Advanced Solar Domestic Hot Water Systems

A Report of the Task 14 Advanced Solar Domestic Hot Water Systems Working Group
October 1996

INTERNATIONAL ENERGY AGENCY
Solar Heating and Cooling Program

IEA Solar Heating and Cooling Programme

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Organization for Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 24 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security and reduce greenhouse gas emissions. The IEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 41 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, fusion technology and energy technology information centers.

The Solar Heating and Cooling Programme was one of the first IEA Implementing Agreements to be established. Since 1977, its 21 members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings.

Australia	Finland	Netherlands	Turkey
Austria	France	New Zealand	United Kingdom
Belgium	Germany	Norway	United States
Canada	Greece	Spain	
Denmark	Italy	Sweden	
European Commission	Japan	Switzerland	

A total of 22 Tasks have been initiated, 17 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities--working groups, conferences and workshops--have been organized.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 20	*Solar Energy in Building Renovation*

Current Tasks and Working Groups

Task 18	*Advanced Glazing Materials for Solar Applications*
Task 19	*Solar Air Systems*
Task 21	*Daylight in Buildings*
Task 22	*Solar Building Energy Analysis Tools*
Task 23	*Sustainable Solar Buildings: The Optimization of Solar Energy Use in Larger Buildings (Project Definition Phase)*
Working Group	*Materials for Solar Thermal Collectors*

Task reports and ordering information can be found in the IEA Solar Heating and Cooling Programme publications list. For additional information contact the SHC Executive Secretary, Pamela Murphy Kunz, Morse Associates Inc., 1808 Corcoran Street, NW, Washington, DC 20009, USA, Telephone : +1/202/483-2393, Fax: +1/2021265-2248, E-mail: 103116.1530@compuserve.com.

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This report documents work performed within the IEA Solar Heating and Cooling Program
Task 14: Advanced Solar Energy Systems
Working Group: Advanced Solar Domestic Hot Water Systems

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TABLE OF CONTENTS

Chapter Page

LIST OF FIGURES

LIST OF TABLES

Task 14 - Advanced Active Solar Systems

Task 14 was initiated to advance the state-of-the-art in active solar energy systems. Many features developed during the few years before the start of the Task, when used alone or in combination, had the potential to significantly improve the performance of these systems. It was the objective of Task 14 to analyze, design, evaluate and, in some cases, construct and monitor a number of different systems incorporating one or more of these features.

The work of the Task was divided into three Working Groups, based on the type of systems studied, and one Sub Task dealing with dynamic testing. The goal of the Working Groups was to facilitate interaction between participants with similar projects. Participants were able to identify and address issues of common interest, exchange knowledge and experience and coordinate collaborative activities.

Domestic Hot Water (DHW) Systems - Working Group

The focus of this Working Group was the development of advanced DHW systems using the "low flow" concept. Participating countries contributed expertise related to different system components. The collaborative work in the Task brought this expertise together to allow participants from each country to design systems which show a significant cost/performance improvement (as high as 48%) over systems on the market in their respective countries when the Task began.

Air Systems - Working Group

Task work concentrated on further development of a commercially available concept for the preheating of ventilation air in industrial and commercial buildings. This concept is a specially designed cladding system to capture the air heated by solar radiation on the south wall of a building. Four projects, two in Canada, one in the USA and one in Germany, were constructed using a perforated version of the wall. The German project adapted the concept to preheat combustion air for a district heating plant. The practical work of these projects was complemented by theoretical work conducted at the University of Waterloo in Canada and the National Renewable Energy Laboratory (NREL) in the United States. Task work demonstrated that the cost/performance of the perforated wall is over 35% greater than earlier versions of the design.

Large Systems - Working Group

The Task also examined large scale heating systems involving temperatures under 200°C. Five large systems were studied. They were all very different but each represented important applications of active solar systems. District heating, the subject of the Swedish project, can be used in most IEA member countries to provide space and water heating for communities. The

German project also involved district heating but with no storage. A tulip bulb drying installation in The Netherlands explored the staggered charging and discharging of long term storage, a strategy which may fmd many uses, especially in agricultural applications. Solar desalination, the subject of the Spanish project, has wide application in water starved areas of the world and could represent a major export opportunity for IEA countries. Industrial process heat was represented by a project in Switzerland. Since virtually all large systems are custom designed, cost/performance improvements for this Group was not a meaningful measure of achievement. Documentation of lessons learned is the most important product of the work.

Dynamic System Testing Sub Task

The work of this Sub Task within Task 14 provided a continuation of work completed earlier by the IEA Dynamic Systems Testing Group. That Group established that dynamic fitting was a suitable tool in processing laboratory tests and in-situ monitoring of solar domestic hot water systems. The objective of the new sub-task in Task 14 is the continued development and evaluation of dynamic testing of solar energy systems, subsystems and components for prediction of long term system performance from short term tests.

Task 14 activities began in 1989 and were completed in 1995.

The following countries participated in this Task:

Canada	The Netherlands	Switzerland
Denmark	Spain	United States
Germany	Sweden	

1. EXECUTIVE SUMMARY

The Task 14 Advanced Solar DHW Working Group set a goal of a greater than 15 percent increase in the cost and performance of solar DHW systems over current practice. This goal is interpreted as achieving designs that have an initial cost to annual energy delivered ratio improvement (dollars/GJ) greater than 15 percent.

Actual cost performance gains ranged from 20-48 percent. These gains were a result of multiple improvements in heat exchangers, storage design, modularization, absorbers and piping.

Because regulations and practices regarding the design and construction of solar DHW systems differed markedly from country to country, it was not possible to propose one universal Task 14 system. Instead, each country developed its own individual "Dream System." In order to measure how well the goal was achieved, one of the most commonly available systems being sold in each country at the time the Task began was selected as a comparative "Base Case."

Despite this lack of commonality, most specific system design features and components could still be made applicable to each country's improved designs. Thus the Working Group's common efforts were focused on compiling and developing design features and components which would improve solar DHW system performance and lower system cost. In this regard, a system design approach termed "low or matched flow," was determined to be the most promising direction for improvements. Thus, from the beginning, Task Working Group efforts were directed primarily toward low-flow design elements.

Many Working Group developments have been implemented by solar industry in several countries. The Dream System of Switzerland and Denmark are currently being commercialized.

Before discussing the Dream System of each country and comparisons with the Base Cases, this summary will address design features and components that were identified by the Working Group to provide improvements in either cost, performance, or both.

1.1. Collector and Load

Often in comparing high- and low-flow designs it was found that good practice in a low-flow design was good practice in a high-flow design. For example: 1) The use of current improvements in top insulation was not cost-effective in either low- or high-flow collectors. 2) When a typical daily load profile was used to size the system for the load, both the low- and high-flow systems showed about the same degree of sensitivity to variations in both daily load profile and day-to-day loads. Variations in the daily load profile had only a small effect on system performance. Task investigations indicate a somewhat greater, but still small, effect for day-to-day load variations. There was some evidence that a larger solar storage would increase annual performance somewhat. Further study in this area is warranted.

For low-flow systems, the following load matching principles should be followed:

- The flow in the collector loop should be approximately 2 to 4 grams/sec-m2.

  Flow into the solar storage or integral heat exchanger design should be such that optimal stratification is maintained.

  Total flow volume through the collector for an average day should be matched to the volume supplied to the load for an average day.

  The collector and load flow rates should be optimally matched.

Since loads and ambient conditions of Task 14 countries are different, application of these principles will result in different optimized designs for each country.

The Task found that absorber design improvement was one area where collector costs can be reduced. And, low flow provides some of the opportunities for absorber cost reduction. Though most current well designed high-flow collectors also perform well in low-flow systems, lower collector cost can be obtained by an absorber optimized for low flow. Costs of low-flow fm-tube absorbers can be reduced substantially by reducing the amount of material that is necessary for the tubes and fins.

Serpentine flow configurations are desirable for low-flow systems since there is a potential for uneven flow distribution in riser/header configurations. Riser/header configurations can be used, but care needs to be exercised in design and construction, especially with horizontal risers, to insure even flow distribution.

Both drainback and glycol/water closed-loop systems can be used for low-flow collector freeze protection. In serpentine drainback systems, a five degree minimum slope, in piping is needed to assure complete drainback.

1.2. Solar Storage, Heat Exchanger, and Auxiliary

The main performance advantage of low-flow systems is due to extensive thermal stratification in solar storage. Solar storage design and the design and interaction with storage by heat exchangers and auxiliary system can effect stratification. Therefore, all three of these components are key components in low-flow systems and they are often considered together as a solar storage system.

These three components in combination with the fluids used are the elements most profoundly affected by differences in regulatory issues and design practices among different countries. For example, some countries have only small manufacturers of DHW tanks and therefore these tanks are relatively expensive as solar storages. In these countries it is more likely that you will find a built-to-order optimized solar storage in a DHW system, rather than a solar storage made by incorporating less than optimum modifications into a standard available DHW tank. In countries with a few large manufacturers of DHW tanks, the opposite is true.

It is likely that less expensive solar storages will be developed based on standard DHW tanks in more countries or that new storages based on system designs that can make use of inexpensive materials, like a cheap unpressurized plastic tank for a drainback system, will eventually emerge.

An optimum solar storage system should have the following characteristics:

- The volume of a tank reserved for solar storage (not auxiliary) should be sufficiently large, depending on solar fraction and economics.
- Temperature differences in the tank should be equalized as slowly as possible.
- The capacitance of the collector side heat exchanger should be sufficiently large, about 50 W/K-m2.
- The storage should be carefully insulated and thermal bridges, such as pipe connections, should be avoided in the upper part of the tank.

Several solar storage systems were evaluated including a mantle tank, side arm heat exchangers, built in helical heat exchangers, stratification manifolds, tank in tanks, two tank systems, internal auxiliaries, and external auxiliaries. Of the several low-flow system storages experimentally evaluated, there was little difference in thermal performance at high solar fractions. Therefore, cost considerations should predominate in selection of storage system type. Only at lower solar fractions, on the order of 20-30 percent, did performance differences become significant.

1.3. Pump and Controller

Though many solar DHW systems take advantage of thermosyphoning in various ways, most require a collector circulation pump. Several classes of small pumps (centrifugal, positive displacement, and thermal self-pumping) were investigated. None of these had a thoroughly acceptable blend of cost, performance, and durability.

A small light weight high speed electronically driven centrifugal pump with the requisite characteristics (called the Task 14 pump in the Dream Systems specifications) is being developed by a Task participant. High durability was gained by keeping the pump simple and shifting most of the pump complexity to the silicon chip. The pump provides the required flow rates for low-flow systems and sufficient start-up pressure for operating drainback systems. The design provides low operating cost with a target power consumption of five watts and can potentially be manufactured, given sufficient sales volume, at a cost lower than that of current competing pumps.

To optimize storage stratification, proportional control of collector flow rate is needed to provide low-flow systems with a fixed delivery temperature equal to the load temperature. Photovoltaic powering of the pump is highly desirable as it can provide a proportional control that can be integrated into the pump itself. However, cost needs to also be considered.

Overheat prevention and, in the case of drainback, freeze protection are other functions of the solar energy system controller.

1.4. Piping

Low flow makes possible compact all-in-one solutions to piping choice, such as having both collector supply and return tubes and control sensor wiring in one envelope. The smaller diameter piping that can be used in low flow also opens possibilities for use of flexible non-metallic materials or easy to bend copper tubing.

Long material lifetime is required in a solar energy installation and therefore the following durability requirements should be noted:

- Piping and insulation must be resistant to temperatures up to 200°C and pressures up 4 bars.
- Piping must be resistant to deterioration by a water-glycol mixture.
- The envelope, insulation, and/or piping must be resistant to ultraviolet radiation.

This approach has many cost and performance benefits, such as:

- Installation of piping and electrical wiring is fast and easy, lowering installation costs.
- Heat losses from the smaller diameter piping and insulated envelope are reduced by a factor of two or more.
- Cost of piping and insulation materials can be reduced by minimizing piping diameter and wall thickness.
- Delivery and handling costs are reduced.

Disadvantages of this approach can be:

- The piping bundles can only be used for smaller solar low-flow DHW installations.
- Some bundle designs have shown a tendency to be damaged during installation.
- There may be a higher pressure drop with the smaller piping diameters.

- There may be additional increases in pressure drop if the piping is bent in a tight radius during installation.

- Too small piping diameters may prevent proper draining in drain-down systems. Problems may occur for inner diameters less than 10 mm.

  There may be a greater risk of a blockage in the collector loop with the small piping diameters.

1.5. Other Low-Flow Considerations

In current practice, lowered cost is the most apparent benefit of the low-flow approach. Performance increases of two to nine percent which were due solely to low flow were measured in two Working Group systems that were not specifically designed for low flow. Over the long term, larger performance increases seem probable for low-flow systems by properly integrating components that have been optimized for maximum system performance in low-flow use. Additional work is warranted here.

1.6. Dream Systems

The Dream Systems of the six Working Group countries are shown in Figures 1-1 through 1-6. As may be seen, there are many common elements, such as piping and sensor wire bundles, combined solar and auxiliary storages, and tank-in-tank storages. Many of the systems use the Task 14 pump. There are also differences which reflect both local regulations and practice, as well as individual preferences.

Table 1-1 provides a summary of Base Case and Dream System cost, performance, and cost to annual energy delivery ratio for each country, as well as the location and ambient conditions on which each country's performance estimates are based. Cost reductions, performance increases, and improvements in the cost to annual energy delivery ratio are also shown. As can be seen, each country has exceed the 15 percent goal.

Significantly, two of the Dream Systems will be introduced as commercial products by the time the Advanced Solar DHW Working Group activities are complete.

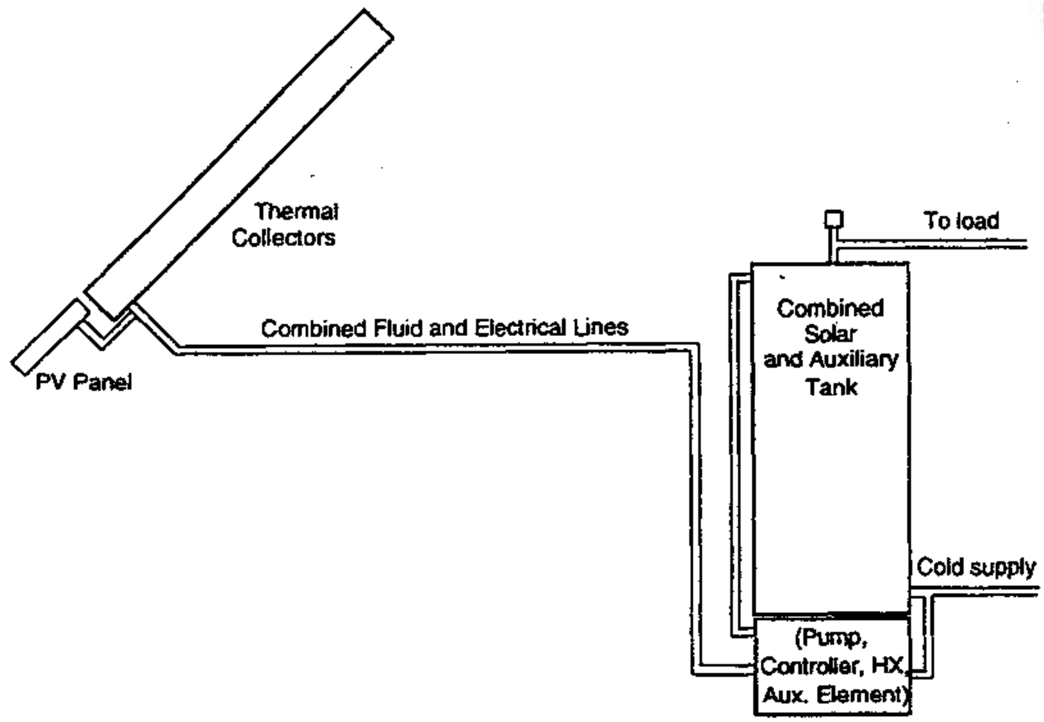

Figure 1-1. Canadian Dream System Diagram.

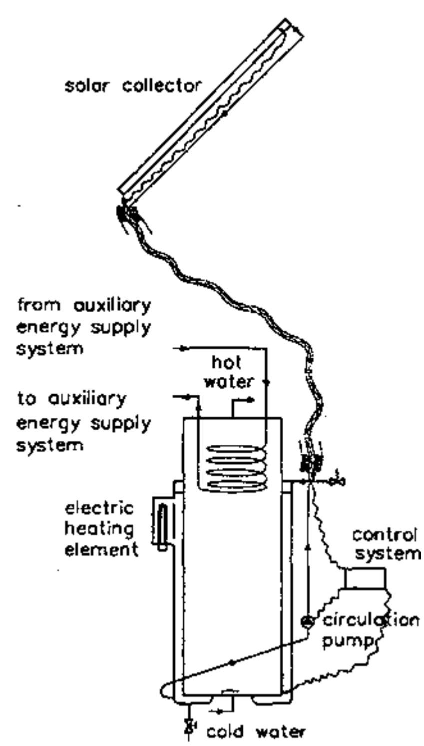

Figure 1-2. Danish Dream System Diagram.

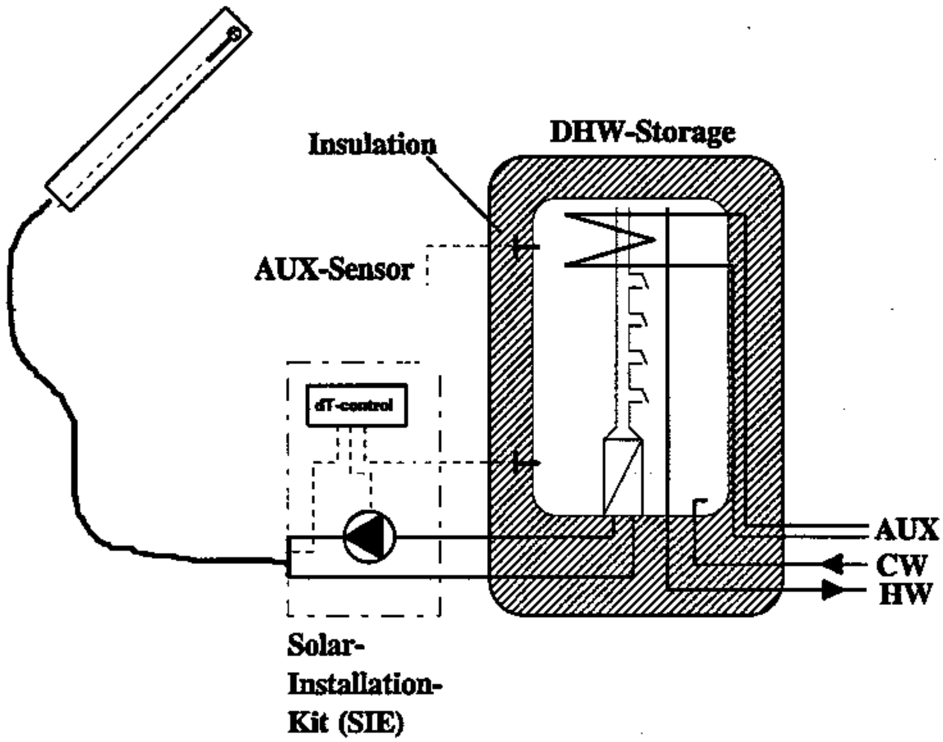

Figure 1-3. German Dream System Diagram.

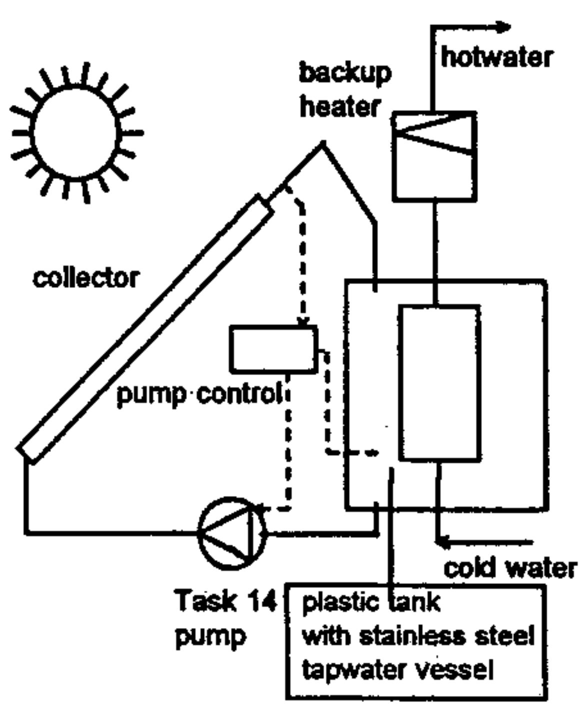

Figure 1-4. The Netherlands Dream System Diagram.

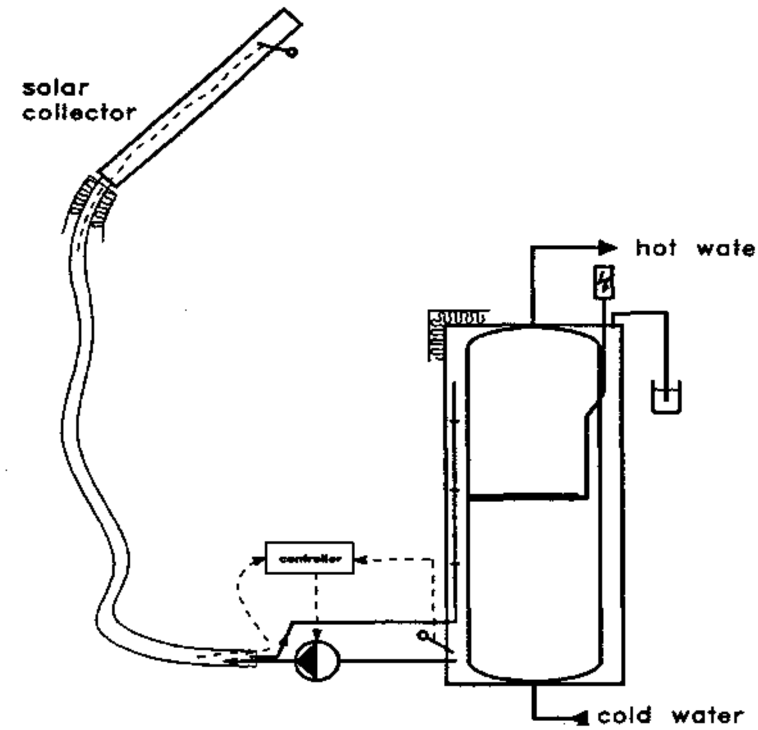

Figure 1-5. Swiss Dream System SOLKIT®.

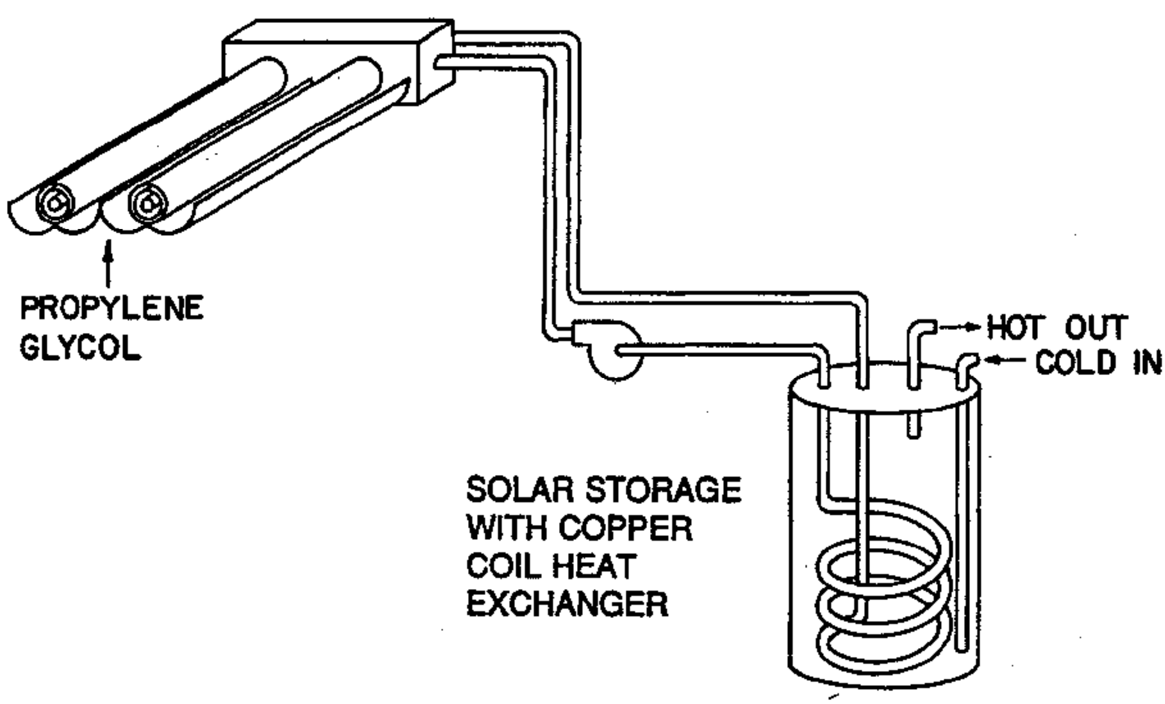

Figure 1-6. United States Dream System for Freezing Climates.

Table 1-1. Costs, Performance, and Comparisons.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Reference quantities for calculations						
Location	Toronto	Copenhagen	Hannover	DeBilt	Kloten 1986	Sacramento, CA
Radiation on collector aperture GJ/m²-yr	5.48	4.262	3.808	3.989	4.5	7.497
Monthly average daytime temperature °C	9 (-6 to 22)	8.1	8.7 (0 to 17)	9.5 (2 to 18)	8.6 (-1 to 19)	16 (7 to 24)
Exchange rate in US$ and basis date	0.87$ 1/94	6.70 DKK 3/94	1.7 DM 4/94	1.86 Df 5/94	1.437 sFr 1/94	1.00/$ 12/93
Base Case manufacturing costing approach and Dream System differences	1993 fabrication, market, methods, and prices; design for automation	1994 conditions	1994 conditions	1989 market and fabrication methods at 1994 prices	Base Case costing approach	1989 market and fabrication methods at 1993 prices
Base Case cost (1993 US$)						
Total*	1862	3098	6608	1985	7134	1925
Operating and maintenance $/yr	< 10	15-22	51-131	17	84-150	10
Base Case performance						
Thermal (Q_{load} - Q_{aux}) GJ/yr	8.7	5.07	6.55	3.70	7.2	7.05
Reliability and Durability	good to excellent	no problems	excellent	no significant problems	same as ordinary water heaters	excellent
Dream System cost (1993 US$)						
Total*	1445	1892	5393	1540	4466	1510
Operating and maintenance	< 5	15	37-117	11	74-140	10
Dream System performance						
Thermal (Q_{load} - Q_{aux}) GJ/yr	12.9	5.04	6.65	4.16	7.2	8.51
Reliability	excellent	freezing problems	excellent	improved	improved	excellent
Cost/performance comparisons						
Cost reductions $	417 (22%)	1206 (39%)	1215 (18.3%)	445 (22.6%)	2667 (37%)	415 (21.6%)
Energy delivery increases GJ/yr	4.2 (48%)	-0.03 (-1%)	0.1 (1.5%)	0.46 (12.4%)	0 (0%)	1.46 (20.7%)
O&M improvements $	slight	~5 (~25%)	~14 (~15%)	6 (35%)	10 (10%)	0 (0%)
Base Case $/GJ/yr	214	611	1009	563	990	273
Dream System $/GJ/yr	112	375	811	370	620	177
Cost/energy delivery improvement $(GJ/yr)	102 (48%)	236 (39%)	198 (19.6%)	193 (34%)	370 (37%)	96 (35.2%)

* This is not the end price to the user. Total does not include marketing, selling and distribution costs. The values in this table do not include the past consequences of higher production volumes and improved installation approaches. See Appendix A for further details.

2. INTRODUCTION

This is the final report of the International Energy Agency (IEA) Solar Heating and Cooling Program Task 14 Advanced Solar DHW Systems Working Group. The Working Group is made up of experts from seven countries: Canada, Denmark, the Netherlands, Germany, Spain, Switzerland, and the United States. Since its start in 1989, the Working Group has been led by the United States.

Since participation of the solar industry was an important planned feature of Task 14, each country sent an industry representative and researcher to the Working Group meetings.

The Working Group's goal was a fifteen or greater percent system cost/performance improvement compared to existing state-of-the-art systems in common use in 1989. The Working Group achieved this goal through lowered costs and increased performance of the system and its components as compared to current practice.

This report is designed to make it easy for a solar equipment manufacturer or marketer to locate information on a particular system or component, including associated cost and performance data, and evaluate how that information may be of benefit.

The Solar DHW Systems Working Group chose to focus its activities on low-flow design, since this approach was judged to hold the greatest promise for near-term performance improvements and cost reductions. The Working Group low-flow activities continued the promising low-flow research and development direction started in the late 1970s and early 1980s by a number of researchers, most notably by Terry Hollands [2-1] and Chris van Koppen [5-1].

Canada, Denmark, Germany, the Netherlands, Switzerland, and the United States participated in the low-flow activities. Denmark, Germany, the Netherlands, and Switzerland conducted extensive side-by-side experimentation of state-of-the-art reference and advanced low-flow DHW systems. Results of these activities may be found in [4-1, 4-6, 5-3, 5-8, and 7-1].

The Netherlands, Spain, and the United States also chose to identify a second path and examined the integral collector storage DHW system. The integral collector storage DHW system holds significant promise for cost performance improvements. This alternative was not explored substantively because priority was given to low-flow.

Each of the seven countries followed different paths to accomplishing the Working Group goal. Each followed various mixtures of system modeling, system testing, system improvement, and component improvement.

Prior research and concurrent research from outside the Working Group were incorporated into the systems of the Working Group when appropriate. Much research and development work generated or stimulated by the Advanced Solar DHW Systems Working Group activity is still ongoing.

As Working Group efforts matured, interaction among the participants evolved the concept of an universal "Dream System." The Working Group soon realized that each country's notion of a Dream System was different because each country's interpretation depended on a unique set of national circumstances, involving regulations, market conditions, the structure of the solar industry, energy policy, component prices, solar design approaches, and traditions. Thus, each country evolved its own "Dream System."

Effects of extraneous factors were explicitly avoided when assessing the value of Working Group accomplishments. This was accomplished by having each country define a "Base Case" that could be compared to its Dream System. Each country selected as its Base Case a solar DHW system typical of those that existed in the country in 1989-90 as the work of the Working Group began. A consistent approach was then used to estimate costs and evaluate the performance of both the Base Case and Dream System.

As the work of the Advanced Solar DHW Systems Working Group progressed, a number of heat exchanger/storage designs were identified as promising low-flow components. In the later stages of the Working Group activities, two of the most promising designs were singled out to be experimentally evaluated in the highly controlled environment of Canada's National Test Facility solar simulator. A series of experiments provided a comparison of the two point designs in a low- and a high-flow mode. This experiment substantiated the advantage of using low flow for the given two systems.

3. JUSTIFICATION FOR LOW FLOW

3.1. Introduction

Over the past 10 or 12 years, the designers of small solar systems, primarily domestic water heaters, have come to realize that lowering the collector loop fluid flow rate (hereafter abbreviated to "low flow") can improve system cost effectiveness. A significant part of this understanding has come about through five years of discussion and study within Task 14.

Though the low-flow strategy typically lowers the cost of the system, the degree of performance enhancement depends very much on the base design chosen for comparison. It is generally agreed that tank thermal stratification is the major contributor to better performance. High-flow systems can have varying degrees of stratification, depending on aspects such as whether there is a heat exchanger, and if so, its design and location. Particular types of exchangers, such as the internal, full-height mantle or spiral, generate gentle, natural convection in the tank with minimum mixing (i.e. plume entrainment), and give some stratification even at high collector flow. Side-arm heat exchangers can minimize plume entrainment using particular auxiliary input and pump control strategies. However, there may be further performance benefits to be gained through a fully integrated low-flow system design.

The low-flow regime can be characterized as follows. "Single pass" is a reference to the quantity of fluid flowing through the collector loop being equal to the load. For typical collectors, this will either be a rate in the range of 2 to 4 grams per square meter-second (water equivalent) or that the total of the collector flow (as water) over the day equals the storage tank volume. If the tank volume equals the daily load (draw-off), then these two are equivalent. High-flow rates have been 5 to 10 times higher than this range.

3.2. Low-Flow Cost Impact

Lower collector flow rates have some immediate and longer-term cost advantages. Most directly, the pump can be made smaller and less expensive, and consume less electricity. Also, the piping to the collectors can be of smaller diameter. This makes it more flexible, easier to install, and less expensive. Smaller tubes lower the thickness, and cost, of the insulation because the R-value is dependent only on the ratio of the insulation's outer-to-inner diameters, not the absolute thickness. Of course, the thinner overall diameter further reduces stiffness. All of this adds up to significantly less piping installation time and costs.

In the longer run, new lightweight, low-flow absorber designs could further reduce the system cost. Since they would also improve performance, they are discussed below.

3.3. Low-Flow Performance Impact

It may be possible to develop lighter weight absorbers having somewhat higher thermal performance. In an overall system design emphasizing low-flow and low pump power, the flow in the absorber tubes should be laminar. It is well known that in fully developed laminar flow the heat transfer rate to the fluid in a length of tube is independent of diameter, and so a smaller bore tube and a narrower fin will have a higher fin effectiveness. Alternatively, the fin can be made proportionately thinner while maintaining the original fm effectiveness. If the tube bore is much smaller than, 8 mm, the two-collector serpentine configuration becomes more difficult to manage with low power pumps, because of excessive hydraulic pressure drop. It then may become advantageous to switch to a parallel riser and horizontal header design. The flow velocity in each vertical tube is low enough to allow natural convection to help to assure uniform flow across the collector, assuming of course that the cool fluid inlet is at the bottom header. The vertical risers will also improve the collectors' drainback capability. Of course, the smaller fin-tubes imply a larger number of tubes for a given size of absorber, and increase the amount of labor needed to assemble it, unless the manufacturer is able and willing to invest in some degree of automation. The choice between the larger tube serpentine and smaller tube parallel configurations is thus very dependent on the costs to each manufacturer in his local environment and at a given production volume.

In the near term, low flow allows existing absorber products, such as copper/aluminum fm-tube, to be connected in a serpentine pattern in the collector without significant hydraulic or thermal penalties. Two large serpentine collectors connected in series (doubling collector pressure drop) plus the losses of the connecting piping, could make the total loss too high for a very low power pump, even under low-flow conditions. However, it may be relatively inexpensive to optimize the bores of both the collector and interconnecting tubing to keep the pump power low enough.

Parallel connected collectors with serpentine absorbers would result in a lower pressure drop but with perhaps poorer heat transfer to the slower fluid, unless the absorber tube bore was reduced.

3.4. Low Flow, Tank Stratification, and Performance

Although some high-flow designs give some degree of tank thermal stratification, low flow will further enhance its usefulness via three effects:

First, the charged tank will be stratified more sharply, making more of the energy in the tank available closer to the desired load temperature. This will increase the solar fraction.

Second, starting the day with a partially charged tank, during subsequent hours of charging, low flow will provide higher water temperatures at the top of the tank. Clearly, high flow from the heat exchanger at the bottom of a cold tank will not deliver water to the top of the tank at a sufficiently high temperature. If a draw must be made this early in the charge cycle, water heated by auxiliary energy must be available somewhere in the system. So low flow will lead to faster recovery for small, but hopefully usable, volumes of hot water. Depending upon the high flow draw profile chosen for comparison, low flow might offer a higher solar fraction by minimizing auxiliary input to these early draws. It is to be noted, though, that variations in the low flow draw profile itself have little effect on low-flow system performance.

Third, for storage tanks with internal auxiliary heaters occupying a top fraction of the tank, excessively strong mixing due to high collector flow rates or high local tank velocities may allow auxiliary heat to reach the solar heat exchanger, and hence, pass that heat to the collector inlet and reduce collector efficiency.

3.5. System Design Considerations

Most important, the tank must be thermally stratified, with the top of the solar portion close to the desired load temperature. Whatever mechanism is used to add heat to the tank, there should be as little mixing as possible. As a corollary, the auxiliary input should be provided so as not to interfere with the operation of the solar part of the tank.

The collector flow rate should be such that fluid is always delivered to the tank at temperatures commensurate with the desired load temperature, while considering the current level of insolation. The best algorithm to control this flow is not yet known, but low fixed-flow works quite well if attention is paid to plume entrainment in the tank. (Better combined solar/auxiliary algorithms could almost eliminate entrainment.)

Too small a heat exchanger will raise both the collector supply and return temperatures, even with an adequate level of collector flow. And if there is mixing with colder water in the tank or in a tempering valve installed at its outlet, either the collector must run hotter or more auxiliary energy must be added to achieve the desired water temperature. These last two effects both lose energy at the hotter collector, create entropy by lessening availability, and so demand more auxiliary energy to make up for it.

4. COMPONENT REPORT: COLLECTORS, ABSORBERS, AND LOADS

4.1. Absorber/Collector

4.1.1. Introduction Low-flow collectors will be designed to deliver temperatures close to the delivered load temperatures. The main operating parameters which distinguish low-flow collectors from high-flow collectors are determined by flow configurations and hydraulics in the absorber tubes. There has been much debate over the way these parameters would influence the overall efficiency of a solar system using the low-flow/matched-flow principle. Specially designed low-flow collectors have been introduced in Canada, Denmark, the Netherlands and Switzerland.

Existing solar collectors can be used for low-flow solar heating systems. Danish investigations [4-1, 4-2] show that the efficiency of Danish solar collectors used for traditional high-flow solar heating systems is not significantly influenced by a reduction of the flow rate. Therefore solar collectors currently marketed can be suitable both for low-flow solar heating systems and for traditional high-flow solar heating systems.

Basic information which was available before Task 14 work began was obtained through two studies conducted at the University of Waterloo in Canada. These studies showed the advantages of material reduction in general for absorbers used under low-flow conditions [4-3]. The studies also demonstrated that drastic reductions in absorber material can be made and that absorber fins have an optimal thickness profile of zero at the tip and their maximum thickness at the base [4-4].

Information obtained on solar energy systems by Task 14 and numerous other studies have provided good insights into the effects of the above mentioned parameters. The product development and manufacture of high-performing, low-flow collectors may now result in a lowered product cost compared to the previous generation of collectors.

Computer models to determine the collector efficiency factor F' for sheet and tube solar collectors use the following expression:

$$F' = \frac{1/U_L}{W\left[\dfrac{1}{U_L[D + (W - D)F]} + \dfrac{1}{C_B} + \dfrac{1}{\pi D_i h_{fi}}\right]}$$

(from Duffie and Beckman [4-5, page 2711). The dependencies in this expression on flow rate are a subject of the Task 14 Dynamic Testing Subtask. A simpler analysis can be carried out by considering the dependence of the heat-removal factor F_R on the flow-rate. This analysis can be performed without a complicated computer model.

4.1.2. Design Guidelines The absorber design for low-flow conditions must be optimized for a typical flow rate and heat-removal factor. This will lead to an optimal absorber design. Design options must be evaluated with respect to manufacturing possibilities and material availability and cost. At some point, thinner material may get more expensive than thicker material, while efficiency changes are minimal.

Under steady-state conditions, the dependence of the heat-removal factor on the flow rate is determined by the equation:

$$F_R = \frac{Q_{gain}}{\tau\alpha\ Q_{solar} - U_L(T_i - T_{amb})} = \frac{\dot{m}C_p}{A_c U_L}\left[1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}C_p}\right)\right]$$

(from Duffle and Beckman [4-5, page 277]).

The fin thickness in relation to the inner diameter of the tube is determined by theoretical optimization and technical limitations in the manufacturing technique. Studies conducted at Waterloo University have determined that the fins do not necessarily need to be rectangular in shape. A step change in fin thickness, so that the fin gets thinner as it is farther from the tube, permits a reduction in material content. Roll-form manufacturing processes, like Sunstrip®, can achieve this type of material reduction [4-6]. A Swiss design (2-shaped tube), combines roll-form and welding techniques in order to optimize the material content in the absorber.

