to qualify for market support mechanisms. AS/NZ 4324 requires performance testing of the tank, pump, controller, heat exchanger(s) and collectors. Collectors are tested to AS/NZS2535.1. As with US system ratings, most systems are not individually tested, reducing the cost of system certification significantly. Systems are tested only when certifying a new type of system for which validation results are non-existent and modelling confidence is low. Otherwise, familiar systems are modelled using well-tested simulations models with measured component inputs.

Given the system model, ratings can be produced in any climate and for any use patterns that the certifying organisation chooses. There are four or five rating climates in Australia and two in New Zealand. Certification bodies review testing results and certify components and products. The main accreditation institute is the Joint Accreditation System of Australia and New Zealand (JAS-ANZ).

Challenges

According to the interviewed expert, an initial barrier was developing accurate testing and modelling. Ongoing efforts are also focused on harmonising national testing and modelling requirements with related ISO standards requirements. There were some inaccurate results until the knowledge was developed to sufficiently understand the testing and the technology.

Possible scenarios for building quality infrastructure

A regional certification beyond Australia is of interest, but it is complicated by the wide range of climates, use patterns and appropriate system types across the regions. Systems built and certified for very cold climates such as Northern Europe may be over-engineered for non-freezing tropical climates, with some unnecessary tests.

Other considerations

The government incentives should be structured so that there is continued opportunity to improve the SWH performance to increase the support. If all systems above a threshold are subsidised equally, there is no incentive to improve performance. The incentive should be performance-based so that increased performance is rewarded with higher incentives.

4.3 Barbados

Barbados has the most active SWH market in the Caribbean region. Historically, it developed with little concern for QA aspects. In 2009, some 4.9 megawatts-thermal (MW_{th}) was installed (for a cumulative total of 92 MW_{th}), almost entirely from three local manufacturers that are well placed to offer after-sales services. The Barbados government supported development of a local SWH industry with incentives and promotions to manufacturers (tax breaks) and end-users (rebates at approximately 50% of system cost). Electricity is the dominant energy source, and unit cost is more than EUR 0.25 per kWh. The market penetration of SWH in water heating applications is high, at approximately 35% in residences (Barbados Statistical Service, 2010). However, SWH sales are diminishing following the recent economic downturn, evidence of saturation in the middle-income target market and a lack of export opportunities.

Challenges

A key barrier mentioned by the expert interviewed is apparent market saturation, a problem that is exacerbated by the rental market, which represents an estimated 25% of homes. Rentals are effectively frozen out of the market because renters will not invest in someone else's property, and owners will not invest because they do not receive the savings. Another barrier is accessing lower-income households, many of which feel no need for hot water in the tropical country with warm water inlet temperatures.

A lack of reporting by manufacturers has led to confusion about the number of SWHs installed annually. This makes it difficult to assess the value of government incentives for SWH. A further barrier is that without any QI providing unbiased information, system suppliers can claim unrealistic savings, creating confusion in a competitive marketplace. QI also could help Barbados manufacturers gain access to regional markets across the Caribbean and into Latin America.

Possible scenarios for building quality infrastructure

The Barbados Standards Institute has drafted standards for SWH, although they are not based directly on ISO standards and were not implemented. The institute is considering starting with ISO-based voluntary certification standards that are linked to incentives. Subsequently the certification will be made mandatory after some time. There is some desire to join a regional QI scheme, to expand markets for the local industry and to initiate QI without having to develop a full QI for SWH in a small country.

Other considerations

An important lesson from the Barbados case is the effectiveness of a strong, long-term commitment from the government to support the developing markets. Investors will not enter the market if the supports are unstable. Another relevant technical aspect is that SWHs in island countries have to endure a marine environment, where corrosion from salt spray can plague the metal parts. Jamaica, with a similar environment, imported systems that were not designed for use in a marine environment, which created problems.

4.4 Brazil

Brazil is the largest country in South America, and it has the largest SWH market in the region. Interest in QI for SWH began in 1994 with a request from the existing industry to the government to support developing a quality programme. National standards for testing were developed, based on ISO standards. Certification was voluntary and became compulsory in September 2015. However, resellers would be allowed to buy non-certified products until March 2016, and from March 2017 on they would be able to buy solar heating system with the INMETRO certificate only (Kriele, 2015). This transition was planned in advance to give the market the required time to develop and to be able to absorb the cost and to develop the infrastructure needed. A national expert indicated that this would be key for a successful implementation of a well-developed QI for SWH.

There are no certified installers or training yet, although a certification programme is under development. There are no government incentives for consumers, although there are incentives for local manufacturers. An industry association in Brazil has been instrumental in developing and supporting QI. Brazil does not accept other countries' certifications. All imports must be tested in Brazil, according to Brazilian standards. There are collector and tank tests, but no system tests.

Challenges

The interviewed expert indicated that the capacity of the test laboratories is a bottleneck, as there are only 2 laboratories and more than 100 companies producing SWHs. Another barrier is implementing standards. When standards are voluntary and relatively expensive, small companies do not certify their systems, and the programme is diluted.

Possible scenarios for building quality infrastructure

Brazil would like to export its locally produced SWH throughout the region. A challenge is accommodating climates significantly colder than in Brazil. Relevant institutes in the country, such as the National Institute of Metrology, Quality and Technology (Inmetro), are collaborating with COPANT and PTB to develop a regional certification similar to Solar Keymark in Europe. Regional certification is challenged by differences in appropriate system types and sizes.

Other considerations

A delicate problem has been building QI gradually while the market grows. QI should not be too burdensome at any stage, but especially it should be inexpensive when the market is small. The industry association helps strike the right balance. If certification can be mandated and tied to incentives, it would help motivate manufacturers to certify systems.

4.5 China

China is by far the largest SWH market in the world, with rural and urban sectors. Until recently, the dominant market (approximately 80%) has been rural, where the majority of the people live. In many areas, SWHs provide the best way to get hot water. The rural systems are mostly simple thermosiphon systems. There are thousands of "system assembly" manufacturers who mostly order evacuated tubes and other components, and then assemble the components (with some modifications) into a system.

China's urban SWH market is growing due to new regulations and great concerns about urban air pollution. Urban systems are mostly active systems, in which the collector can be mounted on the surface at each apartment and the storage is separate from the collector. A rebate of up to 13% of the system cost was started in 2005 but was dropped in 2010 as the rural markets were beginning to saturate (up to 90% market penetration). New incentives are coming for the urban systems, at up to

15% rebated depending on performance. The new incentives will require testing.

Work on Chinese standards began in 2005. There have been 30 standards relating to solar thermal energy.[29] None of these standards are international standards, although to some extent the standards are adapted from and similar to international standards. There are approximately 20 test laboratories in the country and approximately 5 certification bodies. They are preparing to launch programmes related to installation quality, but nothing is in place at present.

Challenges

A major barrier is that there are more than 2 000 SWH manufacturers in China, and it has been impossible to implement certification among the manufacturers, especially in rural areas. The lack of a sufficient number of test laboratories to handle the demand for testing has been a barrier to certification.

Possible scenarios for building quality infrastructure

Chinese authorities would like to bring China's standards for SWH in line with international standards. This will require additions to ISO 9806, because the ISO standards have been developed mostly by Europeans with flat-plate fin-tube technology in mind. The Chinese systems are nearly all evacuated tube systems, which require some different tests than are suitable for flat plates.

