Note: Some Tables and Figures are missing

Executive Summary

A solar water heater (SWH) is a device that uses solar energy to heat water and store the hot water for domestic, commercial and industrial applications. Passive direct SWHs, operating on the natural convection or thermosiphon principle, are the simplest type of SWHs. They are appropriate for use in tropical countries.

SWHs have several advantages over conventional water heating systems. For consumers, they save electrical energy, save interior space (because they are usually located on rooftops), and eliminate the risk of accidents in bathrooms due to electrical water heating equipment. They require little or no care and attention while providing hot water for about 300 days in a year in most parts of India. For the power producer(s) (e.g. Karnataka Power Corporation Ltd), they save power and therefore reduce the need for new generation capacity. For the electricity distributor(s) (e.g. Karnataka Power Transmission Corporation), they make available electrical energy that could be diverted for more profitable sales to consumers on higher tariffs. For society at large, they reduce the need for fossil fuels for electrical generation and for fuels such as firewood, coal, furnace oil, etc., that are used in domestic, commercial and industrial boilers. Thereby, they also reduce degradation of the environment.

The potential demand for using SWHs in industry, commercial organisations and residential houses and apartments is very high in India. The demand is about 263 million m^2 of collector area in 1998. One m^2 of flat-plate collector area would, on average, heat about 50 litres of water per day (lpd) to 60^oC. However, with improved materials and design, this area could be reduced to 0.8 m^2 and also achieve much higher water temperatures.

The basic design of a passive direct SWH is based on a collector box assembly situated below a storage tank. Within the box is an absorber made of black copper sheets, to the back of which are attached copper pipelines. The absorber is covered with a transparent glass and insulated at the back and sides to reduce heat losses. The collector works like a miniature greenhouse trapping heat that is transferred to the water in the pipes. Cold water flows from the bottom of the storage tank to the collector, from which heated water rises to the top of the storage tank. To maintain the functioning of the system, a constant supply of cold water must be available, for which an overhead storage tank on the roof is convenient.

The general requirements for installing SWHs include a shadow-free roof or ground area with sufficient strength to carry the collector and storage tank (3 m^2 of area capable of supporting 200 kg of static load for every 100 lpd). There must also be piped water available at a minimum head of 2m and electricity supply to connect a back-up heater. There must be provision to adjust the inclination of the collector to receive maximum solar radiation, a drain plug to flush the system, an air vent to release air-locks, and proper supports and piping.

The most cost-effective way to install a domestic SWH is to integrate the collector assembly, cold-water supply and piping with the design of a new house under construction. SWHs can easily be installed in group houses and apartments, especially during construction, if adequate provisions are made for piping, collector assembly and cold-water supply. Proper load-matching is required to ensure that the capacity of the system installed is optimised to meet the daily hot-water needs of the end-user.

Current (1999) prices of domestic SWHs are around Rs.11,400 (Rs.9,900 + Rs.1,500 for accessories such as plumbing at 1999 Rs.) for a 100 lpd system. The life-cycle cost of energy of saved electrical energy is Rs.1.56 at the point of end-use and Rs.1.27/kWh at the point of generation by the utility. The life-cycle-cost of saved power by the power producer(s) is Rs.4,986/kW.

If the SWH is purchased as an add-on to an existing geyser, the simple payback period for the consumer would be 5.45 years. The electricity distributor (e.g., KPTC) could gain additional revenues of Rs.2,835/SWH/year by selling the saved electrical energy to higher paying consumers in the commercial sector (i.e., by exploiting the differential tariff of Rs.2.70/kWh).

If the SWH is purchased instead of a geyser, the payback period for the consumer would reduce to 3.58 years. The power producer(s) (e.g., KPCL) would benefit if the consumer also opts for a reduced connected load because electrical water heating equipment would not be used. (This load reduction takes into account a low-wattage backup heater for the SWH.) In this case, given a diversity factor of 0.4, the power producer(s) would avoid 0.8 kW of new generation for every consumer who opts for such a connected-load-reduction scheme.

Conventional manufacturing practices are labour-intensive and tend to waste materials. Individual riser and header tubes for the collector assembly are welded together and sheets or rolls of sheets are cut and processed to form fins, collector box, tank and cladding. In order to improve productivity, more efficient manufacturing processes are required with techniques such as metal pressing and adhesive bonding to fabricate the collector assembly.

The economics of SWHs would be even more favourable if prices dropped due to improved manufacturing practices that optimise material use and/or increase scale of production. Future prices of SWHs are estimated to be between Rs.7,500 and Rs.9,635 for a 100 lpd domestic system. Large-scale dissemination of SWHs would imply at least a ten-fold average increase in sales each year over the next 20 years. In order to increase volumes of annual production and sales of individual manufacturers to about 20,000 systems a year, a number of changes in hardware and "software" are required. Hardware improvements would entail design and manufacturing changes to help boost volumes of production. "Software" changes would entail new financing, new institutional arrangements, training, management, enabling policies, quality control, etc.

Presently, financing schemes exist mainly for consumers. The electricity distributor(s) do not play a role in financing even though they would enjoy significant benefits from increased use of SWHs. Two new financing schemes for the domestic sector are proposed: Scheme 1 to introduce SWHs as add-ons to existing electrical water heaters, and Scheme 2 to introduce SWHs as substitutes for electrical water heaters. In the first case, the electricity distributor(s) (e.g., KPTC) would benefit by diverting sales of additional energy to higher-tariff paying consumers. In the second case, the power producer(s) (e.g., KPCL) would benefit by avoiding new generation if the consumers also reduced their connected loads. The electricity distributor(s) (e.g., KPTC) could play a role in Scheme 1 by allowing consumers to make (purchase or lease) repayments through their monthly electricity bills. The power producer(s) (e.g., KPCL) could play a role in Scheme 2 by collaborating with organisations offering incentives (like grants) to applicants of new AEH connections on condition that they reduce their connected load after installing a SWH. Financing in both schemes would need to be arranged for consumers through SWH contractors (through soft loans from IREDA) and for manufacturers (commercial loans from Banks and also perhaps concessional finance from

IREDA). Both schemes involve [KVNM: Please delete Page Break]growth along a logistic curve over a 20-year period: a gradual increase at first, followed by a steep increase for a few years and a gradual increase to saturation.

A number of new or enhanced institutional arrangements may be needed to increase the volumes of production and sales of SWHs. These perhaps include a government agency or agencies, like the MNES and its state-level affiliate (KREDL), to set quality standards, manage subsidy programmes, hear complaints, etc. and also set up a Licensing Authority for SWH Service Contractors; a Manufacturers' Association for sharing information and setting up funding for Training Centres; special departments/sections in Financial Institutions for extending SWH lease and purchase facilities; Consultancies and SWH contractors to provide support and turnkey services for SWH system design, installation and maintenance; and a Consumer Forum to provide consumers with reports on the design and performance of different SWH models and configurations.

Training is necessary for manufacturers on design features of SWHs, methods to improve productivity and quality, performance standards, testing, financing, etc. Builders, architects and plumbers would also need training on building code requirements, siting and installation, performance standards, piping, etc., and on integrating SWHs in construction designs. Individuals wishing to apply for a service contractor's license would also need special courses on various aspects of the hardware of SWHs as well as financing, contracts, etc. Finally, informative courses could be provided for end-users on basic principles of SWHs their advantages and limitations, maintenance, etc.

Management of a large-scale implementation programme to increase SWH production and sales will have to be directed at the state-level (perhaps by KREDL) through information campaigns, policy formation, co-ordination, licensing, setting and monitoring performance standards, etc. Manufacturers will need to rely on their Association to provide directives regarding financing, infrastructure, marketing and distribution of SWHs for different applications. Finally, manufacturers should also promote the establishment of service contractors, first by developing their own Training Centres and later by using the Association's network to help establish independent Centres and programmes for training a new cadre of service contractors.

One of the most important enabling policies to increase SWH usage would be the introduction of building codes that mandate installation of SWHs in all new houses, apartment buildings, commercial and industrial buildings that intend to use hot water. Such policies have been very successful in Israel. Similar building codes could be introduced by amending the Karnataka Town and Country Planning Act for implementation by municipal governments. Other policy instruments include accelerated depreciation on SWHs, income tax rebates to end-users, mandatory use in government buildings and military facilities, hotels and tourist resorts, and requirements for carrying out feasibility studies for integrating SWHs in all new industrial facilities using steam or heated water. Since power producer(s) and electricity distributor(s) (e.g., KPTC and KPCL) will both be beneficiaries of large-scale production and marketing of SWHs, they must consider playing crucial roles in many aspects of SWH dissemination.

Finally, the implementation of a large-scale programme to promote SWHs will produce many winners -- the power producer(s) and electricity distributor(s), manufacturers of SWHs and associated machinery and equipment, consumers and society. There will be a few losers with only marginal losses. The power producer(s) (e.g., KPCL) would suffer losses only if it had excess generation capacity, because then it would have to back down existing power plants. The electricity distributor(s) (e.g., KPTC) would suffer losses if, as a result of contractual commitments with Independent Power Producers, it had to continue to pay them for "deemed off-take" even though demand for electrical energy was reduced as a result of widespread use of SWHs among other energy efficiency measures. Manufacturers of conventional water heating equipment would also be losers, but they could diversify to become manufacturers of SWHs and back-up heaters.

1 Introduction

Solar Energy

The solar energy incident on the ground in India has an average intensity of 16,700-29,200 kJ/m^2/day. Considering India's geographical area of 3.28 million km^2, the total incident solar energy represents roughly 3,000-5,000 times the country's total commercial energy consumption in 1995-96. Solar energy is, however, a dilute and intermittent energy source. It is not available at night and its intensity is considerably reduced on cloudy days. Hence, it is necessary to convert solar energy into heat, electricity or biomass, to be stored and used as and when required.

SWH Principles

A solar water heater (SWH) is a device that uses solar energy to heat water which is stored. as hot water. In its simplest form, a SWH consists of an absorber, a storage tank, insulation, piping and a transparent cover. Solar energy heats the absorber surface and a heat-transfer fluid (indirect) or water (direct) flowing through tubes attached to the absorber. If a heat-transfer fluid is used, there is a heat exchanger that then heats the water. The heated water is transferred to the insulated storage tank either with a pump (active) or without a pump through natural convection (passive). A transparent cover (glass or plastic) is placed above the absorber to reduce heat losses due to radiation and also on account of wind flowing over the absorber. The bottom and sides of the absorber are covered with insulation to reduce both types of heat losses. The absorber, cover and insulation are placed within a plastic or metal container (see Figure 1).

Figure 1. SWH Flat Plate Collector

Passive SWHs, which operate on the thermosiphon or natural convection principle, have been available since the turn of the century when solar systems were first being developed. Water that is heated in the collector has a reduced density and rises to the top of a storage tank. It is gradually replaced in the collector by colder water of higher density, which is in turn warmed by solar energy. The density difference between hot and cold water thus sets up a natural convection current for continuous circulation of water through the collector and storage tank. Until the heat gain from incoming solar energy is matched by heat losses due to radiation from the collector surface, piping and storage tank and advection by air flowing past these surfaces, the water in the storage tank will continue to get warmer as a result of the thermosiphon currents. At night, flow in the reverse direction could take place as the collector starts to radiate heat. To prevent this, either a check valve is required or the bottom of the storage tank needs to be placed at least 0.3 m above the top of the collector (see Figure 2).

Figure 2. Schematic of Passive Direct SWH

Types of SWHs

SWHs may be classified in many ways, depending on their application: domestic, commercial or industrial; the type of circulation used, passive or active; the collector design, flat-plate or concentrating; and the presence (indirect) or absence (direct) of an intermediate working fluid to heat the water. For large facilities, active, indirect systems are frequently used. These systems use pumps to circulate a heat-transfer fluid between the collector and storage tank, with a heat exchanger to transfer heat from the circulating fluid (typically an antifreeze liquid like propylene glycol, but also water) to water. These systems are useful in situations where the ambient temperature reaches or dips below freezing. If water is used as the heat-transfer fluid, there may be a drain-back facility to drain out the fluid from the collector loop whenever the pump is off, to prevent freezing. Indirect active systems may also be pressurised or non-pressurised, the latter using tanks that are at atmospheric pressure and are less expensive than pressurised metal tanks.