The choice of serpentine or header/riser absorber configurations is determined by a number of factors:

- System design (drainback or closed-loop);
- Velocity in the tubes dependent on tube diameter; and,
- Equal flow distribution in the header/riser configuration.

In general, it is believed that horizontal riser/vertical header construction creates a disadvantage in low-flow conditions because of the difficulty in maintaining equal flow distribution for horizontal mounting. Flow distribution in vertical riser/horizontal header constructions is not a problem because of natural convection

The serpentine configuration requires special consideration in drainback systems in order to allow the tubes to drain completely. When designing low-flow absorbers, these conditions need further investigation. A Dutch study [4-7] demonstrated that a low-flow serpentine absorber with 6 mm ID tubes was still able to drain completely, provided the absorber is mounted at least at a 5° angle to the horizontal.

4.1.3. Test Results A Dutch investigation of four different low-flow serpentine absorbers showed comparable results [4-7]. All absorbers performed almost equally, as expected, under high-flow conditions. However, variations occurred at low-flow conditions below 6 percent.

4.1.4. Insulation The effects of top insulation on the collector were investigated by a Canadian group [4-8]. The study showed a slight change in performance if the top (hot side) of the collector is insulated better than the bottom. In general, the change in performance is considered modest and the study results do not favor investment in thicker insulation materials for the top of the collector. Extra insulation is recommended only if it requires minimal time and cost expenditures.

4.1.5. Conclusions If we consider the effects of the collector and the absorber in relation to a low-flow situation, there is very little evidence that improvements in collector design (apart from the absorber) are cost effective. On the other hand, an absorber designed especially for low-flow conditions is highly advantageous. Drastic material reductions can be accomplished with the absorber. Fin and tube absorbers are preferable for low-flow applications due to their strong potential in reducing the material content. It is believed, from a practical point of view, that serpentine configurations are more reliable than header/riser constructions, since the flow distribution pattern in the absorber is critical under low-flow conditions.

Horizontal mounted serpentine absorbers, used for drainback systems, should allow a slope of the tubes of a minimum 5° angle to drain the tubes completely.

4.2. Load Influence

4.2.1. Introduction The principles involved when using systems with a low-flow collector loop to a heat exchanger/tank are:

- Low flow in the collector loop (approximately 2-4 grams/sec-m2);
- Optimal stratification in the tank;
- Total volume through-put for the collector on an average day equals the total average load in such a day; and,
- Optimization of the flow rate for a specific collector.

Variations in the load and the effects on the system efficiency have been the subject of several previous studies.

One problem is the lack of consistency in the daily load. It is unknown how the individual loads in a household will differ from the original design specifications for a system. Since systems will be designed for the "average" load, variations in each individual household will exist. There is a need to gather more information on the effects of load variations on system performance.

Since the basic principle assumes a match between the load and the total flow through a collector, one can understand that variations in the load on a day-to-day basis would affect the efficiency of the system if flow is kept constant.

These effects were studied by TNO-NL and the United States in [4-9] and [4-10]. The TNO-NL study indicated that variations in load pattern over the day, with a constant collector flow, showed no significant difference between the thermal performance of low-flow and high-flow systems.

The reference load pattern throughout all of the countries involved in Task 14 are different. This implies a system design which will be optimized on the specific average load pattern in each country.

4.2.2. Load Profiles In the studies, three types of analyses have been carried out:

- Variations in the yearly draw with a constant daily load and profile;
- Variations in the daily draw with a constant profile, obtained with a random generator so that the yearly load is comparable with that for a constant daily load; and
- Variations in the daily draw by fixed typical loads for different days so that the load for the week is equal to the average.

4.2.3. Rationale The effects on the yearly system efficiency will be limited to certain periods throughout the year. Typical solar hot water systems are designed to supply enough hot water for a household during the summer. In many cases, the yearly solar fraction will be between 50 and 75 percent. This means that there will be a need for auxiliary heating in the winter. The most critical periods, therefore, are the spring and autumn when the system could on some days meet a 100 percent solar fraction (like in the summer), and on others require auxiliary heating.

Since the effects of load profile on system efficiency are primarily of concern during the autumn and spring, one can rationalize that the effects of load variation are limited to roughly half the year. This, of course, will limit the effects on a yearly basis.

4.2.4. Results The Task 14 studies demonstrate that variations in the load have an effect on the daily efficiency of the system compared to the "average" design load. However, varying the flow rate in the collector loop to achieve a better matched flow may not significantly affect performance. In other words, if the collector loop is designed to operate under optimal low-flow conditions, the effect of the load on a day-to-day variation (both in profile and in total draw-off) is likely to be small.

4.2.5. Conclusions This study concludes that variations in load pattern have a minimal effect on the yearly efficiency. However, it is important to choose an optimal flow rate for a specific system and corresponding solar fraction. The solar fraction relates to the storage volume. A storage volume larger than the daily load will make the system less sensitive to the load and will lead to a higher performance. An economic evaluation should be made to match the extra storage cost to the higher performance.

The fact that the optimum collector flow rate is relatively insensitive to variations in the load and profile is very important for practical applications. A solar energy system, once tuned to the optimum collector flow, is unlikely to need adjustment to maintain high performance when the draw changes.

5. COMPONENT REPORT: HEAT STORAGES, HEAT EXCHANGERS, AND AUXILIARIES

5.1. Introduction

Work on low-flow solar heating systems has been carried out at universities and research institutes in various countries since 1979 [5-1].

The main reason for the thermal advantage of low-flow solar heating systems is the extensive thermal stratification inside the heat storage during the operation of the system. The thermal advantage of the system increases with increasing thermal stratification in the heat storage. The mechanism that transfers heat from the solar collector fluid to storage should therefore ensure maximum thermal stratification. Further, the storage design should ensure that temperature differences are equalized as slowly as possible.

The heat storage, the collector side heat exchanger, and the auxiliary energy supply system are therefore key components for low-flow systems.

The suitability of differently designed heat storages, heat exchangers and auxiliary energy supply systems are described in this section.

5.2. Market and Regulatory Issues in Participating Countries

Regulatory issues concerning hot water tanks and design traditions differ between countries. In addition, in some countries few manufacturers of hot water tanks exist while in other countries many manufacturers are marketing hot water tanks.

Therefore, the designs of standard hot water tanks and standard solar tanks vary from one country to another. Short descriptions of market and regulatory issues in the participating countries follow.

5.2.1. Canada The majority of solar water heating systems in Canada consist of a solar preheat tank connected to an electric auxiliary water heater. Electric water heater tanks are widely available at a low cost and are therefore predominantly used for the solar preheat tank.

5.2.1.1 Tank design.

Canada are generally dictated by requirements specified by the Canadian Standards Association (CSA). The following are noted:

- Construction: Tanks are typically of glass-lined steel construction with anodic protection and include thermal insulation and outer metal jacket. Nominal capacities are 175 and 270 liters. A hydrostatic pressure test to 2.1 MPa is required, in addition to other structural tests. Tanks must be installed with a 98°C/1.0 MPa temperature/pressure relief valve.

- Diffusion Ratio: The tank design must provide means to minimize mixing of the inlet water with water stored in the tank. The diffusion ratio, as determined by test, requires at least 90% of the tank capacity to be delivered before the water temperature drops more than 17°C.

- Energy Efficiency Requirement (Standby Loss): The standby energy loss of tanks ranging in sizes from 50 to 270 liters shall not exceed the standby loss as calculated by the following formula:

  Standby Loss (Watts) = 61 + 0.20 Volume (liters)

5.2.1.2. Heat exchanger. The use of standard electric water heater tanks for the solar preheat tank dictates the use of an external collector side heat exchanger. The most common external heat exchanger is a copper shell and coil, single-wall design with thermosyphon operation on the potable water side.

5.2.1.3. Heat transfer fluid.
propylene glycol and distilled water. The propylene glycol is typically Dowfrost HD which includes additives for corrosion protection at high temperatures (up to 165°C).

5.2.2. Denmark Two types of hot water tanks are commonly used: A hot water tank with a built-in heat exchanger spiral and a hot water tank with a mantle welded around the surface of the tank. Solar collector fluid is circulated through the heat exchanger spiral or the mantle.

The auxiliary energy supply system, either an electric heating element or a heat exchanger spiral, is normally built into the top of the tank. Therefore, one tank provides storage for the solar heating system and the auxiliary energy system.

For systems with a single separation between the solar collector loop and the public water supply, an approved solar collector fluid must be used. If pure water or BP Termovæ ske S is not used, an approved tracer must be added to the fluid. At present, the following heat transfer fluids and tracers are approved:

Heat transfer fluids: Water and propylene glycol.

Tracers: Brilliant Blue, Green S.

The solar collector loop is normally a pressurized loop with a security valve opening at 2.5 bar.

The minimum material thickness of the tank S_{min} is normally determined by the equation:

$$S_{min} = \frac{0.11 \cdot D_y \cdot \sqrt{k \cdot p}}{100} \text{ mm}$$

where D_y is the outer diameter of the tank in mm, k is a constant determined as the ratio between the modulus of elasticity of steel at 20°C and the modulus of elasticity of the tank material at the maximum tank temperature, and p is the design pressure in bar equal to 16 bar.

Hot water tanks are normally made of steel St 37-2 or stainless steel.

The hot water tank and any heat exchanger spirals in the tank must be protected against corrosion. If St 37-2 steel is used for the tank and the spiral material, both are normally enamelled. Tanks with enamelling are equipped with an anode. Alternatively, steel tanks can also be protected against corrosion by means of coating with an approved synthetic material. At present only rilsan coating is approved.

A shut-off valve, a one-way valve, and a safety valve must be installed on the cold water inlet pipe to the tank.

At present, all marketed heat storages are tested at the Danish Solar Energy Testing Laboratory. Thermal characteristics of the heat storage are measured. A data sheet for each heat storage is prepared. The data sheet includes: The heat storage capacity, the thermal loss coefficient of the heat storage and the heat exchange rate.

5.2.3. The Netherlands Both traditional and solar domestic hot water production must comply with regulations as formulated in Dutch working documents from VEWIN (association of water authorities in the Netherlands).

These working documents are presently being reformulated. The new documents will include a section on solar hot water systems. It is expected that the new working documents will be finished in 1995.[1]

The present working document VEWIN WB 5.4b states the following:

> "Hot water apparatus using indirect heating sources must use a double-wall heat exchanger between the heat transfer medium and the drinking water."

As a result of these regulations, water authorities will generally approve use of drinking water from solar energy systems, using a single-wall heat exchanger if they operate under a pressureless condition.

Any addition to the drinking water is prohibited. Recently one water authority allowed addition of a glycol solution with an ATA approval. However, this is disputed by other water authorities, especially since the pressure in the system is not controlled.

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[1]Available from: KIWA n.v.; Certification and Inspection, Sir Winston Churchill-laan 273, P.O. Box 70, NL-2280 AB Rijswijk, the Netherlands, Phone: + 31 70 395 3477, Fax: + 31 70 395 3420

Present solar systems are developed based on these working documents, resulting in drainback systems filled with potable water, in a closed loop.

The majority of hot water tanks are made of copper. For solar tanks, 316 Ti stainless steel the predominant choice, although a few glass-lined tanks are on the market.

5.2.3.1. Conclusion.

as a circulating fluid are currently unresolved, the potential use of these solutions in the future is uncertain. At the present time, regulations prohibit their use with a single-walled heat exchanger. Therefore, water-filled drainback systems or ICS systems which use potable water in the storage are the only systems allowed on the market.

5.2.4. Spain Solar hot water systems in Spain utilize one of three types of tanks: tanks with an external jacket around a part of the surface (with or without an electric heater inside the mantle), tanks with a built-in heat exchanger spiral, and tanks without any exchanger element.

The tanks must be manufactured in accordance with the Regulations of Pressurized Equipments, Instrucción Téc nica Complementaria MJAP11. They must be tested with a pressure double that of the working pressure of the tank, and must be approved by Ministerio de Industria y Energia.

The technical specifications of collector fluids and tanks are as follows:

Potable water is commonly used in the solar collector loop. In some cases, additives are used depending on climatic conditions and the kind of water. In places without any risk of freezing, only water or demineralized water with anti-corrosives can be used. In places with freezing, demineralized water with antifreeze and nontoxic corrosion inhibitors are used. The commonly used antifreeze is propylene glycol.

Spanish tanks are typically constructed of:

- Galvanized steel for any size
- Stainless steel
- Vitrified steel for small sizes (with anodes for cathodic protection)
- Copper

Tank insulation materials must provide thermal conductivity less than 0.52 W/mK and temperature resistance higher than 80°C. The minimum thicknesses for insulation are 30 mm for less than 300 ℓ and 50 mm for more than 300 In case of outside tanks bigger than 2,000 a minimum thickness of 100 mm is required.

The hot water inlet from the solar loop is located at the top of the tank, except in tanks with an electric element located at the top in which the inlet is always below the auxiliary volume. In systems where the heat exchanger is a built-in helix, the helix is located in the lowest part of the tank.

5.2.5. Switzerland

5.2.5.1. Tank concept.

with a 400 to 500 ℓ volume. The heat exchanger spiral is located in the lower part of the tank and an auxiliary energy system is located in the middle of the tank.

In addition to the SDHW systems, systems are often combined with space heating. More than half of the systems are tank-in-tank designs, where a DHW tank is incorporated into a larger tank for space heating. Typical volumes are 200 to 400 ℓ hot water tanks in 1,500 to 3,000 ℓ tanks of water for space heating.

5.2.5.2. Tank design.

water tanks. The responsible organization Schweizerischer Verein der Gas und Wasserfachleute (SVGW) has the authority to test new products before they can be sold on the market. The maximum test pressure is 12 bars and the maximum pressure under operation is 6 bars. Corrosion protection is not incorporated into the test procedures. Cold water inlet equipment is similar to that on non-solar tanks, usually consisting of a shut-off valve, a non-return valve, pressure reduction including a filter (from 6 bars mains pressure to 3 bars tank operation pressure), and a safety valve.

5.2.5.3. Auxiliary energy supply.

lower electricity prices during night hours. A number of systems with an oil- or gas-fired furnace have a second heat exchanger spiral in the upper part of the tank, in addition to the electrical heating element, to supply auxiliary heat during the winter.

5.2.5.4. Collector loop.

water-glycol mixtures. All of the components, such as the pump, expansion vessel, security valve (3 bars), etc., are similar to ordinary heating systems.

5.2.5.5. Heat transfer fluid.

by use of water-glycol mixtures. A number of water-glycol products are marketed by different producers such as Hoechst or BASF etc. (Single-walled heat exchangers are allowed and there is no restriction as to the use of either propylene- or ethylene-glycol.)

5.2.6. United States There are two types of solar storage tanks commonly used in the United States. Both tanks are commercially available and are made by one of the country's largest hot water heater manufacturers. The primary reasons for the use of these tanks are cost and immediate availability.

5.2.6.1. Tank design. Commercial tanks are glassline steel with a volume of 200 to 400 ℓ with optional top electrical heating elements. While both tanks appear identical, one tank has a wrap-around heat exchanger made of copper which is 40 to 50 meters long. This tank can be used in either a closed-loop glycol or drainback system. The tank without the heat exchanger is the most common tank found in the United States. Most are open-loop systems located in non-freezing climates. This tank is also used for side-arm heat exchanger systems and drainback systems, which have separate drainback tanks. These storage tanks are tested to 30 bars and have an operating pressure rating of 15 bars.

5.2.6.2. Heat exchangers. The United States uses all types except the mantel and in-tank heat exchangers. The main reason for not using the in-tank or mantel design is that one code listing group, I.A.P.M.O. (International Association of Plumbing and Mechanical Officials), which is strong in the western United States, requires double-wall, vented heat exchangers for any potable-, non-potable transfer. While industry has repeatedly requested allowance of non-toxic fluids, such as propylene glycol, to be used with a single-wall exchanger, I.A.P.M.O. has resisted any change.

5.2.6.3. Heat transfer fluid. United States systems usually use propylene glycol with a closed-loop design and demineralized water with a drainback design.

5.3. Thermal Performance of Low-Flow Systems with Differently Designed Heat Storages

Heat storage types used in small, low-flow systems employ different heat exchange principles for transferring heat from the solar collector fluid to the domestic water. The auxiliary energy supply system, which heats the water to the required temperature, can also be designed in different ways. Consequently, system types with several designs can be used as low-flow DHW systems.

The thermal performance of the various system types depends on the design of the system. Consequently, before the desirability of each system type is judged, the design and operation mode must first be optimized. This process will result in optimum designs which differ between countries, since the system costs are highly influenced by regulatory issues, common practices, and so forth.

Thermal performance of the system is influenced by the design of the auxiliary energy supply. Therefore, the thermal performance of each system is presented both with and without top-heating by an auxiliary energy supply.

In Denmark, the thermal performance of top-heated systems has been investigated at the Thermal Insulation Laboratory [5-2], [5-3]. The results of these investigations are summarized in Section 5.3.1.

In the Netherlands, the thermal performance of systems without auxiliary top-heating has been investigated at Level Energy Technology [5-4], [5-5] and at TNO Building and Construction Research [5-6]. The results of these investigations are summarized in Section 5.3.2.

5.3.1. Heat Storage With Built-In Auxiliary Energy Supply In Denmark, low-flow systems with four different heat storage/heat exchanger designs have been investigated [5-2], [5-

3]. Figure 5-1 shows a schematic of the four low-flow systems. For simplicity, the auxiliary energy supply systems are not included in the figure.

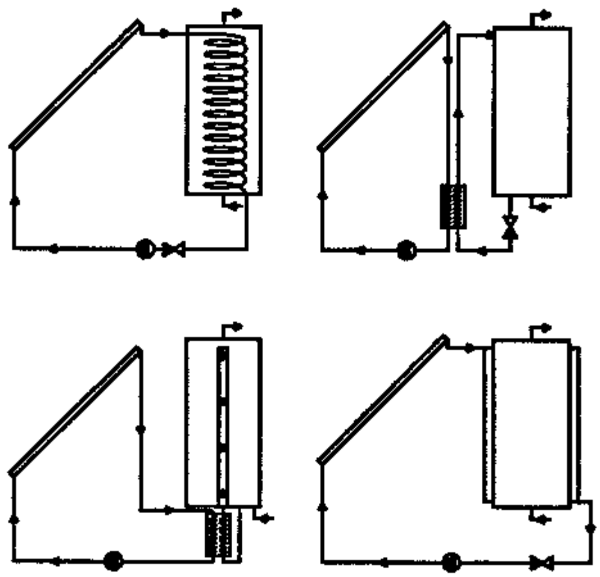

Figure 5-1. Schematic Illustration of Four Low-Flow Solar Heating Systems Investigated in Denmark with Differently Designed Heat Storages.

The first system consists of a hot water tank with a built-in heat exchanger spiral going from the top to the bottom of the tank. Solar collector fluid is circulated through the helical heat exchanger.

The second system consists of a hot water tank and heat exchanger loop with an external heat exchanger placed below the tank. Solar collector fluid is circulated through the heat exchanger. Water from the bottom of the tank is circulated through the heat exchanger to the top of the tank by natural convection.

The design of the third system is similar to the design of the second. This system also makes use of an external heat exchanger. Water is circulated from the bottom of the tank through the heat exchanger back to the hot water tank through a stratification manifold. The stratification manifold ensures thermal stratification inside the hot water tank. Water is circulated by natural convection.

The fourth system uses a mantle hot water tank as the heat storage.

Side-by-side tests with the four systems were carried out under realistic conditions. The hot water tanks of all four systems had electric heating elements located at the top of the tanks as the auxiliary energy sources. Therefore, the design of the auxiliary energy supply system did not influence the results of the investigations.

The detailed designs of the systems and the measured results are provided in [5-2] and [5-3].

The measurements showed little difference at high solar fractions in the thermal performance of the various low-flow systems. The differences between the thermal performance of the four systems are more pronounced during periods of low solar fraction. During these periods, the mantle heat storage system performs better than the other systems.

Differences between the yearly thermal performance of the various systems show up clearly only for relatively small solar fractions.

5.3.2. Heat Storages Without Built-In Auxiliary Energy Supply

5.3.2.1. A Dutch storage concept study. storage concepts provided a basis for the development of the future Dutch advanced solar energy DHW systems. The subject of this study was short-term thermal storage, the central component in a solar energy DHW system. The work embodied the selection of promising storage concepts, testing them at low-flow condition and analyzing the measurements. To support the results of the measurements, numerical simulations for both low-flow conditions and standard-flow conditions were carried out.

5.3.2.2. Storage selection and description. Storage selection was based on a number of conditions:

- The selection was made from currently marketed storage systems, as well as more experimental storage systems. As a reference case, a marketed storage system was used.
- Both collector circuit heat exchange and potable water heat exchange were considered.
- Collector circuit heat exchangers were located at the storage bottom or, for superior performance, run from bottom to top of the storage, being either a mantle or a helix.
- Potable water heat exchange by means of a finned helix or by means of a small potable water tank was considered.

Five storage types that satisfied these criteria were selected. (See Figure 5-2.) Storage 1 and 2 were currently marketed systems. Storages 3, 4 and 5 were experimental systems.

5.3.2.3. The storage tests. collector circuit charge step test was carried out. This test was followed by a mix, or diffusor, test. After reheating, a heat-loss test was carried out, followed by a discharge step test. Finally a simulation of "realistic" operating conditions was achieved with a 50% "noon" draw and a complete tank draw after 8 hours.

5.3.2.4. Results of the Dutch study.

- The perforated, tube inlet diffuser did not function properly. The absence of flow restrictors inside the tube may have caused poor performance. However, the malfunctioning diffusor had little influence on the system performance.

  Storage 4, with the collector inlet at mid-height, maintained heat in the upper part of the tank if colder collector water entered storage. When colder water entered tilt mantle, this inlet configuration functioned better than the tested inlet diffuser because it kept the upper section hot. However, during charging, the plume inlet caused a uniform temperature rise in the upper part of the storage because the plume of hoi water was mixed before it reached the top of the mantle. In this situation, the inlet diffusor functioned better.

  Storage 1 did not utilize its capacity. The collector heat exchanger should be extender to the bottom of the storage.

  Quality of storage insulation varied. One of the marketed storages had the largest heal loss of 1.86 W/K, although all connections were located at the bottom, whereas one experimental storage had the lowest heat loss, 0.93 W/K, although all connections were at the top of the storage.

  Storage 3, with the potable water heat exchanger, was a typical standard flow system The entire heat exchange area of the helix should be utilized for maximum performance. The dynamic test showed that the bottom part of the storage was still al a low temperature. Consequently the heat exchange performance was poor. Standard collector flow would have provided a more uniform storage temperature and consequently, a larger useful heat exchange area for the helix.

  One general conclusion is that the numerical simulations showed the draw pattern hac a much larger influence on storage performance than the primary choice of storage concept.

5.4. Auxiliary Energy Supply System

The auxiliary energy supply system can either be an integrated part of heat storage or i can be separate.

If the system is integrated into heat storage, it is important that the volume of the hea storage reserved for the solar collectors be sufficiently large [5-8]. Also, the auxiliary energy supply system must not heat the water to a temperature higher than required for comfort, health and safety. Finally, it is extremely important that the auxiliary energy supply system be located installed, and insulated in such a way that the extra heat loss from the heat storage caused by the auxiliary energy supply is held to a minimum [5-9].

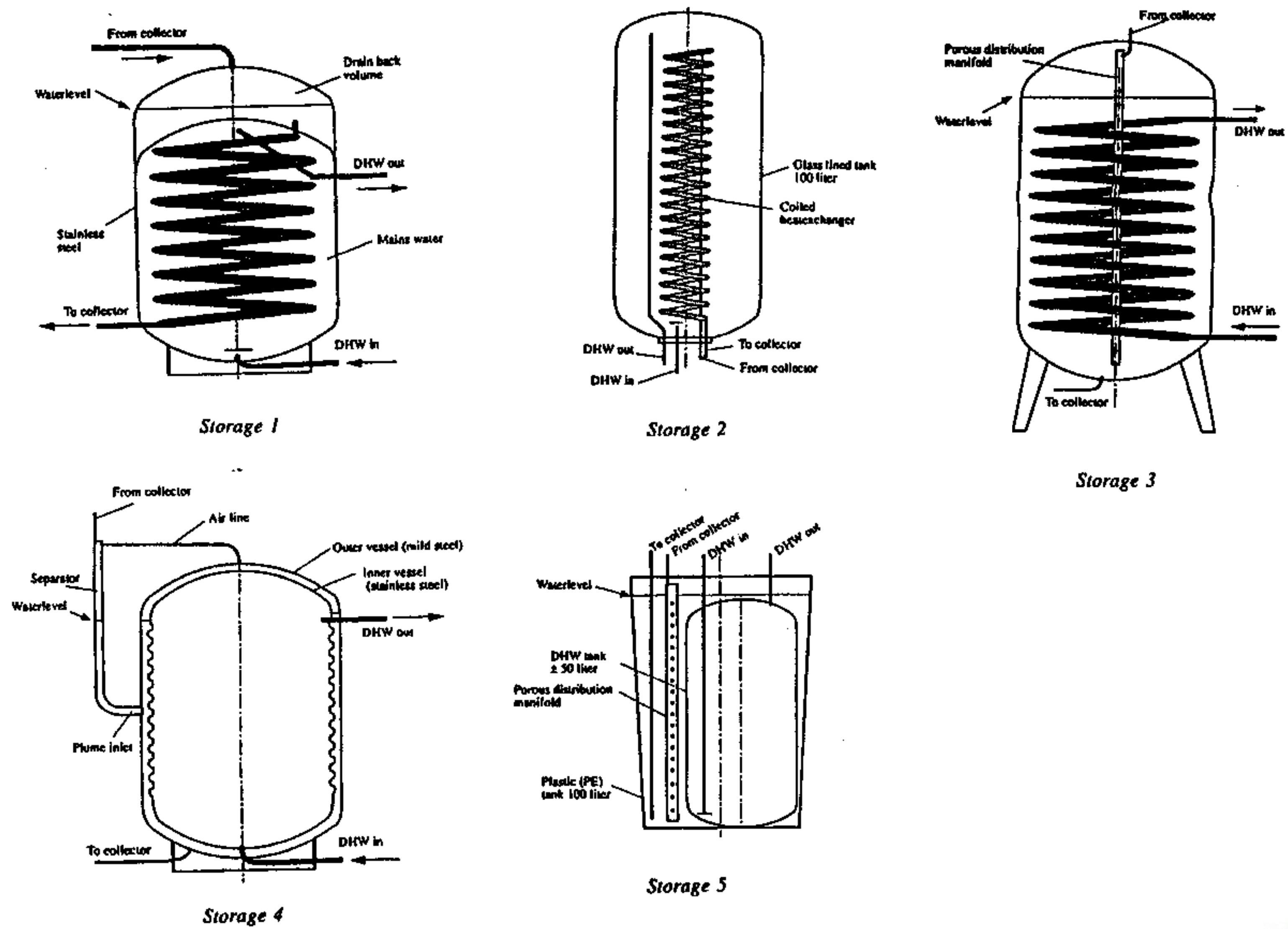

Figure. 5-2. Schematic Illustration of the Five Investigated Heat Storages.

5.5. Conclusions

The suitability of various DHW low-flow systems with different heat storage designs has been investigated, revealing little difference in thermal performance. Only at low solar fractions are there performance differences of importance.

Therefore, cost, rather than performance considerations, is likely to influence decisions on heat storage design.

In order to design an optimum heat storage, the following should be taken into consideration:

- The volume of heat storage reserved for the solar collector should be sufficiently large, depending on solar fraction and economics. A rule of thumb for dwellings is about 50 ℓ/m^2

- The capacity of the heat exchanger used to transfer heat from the solar collector loop to the heat storage should be sufficiently large, about 50 W/K per m^2 solar collector.

- The heat loss of the heat storage should be reduced to a minimum by insulating carefully. Thermal bridges caused by pipe connections should be avoided in the upper part of the heat storage. The total heat loss coefficient should not exceed that corresponding to a perfect insulation with about 5 cm of mineral wool.

In some countries, relatively expensive solar heat storage types are used. These heat storages are manufactured in relatively small numbers. In other countries, inexpensive standard hot water tanks manufactured in large numbers are already used as solar heat storage.

In the future, inexpensive solar heat storage will most likely be developed based on standard hot water tanks and/or utilization of design principles allowing use of inexpensive materials and techniques. For example, the drainback approach makes it possible to use a cheap, unpressurized plastic tank.

6. COMPONENT REPORT: PUMPS AND CONTROLLERS

6.1. Introduction

<u>6.1.1. Overview</u> There are few low-power, low-flow, moderately-high pressure pumps available for "microflow" solar water heaters. Most existing low power and low cost centrifugal pumps do not have a sufficient pressure rating to start drainback systems or to run systems with small bore tubing. Also, some pumps are designed primarily for higher flow and do not easily provide the proper flow rate specified in the system design, necessitating adjustment on site.

Positive displacement pumps readily control flow rate, but tend to be bulky and expensive.

Compared to 100W pumps once in use, a system's net thermal rating could be raised about 10% if 5W pumps were available. Since the start of this Task, 20W to 30W pumps have come into wider use, so the power saving of switching to even lower power pumps is somewhat diminished. However, the capital cost savings could still be substantial. Also, very low power operation would make PV power attractive for off-grid sites now, and for all sites if the price of PV modules dropped sufficiently.

<u>6.1.2. Centrifugal Pumps</u> A number of European participants, including the Dutch, use a Grundfos pump, model UPS 25-40, that uses 30W at its lowest speed and is priced at approximately US$40. Its maximum head of about 1 meter at this speed is marginal for small bore tubing. It can perform a drainback start-up only for systems with up to a 4-m elevation. [illegible] than necessary. (See Figure 6-1.)

Another possibility, being examined by the Dutch team, is a small automotive windshield washer pump, powered by a 12V DC brush-type motor. It has a seal between the motor and pump sections, and motor bushings instead of ball bearings.

At 12V the pump can pump 1 ℓ/minute at an 8 meter head, and consumes 37W of power. The test lifetime at this voltage is 24 hours. By reducing the voltage to 6V, for example, the head drops to 3 meters at 1 ℓ/minute, the power drops to 8.4W, and the test lifetime increases to 2,000 hours (but with significant wear). At 4V, the flow drops to 0.67 ℓ/minute at 1.7 meter head, but the extrapolated lifetime might rise to between 9,000 and 25,000 hours. (See Figure 6-2.)

The Canadian team is developing a small, high-speed centrifugal pump of potentially low cost, with enough pressure to start a drainback system. The design concept emphasizes minimum wear, and hence maximum durability. The variable speed design inherent in the electronic drive allows automatic flow regulation, assuring that the system operates as designed.

Note that closed loop systems (non-drainback, usually with glycol antifreeze) do not need an increased pressure rating at start-up, other than to overcome cold glycol viscosity. This eases the pump ratings and expands the selection available.

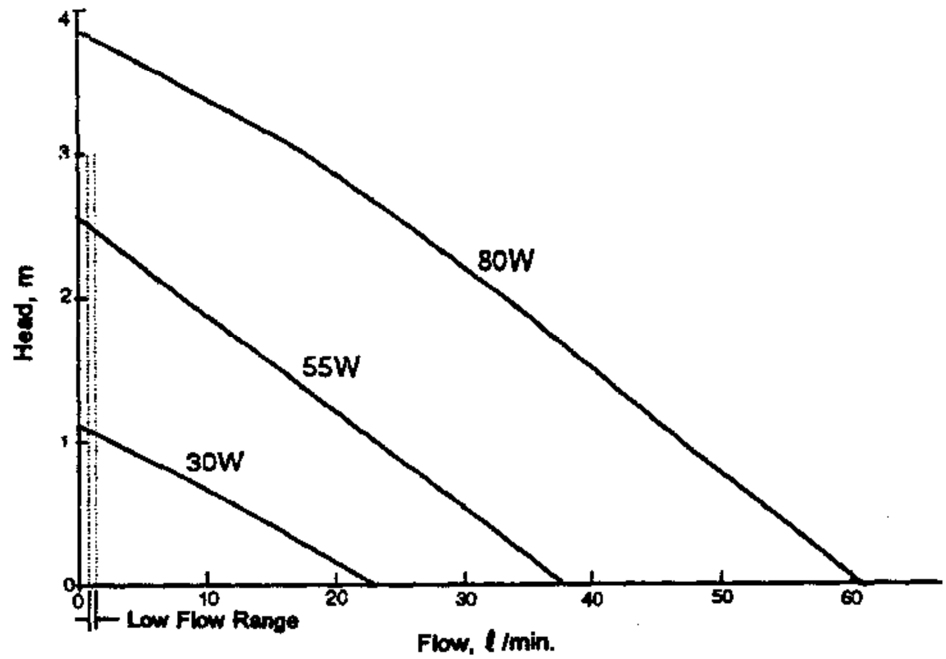

Figure 6-1. Grundfos UPS 25-40 Pump Performance (Source: Grundfos).

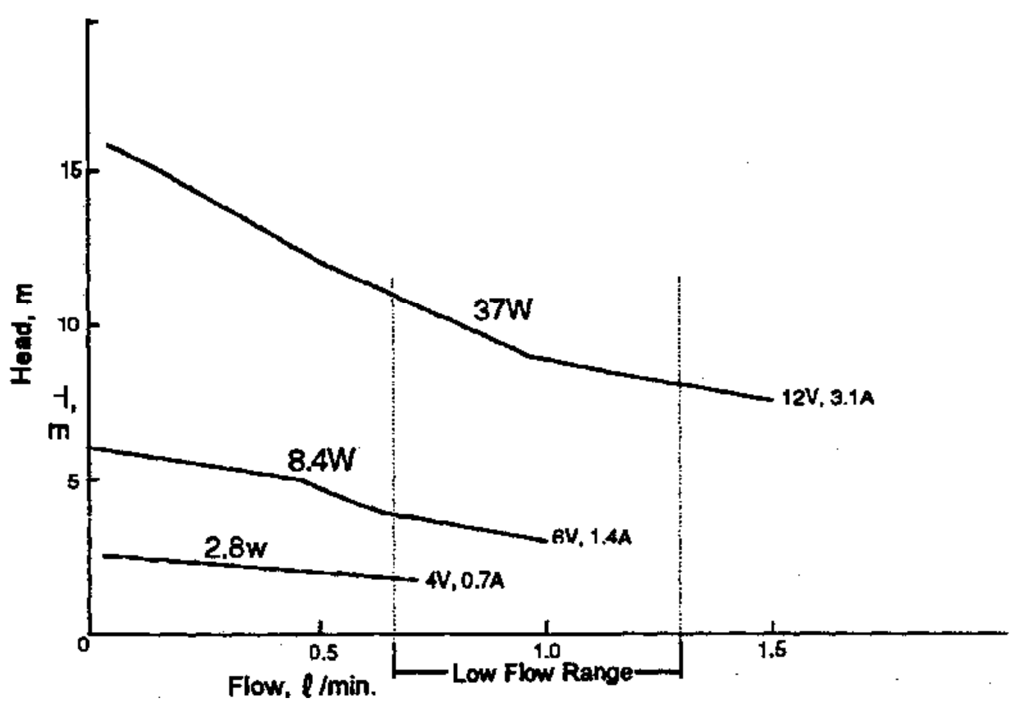

Figure 6-2. Bosch Impeller Pump Performance (Source: TNO, NL).

<u>6.1.3. Positive Displacement Pumps</u> The Swiss participants at SPF/ITR Rappersvil are evaluating a PTFE ("Teflon") diaphragm pump (KNF ND 1.100) requiring 20 to 24W. At one bar it can pump 40 ℓ/hr, or 0.67 ℓ/minute. Start-up pressure can reach 3 bars. Durability is expected to be 20,000 hours. The price in 1000 quantity is about 270 Sfr, or about US$186. (See Figure 6-3.)

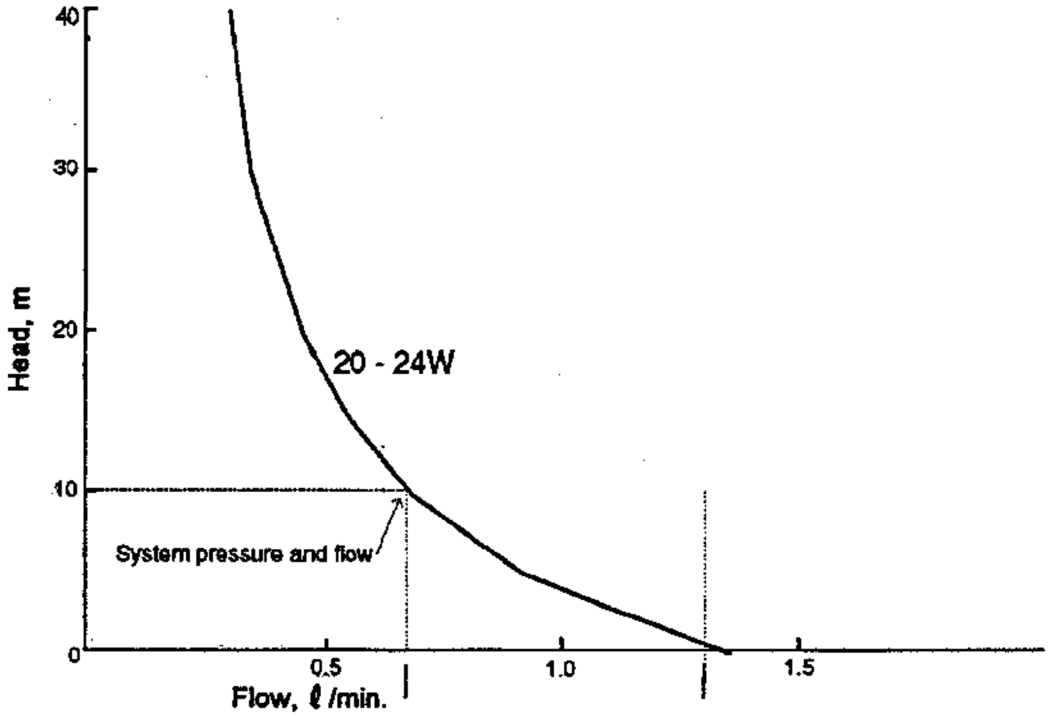

Figure 6-3. PTFE Diaphragm KNF ND 1.100 KT Pump Performance (Source: KNF data sheets via SPF/ITR, Rapperswil).

The pump used in many existing Canadian low-flow systems is a Procon vane pump, powered by an AC motor, or a DC motor with either a transformer/rectifier or a 17 to 20W PV panel. The DC pump is priced at about US$175, and the PV module is about the same. At 1.38 [illegible]
efficiency of 26%. As a relatively high-power capacity, positive displacement pump (about 7 bar and many ℓ/minute), a pressure-flow performance curve is not relevant to the present application.

Both of these pumps are much more expensive than desired for solar DHW systems.

6.2. Comparison of Different Concepts

The nature of centrifugal pumps is such that low speed pumps (i.e. 3,000-3,600 RPM) will have either too little pressure or too much flow, or both, for single-family, SDHW low-flow systems.

Positive displacement pumps have piston, gear, vane, and/or valve wear points that make the pump sensitive to fine debris in the fluid. Diaphragm pumps eliminate sliding contact, but still have valves which are subject to wear.

Two of the known "thermal pumps" are quite complex, both to build and to install, and are expensive. This type of pump was judged by Dutch evaluators to offer no cost/performance benefit

6.3. Design Criteria for Low-Flow Pumps and Controls

6.3.1 Pumps The desired operating characteristics for a pump for solar collector loops depend on the system design. Lower latitude sites may not need a pump at all, the tank being installed on a roof above the collectors to allow the heated water to thermosyphon to the tank.

For the higher latitudes where freeze protection is required, a closed loop can be used, with a water-antifreeze mixture. This approach can use a low-pressure, centrifugal pump because the supply and return fluid columns are always filled and the only pressure demand comes from fluid viscosity. This can be high during a cold start, but a small flow will occur and eventually warm up the loop. Thus operating pump pressure, and hence power, can be fairly low.

Drainback systems can use plain water without antifreeze if the piping and pump design ensures that the water can drain from the outdoor loop. Because the liquid is replaced with air, the pump must refill the loop, starting with the supply side. This results in a static head that may well exceed the running pressure. Centrifugal pumps must run at higher speeds (or have larger impellers) to reach higher pressures. This usually produces flow rate too high for a cost effective system design.