29 As of August 2015, the standards were available only in Chinese; however, the standards are being translated for IEA-SHC Task 43 Rating and Certification of Solar Water Heaters.

4.6 Cyprus

Cyprus has the highest penetration of SWH per capita of any country in the world. The installed capacity is an estimated 550 watts-thermal per person, or approximately 35% higher than Israel, the country with the next-highest SWH per capita. At 5 kWh/m^2-day average incidence, the capacity implies that approximately 2.5 kWh$_{th}$ per person is generated on average, which should cover the majority of the water heating load.

The SWH market began in Cyprus in the 1960s, growing slowly at first. The market grew as the cost of energy increased through the 1970s, turbulent times for energy prices that portended larger increases in the near future. As the market began to grow, products of inferior quality entered the market, giving the growing industry a poor reputation. The industry (approximately 20 firms) banded together in 1977 to form an industry association (the Cyprus Union of Solar Thermal Industrialists). The association helped to develop an early QA programme, as it was seen that poor systems were engendering a distrust of SWH technology in general. Cyprus national testing and certification standards were in place by 1984.

This early application of QA helped nurture the growing market with high-quality systems. This experience indicates that QA should be developed early in the market cycle so as to let the market develop without the hindrance of widespread failures of inferior SWH. Today there are approximately 20 SWH manufacturers based in Cyprus. Imports and locally produced systems now must be certified by Solar Keymark.

A number of favourable factors support the SWH market in Cyprus. Probably foremost is the fact that conventional water heating is done with electricity that costs approximately EUR 0.25 per kWh, typical for islands with oil-fired generators. Hot water expenditure is more than EUR 900 per year at 10 kWh per day usage. Another factor is that Cyprus has a sunny and warm Mediterranean climate. With high insolation, performance is good, and with no freeze issues, lower-cost thermosiphon systems are suitable and dominate the market.

Another factor is good government support. Cyprus has mandated that a SWH be installed in all new construction and major retrofits. In addition, there is a EUR 375 subsidy for retrofitting a system. Lastly, the industry and government collaborated to install national standards for testing and certification by 1984. A Cyprus test laboratory implements performance and quality testing. The market has been well-protected and has grown well under the aegis of a good QI.

In 2004, Cyprus joined the EU, and the Solar Keymark Network standards superseded the existing Cyprus national standards. Mirror committees to the ISO/TC 180 solar thermal committee were formed. The test laboratory and the certification body were certified by European accreditation agencies. There has been significant exchange of SWH technology between Cyprus and other countries, protected by the Solar Keymark certification.

Challenges

Setting up the original Cyprus QI was quite expensive. Costs are contained by being part of the Solar Keymark Network.

Possible scenarios for building quality infrastructure

Cyprus participates in the ISO/TC 180 and Solar Keymark committees. As such, the country stays current on QI matters. In particular, there is support for the evolving world certification of solar collectors.

4.7 United States

The US SWH market exploded in the 1980s, with federal, state and local governments giving rebates totalling up to 90% of the system cost in some locales. There were no requirements for testing or certification as there were no standards, and the market was plagued with poor products that failed, tainting market reputation. When the tax credits were removed in 1984 (due in part to the election of an administration unfriendly towards renewables[30]), the market collapsed.

The market has not recovered, even when the federal tax credit was reinstated in 2006 and other state/local/utility incentives were initiated.[31] The market collapse in 1984 was due primarily to the abrupt removal of the subsidies. The lack of recovery, even after reinstated subsidies, is attributable to a number of factors, including:

- the high system cost relative to fuel cost savings, especially natural gas (55% of all US households),
- the perception that SWHs are unreliable and troublesome; and
- the emergence of solar PV markets and net metering.[32]

National standards were developed in 1980 for collectors and in 1991 for systems, administered by the Solar Rating & Certification Corporation (SRCC). SRCC was created in 1980 to address the poor products in the market and to develop national standards that would lead to uniformity among the many emerging private and state-government-level solar collector and system testing and certification programmes.[33]

There are two certification bodies in the United States: SRCC and the solar division of IAPMO. Multiple certification bodies may motivate the competing organisations to reduce costs. ANSI is the sole accreditation body in the United States (ANSI, n.d.). SRCC and IAPMO are both accredited by ANSI. NABCEP manages a certification programme for installers (NABCEP, 2015b). Further information on NABCEP can found in section 3.2.

Challenges

A newly emerging problem is the near-future existence of two sets of national standards for both collectors and systems, one from ICC/SRCC and one from IAPMO. The collector standards in each case are based on and reference ISO 9806:2013. However, the system test standards, while similar to ISO 9459-4:2013, differ somewhat. In the United States, it is up to industry (not the government) to decide which set of standards to adopt. Some incentive programmes[34] accept either

30 In the 1980 presidential campaign, US President Ronald Reagan opposed supporting renewable energy and pledged to drop all subsidies. Solar water heaters, although functional, were removed from the White House as a symbolic statement.

31 The 2006 federal incentives (and at state, local or utility levels) require approved collector and system certifications for participation in the incentives, removing one obvious problem with the 1978-1984 incentives.

32 The first two factors are discussed in Ghent and Keller (1999). The third factor is from Jack Werner, Executive Director, ISP, USA, personal communication.

33 More US history in SWH QI can be found in Fernandez *et al.* (forthcoming).

34 Examples of programmes that accept either certification include the California Solar Initiative (www.cpuc.ca.gov/puc/energy/solar/aboutsolar.htm) and the Arizona Public Service/Salt River programmes (see www.dsireusa.org/incentives).

SRCC or IAPMO certification. The potential is high for confusion in the market and for gaming from manufacturers seeking the highest ratings by going through both certifications.

Possible scenarios for building quality infrastructure

Both SRCC and IAPMO are considering ways to converge on a single national standard.

Other considerations

It is important to keep certification costs reasonable. Requirements for SRCC system certification were relaxed to permit system certification without testing of most systems, similar to the Australian approach. One principle to note is that if too many requirements are implemented, the industry needs sufficient time to prepare or it simply cannot comply. It is important to keep the industry involved in developing the QI, to keep it realistic and implementable. The certification community needs to keep the technical community engaged, including national laboratories, universities and private research laboratories.

4.8 Other countries

Kenya

There is a small market for imported SWHs in Kenya. National standards for SWHs exist, based on ISO standards. All products in the Kenyan market are required to have a certification mark. Imported systems or components have to be tested in the country of origin for compliance with Kenyan standards or the relevant international standard. There are regular market surveillance visits. There are no testing laboratories or certification bodies specifically for SWHs.

SWH is required on buildings with anticipated hot water load of over 100 litres per day. The installation of a SWH system is governed by a standard[35] and must be completed by a licensed installer. An expert indicated during the interview that there is a lack of adequate capacity to enforce standards and that up-front costs are a major barrier to implementing QI. Kenya has been participating in a discussion among African nations about forming an East African and possibly Pan African regional QI. This would ease the burden of each country having to find the resources for its own test laboratories, certification bodies and accreditation bodies.