Direct active systems run water to be consumed directly through the collector and are about 5-10% more efficient than indirect systems since they do not require a heat exchanger. These systems are, however, more vulnerable to freezing risks unless there are special mechanisms to drain water out or recirculate heated water through the collector whenever the temperatures in the collector are close to freezing.

Passive systems offer very practical and cost-effective solutions for smaller sizes and mild climates. They do not require pumps or electronic controls, which greatly simplifies operation and maintenance. They are, however, subject to greater heat loss from the storage tank, which is usually located at or near the collector. Integrated collector systems store heated water inside the collector itself, whereas thermosiphon systems have a separate storage tank above the collector. In direct thermosiphon systems, heated water rises from the collector to the tank and is replaced by cold water in the tank that sinks to the collector. Indirect thermosiphon systems use a separate heat-transfer fluid that rises from the collector to an outer tank that surrounds the water storage tank. In all passive systems, good insulation is required to minimise heat loss at night.

In the rest of this document, the emphasis is on direct, passive SWHs, since they are most appropriate for use in developing countries (mostly located in moderate or tropical climates) and do not require the costlier controls and equipment needed for active or indirect systems.

Utility of SWHs

There are several important features of SWHs relating to their convenience of use and safety compared with any other mode of heating water. SWHs are typically installed on building rooftops that are sparingly used by occupants. This makes available interior space that would otherwise be used for conventional water heating systems, since a centralised solar water heating system eliminates the need for installing multiple geysers or immersion heaters in a household. Also, the use of SWHs in place of conventional water heating equipment eliminates the danger of electric shock or fires, which is a leading cause of fatal domestic accidents. In addition, most SWH systems have a fairly well insulated hot water tank that keeps water warm for a long time (even through the following day), a feature that is normally absent in conventional systems. Finally, conventional systems that do not operate continuously (when electricity is not available due to breakdowns or load-shedding) or are not centralised (such as bathroom geysers or immersion heaters) require advance planning and attention on the part of users, who either have to switch on the electrical heating system or, in the case of wood-fired boilers, start firing operations and monitor the supply of fuel. SWHs, on the other hand, require very little attention to obtain required quantities of hot water. Since solar heat is mild and dilute, a SWH system that is not used for weeks will also not harm either the equipment or its user.

SWHs can be used to meet the hot water needs of households, commercial establishments and industries. They are ideal for domestic use, since hot water for bathing is essential in many parts of India. In commercial establishments like hotels, hostels, canteens and hospitals, SWHs can also be used extensively, apart from bathing, for cleaning utensils, laundry, housekeeping, preheating water up to 80^0C for food preparation, etc. For chemical and fertiliser manufacturing, paint and anodising shops, textile units and dairies, there are numerous applications like cleaning, washing, pre-heating for process steam, etc.

Solar Energy Potential in India

One m^2 of flat-plate collector area would provide an average of 50 litres of hot water per day at 60^0C anywhere in India. Experience with selectively coated collectors and system optimisation suggests that this can be reduced to about 0.8 m^2 of collector area for 50 litres of hot water per day. The use of concentrator and evacuated tube technologies can raise the temperatures of the working fluid to 500^0C or more. Most parts of the country receive sunlight for up to 300 days in a year, implying that SWHs are practical for use anywhere, as long as there is a back-up system to meet demand during overcast days. The MNES has provided several incentives for increasing SWH use in domestic, commercial and industrial sectors (see Appendix A).

Industry consumes roughly 100 million tonnes of coal per year, of which 20% has been estimated to be required for thermal operations at temperatures below 200^0C (Kishore, 1993). SWHs, either with flat-plate collectors (with or without evacuated tube technology) or with concentrators, could effectively be used for these low temperature operations. This implies that SWH technology using about 128 million m^2 of collector area could potentially replace up to 20 million tonnes of coal per year, for industrial applications alone.[1]

For domestic applications, SWHs could replace geysers and other water heating equipment in most independent houses and apartments in the country. Even if SWHs were assumed to replace only new geyser installations, at the present sales of 120,000 geysers per year (Kishore, 1993), accounting for a modest average consumption of 1,000 kWh per geyser per year, SWHs would save about 120 GWh in the first year, 240 GWh in the second year, 360 GWh in the third year, and so on. If other water heating systems (immersion heaters, wood-fired boilers, etc.) and retrofits are included in the analysis, the total potential for domestic SWH use would be much greater. One way to estimate the potential in Karnataka is to examine the number of All-Electric Homes (3 kW connected load). Using an estimate of approximately 1.2 million AEH connections in 1998 and assuming that 50% of these homes would meet conditions for installing SWHs, the potential within the state for domestic SWH systems is about 0.96 million m^2 of collector area (MW & kWh saving) in 1998 (see Appendix B).

At the national level, based on housing data from the 1991 Census, it is estimated that the actual potential for SWHs in the domestic sector was 43.2 million in 1991 (corresponding to 69.12 million m^2 of collector area at 1.6 m^2 per 100 lpd system). At an annual 3% growth in demand for domestic hot water systems, this potential would have reached 85 million m^2 of collector area by 1998. Similarly, for commercial establishments, like hotels, canteens, hospitals, there is tremendous potential for SWH applications, which could be conservatively estimated to be about 50 million m^2

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[1] This is in fact a short-term goal of MNES, as expressed in its 1987 perspective plan for 2001 (reported in Kishore, 1993).

of collector area.

Overall, the total national market for SWHs represents a demand for about 263 million m^2 of collector area. Considering that the existing installed base of collector area is around 300,000 m^2, only about 0.1% of SWH potential has been realised[2]. Considering an average annual growth in demand at 3%, the total potential demand for solar thermal collector area would be about 475 million m^2 by 2018.

Growth along a logistic curve to reach 25% of this potential by 2018 would mean a gradual increase in production and sales of SWH collectors during the next few years from the present annual volumes of around 50,000 m^2 (based on MNES estimates of all-India growth in SWHs during 1995-97[3]), a very rapid increase during the subsequent 10 years or so, followed by a more gradual increase to saturation. Appendix B provides an indication of the levels of annual production volumes nation-wide that would be required in such an approach.

The actual realisation of the potential would, however, depend on the kinds of hardware and "software" improvements that are implemented at the national as well as state levels. Hardware improvements would entail design and manufacturing changes to help boost volumes of production of individual manufacturers and of the industry as a whole. "Software" changes would entail new institutional arrangements, management, enabling policies, finance, training, etc.

2 Basic Features and Operation of Passive Direct SWHs

Design

The absorber is made of sheets to the back of which are attached pipelines. The sheets have a black coating which is specially designed to absorb as much solar radiation as possible and to prevent heat losses to the surroundings when the absorber is hot. The absorber is covered with a transparent glass and insulated at the back and sides. The collector works like a miniature greenhouse trapping heat under the transparent cover. (Figure 3).

Figure 3. Basic Elements of Domestic SWH System

The pipes at the back of the sheets are filled with water. When the sun shines on the black metal absorber, it up. The collected heat is transferred to the water in the pipes. As seen in the diagram, the collector is situated below the storage tank of the SWH. An insulated pipe is connected from the bottom of the storage tank to the bottom of the collector. The storage tank contains cold water and, as the density of cold water is higher than that of warm water, cold water will flow down to the collector. The water in the absorber is heated, rises through convection and flows through the upper tubes to the top of the storage tank. This circulation will start automatically when the sun's radiation is strong and will continue as long as the water in the tank is colder than that in the absorber. Piping is designed to tap hot water from the top of the tank and to allow cold water to

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[2] Private communication from Dr A. Bandhopadhaya and Dr E.V.R. Sastry, MNES, 1997.

[3] ibid.

enter at the bottom. To maintain the functioning of the system, a constant supply of cold water must be available, for which an overhead storage tank on the roof is convenient.

Solar water heaters are made in various sizes depending upon the requirements. The area of the absorber in a domestic solar water heater of 100 litres capacity is usually around 2 $m^{2,}$ although with selective coating for the absorber, it can be brought down to 1.6 m^2. The storage tank can store 100 litres of hot water, which is often adequate for a small household to meet its hot water needs for bathing, cooking, and washing. An electrical backup can be installed to provide hot water when there is no sunshine for long periods.

The collectors used in this basic design are capable of raising water temperatures to as much as 80^oC. *High-temperature* collectors are more sophisticated, using an evacuated-tube design to increase temperatures to as much as 175^oC. These encase the absorber surface in a tubular glass evacuated for highly efficient insulation[4]. *Parabolic trough* collectors concentrate solar radiation on a receiver tube running through the focal point of parabolic mirrors and raises the temperature of the transfer fluid to 500^oC or more.

Materials and Construction

The materials that can be used for making the absorber are copper, aluminium, iron, steel, or plastic. Absorbers made of aluminium, iron and steel tend to be less reliable than those made of copper because of corrosion problems associated with the former materials. Ordinary plastic is light and inexpensive and does not corrode but degrades slowly on account of exposure to the ultra-violet radiation of the sun. The efficiency of the solar collector is not strongly dependent upon the material used for the absorber. The transparent cover used in the solar collector could be made of glass or plastic. Although transparent plastic covers are inexpensive they are not preferred because they degrade in a few years and hence must be replaced frequently unless UV-resistant grades like polycarbonate are used. Since common glass can break easily due to hail or vandalism, toughened glass is usually preferred.

The absorber surface is generally coated with black paint. Black paint absorbs most of the solar radiation incident on it. Black paint, however, is also a good emitter of infrared radiation. To minimise the infrared radiation emitted by the absorber, a selective coating can be used. An absorber with a selective coating would absorb most of incident solar radiation but allow very little radiative heat loss from the absorber. Selective coatings that have been used are nickel oxide, iron oxide, nickel sulphide, iron sulphide or cupric oxide.

The frame supporting the transparent cover and absorber is usually made of aluminium, although concrete can also be used. The tank in which hot water is stored can be made of steel or plastic. The insulation that is used in the tank and on the sides and back of the absorber is usually glass wool. The piping used to connect the flat plate collector to the storage tank is made of galvanised iron or plastic.

New materials such as anti-reflection films, photochromic materials and optical trapping surfaces

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[4] This technology is extensively used in China, which produced more than 180,000 m^2 of evacuated tube collectors in 1996 alone (see Zuqing et al., 1996).

are also under consideration for improving absorber efficiency. Monolithic silica aerogel insulation over and under the absorber surface has also been attempted to produce high efficiency, simplify construction and use low-cost materials (CEC, 1992: 17-64). A major cost reduction in SWHs is possible if UV-resistant non-degradable plastics become easily available. Then it should be possible to extrude plastic solar collectors containing transparent cover, absorber and storage tank. This integrated design will be lighter and more reliable than the present SWH.

Installation

The flat plate collector and the storage tank of a SWH are usually fabricated in a factory. Before a SWH is installed, a careful study must be made of the roof. The effect of shadows cast by adjacent buildings and trees must be considered. The piping between the storage tank and the user point has to be insulated. Hence piping must be as short as possible. The water tank that supplies cold water to the storage tank must be located at a higher elevation than the storage tank. In the case of commercial establishments and large apartment complexes, one must make sure that sufficient roof area is available (approximately 3 m^2 per 100 lpd capacity). In the case of industrial systems, the area at the ground level may also be used.

3 Development and Manufacturing -- Present SWH manufacturing method

Collector

Most SWH collectors are built using a metal tube and fin concept. Eight to twelve smaller diameter (12 to 15mm) tubes called risers of around 1.8 m long are bonded to thin metal fins (see Figure 1).

The fins have groves to receive the riser tubes and match the external diameter of the tube. Two metal pipes of around 25 mm diameter and 1 m length form the headers. The headers receive the riser tubes in a perpendicular direction and the joints are sealed by welding/brazing/soldering. This whole assembly is called the absorber. The absorber is usually selectively coated on the exposed surface to absorb maximum solar radiation. The absorber and the headers with either flange ends or threaded fittings are housed in a metal or fibreglass enclosure box. A transparent cover, usually a sheet glass, is fixed on the upper side and a pad of insulation is provided at the bottom and sides of the absorber. The collector box not only holds glass and insulation but also protects the absorber and insulation from wind and rain.