Development of easy-to-install, flexible, pre-insulated tubing bundles has made it desirable to use smaller tubes, raising the pumping pressure even at low-flow rates. If a higher pressure pump can be made inexpensive enough not to use up all the cost savings on the tubing, a better system results.

6.3.2. Controls The most common controller is the fixed delta-T type that turns on the pump (at either a fixed speed, or two speeds including a high speed for drainback start-up) when the collector is warmer than the bottom of the tank. For stability, there is hysteresis between the "on" and "off' temperature differences, the "off' being lower. The pump is turned off if the tank temperature rises too high. Such a device is simple and readily available.

Photovoltaic power for the pump can provide an alternative control strategy. The pump will run only when the sun is shining, and the speed will increase with the level of insolation. All that needs to be added is over-heating protection for the tank. If the pump is already DC powered, the electronics design can be very simple. On the other hand, the cost of electronics is decreasing so complexity (e.g. brushes, commutator) may be shifted from the mechanical pump to an electronic circuit. The present, somewhat high, cost of the PV array can in some cases be offset by the cost savings in not having to install a mains cable and outlet in the vicinity of the pump.

Another control device is the so-called "light switch" (a photo-detector), which, like PV powering, runs the pump when the sun shines, although usually at a fixed speed. Power is brought from the mains, as usual.

As low-flow systems have improved, there appears to be a diminishing additional energy benefit to be gained by using variable flow, probably no more than a few percent. Further studies are required before variable flow could be proposed as a significant energy producer. But if the pump is electronically driven, variable flow will add almost no cost, so the additional benefit might be gained for free. On the other hand, variable flow may significantly enhance tank stratification under fluctuating conditions, by minimizing the strength of, or eliminating, thermal inversions.

6.4. Development of a New Low-Flow Pump

The best pump concept is one that is inherently simple, making it possible to avoid mechanical contact and its attendant wear.

6.4.1. Project The project was to design, build, and test a low-flow centrifugal pump, following the above criteria.

6.4.2. Purpose The purpose was to develop a pump with the special characteristics needed in low-flow solar water heaters, including drainback systems with the collectors 20 meters above the pump.

6.4.3. Description of Work A small high-speed centrifugal pump was designed and built. To achieve the speed necessary (up to 40,000 RPM) to break free of the pressure-flow limits of mains-driven pumps, the motor power was provided with electronic frequencies in the 2 to 3 kHz range. The pump weighs about 30 g, of which the rotor contributed two grams.

The pump was designed to minimize parasitic losses within the constraints of physical size (limited by the precision of the smallest components the present tooling can produce). Dimensional inaccuracies in the first prototype appeared to cause hydraulic losses higher than those predicted.

The motor has no brushes, allowing it to be immersed in the fluid. Because of this, the pump has no shaft penetrations and hence no seals to the outside. Being centrifugal, it has no valves. The result offers low friction, low complexity, and potentially high durability.

The target flow and pressure were 1.3 ℓ/minute at 0.9 atm, with a pressure maximum of 2 atm at start-up. One set of tests at 13.2W of DC input achieved target pressure and flow, with a maximum pressure of 2.2 atm (no flow), and a maximum flow of 1.9 ℓ/minute (no pressure). (See Figure 6-4.)

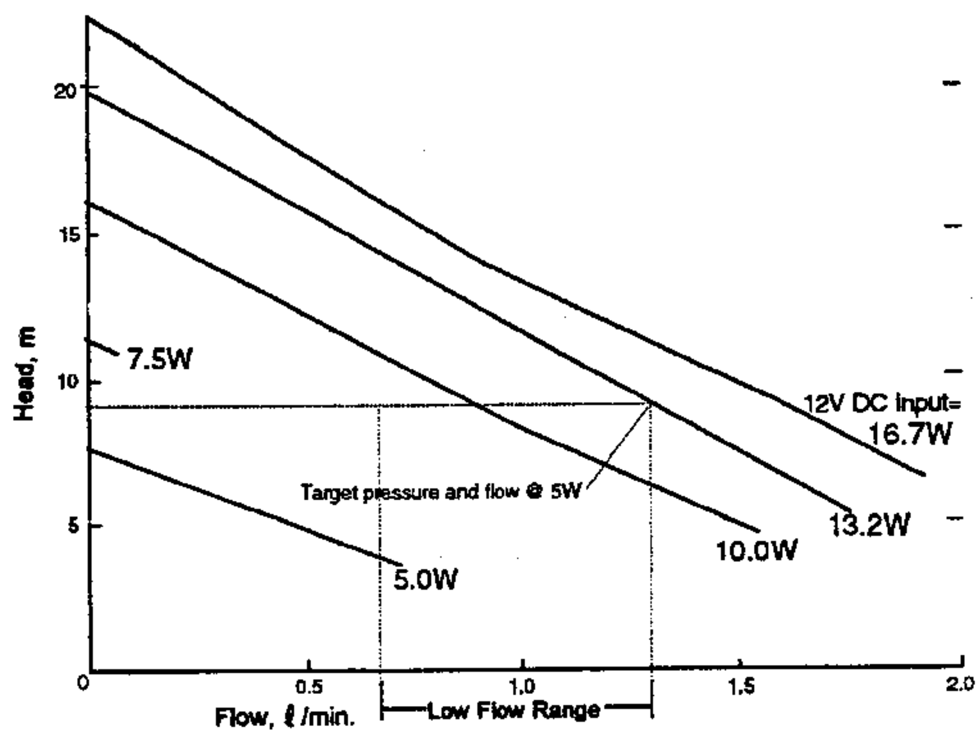

Figure 6-4. Canadian Nanopump First Prototype Performance (Source: Negentropy Inc. in-house tests).

The target power consumption was 5W. The pump was tested at power levels from 0.75W to 16.7W, and at speeds from 12,000 to 43,000 RPM. It did not achieve target flow and pressure at 5W.

The pump drawing cannot be supplied until the patent application has been filed.

The pump was initially intended to be grid powered (by means of a small AC adapter), with PV power as an option.

The bearings are hydrodynamically lubricated with water. There was momentary low speed rubbing contact at a two gram load on these bearings as the pump started, but none during operation.

No corrosion is expected. Exposed parts will be of ceramic, plastic, or stainless steel. Since the total weight is only 30 grams, corrosion resistant materials do not appreciably affect cost.

The pump is not intended for applications involving a continuous throughput of hard water. Small internal clearances have little tolerance for lime build-up. The normal use of the pump is in closed systems only, where the sole source of lime is the initial charge of water, plus any replacement over the life of the system. These charges normally consist of an antifreeze mixture, and can economically be made with distilled water since the total fluid volume is only a few liters in the full microflow design.

How much filtering the pump inlet will require is unknown as yet. Small internal clearances would suggest a 25-micron filter.

There are no restrictions on the location of the pump. It is designed for the start-up of drainback systems up to 20 meters in height.

The system connections are as simple as possible for a pump having inlet and outlet connections. A simpler, slightly less expensive option is to use the pump in its submersible version installed in the fluid reservoir, saving a reservoir-to-pump connection.

6.4.4 Control The pump is inherently capable of variable flow, but the initial control algorithm will incorporate fixed flow for grid-connected systems. The PV-powered option will naturally exhibit variable flow.

Integrated auxiliary control is planned for the controller but is not part of the present prototype power driver. When in-line-auxiliary control is implemented, the tank stratification can be guaranteed, and more electricity consumption can be shifted to off-peak.

Boiling protection will be the responsibility of the controller, by draining the collectors when they cannot be cooled. It is suggested that microflow systems use antifreeze due to small-bore pipe (Life-Line®) draining considerations under freezing conditions, so the controller is not strictly necessary for freeze protection. The collector loop would still be drained during freezing conditions, or when there is no energy to collect, but mostly to save energy and reduce viscosity during initial fluid heating on re-start.

6.5. Future Developments

Further developments could reduce the size and increase the efficiency of the pump. The motor electromagnetic efficiency is currently 85%, including electronics, but the overall efficiency is only 14%. All of the parasitic hydraulic losses are surface area dependent, and both the motor and the impeller could be made smaller with the right manufacturing equipment. Future bearing designs could eliminate all wear. The present 12V control chip uses bipolar transistor technology, and about 0.7W could be saved using a CMOS chip.

6.6. Conclusions

6.6.1. Common Conclusions Some low cost centrifugal pumps may prove to have enough durability and pressure rating to be competitive. Usually, though, they have too much flow capacity and are not easily regulated to provide predictable flow at lesser rates.

Most existing positive displacement pumps are too expensive, although some are low power. Their durability may not always be adequate. They do, however, provide good flow rate control.

6.6.2. Specific Conclusions (Canadian Pump) It appears possible to develop and build efficient, low cost, high reliability pumps weighing 30 grams or less. A major cost is in the electronics, and is amenable to dramatic reduction with volume production.

The basic motor design works well. The pump needs further technical development in the fabrication of hydraulic components to achieve maximum efficiency. The commercial electronic 12V control chip works reasonably well, once the original circuit design was severely modified to overcome chip limitations, but that chip consumes nearly 3/4W. A new (and smaller) circuit board with a lower power 5V chip is in final development, and with minor hydraulic improvements, lOW power consumption is anticipated. Ultimately, a more sophisticated control chip is needed.

There is no real manufactured cost data yet, but the pump is expected to be priced at perhaps US$50 or less in large volume, more likely US$150 in preliminary low volume. The initial cost of parts and materials is about US$15.

The pump is expected to save between 0.15 GJ/an (compared to a 20W alternative) and 0.95 GJ/an (compared to 100W). The former figure is a bit more than 1% of system output. At an estimated median price of US$100, plus US$50 for the PV panel, the pump lowers the Canadian base system cost by about US$140, for a system cost/performance reduction of 9%. If PV costs do not drop soon, there may be further interim cost savings in using a small 12V AC adapter instead of the panel. For these non-PV systems, the main benefits of the pump may be in higher pressure for drainback operation and for small-bore piping, and ultimately an even lower price due to its small size.

6.6.3. Direct Comparison with Other Pump Designs Compared to positive displacement pumps, this pump is expected to be more durable, have lower power consumption, and be less expensive.

Compared to more conventional centrifugal pumps, it should be no more expensive, consume less power, and have a higher pressure rating relative to the flow rating.

Compared to thermally driven pumps, it will offer more net system output and, be less expensive, less complex, and easier to install.

7. COMPONENT REPORT: PIPING

7.1. Introduction

Today the piping of the solar domestic hot water system collector loop is usually built with copper, steel or stainless steel tubes. Return and feeding pipe from and to the storage are separately insulated. The expense of materials and the installation costs of the rigid pipes and insulation are substantial.

The low-flow principle makes it possible to reduce the system flow rate by a factor of 5-10. Therefore, much smaller tubes with inner diameters in the range of 5 to 8 mm can be used. To optimize the advantages of smaller diameter piping we can introduce more compact all-in-one solutions, such as both tubes and the electrical wiring for temperature sensors in one envelope. The use of smaller diameter piping also lends itself to the use of flexible non-metallic materials or easy-to-bend copper tubing.

To ensure a long material lifetime, the following requirements for tubing materials should be considered:

- Durability at temperature and pressures up to 200°C and 4 bars
- Durability using water-glycol mixture
- Durability when exposed to UV-radiation

An overview of the different concepts concerning the use of flexible tubing for "low-flow" DHW systems is presented in this chapter. This chapter also includes discussions on the types of piping materials, pressure drop and heat losses.

The potential benefits of the use of flexible tubing are:

- Reduction of installation cost by the use of flexible tubing (fast and easy installation) including electrical wiring
- Reduction of heat losses by the use of smaller tube diameters and combining the insulation of the "hot" and "cold" tubing
- Reduction of used row materials by minimizing tube diameter and wall thickness
- Easy handling and delivery of the complete tubing

The disadvantages of using flexible tubing are:

- To be used only for "low-flow" concepts in small DHW-installations

- Some designs of flexible tubing with factory fitted insulation show a tendency toward mechanical damaging of the insulation during installation

- Small bend radius might lead to additional, undesired pressure drop due to reduction of the diameter

- Small diameter may cause problems for proper draining of drain-down systems (inner diameters below 10 mm are critical)

- Larger risk of blocking up the solar collector loop

7.2. Comparison of Flexible Piping for Low-Flow DHW Systems to Fixed Piping in Traditional DHW Systems

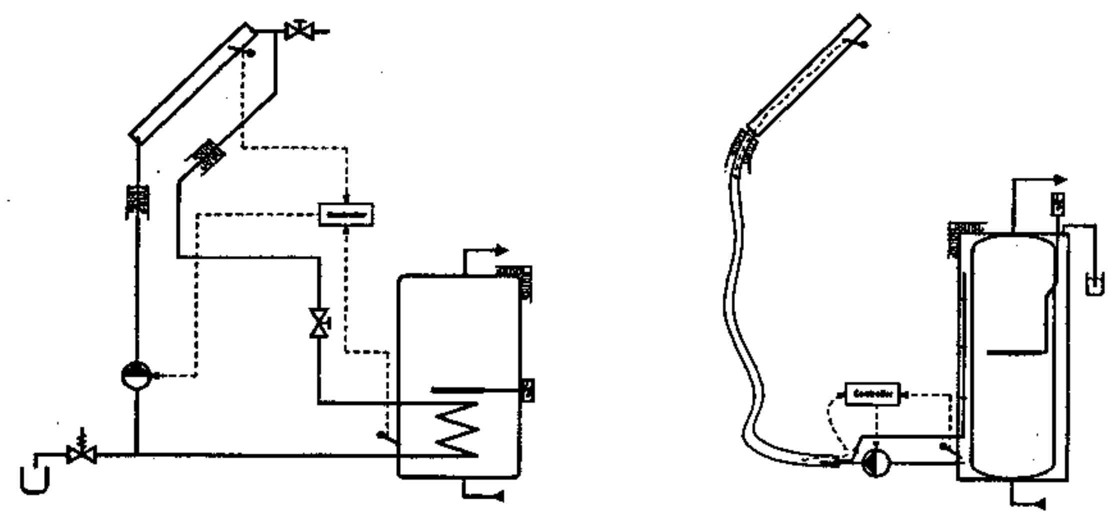

Figure 7-1. Scheme of the Traditional and Low-Flow Systems.

Figure 7-1 illustrates the differences in fixed and flexible tubing. In the flexible tubing the return and feeding pipes from and to the storage are both in one envelope. The tubes are separately insulated to reduce heat transfer between them. In a low-flow system the temperature difference between in and outlet of the solar collector could be as high as 40 - 50°C when maximum insolation occurs. In the improved design shown in Figures 7-3 and 7-5, the "hot" tube is more heavily insulated than the cold. The flexible system also includes a wire for the temperature sensor and/or photovoltaic module. The flexible tubing is easily connected to the collector via special fittings.

7.3. Design of Different Concepts

The most obvious difference between the fixed and flexible tubing in these examples is the diameter of the tubes. The typical inner diameter for traditional systems of 12 to 15 mm relates to the necessary flow rate of 200 to 400 ℓ/hr. By using the low-flow principle,
the flow rate is reduced to 30 to 60 ℓ/hr,
mm. The use of rigid tubing in low-flow systems seems as unlikely as using flexible tubing in traditional systems. Nevertheless, a Dutch approach provides an interesting compromise: a semi-flexible copper tube with an inner diameter of 10 mm leads to an acceptable flow rate range of 60 to 200 9/hr regarding pressure drop. For this diameter, pipes need to be correctly installed (sloped) to drain properly.

7.3.1 Fixed Tubing

Design:

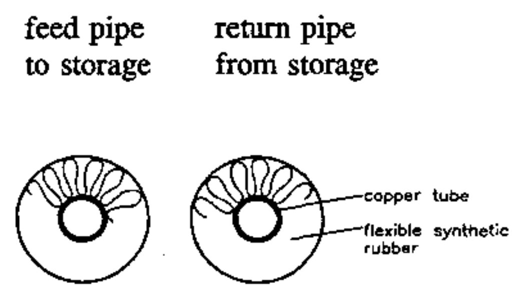

Figure 7-2. Cross Section of the Typical Fixed Tubing.

• Tube: Material: copper Dimensions: d_o = 15 mm d_i = 13 mm	**• Insulation:** Material: flexible synthetic rubber Dimensions: d_i = 15 mm d_o = 33 mm
• Cost: approx. 10-12 US$/m	**• Installation time:** typically 6 hours for 15 m

7.3.2 Flexible Tubing Swiss Flextube®

Design:

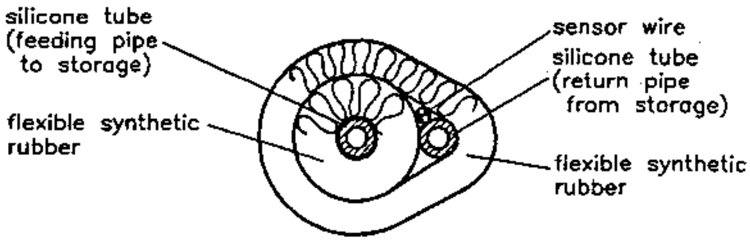

Figure 7-3. Cross Section of the Swiss Flextube®.

• **Tube:** Material: silicone Dimensions: d_o = 9 mm d_i = 5 mm	• **Insulation:** Material: flexible synthetic rubber Dimension inner insulation: d_i = 10 mm; d_o = 28 mm Dimension outer insulation: d_i = 35 mm; d_o = 53 mm
• **Cost:** - approx. 12 US$/m for purchase of 1000 m or more - additional costs for four fittings of approx. 5 US$	• **Installation time:** typically 3 hours for 15 m

Comment:

The advantage of the Swiss Flextube® is the high degree of flexibility of the tubing. Fast and easy installation is possible. Additionally, the "hot" pipe is red and the "cold" pipe is grey, so mistakes during installation are unlikely. The "hot" pipe has more insulation than the cold pipe, and the bundle includes a wire temperature sensor. The disadvantage is the sensitivity to insulation damages during installation. A protective jacket is recommended. Furthermore, if installed outdoors, the Flextube® should be protected against weathering.

Fittings:

The fittings shown in Figure 7-4 are part of both the collector and the storage tank (refer to Figure 7-1). Rubber tubing can be mounted by sliding the tube onto the nipple portion of the fitting and securing it with the spring loaded clip shown.

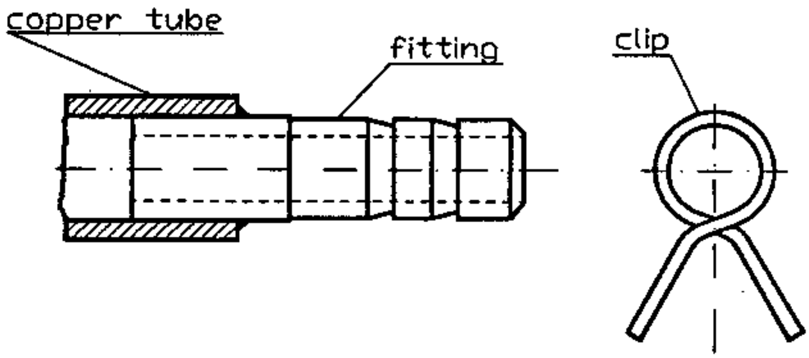

Figure 7-4. A Diagram of the Fittings Connecting the Collector / Flextube® and the Storage / Flextube®.

7.3.3. Flexible Tubing Canadian Life-Line®

Design:

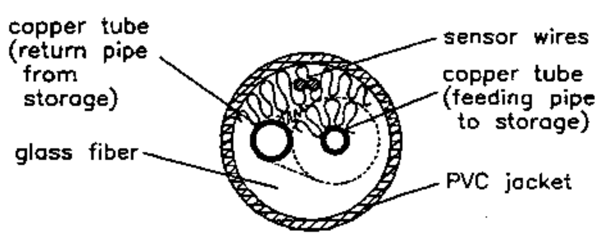

Figure 7-5. Cross Section of the Canadian Life-Line®.

• **Tubes:** Material: copper Dimension feeding pipe: d_i = 4.83 mm; d_o = 6.35 mm Dimension return pipe: d_i = 7.90 mm; d_o = 9.53 mm	• **Insulation:** Material: non-hygroscopic glass fibre with exterior PVC jacket Dimension: d_i = 6.35 mm; d_o = 40-42 mm thickness inner insulation s_1 = 7 mm thickness outer insulation s_2 = 7 mm thickness of PVC jacket s_3 = 2.5 mm
• **Cost:** - approx. 20 US$/m (purchase of 2000 m) - additional cost for fittings approx. 5 US$	• **Installation time:** Typically 1-2 hours for 15 m Life-Line®

Comment

The Canadian Life-Line® consists of a 1/4 in. copper feeding pipe, a 3/8 in. copper supply pipe, two sensor wires, non-hygroscopic glass fibre insulation, and an exterior PVC jacket. Hot solar collector fluid flows through the small pipe towards the centre of the Life-Line® while the cold solar collector fluid from the heat storage flows in the larger pipe located closer to the outside of the Life-Line®.

Fittings:

Compression fittings (3/8 in. and 1/4 in.) on soldered copper couplings

7.4. Pressure Drop of Different Concepts

Figure 7-6 shows a comparison of calculated pressure drop curves with the fixed tubing, Swiss Flextube®, and Canadian Life-Line® at volume flow rates of 20, 40, and 80 Whr. Calculation of pressure drop based on a mixture of 1/3-vol.% Ethyleneglycol and 2/3-vol.% water and one meter length of either supply or feeding pipe.

7.4.1. Discussion of Results Figure 7-6 shows large differences in the pressure drop between the fixed and the flexible tubings.

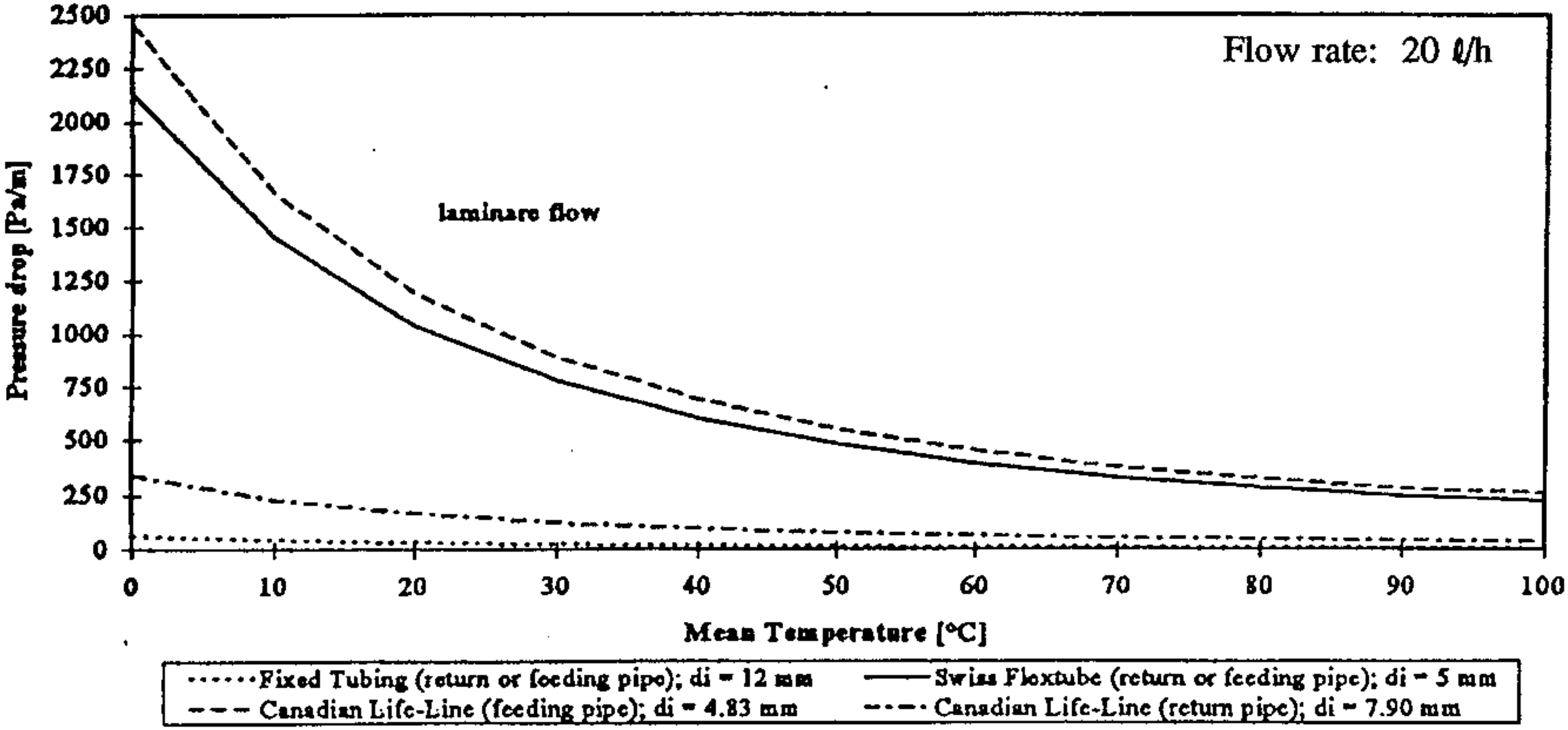

Figure 7-6. Comparison of the Pressure Drop for Different Tubing Designs and Flow Rates.

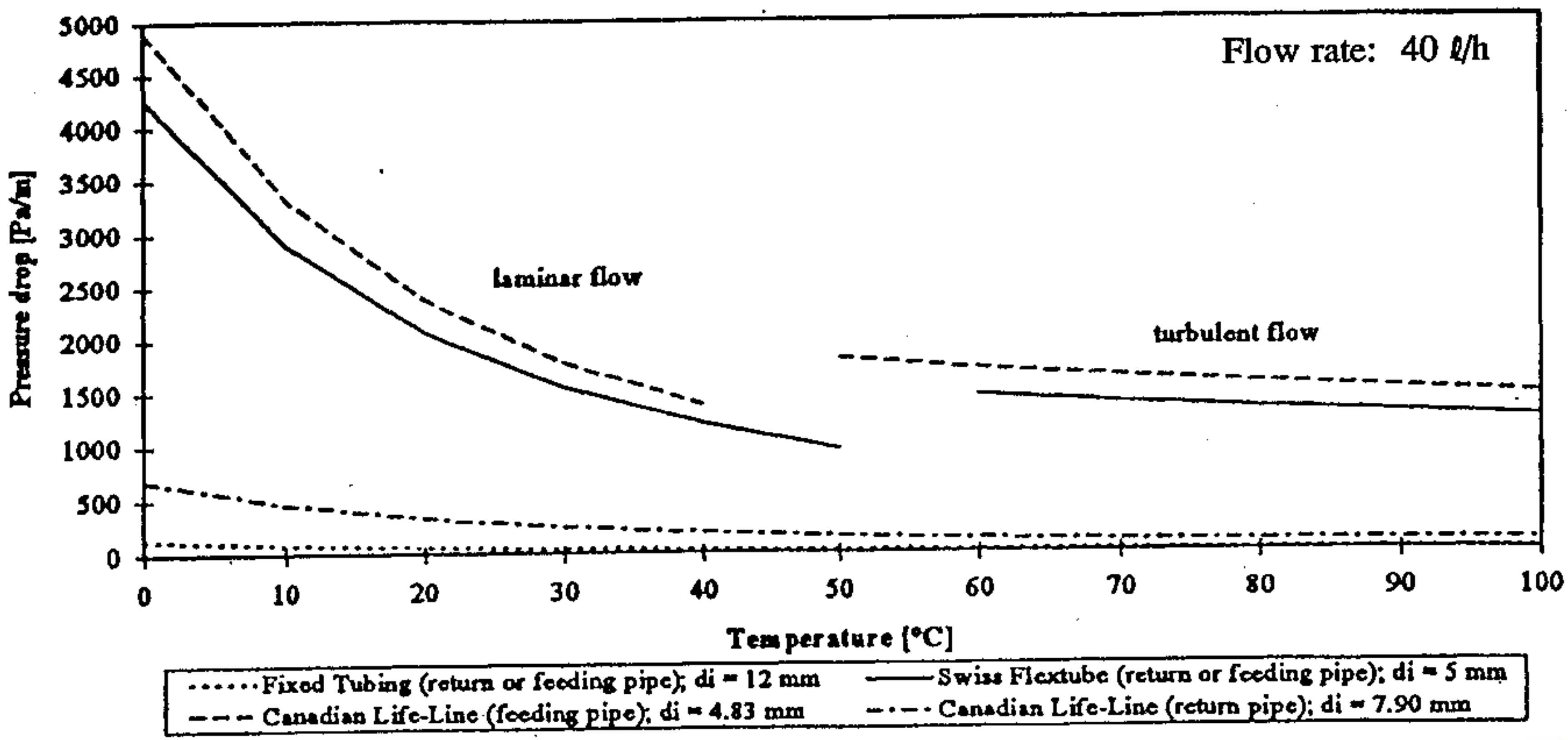

Figure 7-6 (cont.). Comparison of the Pressure Drop for Different Tubing Designs and Flow Rates.

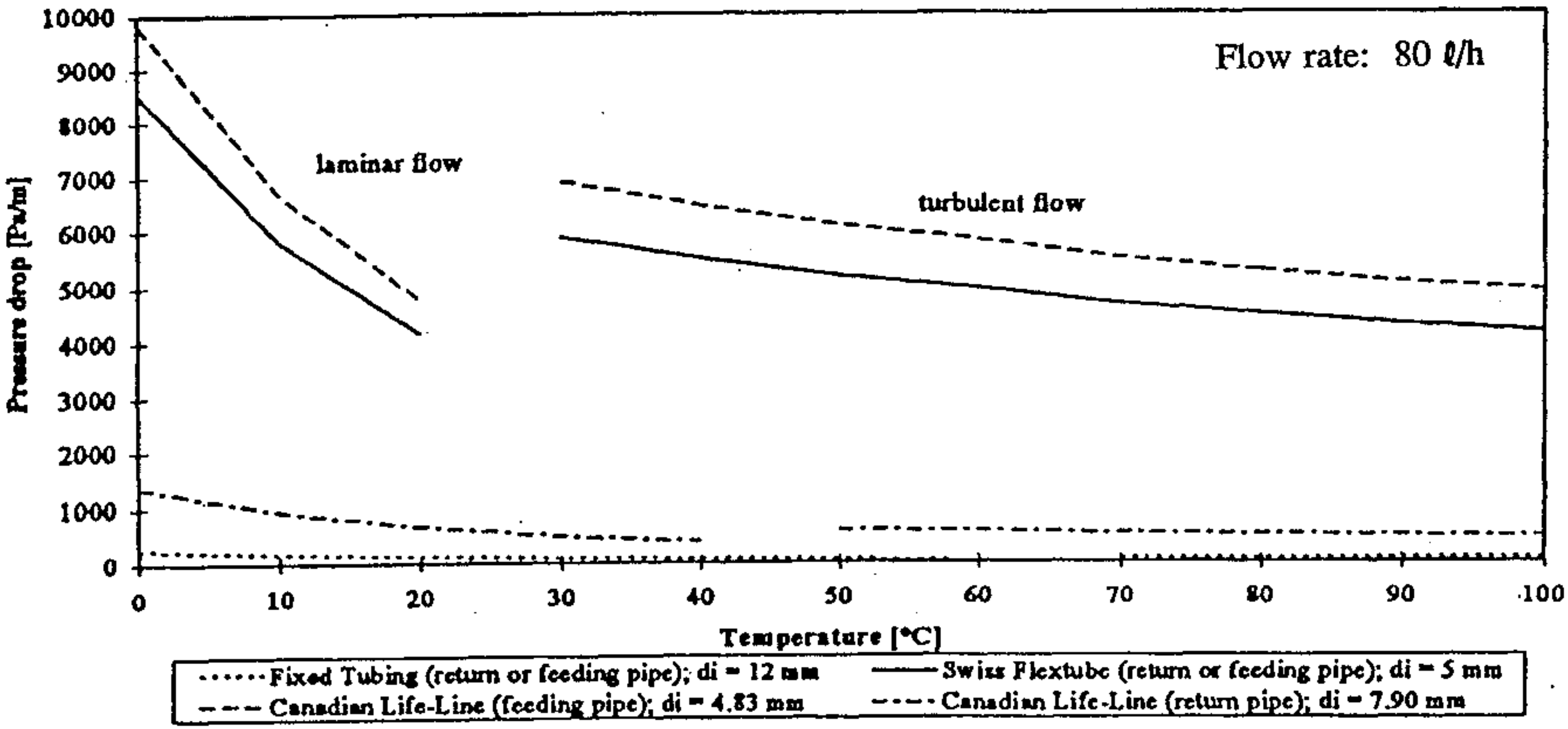

Figure 7-6 (cont.). Comparison of the Pressure Drop for Different Tubing Designs and Flow Rates.

During system operation, the maximum pressure drop occurs when the fluid in the cold tube is near cold water temperature of the storage and the pump begins to run. At this moment the temperature of the hot tube is nearly the same as the cold tube.

The following example shows values for a flow rate of 40 Or, a mean temperature of 10°C for the return pipe, a mean temperature of 12°C for the feeding pipe and 15 m length of piping:

	Pressure drop of Fixed Tubing	Pressure drop of Swiss Flextube®	Pressure drop of Canadian Life-Line®
Return pipe from storage	1311 Pa	43500 Pa	6980 Pa
Feeding pipe to storage	1237 Pa	41030 Pa	47120 Pa
Total	**2548 Pa**	**84530 Pa**	**54100 Pa**

On a sunny day, the cold tube in a low-flow system operates near cold water temperature of the storage while the hot tube is often in the range of 50 to 70°C. Therefore, the pressure drop of the return pipe from the storage is higher than the pressure drop of the hot feeding pipe.

The following example shows values for a flow rate of 40 9/hr, a mean temperature of 10°C for the return pipe, a mean temperature of 60°C for the feeding pipe and 15 m length of piping:

	Pressure drop of Fixed Tubing	Pressure drop of Swiss Flextube®	Pressure drop of Canadian Life-Line®
Return pipe from storage	1311 Pa	43500 Pa	6980 Pa
Feeding pipe to storage	357 Pa	21875 Pa	25781 Pa
Total	**1668 Pa**	**65375 Pa**	**32761 Pa**

These two examples show pressure drop for typical operating conditions. Large differences in the pressure drop between the three concepts could be seen.

7.5. Heat Loss

There is a large difference between the operation of a low-flow system and a traditional system. Figure 7-7 shows the radiation and temperatures over time for a typical sunny day for a low-flow system and a traditional system.

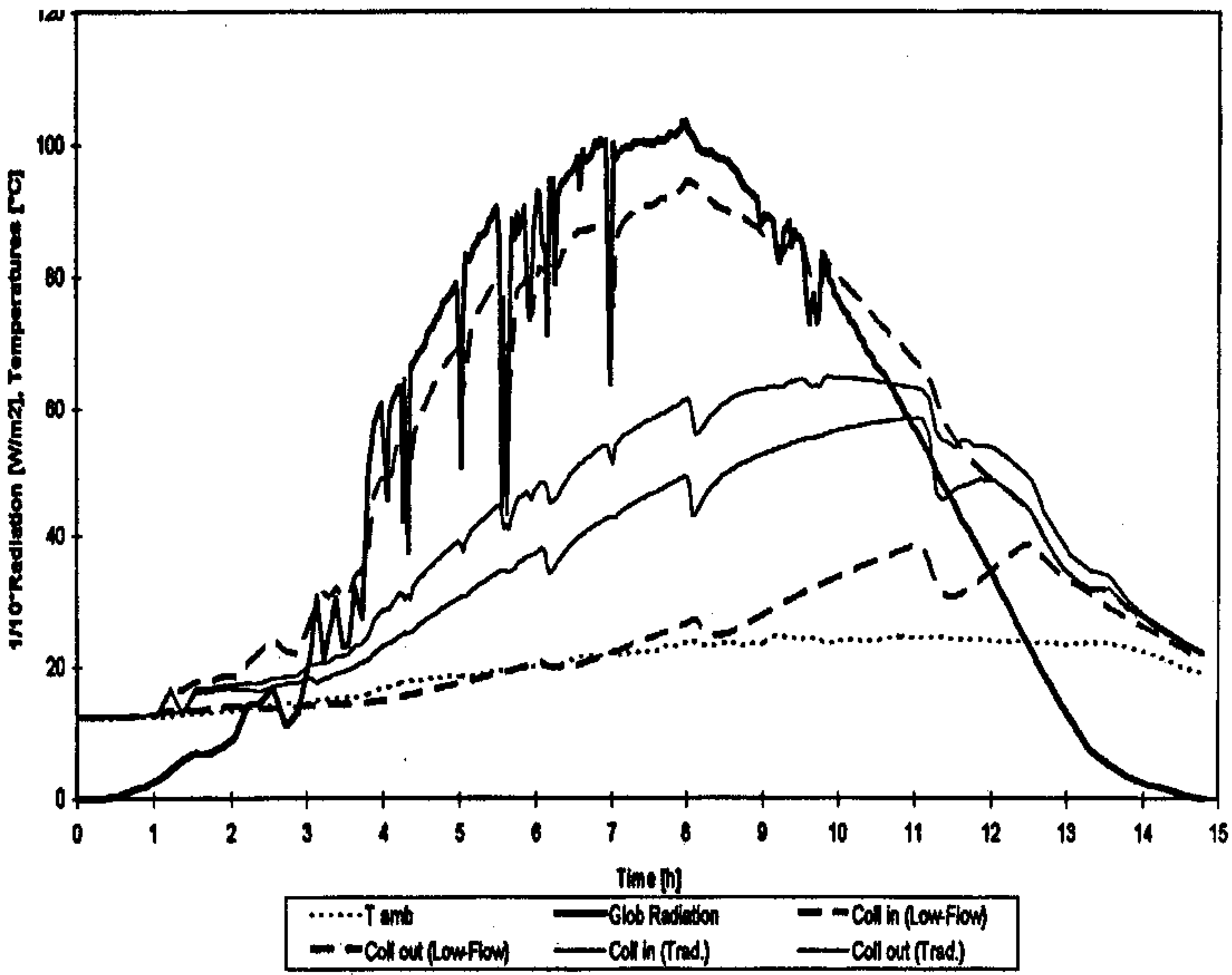

Figure 7-7. Typical Operation of a Low-Flow and a Traditional System on a Sunny Day.

The cold tube in the low-flow system operates near ambient air temperatures while the hot tube is often in the range of 50 to 70°C. Therefore, the use of the Canadian and the Swiss flexible tubing can result in losses from the hot tube to the environment or heat transfer from the hot to the cold tube. In the traditional system, both tubes are operating at the same temperature range (temperature differences from 5 to 15 K). Both are above the ambient air temperature, and therefore both have heat losses to the environment.

<u>7.5.1. Results of Heat Loss Measurements</u> Measurements of different tubing under different conditions were taken at various laboratories. The fixed piping and the Swiss Flextube® were measured at the Solar Energy Laboratory in Rapperswil/CH while the Canadian Life-Line® and the Swiss Flextube® were measured at the Thermal Insulation Laboratory at the Technical University of Denmark.

The Swiss measurements were taken during the testing of complete systems. The inlet and outlet tubing temperatures (return and supply) were measured during the operation of the systems. Therefore, dynamic and system operation effects, as well as changing weather conditions, might influence the results. Nevertheless, the values presented show how the different concepts perform under realistic conditions. The mean piping losses for traditional systems range from 0.5 to 0.9 WK ; however, most of the values vary over a wide range in the order of 0.8 $WK^{-}m^{-1}$. The values include losses for both return and supply tubes. Losses for the Swiss Flextube® in a low-flow system are much lower, in the range of 0.35 to 0.5 .

The investigations done by Denmark were conducted in the laboratory. Values are much lower than shown by the Swiss measurements. The losses for either the Canadian Life-Line® or the Swiss Flextube® are in the range of 0.2 to 0.3 $WK^{-1}m^{-1}$. The results from the simulations done by Canada [7-2], [7-4] and Denmark [7-1] show a very good agreement to the laboratory results from Denmark [7-1].

Due to the different testing conditions of the Swiss and the Danish investigations, the results are difficult to compare. Nevertheless, the Swiss results show for the flexible tubing in a low-flow system lower losses by a factor of two compared to ordinary piping in a conventional system.

However, the heat loss and the heat exchange between the cold and the hot tube can be calculated. These calculations can be used for the optimization of insulation of flexible tubing. In the reports [7-1] from Denmark and [7-2] to [7-4] from Canada, calculations of heat loss coefficient are presented and compared with measurements performed in Denmark [7-1].