Nepal

Nepal has a small SWH market, with some local industry producing SWHs without a major emphasis on quality. There is no certification infrastructure, and there are no SWH testing laboratories. With EU support, an effort was made in 2006-08 to develop a test laboratory. There was some interest in acquiring the

35 Code of Practice – Solar Water Heating For Domestic Hot Water; Kenya Standard KS 1860:2008.

"test laboratory in a box" from one of the German suppliers; however, it was deemed too expensive. It was decided to implement the test laboratory internally, with expenditures benefiting Nepal and more flexibility for testing. Although plans were finalised, the test laboratory has not been completed. According to an interview with an expert who worked in the country, in terms of funds (including local personnel salaries), it may have been less expensive in the long run to have purchased the "laboratory in a box" kit.

A clear path to lower-cost certification may be a regional QI so that each country need not have a test laboratory and other infrastructure of an ideal system. To keep certification costs low initially, one suggestion is to test mainly for durability/reliability to provide a good screen for inferior products. Performance is not unimportant but could be established with methods discussed in the appendix.

South Africa

South Africa has a growing solar thermal market. During 2011, 91 megawatts (MW) of flat plate collectors was installed, with 58 MW glazed and 34 MW unglazed (IEA, 2014). Incentives are in place, with rebates available for between 25% and 45% of the system cost, depending on the system performance and cost. It is compulsory for new construction to apply non-fossil fuel-derived energy to meet at least 50% of the building's water heating load. The South African National Accreditation System gives formal accreditation for all aspects of QI, including laboratories, certification bodies, inspection bodies, proficiency testing scheme providers and good laboratory practice test facilities. There is only one test laboratory and one certification body in the country (SABS, n.d.). It was thought that this contributes to high test costs. There is some activity on installer training.[36]

4.9 Regional initiatives

European Union: Solar Keymark, a regional quality assurance framework

The European Solar Thermal Industry Federation (ESTIF) and the EU have developed the most mature and well-enforced regional QA scheme for SWH in the world under the Solar Keymark Network, supporting the second-largest market in the world. Markets and QI for SWH developed in each EU country after the peak in oil prices in the 1970s, creating a patchwork of requirements that made trading of technologies between countries difficult. In the early 2000s, solar manufacturers appealed through ESTIF to the European Committee for Standardization to develop an EU-region set of standards and certifications that would be accepted everywhere in the EU. The Solar Keymark Network was

36 The Southern African Solar Thermal Training and Demonstration Initiative (SOLTRAIN) is currently developing training and demonstrations. PIRB (Plumbing Industry Registration Board) is working on installation accreditation; see PIRB (n.d.).

developed and established in 2003. European standards (EN) were enacted based on ISO standards. Solar Keymark is based on three EN standards: EN12975, EN12976 and EN12977.

Although there are large differences in climate in the EU, these variations were not an issue. This is because: 1) the EN/ISO performance test standards produce general performance models that can accurately predict performance in any climate, and 2) climate-contingent durability tests (*e.g.* freeze and hail) are voluntary, or as required by particular national standards when appropriate.

There has been an interesting interaction between ISO standards and EN standards. EN standards were adopted from corresponding ISO standards in many cases. The EN standards have been improved greatly over the past several decades. The collector test standard was improved for outdoor testing with the development of a dynamic collector test, where, among other things, a collector capacitance term was added. Furthermore, concentrating collectors and unglazed flat plate collectors were included in the standard. After these upgrades were made in EN12975 – Part 2, identical upgrades were then made to the ISO 9806:2013 collector test standard. Important work in harmonising international and EU standards resulted in 2013 in ISO 9806:2013, accommodating and replacing EN12975 – Part 2. Work is ongoing to maintain and improve the ISO 9806:2013 standard.[37]

Challenges

According to the information gathered in this study, there were no real barriers to implementing the Solar Keymark Network. Europe was conditioned and willing to accept standards, certification and accreditation activity, as these bodies had been active in other areas for many years, and benefits from this process are well known. There was significant government support for developing Solar Keymark. There was a strong industry and a well-organised industry association pushing for Solar Keymark to facilitate exports within the EU. It is noteworthy that Denmark ceased testing and certifying activity, as this was available at many other locations in Europe.

Middle East and North Africa: SHAMCI

There has been a modest market for solar thermal systems in the Middle East and North Africa (MENA), with 1.1 GW_{th} installed cumulatively through 2012 (IEA, 2011). Over time, many stakeholders have realised that a regional certification was in their best interest. As a result of a collaboration in 2011-12 among the Regional Center for Renewable Energy and Energy Efficiency (RCREEE) in Egypt, the League of Arab States, the

37 More details on Solar Keymark can be found at www.solarkeymark.org.

Arabian Industrial Development and Mining Organization, and the University of Stuttgart in Germany, a framework for a regional certification system for SWH was released in 2012.[38]

The Solar Heaters Arab Mark and Certification Initiative (SHAMCI) is very similar to the Solar Keymark Network. It explicitly references EN12975 and ISO 9806:2013 for collectors and EN12976 and ISO 9459-1:1993 – Part 5 for systems. A major difference between SHAMCI and the Solar Keymark Network is that the test laboratories and certification bodies are to be approved by SHAMCI but are not yet required to be formally accredited, making the system flexible and allowing time to be prepared for an accreditation process. Plans are under way to eliminate that difference in 2017, following ISO/IEC 17025:2005 for test laboratories and ISO/IEC 17065:2012 for certification bodies. SHAMCI also includes provisions for factory and site inspections.

The members of SHAMCI include representatives from 15 countries in the Middle East and North Africa: Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Palestine, Qatar, Saudi Arabia, Sudan, Syria, and Tunisia. So far, the scheme is in the implementation process for Egypt, Jordan, Lebanon, Libya and Tunisia. It offers member countries a pathway to a high level of QI with very low scheme development costs, through: 1) sharing of costs for test laboratories, standards development, standards bodies and certification bodies; and 2) having completion between multiple instances of the same body. Because of local implementation, the costs for product certifications are projected to be somewhat less than the costs for Solar Keymark Network certification.

Challenges

The countries in MENA have generally not yet developed QI for SWHs. Funding for national test laboratories and certification bodies has generally been lacking, with only a few countries having such facilities at present. Many of these countries lack QI of any sort for any products, making the establishment of these organisations for SWHs a more difficult task. In addition, in many of the countries there is a need to better understand the value and benefits of QI, making allocation of funds for SWH QI development very difficult to obtain. There are also significant cultural and political differences among countries in the region which may impede collaboration.

Possible scenarios for developing quality infrastructure

SHAMCI is a very important regional initiative with a great potential to jump-start solid SWH markets in the MENA region. Once there is a certification scheme in place that guarantees policy, policy makers can implement promotion schemes with confidence that the market that

38 The international standards for solar thermal collectors and components as a medium of quality assurance, Preprint.

develops will be sound and appropriately nurtured. For example, Tunisia has a certification scheme in place- it was one of the first countries to implement SHAMCI and has seen significant market benefits.

4.10 Global certification

Regional networks have many advantages, including lowered per-country QI cost and increased trade opportunities. Motivated by the results of Solar Keymark in Europe, EU members and others participating in the IEA-SHC's Task 43 "Rating and Certification" have been gathering momentum towards a global collector testing and certification scheme based on ISO 9806:2013.