Storage Tank

Stainless steel is normally used to fabricate the inner container of the hot water storage tank. Sheets of stainless steel are cut and rolled to the required sizes and welded (butt or lap welding) to form a leak-proof tank. Threaded fittings or pipes are welded to this tank at appropriate positions to connect the collector, cold water pipe from the overhead tank, hot water pipe to the usage point, electrical backup heater element and, if required, an air vent. The tank is insulated with glass wool/mineral wool/polyurethane foam (PUF) to retain the heat in the water. The entire assembly is cladded with aluminium/GI sheets/fibreglass to protect it from wind and rain.

Stand

The support stand is usually fabricated using mild steel angles to support the insulated hot water tank at a height greater than 300 mm above the top of the collector box. In small domestic systems, this stand is also fabricated in such a way as to support the collector at an angle to receive maximum solar radiation on the absorber[5]. In a larger system, the storage tank and collector support tanks are fabricated separately. The stand is either painted or galvanised to protect it from rusting.

Assembly

The storage water tank and collectors are installed at the site separately. In areas that are north of the Equator, the collector must face south with the storage tank to its north. The tank and the collector(s) are joined at the site by using GI plumbing pipes and the entire pipe connection is insulated with glass wool/mineral wool/PUF. A protective cladding is provided for this insulation with an aluminium or GI sheet. The cold water connection is provided from the overhead tank with a minimum water head of 300 mm above the top of the insulated water tank. Hot water lines are drawn to the end-points of use and are insulated and cladded.

Process involved in the current system of manufacturing

Since the demand is low, the volume of production at present is not more than about 100 collectors per month in any individual manufacturer's facility. Manufacturing of SWHs involves fabrication of each of the following separately:

1. Absorber
2. Collected box
3. Storage tank (insulated)
4. Support stand
5. Interconnection of pipes

Standard tubes of various sizes are taken from the market and are cut to required sizes. Similarly, sheets or rolls of sheets are cut and processed to form fins, collector box, tank and cladding. The process is highly labour-intensive and the wastage in material and labour is very high. Maintaining interchangeability of components is also a difficult job and the tolerances allowed are very wide. This brings down the product quality and adds to the cost. Installation is presently carried out for each individual model/brand by a factory-trained mechanic. Too many jigs and fixtures are required and even these are often not fabricated accurately. Hence, modular assembly cannot be adopted. All this restricts the growth of production in the manufacturing facility. .

Automated, high-volume production of SWHs is possible through new design concepts for the collector, tank and piping and the use of advanced materials and/or modular assembly without the need for manual welding and fitting. Appendix C shows a design that would use a more efficient manufacturing process involving metal pressing and adhesive bonding to fabricate the collector

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[5] This is usually placed at an angle from the horizontal that roughly equals the latitude of the site. Latitude plus 15 degrees maximizes heat collection in winter, whereas latitude minus 15 degrees maximizes heat collection in the summer.

assembly. See also Appendix K, which describes one manufacturer's approach to increasing productivity by using a selective coating oxide film and seam and interrupted seam welding of stainless steel sheets for the absorber.

4 Installation

Siting and installation

General site requirements include the following (see Appendix D for a draft user's manual):

- Shadow free surface, preferably flat roof of 3 m^2 for every 100 lpd.
- Roof should be strong enough to carry 200 kg of static load for every 100 lpd and half of this as wind load.
- Piped water at a minimum head of 2 m. Total hardness of water ($CaCO_3$) should not exceed 200 ppm to avoid excessive scaling in the absorber tubes. Water softeners have to be installed if the hardness is above 200 ppm.
- To reduce heat losses, the SWH site should be as close as possible to the room where most of the hot water is used, for example, a bathroom directly below the roof.
- Electricity supply to connect the electrical back-up heater.
- Preferably away from the reach of children.

System requirements include the following:

- Support stand must be designed to support tank and collector firmly on the roof at the highest wind speeds in that area.
- Provision to adjust the inclination of the collector to receive maximum solar radiation.
- System installation to be carried out without, or with minimal, civil works.
- Suitable arrangement to be provided for maintenance of the system.
- Drain plug at the bottom of the collector to flush the system and an air vent to release air lock.
- Proper supports for the pipelines to be provided, preferably pipelines to be drawn along roof and walls.
- Steps must be taken to keep the transparent cover clean and to keep the insulation dry in the flat plate collector and in the storage tank.

Considerations for Domestic SWH installation

Domestic SWHs can be installed in various types of houses..

New house under construction
The ideal situation would be to include incorporation of a SWH in the house construction plan. The net cost of installation of a SWH system is then limited to the cost of the SWH system alone plus the marginal plumbing and electrification costs (compared to that required for a geyser).

The guidelines to be considered in the house plan for a SWH of 100 lpd capacity are

- Provide shadow-free roof area (approximately 3.5 m^2) close to the room where most of the hot water will be used.
- Locate the cold water tank at a height equal to or more than 2 m directly above the collector.
- Run a 15 mm insulated metal pipe (either embedded in the wall or open on the wall) from the SWH site on the roof to each of the rooms with hot water usage points.
- Run a power line to take a 2 kW load to the SWH site with a conveniently located control switch (for the electrical backup heater).

Existing houses with overhead cold water tank with 2 m or greater water head at the roof level In this case, the total system cost is the cost of the SWH plus the plumbing costs of drawing a cold water pipe from the overhead tank to the SWH and an insulated hot water pipe line from the SWH to the hot water usage room(s) plus the cost of providing electrical connection to the backup heater in the SWH. For a normal one- or two-storied house, this could be between Rs.500 to Rs.1,500 over and above the cost of the SWH.

Existing houses with overhead cold water tank just on the roof
Here, the total system cost is the cost in the previous case plus the cost of either raising the level of the existing cold water tank or of installing a special HDPE tank of 150 to 200 litres with a minimum head of 2m. The incoming cold water line has to be diverted to the additional tank to which the SWH must be connected.

Existing houses without overhead cold water tank
This is generally the costliest case for installing a SWH system. The total cost is the cost of the SWH, the plumbing cost of drawing hot water pipes to usage points, the cost of an overhead tank and support structure (minimum 2 m head), the cost of drawing a cold water pipe from the overhead tank to the storage tank of the SWH and, if the water supply does not have enough head to reach the rooftop, the cost of a water pump and accessories.

Since solar energy is not available on cloudy or rainy days, a built-in electric heater is provided in many SWHs. In a city like Bangalore, which has on an average about 60 rainy days a year (see Appendix E), the electrical energy used by the back-up electric heater will be around 210 units/year for a 100 lpd system.

SWHs can also be installed in apartments and group housing (see Appendix F).

Load matching

Much of the success of a SWH system depends on the initial feasibility study. A number of items must be addressed during the feasibility study of a SWH project, whether it is for domestic, commercial or industrial use. These include answering the following questions:

- Is the load being considered a good application for a solar heating system?
- Can the solar heating system be easily integrated with an existing energy system?
- Is there sufficient space available for the solar collector, heat exchanger (if necessary), thermal storage and other system components?

- If the collectors are to be roof-mounted, is the existing roof structure adequate to carry the collectors without significant modifications?
- Can piping be installed in such a way that required slopes are available, particularly in the case of thermosiphon systems?

A No answer to any of the above questions may indicate that a solar heating system is not appropriate for the heating load being addressed.
One of the areas often neglected in the initial feasibility phase of a SWH project is the accurate assessment of the total load (hot water requirement) and load profiles. Many systems have been carefully designed, but based on totally erroneous load profile estimates. Often, because details of load profiles were not necessary to the operation of the existing energy system, the system owner or operator has very little knowledge of the details of these load profiles. Experience has shown, in a costly manner, that if good load profile data is not available, it must be developed before system design.

Good records of past hot water use will be very useful in planning an effective system. In general, for domestic use, 100 litres per day per household with 4 members or less is considered to be adequate. For industrial use, the changes anticipated in the plant's operation must also be assessed at the time of the feasibility study. As an example, the addition of heat recovery equipment in an existing plant will seriously affect the operation of a solar heating system. In some cases it will preclude the use of solar heating and in others radically change the required design.

In order to match the solar system size to the load required, we should consider load requirements on a daily basis and on a seasonal basis. When matching the load to available solar energy, the following must also be considered:

- Time at which load is met
- Amount of collector area
- Storage

It is important if possible to control the time of the day when the heating load arises. If such control is possible, it would possibly limit or eliminate storage and make the solar system much more cost effective.

Example of load matching to optimise system design

Consider a canteen with a daily hot water demand as shown in Table 1 below (see also Figure 4).

Use	Canteen
Pattern	One shift
Hot water demand	For cooking and dish-washing
Time of use	6 am to 6 pm

Table 1. Example of Load Matching in a Canteen

Time	*Water*	*Cumulative*	*Hot water*	*Cumulative*	*Storage*

	required (litres)	*water required*	*available*	*water available*	*required (litres)*
6-7 am	200	200	0	0	200
7-8 am	100	300	0	0	300
8-9 am	50	350	0	0	350
9-10 am	0	350	100	100	350
10-11 am	250	600	150	250	500
11am-12 noon	75	675	250	500	425
12 noon-1pm	25	700	250	750	200
1-2 pm	50	750	150	900	0
2-3 pm	0	750	100	1,000	-150
3-4 pm	150	900	0	1,000	-100
4-5 pm	0	900	0	1,000	-100
5-6 pm	100	1,000	0		0
Total	1,000		1,000		

Figure 4. Example of load matching for a canteen

Note that an initial assessment of the demand might indicate that the system should be designed to have a 1,000 lpd collector with a storage capacity of 1,000 litres. However, as shown in Table 1, it would be optimum to design a system with a storage tank of 500 litres (to cover the following day's demand before 11 am). Only 500 litres would be used as and when required (from the previous day's storage) and the remaining 500 litres would be available in the course of the day's insolation. This implies that the built-in compensation for heat losses due to storage of an additional 500 litres could be reduced in the collector. Assuming that 15% of heat loss of excess 500 litres can be avoided overnight, the collector capacity required will also reduce as follows:

1000 -15% of 500 = 925 lpd.

The new design (see Table 2) optimised to match load will have several advantages over a conventional 1,000 lpd system with a 1,000 litre storage tank. These will include a lower cost, a lower load on the roof, and less roof area required.

Table 2. Conventional and optimised design after load matching

	Conventional Design	*Optimised Design*
Capacity	1000 lpd	925 lpd
Temperature	60°C	60°C
Collector Area	16 m^2 (1000 litres X 1.6 m^2/litre)	14.8 m^2 (925 litres X 1.6

		m^2/litre)
Storage Tank	1,000 litres	500 litres
Roof Area Required	21.5 m^2 (1.25X16 m^2 + tank area)	19.5 m^2 (1.25X14.8 m^2 + tank area)
Highest Load on Roof	1,500 kg (1.5 kg/litre X 1,000 litres)	750 kg (1.5 kg/litre X 500 litres)
System Cost	Rs.106,000 (6,000 Rs./m^2 X collector area + 10 Rs./litre X tank volume)	Rs.93,800 (6,000 Rs./m^2 X collector area + 10 Rs./litre X tank volume)

Load matching for domestic SWHs

Domestic SWHs are typically not custom-built because of the larger volumes of production and smaller sizes required compared to commercial and industrial systems. Nevertheless, it is useful to examine whether the standard 100 lpd collector with 100 litre storage capacity can meet typical household loads.

In domestic situations, SWHs are used mainly for bathing, cooking and dishwashing. Although individual needs vary, it is reasonable to assume that the average daily hot water need per capita for bathing is 30 litres at 38°C. Thus, a family of four would require 120 litres of water at 38°C. If all the members bathe in the morning before solar insolation has a chance to heat the water in the collector, sufficient water must be available in the storage tank from the previous day's heating.