<u>7.5.2. Analysis of Heat Losses in Flexible Piping Bundles</u> An analysis of the heat transfer taking place between the components of flexible tubing bundles has been carried out in Canada [7-2, 7-4, 7-5]. In DHW systems employing such tubing bundles, there is a thermal performance penalty caused by heat transfer from the hot tube to the cold tube. The penalty in system performance happens because the cross heat transfer results in higher collector inlet temperatures, lower collector efficiency, and lower solar energy being delivered

to the DHW storage system. The Canadian work has shown that the standard Hottel-Whillier-Bliss (HWB) equation can be modified to simultaneously take into account both the pipe heat losses to the ambient environment and the cross heat transfer between the hot and cold streams. Parameters in these equations are the thermal resistances between the fluids in the two tubes, and between each fluid and the ambient air. Methods are presented in reference [7-5] for both calculating and measuring these thermal resistances.

The parameters in the modified HWB equation were calculated for the case of a representative solar D11W system (delivering about 50% of the energy required to supply 300 liters/day of water at 60°C) equipped with either of two different flexible tubing bundles: Life-Line-C®, and one consisting of two Nylon-11 tubes inside a PVC cover that contained no thermal insulation. The thermal effects of the tube bundles reduce the net delivered solar energy by 6 to 14%. The loss in system performance due to cross heat transfer was found to be practically independent of the loss in performance due to heat losses from the tubes to the ambient air. Moreover, heat loss to the ambient air was found to be more detrimental to system performance than is heat transfer from the hot to the cold conduit.

7.6. Materials and Requirements

Materials used and requirements for their use are given in Table 7-1.

Table 7-1. Materials.

Type	Material	Dimension d_i/d_o [mm]	Bend radius [mm]	Density [kg/dm³]	T_{max} [°C]	P_{max} [bar]	UV-stability yes/no	Component costs * [US$/m]
Fixed:								
tube	copper	13/15	40	8.9	>200	>20	yes	3
insulation	synthetic rubber	15/41		0.067	120	-	no**	3
fitting	-	-		-	-	-		-
Swiss Flextube®:								
tube	silicone	5/9	50	1.61	>200	4	yes	2
insulation	synthetic rubber	10/28		0.067	120	-	no**	1.5
insulation	synthetic rubber	35/53		0.067	120	-	no**	1.5
fitting	brass	5/7.6		8.5	>200	>20	yes	1
Canadian Life-Line®:								
tube	copper	4.8/6.4 + 7.9/9.5	230	8.9	>200	>20	yes	2
insulation	fiberglass	6.4/30.4		0.15	200	-	-	1.50
insulation	fiberglass	30.4/34.4		0.15	200	-	-	1.50
jacket	PVC	35/40		1.38	100	-	yes	-
fitting	brass	3/8 in. + 1/4 in.		8.5	>200	>20	yes	-

*Component costs only includes raw material costs without marketing, selling and distribution costs (not the end price to the user)
**To install outdoors UV-protection is needed

7.6.1. Results of Aging Tests, Experiences in the Field The most important aspect regarding new tubing materials such as plastics or rubber is their durability! Short lifetimes have been reported in Canada with Nylon-11 tubing. Besides the lifetime of the tubing material itself, the fittings and connecting tubing material are of great importance. Compression fitting leaks in combination with some tubing materials (e.g. Teflon or Nylon) have been reported in Canada [7-3], and 0-ring fittings rather than compression fittings should be used on all plastic tubing connections.

The use of silicone rubber hoses for automotive application is well known. Also, silicone hoses have been used in solar applications for collector couplings for more than 15 years. The fittings and clips used to connect the silicone tubing to the collector and storage tank have also been used for many years in similar applications without any problems.

More work is needed to find other suitable materials which are cheaper than the present silicone rubber tubes.

7.7. Conclusion

Integrated flexible tubing is of great interest to the development of better domestic solar water heaters for low-flow applications for the following reasons:

The heat losses are lower by a factor of two or more compared to fixed piping.

Installation time is shorter and therefore cost of installation is lower.

In addition, the cost of silicone hoses with an inner diameter of 10 mm or more for traditional high-flow systems is very high and the copper alternative for these diameters is more difficult to install because of its poor flexibility. Therefore, the advantage of flexible tubing is mainly realized in combination with low-flow systems, where smaller diameters are needed.

Further developments are required to achieve the ideal tubing including:

Finding more appropriate production techniques for lower cost products.

Finding new non-metallic materials with lower prices for the tubes, as well as for the insulation.

8. LOW-/HIGH-FLOW TEST

8.1. Introduction

Both experimental and theoretical investigations which compare the thermal performance of low-flow systems and of traditional high-flow systems have been carried out [8-1], [8-2], [8-3], [8-4].

The designs of the systems, as well as the test conditions, influence the relative performances of the systems in experiments. The relative performances of the systems determined by means of simulation programs are influenced by the suitability of the programs and by the input data. Therefore, it is extremely difficult to draw general conclusions about the thermal performance of low-flow and high-flow solar heating systems that are valid for a large variety of solar heating systems under many operating conditions from a small number of tests or calculations.

In an experimental comparison of low-flow and high-flow solar heating systems two approaches can be followed:

1. Detailed tests of the systems are conducted and the results used for verification of calculation models. That is, information about the system properties is collected, followed by performance calculations with the models. In this case, tests will be performed under extreme conditions in order to characterize the various system properties. Subsequent calculation then produces the desired annual system performance under normal operating conditions.

2. A less thorough investigation of the systems is conducted that does not reveal detailed information on system properties or long-term system performance. In this case, tests are performed for normal conditions. A comparison is made only for those conditions and no extrapolation to yearly performances is made.

Inevitably, the first approach is more extensive and it can reveal much more information than the second approach.

In this study the second approach was followed to make results more quickly available. Two different solar DHW systems were tested under the same conditions in an indoor solar simulator. Both systems were preheating systems. A high- and a low-flow rate was used in the solar collector loop.

8.2. Description of the Tested Systems

There were two solar pre-heat systems with remote heat storages tested. One used a helix and the other a mantle heat exchanger. For both systems, the solar collector, collector pump and pump control system were the same. The collector circuit was always filled with water, also during periods without sufficient solar irradiation. A check valve prevented undesirable backwards thermosiphoning. Both systems are made as suitable as possible for low flow. However, piping and pump are conventional. Figure 8-1 shows both systems and Table 8-1 lists their main characteristics.

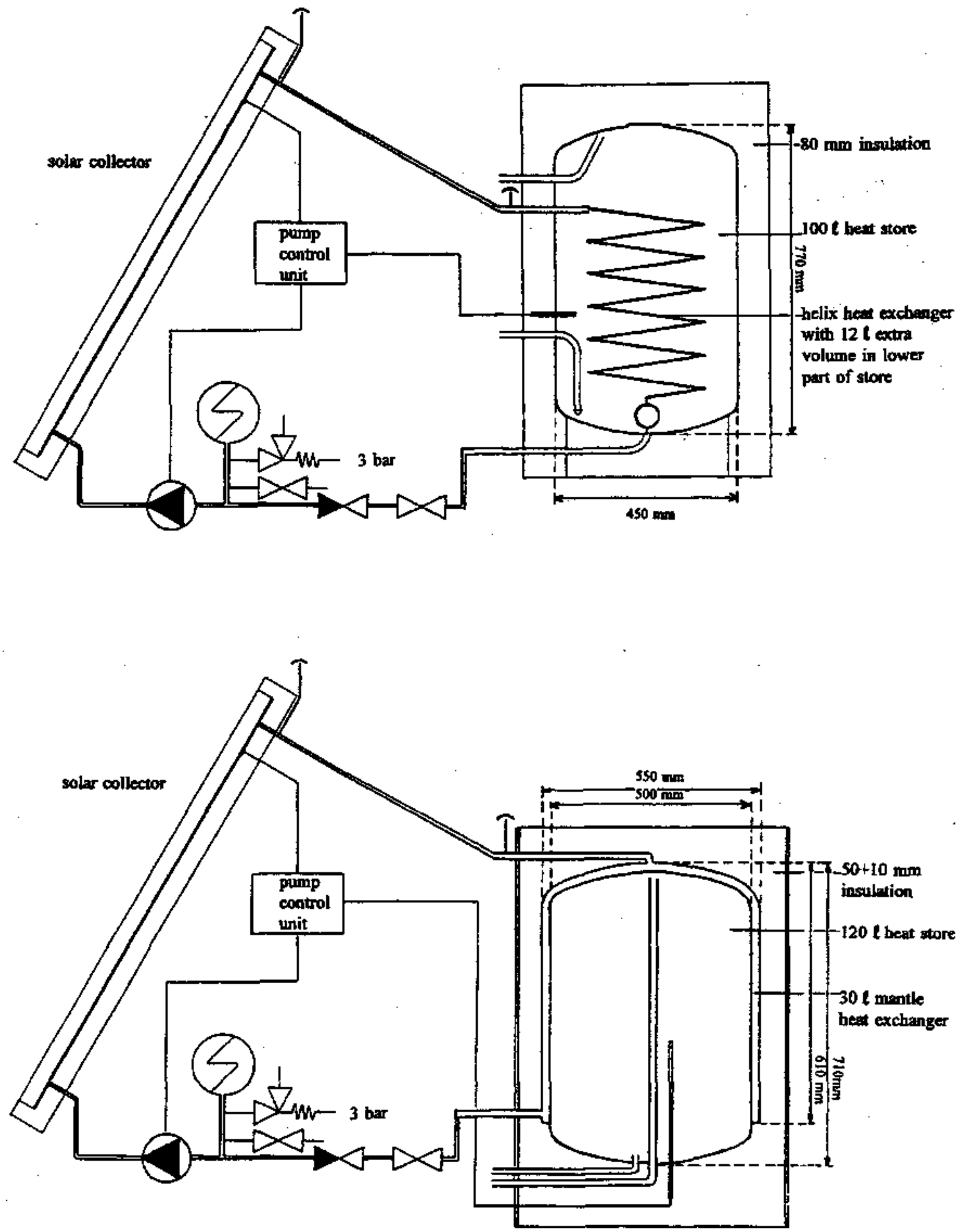

Figure 8-1. Scheme of the Tested DHW Pre-heat Systems.

Table 8-1. Main Characteristics of the Tested DHW Pre-Heat Systems.

<u>Solar collector circuit</u>	
•collector area	2.67 m^2
•collector efficiency [8-5]	$\eta = 0.815 - 3.5 \cdot T^{*} - 0.018 \cdot G \cdot (T^{*})^2$
•insulated collector piping	20 m
•pump control sensor on collector	on absorber back side near the top
•pump control sensor in heat storage	helix store: In tap water part, 30 cm from bottom mantle store: In tap water part, 18 cm from bottom
•pump control	ΔT_{on} = 10 K, ΔT_{off} = 2 K
•pump power	30 W
<u>Helix heat storage</u>	
•tap water volume	100 ℓ
•helix plus extra volume in lower part of storage	12 ℓ
•insulation	80 mm polyethylene
•storage and helix material	stainless steel
<u>Mantle heat storage</u>	
•tap water volume	120 ℓ
•effective heat storage volume in tap water part	105 ℓ
•mantle volume	30 ℓ
•insulation	50 mm caril + 10 mm polyethylene
•storage and mantle material	stainless steel

8.3. Test Procedure

The two systems were tested in an indoor solar simulator test facility, [8-6].

Each system was tested at a high-flow rate of about 2.3 //minute corresponding to about 0.9 //minute per m^2 solar collector and at a low-flow rate of about 0.5 //minute corresponding to about 0.2 //minute per m^2 solar collector in the solar collector loop.

The duration of each test was about 3 days. Figure 8-2 shows the total irradiance on the solar collector and the ambient air temperature of the collector during the 3-day test. The weather data were changed every half hour. The irradiance profile was derived from the Test Reference Year for De Bilt, the Netherlands.

The ambient air temperature of the heat storage was about 20°C.

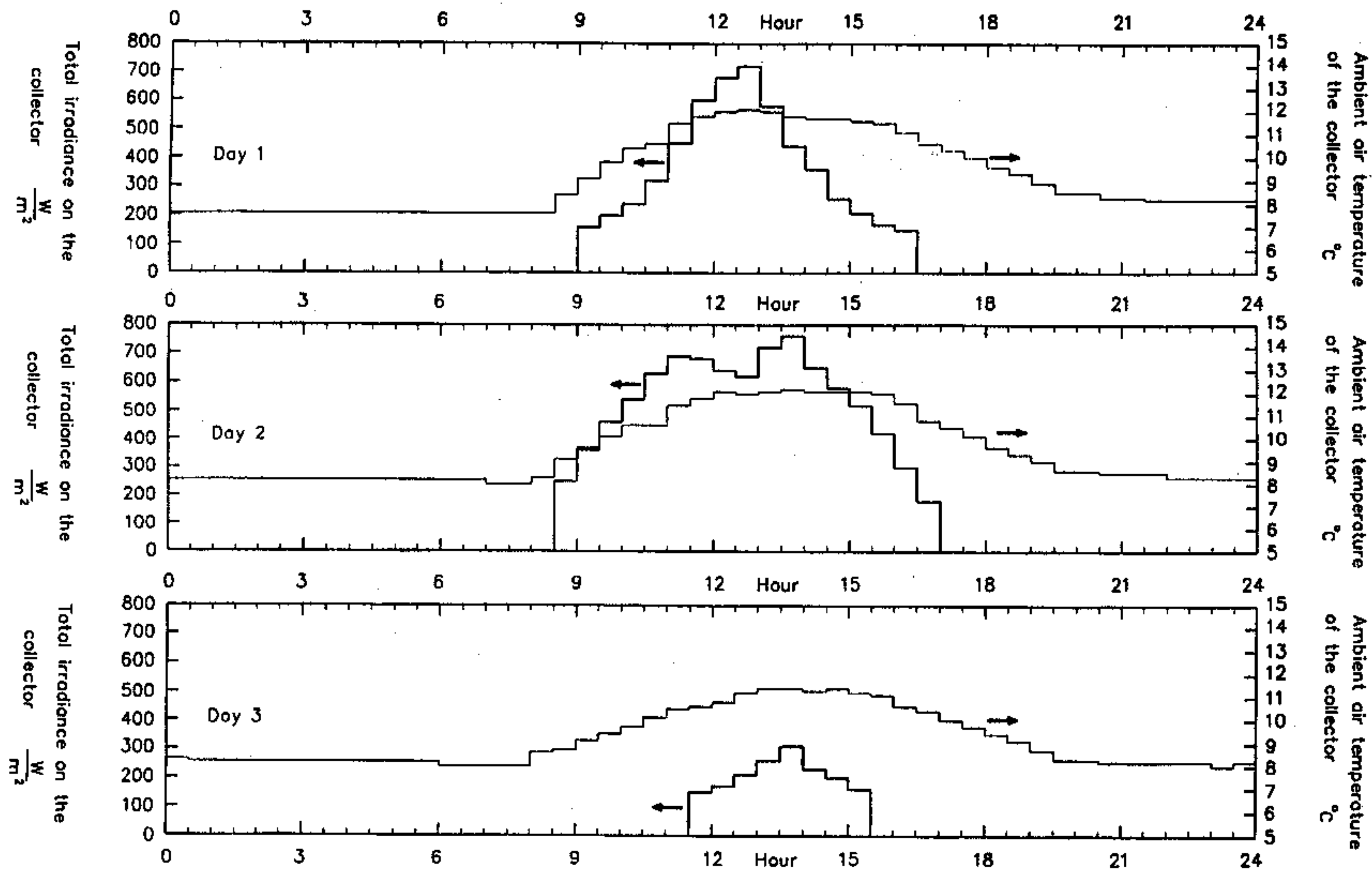

Figure 8-2. Weather Data for the Three-Day Test Period.

Table 8-2 shows the hot water consumption during the test. The cold water temperature was about 15°C and the hot water temperature was 65°C at maximum, *i.e.* if the temperature of the tapped water was above 65°C in the 36.7 ℓ tappings, a smaller water volume was tapped. In this case, an energy quantity corresponding to 36.7 ℓ of water, heated from 15°C to 65°C, was tapped. Tappings no. 11 and 12 reveal the energy left in the storage after the three-day period.

Table 8-2. Hot Water Consumption During the Test Period.

Day no.	Hour	Hot water tapping	
		No.	Volume
1	8^{30}	1	tapping until steady state
	12^{00}	2	36.7 ℓ
	18^{00}	3	36.7 ℓ
2	8^{00}	4	36.7 ℓ
	12^{00}	5	36.7 ℓ
	18^{00}	6	36.7 ℓ
3	8^{00}	7	36.7 ℓ
	12^{00}	8	36.7 ℓ
	18^{00}	9	36.7 ℓ
	18^{30}	10	36.7 ℓ
	19^{00}	11	100.0 ℓ
	20^{00}	12	100.0 ℓ

8.4. Test Results

The tests and the test results are described in detail in [8-7]. An overview of the results is given below. Table 8-3 shows the volumes and energy quantities of the various tap water draw-offs for the system with the helix heat exchanger, both for the high and low-flow regime. For every day, subtotals of the volume and energy draw-offs have been made. For the third day, the energy contents in the final large draw-offs have been summed additionally. Moreover, sums have been made for the draw-offs of all days. Table 8-4 presents the same overview for the system with the mantle heat exchanger.

Table 8-3. Tapped Energy Quantities for the Helix System, Both for High and Low Flow.

Day no.	Draw-off no.	Hot water demand		High flow		Low flow	
		Volume [l]	Energy [MJ]	Volume [l]	Energy [MJ]	Volume [l]	Energy [MJ]
1	2	36.7	7.6	37.2	2.2	36.6	2.4
	3	36.7	7.6	36.2	3.7	37.0	3.8
	total day 1	73.3	15.1	73.4	5.9	73.6	6.2
2	4	36.7	7.6	37.0	3.0	37.2	2.9
	5	36.7	7.6	36.6	4.4	36.4	4.8
	6	36.7	7.6	36.4	6.0	36.8	6.4
	total day 2	110.0	22.7	110.0	13.5	110.4	14.0
3	7	36.7	7.6	37.2	5.0	36.8	4.9
	8	36.7	7.6	36.2	3.2	37.0	3.0
	9	36.7	7.6	36.0	2.1	37.0	2.3
	10	36.7	7.6	37.2	2.0	36.2	1.9
	subtotal day 3	146.7	30.3	146.6	12.4	147.0	12.2
	11			100.0	1.7	100.0	1.5
	12			100.4	0.7	100.2	0.6
	total of 11 and 12			200.4	2.4	200.2	2.1
	total day 3			347.0	14.7	347.2	14.3
1-3	total of 2-9	293.3	60.5	292.8	29.7	294.8	30.5
	total of 2-10	330.0	68.1	330.0	31.7	331.0	32.4
	total of 2-12			530.4	34.1	531.2	34.5

Table 8-4. Tapped Energy Quantities for the Mantle System, Both for High and Low Flow.

Day no.	Draw-off no.	Hot water demand		High flow		Low flow	
		Volume [l]	Energy [MJ]	Volume [l]	Energy [MJ]	Volume [l]	Energy [MJ]
1	2	36.7	7.6	36.0	1.9	36.4	2.8
	3	36.7	7.6	37.4	3.4	37.0	3.5
	total day 1	73.3	15.1	73.4	5.4	73.4	6.3
2	4	36.7	7.6	36.8	2.9	37.0	3.0
	5	36.7	7.6	37.0	4.4	35.8	5.4
	6	36.7	7.6	36.0	5.6	36.8	6.0
	total day 2	110.0	22.7	109.8	12.9	109.6	14.3
3	7	36.7	7.6	36.8	5.0	36.8*	4.8*
	8	36.7	7.6	36.4	3.4	36.6	3.6
	9	36.7	7.6	36.6	2.6	36.6	2.7
	10	36.7	7.6	37.2	2.6	36.6	2.6
	subtotal day 3	146.7	30.7	147.0	13.5	146.6	13.7
	11			100.2	3.9	100.2	3.6
	12			99.8	0.8	100.0	0.8
	total of 11 and 12			200.0	4.7	200.2	4.4
	total day 3			347.0	18.2	346.8	18.1
1-3	total of 2-9	293.3	60.5	293.0	29.2	293.0	31.8
	total of 2-10	330.0	68.1	330.2	31.8	329.6	34.4
	total of 2-12			530.2	36.5	529.8	38.8

* A power failure at the test facility on the beginning of Day 3 resulted in a 38-minute delay to the start of the solar irradiance schedule. Test time was extended to accommodate the difference. The first draw for Day 3 scheduled for 8 a.m. was carried out at 11 a.m. The effect on the thermal performance of the system is considered to be minor.

Other test results:

- For the low-flow regime, higher tap water temperatures were measured than with high flow. This result was most pronounced for the mantle system at the midday draw-off, *i.e.*, after a relatively cold start for the top level of the heat storage in the morning. In that case, differences in tap water temperatures of over 10 K were observed.

- During the first day, for low flow, the collector pump was in operation for a longer period, about half an hour. For the other days, it was about the same. This was observed for the helix as well as the mantle system.

Discussion of the results:

- In the discussion of the results below, no comparison is made between the thermal performance of the helix and mantle system as this was not the aim of the tests. The aspect under investigation is the difference in thermal performance between low-flow and high-flow operation. This difference has been determined for two specific solar DHW systems.

- For the helix system, the solar fractions for high- and low-flow operation are 46% and 47%, respectively, for the draw-offs 2-10. For the mantle system, these fractions are 47% and 51%, respectively. These solar fractions correspond well with the annual solar fraction calculated for similar systems in the tests using meteorological data of TRY - De Bilt, Netherlands, for a demand of 110 liters per day, heated from 15°C to 65°C.

- For the helix system, the measured difference in thermal performance between low-flow and high-flow operation is 1 - 3%, depending on whether energy left over in the storage after draw-off of 330 liters is taken into account and whether draw-off no. 10 is considered. Notice the measuring error is about the same.

- For the mantle system, this difference is greater, 6 - 9%.

- Once again, notice that the differences in thermal performance between low-flow and high-flow operation as discussed above are valid for the conditions during the three-day test, and cannot be extrapolated to predict the annual system performance.

8.5. Conclusions

For well-designed, high-flow systems such as the two tested, low-flow operation can obtain slightly greater thermal performance than that of high flow for a choice of realistic meteorological and draw conditions. The difference in thermal performance between high-flow and low-flow operation appears to be larger for the tested mantle system.

8.6. Final Remarks

When designing a system, comparison testing with high and low flow can provide guidance for the choice of flow regime. In this regard, improvement of thermal stratification by changing from high flow to low flow is of major interest. Valuable information can be obtained with respect to the flow regime by these comparative tests without the use of computer models.

In the tests, two different solar pre-heat systems which closely match those on the Dutch market have been investigated for specific meteorological and tap water draw-off conditions. The results are specific to the systems and the test conditions. Broader conclusions cannot be drawn for other solar DHW systems and conditions.

Both tested systems had well-stratified heat storages for high-flow as well as for low-flow operation. Therefore, the thermal advantage of low-flow operation was relatively small.

The difference in thermal performance between low- and high-flow operation is larger if the difference in the thermal stratification in the heat storage is greater. In the investigations, thermal stratification was most improved for the tested mantle system.

Furthermore, if a system is optimally designed for low-flow operation, the extra thermal performance obtained by reducing the flow rate would be greater than found in the tests.

For extensive research on a vast variety of solar DHW system types under different meteorological and tap water draw-off conditions, the first approach mentioned in Section 1 must be used. Through verification of mathematical models and subsequent calculation of system performance annual system performance can be predicted as well. With this approach, models need to be verified on a rather detailed level, which requires considerable effort.

9. COUNTRY INFORMATION AND STATISTICS

9.1. Introduction

This chapter presents a common set of statistics and other information about each country. A tabular presentation makes it easy to contrast country activities and approaches. The information provided illustrates that circumstances vary widely from country to country and provides insight into why each country took a different approach to task activities.

9.2. Tables

The country information is organized into four tables.

Table 9-1 provides information on the climate factors that are most relevant to solar DHW system performance. As shown, these conditions can vary greatly between and within countries. Although conditions vary only slightly within smaller countries, within larger countries they can vary dramatically.

Table 9-2 lists information on government and utility initiatives, regulations, and consumer characteristics that can influence solar DHW system design and development paths.

Table 9-3 gives key statistics about the solar industry, consumers, and the economic environment in which solar must compete.

Some of the Task 14 Solar DHW Systems Working Group meetings have included a solar DHW industry workshop in which the industries of the host country and Task 14 industry representatives made presentations, exchanged information, and discussed issues and common interests. Table 9-4 provides information on these workshops.

For further details on the information presented see Appendix B.

Table 9-1. Climate.

Climate Characteristics	Canada	Denmark	Germany	Netherlands	Spain	Switzerland	United States
Locations Annual radiation on tilt=latitude GJ/m^2 Locations Average daytime temperature °C	southern regions 4.4 to 6.4 three locations 10 to 15	all 4.0 to 4.1 all 8.7	all 3.8 to 5.2 all 8.7	all 3.9 to 4.4 all 10.2	southern regions 6.8 to 7.5 southern regions 17.5	lower areas 4.1 to 5.0 Kloten 8.6	all 5.3 to 9.1 four locations 13 to 24

Table 9-2. Infrastructure and Demographics.

Subject	Canada	Denmark	Germany	Netherlands	Spain	Switzerland	United States
Important government initiatives	S-2000 Program to encourage solar DHW utility activities	energy tax CO_2 tax CO_2 reduction water tax up to 30% subsidy	income tax deduction national subsidy state subsidies	subsidies awareness campaigns long-term agreements with industry	national and regional subsidies	Program Energy 2000 subsidies for multi-family	state tax credits agency subsidies
Important utility initiatives	pilot projects market survey long-term funding	demonstrations	utility programs	leasing programs	pilot projects R&D investment	none	DSM subsidies peak penalty pricing
Important regulations	none	subsidized systems must be tested and approved	none	double-walled HX or drain back	technical guidelines that are obligatory for subsidies	none	double-walled heat exchangers
Population	25 million	5.2 million	80.7 million	15.5 million	40 million	7 million	260 million

Table 9-3. Statistics.

Subject	Canada	Denmark	Germany	Netherlands	Spain	Switzerland	United States
Energy prices 1993 US$/GJ							
Electricity	14.3 to 20.7	41	49	60 day/22 night	N/A	80 day/40 night	11 to 27
Natural gas	10.4 to 17.0	16.5	8 to 13	14	N/A	12	4 to 11
Oil	18.9 to 20.4	18	7 to 10	18	N/A	10	12.45
Hot water usage							
Average liters per person per day	60	40	50	30	40	50	60
Average set temperature °C	57.5	50	45	65	45	55	54
Average mains temperature °C	12	10	11	9	13	10	10
Residential DHW installations 1000/year							
Electric	3501	0	N/A	~80	N/A	N/A	3538
Natural Gas	2965	22	N/A	~215	N/A	N/A	4427
Oil	267	0	N/A	0	N/A	N/A	?
District Heating	0	28	0	0	0	0	0
Solar	0.4	2.5	~17.5	~3.5	N/A	0.5	4.5
Total	6733	52.5	N/A	~299	N/A	N/A	7970
Number of solar DHW manufacturers	4	16	6	6	4	10	12

Table 9-4. Manufacturers' Workshops Held in Conjunction with Task Meetings.

Subject	Canada	Denmark	Germany	Spain	United States
Co-sponsors	EMR Canmet	Danish ISES Section	none	Junta del Andalucia	none
Description	Review of recent advancements and benefits to utilities	active solar heating systems market situation in various countries	active solar heating market, actual situation and trends in IEA countries	State renewable energy policy and market situation	Review of recent developments
Country: Companies Presenting	Canada: ThermoDynamics Fournelle Netherlands: Solair Systems United States: Solar Works	Canada: ThermoDynamics Denmark: CowiConsult Batec Germany: ISFH Netherlands: Solair Systems Sweden: Andersen and Hultmark Switzerland: Sede	Canada: ThermoDynamics Denmark: Batec Germany: SOLVIS Microtherm Netherlands: Solair Systems Sweden: University Börlänge-SERC United States: SEIA	Canada: ThermoDynamics Denmark: Batec Spain: Junta de Andulucía Sodean INTA PMP Isofotón Técnicas de Energía Ambiental Disol United States: The Art of Solar	Canada: ThermoDynamics Denmark: Batec Netherlands: Solair Systems United States: Independent Energy and Elect. SEIA San Diego US DOE

No workshops -- The Netherlands and Switzerland. No information supplied -- Sweden.

10. BASE CASE AND DREAM SYSTEM

10.1. Introduction

This chapter provides pertinent attributes, key reference quantities, and cost and performance results for the Base Case and Dream Systems of each country. A tabular presentation makes it easy to contrast and compare the Base Case and Dream System of each country.

10.2. System Diagrams

Figures 10-1 through 10-12 show each country's Base Case and Dream System. A wide variety in system selection, as well as some common elements, is apparent.

10.3. Tables

Base Case and Dream System information is arranged into three tables.

Table 10-1 provides information for the country Base Cases. The table is organized by solar **DHW** system component, and values have been provided for the key attributes of each component and for the DHW load. The table also gives the rationale for each country's Base Case selection. A typical system can be quite different in type and size from one country to the next.

Table 10-2 provides the same information for the Dream System as was given for the Base Case in Table 10-1. It also provides a justification as to why the particular type of solar DHW system was chosen for the Dream System. As can be seen, the Dream Systems vary in type and size from country to country.

Table 10-3 displays cost, performance, and combined cost and performance of the various Base Case and Dream Systems. It also provides some key reference quantities to enable the reader to gain context for the cost and performance evaluations of each country. The basis for cost estimates are stated. These are applied to the Base Case and Dream System so that resulting cost estimates reflect the real differences between the Base Case and the Dream System, and not influences of different production rates, automation, etc. The task goal of fifteen percent or better for cost/delivered energy improvement has been achieved for all countries.

For further details on the information presented in the tables see Appendix A.

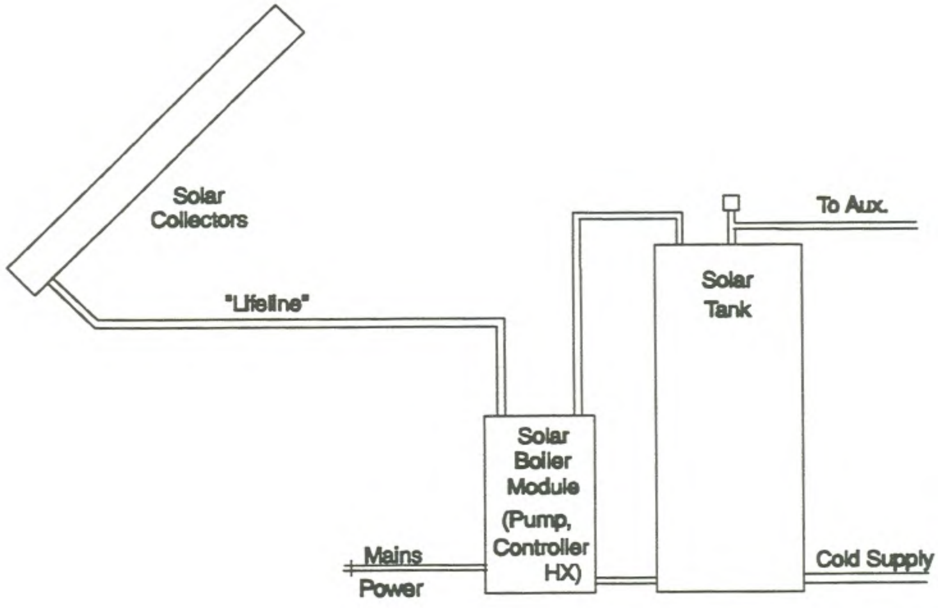

Figure 10-1. Canadian Base Case System Diagram.

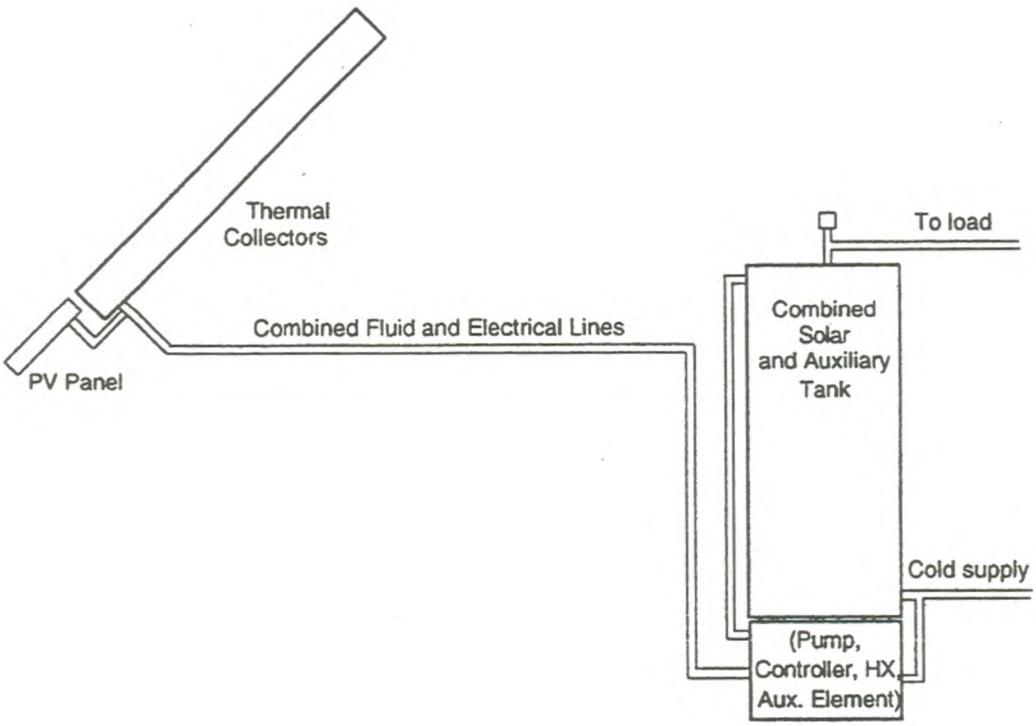

Figure 10-2. Canadian Dream System Diagram.

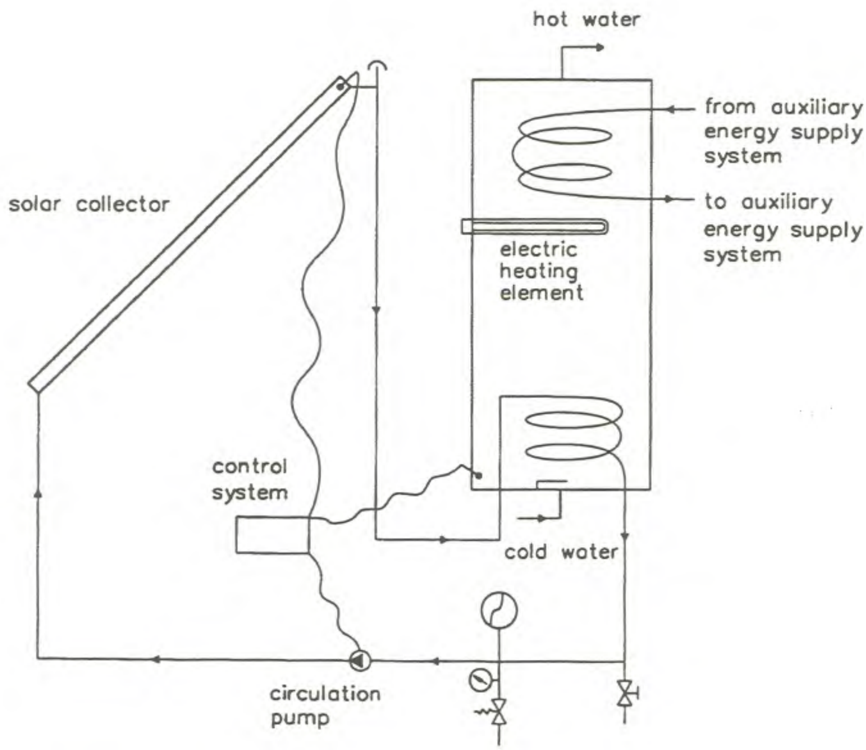

Figure 10-3. Danish Base Case System Diagram.

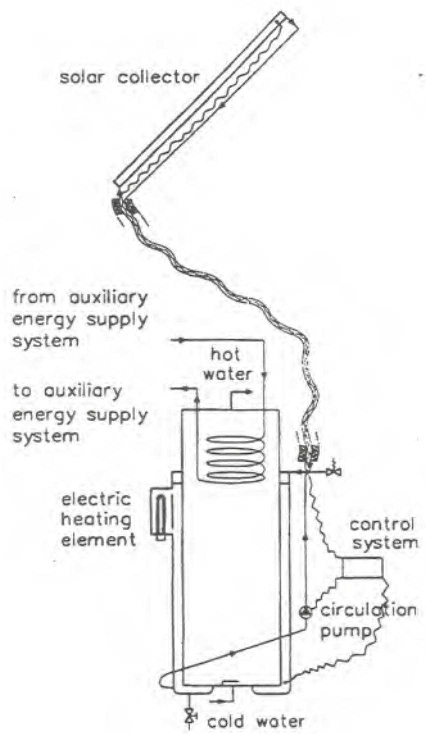

Figure 10-4. Danish Dream System Diagram.

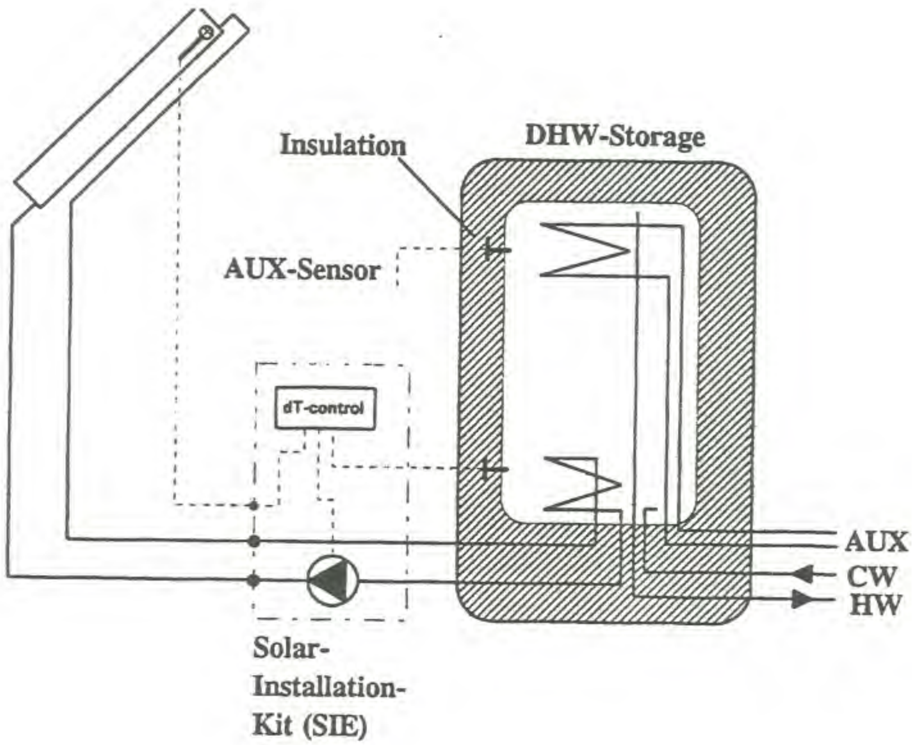

Figure 10-5. German Base Case System Diagram.