IEA-SHC's Task 43 studied the precedents from other fields and issues particular to solar products. They express some optimism that a global collector certification can be established. Organisational structures from six functioning QA schemes were presented, and there was a high level of agreement among countries on testing methods. Most countries surveyed already had based their national collector standards on ISO 9806:2013. It helps that ISO 9806:2013 outputs a universal collector model applicable to any country; all the hard work developing and testing the standard is embodied in the standard. There is really no fundamental impediment to implementing the testing aspects of ISO 9806:2013.

The more challenging issue is collector certification. Here, a collector must meet a number of criteria for safety, health, durability, etc. These standards often refer to national standards in plumbing, electrical or buildings, and, as such, it will be difficult to even understand all the different requirements. The differences between the Solar Keymark Network and the US SRCC SWH standards are not serious, but neither are they negligible. Different system types and sizes are relevant to different countries, which reflect different climates (from very cold to very hot) and hot water use patterns. This worldwide diversity must be accommodated in a global certification standard.

5 KEY CHALLENGES AND OPPORTUNITIES FOR DEVELOPING QUALITY INFRASTRUCTURE FOR SOLAR WATER HEATING

The key issue for emerging renewable technologies is cost, and the same is true for emerging QI. Cost issues, methods to contain costs, and other issues are discussed briefly in this section.

5.1 Cost

Probably the key challenge to developing and implementing QI for SWH is how to contain the costs while maintaining the integrity and reliability of QI. The cost of QI to governments depends on many factors and is hard to estimate, but it can range from millions to tens of millions of US dollars for a high-quality QI scheme, including establishment of national standardisation bodies, testing laboratories, certification and accreditation bodies, metrology institutes, etc. QI cost issues and suggestions on how to lower those costs include:

- ***Standards.*** Standards development is a very costly endeavour, particularly when starting from scratch, with very high levels of paid staff and volunteer activity.

  Solutions: Recognise that SWHs are relatively mature and that much basic work on test procedures has been done. Adopt or adapt the existing ISO standards in regional or national SWH standards. This assures a higher quality of the standard as there has been time to address issues in those long-standing standards. Collaborate as much as possible with other nations. Consider regional networks that will share costs of developing and maintaining standards, test laboratories and certification bodies.

- ***Test laboratories.*** Developing a SWH test laboratory can cost roughly USD 0.5 million-2.0 million.[39]

  Solutions: Testing services can be offered at various levels, starting with low-cost methods, then unaccredited fuller testing, and finally full accredited testing. Do not do it alone. Consider observing practices

39 Estimates provided by SWH interviewees.

and consulting with mature test laboratories in neighbouring countries or in Europe and North America. It is very useful to participate in proficiency tests, which for SWH consist of all the test laboratories testing a common set of collectors. Having multiple sources of testing and certification breeds competition among the QI providers and reduces costs. In a regional network, it is not necessary for each country to have its own test laboratory.

- ***Manufacturers***. Collector and system tests cost on order of USD 10,000 per collector type or system type. This is a high burden in an emerging market.

  Solutions: Keep test costs low in the beginning by initially using lower-cost instrumentation and keeping the tests simple and focused on durability. Introduce more demanding performance testing when the market matures.

- ***Factory certification.*** Certification of manufacturers/factories in conformity to quality management systems (such as ISO 9001:2008 "Quality management systems – Requirements") is an important step to guarantee consistent quality. However, it is very expensive (approximately USD 100,000, including the preparation time). Besides the initial inspection and certification, similar activity is repeated annually under ISO standards, another significant time/cost burden.

  Solution: One approach is to require manufacturer certification only in mature markets where they can absorb the costs without raising prices much.

- ***Certification bodies***. It is costly to set up a certification body, involving establishment of design review guidelines from the certification standard, hiring staff with the technical capabilities to assess design, setting up procedures for generating ratings and creating/ maintaining websites, accrediting the body, etc.

  Solutions: During implementation when there are few systems to certify, it is cost-effective to hire outside experts with experience in assessing SWH designs. It would be helpful to contract with an experienced analyst from an established test laboratory/ certification body to help guide the process development. Accreditation of the body can be delayed until there is sufficient business to cover the costs without increasing certification cost significantly.

5.2 Other challenges

- ***Country expertise***. It can be difficult to find in-country technology experts when there is little or no market. It can be difficult to keep staff at the test laboratories once they are trained and have marketable skills, as they may have access to more job offers.

Solution: Seek outside expertise initially. As training, test laboratories and certification bodies develop, they will naturally attract experts.

- ***The chicken-and-egg paradox.*** The classic conundrum applies here: *Which comes first, the market or the QI?*

  Solutions: The market should dictate the level of QI development needed. If market regulation is too strict (requiring full testing initially), it will inhibit the market. If regulation is too lax or if QI is not required by law or to access incentives, poor-quality systems will tarnish the reputation of the entire product category. When a change is being contemplated, consider hiring SWH QI experts to advise.

- ***Industry communications.*** It is challenging to have the industry fully aware of the SWH QI developments, and even more difficult to have industry accept the increasing regulations.

  Solutions: At all stages of the process, industry and all other stakeholders must be fully engaged in the process. These regulations will affect their businesses significantly, and it should not be difficult to persuade industry and others to sit at the table. Industry participation makes for a more workable QI. Furthermore, given that industry is involved from the outset, they are much more likely to accept the regulations without creating an uproar. It is very helpful to have an industry association representing the manufacturers' voices and communicating QI development.

6 RECOMMENDATIONS FOR DEVELOPING AND IMPLEMENTING QUALITY INFRASTRUCTURE FOR SOLAR WATER HEATING

QI development should be in balance with market development. This section suggests a set of QI stages for SWH corresponding to five qualitative stages of the market. Figure 11 shows the build-up of QI as the market develops. Some

Figure 11: Possible quality infrastructure stages as a function of the market stage

discussion of the actions recommended at each stage follows. The recommendations aim at guiding SWH QI stakeholders, but they are not rigid; a country-specific optimal path depends on many country-specific variables. Choosing options from different QI stages is expected. Readers will apprise their country as situated initially at some level: most will find their country at or near the starting stage, with little experience with SWH technology in their country, while others may find their country's QI to be in one of the last stages.

6.1 Suggested quality infrastructure stages for solar water heating

Stage 1: Market assessment

At this stage, there is some interest in considering or developing a SWH market in the country. Projection of potential fuel savings nationwide is important in prioritising SWH activities relative to other renewable technologies; this requires quantitative knowledge of the solar resource. Understanding existing in-country QI and expertise (such as the installed base of SWH, university/training organisations focused on practitioners, professional associations, test laboratories, etc.) will be helpful in establishing a baseline for future QI development work.

Several actions can be taken:

- *Develop a QI strategy.* The QI must incorporate the standards and bodies for testing and certification of hardware and practitioners. Consider developing or joining a regional QI if there is any indication of a common political willingness. Sharing responsibilities and costs regionally is perhaps the most cost-effective way to develop QI. Regional networks include Solar Keymark in Europe, SHAMCI in the Middle East and the emerging network in Latin America.

- *Develop in-country resources.* Consider how to develop the in-country human resources needed to support a local SWH industry. Consider joining competence training networks like ISPQ or NABCEP that have established training courses and curricula that can be licensed with much less cost than funding development of the materials from scratch. Plan for some expenses to adapt training details to local needs.