The SWH provides hot water at about 60°C in the evening, which is available for use the following day at an average temperature of 55°C. Using simple energy conservation principles, the volume, Q, of hot water at 55°C to meet the demand of 120 litres at 38°C can be computed as follows, assuming that mixing takes place with cold water at 22°C:

$$38 \text{ x } 120 = 55Q + 22(120-Q)$$
$$Q = 58 \text{ litres}$$

If it is further assumed that about 15 litres of water at 55°C would be used for cooking and dishwashing, a SWH with 73 lpd capacity should be sufficient to meet the hot water needs of a family of four. Thus, the standard 100 lpd SWH with 100 litres of storage is more than adequate to meet typical domestic requirements for hot water.

5 Economics of solar water heaters

A SWH has financial benefits for the end-user in addition to being advantageous to the power producer(s) and electricity distributor(s). It is also environment friendly and provides social benefits by saving conventional fuels such as firewood, coal, fuel oil, etc., for uses other than water heating. Also, there are the added advantages of safety and the convenience of easy operation, which may not be adequately reflected in the conventional economic calculations.

For the power producer(s) (e.g., Karnataka Power Corporation Limited), there is the economic benefit of avoiding investments in new generation capacity. This benefit is derived when applicants for electrical connections choose SWHs instead of geysers and other electrical water heating systems provided that these customers undertake to reduce their connected loads. Since electrical water heating constitutes the single largest load (up to about 2 kW) for a domestic household, a consumer choosing a SWH instead of a geyser could forego a standard 3 kW (AEH) connected load and reduce it by say 2 kW ***without suffering any loss in energy services***[6]. Thus, a consumer who opts for such a connected-load-reduction scheme would benefit the power producer by reducing the need for generating power by an amount equal to the reduction in connected load corrected by the diversity factor for that category of loads (typically about 0.4 for LT).

If SWHs are installed as add-ons to existing electrical water heating equipment, additional revenues could be earnedby the distributor(s) (e.g., Karnataka Power Transmission Corporation), if the electrical energy thereby saved is sold to higher tariff paying consumers in the commercial or industrial sectors.

The detailed computation of the life-cycle costs of a domestic SWH is presented in Appendix G. Appendix H shows some actual case studies of savings with the use of SWHs in domestic, commercial and industrial settings.

The assumptions used in Appendix G are as follows (all prices in 1999 Rs.):

- A SWH of 100 lpd costs around Rs.11,400 (= Rs.9,900 + Rs.1,500 for piping and accessories).
- A SWH can be expected to be used without the back-up heater for 300 days in the year.
- An existing or new geyser with 2 kW electrical load would be used on average for 1.75 hours a day.
- A new geyser costs Rs.3,500.
- The annual O&M for a geyser and SWH is 1% of capital cost.
- The back-up heater in the SWH, used for 1.75 hours a day for the remaining 65 days in the year, would also have 2 kW electrical load.
- The Domestic tariff is Rs.2.10/kWh.
- The Commercial tariff is Rs.4.80/kWh.[7]

Two cases are considered: Case I in which the domestic consumer has an existing electrical water heating system installed and Case II in which the consumer makes a choice between buying a new geyser and a SWH. In both cases, the annual energy savings from using the SWH will be 1,050 kWh, the life-cycle cost of the energy saved by the SWH will be Rs.1.56/kWh (at the point of end-use) and Rs.1.27/kWh (at the point of generation)

Case I. Consumers with existing electrical water heating systems

- By buying a SWH, the consumer has a benefit-cost ratio of about 1.34 and a simple payback period of 5.45 years.
- The power producer (e.g., KPCL) will not enjoy any benefits for this case because

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[6] This assumes that the back-up electrical heater in the SWH is of the low-wattage type (about 300W).

[7] Tariffs in Karnataka in December 1997, assuming second lowest slabs for domestic consumers (between 201 and 300 kWh/month) and commercial consumers (over 51 kWh/month).

the capacity to meet the extra connected load of the electrical water heater has already been installed.

- The distributor (e.g., KPTC) will be able to sell the saved electrical energy, i.e., the electrical energy that would otherwise have been used by the domestic consumer for electrical water heating, to a higher tariff consumer. This amounts to 1,050 kWh/year/SWH x (Rs.4.80/kWh – Rs.2.10/kWh) = Rs.2,835/SWH/year.

Case II. Consumers without existing electrical water heating systems

- The consumer choosing to install a SWH instead of a geyser will enjoy a benefit-cost ratio of about 1.65 and a payback period of 3.58 years.
- The power producer (e.g., KPCL) will be able to avoid investments on new generation capacity if new applicants for AEH (3 kW) connections (a) installed SWHs instead of geysers and (b) reduced the connected load for these connections to 1 kW since the main need for a higher connected load would have been satisfied. In this case, the SWHs would have to be equipped with low-wattage (300 W) backup heaters. The power producer (e.g., KPCL) would enjoy savings of Rs.85,300 in avoided thermal generation investment (capital + fuel + O&M) for every 2 kW reduction in connected load because of the installation of a SWH (assuming diversity factor of 0.4).

Thus, the power producer (e.g., KPCL) gains when new consumers opt for SWHs instead of geysers. There is also a gain when existing and new industrial and commercial consumers opt for SWHs instead of using (existing or new) electrical water heating equipment because they could lower their connected loads accordingly. Therefore, the power producer (e.g., KPCL) would benefit from promoting SWH purchases among new domestic consumers and industrial/commercial consumers.[8]

Similarly, since the electricity distributor (e.g., KPTC) gains when their domestic consumers decide to install SWHs in addition to their geysers and use solar energy for water heating, it should play a key role in financing schemes that promote SWHs in AEH homes with existing geysers. Details of such schemes are provided in the next chapter.

Society would enjoy several positive benefits from increased use of SWHs. These include a reduced need for (a) fossil fuels for electrical generation and (b) fuels like firewood, coal, furnace oil, etc., that are used in domestic, commercial and industrial boilers and, consequently, reduced harm to the environment. There are no net costs to society due to SWHs replacing conventional types of water heating equipment.

Future costing

The price of SWHs used in the economic analysis reflects the costs of production and marketing at *current* volumes of sales. As previously mentioned, these volumes are a small fraction of the actual potential for SWH use in the country. There is considerable scope for improving the productivity of existing manufacturing processes, by optimising material use, applying less labour-intensive designs and increasing the scale of production. These

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[8] If the mission of the power producer(s) is to meet the gap between demand and supply, it is as important to reduce demand as to increase supply. Whether the choice is between decreasing demand and increasing supply should depend on which is cheaper.

improvements would considerably reduce the costs of production and ultimately the selling price of SWHs. In order to analyse the economics of SWHs in a mature market, therefore, it is important to estimate the future costs of SWHs based on these considerations.

The future costs of SWHs can be estimated using three different approaches. In the first approach, it is assumed that increasing industry-wide rates of production would yield cost-reductions through organisational learning as well as economies of scale (cf. Williams and Terzian, 1993). For SWHs, however, because of the significant capital subsidy (22-75%) provided by MNES until 1992, price trends are not true indicators of the effects of economies of scale and organisational learning. Moreover, in subsequent years, MNES stopped collecting production and sales data and no other reliable sources of such information exist. In these circumstances, this approach is perhaps not suitable for estimating future costs of SWHs.

The second is a bottom-up approach (described in Appendix I) that uses value-engineering to estimate the future production costs of SWHs. Here, the conventional design of SWHs is assumed coupled to optimum material use. The collector area has been minimised to 1.6 m^2 for a 100 lpd system and the insulated storage tank is expected to be out-sourced from a manufacturer using barrel technology. The production cost is estimated to be Rs.8,029 (in 1997 Rs.) and, at a reasonable 20% profit, the selling price should be Rs.9,635. This scenario would therefore be appropriate for the labour-intensive approach used by existing manufacturers, with optimised material use and out-sourced storage tanks.

The third approach assumes that an integrated design is used to facilitate high-volume capital-intensive manufacturing. Use would be made of techniques like barrel technology for storage tanks and sheet pressing and bonding for collectors rather than manual fabrication of these components. Design concepts based on these and other high-productivity techniques are described in Appendix C and Appendix K. Since the market for SWHs is very large nation-wide (see Appendix B), it is reasonable to expect manufacturers to shift to revamped production systems to boost their volumes of production if an assured market is available. In Chapter 6, schemes are proposed for Karnataka whereby annual sales of more than 100,000 domestic SWHs alone may be achieved by manufacturers after about 2006. Under these circumstances, at least a few individual manufacturers in Karnataka may need to bring their annual production volumes up to the range of 10,000-20,000, from existing rates of under 1,000 systems a year.[9]

The production costs based on material requirements provided in Appendix C are estimated in Appendix J. The selling price of SWHs using this approach works out to be Rs.7,500 (in 1997 Rs.) in the first year of production. The internal rate of return works out to be about 24.6% post-tax.

In both cases, it appears that sale prices of SWHs under Rs.10,000 per unit are achievable.

Economic analyses of SWHs assuming future prices at Rs.9,635 and Rs.7,500 (both in 1997 Rs.) are also included in Appendix G. It may be noted that benefit-cost ratio and payback periods for the consumer improve considerably. At a future price of Rs.9,635 for the SWH, the life cycle cost at the point of generation is Rs.1.07/kWh; at a price of Rs.7,500, it is Rs.0.84/kWh. This should be compared against the life cycle cost of generating energy from a new thermal station in Karnataka at about Rs.3.00/kWh.[10]

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[9] Based on telephone survey of about 10 leading manufacturers in Banga lore in 1997.

[10] At 1997 Rs., based on analysis of Raichur 5&6, inflated to account for T&D losses, IEI, 1998.

6 Financing

In order to promote the production and sales of SWHs, financing is required for manufacturers, training centres and consumers (domestic, commercial and industrial). Presently, financing schemes exist mainly for manufacturers and consumers. Currently, neither the power producer nor distributor plays a role in financing, even though they would enjoy the greatest benefits from increased use of SWHs (see Appendix L).

As noted in Chapter 5, the electricity distributors (e.g., KPTC) would benefit from increased SWH sales as add-ons to existing electrical water heaters (EWHs) in the domestic sector. This benefit can be derived from the diversion of sales of saved electrical energy to higher tariff paying consumers, say, in the commercial sector. Similarly, the power producer (e.g., KPCL) would benefit from increased SWH sales to consumers who undertake to reduce their connected load by using SWHs instead of EWHs. Thus, the power producer (e.g., KPCL) could avoid investing in new generation to the extent of the reduction in connected load corrected by the diversity factor.

Figure 5 is a schematic of a proposed financing scheme to introduce SWHs as add-ons to existing Electrical Water Heaters (Scheme 1). Table 3 indicates the trend in the projected number of domestic SWHs sold each year if the growth in SWHs as add-ons to existing EWHs follows a logistic curve to reach about 50% of the 1998 AEH connections by the year 2018. It may be noted that if the existing differential in electricity tariffs between the AEH domestic and commercial sectors persists and the distributor (KPTC) is able to divert saved electricity due to SWH use from domestic to commercial consumers, KPTC can realise net annual revenues (less nominal administrative costs of Rs.100/AEH consumer/year) increasing from Rs.16 million in 1998, rising to Rs.1,640 million in of 2018 (see Figure 6). The present value of the revenue stream over this period is Rs.4,471 million (in 1997 Rs.).

Figure 7 is a schematic of a proposed financing scheme to introduce SWHs instead of new EWHs, with penalties/incentives to reduce the connected load of the consumers (Scheme 2). Table 4 indicates the trend in the projected number of new domestic SWHs sold each year to applicants for new AEH connections in this scheme. The trend follows a logistic curve such that up to 50% of new AEH applicants in 2018 could be induced to install SWHs and lower their connected load by 2 kW. Under this scheme, the number of AEH connections in Karnataka in 2018 would be about 3.2 million, or about 30% less than the expected number of about 4.65 million AEH connections, under a modest annual growth rate of 7% (see Figure 8). Thus, the power producer (e.g., KPCL) could avoid investments in about 821 MW of new generation over the next two decades. If it also offered a 25% rebate on the price of a SWH to consumers who participate this scheme, the system would still enjoy savings of nearly Rs.16 billion in present value terms (this assumes a life-cycle cost of new thermal generation capacity of Rs.106,625/kW in 1997 Rs.).

The discussion that follows describes the financing mechanisms for manufacturers and consumers in both these schemes.