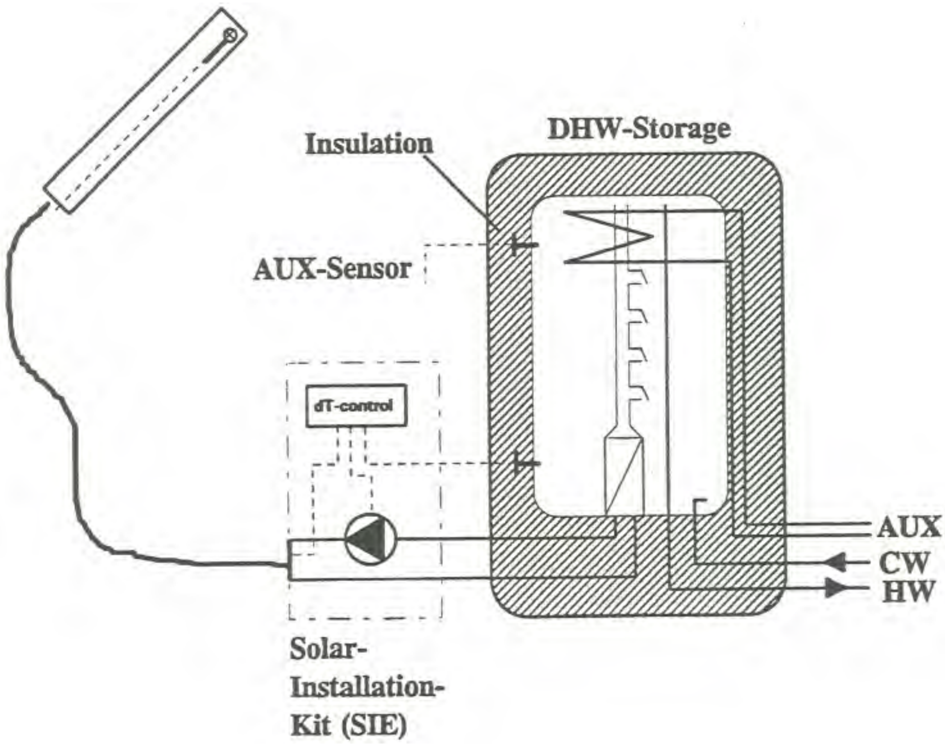

Figure 10-6. German Dream System Diagram.

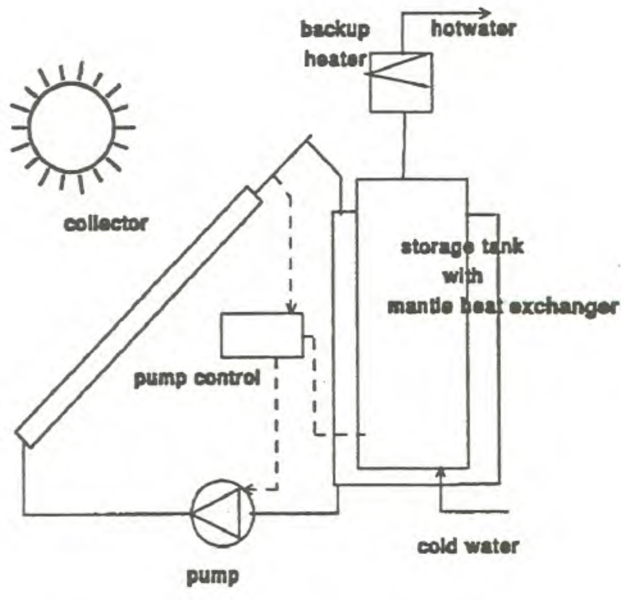

Figure 10-7. The Netherlands Base Case System Diagram.

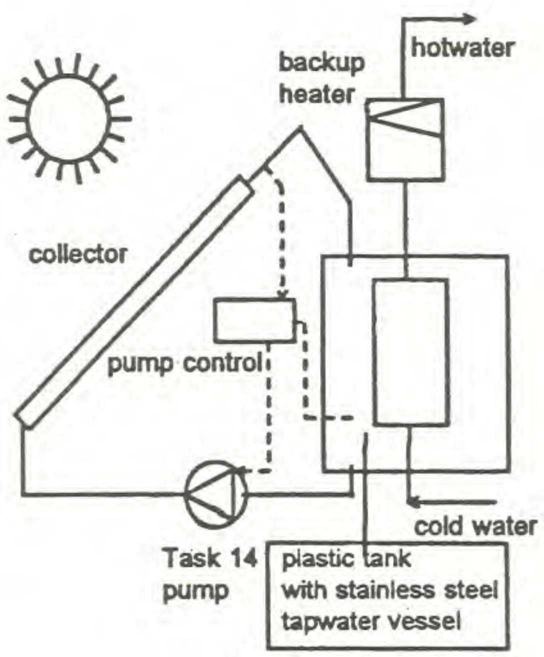

Figure 10-8. The Netherlands Dream System Diagram.

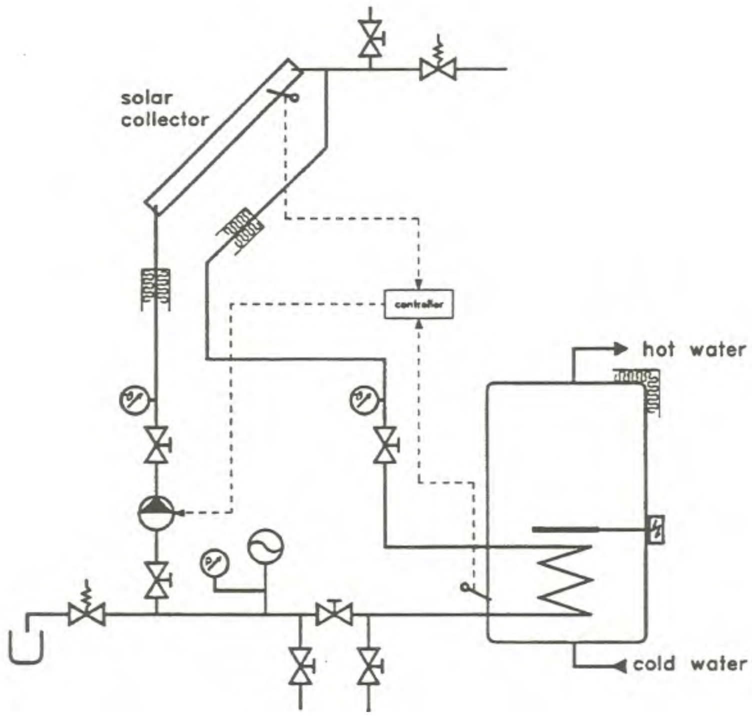

Figure 10-9. Common Domestic Hot Water System in Switzerland.

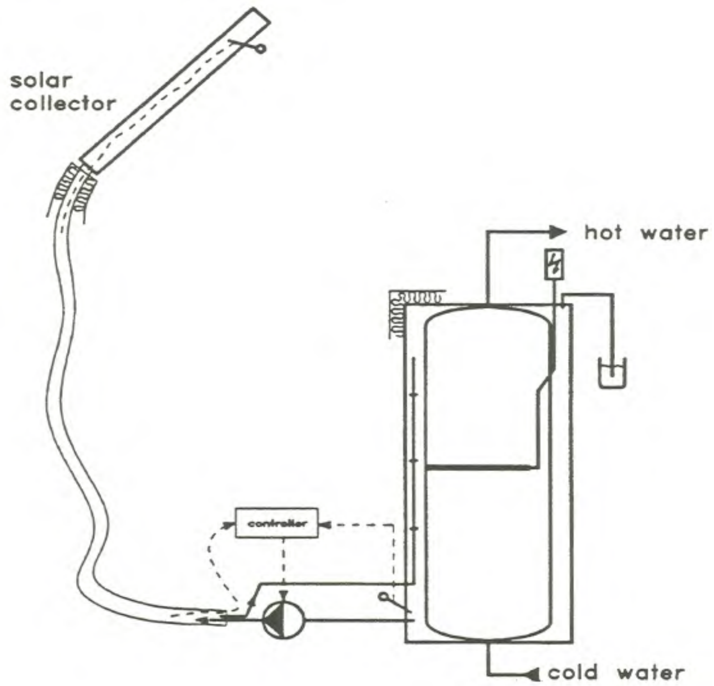

Figure 10-10. Swiss Dream System SOLKIT®.

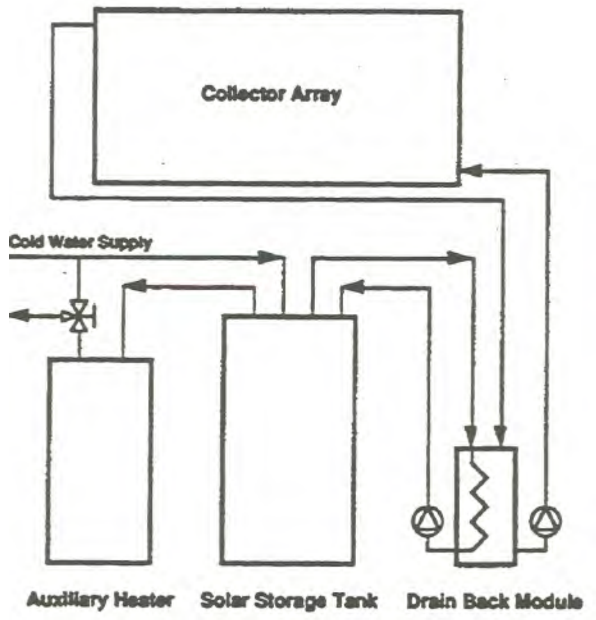

Figure 10-11. United States Base Case System for Freezing Climates.

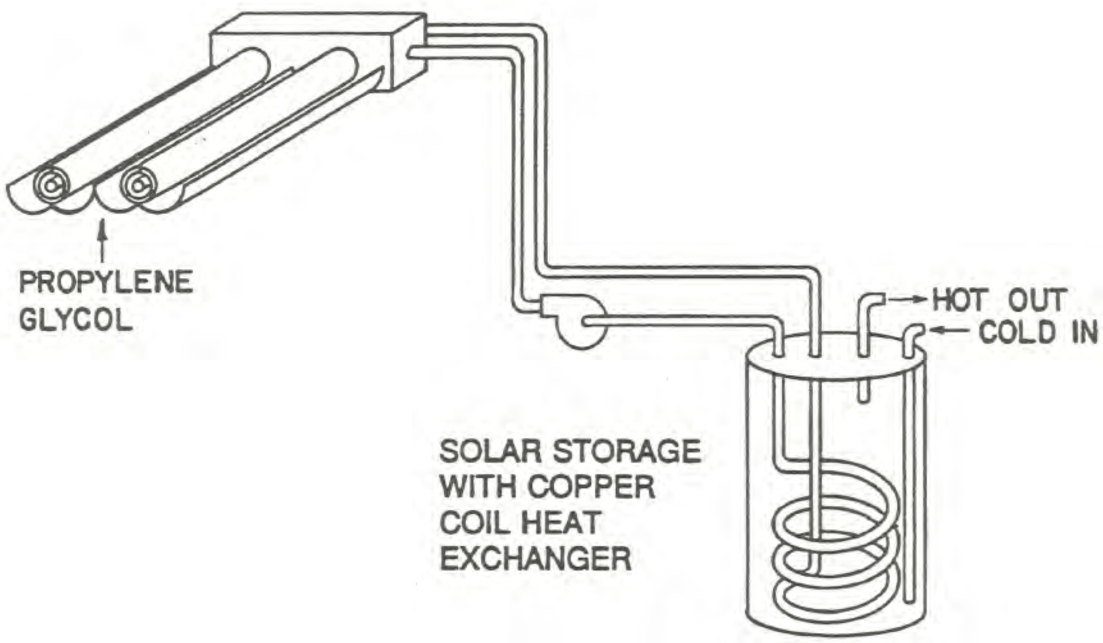

Figure 10-12. United States Dream System for Freezing Climates.

Table 10-1. Base Case Description.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Rationale for choice	Common in Canada in 1989/90	Common in Denmark in 1989/90	Typical of well-designed 1990 German system	Common in the Netherlands in 1989/90	Common in Switzerland in 1989/90	Common in the United States in 1989/1990
Collector						
Geometry	flat plate	flat plate	flat plate	flat plate	flat plate	flat plate
Covers	single	single	single	single	single	single
Cover material	low iron glass	low iron glass	low iron glass	low iron glass	low iron glass	low iron glass
Transmittance	0.91	0.91	0.91	0.92	0.91	0.91
Absorber material	annodized Al/Cu	annodized Al/Cu	copper	annodized Cu/Al	copper	copper
Selective surface	black nickel	black nickel	black chrome	black nickel	black chrome/Ni/Cu	black chrome
α/ε @ 100°C	0.95/0.15 (@20°C)	0.95/0.15	0.96/0.11	0.94/0.18	0.95/0.15	0.95/0.15
Tube OD/fin width	8/143 mm Sunstrip®	10/143 mm Sunstrip®	12.6/112 mm	8/125 mm Sunstrip®	12/112 mm	10/127 mm
Flow design	serpentine	parallel	2x6 parallel	parallel	parallel	parallel
Freeze protection	drainback & glycol	glycol	propylene glycol	drainback	glycol	drainback
Frame materials	aluminium	aluminum	aluminun	aluminum	aluminum	aluminum
Insulation material	fiberglass	mineral wool	foam/mineral wool	polyurethane	rockwool	fiberglass
Back/edge insulation	25/25 mm	50/15 mm	70/30 mm	40/20 mm	50/30 mm	51/32
Length/width/height	2.47/1.20/0.084 m	2.070/1.120/0.090 m	4.76/1.45/0.146 m	1.740/1.740/0.105 m	2.027/0.861/0.127 m	2.32/1.22/0.127
Aperture area x #	2.80 m² x 2	2.19 m² x 2	6.35 m²	2.84 m²	1.48 m² x 4	2.56 x 1
Gross area x #	2.98 m² x 2	2.32 m² x 2	6.90 m²	3.028 m²	1.745 m² x 4	2.84 x 1
Efficiency curve $\eta_0/a_0/a_1$	0.645/3.93/0.0070	0.75/4.85/0.016	0.802/3.69/0.007	0.79/3.78/0.0220	0.797/3.89/0.011	.701/3.97/0.0
Heat capacity	~5 kJ/K-m²	7 kJ/K-m²	41 kJ/K-m² with fluid	4 kJ/K-m²	9 kJ/K-m²	6 kJ/K-m²
Overheat protection	pumps stops > 95°C	none	oversized exp. tank pump stops T > 90°C	pump stops > 90°C	T_s > 80°C, cool at night	pump stops > 95°C
Piping						
Piping material	nylon	copper	copper	copper	copper	copper
Insulation material	none: PVC jacket	PUR foam 10 mm	closed cell foam	12 mm softflex	16 mm armaflex	19 mm closed cell foam
ID/OD/length one way	4.8/6.4 mm/15 m	13/15 mm/5 m	16/18 mm/20 m	13/15 mm/3.5 m	13/15 mm/10 m	16/18 mm/7.6 m
Solar storage & HX						
Diameter/height	0.6/1.5 m	0.50 m/1.60 m	0.620/1.47 m	0.610/0.96 m	0.6/1.8 m	0.50/1.40 m
Volume	273 ℓ	295 ℓ	400 ℓ	115 ℓ	500 ℓ	189 ℓ
Material	glass-lined steel	St 37-2 steel	enameled steel	stainless steel	glass-lined steel	glass-lined steel
Heat exchanger	side arm	bottom helix	bottom finned tube	bottom helix	bottom helix	helix in drainback tank
Heat capacity	150-380 W/K	~200 W/K	180 W/K	300 W/K	300 W/K	200 W/K
Tank insulation	50 mm fiberglass	~50 mm PUR foam	100 mm PUR foam	80 mm PUR foam	100 mm PUR	51 mm fiberglass

Table 10-1 (cont.). Base Case Description.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Auxiliary						
Tank dimensions	0.6/1.5 m	none	none	none	none	0.50/1.40 m
Volume	273 (182) ℓ					189 ℓ
Tank material	glass-lined steel					glass-lined steel
Insulation	50 mm fiberglass					51 mm fiberglass
Power	2 x 4.5 kW U-tubes	~300 W/K/1000W	500 W/K	20-30 kW	3 kW	2 x 4.5 kW U-tubes
Location	10 cm from bottom 50 cm from top	HX spiral top heating element top	HX spiral top finned tube	adjacent separate	middle	35 cm from top 5 cm from bottom
Pumps						
Model	Procon 1521	Grundfos 25-40 180	Grundfos UPS 25-40	Grundfos UPS 25-40	Grunfos UPS 25-40	Grunfos UPS 25-40
Flow rates	0.4 to 1.3 ℓ/min	4 ℓ/min	4 ℓ/min	4 ℓ/min	~6 ℓ/min	6 ℓ/min/4 ℓ/min
Power	120 W	30 W	55 W	30 W	60 W	30 W/60 W
Load						
Volume	300 ℓ/day at 50°C	200 ℓ/day at 45°C	250 ℓ/day at 45°C	110 ℓ/day at 65°C	220 ℓ/day at 50°C	265 ℓ/day at 55°C
Cold water inlet	10°C	10°C	11°C (5 - 17°C)	15°C	10°C	17°C
Draw profile	4 equal draws at 8, 12, 16, and 19:00	4 equal draws at 8, 12, 18, and 20:00	f-chart profile	5 equal draws at 7, 8, 13, 18, and 19:00	8 equal draws at 7, 8, 11, 12, 13, 18, 19, 20	3 equal draws at 8, 13, 17:30
Controls						
Type	differential	differential	differential	differential	differential	differential
On/off ΔT	10/2 K	10/2 K	5/2 K	10/2 K	8/4 K	2.8/0 K

Table 10-2. Dream System Description.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Justification for choice	Lower power pump, more efficient glazing and absorber, more uniform sidearm flow, lower cost PV panel and pump are used.	Low flow and drainback reduce costs and increase performance.	Low-flow, high-performance collector, advanced storage design, and Life-Line® piping are used.	Low flow as well as other improvements are used to reduce costs and improve performance.	Components are ***system***-optimized and system is designed for ease of installation.	Modifications are made to improve performance and lower the cost of a system that already has high performance.
Collector						
Geometry	flat plate	flat plate	flat plate	flat plate	flat plate	ETC with reflector
Covers	double	single	single	single	single	126 mm diam. tube
Cover material	low-iron glass/PTFE	low-iron glass	low-iron glass	low-iron glass	low-iron glass	SK glass
Transmittance	0.88	0.91	0.91	0.92	0.91	0.91
Absorber material	Cu alloy	annodized Al/Cu	copper	Cu	Cu	stainless steel
Selective surface	sputtered carbide	black nickel	sputtered material	black chrome	black chrome/Ni/Cu	chemical treatment
α/ε @ 100°C	0.95/0.05	0.95/0.15	0.95/0.08	0.96/0.12	0.96/0.10	0.93/0.11
Tube OD/fin width	8/125 mm Sunstrip®	10/143 mm Sunstrip®	5/137 mm copper	10/100 mm	8/110 mm	114 mm cylinder
Flow design	parallel	parallel	2x5 parallel	serpentine	serpentine	single pass
Freeze protection	drainback & glycol	drainback	propylene glycol	drainback	ethylene glycol	propylene glycol
Frame materials	aluminium or steel	aluminum	aluminum	aluminum	aluminum	steel
Insulation material	iscyanurate	mineral wool	foam/mineral wool	PUR-glass foam	PUR - rockwool	vacuum/fiberglass
Back/edge Insulation	25/25 mm	50/15 mm	70/30 mm	55/30 mm	50/35 mm	vacuum/25 mm
Length/width/height	2.3/1.15/0.07 m	2.820/1.125/0.090 m	3.81/1.45/0.146 m	1.776/1.751/0.105 m	3.0/1.6/0.128 m	2.477/0.711/0.165 m
Aperture area x #	2.58 m² x 2	3.00 m²	5.08 m²	2.75 m²	4.48 m²	1.49 m²
Gross area x #	2.72 m² x 2	3.17 m²	5.53 m²	3.11 m²	4.8 m²	1.76 m²
efficiency curve $\eta_0/a_0/a_1$	0.756/2.91/0.0024	0.75/4.62/0.013	0.83/3.7/0.07	0.785/3.475/0.0157	0.8/3.5/0.010	0.5331/0.1650/0.0 m
Heat capacity	~1 kJ/K-m²	7 kJ/K-m²	6.8 kJ/K-m² with fluid	4 kJ/m²-K	~3 kJ/m²-K	2.5 kJ/m²-K
Overheat protection	pump stops > 90°C	pump speed up and pump stops	oversized expansion tank and pump stops > 90°C	pump stops > 90°C	fluid purge	pump circulation
Piping						
Piping material	nylon or PTFE	EPDM	silicon rubber	copper	silicon rubber	Thermoplastic
Insulation material	fiberglass	14 mm trocellen	closed cell foam	15 mm fiberglass	Armaflex	9 mm polyethelene
ID/OD/length one way	7/9 mm/15 m	10/18 mm and 8/18 mm/5 m	5/9 mm/20 m	8/10 mm/3.5 m	10/20 mm/13.75 m	16/20 mm/8 m

Table 10-2 (cont). Dream System Description.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Solar storage & HX						
Diameter/height	0.6/1.5 m	0.415/1.20 m (150 ℓ)	0.500/1.48 m	0.750/0.900 m	0.54/1.87 m	0.114/2.042 m x 2
Volume	270 ℓ	175 ℓ	300 ℓ	100 ℓ	430 ℓ	38 ℓ + 151 ℓ
Material	glass-lined steel	St 37-2 steel	enameled steel	plastic	stainless steel	copper
Heat exchanger	thermosyphon under	mantle	small spiral tube	none - direct	tank within a tank	copper coil
Power	300 W/K	variable	600-700 W/K		variable	
Tank insulation	70 mm fiberglass	~50 mm PUR foam	100 mm	80 mm PS foam	100 mm PUR foam	vacuum
Auxiliary						
Tank dimenesions	none	none	none	none	none	0.50/1.40 m
Volume						189 ℓ
Tank material						glass-lined steel
Insulation						51 mm fiberglass
Power	1 kW	~300W/K/1000 W	500 W/K	20-30 kW	2 kW	4.5 kW x 2
Location	side-arm	HX spiral top heating element top	HX spiral top finned tube	adjacent	adjustable	35 cm from top 5 cm from bottom
Pumps						
Model	T14 pump	Grundfos 25-40 180	T14 pump	T14 pump	membrane	T14 pump
Flow rates	1.3 ℓ/min	0.5 ℓ/min	1.0 ℓ/min	1.3 ℓ/min	0.66 ℓ/min	1.3 ℓ/min
Power	5-10 W	30 W	5-10 W	5-10 W	7 W	5-10 W
Load						
Volume	300 ℓ/day at 50°C	200 ℓ/day at 45°C	250 ℓ/day at 45°C	110 ℓ/day at 65°C	220 ℓ/day at 50°C	265 ℓ/day at 55°C
Cold water inlet	10°C	10°C	11°C (5 - 17°C)	15°C	10°C	17°C
Draw profile	4 equal draws at 8, 12, 16, and 19:00	4 equal draws at 8, 12, 18, and 20:00	f-chart profile	5 equal draws at 7, 8, 13, 18, and 20:00	8 draws at 7, 8, 11, 12, 13, 18, 19, 20:00	3 equal draws at 8, 13, and 17:30
Controls						
Type	AC adaptor or PV	differential	differential	differential	differential	photovoltaic
On/off	5K or proportional	adjustable	8/3 K	10/1 K	5/2 K	proportional

Table 10-3. Costs, Performance, and Comparisons.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Reference quantities for calculations						
Location	Toronto	Copenhagen	Hannover	DeBilt	Kloten 1986	Sacramento, CA
Latitude °	43	56	52.5	52	47	38.5
Collector slope °	45	45	38	45	45	28.5
Radiation on collector aperture GJ/m²-yr	5.48	4.262	3.808	3.989	4.5	7.497
Monthly average daytime temperature °C	9 (-6 to 22)	8.1	8.7 (0 to 17)	9.5 (2 to 18)	8.6 (-1 to 19)	16 (7 to 24)
Exchange rate in US$ and basis date	0.87$ 1/94	6.70 DKK 3/94	1.7 DM 4/94	1.86 Df 5/94	1.437 sFr 1/94	1.00/$ 12/93
Base Case manufacturing costing approach and Dream System differences	1993 fabrication, market, methods, and prices; design for automation	1994 conditions	1994 conditions	1989 market and fabrication methods at 1994 prices	Base Case costing approach	1989 market and fabrication methods at 1993 prices
Base Case cost (1993 US$)						
Components						
Collector (x number)	329 (x 2)	748 (x 1)	1680 (x 1)	700 (x 1)	1200 (x 1)	350 (x 1)
Solar storage	187	1423	1453	420	1667	325
Pump/controls	290	in storage	625	195	267	650**
Piping/fittings	122	150	300	100	666	300
Fluids/other	345	27	0	0	333	0
Installation materials and labor	260	750	2550	570	3000	300
Total*	1862	3098	6608	1985	7134	1925
Operating and maintenance $/yr	< 10	15-22	51-131	17	84-150	10
Base Case performance						
Aperture m² (x number)	2.835 (x 2)	4.38 (x 1)	6.35 (x 1)	2.83 (x 1)	1.74 (x 4)	2.56 (x 1)
Thermal (Q_{load} - Q_{aux}) GJ/yr	8.7	5.07	6.55	3.70	7.2	7.05
Reliability and Durability	good to excellent	no problems	excellent	no significant problems	same as ordinary water heaters	excellent
Dream System cost (1993 US$)						
Components						
Collector	530	490	1428	550	853	650
Solar storage	175	552	1095	385	800	integral + 250
Pump/controls	100	163	570	145	300	125
Piping/fittings	175	120	100	100	280	125
Fluids/other	205	0	0	0	233	50
Installation materials and labor	260	567	2200	360	2000	300
Total*	1445	1892	5393	1540	4466	1510
Operating and maintenance	< 5	15	37-117	11	74-140	10

* This is not the end price to the user. Total does not include marketing, selling and distribution costs. The values in this table do not include the consequences of higher production volumes and improved installation approaches. See Appendix A for further details.

**Including drainback tank and heat exchanger.

Table 10-3 (cont.). Costs, Performance, and Comparisons.

Subject	Canada	Denmark	Germany	Netherlands	Switzerland	United States
Dream System performance						
Aperture m² (x number)	2.575 (x 2)	3.00 (x 1)	5.08 (x 1)	2.75 (x 1)	4.48 (x 1)	1.45 (x 1)
Thermal (Q_{load} - Q_{aux}) GJ/yr	12.9	5.04	6.65	4.16	7.2	8.51
Reliability	excellent	freezing problems	excellent	improved	improved	excellent
Cost/performance comparisons						
Cost reductions $	417 (22%)	1206 (39%)	1215 (18.3%)	445 (22.6%)	2667 (37%)	415 (21.6%)
Energy delivery increases GJ/yr	4.2 (48%)	-0.03 (-1%)	0.1 (1.5%)	0.46 (12.4%)	0 (0%)	1.46 (20.7%)
O&M improvements $	slight	~5 (~25%)	~14 (~15%)	6 (35%)	10 (10%)	0 (0%)
Base Case $/GJ/yr	214	611	1009	563	990	273
Dream System $/GJ/yr	112	375	811	370	620	177
Cost/energy delivery improvement $(GJ/yr)	102 (48%)	236 (39%)	198 (19.6%)	193 (34%)	370 (37%)	96 (35.2%)

11. CONCLUSIONS AND FINAL REMARKS

The Working Group began its work in 1989 with the purpose of advancing the state-of-the-art in solar DHW systems. The Working Group assembled and developed many design features and components. They analyzed, designed, evaluated, constructed, monitored, and commercialized different systems incorporating these features and components.

The Working Group's goal of a 15 percent increase in the initial cost to annual performance ratio (cost/performance), as compared to 1989 practice, was exceeded by all countries. The Working Group exceeded their cost/performance goal by both lowering cost and increasing performance. Though the Working Group's chosen primary focus was low-flow systems, in many cases the improved components also provided similar gains for high-flow systems. In fact, most of the Working Group's advances can be classified as general improvements to solar DHW systems, and not just for low flow.

Cost/performance gains ranged from 20 to 48 percent, depending on the country. These gains are a collective result of multiple improvements, including the following:

- Using mantle, in-tank helical, and other improved heat exchangers.
- Using tank-in-tank storages with an inexpensive unpressurized outer drainback tank.
- Using single tanks that combine solar and auxiliary storage.
- Using external auxiliary heaters.
- Modularizing several components, such as pump, controller, heat exchanger, and auxiliary.
- Selecting inexpensive low power consumption pumps.
- Making use of stratification enhancement devices.
- Using lower cost low-flow absorber designs and materials.
- Using easy to install Life-Line® type piping products that have lower net installed costs.
- Designing CPC reflectors to reduce the number of currently expensive evacuated tubes.

These components and other features were well designed or logically selected within a systems optimization context. All optimization was constrained, often substantially, by the regulations and practices of each country. Many of these features are the subject of continuing research in the Working Group countries.

Other Working Group results were

- For high solar fraction low-flow systems different designs of solar storage/auxiliary/heat exchanger systems performed about equally. For low solar fractions, there were clear differences. (See Chapter 5 references.)

- Working Group load variability studies have indicated that daily and day-to-day variation in DHW load does not significantly impact performance of low-flow systems with set flow rates.

- Many of the Solar DHW Working Group systems developments have been implemented by industry or are gaining acceptance in Task 14 countries. Two of the Dream Systems, those of Switzerland and Denmark, are currently being commercialized.

- In the near term, improvements from lowering collector flow rates have accumulated more on the cost side than on the performance side. However, over the longer term better systems may result when all components are designed specifically for low-flow and are properly integrated into the system.

In addition to sharing components and features there was a general and very productive exchange of ideas. This took place as a matter of course in the meetings and conduct of the Task, as well as more formally through

- exchange of component development information

- comparison of simulation and test results

- study trips and technical tours of installations

- organization of solar industry/Task 14 workshops as a part of nearly all Task meetings.

The Netherlands and Denmark entered into joint model validation and experimentation to resolve a storage/heat exchanger performance issue. The two most promising designs were experimentally evaluated in Canada's National Test Facility solar simulator. This resulted in an exacting comparison of the two point designs in a low and a high flow mode and substantiated the advantage of using low-flow for the given two systems.

In general the partnership of researcher and industry representative worked well as a task structure. The general feeling within the Working Group was that the international collaboration among researchers and industry has spawned long term relationships which will benefit the worldwide market situation. There was also a general opinion that more was accomplished collectively and more was achieved in each country than would have been the case without the Working Group collaboration.

12. ACKNOWLEDGEMENTS AND CONTACTS

12.1. Acknowledgements

The low-flow concept explanation chapter was contributed by Canada. The Netherlands contributed the chapter on collectors, absorbers, and loads. Denmark contributed the chapter on thermal storages, heat exchangers, and auxiliaries. Switzerland contributed the chapter on piping, and Canada contributed the pumps and controller chapter. Denmark and The Netherlands contributed the chapter on the low-flow/high-flow experiment. The material in the appendices was contributed by the various countries.

The editor (United States) refined and assembled the report contributions, including the appendicies and wrote the Base Case and Dream System summary chapter, the summary chapter on country information, the Executive Summary, the Introduction, and the Conclusions.

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APPENDIX A

BASE CASE AND DREAM SYSTEM COUNTRY CONTRIBUTIONS

A1. CANADA

A1.1. Base Case System Description

The Base Case system consists of a pair of solar collectors connected together in series, a "Boiler Module," and a solar storage tank. The auxiliary tank is separate. The hydraulic configuration is drainback with a propylene glycol antifreeze solution. The collectors are connected to the heat exchanger and pump module via Life-Line® tubing, which integrates the supply and return Nylon tubes with a pair of wires for the delta-T controller. One insulation jacket covers the hot return line, and a second covers the whole assembly. An outer vinyl sleeve provides environmental protection. The pump is AC powered.

Solar energy is transferred from the heat exchanger to the tank via natural convection in the sidearm loop connecting the module to the tank. See Figure Al-1.

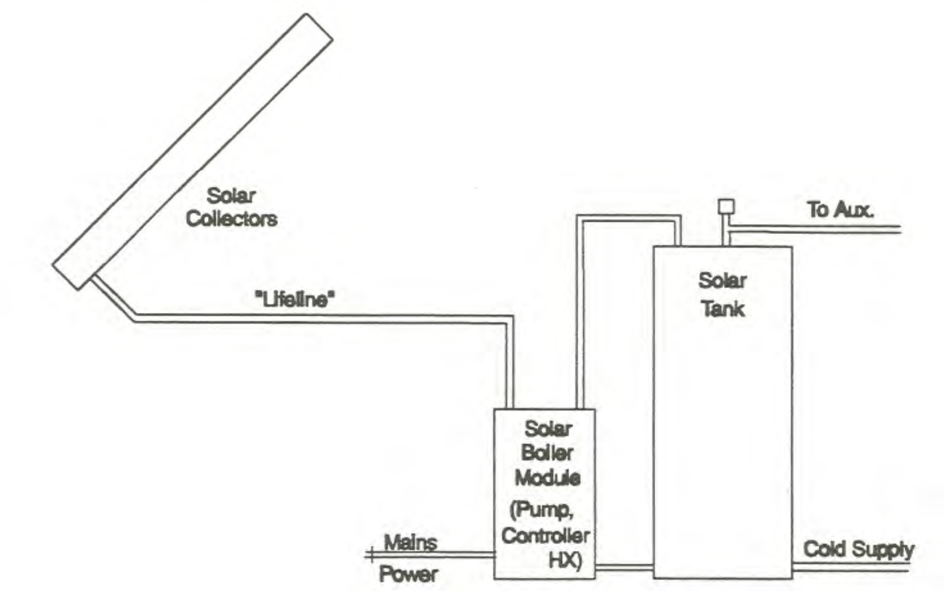

Figure A1-1. Canadian Base Case System Diagram.

<u>Operating Modes:</u>

The pump is off if the collector is cooler than the tank bottom,
or if the solar tank is over temperature.

The pump is on if the collector is warmer than the tank bottom, *and* the tank is not over temperature.

Rationale for Choice of Base Case System:

This system has been the one most commonly installed in Canada over the last few years. It was first marketed in late 1988.

A1.1.1. Collector

A1.1.1.1. Collector geometry. The are two collectors connected in series. Internally, there are eight fin-tubes connected in a series (serpentine) arrangement. Each collector has a single glazing.

A1.1.12. Collector cover material. The cover is pebble-surface, low-iron glass.

A1.1.13. Absorber material. The absorber consists of a two-layer aluminum fin roll-bonded over a copper tube, which is inflated with air after rolling. The optical surface is an aluminum anodized layer impregnated with black nickel to impart selectivity.

A1.1.1.4. Absorber fin/flow design. The 143 mm wide, roll-bond, fin tubes have an 8 mm (hydraulic) bore to facilitate the total design flow rate. Eight such units are connected in series in each collector.

A1.1.1.5. Drainback design. The solar collector loop is designed to drainback whenever the pump stops.

A1.1.1.6. Frame materials. The frame is fabricated from pieces of aluminum extrusion.

A1.1.1.7. Insulation material. The back of the collector is insulated with a layer of semi-rigid low-outgas fiberglass.

A1.1.1.8. Dimensions, specifications, and properties. Each collector is 2.47 m long by 1.20 m wide. The second order efficiency equation follows. This was produced by a numerical model whose input was adjusted to make the output fit a graphed test result that reported dT/G only to 0.10, for an actual collector.

$$\eta = 0.645 - (3.93 + .0070 * dT) * dT/G$$

A1.1.2. Piping Runs

A1.1.2.1. Piping material. The piping material is Nylon.

A1.1.2.2. Insulation material. The pipe insulation material is non-hygroscopic fiberglass.

of a 6.4 mm outside diameter (OD) (4.8 mm inside diameter (ID)) supply tube wrapped in insulation and paralleled with the 6.4 mm OD return tube and the two sensor feed wires. The whole bundle is wrapped in another layer of insulation, plus an outer PVC environmental jacket.

A1.1.3. Solar Storage and Heat Exchanger

A1.1.3.1. Tank dimensions and specifications. The standard solar tank has a capacity of 273 ℓ.

A1.1.3.2. Heat exchanger type and location. The heat exchanger has a coil-in-shell configuration, and is incorporated in the "Boiler Module."

A1.1.3.3. Heat exchanger specifications. The heat exchanger has a rating of 380 W/K.

For the current heat exchanger the UA value varies from 100 to 300 W/K as the sidearm flow rate varies.

A1.1.4. Auxiliary

A1.1.4.1. Tank dimensions and specifications. Not applicable. (Separate tank--not included in system.)

A1.1.4.2. Auxiliary element location and specifications. Not applicable. (See above.)

A1.1.5. Pump

A1.1.5.1. Flow rates and specifications. The pump is a Model 1521 Procon positive displacement, driven by a 120 W GE AC motor. The flow is assumed to be 1.3 ℓ/minute.

A1.1.6. Load

A1.1.6.1. Specifications. The total hot water load is 300 ℓ/day at 50°C.

A1.1.7. Controls

A1.1.7.1. Controller specifications. The controller is a delta-T model DTT84 made by Heliotrope, dT = 10/2 K.

A1.1.7.2. Operating modes.

The pump is off if the collector is cooler than the tank bottom,
or if the solar tank is over temperature.

The pump is on if the collector is warmer than the tank bottom, *and* the tank is not over temperature.

A1.2. Dream System Description

The Dream System is essentially the same as the Base Case, with the following exceptions:

- The pump is powered by a 5 W PV panel.
- The collectors have a light-weight absorber design with narrow, small-bore, fm tubes connected in parallel, and a PTFE convection bather (inner glazing).
- The tubing in the Life-Line® lines is polymeric rather than copper.
- The pump/heat exchanger module is below the solar tank to maximize the flow in the sidearm thermosyphon near the end of a charge cycle.
- The pump is much smaller, cheaper, and more efficient.
- The auxiliary electric element is installed in the outlet header of the heat exchanger, and the auxiliary storage shares the solar tank, which is larger. See Figure A1-2.

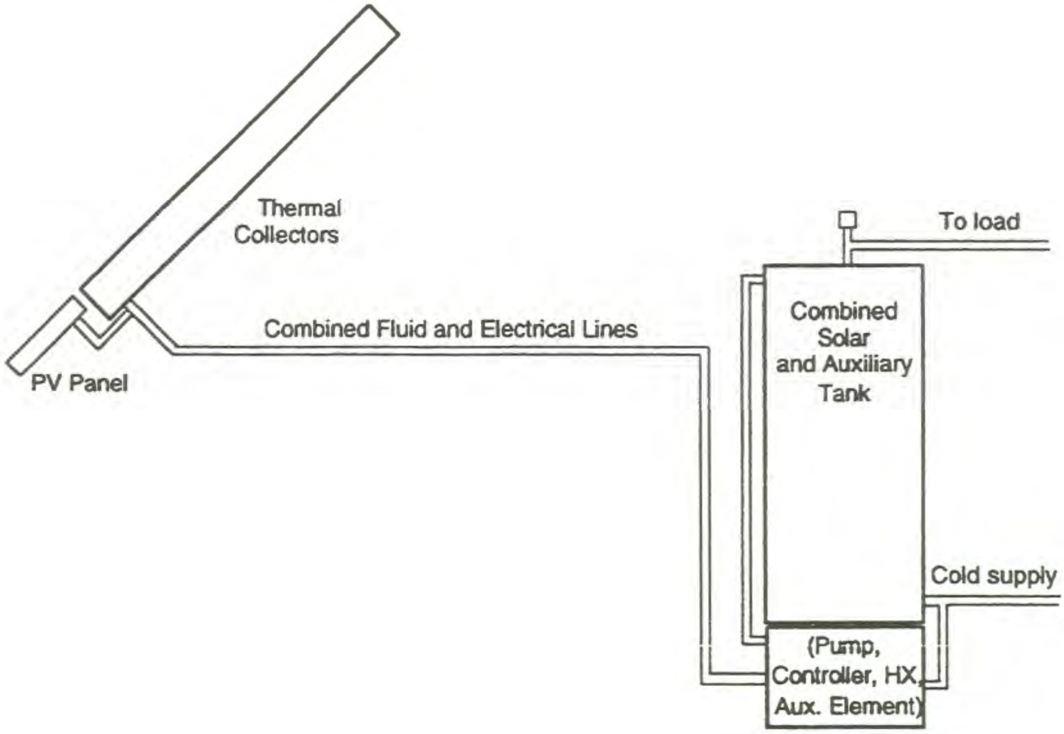

Figure A1-2. Canadian Dream System Diagram.

Operating Modes:

Pump off, due to:

a) Low delta-T.
b) Tank at or above temperature limit. (Collector loop drains whenever pump stops.)