- *Develop market stimulation plans.* Consider making certified SWH mandatory on new construction, major building retrofits and government buildings. Benefits and costs of setting up potential market incentives should be estimated. Any incentive must require at least existing levels of national certification to qualify for the incentives.

- *Standards development.* It is necessary to set up a standards developing organisation if that does not exist already. Consider requiring the SDO to adopt or adapt parts of existing SWH international standards to efficiently start the basis for a sound QI, rather than considering development from scratch. Most national SWH collector standards adapt or reference ISO 9806, and national SWH system test standards reference ISO 9459. Bear in mind that by adopting a specific SWH standard, it sets the basis for reciprocity in certification and for trade with countries which also have that standard.

Stage 2: Market introduction

At this stage, the market is small, but there are importers and local manufacturers supplying systems, and the market is growing. Training for practitioners is the highest-priority item. The quality of imports must be controlled to protect the reputation of a fragile, emerging market. Some consideration should be given to supporting demonstration projects, which provide training opportunities and educate the public and potential manufacturing groups about the technology. At this time it is not worth setting up testing or certification unless there are local manufacturing firms producing at moderately high volume. In that case, starting with the durability testing of prototypes (as per stage 3 below) would be recommended.

Several actions can be taken during this stage:

- *Develop training courses.* Training courses are needed on SWH installation and O&M to expand in-country expertise. Courses should include: 1) general understanding: physics of operation, principles of sizing, load estimation, plumbing principles and basic techniques such as proper soldering; and 2) specific techniques for installing and maintaining systems, including placement of pumps, sensors, heat exchangers, etc., for all types of systems that will be used in the country. Training has most often been too low a priority in QI schemes, leading to high levels of system failures; this needs to be emphasised in emerging markets, where competent installers tend to be scarce. An installation manual and possibly an installation video should be required for every set of hardware (especially imported hardware) to help installers understand the peculiarities of a particular system.

- *Develop import control.* One relatively easy way to control import quality is to require an approved SWH certification. It will be necessary to develop a listing of approved certification programs, to specify the documentation needs, and to establish procedures for affirming appropriate certification exists. There must be both collector and system certification. The approved list should include the EU's Solar Keymark, North America's SRCC and IAPMO, Canadian certification and the highest level of Chinese SWH standards. A required user's manual should explain the system and its operation in detail and provide contact information for parts and repairs. A required installation manual should detail installation of the system; an accompanying video would be very useful. Some funding is required for instituting these processes and for training the staff that regulates the imports.

- *Educate local regulatory agencies.* Enable local agencies to understand what certification can bring and how to use the certificates for permitting approval.

- *Support the national SWH industry association.* If it does not exist, consider some support to initiate one. Besides promoting the industry through various means, the association can interface with the government and other stakeholders on QI needs, standards, upcoming QI requirements, etc., facilitating acceptance of those requirements and costs by the industry.

Stage 3: Market growth

At this stage, the market is still small but emerging and beginning to contribute to national energy and economic goals. Installer training should be made more rigorous and comprehensive. Imports should continue to be controlled by demanding external certification. There are likely local manufacturers, and, if so, some QA is needed. Consumers and other stakeholders should be provided access to certification and testing results and will begin to have some understanding of a given SWH's performance.

Several actions can be taken during this stage:

- *Develop test laboratories.* Identify and support initial development of test laboratories for basic testing. Durability testing emulating ISO 9806:2013 "Solar energy – Solar thermal collectors – Test methods" is recommended, where the test protocols and equipment needed are defined. At a minimum, there should be an instrumented test stand. There is likely a separate shed housing the data acquisition and storing device. The minimum instrumentation would include a pyranometer (for global horizontal), solar-shielded ambient temperature, wind velocity, low-accuracy temperature sensors and a fluid pressure sensor. These data need not be high-precision initially, especially if only durability testing is done; for example, it is possible to use inexpensive photo-diode pyranometers and to use thermocouples for temperature measurements. Test laboratories should be continuously improving, with the end goal of ultimately being accredited to the international standards.

- *Continue to support an industry association.* Elicit the industry association's help to educate all stakeholders involved with SWH QI projects, including government officials for zoning/planning and for building inspections (if a permit is required to install SWH).

- *Develop regional QA schemes.* The same collector and system performance models work in all climates. There can be different requirements on systems and certification criteria regionally (*e.g.* freeze vs. non-freeze sub-regions that require different system types and installation techniques). Note that such system diversity is not a fundamental barrier, although it does require making multi-part standards that address these multiple levels. The basic certification standard should have sections appropriate for freezing and non-freezing climates, for example, and relevant sections can be made mandatory based on climate statistics such as hours below freezing.

Stage 4: Market consolidation

At this stage, the market is moderate to large and still growing. All of the elements of a comprehensive QI system are instituted, including certification and posted ratings. Most elements of the international standards ISO 9806:2013 and ISO 9459 series are in place at the national or regional test laboratories. Installer training should have defined curricula and testing for master trainers, instructors and installers, providing certified installers. However, all of these bodies are not necessarily accredited at this stage.

Several actions can be taken during this stage:

- *Improve test laboratories.* The laboratories should be able to fully and accurately test collectors and systems in this stage. To speed up collector testing and improve accuracies, consideration should be given to acquiring two-dimensional trackers. System tests demand a stationary rack that mimics a rooftop. High-accuracy sensors and data-loggers are needed. Added sensors include a pyrgeometer, flow meter and humidity device. Consider purchase of a complete test laboratory in a mobile trailer, as described in Bestenlehner *et al.* (2008).

- *Set up certification bodies.* The certification bodies should be independent of the test laboratories. The design evaluation function demands SWH experts who can evaluate SWH designs; open contracts can be given that specify cost for a given review and do not specify how many will be performed. The experts must be educated on any idiosyncrasies in the country's certification standard. They can be sub-contracted in-country or from abroad to work "by the system". Special consideration will include examining overheating protection for all climates and freeze protection for climates where temperatures could ever fall below 4oC. The certification body (or another rating body) will use the collector and system models provided by the test laboratory to generate the collector and system ratings for the one or more sets of conditions chosen for that country.

Stage 5: Market maturity

At this stage, all the QI elements are well-established and accreditation is done by the national accreditation body to ISO standards. Accreditation is the final step necessary to guarantee the adequacy of the testing, certifying and training bodies. All of the QI elements are brought up to international standards. Accreditation is the main difference between this stage and the previous stage. It is the final stage of moving the QI up to the highest level.

6.2 Conclusions

Quality assurance is key to any new technology, to nurture emerging markets, assure good reliability with known performance and provide a credible basis for sound market-growth incentives. Solar water heating is relatively mature, with hundreds of different system types available. Part of that diversity is due to varying approaches for overheat protection and for freeze protection. Given that new systems and manufacturing are evolving and new companies enter the field, QA is always required. Furthermore, SWH are complex to install, and poor installations can negate the best equipment. Thus, along with educating customers on the importance of QI, another ongoing need is that practitioners must be appropriately trained and certified. Without significant QI for both hardware and installation, the SWH market can be irrecoverably harmed, as has been observed time and time again.