Table 3: Trend in projected SWH sales in Scheme 1 (KPTC).

Figure 5. Financing scheme to introduce SWHs as add-ons to existing Electrical Water Heaters (Scheme 1 involving the distributor).

Figure 6. Projected annual net revenues to the distributor from Scheme 1.

Figure 7. Financing scheme to introduce SWHs instead of Electrical Water Heaters (Scheme 2 involving the power producer).

Figure 8. AEH Connections in Karnataka with and without Scheme 2.

Table 4: Trend in projected SWH sales in Scheme 2 (the power producer)

Manufacturers

Manufacturers would require financing mainly for new machinery to boost volumes of production. They may also need financing for marketing campaigns to boost sales, although this would depend on the pricing strategies of individual manufacturers. As indicated in Appendix J, a single manufacturing plant producing about 20,000 units per year would require investments in the order of Rs.4 crores. Since the internal rate of return is quite high (24.6% post-tax) even if the SWHs are priced at Rs.7,500, even a low debt-equity ratio would be attractive for promoters. Assuming a debt-equity ratio of 7:3 (compared to the typical ratio of about 3:1 in many private power plant projects), debt finance of the order of Rs.30.45 millions needs to be arranged for a single plant.

If both schemes were implemented, manufacturers would have an assured market of over 50,000 domestic systems beyond about 2004, rising to about 100,000 systems by 2006 and remaining roughly at that level for at least the following decade (see Figure 9).

Figure 9. Projected assured Annual Sales of SWHs due to Schemes 1 and 2.

Manufacturers would require financing from industrial banks like the Industrial Development Bank of India (IDBI) to enhance their manufacturing capability, leading to improved productivity and eventually to lowered prices. The industrial bank(s) may offer financing at commercial rates but with an interest-free 2-year moratorium on loan repayment. In addition, given the high avoided cost of new thermal generation for the power producer(s) (Rs.106,625/kW) in Scheme 2, where SWHs use can lead to reduced connected loads, equity participation from the power producer may be considered. Note that the power producer(s) would enjoy a 24.6% post-tax return on its equity by investing in high-volume SWH manufacturing (Appendix J), which is much higher than its average annual return of about 2%[11]. In addition, equity participation would give the power producer a direct stake in the promotion of SWH sales to applicants for new AEH connections, especially if it is coupled with incentives to reduce their connected loads. Soft loans may also be sought from IREDA for capital finance, which presently gives attractive terms for manufacturers, other intermediaries (like SWH contractors) and end-users for marketing SWHs (see Appendix L).

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[11] Approximate return of 2% on KPCL's existing investments is based on the consideration that it invested Rs.17,450 million over two decades between 1972-1992 and earned Rs.24,650 million during this period (KPCL, 1993).

SWH Contractors

SWH contractors are intermediaries that could be exclusive leasing and service companies for SWHs, dealerships for SWH manufacturers, or new Energy Service Companies that take on both of these functions. They could avail soft loans (2.5%-8.3% interest for up to 75% of project cost) from IREDA and pass on these benefits to consumers for purchase of SWHs under both schemes. In addition, in Scheme 2, they could make arrangements with the distributor to recover loan repayments through the monthly electricity bills, so that the consumer would have the convenience of making a single payment. In particular, the loan repayments would typically be lower than the monthly savings in electricity bills due to the SWH, so that the consumer would incur no net increase in expenditure, apart from a possible down payment, in case of outright purchase.

Leasing companies could directly offer packaged services to domestic consumers of installation, periodic maintenance, and closed-end sale after set terms of 5, 7 or 10 years. Lease terms will depend upon rates of depreciation of equipment, installation and maintenance costs, and reasonable returns to the leasing and service company.

Domestic Consumers

Financing for domestic consumers could cover outright purchase as well as term-lease. The former has been the favoured method for most types of consumer durables in India, but the latter has been gaining some ground. Leasing has the advantages of allowing faster negotiation with financial institutions than loans, greater flexibility to the lessee, depreciation benefits to be passed to institutional lessors, and the possibility of maintenance and specialised services.

In Scheme 1, the consumer would have the benefit of easy billing through an arrangement between the distributor (e.g., KPTC) and the SWH contractor. In Scheme 2, the power producer(s) (e.g., KPCL) may offer a special incentive in terms of a direct subsidy to consumers who reduce their connected load.

Industrial and Commercial Consumers

The financing options that would benefit industrial and commercial SWH consumers could include:

- Direct purchase from manufacturers with bank loans
- Term lease with leasing companies
- Scheme 2 finance similar to domestic SWH case (applicable when connected loads can be reduced -- see Figure 10)

Figure 10. Scheme 2-type financing for industrial and commercial consumers

In addition, industrial and commercial consumers that decide to install SWHs to offset electrical heating could bank their saved energy with the electricity distributor (e.g., KPTC), just as in the case of industries with captive generation sets in Karnataka. This would provide them with a net financial advantage that would equal the difference between the cost of saved energy due to the SWH and the energy cost of equivalent grid power less any banking charges (currently set at 2% for Karnataka).

Training Centres

Training at different levels is essential for manufacturers, builders/architects and service contractors (see section on Training). Since existing manufacturers would have a clear interest in maintaining or improving their market share as sales of SWH increase, it would be appropriate for a Manufacturers Association (see section on Institutional Arrangements) to contribute funds to the establishment of such training centres. Additional financing could come from the government (MNES), utilities and their lending sources and development aid sources that are specifically meant for training in renewable energy systems.

7 Institutional Arrangements

Large-scale dissemination of SWHs requires the establishment of new institutional arrangements or the improvement of existing arrangements (see Figure 11).

Figure 11. Institutional arrangements for large-scale dissemination of SWHs

These include

1. *An Agency or Agencies* to set quality/performance standards, facilitate training, introduce subsidies, provide information to the public, hear complaints, etc. MNES, for instance, could play this role at the Central Government level. At the state-level, the Karnataka Renewable Energy Development Limited (KREDL) could provide staff-support to manage programmes under a Task Force headed by a senior government officer. KREDL could also act as a *Service Contractors Licensing Authority* with guidance from manufacturers and independent experts to develop a licensing programme for service contractors for installation and maintenance of SWHs.

2. *A Manufacturers Association* to provide internal training and audit facilities for adhering to quality/performance standards and share R&D information. Currently, no such association exists, but with more than 100 SWH manufacturers around the country at present, the formation of such a body may not be difficult.

3. *Financial Institutions* to arrange finance for domestic, commercial and industrial consumers. In addition to Canara Bank which has a financing scheme for domestic consumers, housing finance organisations such as HDFC, CanFinance and LIC Housing Finance could be perhaps be persuaded to extend special credit facilities provided by IREDA to domestic consumers of SWHs. For industrial and commercial applications, institutions such as IDBI, ICICI and Tata Finance could be persuaded to develop special wings for solar thermal finance, perhaps as extensions to their existing renewable energy and energy efficiency finance programmes.

4. *Training Centres* for providing training to (a) small-scale manufacturers, (b) architects/builders/plumbers, and (c) service contractors. [See separate section on Training.]

5. *Consultancy organisations* to help large consumers to carry out detailed project reports (DPRs) for designing and installing custom-built SWH systems. Presently,

manufacturers themselves tend to carry out this function (for instance, Tata BP Solar). Energy consultants could be persuaded and helped to develop special expertise for this purpose so as to provide industrial and commercial consumers independent means to determine system requirements.

6. *Autonomous Consumer Forum(s)* that would provide unbiased reports of in-use performance of different SWH designs and systems. The Manufacturers' Association could contribute to an autonomous fund to set up an independent testing facility and to manage the administrative expenses of independent body of experts, which publishes periodic reports on the quality and performance of existing SWH systems. This body could also provide support to MNES to review and update their performance standards.

7. *The electricity distributor (e.g., KPTC) and the power producer(s) (e.g., KPCL)* may consider collaborating with KREDL to introduce their respective schemes for dissemination of SWHs. The next section describes the special roles of the generation and distributors and the power producer in this regard.

Roles of the power producer(s) and electricity distributors

As mentioned in previous chapters, both power producers and electricity distributors can benefit from large-scale dissemination of SWHs. Since electricity distributors are responsible for providing sanctions to connected loads, and power producers would benefit most from Scheme 2 (see Chapter 6), where the installation of SWHs instead of EWHs leads to the reduction in connected loads, the two categories of organisations may consider efforts to introduce incentives and penalties to promote SWH use. These measures must be taken in consultation with KREDL under the direction of the Task Force.

Incentives

Electricity distributors (e.g., KPTC) could introduce a bill adjustment scheme for consumers buying SWHs by agreeing to add monthly instalments for lease or purchase of SWHs to the electricity bills of identified customers and then passing on these proceeds to SWH contractors. Although this scheme would be meant primarily for consumers buying SWHs as add-ons to existing EWHs, KPTC could also offer this service to consumers buying SWHs instead of EWHs.

For larger consumers, the electricity distributor(s) (e.g., KPTC) could offer wheeling and banking arrangements on the saved electrical energy through installation of SWHs. These arrangements could be provided for a limited period of time, say, 2 years, to avoid misuse of the facility.

The power producer(s) (e.g., KPCL) could offer a 25% grant to new applicants of AEH connections who are willing to forego 2 kW of connected load. This could be started on an experimental basis to cover a few applicants initially, on the basis of household income, and gradually follow a logistic curve to cover 50% of all new AEH applicants by the year 2018 (as shown in Table 4).

Penalties

In consultation with KREDL, the electricity distributor (e.g., KPTC) could introduce measures requiring from new apartment and commercial buildings seeking electricity sanctions, a feasibility report for SWH installation. In addition, applicants for new AEH connections should be informed of KPCL incentives to offer grants, with restrictions, to new AEH applicants, provided they agree to reduce their connected load by 2 kW.

Finance

As described earlier, the power producer(s) (e.g., KPCL) and electricity distributors (e.g., KPTC) could play two separate roles for financing SWH implementation. The power producer(s) (e.g., KPCL) could serve as equity partners with certain large manufacturers, by investing in machinery and equipment to increase the volumes of production of SWHs. The investments in machinery will be substantially less (on a per kW of power saved) than the utility's investment in new generation capacity, as borne out in the economic analysis carried out earlier. Apart from the help rendered in terms of funds, equity participation by the power producer(s) will also reduce the perceived risk to the manufacturers.

The electricity distributor(s) (e.g., KPTC) could directly help finance purchase of SWHs through SWH contractors acting as intermediaries by offering a scheme to domestic consumers whereby SWH systems would be installed in their homes by SWH contractors, and the lease or purchase amounts would be recovered in the monthly electricity bills.

8 Training

Training is required for manufacturers to improve productivity and quality to meet performance standards, for architects and builders to integrate SWHs into their construction plans, for plumbers and fitters to install insulated water lines to support SWHs in domestic and commercial settings, and for service contractors to provide turnkey services. Some training is also required for end-users on the care of their SWH systems.

All these types of training can be carried out through Training Centres like the Industrial Training Institute (ITI) or by other Centres, initially set up by MNES/KREDL and later by private parties, including the Manufacturers' Association. Accreditation procedures and the curricula for the Centres could be established by MNES. Some aspects of SWH training could be featured in the curricula of professional colleges and technical training schools, for instance, for architects, builders and plumbers.

Manufacturers

The curriculum for a training programme for manufacturers would include broadly the basic design features of SWHs and the optimisation of materials and fabrication procedures to maximise productivity and quality. In addition, training should be provided on performance standards, testing facilities, financing, market potential and marketing issues including providing arrangements for service contracts. Courses could be designed to last up to one week. Trainers would include consultants, engineers in high-volume SWH production plants, inventors, etc.

Builders/Architects

Short training courses (for instance, 2-day workshops) are needed for builders and architects to provide information on SWHs and also on the importance of integrating SWHs in their construction plans. Training is also needed on performance standards of SWHs, building code requirements, siting and installation, maintenance of SWHs, etc. Trainers could include solar thermal designers, consultants and NGOs. Preliminary training on SWHs could be included in the curricula of architectural schools and civil engineering programmes.