Pump on, due to:

c) High delta-T, with pump start-up at high speed (to fill drainback syphon loop).
d) High delta-T; normal operation at medium speed and fixed flow.

Auxiliary:

The auxiliary control algorithm is not yet determined. Options include off-peak heating, and in-line boost of solar input during periods of weak insolation to guarantee stratification.

A1.2.1. Collector

A1.2.1.1. Collector geometry. There are two collectors in parallel, with parallel-riser fin tubes and headers.

A1.2.1.2. Collector cover material. The outer cover is low-iron tempered glass, with a PTFE inner glazing with a compliant mounting for stress and sag control.

A1.2.1.3. Absorber material.

integral, fin-tube shape. The optical surface is a high performance sputtered coating such as the University of Sydney "stainless steel carbide." The surface absorptivity is 0.95, and the emissivity 0.05.

A1.2.1.4. Absorber fin/flow design. The absorber fm tubes have a small bore (2-3 mm), and are connected in parallel between upper and lower horizontal headers.

Drainback design. The collector parallel risers facilitate drainback.

A1.2.1.6. Frame materials. The outside frame will be fabricated in one piece from roll-formed, pre-painted sheet steel or aluminum.

A1.2.1.7. Insulation material. The back and sides will be insulated with isocyanurate foam or fiberglass.

A1.2.1.8. Dimensions, specifications, and properties. Each collector is about 2.3 m long by 1.15 m wide. The efficiency equation is predicted to be (using the same model as for the Base Case collectors):

$$\eta = 0.765 - (2.91 + .0024*dT) * dT/G.$$

A1.2.2. Piping Runs

A1.2.2.1. Piping material. The piping material will be a thermoplastic. It is possible that a proposed newer Nylon composition will be adequate for pressure and temperature. Alternatively, a custom-designed, custom-built, thin-wall PTFE tube with fibre reinforcement may prove low enough in cost if the PTFE content can be reduced.

A1.2.2.2. Insulation material. The insulation material will be fiberglass, or polymer foam if its temperature rating can be consistent with the higher temperature ratings of the collectors and of the PTFE tubing. The pipe heat loss is calculated to be 0.5 W/m^2K, referred to collector area.

A1.2.2.3. Configuration, dimensions, and specifications. The Life-Line® collector connection bundle is expected to have 6-7 mm ID supply and return tubes (above), and PV power and sensor wires, all in an insulated jacket 35-40 mm OD.

A1.2.3. Solar Storage and Heat Exchanger

A1.2.3.1. Tank dimensions and specifications. There will be one tank about 1.5 m high by 0.6 m diameter, and having a capacity of 270 ℓ, about one day's load. The insulation will be fiberglass, about 70 mm thick.

A1.2.3.2. Heat exchanger type and location. The heat exchanger will have a fin/tube-in-shell configuration, with potable water on the shell side, antifreeze in the tube side. Its location will be external to, and underneath, the tank. The tank-side flow will be by natural thermosyphon.

A1.2.3.3. Heat exchanger specifications. 300 W/K at 1.3 ℓ/minute.

A1.2.4. Auxiliary

A1.2.4.1. Tank dimensions and specifications. None. Auxiliary storage will be integrated with the solar tank.

A1.2.4.2. Auxiliary element location and specifications. It [illegible] located, in-line, in the top of the shell of the solar heat exchanger, and have a rating of about 1 kW. This location is to enhance thermal stratification, particularly when coupled with innovative auxiliary control strategies.

A1.2.5. Pump

A1.2.5.1. Flow rates and specifications. The pump's flow and pressure ratings at operating speed are 1.3 ℓ/minute at 0.9 atm at 5W. The pump is to be driven at higher speed on system start-up to achieve two atmospheres of pressure to fill the drainback syphon.

A1.2.6. Load

A1.2.6.1. Specifications. The total design load for the system is 300 ℓ/day at 50°C, and is insensitive to the time-of-day due to the high degree of thermal stratification in the tank, as long as the tank is sized for about one day's load.

A1.2.7. Controls

A1.2.7.1. Controller specifications. The controller is expected to have an on-off delta-T of 5 K, and includes a 5 W 3-phase driver for the pump.

A1.3. Justification for Dream System Choice

The Dream System will have higher performance due to the lower power pump, more efficient collector glazing and absorber, and, to some extent, more uniform sidearm flow.

Lower cost will result primarily from the pump price reduction and the small PV panel. There will be an additional saving by not having to buy an auxiliary tank in new installations.

Like the Base Case system, it will be easy to install, reliable and durable.

A1.4. Cost of the Base System

(US Dollars; *before* subsidy)	$1862

($CDN @ US$ 0.8681; at the time of writing, it is about 0.73 US$)

A1.4.1. Component Costs

Collectors (5.95 m^2)		$658
Solar Storage(s) (273 ℓ)		$187
Overheat and Overpressure Prevention - with tank		
Auxiliary Storage - N/A		
Auxiliary - N/A		
Fluids Other Than Water		$635 (covers Fluids Other Than Water through Controller)
Heat exchanger(s)		
Pump(s): Procon 1521 + 120 W GE motor	($190)	
Controller: Heliotrope DTT84	($100)	

Solar Energy System Piping $122
Solar Energy System Fittings - N/A

A1.4.2. Installation Cost $260

A1.4.3. Operating and Maintenance Costs N/A

A1.5. Performance of the Base Case System

A1.5.1. Thermal Performance. See Table A1-1.

Location for Simulation: Toronto
Latitude: 43 °
Collector slope: 45 °
Collector Aperture Area: 5.67 m2

Table A1-1. Thermal Performance of Canadian Base Case System.

	Radiation on the Collector, $MJ/m^2/day$	Daytime Ambient Temperature °C	Daily Solar Contribution, $MJ/m^2/day$	Auxiliary Required, $MJ/m^2/day$	Total DHW Load, $MJ/m^2/day$
Jan	9.8	-5	2.4	6.0	8.3
Feb	13.0	-6	3.1	5.3	8.3
Mar	17.2	-1	4.4	4.0	8.3
Apr	17.0	7	4.6	3.7	8.3
May	17.0	12	4.8	3.5	8.3
Jun	20.1	19	5.9	2.4	8.3
Jul	19.0	22	5.9	2.5	8.3
Aug	20.7	21	6.3	2.1	8.3
Sep	17.2	17	5.4	2.9	8.3
Oct	14.0	10	4.2	4.2	8.3
Nov	8.6	4	2.3	6.0	8.3
Dec	6.2	-3	1.5	6.9	8.3
Ann	15.0	9	4.2	4.1	8.3

Total Solar Energy Delivered: about 8.7 GJ/an. (2428 kW-hr/an)
Annual Solar Fraction: 0.57

A1.5.2. Reliability and Durability Not available.

A1.6. Costs of the Dream System (US Dollars) $1445

A1.6.1. Component Costs

Collectors (5.3 m² @ $100/m²)		$530
Solar Storage(s)		$175
Overheat and Overpressure Prevention	- (with tank)	
Auxiliary Storage	- Part of solar tank.	
Auxiliary (integral with HX assembly)	- $ 20	$305 (Auxiliary through Pump(s))
Module housing/frame	- $ 50	
Fluids Other Than Water	- $ 15	
Heat exchanger(s)	- $ 70	
PV Panel for pump	- $ 50	
Control System - Part of pump drive.		
Pump(s), incl. drive electronics	- $ 100	
Solar Energy System Piping		$175
Solar Energy System Fittings - N/A		

A1.6.2. Installation Cost $260

A1.6.3. Operating and Maintenance Costs N/A

A1.7. Performance of the Dream System

A1.7.1. Thermal Performance See Table A1-2.

Location for Simulation:	Toronto
Latitude:	43°
Collector slope:	45°
Collector Aperture Area:	5.15 m²

Table A1-2. Thermal Performance of Canadian Dream System.

	Radiation on the Collector, $MJ/m^2/day$	Daytime Ambient Temperature °C	Daily Solar Contribution, $MJ/m^2/day$	Auxiliary Required, $MJ/m^2/day$	Total DHW Load, $MJ/m^2/day$
Jan	9.8	-5	4.6	4.6	9.2
Feb	13.0	-6	5.7	3.5	9.2
Mar	17.2	-1	7.1	2.1	9.2
Apr	17.0	7	7.5	1.6	9.2
May	17.0	12	8.1	1.1	9.2
Jun	20.1	19	8.8	.4	9.2
Jul	19.0	22	8.8	.4	9.2
Aug	20.7	21	9.0	.2	9.2
Sep	17.2	17	8.6	.6	9.2
Oct	14.0	10	7.3	1.9	9.2
Nov	8.6	4	4.3	4.9	9.2
Dec	6.2	-3	2.8	6.4	9.2
Ann	15.0	9	6.9	2.3	9.2

Total Solar Energy Delivered: about 12.9 GJ/an. (3583 kW-hr/an)
Annual Solar Fraction: 0.75

A1.7.2. Reliability and Durability Not known.

A1.8. Cost Performance Comparisons

Cost Improvement over Base Case: -22%
Performance Improvement over Base Case: +48%

Base Case Cost/Performance Ratio $214 / (GJ/an)

Dream System Cost/Performance Ratio: $112 / (GJ/an)

Improvement over the Base Case: 48%

A2. DENMARK

A2.1. Base Case System Description

A2.1.1. System Diagram/Description of Operating Modes The Base Case system is designed as were all Danish marketed systems when the Task began. The solar collector loop is a pressurized loop with an expansion tank and security valve opening at 2.5 bar. A glycol/water mixture is used as the solar collector fluid.

A diagram of the system is shown in Figure A2-1.

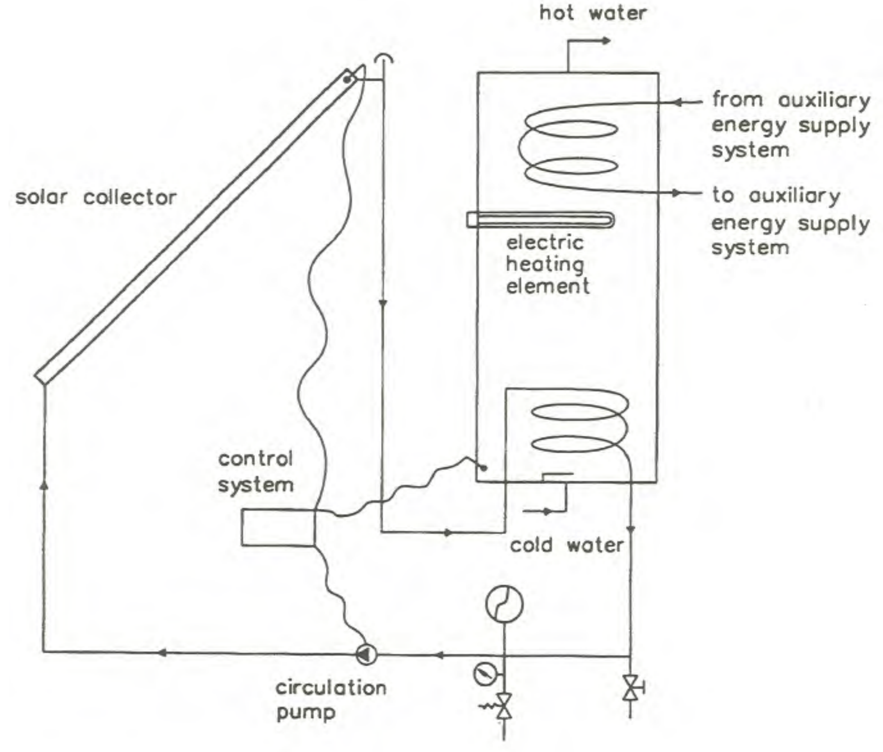

Figure A2-1. Danish Base Case System Diagram.

A2.1.2. Collector

A2.1.2.1. Collector geometry. Each system employs two standard flat-plate solar collector panels. The panel has 50 mm of insulation on the back and an air gap of 25 mm in the front. The overall dimensions are: 2.070 m x 1.120 m x 0.090 m. The aperture area of one panel is 2.19 m^2. The aperture area of the system's solar collectors is 4.38 m2.

A2.1.2.2 Collector cover material. The collector cover consists of 4 mm of tempered iron-free glass.

A2.1.1.3 Absorber material. The absorber consists of Sunstrip® tube plates with a black nickel selective surface. The tubes are made of copper and the plate of aluminum.

A2.1.2.4 Absorber fins/flow design. ®

mm x 143 mm and the tube dimensions are 8 mm x 12 mm. The thickness of the tubes is 0.35 mm.

Manifold pipes are located at the bottom and top of the collector. The two pipes are connected through eight lengthwise parallel Sunstrips®. An inlet pipe branch is located at the bottom of the collector and is directly connected to the lower manifold pipe. An outlet pipe branch is located at the top of the collector and is directly connected to the upper manifold pipe.

Solar collector fluid enters the absorber through the lower manifold pipe and is pumped through eight Sunstrips® to the upper manifold pipe and out the outlet pipe branch.

A2.1.2.5 Insulation material. To insulate the solar collector panels, a 50 mm thickness of mineral wool is applied to the back and 15 mm to the edges.

A2.1.2.6 Dimensions/specifications. The measured efficiency of the solar panel, mounted at a tilt of 45° and with an aperture area of 2.19 m^2, is calculated by:

$$\eta = 0.75 - 4.85 \times T^* - 0.016 \times G \times (T^*)^2$$

where $T^* = ((T_{coll,in} + T_{coll,out}) / 2 - T_{amb}) / G$

The measured effective heat capacity of the collector is 7 kJ/K/m2.

The empty panel weight is 39 kg.

The volume of solar collector fluid in the panel is 1.9 ℓ.

A2.1.3. Piping Runs

A2.1.3.1. Piping material. Standard 15/13 mm copper pipes are used.

A2.1.3.2. Insulation material. The insulation material is 10 mm PUR foam with a thermal conductivity of 0.03 W/mK.

A2.1.4. Solar Storage and Heat Exchanger

A2.1.4.1 Tank dimensions and specifications. The storage is a hot water tank with two built-in heat exchanger spirals. The lower spiral is connected to the solar collector loop and the upper spiral to the auxiliary energy source.

The volume of the hot water tank is 295 ℓ, the tank material is St 37-2 steel, the diameter is 500 mm, the height is 1600 mm and the thickness of the tank material is 3 mm. The bottom, sides and top of the tank are insulated with PUR foam. The top is insulated with additional mineral wool.

The heat storage is enclosed in a cabinet with dimensions 600 mm x 600 mm x 1900 mm. The weight of the empty heat storage is 125 kg and the heat loss coefficient is 2.8 W/K at 50°C.

A2.1.4.2. Heat exchanger type and specifications. The bottom heat exchanger spiral consists of three 6 meter long stainless steel tubes. The heat exchange capacity rate for typical operating conditions is approximately 200 W/K.

A2.1.5. Auxiliary Two auxiliary energy supply systems are integrated into the storage. The upper heat exchanger spiral is connected to the auxiliary energy source and heats approximately 95 ℓ of water. The heat exchange capacity rate of the auxiliary system during typical operating conditions is approximately 300 W/K. The auxiliary heat exchanger spiral is normally in operation during the winter.

An electric heating element, which heats about 60 ℓ water, is built into the top of the hot water tank and is normally in operation during summer months.

A2.1.6. Pump

A2.1.6.1. Flow rate and specifications. The circulation pump is a Grundfos UPS 25-40 180. Power consumption at normal speed (1) is 30 W, which circulates the solar collector fluid at a volume flow rate of 4 ℓ/minute.

A2.1.7. Load

A2.1.7.1. Specifications. The Danish standard load for determining the state subsidy is 200 ℓ water per day heated from 10°C to 45°C.

A2.1.8. Controls

A2.1.8.1 Controller specifications. The differential controller starts and stops the circulation pump. Both the start and stop temperature differences are adjustable.

A2.1.8.2 Operating modes. [illegible] of the absorber and the bottom of the heat storage is set at 10 K and the stop temperature difference is at 2 K.

A2.2. Dream System Description

A2.2.1. System Diagram and Description of Operating Modes The Dream System is a drainback design, which utilizes water as the solar collector fluid. During operation, an air pocket forms at the top of the mantle. Otherwise the air is located in the solar collector and pipes.

A diagram of the Dream System is shown in Figure A2-2.

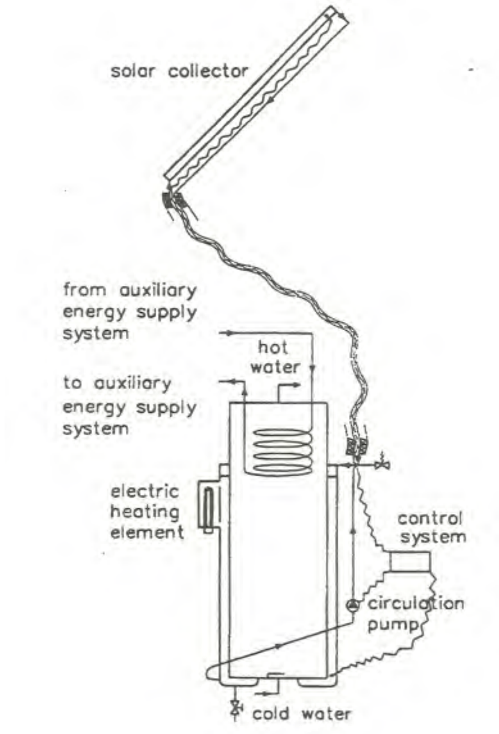

Figure A2-2. Danish Dream System Diagram.

A2.2.2. Collector

as the solar collector for the system. The panel has a 50 mm thick layer of insulation on the back and an air gap of 25 mm in the front. The overall dimensions are 2.820 m x 1.125 m x 0.090 m. The aperture area of the panel is 2.99 m2.

A2.2.2.2. Collector cover material. The collector cover consists of 4 mm thick tempered, iron-free glass.

A2.2.1.3. Absorber material. The absorber consists of Sunstrip® tube plates with a black nickel selective surface. The tubes are made of copper and the plates of aluminum.

A2.2.2.4. Absorber fins/flow design.
143 mm and the tube dimensions are 8 mm x 12 mm. The thickness of the copper tubes is 0.35 mm.

Pipes are located at the bottom and top of the collector manifold pipes. These two manifold pipes connect eight lengthwise parallel Sunstrips ®. An inlet pipe branch is located at the bottom of the collector and directly connected to the lower manifold pipe. An outlet pipe branch is located at the top of the collector and is directly connected to the upper manifold pipe.

Solar collector fluid thus enters the absorber through the lower manifold pipe and is pumped through the Sunstrips® to the upper manifold pipe and out the outlet pipe branch.

A2.2.2.5 Drainback design.
in periods of no solar gain. A separate drainback vessel is not part of the system, since the mantle serves as the drainback vessel.

A2.2.2.6. Insulation material. The back and edge of the collector are insulated with mineral wool at thicknesses of 50 mm and 15 mm, respectively.

A2.2.2.7. Dimensions/specifications. The measured efficiency of the panel, mounted at a tilt of 45° and with an aperture area of 3.00 m^2, is calculated by:

$$\eta = 0.75 - 4.62 \times T^* - 0.013 \times G \times (T^*)^2$$

where $T^* = ((T_{coll,in} + T_{coll,out})/2 - T_{amb})/G$

The calculated effective heat capacity of the collector is 7 kJ/K/m2.
The empty panel weight is 50 kg.
The volume of solar collector fluid in the panel is 2.3 ℓ.

A2.2.3. Piping Runs

A.2.2.3.1. Piping material.
material consist of a 18/8 mm EPDM pipe and a 18/10 mm EPDM pipe. The smaller pipe is used to transport the solar collector fluid from the solar collector to the heat storage and the larger pipe is used to transport the solar collector fluid from the heat storage to the solar collector. The pipes are adjacent and a wire for the control system is placed between the pipes, which are jointly insulated.

A2.2.3.2. Insulation material. The insulation material is a 14 mm thickness of trocellen with a thermal conductivity of 0.045 W/mK.

A2.2.4. Solar Storage and Heat Exchanger

A2.2.4.1. Tank dimensions and specifications. The heat storage is a mantle hot water tank. The inlet from the solar collector loop to the mantle is located at the top of the mantle and the outlet is located at the bottom of the mantle.

The volume of the hot water tank is 150 ℓ, the volume of the mantle is 25 ℓ and the tank material is St 37-2.

The heat storage is insulated with a 5-cm thick layer of PUR foam. The heat loss coefficient of the heat storage at 50°C is 0.9 W/K.

The diameter of the hot water tank is 415 mm and the height is 1200 mm. The diameter of the mantle is 465 mm and the height is 835 mm. The mantle surrounds the bottom of the hot water tank.

In periods of pump operation, the upper part of the mantle is filled with air. When the pump is not operating, water fills this space.

collector loop and surrounds a large part of the solar storage tank. This design allows for a build-up of thermal stratification in the solar storage. The heat exchange capacity rate is highly influenced by the conditions in the solar collector loop and in the heat storage. The heat exchange capacity rate is located in the interval from 60 W/K to 310 W/K.

A2.2.5. Auxiliary Two auxiliary energy supply systems are integrated into the heat storage of the solar heating system. The upper part of the hot water tank is equipped with a heat exchanger spiral connected to an auxiliary energy source. The heat exchange capacity rate for typical operating conditions is approximately 300 W/K. The heat exchanger spiral is normally in operation during the winter.

An electric heating element is located in a pipe connected to the upper part of the mantle. Heat is transferred from the electric heating element to the upper part of the mantle by thermosyphoning. The electric heating element is normally in operation during the summer.

Both auxiliary energy supply systems can heat about 60 ℓ water at the top of the tank.

A2.2.6. Pump

Power consumption in the short start-up periods, at speed 3, is 80 W. During normal operation, at speed 1, the power consumption is 30 W. The volume flow rate of the solar collector fluid is approximately 0.5 ℓ/m.

A2.2.7. Load

A2.2.7.1. Specifications. The Danish standard load for determining the state subsidy is 200ℓ water per day heated from 10°C to 45°C.

A2.2.8. Controls

A2.2.8.1. Controller specifications. The controller has an advanced differential temperature control to start and stop the circulation pump.

A2.2.8.2. Operating modes.

of the absorber and the bottom of the heat storage is 10 K, and the stop temperature difference is 5 K. When the pump is started, speed 3 is used for a short period in order to fill the solar collector with water from the mantle. When circulation has started, the speed of the pump is reduced from speed 3 to speed 1.

If the temperature of the solar collector reaches 100°C, the pump speed is increased from speed 1 to speed 3.

The pump can be stopped if the water temperature at the top of the tank becomes too high. In this way, scalding temperatures may be avoided. The control system will also indicate a lack of fluid in the system or a lack of circulation in periods when circulation is intended.

A2.3. Justification of the Dream System Choice

Utilization of the low-flow and drainback principles makes it possible to reduce the costs of the system, since a number of components can be saved. Additionally, the use of these principles increases the thermal performance of the system.

The design and control system ensures against boiling of the solar collector fluid during the summer. The installation of this system is somewhat easier than for the Base Case system since glycol is not used as the circulation fluid.

Furthermore, the smaller solar collector area avoids an oversized system for users with lesser hot water needs.

A2.4. Cost of the Base Case System

The costs are:

1 US$ – 6.7 DKK

A2.4.1. Component Costs

Collectors	748 US$
Solar storage, Pump/controls	1423 US$
Piping/fittings	150 US$
Fluids/other	27 US$
Total system components	2348 US$

A2.4.2. Installation Costs The installation costs for a typical house are about 750 US$.

A2.4.3. Operating and Maintenance Costs

Operating costs:, Maintenance costs:	15-22 US$/Year

A2.5. Performance of the Base Case System

A2.5.1. Thermal Performance The calculated overall yearly performance of a system with a south-facing solar collector tilted at 45°, using data from the Danish Test Reference Year, is 5070 MJ. The yearly electric operating needs for the pump and control system are 200 MJ. The thermal performance is based on detailed tests and on calculations by means of a detailed simulation program.

A2.5.2. Reliability and Durability The system has been on the market for several years without significant problems, and both reliability and durability have been excellent.

A2.6. Cost of the Dream System

The costs are determined by the manufacturer, who also determined the costs of the Base Case system.

A2.6.1. Component Costs

Collector	490 US$
Solar storage	552 US$
Pump/controls	163 US$
Piping/fittings	120 US$
Fluids/other	0 US$
Total system components	1325 US$

A2.6.2. Installation Costs The installation costs for a typical house are about 567 US$.

A2.6.3. Operating and Maintenance Costs

Operating costs: Maintenance costs:	15 US$/Year

A2.7. Performance of the Dream System

A2.7.1. Thermal Performance The calculated overall yearly performance for a system with a south-facing solar collector tilted at 45°, using data from the Danish Test Reference Year, is 5040 MJ. The yearly electric operating needs for the pump and control system are 230 MJ. The thermal performance is determined by means of calculations with a detailed simulation model.

A2.7.2. Reliability and Durability Both the reliability and durability of the Dream System are expected to be excellent.

A2.8. Cost Performance Comparison

Cost reduction: 3098 US$ - 1892 US$ = 1206 US$

Performance decrease: 5070 MJ/year - 5040 MJ/year = 30 MJ/year

Operating and maintenance cost reduction: ~ 20 US$ - 15 US$ = 5 US$

Base Case cost/performance ratio: 611 US$/GJ/year

Dream System cost/performance ratio: 375 US$/GJ/year

Cost/performance improvement: 236 US$/GJ/year ~ 39%

A3. GERMANY

A3.1. Base Case Description

A3.1.1. Scheme and Operation Mode Base Case for this evaluation is a SDHW system designed according to the state of the art and public demand during the year 1990 (Figure A3-1). The system layout is based on high demand for quality and durability expected by the German public and was designed by SOLVIS, the project partner of ISFH in the long-term, low-flow system evaluation. Customers expected solar fractions of 100 percent in late spring and early fall. The Base Case design reduces surplus energy in summer and, therefore, reduces system costs.

Typical specifications are a flat-plate collector, forced circulation of antifreeze in the solar loop, pressurized tank and two internal finned, copper pipe heat exchangers for solar and auxiliary energy input.

A3.1.2. Collector One single FPC module with selective finned-tube absorber (6 m^2), back insulation 70 mm thick and low iron glazing is used. Other manufacturers suggest the use of a number of standardized small modules for the same required collector aperture. To facilitate installation, the collector glazing is mounted on site.

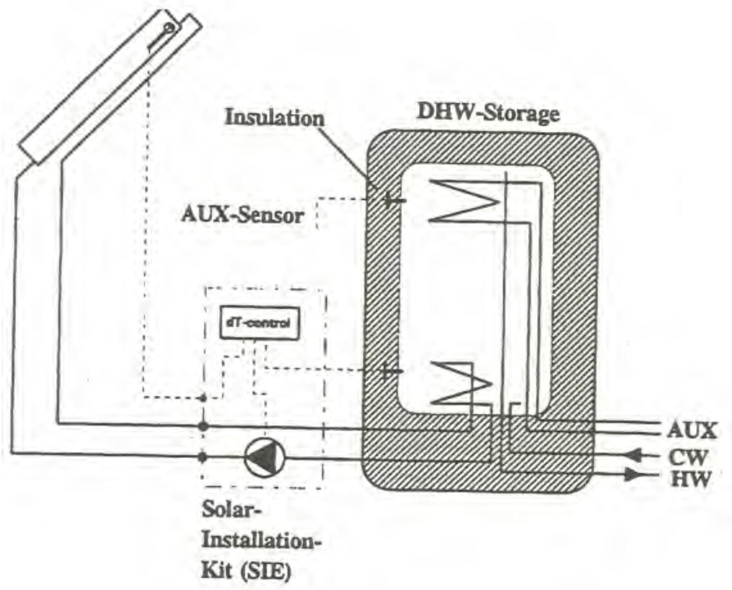

Figure A3-1. German Base Case System Diagram.

- Collector Geometry

* Overall:	4.76 x 1.45 m2
	6.9 m2
* Absorber	6.03 m2
* Mass	60 kg, without glazing

* Fluid contents 7.0 ℓ
* Heat Capacity 41 kJ/K, with fluid

- Collector Cover Material

* low-iron glazing, structured and tempered (SOLITE from AFG, USA)

* Global transmission 0.91

- Absorber Material

  * Selective, finned tube, copper absorber (MTI, USA)
  * Galvanic black-chrome layer, $\alpha = 0.96^{\pm.02}$, $\varepsilon = 0.11 \pm 0.02$

- Absorber Fin/Flow Design

* Fin	Cu, 4472 x 112 x 0.3 mm3
* Tube	Cu, 12.6 x 0.4 mm
* Flow Design	12 Fins connected in 2 groups of 6 parallel tubes
* Connection	Fittings at collector in- and outlet

- Freeze Protection/Corrosion Protection

  * 40 percent by volume propylene glycol (greater where necessary).

- Frame Material

  * Aluminum

- Insulation Material

* Back	1. layer:	30 mm thickness of PUR foam (CFC-free)
	2. layer:	40 mm thickness of Mineral Wool
* Side	Thermally insulated air gap	

- Specifications

$$\eta = 0.802 - 3.69 \cdot \frac{\Delta T}{I} - 0.007 \cdot \frac{\Delta T^2}{I}, \quad \Delta T = \frac{T_{col,i} + T_{col,o}}{2} - T_{amb}$$

- Overheat Protection

  * This feature is not necessary because the collector is not damaged by stagnation and the expansion vessel is oversized to accommodate the entire fluid content of collector and piping.

A3.1.3. Piping Fairly large copper tube with low pressure drop and rather high installation costs is standard.

* Material	Cu
* Dimensions	18 x 1 mm

- Insulation

  * Temperature and UV- resistant closed cell foam.
  * Thickness 24 mm
  * Conductivity 0.04 W/(m•K)

- Specifications

  * Typical length 20 m each way
  * Heat capacity 40 kJ/K
  * Heat loss 8 W/K

<u>A3.1.4. Solar Storage and Heat Exchanger</u>

- Storage Dimensions and Specifications:

  * 400 ℓ cylindrical storage tank designed for use in SDHW systems.
  * Heat loss reduction by:
    All solar and load piping to the storage enters through a flange from underneath the storage tank.
    Closed insulation hood, PUR-foam, CFC-free
  * Extended longevity by double-enamel inner coating and active corrosion protection via electric current.

  Data

* Volume	400 ℓ
* Diameter	620 mm, without insulation
* Aspect-ratio	H/D = 2.4
* Insulation	λ= 0.04 W/mK
side and bottom:	10 cm thick
top:	15 cm thick
* Mass	93 kg, without HX
* Heat Loss	UL = 2.1 W/K

- Heat Exchanger

  * Internal heat exchanger of finned copper tubing in the bottom of the storage tank.

  Data

* U	180 W/K
* A_{HX} 1.8 m2	
* Mass	6.7 kg

* Diameter 170 mm
* Height 440 mm (overall), 390 mm (helix)

Charging Strategy

Temperature stratification is induced by draws and solar charging of the storage tank, and reduced by convective mixing. Energy can only be provided to the top layer of the storage, draw region, when the whole tank volume is at the same temperature. The bottom layer of the tank is therefore directly affected by any solar input, causing a temperature rise and reduced collector efficiency.

A3.1.5. Auxiliary Back-up heating is usually provided by a secondary heating circuit of an oil or gas furnace boiler, whose primary purpose is space heating. The default control setting gives priority to DHW.

There is a copper, finned tube heat exchanger in the top region of the storage tank with piping connected to the bottom flange.

Data

* Aux-Volume 120
* HX-Type Finned copper tube, helix
* $A_{HX,Aux}$ 1.3 m2
* Mass 4.7 kg
* Diameter 147 mm
* Height 360 mm (helix)

In case thermal back-up heating is not applicable, an electric heater can be mounted vertically through a flange in the top of the tank.

A3.1.6. Pump Common rotary pumps are available on the market for small heating systems. Values for volume flow and head for use in SDHW systems are not provided by the manufacturers. Therefore, they can only be estimated.

* Type Grundfos UPS 25/40
* Elt. Power 80, 55, 30 W (Level III, II, I)
* Volume Flow (240 ℓ/h)
* Head (2.5 m)

A3.1.7. Load

• Specifications

The load is chosen according to German standards for average demand. Performance calculations will be based on today's standard demand for 5 persons.

Demand per 5-Person-Household

* Load	250 ℓ/d
* Temperature	45°C
* Energy	36.0 MJ/d (10.0 kWh/d)

A3.1.8. Controls

Specifications

Differential temperature control uses absorber and bottom storage temperatures. Storage overheat protection is achieved by setting the maximum temperature at the lower storage T-sensor and turning off the pumps when the limit is reached.

Operation Mode

*ΔT 5K
*ΔT 2K
*$T_{STO, max}$ 95°C

A3.1.9. Rationale for Choice of Base Case The Base Case system is a well-designed, high-performance SDHW system, based on a widely marketed system in Germany in 1990.

A3.2. Dream System Description

A3.2.1. Scheme and Operation Mode The proposed Dream System for one- and two-family houses in Germany is a pump-driven SDHW system with a pressurized tank, Life-Line® piping, and storage stratification, as shown in Figure A3-2. Propylene glycol is used in the solar circuit as antifreeze and corrosion protection.

• Easy and inexpensive installation

The one-module, flat-plate collector is connected to Flextube® Swiss lifeline-design and may be installed in or on the roof. On-roof installation is suggested for easy and cheap retrofitting. The premanufactured Solar-Installation-Kit (SIE), as an interface between the Flextube® and storage, integrates all peripheral components such as the circulation pump, control-box, expansion vessel and safety devices. SIE is easily attached to the storage connection pipes that are brought to the front of the tank and mounted on an installation bracket as shown in Figure A3-3.

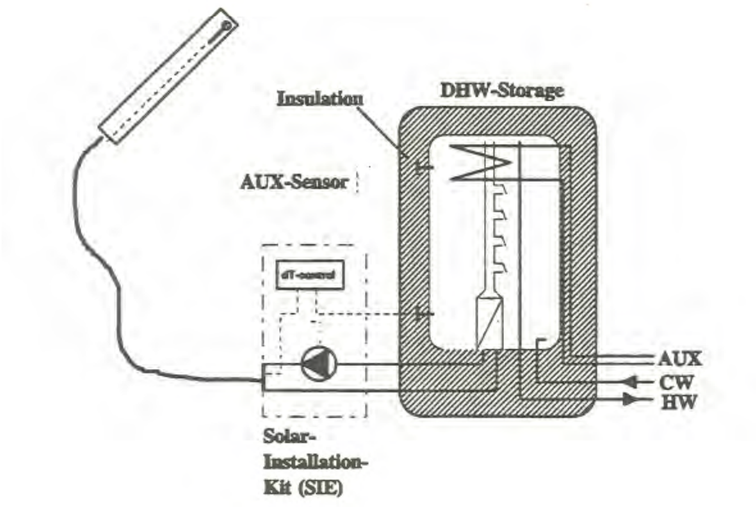

Figure A3-2. German Dream System Diagram.

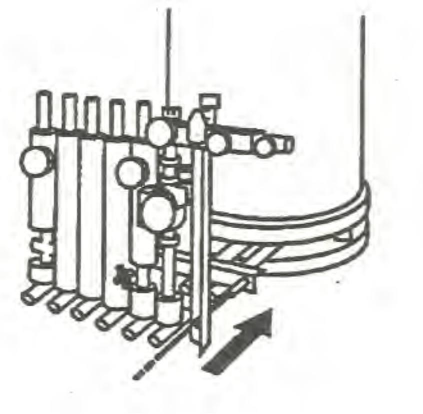

Figure A3-3. Storage-Installation-Kit and Bracket.

The storage tank is charged by an internal heat exchanger combined with a stratification manifold, as it is known from the ISFH long-term, low-flow system evaluation. The heat exchanger and manifold assembly was originally developed for this type of low-flow application (see Section A3.2.4).

A3.2.2. Collector A single-glazed, flat-plate collector with a selective, finned tube absorber and a back layer of insulation 70 mm thick is built in one unit for easy installation and reduced thermal losses. To facilitate installation, the collector glazing is to be mounted directly on site.

- Collector Geometry

* Overall:	3.81 x 1.45 m^2, 5.5 m2
* Absorber	4.9 m2
* Mass	55 kg, without glazing
* Fluid content	1.3 ℓ
* Heat Capacity	7 kJ/K, with fluid

- Collector Cover Material

  * Iron-free glazing, structured and tempered (SOLITE from AFG, USA)
  * Global transmittance 0.91

- Absorber Material

  * Copper
  * Sputtered selective layer, α = 0.95, ε = 0.08
  * Optimized thermal contact between fluid pipe and absorber plate, therefore increased G value.

- Absorber Fin/Flow Design

* Fin	Cu, 3577 x 137 x 0.3 mm^3
* Tube	Cu, 5 x 0.5 mm
* Flow Design	10 fins, connected in 2 groups of 5 parallel fins (See Figure A3-4)
* Connection	Internal connection to Flextube®

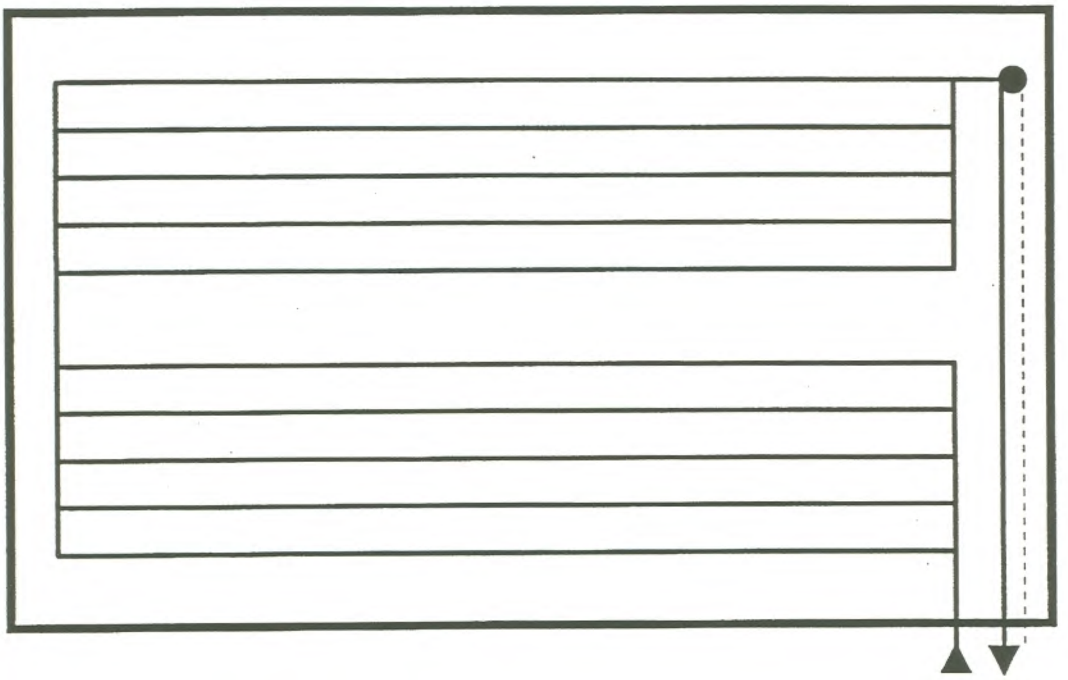

Figure A3-4. Absorber Flow Design.

- Freeze Protection/Corrosion Protection

  * 40 % by volume of propylene glycol (more where necessary)

- Frame Material

  * Aluminum

- Insulation Material

  * Back: first layer: 30 mm thick PUR Foam (CFC-free)
    second layer: 40 mm thick mineral wool
  * Side Thermally insulated air gap

- Specifications

$$\eta = 0.83 - 3.7\cdot\frac{\Delta T}{I} - 0.07\cdot\frac{\Delta T^2}{I}, \quad \Delta T = \frac{T_{col,i}+T_{col,o}}{2} - T_{amb}$$

- Overheat Protection

  Overheat protection is not necessary because the collector is stagnation proof and the expansion vessel is large enough to accommodate the entire fluid content of the collector and piping.

A3.2.3. Piping The Swiss Flextube® system (Figure A3-5), as presented by SPF-ITR in their Dream System, is well-designed for small solar domestic hot water systems and should be used in the German Dream System as well.