Quality infrastructure is the framework that provides QA for the marketplace, including standards, testing, certifications and inspections. International SWH standards are well-developed and should always be the basis for developing any national or regional standards. ISO 9806:2013 provides for performance and durability testing of collectors. The ISO 9459 series provides for performance of whole systems. In both cases, the standards produce general mathematical models of performance that can be used to provide ratings in any climate or under any assumed use profile. Test laboratories are expensive to set up, and strong consideration should be given to sharing test labs in a given region. QI in a number of countries and regions is detailed, from fully developed QI under Solar Keymark in Europe, to countries just beginning to develop QI, such as Ethiopia.

QI has a cost to establish and maintain, and it can be expensive for a manufacturer to go through full certification. It is reasonable to gradually phase in QI as the market develops, starting with low-cost methods that assure quality first, and then to morph into more-rigorous but more costly methods as the market grows and is able to absorb certification costs. Five stages of market development are defined, from emerging to fully mature. It is important to involve the local industry at all levels of the QI and market development, through a national industry association. With sufficient QI in place, solar water heating can become an important part of the energy system, providing reliable hot water to households and communities in an affordable and sustainable manner.

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APPENDIX A

Low-cost methods for rating solar water heating system performance

Even as markets begin to emerge, before test laboratories or other QI have been implemented, consumers and others would like estimates of the amount of energy that a given SWH can save in their climate for their usage patterns. However, detailed methods following international standards might be missing in emerging markets. Lower-cost means of providing SWH performance information for SWHs are thus important. Three methods which are variations of ISO 9457-4 are presented here that are useful for inexpensively addressing SWH system performance.

The attractiveness of these approaches hinges on the availability of previously developed, validated and easy-to-use SWH simulation models. Having all such models available in one software package would be preferred.[40] The computational algorithms in the TESS software have been validated empirically in essentially thousands of previous SWH studies comparing the physics-based algorithms to test data at the component and system level. In general, there is a high level of confidence in models predicting behaviour of SWH that correspond literally to behaviour of each of the components, given adequate characterisation of those components.[41]

In the aforementioned package, all models are subject to a series of analytical tests that assure that the basic algorithms are implemented correctly (Burch *et al*., 2011). To derive a given systems model, spreadsheet forms are filled out that give the characterising parameters for the system's components, including the collector, tank, controls/pumps and auxiliary backup. These files are fed into the generic model for that system, instantiating the general model to the specific system to be rated. The sites (essentially weather files) and user hot water draw profile files (chosen by the rating organisation to be consistent with the country's usage) are inputs chosen by the user. The annual savings and other metrics are calculated.

The three methods presented here are based on using a simulation model that represents the SWH system, with varying accuracy. An SWH simulation model incorporates algorithms for energy

40 One such modelling package is available from Thermal Energy System Specialists, Madison, Wisconsin, USA.

41 In one set of tests on three systems, system performance was predicted with RMS deviation under 5% when measured component inputs were used in the models; see Davidson *et al*. (1993).

performance of each component and means of converging to a solution at each time step of the simulation. Perhaps the most well-used simulation environment is the modular, extensible package TRNSYS (TRaNsient System Simulation),[42] which is the simulator used in the ratings package described above. The three methods are:

- System simulation with estimated component inputs (*component estimation method*). The least expensive and least accurate (± ~30%) projections are derived by estimating component inputs from the component description coupled with historical test data and/or manufacturer's data, rather than testing components directly. The system model must be well-validated.

- System simulation with measured component inputs (*component test method*). More expensive (for manufacturers) and more accurate (± ~10-15%) projections result when the components are tested. Collector and other key components are tested, and simulation models are derived for each component. These models are embedded in the simulator. The system model must be well-validated. System simulation with measured component inputs or calibrated system (*dual-path method*). There are two paths: 1) the same as the component test method above, or 2) install and instrument the SWH at the laboratory, test under a prescribed protocol that enables accurate parameter regression, and derive from that test data an equivalent model. In this latter case, the system model need not be well-validated.

42 See www.trnsys.com.

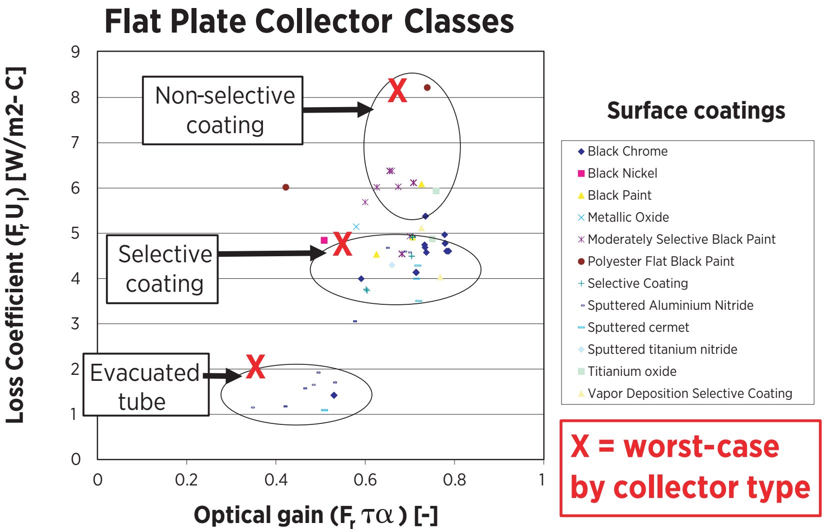
A.1. System simulation with estimated component inputs: component estimation method

The least-expensive and least-accurate projections are derived by estimating component inputs from the component description coupled with historical data or manufacturer's data, rather than by testing components directly. Figure A-1 illustrates a process for estimating the inputs for a collector; it is a plot of some historical data using available collector rating summaries.[43] The process selects the worst reasonable value for the collector type (which also encourages the manufacturer to get actual test results).

For example, a collector may be indicated as a glazed flat plate collector with a selectively coated absorber. There is a characteristic grouping of the optical gain and loss coefficients for that type of collector, as in Figure A-1. A "worst case" value is chosen, as indicated by the red "X." Similar estimates could be made for other important component inputs, such as the loss coefficient of the storage tank. In the

43 These data were taken from SRCC (n.d.).

Figure A-1: Plot of the loss coefficient (FrUl) vs. the optical gain coefficient for all collectors in the SRCC database as of 2005, showing how the points group according to collector type. The symbol "X" indicates a generic conservative value for each class.

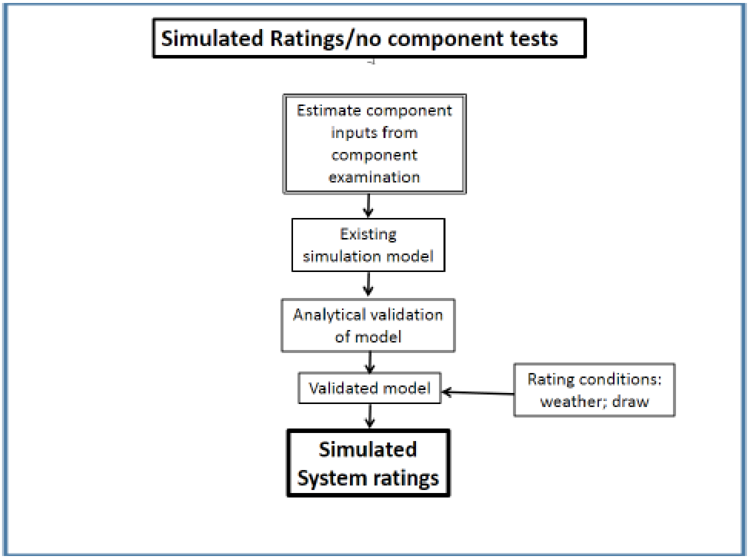


case of the tank, estimates would need to accommodate the fact that estimates of the load coefficient based upon 1-D heat loss calculations through the tank wall are significantly low vs. measurement, because of several unaccounted-for loss mechanisms, including thermal shorts and single-pipe thermosiphoning. When this process was used in the United States at SRCC, 1-D estimates of the tank loss coefficient were doubled to estimate real losses.