In addition, short training workshops could be held for plumbers to inform them of the special insulation requirements for drawing hot water lines and installation methods to minimise pipe joints and avoid wastage. Training could be carried out by certified persons with field technical experience.

Service Contractors

Certificate programmes lasting around four weeks should be established for persons interested in preparing to apply for a SWH service contractor's license. Curricula would include basic solar thermal principles, materials, standard specifications, capacity requirements, siting and installation, insulation, plumbing, issues related to corrosion, hard water deposits, cleaning, etc. In addition, training is also required on financing, contracts, grievance procedures, etc. Training may also be conducted at different levels, for instance, beginners, advanced, refresher, etc.

Consumers

Although the SWH is a maintenance-free and rugged product, it is highly sensitive to factors like usage pattern, varying weather, site specificity, etc. It is therefore important to provide information on SWHs in simple language targeted at end-users. In this regard, IEI prepared a 16-page pamphlet on Solar Water Heaters in 1995 (IEI, 1995), that describes the technology in simple terms, explains their advantages and economics, and outlines the procedures for their installation in homes, industrial establishments and institutions such as hospitals, milk dairies, canteens, etc. Around 7,500 copies were printed and distributed free among potential end-users in the state of Karnataka in India through Mysore Sales International Limited (MSIL) as well as a few manufacturers of SWH.

Additional information could also be produced in this form, containing basic solar thermal principles, required capacity system for the family size (load), minimum pre-installation site requirements, limitations of the system, maintenance, options available in the market, financial schemes and incentives, performance monitoring, service network available, etc. Finally, comprehensive instruction manuals containing trouble-shooting and servicing procedures must be provided by manufacturers at the time of SWH installation.

9 Management

State level

Management of various aspects of large-scale SWH implementation will demand involvement at the state level. Since SWHs are likely to be disseminated first in cities and towns, the Urban Development Department, Housing Board, Town Planning Department, and the state's nodal agency for Renewable Energy Development will have to co-ordinate their efforts to manage large-scale SWH implementation. Government should constitute a Task Force headed by an appropriate person and backed by staff support by KREDL to carry out the following tasks:

- Information and Publicity
- Policy Formation and Implementation
- Co-ordination and Liaison with other Institutions
- Licensing of SWH Service Contractors
- License Enforcement, Renewal, Etc.
- Monitoring of Performance Standards and Quality Control
- Setting Legal Grievance Hearing Procedures

Manufacturers level

Manufacturers, with guidance from government and NGOs, would need to take the initiative in establishing a SWH Manufacturers Association that would play a key role in the management of a large-scale implementation programme. The Association will have to identify the key issues of financing, infrastructure, marketing and distribution for large scale production of SWHs and also set up internal audit facilities, provide a forum for sharing R&D information and promote a healthy competitive environment among its members.

The Association should also promote the creation of the Consumer Forum and Training Centres by pooling contributions from its members to fund these institutions, while permitting them to function autonomously. For this purpose, the Association should set for itself the clear long-term goal of rapid growth in the sector and thereby inculcate among the members a co-operative strategy of capacity building to increase overall revenues. The companies with the highest market share should play a key role in this venture, recognising that they cannot boost their own revenues single-handedly.

Servicing of SWHs

With the growth in sales, it is imperative that a wide network of qualified service-professionals be established. Each manufacturer should have an in-house service team to attend to sundry problems of quality relating to individual products. In addition, the Manufacturers Association should promote service quality and training, by setting up its own Training Centres for service contractors.[12] At the same time, manufacturers should distinguish between their SWH production functions and their installation/servicing obligations. It would be more efficient for most manufacturers to carry out their distribution operations through independent certified service contractors who would handle all installation and routine maintenance calls with consumers than to send their own personnel for all service calls.

10 Enabling Policies

Building codes

SWH use can be greatly enhanced if municipal governments modify their building codes to

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[12] Tata BP Solar has played an important role in this area by establishing Arunodaya, which is a training centre meant for building professionals, contractors, service per sonnel, etc.

require SWH installation in all new houses, apartment buildings, or commercial or industrial buildings where hot water will be required.

Israel has the following legislation for SWHs:

> "No new building in which there is a system of installations for supplying hot water shall be built unless the system is a solar installation"

The city of Jerusalem has applied an amendment to the Land Law (since 1991) to encourage SWHs in existing buildings:

> " If the roof is large enough for a number of solar boilers equal to the number of apartments in the building, an apartment owner may, without the consent of other apartment owners, install in a reasonable place on the roof of the co-operative house which is common property, a boiler for the solar heating of water, and to install in a reasonable manner the installations relating thereto and the pipes for transporting water to his/her apartment (provided that certain provisions are fulfilled)."

As a result of the above regulations, 57% of the one lakh apartments surveyed in Jerusalem in 1995 were using water heated by solar energy. The Karnataka Town and Country Planning Act could be amended to include similar clauses.

Other instruments to promote SWH sales

- Accelerated depreciation allowances can provide an incentive for profit-making companies to invest in renewable energy equipment like SWHs. These already exist in India (100% depreciation in one year, which has recently been increased to two years).
- Alternatively, income tax rebates for end-users for a limited period will provide initial incentives to individuals to buy SWHs. During the 1980s, the USA had tax rebates of up to 40 % of the cost of SWH systems.
- Government orders could be passed to ensure that all new State and Central Government buildings with hot water requirements should have SWHs installed and all existing facilities should be examined for the technical and financial feasibility of retrofits.
- Orders could be passed to ensure that all military quarters have SWHs for meeting hot water requirements.
- Legislation could be passed to require all new hotel and tourist resort permit applications to include SWHs in their plans.
- Legislation could be passed to require all existing and new process industries using steam or heated water to submit to Ministries of Coal and Petroleum a techno-economic evaluation for integrating SWHs for pre-heating to reduce fossil fuel consumption.

11 Quality Control

Strict system quality needs to be maintained during the implementation of a large-scale SWH dissemination programme. The initial scepticism of consumers has to be overcome convincingly, and they should not have any lingering doubts about the viability of using free and abundantly available solar energy for water heating. The advantages as well as limitations of SWHs compared to conventional methods must be made public at initial stages so that anecdotal reports of minor problems are not magnified.

A few points worth noting in this regard:

- A SWH is not a source for hot water for critical applications without back-up heating on cloudy days.
- For a family of four, 100 lpd is sufficient for normal domestic hot water needs in average size families. An appropriately larger capacity should be recommended for larger families.
- The collector should always face south, and installed in a shade-free area.

Individual manufacturers should carefully chose the design and material specifications that they consider to be appropriate for collectors, including auxiliary components like storage tank, internal plumbing, installation procedures, operation and maintenance manual, user guidelines etc. Once these designs and material specifications have been chosen, manufacturers should use them consistently in subsequent production batches to ensure quality.

Bureau of Indian Standards (BIS) specifications should to be changed to reflect performance rather than product standards. This will promote competition and also allow manufacturers to experiment with advanced materials and new production processes.

Performance standards

An important policy instrument for ensuring that the reputation of SWHs do not suffer as a result of a few poorly manufactured systems is the establishment of minimal performance standards for all systems. For instance, a domestic SWH can be specified with the following performance standards:

- System to deliver rated capacity of hot water at an average 30^0C rise in temperature
- Overnight drop in temperature should not exceed 5^0C
- System to perform at least 300 days in a year without electrical back-up heater.
- System should be leak proof and maintenance free in normal conditions but for the following maintenance procedures to be carried out regularly by the user.
  a) Flushing of the system for removing sediments once a year
  b) Cleaning of glass cover for dust once a fortnight
- Guaranteed system life of minimum 20 years.

12 Winners and Losers

Any major social intervention is likely to produce both winners and losers. But, as shown below, the large-scale dissemination of SWHs produces a number of winners and very few losers and even these losers only have marginal losses.

Winners

- Power producers (e.g., KPCL) can reduce investments on new capacity when SWHs are installed instead of EWHs and the connected loads are lowered
- Electricity distributors (e.g., KPTC) can gain additional revenues by diverting sales of energy to domestic consumers (who have installed SWHs in addition to existing EWHs) to higher-tariff paying commercial consumers.
- Existing manufacturers of SWHs and new entrants to the field can enhance their revenues considerably by increasing their sales.
- The copper industry and manufacturers of selective coating equipment, insulation and ancillary equipment
- Energy consultants, trainers, solar thermal designers and other professionals, whose competence will be called upon with much greater frequency than at present
- Consumers will enjoy an assured and safe energy service for water heating with clear financial advantages and reduced dependence on external factors like fossil fuels or electricity supply, and also contribute to environmental quality by using a clean, renewable resource
- Society will benefit from the reduced need for fossil fuels for electrical generation and for fuels like firewood, coal, furnace oil, etc., which are used in domestic, commercial and industrial boilers, and thereby also reduce harm to the environment.

Losers

- Power producer(s) with surplus generating capacity would be forced to back down their power plants because of lowered demand.
- Under normal circumstances, energy demand would shift to other uses than water heating as a result of widespread SWH use. Only when energy demand for other uses is more than offset by savings due to widespread SWH use would there be a net decrease in energy demand. In these circumstances, electricity distributors (e.g., KPTC) would suffer losses because contractual commitments with power producers would force them to pay them for "deemed off-take".
- Geyser and boiler manufacturers whose sales would be reduced, but who could also diversify to manufacture SWHs or the back-up heater components for SWHs.

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14 Appendix A Indian Experience With SWHs

*MNES programme on SWH*s

After the oil shocks in the early 1970s, the Government of India and some states provided several incentives to promote SWHs for domestic and industrial use. In India, Gujarat has been the leader in the use of SWHs in domestic and industrial sectors, followed by Tamil Nadu and Karnataka[13]. A large number of SWHs have been installed in many places including dairies all over India. For instance, Bangalore Dairy has been using a SWH with a capacity of 1,00,000 litres per day for boiler feed water and cleaning for over ten years.

Under the Solar Thermal Extension Programme (STEP) of the Ministry of Nonconventional Energy Sources (MNES), SWHs were installed both in domestic and industrial sectors. Between 1984 and 1992 a subsidy of 22% to 75% was given to Industrial, Institutional and all commercial systems and 50% subject to a maximum of Rs.3000 per beneficiary was given to domestic installations. Table 5 shows the level of subsidy provided by the Karnataka State Council for Science and Technology (KSCST), which was the nodal agency for MNES programmes in Karnataka until 1996.

Table 5. Annual subsidy released under STEP in Karnataka

Year	Subsidy released (Rs.)
1985-86	1,478,425
1987-88	552,167
1988-89	763,064
1989-90	2,768,688
1990-91	3,409,433
1991-92	3,359,536
1992-93	2,660,465

In addition to providing subsidy KSCST performed the following tasks,

- Identifying and approving of reliable manufacturers of SWH
- Assisting these manufacturers in design evaluation and testing of SWHs
- System design cost estimation, tender evaluation on behalf of SWH beneficiaries
- Quality control of SWH systems installed in Karnataka
- Installation supervision and performance evaluation of non-domestic SWHs in Karnataka.
- Regular monitoring and analysis of the monitored data on non-domestic SWHs.

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[13] Until 31 March 1993, Gujarat had 1,561 industrial SWH units and 5,521 domestic units, compared with 267 and 1,945, respectively, for Tamil Nadu, and 340 and 1,657, respectively, for Karnataka. Source: MNES.

Canara Bank Scheme

Canara Bank is one of the financial institutions that have been selected by MNES to extend soft loans for SWHs in a few cities in India. Loans are provided for BIS-approved models at 5% per year and for others at 5.5% per year. Loan-eligibility will be determined on the basis of income (net annual over Rs.50,000) and repayment capacity. Up to 85% of the invoice value of the system (up to a maximum capacity of 500 lpd) will be financed for a 5-year term and a moratorium of 3 months.

15 Appendix B Market potential and marketability of solar water heaters

SWHs for domestic use are still in the introductory phase of the product life cycle even after a decade of use. This may be attributed to (i) high initial costs; (ii) lack of awareness among people regarding the product and reluctance to change from conventional heating systems (iii) inadequate marketing efforts by manufacturing organisations who may be satisfied with low volumes of sales to meet current rates of production.