Flextube® is fully insulated, consists of two silicon hoses (d_i = 5 mm, d_o = 9 mm) and the wiring for the absorber T-Sensor. It may be installed in a single long piece. For trouble-free installation, the hoses are colored *grey* and *red.*

The connection to either the collector or Solar-Installation-Kit can be made by a simple nipple fitting and a clip. The durability of this installation, particularly its hoses and fitting clips, must be examined at collector stagnation temperatures.

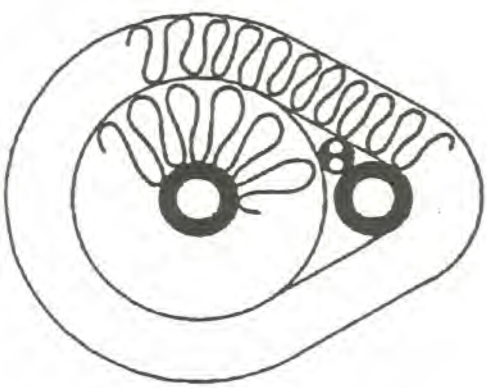

Figure A3-5. Flextube® System.

- Insulation

  The type of insulation used was temperature-resistant, closed-cell foam, which is UV-protected by an outer coating.

* Conductivity	0.04 W/(m•K)
* Collector	Inlet 10 mm thickness
* Outlet	10 + 10 mm thickness (Refer to Figure A3-5)

- Configuration and Specifications

* Typical length	20 m each way		
	Heat capacity:	~ 9 kJ/K	
	Heat loss:	~ 7 W/K	
* Recc. length	< 10 m for loft installation of the storage tank		

A3.2.4. Solar Storage and Heat Exchanger

- Storage Dimensions and Specifications

The 300 ℓ storage tank has been developed for use in SDHW systems and, therefore, matches solar application requirements.

Advantages of the Selected Design are:

* Storage stratification is supported by the high aspect ratio.
* Heat losses are reduced by:
  - All solar and load piping to the storage entering through a flange from underneath the storage tank.
  - A closed insulation hood that is PUR foam, CFC-free.
* Extended longevity by double-enamel inner coating and active corrosion protection by an external current.
* Easy connection to the SIE by mounting of all pipe connections on the installation-bracket.

Data

* Volume		300 ℓ
* Diameter		500 mm, without insulation
* Aspect-ratio		H/D = 3
* Insulation		λ = 0.04 W/m•K)
	side and bottom:	10 cm
	top:	15 cm
* Mass		70 kg, without HX
* Heat Loss		U_L= 1.6 W/K

- Heat Exchanger/Storage Management

The chosen heat exchanger, developed by Klaus Lorenz from the Solar Energy Research Center (SERC), Sweden, and presented in Sevilla in 1994, is well designed for low-flow application without the need of an additional pump in the storage loop.

The design consists of an internal HX with a forced flow of glycol in the solar loop. It has a very low pressure drop and therefore can thermosyphon in the DHW storage loop.

Data

* U_{HX} 600-700 W/K at a solar flow rate of 60-120 ℓ/h
* Mass 4 kg
* $\Delta T_{log,}$ 5K

Charging Strategy

The storage loop of the heat exchanger leads directly into a stratification manifold that is specially designed for very low volume flow. Cold water enters the heat exchanger and the tank bottom, and rises by natural convection into the flap valve-operated manifold. The silicon flap valves are operated by the density which is induced by temperature differences between the inside and outside of manifold. Where this temperature difference diminishes, the valve closest to the tank layer opens and the solar-heated water is stored in a nearly isothermal region of the tank. Hot water is stored at the top and colder water at the bottom layer of the storage tank. This strict suppression of thermosyphoning mixing increases the overall efficiency and enables the direct use of solar-heated water by charging to or drawing from the top of the tank. Enhanced storage stratification also ensures the reduction in collector inlet temperature necessary for best collector performance at low-flow operation.

A3.2.5. Auxiliary A bare-tube heat exchanger is installed into the top layer of the storage tank, and mounted on the side wall of the tank with piping running inside the insulation down to the installation bracket (Figures A3-2 and A3-3).

Data

* Aux-Volume	85 ℓ (28 percent of storage volume)
* HX-Type	Bare copper tube, helix
* $A_{HX, Aux}$	1 m2

In case thermal back-up heating is not applicable, an electric heater can be installed horizontally through a flange in the tank side wall.

A3.2.6. Pump The German Dream System uses a special low-flow, high-head pump, which meets or exceeds the following specifications:

* Volume Flow	60-120 ℓ/h
* Maximum Head	20 m
* Elt. Power	Not exceeding 33 W
* $\eta_{hydrodynamic}$	20 percent

In Task 14, promising work in pump development is currently being conducted by Antony Caffell of Canada, Ueli Frey of Switzerland, and Klaus Lorenz of Sweden, in order to meet these specifications.

A3.2.7. Load

• Specifications

The Dream System load is based on German standards for average demand. Based on the increased use of water-saving devices in German households, a review of these standards is in progress. Performance calculations are based on current demand for 5 persons.

Current Standard Demand per 5-Person-Household

* Load 250 ℓ/d
* Temperature 45°C
* Energy 36.0 MJ/d (10.0 kWh/d)

Recommended Standard Demand per 5-Person-Household

* Load 225 ℓ/d
* Temperature 45°C
* Energy 32.5 MJ/d (9.0 kWh/d)

A3.2.8. Controls

Specifications

Differential temperature control uses absorber and bottom storage temperatures. Due to a high degree of storage stratification, storage overheat protection must be based on an evaluation of the storage top temperature, possibly combined with storage bottom temperature.

Compared to the Base Case system, the Dream System uses fairly high control thresholds to reduce operating time at low insolation levels, thus reducing tank recirculation during the day.

Operation Mode

* ΔT_{on} 8K
* ΔT_{off} 3 K
* $T_{STO,\,max}$ 95°C

A3.2.9. Rationale for the Choice of the Dream System

* Increased storage stratification

* Use of special low-flow components for the collector, Life-Line® piping, pump, heat exchanger, and stratification manifold.

* Ecologically based production of the sputtered selective layer and lowered toxic waste.

* Reduced component and installation costs.

A3.3. Justification of Dream System Choice

The German Dream System combines the advantages of low-flow operation with advanced storage management economic incentives, and a high annual solar fraction. The Dream System is designed for approximately the same solar fraction as the Base Case system but with more advanced and reliable components.

Rotary pumps commonly used for space heating and DHW circulation systems are designed for high-volume flow and low head, and therefore are not particularly applicable to small, low-flow DHW systems. The Dream System will utilize a special low-flow pump with advanced specifications.

The Dream System also employs a reduced piping diameter in the collector and the Life-Line® piping. Thus, a very small expansion vessel will accommodate the entire volume circulating in the solar loop (< 5 ℓ with 20 m piping).

Some unique features of the Dream System are:

- High-performance, low-flow absorber with a greatly reduced fluid volume
- Enhanced storage stratification through optimizing tank geometry and the stratification manifold
- High performance heat exchanger with thermosyphon storage circuit
- Low-flow pump with optimized hydraulic features and reduced electrical power consumption
- Temperature-resistant Life-Line® piping with stagnation-proof installation technology

Major advantages of the Dream System are:

- Decreased collector area for the same annual solar fraction through utilization of a high-performance, low-flow collector

- Enhanced low-flow performance of solar storage through design advancements
- Reduced storage losses through increased insulation and a piping installation flange located underneath the tank
- Reduced piping and installation costs through the use of Life-Line ® piping
- Enhanced pump performance and low power consumption in the collector circuit by use of a low-flow, high-head pump
- Simplified installation due to premanufactured and fewer components
- Extended durability through high component quality
- Reduced pollution during manufacture of the absorber through an improved sputtering process, the effect of which increases with production volume

A3.4. Cost of Base Case System

The estimated market price of the components, installation, and maintenance of a Base Case system in 1994 US$ is outlined below. Marketing and distribution are not included.

A3.4.1. Component Costs

Collector and installation-kit	1,680 $
Storage and both heat exchangers	1,453 $
Solar installation kit, control, pump	625 $
Piping, insulated	300 $
Total component costs	4,058 $

A3.4.2. Typical Installation Costs

Installation material	150 $
Labor	2,400 $
Total installation costs	2,550 $

A3.4.3. Operating and Maintenance Costs

Operation (180 kWh/a)	31 $
Maintenance	20-100 $
Total	51-131 $

A3.5. Performance of Base Case System

A3.5.1. Thermal Performance The thermal performance of the Base Case system was calculated with the ISFH program, Version 5.94, extended mode, using a collector slope in the range **of** a typical roof slope in Germany.

• Specifications

* Location	Hannover
Ann. Insolation	953.4 kWh/m^2-year, on the horizontal
Latitude	52.5° North
Absorber Area	6.03 m2
Collector Slope	38°, facing south
Average Load	36.0 MJ/d (10.0 kWh/d)
Demand Profile	US Random Profile
T_{CW}-Variation	Average: 11°C, Maximum: 17°C in August
Piping Length	20 m

Table A3-1. Radiation and Annual Performance for the German Base Case System.

	H100		Q102		Q332		SF
	MJ/m^2d	kWh/m^2d	MJ/m^2d	kWh/m^2d	MJ/m^2d	kWh/m^2d	%
Jan	2.9	0.81	1.0	0.29	0.9	0.26	13.57
Feb	5.9	1.63	2.4	0.68	2.1	0.59	30.83
Mar	9.7	2.70	4.1	1.13	3.6	1.00	52.72
Apr	13.1	3.63	5.0	1.38	4.4	1.22	68.59
May	15.8	4.39	5.4	1.50	4.7	1.30	79.57
Jun	18.2	5.06	5.9	1.65	4.6	1.28	85.78
Jul	15.8	4.39	5.1	1.42	4.1	1.15	83.24
Aug	15.7	4.37	5.2	1.44	4.1	1.14	84.72
Sep	11.4	3.18	4.0	1.12	3.6	0.99	71.73
Oct	7.2	1.99	2.7	0.76	2.3	0.65	43.43
Nov	3.4	0.94	1.0	0.29	0.9	0.24	14.82
Dec	2.1	0.58	0.5	0.15	0.4	0.12	6.94
Ann	**3808.4** MJ/m^2yr	**1057.9** kWh/m^2yr	**1292.4** MJ/m^2yr	**359.0** kWh/m^2yr	**1091.9** MJ/m^2yr	**303.3** kWh/m^2yr	**50.76** %

Table A3-2. Annual Values for Friedrichshafen, the Location With the Highest Annual Solar Insolation in Germany (4523 MJ/m²yr; 1256.4 kWh/m²yr).

	H100		Q102		Q332		SF
	MJ/m²a	kWhJ/m²a	MJ/m²a	kWh/m²a	MJ/m²a	kWh/m²a	%
Ann	5212.4	1447.9	1742.4	484.0	1460.5	405.7	67.91

H100 Solar insolation on the collector
Q102 Solar energy delivered to storage
Q332 Q102 - Auxiliary (storage losses are solar)
SF Solar Fraction, Q332 / Q_{Net}

A3.5.2. Reliability and Durability The Base Case system is a high quality system and all of its components have been on the market for a long time. If installed with care, the system is expected to last over 20 years, just as long as conventional heating systems in Germany. The flow volume and antifreeze/anticorrosion properties of the solar fluid should be checked regularly. The storage tank is more heavily corrosion protected than ordinary DHW systems. It should be tested for proper operation of the active protection system at the same frequency as ordinary DHW systems. The durability of this system is excellent.

A3.6. Cost of Dream System

The following figures represent the estimated market price of the components, installation, and maintenance of the Dream System in 1994 US$, not including marketing and distribution, assuming the sale of 1000-1500 identical systems per year.

A3.6.1. Component Costs

Collector and installation-kit	1,428 $
Storage and both heat exchangers	1,095 $
Solar installation kit, control, pump	570 $
Piping, insulated	100 $
Total component costs	3,193 $

A3.6.2. Typical Installation Cost

Installation material	150 $
Labor	2,050 $
Total installation costs	2,200 $

A3.6.3. Operating and Maintenance Costs

Operation (100 kWh/a)	17 $
Maintenance	20-100 $
Total	37-117 $

A3.7. Performance of Dream System

A3.7.1. Thermal Performance The thermal performance of the Dream System has been calculated with the ISFH Program, Version 5.94, extended mode, using a collector slope in the range of a typical roof slope in Germany.

Specifications

* Location Hannover
* Ann. Insolation 953.4 kWh/m^2-year, on the horizontal
* Latitude 52.5° North
* Absorber Area 4.90 m2
* Collector Slope 38° facing south
* Average Load 36.0 MJ/d (10.0 kWh/d)
* Demand Profile US Random Profile
* Tc_w-Variation Average: 11°C, Maximum: 17°C in August
* Piping Length 20 m

Table A3-3. Radiation and Annual Performance for the German Dream System.

	H100 MJ/m²d	H100 kWh/m²d	Q102 MJ/m²d	Q102 kWh/m²d	Q332 MJ/m²d	Q332 kWh/m²d	SF %
Jan	2.9	0.81	1.4	0.39	1.3	0.37	15.90
Feb	5.9	1.63	3.1	0.85	2.8	0.77	32.70
Mar	9.7	2.70	4.9	1.36	4.5	1.24	53.60
Apr	13.1	3.63	5.9	1.64	5.4	1.50	68.87
May	15.8	4.39	6.3	1.75	5.7	1.57	78.43
Jun	18.2	5.06	6.7	1.87	5.6	1.55	84.95
Jul	15.8	4.39	5.9	1.64	5.0	1.39	81.67
Aug	15.7	4.37	6.0	1.66	4.9	1.37	83.28
Sep	11.4	3.18	4.8	1.33	4.4	1.22	71.66
Oct	7.2	1.99	3.3	0.92	3.0	0.83	45.23
Nov	3.4	0.94	1.4	0.39	1.3	0.35	17.45
Dec	2.1	0.58	0.8	0.23	0.8	0.21	9.65
Ann	3808.4 MJ/m²yr	1057.9 kWh/m²yr	1537.2 MJ/m²yr	427.0 kWh/m²yr	1356.5 MJ/m²yr	376.8 kWh/m²yr	51.50 %

Table A3-4. Annual Values for Friedrichshafen, the Location With the Highest Annual Solar Insolation in Germany (4523 MJ/m^{2}yr; 1256.4 kWh/m2yr).

	H100		Q102		Q332		SF
	MJ/m²a	kWh/m²a	MJ/m²a	kWh/m²a	MJ/m²a	kWh/m²a	%
Ann	5212.4	1447.9	2055.6	571.0	1784.5	459.7	67.76

H100 Solar insolation on the collector
Q102 Solar energy delivered to storage
Q332 Q102 - Auxiliary (storage losses are solar)
SF Solar Fraction, Q332/$Q_{Net.\ Demand}$

A3.7.2. Reliability and Durability The Dream System is designed and manufactured with the same quality as the Base Case system. The low-flow collector and storage are of advanced design, as are the Base Case system components. The stratification manifold was tested and showed no excessive degrading for several years.

The durability of the newly designed, low-flow components will be tested before the Dream System is marketed. It is believed that these system components will easily pass the standard durability test.

Problems to be Watched

* Durability of the heat exchanger, expected to be good.
* Temperature durability of the silicon piping in case of collector stagnation.
* Durability of the Life-Line® piping connection after collector stagnation

The durability of the Dream System is expected to be 20 years, similar to that of the Base Case system. Routine periodic checking of the solar fluid and active corrosion protection in the storage tank should be conducted at the same interval as for the Base Case system.

A3.8. Cost Performance Comparison

The total component costs are reduced by 21 percent compared to the Base Case system, with major savings in collector and storage costs. The estimated high volume sales of the standardized Dream System mainly affects the storage costs (-25 percent), whereas the decrease in collector costs (-15 percent) is due to current differences between the Base Case system 6-m2 collector module and the Dream System 5-m^2 collector module.

The reduction in installation costs is primarily due to the easy installation of the Dream System and is based on current installation costs. The marketing of standardized, premanufactured, easy-to-install Dream Systems stimulates growth of the do-it-yourself consumer market.

Table A3-5 shows a cost/performance ratio comparison of the Base Case and Dream Systems at locations in Hannover and Friedrichshafen, Germany. The results indicate that for the annual overall solar output of the DHW system ($Q332 \cdot A_c$ and system costs, the price of the Dream System is 1.73 US$ per saved kWh/yr and 2.23 US$ per saved kWh/yr for the Base Case system: A savings of .50 US$ per kWh/yr saved (-22 percent). With respect to the component, labor, and sales costs, the relative advantages are about the same for both systems.

Compared with the Base Case system, there is slightly less overall solar energy delivered by the Dream System in Friedrichshafen, Germany. However, this does not affect the relative cost reduction. Regarding component costs, the savings are .36 US$ per saved kWh/yr, based on a 1.67 for the Base Case and 1.31 for the Dream System US$ per saved kWh/yr.

Table A3-5. Cost Performance Comparison.

	Cost	BC-H	DS-H	BC-F	DS-F	Unit
I	Component	4058	3193	4058	3193	US$
II	Sales	2705	2129	2705	2129	US$
III	Labor	2550	2200	2550	2200	US$
	SF	50.76	51.50	67.91	67.76	%
	$Q102 \cdot A_c$	2154	2092	2904	2798	kWh/yr
IV	$Q332 \cdot A_c$	1820	1846	2434	2429	kWh/yr
	I / IV	**2.23**	**1.73**	**1.67**	**1.31**	US$/kWh/yr
	(I+II) / IV	3.72	2.88	2.78	2.19	US$/kWh/yr
	(I+III) / IV	3.63	2.92	2.71	2.22	US$/kWh/yr
	(I+II+III) / IV	**5.12**	**4.07**	**3.83**	**3.10**	US$/kWh/yr

Operating costs are slightly reduced due to a decreased power consumption by the low-flow, high-head pump. Savings, however, are marginal compared to the other cost factors.

A3.9. Conclusions

- The advanced technology and expected market penetration of the Dream System provides a significant reduction in system costs with the same annual solar fraction.
- Low-flow is perhaps too much of a hi-tech solution for small SDHW systems. However, for large multi-user systems, low-flow is the Dream mode of operation. Incorporating the Dream System collector will result in significant savings.
- The simplified installation of the Dream System may open new consumer markets for system distribution. Future consumers may be able to purchase a Solar-Energy-Kit

from a neighborhood building supply store. However, several hurdles impede the development of this idea: the manufacture of a fool-proof installation and adjustment kit, testing to determine the reliability of the system, and manufacturer warranty and liability. These are key factors for market sustainability of a Dream System Solar Energy Kit in Germany. Therefore, any price reduction of residential SDHW systems within the German market will be influenced by these factors.

A4. THE NETHERLANDS

A4.1. Base Case System Description

A4.1.1. System Diagram and Description of Operating Modes For the base case we considered two Dutch systems on the market at the time of the definition phase of the Task. One system uses a Sunstrip® absorber and a mantle heat exchanger and is still on the market. The other system uses a steel absorber and heat storage with a helix heat exchanger. Both are drainback systems. The price performance ratio at the time was more or less equal. Because the Sunstrip® system did not change much in this past period, we decided to use this system as the base case.

The diagram of the system is shown in Figure A4-1.

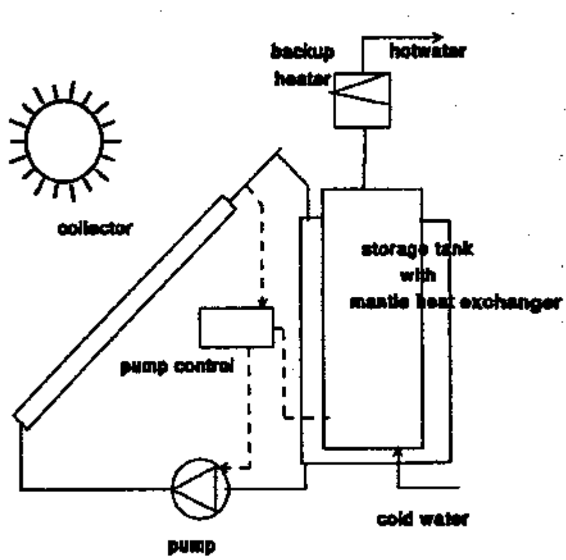

Figure A4-1. The Netherlands Base Case System Diagram.

A4.1.2. Collector

A4.1.2.1. Collector geometry. The flat plate collector had 40 mm thick insulation on the back and an air gap of 40 mm in the front. The overall dimensions are 1740 by 1740 mm. The aperture area is 2.83 m2.

A4.1.2.2. Collector cover material. The collector cover consists of 3.2 mm low-iron, tempered glass, produced by AFG, USA.

A4.1.2.3. Absorber material. T

Sunstrip® absorber is mounted in a parallel configuration. The optical properties are α 0.84 and c 0.16-0.18

A4.1.2.4. Absorber fins/flow design. The parallel-strip configuration is mounted on two parallel headers. In this way, there is a more or less equal flow distribution.

A4.1.2.5. Drainback design.

regulations, in which antifreeze additives require a double-walled heat exchanger. The performances of drainback systems in general are even better than closed loop systems with additives, while the maintenance is easier and cheaper. In general, the drainback vessel is integrated in the tank, either in the double wall of the tank or in a separate integrated unit in the storage.

A4.1.2.6. Insulation material. The base case system has 40 mm thick insulation on the back, consisting of polyurethane.

A4.1.2.7. Dimensions/specifications. The collector efficiency curve is shown in Figure A4-2.

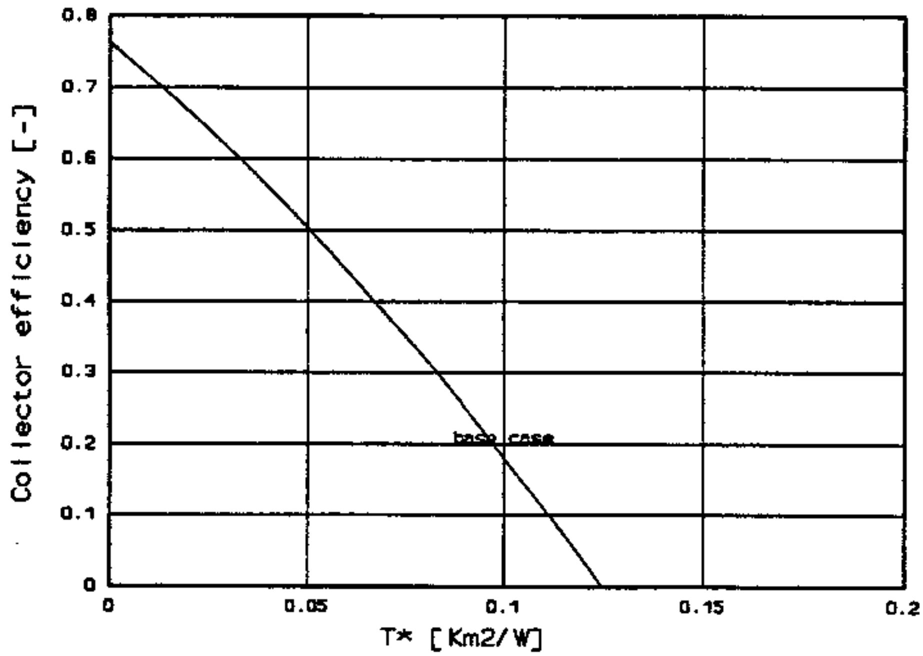

Figure A4-2. Base Case System Collector Efficiency Curve.

A4.1.3. Piping Runs

A4.1.3.1. Piping material. For the piping, normal 12/15 mm copper tubing is used. This material is readily available from every heating installer.

A4.1.3.2. Insulation material. The insulation material applied to the piping is 12 mm SOLFLEX, a heat resistant flexible piping insulation.

A4.1.4. Solar Storage and Heat Exchanger

A4.1.4.1. Tank dimensions and specifications. Various tank designs are being used. Most of the systems are connected to a so-called combi-central heating system. These furnaces supply the central heating system, while at the same time they supply hot water as a "go-through-heater." Because of the cheap and generally available natural gas supply, all auxiliary heat is supplied by natural gas.

The tank capacity of 110 liters is based on the average Dutch load for a four-person household of 110 liters at 15-65°C/day. The helix heat exchanger is integrated in the tank.

The tank is made of stainless steel, due to the high mineral content of the average water (DIN. 1.4510).

The test pressure is 13 bar, while the operating pressure of the drinking water section is 8 bar.

A4.1.4.2. Heat exchanger type and specifications.

made of stainless steel, 300 W/K. In case the mantle tank is used, it is also made of stainless steel.

A4.1.5. Auxiliary

A4.1.5.1. Tank dimensions and specifications. The auxiliary is separated from the solar system. The solar system operates as a preheater.

A4.1.5.2. Auxiliary element location and specifications. Generally the back-up furnace (combi-heating unit) is located next to the solar system. These systems normally operate under 20-30 KW.

A4.1.6. Pump

A4.1.6.1. Flow rate and specifications. The pump is a three speed Grundfos pump type UPS 25/40. The average flow rate is 4 ℓ per minute, with a power consumption of approximately 30 W.

Because of the drainback function, the pump is automatically switched to high speed during the first three minutes of operation in order to pump water to the (empty) collector. After three minutes, the control unit automatically switches the pump to its lowest mode.

A4.1.7. Load

A4.1.7.1. Specifications. The general load under which Dutch SDHW-systems are tested is: 110 ℓ at 15-65°C.

A4.1.8 Controls

A4.1.8.1. Controller specifications. The control unit is a ΔT-controller with the following functions:

Measures temp. difference between the collector and storage. Δ 10°K will switch the pump on its highest mode. Δ2°K will switch the pump off, in order to facilitate the drainback function. The control unit also protects the storage from overheating by switching the pump off when it detects a 90°C temperature in the storage.

A4.1.82. Operating modes. See A4.1.8.1.

A4.2. Dream System Description

A4.2.1. System Diagram and Description of Operating Modes The Dream System is an optimization of the Base Case system. The improvements made in the system do have an effect on the system performance, both under high- and low-flow conditions. The primary benefits from the design of the Dream System are related to cost effects, as well as performance improvement. The performance for variations in flow rate are within the limits of measurement accuracy. See Figure A4-3.

A4.2.2. Collector

A4.2.2.1. Collector geometry. The flat plate collector has a 55 mm thickness of insulation on the back and an air gap of 20 mm in the front. The overall dimensions are 1776 x 1751 x 105 mm. The aperture area is 2.71 m^2.

The collector cover consist of 3.2 mm low-iron, tempered glass, produced by AFG, USA.

copper absorber is made out of spectral selective material on which the serpentine copper tubing is soldered. The optical properties are: α 96 and ε 12-14.

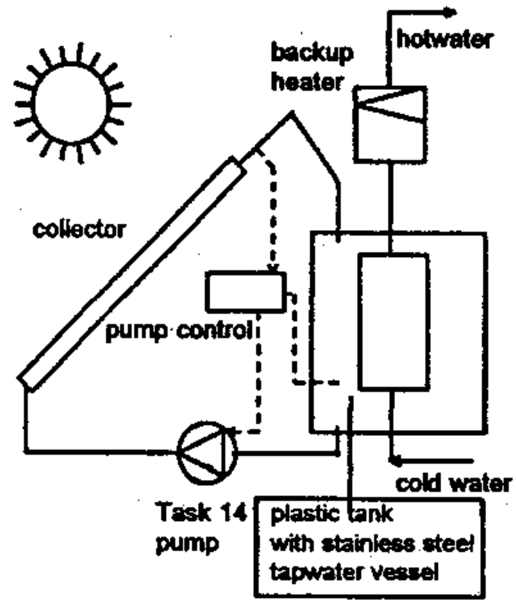

Figure A4-3. The Netherlands Dream System Diagram.

The distance between the tubes of the serpentine configuration is 100 mm. Each absorber consists of 4 equal absorber plates, which are interconnected.

A4.2.2.5. Drainback design. The drainback design is needed under present Dutch regulations, in which antifreeze additives require a double-walled heat exchanger. The performances of drainback systems in general are even better than closed loop systems with additives, while the maintenance is easier and cheaper. In general, the drainback vessel is integrated in the tank, either in the double wall of the tank or in a separate integrated unit in the storage.

A4.2.2.6. Insulation material. The Dream System, which is resistant to high stagnation temperatures, has a 55 mm thickness of insulation on the back, consisting of 30 mm CFK-free PUR-foam-board and 25 mm foam-glass.

A4.2.2.7. Dimensions/specifications. The collector efficiency curve is shown in Figure A4-4.

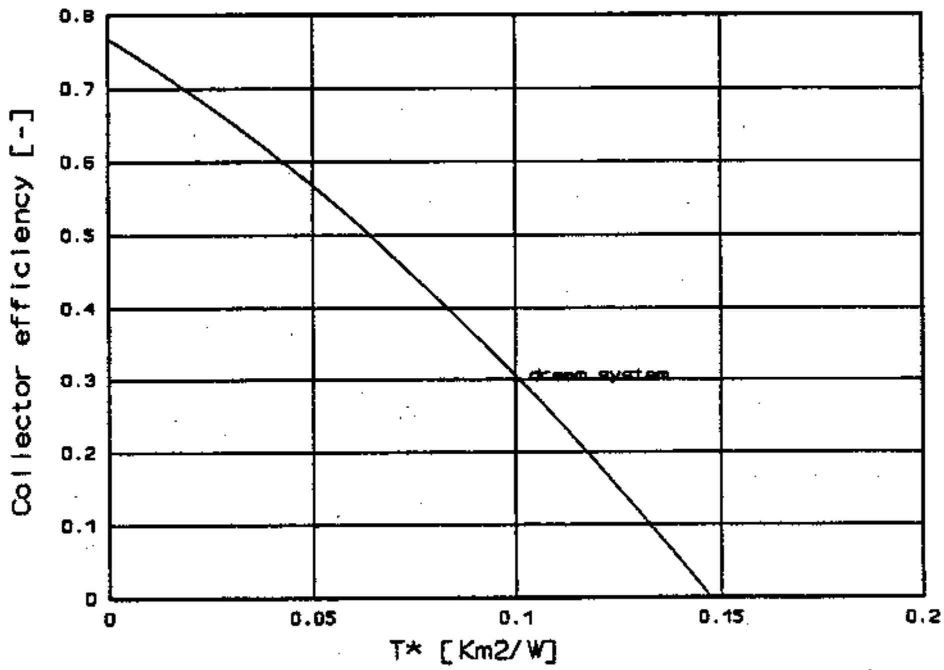

Figure A4-4. The Netherlands Dream System Collector Efficiency Curve.

A4.2.3. Piping Runs

A.4.2.3.1. Piping material. Normal 8/10 mm copper tubing is used for the piping. Life-Line® is used if the price is reasonable.

A4.2.3.2. Insulation material. The pipe insulation material is 15 mm fiberglass.

A4.2.4. Solar Storage and Heat Exchanger

A4.2.4.1. Tank dimensions and specifications. The optimal tank design consist of a plastic container of approximately 100 liters, with a stainless steel tap water tank. See report number TNO BBI-R0777.

The test pressure is 13 bar, while the operating pressure of the drinking water section is 8 bar.

A4.2.4.2. Heat exchanger type and specifications. There is no heat exchanger in the system. The tank itself will function as the drainback vessel. The tap water tank itself is the heat exchanger.

A4.2.4.3.

were of the same order as the accuracy of measurements. Therefore, it is not necessary to actually choose this tank. It is proven that other tanks, provided they are well designed, can perform on an equal basis. In this respect, it is more important to take practical experiences, cost, and regulations into account.

A4.2.5. Auxiliary

A42.5.1. Tank dimensions and specifications. As mentioned under A4.1.4.1 the auxiliary is separated from the solar system. The solar system operates as a preheater.

A4.2.5.2. Auxiliary element location and specifications.

furnace (combi-heating unit) is located next to the solar system. These systems normally operate at 20-30 KW.

A4.2.6. Pump

A4.2.6.1. Flow rate and specifications. The pump is presumed to be the Canadian low-flow pump, adapted to drainback conditions. Because of the drainback function, the pump is automatically switched on high speed during the first three minutes of operation, in order to pump water to the empty collector. After three minutes, the control unit automatically switches the pump to its lowest mode.

A4.2.7. Load

A4.2.7.1. Specifications. The general load under which Dutch SDHW-systems are tested is 110 liter heated from 15-55°C.

A4.2.8. Controls

A4.2.8.1. Controller specifications. The control unit is a ΔT-controller with the following functions: It measures temperature difference between the collector and storage. Δ 10°K will switch the pump to its highest mode. A temperature difference of 1°K will switch the pump off, in order to facilitate the drainback function. The control unit also protects the storage from overheating by switching the pump off when it detects a 90°C temperature in the storage.

A4.2.8.2. Operating modes. See A4.2.8.1.

A4.3. Justification of Dream System Choice

The Dream System has been developed based on information available directly or indirectly as a result of research carried out in matched-flow systems. It should be mentioned that a great deal of the improvements do not have a direct impact on the flow of the collector loop. However, the information generated as a result of the research, led to system performance improvements in general. In that sense, the results of the research have surpassed the original goal, which was to show the effects of low flow. In any case, the justification of the Dream System is based on the results which came out of the research carried out to increase insight about matched- and low-flow principles.

As shown later, the Dream System meets the requirements of cost reduction, as well as system performance improvement. However, we emphasize the fact that it is not the matched-flow itself which is responsible for the system performance improvements, but the system improvements that are the result of the research carried out, which shows performance improvements both for low-flow, as well as high-flow, systems.

A4.4. Cost of the Base Case System (US$) (1 US$ Df 1.86)

The cost of the system described is defined as factory costs of the system hardware, including factory overhead and profit. We have not integrated cost for sales, distribution and marketing into this price analysis. Those costs are considered equal for both the Base Case system, and the Dream System.

A4.4.1. Component Costs

The component costs are:

Collector	700 US$
Tank	420 US$
Pump/control	195 US$
Miscellaneous	75 US$
Total system components	1,390 US$

A4.4.2. Installation Costs For the installation costs, we averaged the cost for installing the systems on an individual basis and installing the systems in a project of more than 10 houses in a series. The installation cost are 670 US$.

A4.4.3. Operating and Maintenance Costs The average operating and maintenance cost are:

Operating cost: 60 KWh	7 US$
Maintenance contracts:	10 US$
Total for operating and maintenance:	17 US$

A4.5. Performance of the Base Case System

A4.5.1. Thermal Performance The thermal performance is calculated with the VABI-SDHW (TNO-model) program, using standard tanks and Sunstrip® collectors from 1989. The overall yearly performance is 3700 MJ. The electrical operating needs are 60 KWh.

A4.5.2. Reliability and Durability The Base Case system proved to be reliable. The durability is questioned for the Sunstrip® absorber in a number of studies. However, practical experiences so far have not shown significant problems with systems as installed in the period 1985-1990. One manufacturer used an open, drainback loop in the system. This proved to be a source of extra corrosion.

A4.6. Cost of the Dream System (US$)

A4.6.1. Component costs. The component costs are:

Collector	550 US$
Tank	385 US$
Pump/control	145 US$
Miscellaneous	60 US$
Total system components	1,140 US$

Note: This cost is the result of improvements in the components, as well as a price reduction as a result of the growing number of systems produced. The market situation during the Base Case was only a few hundred systems a year, while the present market consists of a few thousand per year. This implies a partial price reduction based on high volume effects during production. A major Dutch manufacturer estimates the effects of price reduction of 50 percent due to high volume effects, while the other 50 percent is caused by material and component improvements.

For these reasons, we define the component costs of the Dream System at 1,265 US$.

A4.6.2. Installation Costs For the installation costs, we have averaged the cost for installing systems on an individual basis and installing systems in a project of more than 10 houses in a series. The installation cost is 460 US$.

In the same way that we corrected the cost of the components, the reduction of installation costs is not only the result of simpler installation. It is also partly the result of a better understanding by installers of solar systems. This is the result, not only of more systems being installed and more experience, but also of intensive training programs. For that reason, we also corrected the installation cost with 50 percent of the reduction. The total installation cost of the Dream System is 565 US$.

A4.6.3. Operating and Maintenance Costs The average operating and maintenance costs are:

Operating cost: 9 KWh	1 US$
Maintenance contracts:	10 US$
Total for operating and maintenance:	11 US$

A4.7. Performance of the Dream System

A4.7.1. Thermal Performance The Dream System is evaluated with the VABI-SDHW-program. The yearly performance is calculated at 4160 MJ.

A4.7.2. Reliability and Durability In general, the concept of the Dream System incorporates the experience of 15 years of SDHW-applications. Therefore, it is more reliable and durable. Although the pump still has to be tested for durability, it is expected to fulfill the requirements. The absorber is now made of copper and is very durable.

A4.8. Cost Performance Comparison

If we evaluate the cost/performance information of the Base Case and the Dream Systems, we can conclude that the price has dropped 11.2 percent, while the performance of the system has improved by 12.4 percent. The cost for operating and maintenance has been reduced by almost 30 percent. We conclude that the overall improvement in cost/performance is approximately 20 percent, which is more than the target of 15 percent.

Note 1: This evaluation takes into account the effects which come from larger market volumes and better installation skills.

Note 2: The effects on the price and performance are to a large extent the result of research carried out on the effects of matched- and low-flow. However, the studies showed no considerable dependence on the flow rate in the system. Therefore, we have labelled the improvements in price/performance as spin-off effects of the matched flow research.

A5. SWITZERLAND

A5.1. Base Case Description

A5.1.1. Scheme and Modes of Operations The common domestic hot water system is presented in Figure A5-1. The pressurized solar collector loop has forced circulation. Ethylene or propylene glycol with inhibitors is used for freeze and corrosion protection. The pressure relief valve opens at 3 bars.

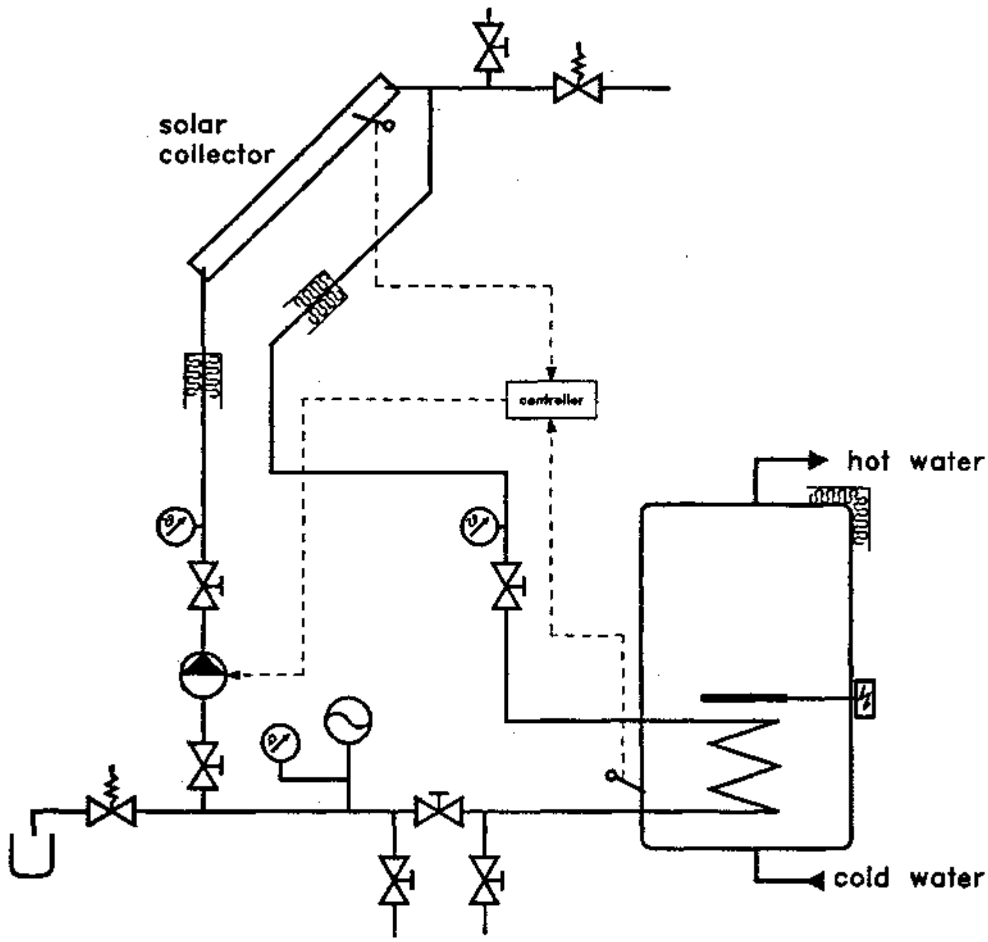

Figure A5-1. Common Domestic Hot Water System in Switzerland.