A schematic of the process of the system rating process is given in Figure A-2. The analyst must first identify which of the simulation models matches the system at hand. The software then uses the defaults for non-critical components. When all components not defaulted are described (typically the collector, tank, heat exchanger, pipe insulation and pump would be a minimum set), the resulting simulation model is then used to compute ratings for that system.[44] The rating

44 The rating metrics would normally include a subset of these data: {hot water reference load; auxiliary energy with solar; energy saved; solar fraction}$_{i,j}$, where "i" labels water use patterns, and "j" labels locations/weather files.

Figure A-2: Schematic process for producing solar water heater system ratings based on pre-existing simulation models and estimation of key component parameters

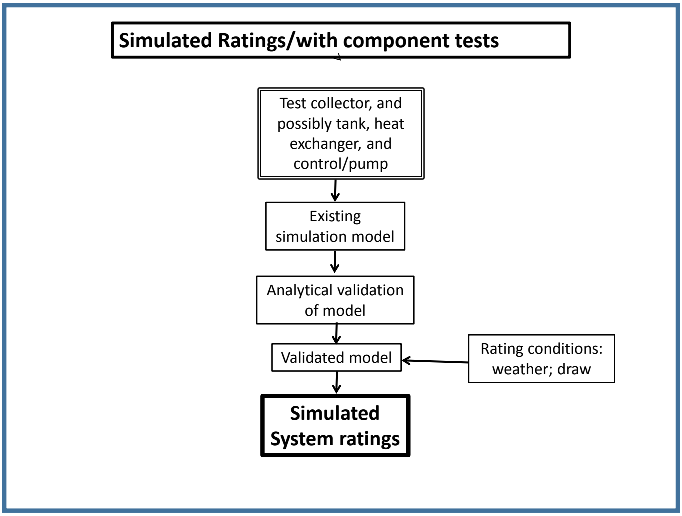


would be identical for two systems of the same type and general description from two manufacturers, even though some differences between the two systems would probably exist.

The rating conditions include the weather file(s) and the hot water draws. There must be a year of hourly weather data for each site for which ratings are desired. It is possible to generate synthetic files from monthly averages. It is easy to extend ratings to multiple sites and draw volumes. The point is that although this is a crude estimate (2s uncertainty is ~30%), it provides a reasonable expectation of system performance at very low cost for all involved. The simulated values cap what a manufacturer could legally claim in advertising. The burden would be on the supplier to prove that other numbers are appropriate, which is quite possible but requires some testing (*e.g.* testing of the collector would be required, at a minimum). If the supplier chooses, s/he can bear this expense and have presumably improved rating numbers.

Besides low accuracy, a weakness in the *component estimation* method (and the method, in section A.3) is that systems without a validated model cannot be rated. However, if the TESS rating software is used, there are more than

Figure A-3: Component test/system simulation process for deriving solar water heater system ratings under any assumed rating conditions, using measured component parameters



200 systems modelled, and almost all SWHs are covered.[45] New and innovative systems that have not been thoroughly studied and modelled/tested previously by definition would not be included in this approach. The method in section A.3 below shows how to overcome this limitation through system testing to derive a calibrated model that effectively represents system performance.

45 It is noted that in the United States, over the past 20 years, few SWH certifications were performed using system test data: <3 out of ~2 000 system certifications.

A.2: System simulation with measured component inputs: component test method

This method is illustrated in Figure A-3. The process is the same as that in section A-2 with one significant difference: the parameters of the key components are measured rather than estimated. The estimated 2s error interval is reduced from ±30% to ±10-15%, depending on whether the tank, heat exchanger(s) and other components are tested. Testing of the collector should always be performed, as it dominates SWH performance. Costs can be lowered by foregoing direct tank, pump and heat exchanger testing, and by using available manufacturer's data or defaults for the given models, although accuracy is degraded when such estimates are used. This method is used in Australia and the United States, with minor variations. As with the component estimation method above, this method requires the existence of a well-validated literal simulation model that accurately describes the heat flows in the system. The method in section A.3 below shows how to overcome this limitation through system testing to derive a calibrated "effective" model.

The cost for this method can be very low if the required component tests have already been done. This makes this rating approach very appealing, as the costs to implement reasonably accurate system estimates are quite low. Note that this method forces the use of tested and certified collectors, upping the bar on reliability.

If none of the system components have been tested, the costs for this method are substantial, more than for a single direct system test. A reliable collector test costs approximately USD 7 000; tank and heat exchanger tests are roughly half that. Testing the collector, tank and heat exchanger together would cost almost USD 15 000,[46] more than a system test. The situation changes somewhat when certification/rating is desired for more than one size of a given SWH type[47] (this is very typical). In ISO 9459-4 based methods (like the method here), additional sizes are *very* inexpensive to add once the model is developed for one size; only the size inputs need be changed. On the other hand, extrapolation to different system sizes in ISO 9459-5 demands testing of at least one additional system size because the inputs such as collector area are effective values that cannot be extrapolated by geometry alone. This increases cost in ISO 9459-5 above the worst case for the method here.

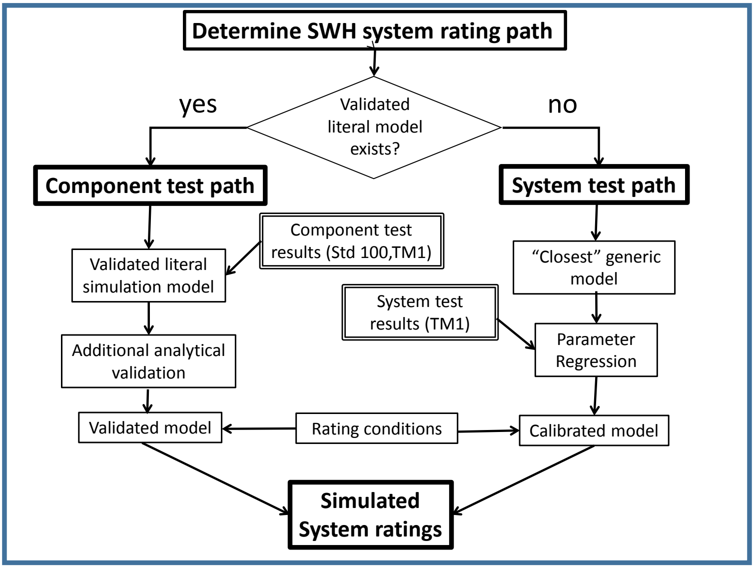
A.3: Dual-path method: component test and system test options

The *dual-path* method is illustrated in Figure A-4. It is essentially the previous *component test method*, with addition of a *system test* path when the system is a new type and a validated model that describes system heat flows is not available. This overcomes the issue in the previous two approaches of not being able to rate systems whose models have not been developed or validated previously. The system test path is very similar to ISO 9459-5, the *dynamic system test.* One difference is that ISO 9459-5 uses a single simplified model as the base model for all tested systems, and that model is

46 As mentioned, the tank and heat exchanger testing can be avoided by using estimated values to save on costs.

47 Many suppliers have different sized collectors with different numbers of collectors per system (with other components sized accordingly) to meet a variety of loads, from small to very large.