Till 1994 only 2,242 solar water heaters were sold in the state of Karnataka. All over India, only 12,517 domestic SWHs were sold until the end of March 1993 (TERI, 1997). During this period, marketing efforts of the manufacturing organisations were meagre although the government tried to promote the product by providing a maximum subsidy of Rs.3,000. Subsequent removal of subsidy and entry of new players have reportedly resulted in sales increasing, but data on these increases are not available. Based on informal interviews with a few major manufacturers in the state, a gross sales target for 1998 appears to be about 6000 domestic SWHs.[14]

Potential for Domestic SWHs in Karnataka

A survey was conducted by Karnataka State Council for Science and Technology in 1990 in Bangalore city for establishing the potential for domestic solar water heaters. The data on the following aspects were collected from a sample of about 1000 houses.

- Various gadgets used in All Electric Homes (AEH) in Bangalore for meeting domestic hot water demands, and
- The percentage of AEHs suitable for installing solar hot water systems.

The results of the survey were,

- The average family size in Bangalore was 5.5 members/household; 64 percent of the households have a family size between 4 and 6.
- In Bangalore 24.2 percent of the existing AEHs constitute the immediate market potential for 100 litres per day solar water heater system installation, based on location of overhead tank, roof area available, hot water needs, etc.

In 1994-95, there were about 900,000 AEH connections (KPTC Annual Report), suggesting an annual growth rate until 1996-97 of about 11%. Nevertheless, the rest of the analysis in

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[14] Communications with Peenya Alloys, Tata BP Solar, Sabha SWHs, and others in 1997.

this report uses a more conservative annual growth rate of 7% in AEH connections over a 20-year period 1999-2018. Applying this rate, we obtain a figure of about 1.2 million AEH connections in 1998. Assuming that about 25% of these AEHs have immediate potential for SWH installation (following the results of the 1990 survey), and that each SWH would require 1.6 m^2 of collector area, the immediate domestic SWH potential in Karnataka represents about 480,000 m^2 of collector area.

A survey of 369 AEH households in Karnataka in 1994-95, which was part of a larger survey conducted by IEI of end-uses of electrical devices in 1165 households in Karnataka, revealed that about 60% of AEH households used electrical water heating systems, but that 71% regularly used some form of water heating equipment, including commercial fuels like firewood, kerosene or LPG (IEI, 1997). Based on the high demand for hot water and using the results of the previous survey, it may be reasonably assumed that the potential demand for SWHs may be as high as 50% of existing AEH households, the additional 25% of households having to apply minor construction modifications with regard to cold water supply and plumbing to install and use SWHs (see Chapter 4). Therefore, the total domestic SWH potential in Karnataka represents about 960,000 m^2 of collector area. Non-AEH households need not be included in this estimate initially, since they may not all have pucca roofs or piped water.

National Potential for Domestic SWHs

A first estimate of the potential demand for domestic solar water heater can be made as follows, based on the 1991 Census.

Initially, solar water heaters are likely to be sold mainly in the urban areas due to a number of factors ease of installation and servicing.

1. Number of houses in India - 195.00 million
2. Number of pucca houses (41.6% of 1) - 81.12 million
3. Number of pucca houses in the urban region - 24.34 million(30% of 2)
4. Number of urban owner-occupied pucca houses (50% of 3) - 12.17 million
5. Number of urban owner-occupied pucca houses with solar - 9.13 million energy potential and demand for hot water (75% of 5)

The following assumptions are made in this analysis:

1. Only pucca houses (with RCC roof) are considered for the use of solar water heaters
2. Only households that are owner occupied are considered (assumed at 50%)
3. Only those houses with 300 sunshine days in a year and hot water demand are considered (75%)

After an initial period, penetration of solar water heaters is anticipated to take place among rural households. Based on the 1991 Census data the following demand potential in rural households is estimated:

1. Number of pucca houses (from 2 above) - 81.12 million
2. Number of pucca houses in the rural region (70% of 1) - 56.78 million
3. Number of rural owner-occupied pucca houses (80% of 2) - 45.43 million
4. Number of rural owner-occupied pucca houses with solar - 34.07 million

energy potential and demand for hot water (75% of 5)

The following assumptions are made in this analysis:

1. Only pucca houses (with RCC roof) are considered for the use of solar water heaters
2. Only households that are owner occupied are considered (assumed at 80%)
3. Only those houses with 300 sunshine days in a year and hot water demand are considered (75%)

The total potential demand for domestic SWHs is therefore estimated to be around 43.2 million in 1991. Assuming that this potential demand grows at an annual rate of 3% (at a conservative average growth rate in GDP between 1991-2018), the total market for domestic SWHs in 1998 is about 53 million (85 million m^2 of collector area at 1.6 m^2 per 100 lpd system).

National Potential Demand for Commercial SWHs

While data is not available on the hot water needs of commercial establishments, like hotels, canteens, hospitals, there is obviously tremendous potential for SWH applications, which could be conservatively estimated to be about 50 million m^2 of collector area in 1998 (or roughly 60% of the domestic potential).

National Potential Demand for Industrial SWHs

In industry, roughly 100 million tonnes of coal per year are used in boilers to generate steam. Of these, it is estimated that roughly 20% of the coal use is for applications to heat water below 200^{o}C. SWHs can be used to fulfil this demand:

1.6 m^2 of collector area will raise the temperature of 100 lpd by 35^{o}C
=> 9.16 MJ/m^2/day of energy made available by tapping solar energy
=>2,748 MJ/m^2/year (at 300 days of operation).

1 tonne of coal has a calorific value of 29.3 GJ

At 60% efficiency, 20 million tonnes of coal will generate 586 X 60%PJ=351.6PJ of useful energy per year. This would be equivalent to 127,947,598 m^2 of collector area.

Overall, the total nation-wide potential demand for SWHs represents a demand for about 263 million m^2 of collector area. Considering that the existing installed base of collector area is around 300,000 m^2 (MNES, private communication, 1997), only about 0.11% of SWH potential has been realised. Considering an average annual growth in demand at 3%, the total potential for solar thermal collector area would be about 475 million m^2 by 2018.

Growth along a logistic curve to achieve 25% of this potential would mean a tremendous boost in production of collectors from the present annual sales of around 50,000 m^2 (based on MNES estimates of all-India growth in SWHs during past three years). Table 6 shows the details of the strategy. After a gradual increase in production and sales of SWH collectors until around 2002, there would need be a very rapid increase during the next 10 years, followed by a more gradual increase to saturation. Production volumes and sales will have to reach about 18 million m^2 by 2010-2011, representing a 360-fold increase in total annual sales in the country. This implies production volumes of even the largest existing manufacturers (estimated to be about 1000-5000 m^2 per year) may have to be boosted by 100-fold or more, and that new players would have to come into the market.

Table 6. Annual growth in sales required to meet 25% of total SWH potential in India by 2018

Year	Collector area sold per year (m^2)	Cumulative sales as fraction of potential	Cumulative sales (m^2)
1998	50,000	0.01%	50,000
1999	45,779	0.02%	95,779
2000	87,630	0.04%	183,409
2001	167,566	0.07%	350,975
2002	319,792	0.14%	670,767
2003C-39	608,023	0.27%	1,278,789
2004	1,147,842	0.51%	2,426,631
2005	2,138,104	0.96%	4,564,735
2006	3,885,120	1.78%	8,449,855
2007	6,751,530	3.20%	15,201,384
2008	10,870,761	5.49%	26,072,145
2009	15,521,517	8.76%	41,593,662
2010	18,744,865	12.70%	60,338,528
2011	18,553,089	16.61%	78,891,617
2012	15,077,812	19.79%	93,969,429
2013	10,410,050	21.98%	104,379,479
2014	6,404,315	23.33%	110,783,793
2015	3,664,346	24.10%	114,448,139
2016	2,010,114	24.52%	116,458,254
2017	1,077,237	24.75%	117,535,491
2018	570,088	24.87%	118,105,578
Total Sales	118,105,578		

16 Appendix C Alternative hardware for high-volume manufacture of SWHs

As an alternative to the fin & tube technique used in the conventional design, the whole collector box, absorber, glass retainer and insulation for the absorber can be developed by using two stainless steel thin sheets with corrugations to form risers and headers as well as connecting tubes. The same sheet, which forms the absorber, is shaped to hold glass at the top and PUF insulation at the bottom and sides. This eliminates fabrication of fins and tubes, the riser header assembly, collector box and other labour intensive tasks. Since the entire sheet is pressed, rolled and formed under precision dies and tools, the necessary dimensional tolerances can be easily maintained, which also permits interchangeability of parts among different systems.

One of the most efficient techniques to build a liquid container is to spin a barrel. Barrel technology is well accepted in industrial liquid handling and transportation. It is logical to use this technique to fabricate both the hot water tank as well as the cladding on the insulation. Since this process does not involve welding and metal melting, relatively inexpensive GI sheets rather than stainless steel can be used. In addition to using less expensive material, the labour required is considerably reduced and high quality leak-proof insulated tanks can be produced at a faster rate.

The collector and tank thus obtained from the above process are far lighter in weight compared to a conventional system and require a simpler support stand. Interconnections between the collector and tank are integral part of the collector and tank assembly and do not require separate plumbing and insulation.

Material requirement and process of manufacturing

Collector

Stainless steel sheet
24 SWG 1120 x 1840mm (two)
Both the sheets are to be pressed/rolled to form 7 riser sections and 2 header sections. Risers will be 50mm wide and 10mm deep, and the headers 30mm wide and 10mm deep. Each header will be placed at the top and bottom of the sheets. All the risers are to start from bottom header and stop at top header. Headers will connect all the risers at the top and bottom and have blunt ends on the sides. One of the sheets should be bent at an angle of 90^0 from all sides to hold the glass cover. A minimum gap of 20mm should be maintained between the glass and the absorber sheet. Side folding is done to leave a minimum area of 1700 x 930mm of absorber area for selective coating and all raisers and headers will start and end in this area, leaving the sheet outside this area plain without any corrugations. The joints between the top and the bottom sheets can be made by resistance welding or by using heat resistant glue.

Two pipe connections have to be taken, one from each header with a minimum water flow cross section area of 300 mm^2. These connections can either be formed while pressing/rolling risers and headers or by welding separate pipes. The exposed side of the absorber should be coated with selective coating for higher solar radiation absorption and the top cover should be made of toughened sheet glass of 4mm fixed with a rubber-based sealant. The corner joints should be sealed using heat resistant glue. The bottom and sides of the absorber should be coated with PUF and the surfaces hardened and weather-proofed. See Figures 12, 13, 14.

Hot water tank

Galvanized iron sheet

20 SWG 1580 x 500mm and 500 x 1000mm

22 SWG 1900 x 600mm and 600 x 1200mm

The technique used in fabrication of barrels can be adopted to form a 100 litre inner tank with four openings for connecting cold water from the overhead tank, hot water to user taps, the collector connections and an electrical heating coil (see Figure 15). The diameter-to-height ratio of the barrel is maintained at one to reduce thermal losses. The outer cladding is also formed using the barrel technique with provision to place the hot water barrel inside it and to insulate the volume around it. PUF insulation should either be injected or cast in between the outer cladding and the inner tank to provide sufficient insulation to keep the overnight drop in temperature below 5^0C.

Support stand

MS sections can be used to fabricate a stand to support the insulated hot water tank and the collector. Provision must be made to position the collector at an angle of 10^0 plus latitude of the site and to allow minimum head deference of 300 mm between bottom of the hot water tank and the top of the collector. The stand can either be painted or hot-dip-galvanized for corrosion resistance.

17 Appendix D Draft User's Manual

ROUTINE MAINTENANCE

Solar water heaters are designed to be almost maintenance-free. Because they operate on the thermosiphon principle, there are no moving parts and no control units that could malfunction. The system will work automatically but there are some operations on the part of the user that will improve its functioning and thereby increase electricity savings:

- Clean the glass cover regularly. Dust and dirt will settle on the glass cover and this will block the sun's rays, thereby decreasing the output of the system. Depending on the surroundings (proximity to a road, dusty environment, etc.) it is advised to clean the glass cover about once a fortnight or at least once a month.
- Try to prevent any shade falling on the collector. If trees are growing nearby, trim them to provide as much sunshine on the collector as possible.
- Be sensitive about the use of hot water. Try to minimise the frequency of hot water use because every time a tap is opened it takes some time to warm up the pipelines from the SWH to the tap. When the pipes are long and the frequency of hot water use is high, the heat lost in the pipeline can be significant.
- Draw hot water at a slow rate, this will avoid mixing of hot and cold water in the storage tank.

- Leave the thermostat setting of the electric backup at as low a value as possible. A temperature of 60^0C is usually sufficient. A higher setting will cause a higher electricity bill.
- Ensure that cold water supply is always available to the solar water heater. Leave the valve on the cold water inlet open at all times and take care to ensure that the cold water tank is always filled with water.
- Inspect the cladding of the storage tank, collector and the pipelines about once a year. See if there are any openings or damage to the cladding and repair them when necessary. This would ensure that no rainwater runs into insulation of the collector, tank and pipes, which could make the system less efficient and also shorten its life.
- Flush the entire system to remove floating and settled dirt in the system about once a year. If the water is hard, use a water softener to prevent scaling leading to blocking of the collector.

WHAT SHOULD NOT BE DONE

Although the SWH is a relatively simple system and there is not much that can go wrong with it, there are a few things one should avoid:

- Do not close or block the vent pipe. It is essential that this vent pipe is open to the atmosphere and at a level higher than the cold water storage tank.
- Do not place any obstacles in front of the collector.
- Do not use sharp materials when cleaning the collector.
- Do not leave the electric backup switch on when necessary. If the switch is on, the sun will not have a chance to warm the water and the electricity consumption will be high.

TYPICAL WARRANTY STATEMENT

Your SWH is guaranteed for a period of one year from the date of purchase against any manufacturing defect and the flat plate collector would continue to enjoy the manufacturer's guarantee for 7 years. This includes repairs and/or replacement at of parts relating to manufacturing defects that are detected during this period, provided the customer adheres to the instructions printed in the operation manual and carries out routine maintenance.

However the following parts/events are excluded from the scope of the guarantee

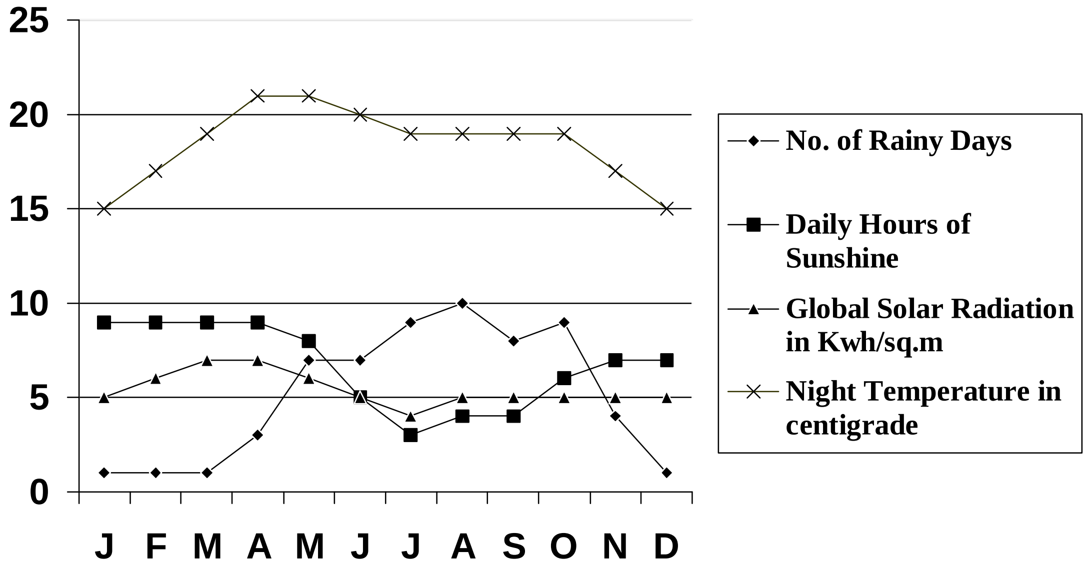
- glass
- All sealants, Grommets, Gaskets and Beading
- Interconnecting pipes and fittings
- Normal wear and tear
- Accidents/events/transformations forced by nature
- Mechanical damages
- Mishandling or negligence on the part of the customer
- Any other occurrence, which cannot be attributable to manufacturing, defect.

18 Appendix E Bangalore Weather

Bangalore weather

Month	J	F	M	A	M	J	J	A	S	O	N	D
No. of rainy days	1	1	1	3	7	7	9	10	8	9	4	1
Daily hours of Sunshine	9	9	9	9	8	5	3	4	4	6	7	7
Global solar radiation in kwh/m^2 *	5	6	7	7	6	5	4	5	5	5	5	5
Night temperature ^{o}C	15	17	19	21	21	20	19	19	19	19	17	15

* Solar energy received on a horizontal surface of one square meter in kilowatt-hour.



19 Appendix F SWHs for group houses and apartments

Solar water heaters can be installed for both group houses and as well as apartments. It is well known that retrofitting is always a costly proposition compared to planning in advance of construction. Two types of systems can be designed for this need.

1. One or more large systems to cater to all the individual houses.
2. Small individual systems to cater to each house.

In both the cases the roof area required is almost the same ($3m^2$ for every 100 lpd). The cost of the larger system is cheaper than an individual system on a per user basis. In large systems serving a group of houses sharing of hot water has to take place through mutual understanding or metering. Provisions should be made for a shadow-free roof and a hot water insulated pipeline to each house. The system capacity has to compensate for the heat losses in the long pipeline carrying hot water from the rooftop to individual homes. It is even possible to integrate the SWH system into the construction of each individual apartment or group house so that each collector sub-unit is housed on a projection over a window or a south-facing door of that particular apartment or house. In large systems the collector bank can form a shaded roof for social gatherings and other functions. In the case of large systems the structural design of the building has to allow for the weight of the large hot water tank on the roof.

20 Appendix G Economics of SWHs

21 Appendix H Case Studies

Case study 1

1. SWH system installed at : Residence
Name of the person/organisation : Saraswathi
Address : No, 511, 2nd cross, 3rd stage, 3rd block, W.C. Road, Basaveshwarnagar, Bangalore-560 079.

2. Date of installation and cost of SWH : 29.01.94 Rs.13,000

3. Installed by (System Manufacturer) : MSIL

4. Capacity of the system (LPD at ^{0}C) : 100 lpd at 60^{0}C

5. Type of the system
(Thermosiphon/forced circulation) : Thermosiphon

6. Hot water is used for
(Bathing, Cooking, Dish washing, etc.) : Bathing

7. Solar water heater replaces/augments
(Boiler, Geyser, etc.) : Boiler

8. Monthly fuel/electricity bill before SWH : Rs.285 to Rs.300

9. Monthly fuel/electricity bill after SWH : Rs.160 to Rs.180

10. SWH system performance
(good/satisfactory/bad) : Good

11. Major maintenance problems
(number & kind) : nil

12. Minor maintenance problems
(number & kind) : nil

13. Maintenance attended by : MSIL

14. Average maintenance cost per year : nil

15. Service given by system manufacturer
(good/satisfactory/bad) : good

16. SWH is on annual maintenance contract (AMC)
(yes/no, if yes, with whom & at what cost) : no

17. Weakest point in the system : nil

18. Your suggestions for the
feature system design : -

Case study 2

1. SWH system installed at : Residence
Name of the person/organisation : Dr.S.R. Valluri,
Address : 659, "Prashanti", 100 Feet Road, Indira Nagar, Bangalore - 560 038.

2. Date of installation and cost of SWH : 1991 Rs.10,500

3. Installed by (System Manufacturer) : Tejus Solar System

4. Capacity of the system (LPD at ^{0}C) : 100 lpd at 60^{0}C

5. Type of the system
(Thermosiphon/forced circulation) : Natural Thermosiphon.

6. Hot water is used for

(Bathing, Cooking, Dish washing, etc.) : Bathing

7. Solar water heater replaces/augments
(Boiler, Geyser, etc.) : Electric geyser

8. Monthly fuel/electricity bill before SWH : 329 kWh *

9. Monthly fuel/electricity bill after SWH : 181 kWh *

10. SWH system performance
(good/satisfactory/bad) : Good

11. Major maintenance problems
(number & kind) : nil

12. Minor maintenance problems
(number & kind) : nil

13. Maintenance attended by : nil

14. Average maintenance cost per year : nil

15. Service given by system manufacturer
(good/satisfactory/bad) : good

16. SWH is on annual maintenance contract (AMC)
(yes/no, if yes, with whom & at what cost) : no

17. Weakest point in the system : nil

18. Your suggestions for the
feature system design : -

* Average consumption of electricity per month.

Case study 3

1. SWH system installed at : Bangalore Dairy
Name of the organisation :
Address : Dharma Ram College post, Hosur Road, Bangalore 560 029.
Contact person : Manager (Engineering)
Telephone No : 5536295, 553626

2. Date of installation and cost of SWH : 1986 Rs.48,00,000

3. Installed by (System Manufacturer) : BHEL, Jyothi and Scarab.

4. Capacity of the system (LPD at ^{0}C) : 1,00,000 lpd at 70^{0}C

5. Type of the system (Thermosiphon/forced circulation) : Forced circulation

6. Hot water is used for (Bathing, Cooking, Dish washing, etc.) : Boiler feed water, floor washing and canteen.

7. Solar water heater replaces/augments (Boiler, Geyser, etc.) : Boiler

8. Monthly fuel/electricity bill before SWH :

9. Monthly fuel/electricity bill after SWH : Savings of Rs.55,800

10. SWH system performance (good/satisfactory/bad) : Satisfactory

11. Major maintenance problems (number & kind) : Removal of weeds, pipeline repair and replacement of MS collector boxes.

12. Minor maintenance problems (number & kind) : Glass cleaning

13. Maintenance attended by : Dairy technical staff

14. Average maintenance cost per year :

15. Service given by system manufacturer (good/satisfactory/bad) : Satisfactory

16. SWH is on annual maintenance contract (AMC) (yes/no, if yes, with whom & at what cost) : no

17. Weakest point in the system : Corrosion in MS collector boxes

18. Your suggestions for the feature system design : Avoid deep grout on the concrete roof. Prepare the ground before installation of collectors if mounted on the ground.

Case study 4

1. SWH system installed at : Hotel
   Name of the person/organisation : Hotel Mothimahal
   Address : Gandhi Nagar, Bangalore.
   Contact person : Raghupathi
   Telephone No : 2267646

2. Date of installation and cost of SWH : 1992 Rs.9,50,000

3. Installed by (System Manufacturer) : Best & Crompton

4. Capacity of the system (LPD at ^{0}C) : 10,000 lpd at 60^{0}C

5. Type of the system
   (Thermosiphon/forced circulation) : Forced circulation with heat exchanger.

6. Hot water is used for
   (Bathing, Cooking, Dish washing, etc.) : Bathing

7. Solar water heater replaces/augments
   (Boiler, Geyser, etc.) : Electric geyser

8. Monthly fuel/electricity bill before SWH : 33,559 kWh *

9. Monthly fuel/electricity bill after SWH : 25,761 kWh *

10. SWH system performance
    (good/satisfactory/bad) : Good

11. Major maintenance problems
    (number & kind) : nil

12. Minor maintenance problems
    (number & kind) : nil

13. Maintenance attended by : NAMSI solar systems Bangalore

14. Average maintenance cost per year : nil

15. Service given by system manufacturer
    (good/satisfactory/bad) : good

16. SWH is on annual maintenance contract (AMC)
    (yes/no, if yes, with whom & at what cost) : no

17. Weakest point in the system : nil

18. Your suggestions for the
    feature system design : -

* average electricity consumption per month.

22 Appendix I A Value-Engineering Approach to Determining SWH Costs

23 Appendix J Estimating Sale price of SWHs with High-Volume Manufacturing

24 Appendix K Example of International SWH Manufacturer Using High-Productivity Manufacturing Methods

25 Appendix L: IREDA's Concessional Finance Norms for Solar Thermal Systems