Figure A-4: The dual-path test/rate system under the US SRCC's Standard 300



embedded in proprietary software and, strangely, not available for examination by users; whereas in this variation, the existing simulation model closest in physics/structure to the actual system is adopted as the base model. It is convenient to use the entirely transparent models in the TESS software package. It is necessary to test the system according to a flexible protocol designed to elicit robust parameter values for the calibrated model, similar to as specified in ISO 9459-5.

APPENDIX B

Summary of national QI schemes for solar water heaters

Table B-I: Quality infrastructure schemes for solar water heaters in selected countries

Country/ scheme	Standards used	National metrology institute	Test laboratories (U = unaccredited, A = accredited)	Certification bodies (U = unaccredited, A = accredited)	Accreditation organisations
Argentina	There are 13 solar-related national standards from the 1980s. The solar thermal series ranges from standards IRAM 210001 to IRAM 210009. They are being updated based on ISO standards. Iram.org.ar and www.oaa.org.ar	INTI	A: None U: Under development at the National Technological University (UTN-BA) and other institutions such as INTI, INENCO, UNRC, UNLU FUNDACION ECOANDINA	None	OAA
Australia	**Collector**: AS2535.1 **Collector durability**: AS/NZS2712 **System**: AS/NZS 4234 (like ISO 9459-4)	National Measurement Institute	A: Vipac, Uni SA, ANTL, UNSW	SAI Global, Globalmark	JAS-ANZ, NATA
Barbados	Adapting ISO standards	None	None	None	None
Brazil	Has national standards	Inmetro	Two test labs, one at Catholic University of Minas Gerais, Belo Horizonte		
Chile	Standard #2365; EN12975 and EN12976 are used for durability testing of collector and system	INN/RNM	One test lab	Four certification bodies; three inspection bodies	
China	**Collector**: GB/T 4271-2007 **Collector durability:** Flat plate: GB/T 6424-2007 Evactube: GB/T 17581-2006 **System**: GB/T 19141-2011 (like ISO 9459-2); GB/T 18708-2002	www.nim.ac.cn	A: National labs for solar water heating system in Beijing, Wuhan and Kuming www.hbzj.org.cn/rsq_index.asp www.solar-testing.org.cn	A: China quality certification center, www.cqc.com.cn/english/index.htm A: Certification center of China academy of building research, www.cabrcc.com.cn A: China General Certification Center, www.cgc.org.cn	China National Accreditation Service for Conformity Assessment, www.cnas.org.cn/english/index.shtml
Costa Rica	Standards in development under law 8729	Lacomet	ICE		

Country/ scheme	Standards used	National metrology institute	Test laboratories (U = unaccredited, A = accredited)	Certification bodies (U = unaccredited, A = accredited)	Accreditation organisations
Cyprus	**Collector**: UNE EN 12975 1-2 2006 **System**: UNE EN 12976	Euromet	Applied Energy Laboratory, www.irena.org/DocumentDownloads/events/2014/June/8_Roditis.pdf	TÜV Cyprus, www.tuv-nord.com/cy/en/index.htm	Cyprus Organization for the Promotion of Quality, www.cys.mcit.gov.cy/english/main.html
Denmark	**Collector:** EN12975-1,2 (in EU) **System**: UNE EN 12976	www.dfm.dtu.dk	A: None (use EU labs) U: Danish Technical University	None (use EU certification bodies)	DANAK, www.danak.dk
Ecuador	**Collector**: UNE EN 12975 1-2 2006 **System**: UNE EN 12976	www.inen.gob.ec	U: Energy Laboratory, Mechanical Engineering Faculty of National Polytechnic School	Energy Laboratory, Mechanical Engineering Faculty of National Polytechnic School	INEN, www.inen.gob.ec
Ethiopia	None	http://nmie.net	http://eca-e.com is the Ethiopian test lab, but it has not set up solar testing	None	Ethiopian National Accreditation Office (ENAO), http://enao-eth.org/
European Union	**Collector**: EN12975 **System**: EN 12976	Metrology is on the national level	17 accredited: www.estif.org/solarkeymark-new/contacts/recognised-test-labs	11 accredited: www.estif.org/solarkeymark-new/contacts/certification-bodies	
Germany	**Collector**: ISO/EN 9806 **System**: EN 12976	www.ptb.de	A: Institut für Thermodynamik und Wärmetechnik, www.itw.uni-stuttgart.de A: Institut für ZukunftsEnergieSystem, www.izes.de A: Institut für Solarenergieforschung, www.isfh.de	Gesellschaft für Konformitätsbewertung mbH, www.dincertco.de	DAkkS, www.dakks.de
Kenya	**Collector**: KS 1851-1,2; KS 1871:2009 (hail resistance), http://onlinecatalogue.kebs.org **System**: (3 paths) KS ISO 9459-1: 1993; KS ISO 9459-2:1995; KS ISO 9459-5:2007 **System durability**: KS 1852-1:2009, 1,2, http://onlinecatalogue.kebs.org/webquery.dll; KS ISO 9806:2013, http://onlinecatalogue.kebs.org/webquery.dll	www.kebs.org/index.php?opt=metrology	A/U: None specific to SWH	KEBS	

Country/ scheme	Standards used	National metrology institute	Test laboratories (U = unaccredited, A = accredited)	Certification bodies (U = unaccredited, A = accredited)	Accreditation organisations
Mexico	Adapting four ISO standards into Mexican National Standards, prepared by the *Dirección General de Normas* (General Directorate of Standards)	CENAM	Four labs, now seeking accreditation with ILAC	Private body	ILAC
South Africa	**Collector:** SANS 1307, www.store.sabs.co.za/sans-1307-2012-ed-5-00 **Collector durability:** SANS 6210, www.store.sabs.co.za/sans-6210-2013-ed-3-01 **System**: SANS 151; SANS 1307; SANS 6210, www.sabs.co.za/Sectors-and-Services/Sectors/ Solar/solar_sp.asp **System durability**: SANS 1307, SANS 6211	www.nmisa.org/Pages/default.aspx	A: South African Bureau of Standards (SABS), www.sabs.co.za U: Stellenbosch University; Tswane University of Technology, www.tut.ac.za U: Stellenbosch University, CRSES, Sterg, ME, www.crses.sun.ac.za U: Centre for Energy Research NMMU; EEDSM Hub at the University of Pretoria, http://eehub.up.ac.za	SABS, www.sabs.co.za	South African National Accreditation System (SANAS), http://home.sanas.co.za/
United States	**Collector**: SRCC Standard 100 (= ISO 9806); SRCC Standard 600 (concentrating collector) **System**: SRCC Standard 300; SRCC TM-1	National Institute for Standards and Technology, www.nist.gov	19 approved: http://solar-rating.org/test_labs/approved_labs.html	SRCC, www.solar-rating.org IAPMO, www.iapmo.org	ANSI, www.ansi.org

Information up-to-date as of June 2014

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