A5.1.2. Collector

A5.1.2.1. Collector geometry. The standard size of flat-plate collectors used in Switzerland is about 1.5 to 2 m2. The collector presented here has the following dimensions:

Overall dimensions 2.027 m x 0.861 m
Overall area 1.745 m2

Absorber dimensions 1.877 m x 0.77 m + connections
Absorber area 1.48 m2

A5.1.22. Collector cover material. The collector cover material is SOLITE produced by AFG (USA). It is a tempered and structured low-iron glass with a solar transmittance of τ = 0.91.

A5.1.23. Absorber material. The black chrome absorber coating is plated by MTI, while the fins are roll formed by Northstar. Both companies are in the United States.

Typical performance values: $\alpha > 0.94$; $\varepsilon < 0.15$

A5.1.2.4. Absorber fins and flow design. The flow design is a grid pattern including 2 manifolds (copper tube 18 mm/16 mm) and 7 all-copper fins, 112 mm wide, with a thickness of 0.22 mm. The finned tubes have an inner diameter of 11.8 mm, a wall thickness of approximately 0.4 mm, and there is just one inlet and outlet per collector (crosswise).

A5.1.2.5. Insulation material. The insulation consists of a 50 mm layer of rockwool on the back of the collector and a 30 mm layer of rockwool on the sides and edges.

A5.1.2.6. Specifications. The measured efficiency for an absorber area of 1.48 m2:

$$\eta = 0.797 - 3.89 * x - 0.011 * G * x^2$$

where $x = ((T_{coll,\ in} + T_{coll,\ out}) / 2 - T_{amb}) / G$

The weight of the empty collector is 50 kg. The volume of the heat transfer fluid is 1.8 ℓ.

A5.1.3. Piping

A5.1.3.1. Piping material. Copper tubes 15/13 mm are used.

A5.1.3.2. Insulation material. The insulation material is synthetic rubber with a thickness of 16 mm. The synthetic rubber is protected against UV by a special paint.

A5.1.4. Solar Storage and Heat Exchanger

A5.1.4.1. Tank dimensions and specifications. The storage tank holds 500 ℓ.
heat exchanger built into the bottom of the storage tank and an electrical backup heater is located in the middle. Due to the availability of cheaper electricity during the night, half the tank volume may be heated at night to ensure enough hot water for the following day.

The insulation is 100 mm PUR foam on the sides and on the top. The total weight is 130 kg. The heat loss coefficient is around 2.5 W/K if the whole storage tank is at 60°C.

A5.1.4.2. Heat exchanger type and specifications.

collector loop consists of a smooth tube copper spiral (15/13 mm) with an area of about 1 m^2. The heat exchanger capacity rate is approximately 300 W/K.

A5.1.5. Auxiliary The tank's electric heater, located in the middle of the tank, provides about 3 kW of power. It operates only at night due to cheaper off-peak electricity and during the day only if solar energy is unavailable.

A5.1.6. Pump

A5.1.6.1. Flow rate and specifications. The pump used is a Grunfos UPS 25-40/180, with a power consumption of approximately 60 W on speed 2 and a flow rate of about 30 ℓ/m2/h.

A5.1.7. Freeze Protection Freeze protection is guaranteed by the use of ethylene glycol mixtures as the heat transfer fluid (1 part ethylene glycol to 2 parts water).

A5.1.8. Load

A5.1.8.1. Load specification. The Swiss standard (SIA) asks for 50 ℓ per day of 50°C hot water. Therefore, about 2.5 kWh of energy are needed per person per day.

A5.1.9. Controls

A5.1.9.1. Controller specifications. A differential controller starts and stops the circulation pump. An additional thermostat prevents overheating. Start and stop temperature differences (0-20°C), as well as the maximum temperature (60-90°C), are adjustable.

A5.1.9.2. Operating modes.

the stop temperature is set to 2°C. If the storage tank temperature is above 80°C (adjustable 60-95°C), then the pump does not stop working in the evening until this temperature has decreased to 80°C.

A5.2. Dream System Description

A5.2.1. Scheme and Modes of Operations The Swiss Dream System is a highly stratified, low-flow system. It consists of a single element collector with only one opening for the inlet and outlet. The advanced Flextube® tubing connects easily to the collector and storage tank. The storage tank is a tank-in-tank design. A stratification device inside the heat exchanger mantle provides excellent stratification. The solar loop is unpressurized but connected to a small external fluid vessel. The auxiliary heater is introduced in the outer tank. Therefore, deposition of lime is reduced, due to lower specific heating power. See Figure A5-2.

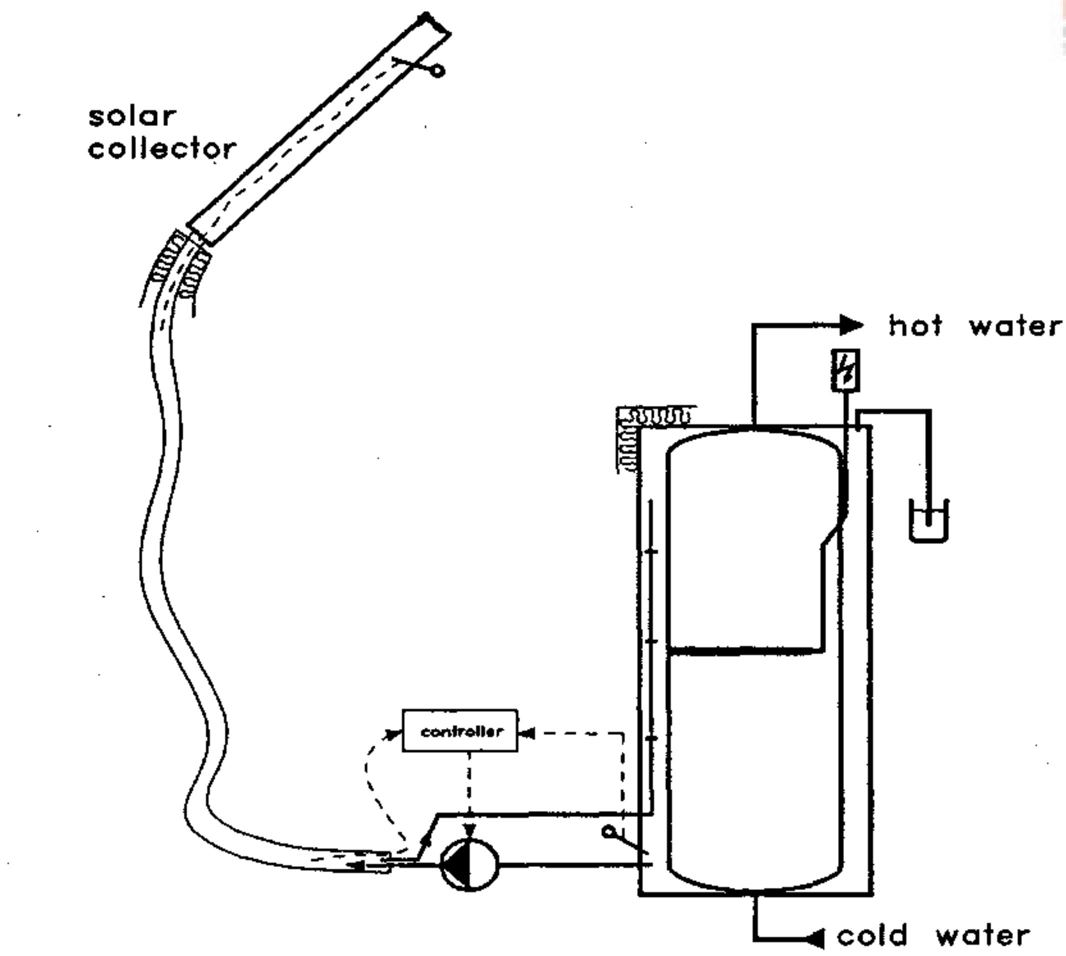

Figure A5-2. Swiss Dream System SOLKIT ®.

A5.2.2. Collector

A5.2.2.1. Collector geometry. The system has a single collector with about 4.5 m2 absorber area. The dimensions are:

Overall dimensions	3.0 m x 1.6 m
Overall area	4.8 m2
Absorber dimensions	2.87 m x 1.53 m
Absorber area	4.4 m2

The inlet and outlet use just one opening.

A5.2.2.2. Collector cover material. The cover material used is SOLITE produced by AFG (USA). It is a tempered and structured low-iron glass with a solar transmittance of $\tau = 0.91$.

A5.2.2.3. Absorber material. the fins are formed by a newly founded Swiss Company "Innovar." The advantage of this a-fin, is that the tube is formed from a copper strip with a selective coating and, therefore, no tube is needed.

Typical performance values are $\alpha > 0.94$; $\varepsilon < 0.15$.

A5.2.2.4. Absorber fins and flow design. The flow design is a serpentine flow pattern. The fans are 110 mm wide, with a thickness of 0.22 mm. The formed tubes have an inner diameter of 8 mm.

A5.2.2.5. Insulation material. Two layers of insulation are used on the backside of the collector 30 mm PUR foam and 20 mm rockwool. The sides and edges are insulated with 35 mm of rockwool.

$$0=0.8-3.5*x-0.010*G*x2$$

where $x = ((T_{coll,in} + T_{\mathbf{coll, out}}) / 2 - T_{amb}) / G$.

The weight of the empty collector without cover is 50 kg. The cover is put on the collector during installation of the system. The volume of the heat transfer fluid for 4.5 m^2 is 2.5 1.

A5.2.3. Piping

A5.2.3.1. Piping material. A new flexible tubing, Flextube®, is developed. Silicon rubber hoses with an inner diameter of about 5 mm are used.

A5.2.3.2. Insulation material. of 10 mm for the return tube from the collectors. An additional 10 mm thickness is used around both the previously insulated "hot" tube and the "cold" tube. The synthetic rubber is protected against UV by a special paint.

A5.2.4. Solar Storage and Heat Exchanger

[illegible] storage tank is made of stainless steel. It is basically a tank-in-tank design where the outer tank is equipped with a stratification device. The stratification device leads to a much better stratification than an ordinary mantle tank. The inner tank meets all necessary Swiss standard requirements regarding service and maximum pressure or maintenance etc. The outer tank is unpressurized and, therefore, open to the environment.

Total volume 400 ℓ

Inner Tank volume 300 ℓ

Outer Tank volume 100 ℓ

The side insulation is a 100 mm thickness of soft PUR foam, a 150 mm thickness on top, a 50 mm thickness on the bottom (no FCKW), and a cotton cover.

A5.2.4.1. Heat exchanger specifications. [illegible]
inner tank. Including the top, bottom and mantle, it has an area of about 3 m^2. Depending on the actual temperature, the heat transfer coefficient might reach much higher values than the heat exchanger spiral in the Base Case system.

A5.2.5. Auxiliary Half of the tank volume can be heated by electricity or through an additional heat exchanger. The position of the electric heater can be adjusted.

A5.2.6. Pump

A5.2.6.1. Flow rate and specifications. [illegible]
the requirements of a low-flow pump. The flow rate is far too high, while the achievable maximum pressure is too low. Therefore, a different design, the membrane pump, was chosen. It is capable of delivering the optimal flow rate over a wide range of pressure differences. This pump is able to reach about 8 bars; however, the rated maximum pressure is 4 bars and thus is controlled by a bypass valve. The power consumption is about 20 W.

A5.2.7. Freeze Protection Freeze protection is guaranteed by the use of an ethylene glycol mixture as the heat transfer fluid. (The ratio of ethylene glycol to water is 1:2.)

A5.2.8. Load

A5.2.8.1. Load specifications. The Swiss standard (SIA) is 50 ℓ per person per day of 50°C hot water. Therefore, about 2.5 kWh of energy are needed per person per day. The system is designed for a family of 4-5 people.

A5.2.9. Controls

A5.2.9.1. Controller specifications. [illegible]
pump. An additional thermostat in the collector prevents overheating. Start and stop temperature difference (0-20°C) are adjustable.

A5.2.9.2. Operating modes. [illegible]
the stop temperature is set to 2°C. If the collector temperature is above 100°C, the pump stops working until the temperature is decreased to about 95°C. During this procedure, the heat transfer fluid in the collector (2.5 ℓ) is evaporated and transported to the tank. At this time, no

additional fluid enters the collector. Therefore, the collector remains empty during high stagnation temperature, and the heat transfer fluid is not affected by high temperatures.

A5.3. Justification of the Dream System

The SOLKIT project, is under a contract within the official program "Energy 2000," is a technology transfer project to bring new ideas for DHW systems to industry. The aim is simply to reduce the costs of small DHW systems. The approach of the SOLKIT® system is completely different from the current state of the art.

The following basic ideas are incorporated in the Dream System design:

- Make use of the low-flow ideas
- The solar fraction for a 4-person family under Swiss conditions (basis Kloten) should be around 50 percent
- All components (including storage tank, collector, advanced tubing etc.) are specially designed and optimized
- A minimum series of 1,000 systems per year is the basis for the production facility chosen
- The overall costs per kilowatt-hour should be in the same order of magnitude as for electrical water heaters
- The lifetime of all components should be more than 10 years
- The system should be very easy to install

A5.4. Cost of the Base Case System

A5.4.1. Component Costs (US$)

(Prices without marketing distribution and sales)

Collectors	1200 US$
Solar storage unit	1667 US$
Pump/Control	267 US$
Piping	333 US$
Fittings, valves	333 US$
Fluids, others	333 US$

Total system components 4,133 US$

A5.4.2. Installation Costs The installation costs are in the order of 3,000 US$, depending on the structure of the building.

A5.4.3. Operating and Maintenance Costs

Operating cost	125 kWh/Year at 0.13 US$ per kWh; Total 16 US$
Maintenance cost	typically about 84 to 150 US$ per year (this includes one visit from a specialist every 5 years)

A5.5. Performance of the Base Case System

A5.5.1. Thermal Performance The thermal performance of the system is analyzed by the dynamic system testing procedure "DST":

System key parameter	Base Case, 6 m^2 collector area, 500 Q storage tank
Weather data	Kloten 1968
Collector installation	tilt: 45°; azimuth: south, no obstructions.
Draw off profile	Swiss profile, 10 kWh/day
Solar fraction (SFO)	0.50

A5.5.2. Reliability and Durability Excellent, > 20 years!

A5.6. Cost of the Dream System

A5.6.1. Component Costs (US$)

(Prices without marketing, distribution and sales)

Collectors	853
Solar storage unit	800
Pump/Control	300
Piping, fittings	280
Fluids, others	233

Total system components 2,466

A5.6.2. Installation Costs The installation costs are in the order of 2,000 US$, depending on the building type.

A5.6.3. Operating and Maintenance Costs

Operating costs	50 kWh/Year at 0.13 US$ per kWh; Total 6.50 US$
Maintenance costs	typically about 84 to 150 US$ per year (this includes one visit from a specialist every 5 years)

A5.7. Performance of the Dream System

A5.7.1. Thermal Performance The thermal performance of the system is analyzed by the dynamic system testing procedure "DST":

System key parameter	SOLKIT® system, 4.5 m^2 collector area, 430 Q storage tank
Weather data	Kloten 1968
Collector installation	tilt: 45°; azimuth: south, free horizon
Draw off profile	Swiss profile, 10 kWh/day
Solar fraction (SFO)	0.48

A5.7.2. Reliability and Durability The reliability and durability are similar to that of conventional systems.

A5.8. Cost Performance Comparison

For the above-described conditions, the performance of the Base Case and Dream Systems is about the same. However, the costs of the Dream System are reduced by more than 30 percent over the Base Case system.

A6. UNITED STATES

A6.1. Base Case System Description

<u>A6.1.1. System Diagram and Description of Operating Modes</u> The Base Case system for freezing climates is shown in Figure A6-1. This system, typical in the United States, consists of separate solar and auxiliary tanks and a small drainback tank with a helical heat exchanger coil.

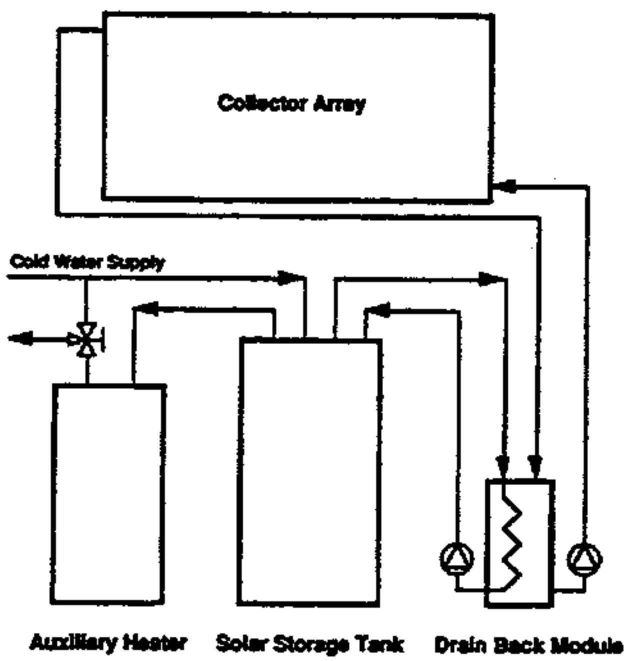

Figure A6-1. United States Base Case System for Freezing Climates.

<u>A6.1.2. Collector</u>

A6.1.2.1. Collector geometry. The collector geometry is a conventional, single-glazed flat plate.

A6.1.2.2. Collector cover material. The collector cover is low-iron soda lime glass with a transmittance of 0.91.

A6.1.2.3. Absorber material. Copper with black chrome 0.95/0.15 selective coating is used as the absorber material.

A6.1.2.4. Absorber fin/flow design. A copper fin-tube design with parallel risers is used. The tube inner diameters are 10 mm and the riser tube pitch is 127 mm.

A6.1.2.5. Freeze protection. A drainback system provides freeze protection.

A6.1.2.6. Frame materials. The frame materials are aluminum.

A6.1.2.7. Insulation material. There is 51 mm of fiberglass on the back of the collector and 32 mm on the edges.

A6.1.2.8. Dimensions, specifications, and properties.

Number of modules	1
Length	2.32 m
Width	1.22 m
Height	0.127 m
Gross area	2.84 m2
Aperture area	2.56 m2
Cover transmittance	0.91

The efficiency curve used in the TRNSYS program is

$$= 0.70 - 3.97T^{*} - 0.0G[T^{*}]2$$

where $T^{*} = [(T_{col,in} + T_{col,out})/2 - T_{amb}] / G$.

A6.1.2.9. Overheat protection. Collector pump stops when the collector temperature is greater than 95°C.

<u>A6.1.3. Piping Runs</u>

A6.1.3.1. Piping material. The system uses copper piping.

A6.1.3.2. Insulation material. Piping is insulated with 19 mm polyethylene, closed-cell foam.

A6.1.3.3. Configuration, dimensions, and specifications.

Specified outer diameter	18 mm
Typical length	7.6 m each way

<u>A6.1.4. Solar Storage and Heat Exchanger</u>

A6.1.4.1. Tank dimensions and specifications. There is a glass-lined, steel storage tank has a volume of 0.189 m^3. The tank is insulated with a 51 mm thickness of fiberglass on the sides and bottom, and with foam insulation on top.

A6.1.4.2. Heat exchanger type and location. is used. In freezing climates, a helix heat exchanger is located in a small, separate, drainback tank.

A6.1.5. Auxiliary and Heat Exchanger

A6.1.5.1. Tank dimensions and specifications. A glass-lined, steel storage tank has a volume of 0.189 m3.

The tank is insulated with a 51 mm thickness of fiberglass on the sides and bottom, and with foam insulation on top.

A6.1.5.2. Auxiliary element location and specifications. There are two 4500-W electric auxiliary U-tube elements, one located approximately 5 cm from the bottom and the other approximately 35 cm from the top of the tank.

A6.1.6. Pumps

A6.1.6.1. Flow rates and specifications.

	collector side	storage side
Type	Grundfos UPS 25-40	Grundfos UPS 25-40
Flow	6 ℓ/mm 4 ℓ /mm	
Power	60 W	30 W

A6.1.7. Load

A6.1.7.1. Specifications. The load specifications are 0.265 m^3 per day at 55°C in three equal draws at 8:00, 13:00, and 17:30.

A6.1.8. Controls

A6.1.8.1. Controller specifications. A differential controller is used. Turn-on occurs at 2.8°C, turn-off occurs at 0° and where the collector fluid temperature exceeds 95°C.

A6.1.9. Rationale for Choice of Base Case The system type was widely sold in the United States.

A6.2. Dream System Description

A6.2.1. System Diagram and Description of Operating Modes The Dream System for freezing climates is shown in Figure A6-2. Two collector tubes are used with reflectors, rather than the four collector tubes, as is currently the case. Since collector storage is smaller, proportionally less fluid is circulated to the auxiliary to avoid overheating.

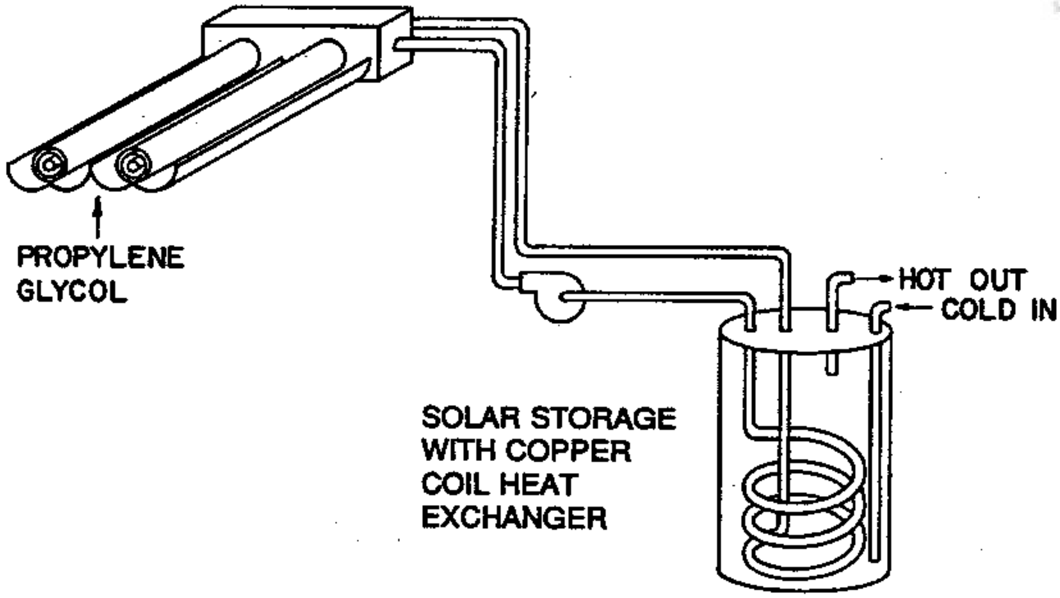

Figure A6-2. United States Dream System for Freezing Climates.

A6.2.2. Collector

A6.2.2.1. Collector geometry. The collector geometry consists of integrated collector storage evacuated tubes with CPC reflectors.

A6.2.2.2. Collector cover material. Collector covers are soda lime glass cylinders. Reflectors are anodized aluminum with a reflectance of .80.

A6.2.2.3. Absorber material. Stainless steel with black chrome 0.93/0.11 selective coating is used *as* the absorber material.

A6.2.2.4. Absorber finIflow design. The absorber fin/flow design consists of a 114 mm cylindrical, integral, collector storage tanks.

A6.2.2.5. Freeze protection.

through the collector. In freezing climates, the system is redesigned using propylene glycol in the collector storage, piping, and the helical heat exchanger of the auxiliary storage.

A6.2.2.6. Frame materials. The frame is constructed of steel.

A6.2.2.7. Insulation material. Insulation is achieved through a vacuum in the evacuated collector tubes and a 25 mm thickness of fiberglass in the manifolds.

A6.2.2.8. Dimensions, specifications, and properties.

Number of tube/reflector units	2
Pitch	0.356 m
Gross area	1.76 m2
Aperture area	1.49 m2
Heat capacity	2.5 kJ/m2-K

Efficiency curve based on gross area.

$$= 0.5331 - 1.650T^*$$

where $T^* = [(T_{col,in} + T_{col,out})/2 - T_{amb}] / G$.

A6.2.2.9. Overheat protection. Fluid is pumped between the collector and auxiliary storage at timed intervals and when the high temperature limit is exceeded.

A6.2.3. Piping Runs

A6.2.3.1. Piping material. Pipes are made of thermoplastic.

A6.2.3.2. Insulation material. Piping is insulated with a 9.5 mm thick layer of polyethylene, closed-cell foam.

A6.2.3.3. Configuration, dimensions, and specifications.

Specified diameter	20 mm
Typical length	8.0 m each way

A6.2.4. Solar Storage and Heat Exchanger

[illegible]

each collector tube. Each has a volume of 0.197 m^3, with a total volume of 0.384 m^3. This integral storage is connected, via a copper coil heat exchanger with a glass-lined steel storage tank with a volume of 151 m^3. The tank is insulated with 51 mm fiberglass on the sides and bottom, and with foam insulation on the top.

A6.2.5. Auxiliary and Heat Exchanger

[illegible]

	Collector	Solar Storage
Tank material	stainless steel	glass-lined steel
Height	2.04 m	1.20 m
Diameter	0.114 m	0.42 m
Volume	0.0189 m^3 x 2	0.151

The tank is insulated with a 5.1-cm thick layer of fiberglass on the sides and bottom and with foam insulation on top.

A6.2.5.2. Auxiliary element location and specifications.

auxiliary U-tube elements, one located approximately 5 cm from the bottom and the other approximately 35 cm from the top of the tank.

A6.2.5.3. Heat exchanger type and location.

is used. In freezing climates, a helix heat exchanger is located in the bottom of the solar storage tank.

A6.2.5.4. Heat exchanger specifications. None.

A6.2.6. Pump

A6.2.6.1. Flow rates and specifications.

Type	Task 14 Pump
Flow	1.3 //minute
Power	5-10 W

A6.2.7. Load

A6.2.7.1. Specifications. The load specifications are 0.265 m^3 per day in three equal draws at 8:00, 13:00, and 17:30.

A6.2.8. Controls

A6.2.8.1. Controller specifications. A photovoltaic driven proportional control is used. Differential control is used for overheating conditions.

Turn-on occurs when collector temperature exceeds 95°C.

A6.3. Justification for Dream System Choice

A high-performance system is used that improves performance and reduces costs.

A6.4. Costs of the Base Case System (1993 US$)

A6.4.1. Component Costs

Collector	$350
Solar Storage	$325
Pump/Controls	$650

System Piping/Fittings	$300
Fluids/Other	0

<u>A6.4.2. Typical Installation Costs</u> $300

<u>A6.4.3. Annual Operating and Maintenance Costs</u> $10

A6.5. Performance of the Base Case System

<u>A6.5.1. Thermal Performance</u> The thermal performance of the system is 7.05 GJ per year.

Location or basis	Sacramento, California
Latitude	38.5°
Collector slope	28.5°

<u>A6.5.2. Reliability and Durability</u> According to experience thus far, the reliability and durability has been excellent.

A6.6. Costs of the Dream System (1993 US$)

<u>A6.6.1. Component Costs</u>

Collector	$650
Solar Storage	integral + $250
Pump/Controls	$125
Solar Energy System Piping/Fittings	$125
Fluids/Overheat and Over-pressure Prevention/Other	$50

<u>A6.6.2. Typical Installation Costs</u> $300

<u>A6.6.3. Annual Operating and Maintenance Costs</u> $10

A6.7. Performance of the Dream System

<u>A6.7.1. Thermal Performance</u> The thermal performance of the system is 8.51 GJ per year.

Location or basis	Sacramento, California
Latitude	38.5°
Collector slope	28.5°

<u>A6.7.2. Reliability and Durability</u> The reflector may deteriorate some before the end of the system's useful life. Otherwise, the reliability and durability is expected to be about the same as for the Base Case system.

A6.8. Cost/Performance Comparisons

The costs for the Dream System have been reduced by $415, or 22%, over that of the Base Case.

The annual performance of the Dream System has been increased by 1460 MJ per year, or 21 percent, over that of the Base Case system.

The annual cost/performance ratio of the Dream System has been improved by 35% over that of the Base Case system, exceeding the 15 percent Task goal.

APPENDIX B

COUNTRY REPORTS

B1. CANADA

B1.1. Market Overview

Energy consumption by the residential sector accounts for approximately one-fifth of total energy use in Canada. Of this, approximately 17 per cent is used to heat water, making water heating one of the most energy-intensive, domestic, end-use applications.

Eighty per cent of this load, the equivalent of 52 million MWh, is attributed to single-family residences. Of the estimated 6.7 million single-family homes in Canada, 53% rely on electricity for water heating, with 42% using gas and an additional 4% consuming oil. Table B 1-1 provides an overview of the single-family residential water heater market, including province-by-province and national values of water heater installations by fuel type and associated growth rates. It is estimated that a modest number 15,000 homes, currently use solar energy to heat water.

Table B1-1. Canadian Water Heater Market Data (# in 000's).

Province	Electric		Gas		Oil	
	#	Growth %	#	Growth %	#	Growth %
Nfld	128	1.67	-	-	19	2.94
PEI	7	-5.55	-	-	27	7.14
NS	148	3.24	-	-	88	2.16
NB	189	4.17	-	-	17	-8.00
Que	1248	3.06	42	0.00	71	-6.12
Ont	1105	-0.68	1428	6.04	27	-4.54
Man	143	0.53	154	2.11	-	-
Sask	83	-1.15	211	1.51	-	-
Alta	60	6.25	641	2.77	4	-8.33
BC	390	0.06	489	6.03	14	-8.33
Canada	3501	1.25	2965	4.59	267	-2.67

Source: Statistics Canada 1993

The average Canadian household consumes 240 ℓ of hot water each day. Although widely varied between individual households, the diversified profile is as shown below in Figure B1-1. In terms of temperature, city 'mains' supplies undergo large seasonal variations that can range from a few degrees above zero in February up to 20°C or higher in September. Water storage tanks are typically maintained at 55°C to 60°C.

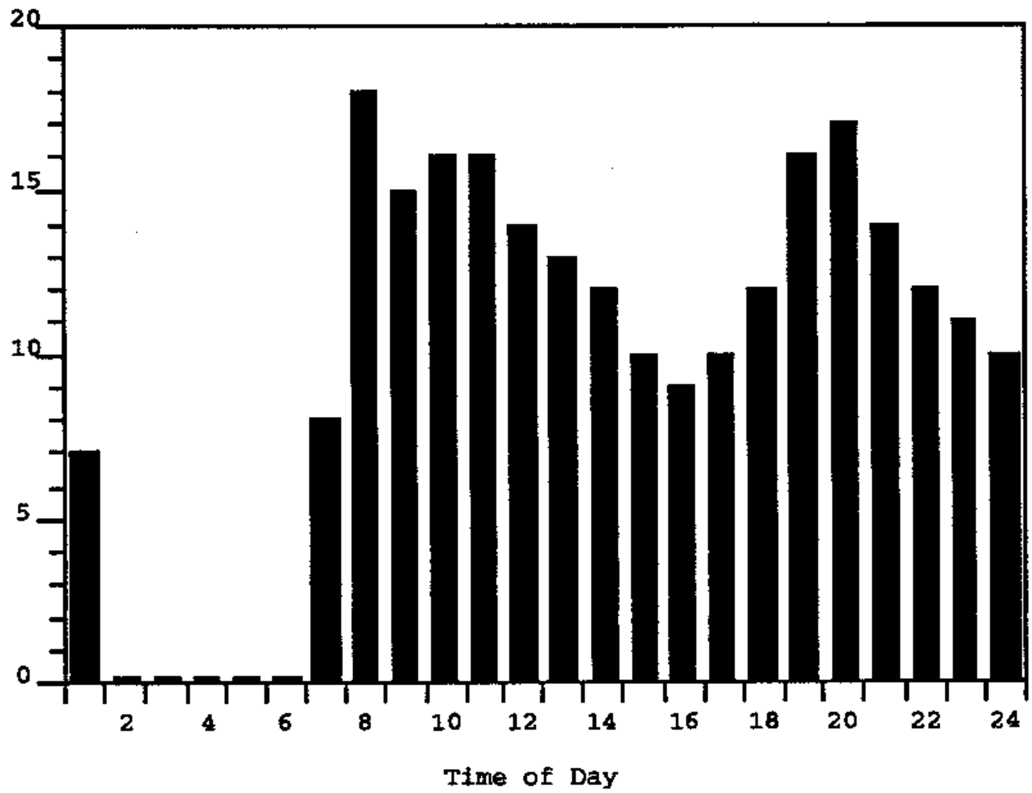

Figure B1-1. Hot Water Usage for a Typical Canadian Household (ℓ/hr).

B1.2. The Solar Industry in Canada

The Canadian solar industry is not as large as it once was due, in large part, to the termination of federal subsidies and demonstration programs. Nevertheless, there are a couple of Canadian companies that are producing and/or selling equipment without government subsidies.

Thermo Dynamics of Dartmouth, N.S. is the largest supplier of solar DHW systems in Canada. It produces a micro-flow system with collectors using Sunstrip® absorber technology.

Thermomax in Victoria B.C. supplies solar collectors and systems using evacuated tubes for DHW, space heating and high-temperature applications. The manufacturing of the tubes takes place at Thermomax's main production facility in the UK. Other SDHW system manufacturers include Solcan of London, Ontario, producing a thermosyphon SDHW system, and Powermat Manufacturing of Vancouver, which produces SDHW systems based on an unglazed collector design.

B1.3. Solar Resource

The solar industry's ability to capture a share of the heating market depends on many factors which have been addressed by NRCan/Canmet in a recently completed technology and market potential assessment for solar thermal applications. One of these factors is the available solar radiation which varies significantly both by season and by location within Canada's vast land mass. To get a full appreciation for the solar resource in Canada relative to other lEA member countries, Figure B 1-2 was constructed showing daily average solar radiation on a surface with tilt equal to latitude. In most cases, a range is also indicated to represent the geographic variability of the resource within each country. The figure shows a Canadian solar resource which is lower than that for the sunniest climates, such as Australia and the US, yet higher than that of virtually all Northern European climates. For the southern regions of Canada, it varies from a high of 17.4 MJ/m^2/day in western Canada to a low of 12.1 MJ/m^2/day in Newfoundland as shown in Figure B1-3.

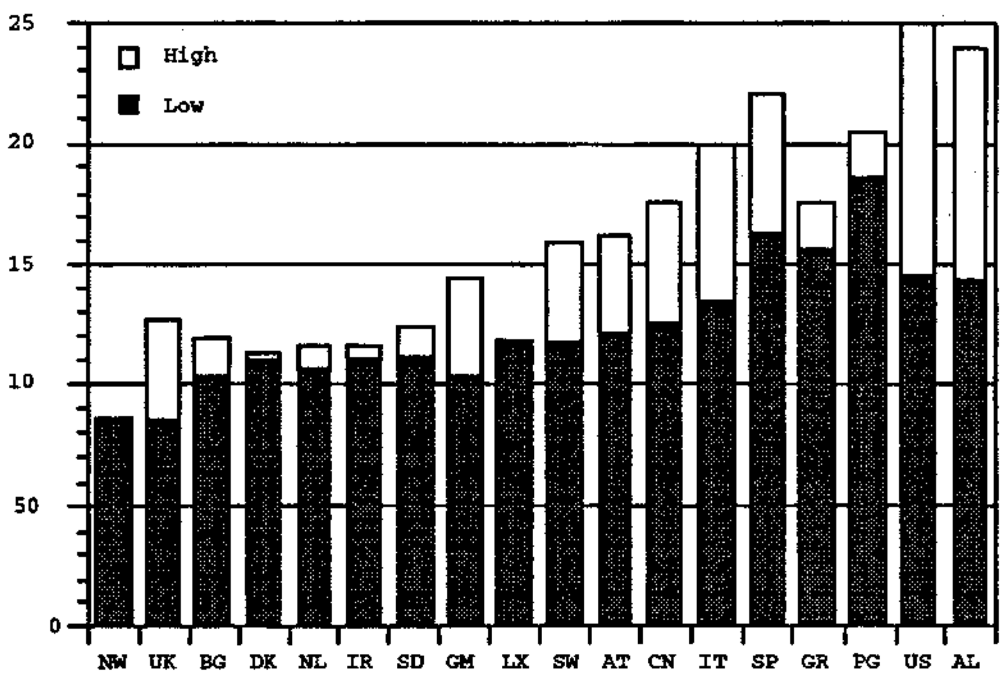

Figure B1-2. Average Daily Radiation on Surface at Tilt = Latitude for Various lEA Member Countries (MJ/m2-day).

Figure B1-3. Comparison of Total Solar Radiation at Tilt = Latitude for Various Canadian Locations (MJ/m2/day).

Because of the northerly latitude of Canada, there is a significant variation in solar radiation from summer to winter. Figure B1-4 shows the variation in monthly average solar radiation in Toronto for a collector tilt equal to latitude to maximize total yearly radiation.

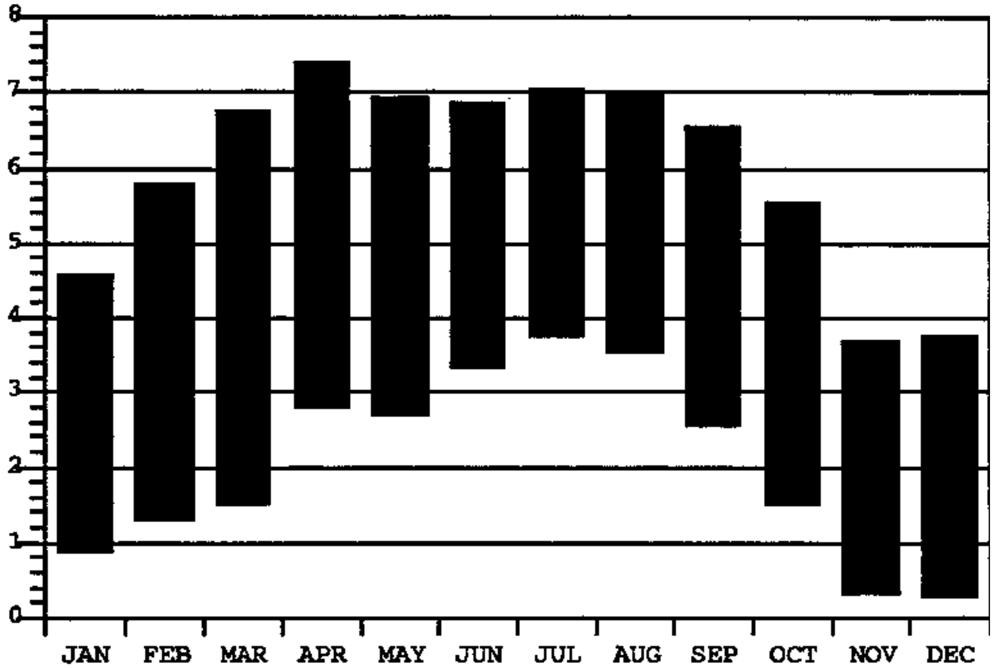

Figure B1-4: Solar Resource for Toronto at Tilt = Latitude (kWh/m2/day).

While solar radiation data on a tilted surface is a more useful measure of solar availability for solar heating systems, horizontal radiation measurement is the most common method of collecting solar radiation data in many areas of the world. The Atmospheric Environment Service of Environment Canada maintains an extensive network of monitoring sites throughout the country. Month-by-month average daily values of solar radiation on the horizontal and daytime high temperatures are shown in Table B 1-2 for three geographically diverse population centers to indicate typical seasonal climate characteristics.

Table B1-2. Monthly Average Horizontal Radiation and Daytime High Temperature for Selected Canadian Cities.

Month	Calgary		Toronto		Halifax	
	Hor Rad MJ/m^2-d	Temp °C	Hor Rad MJ/m^2-d	Temp °C	Hor Rad MJ/m^2-d	Temp °C
Jan	4.69	-6.0	5.14	-1.3	5.65	0.5
Feb	8.19	-1.5	7.86	-0.5	8.52	0.6
Mar	13.08	1.7	11.55	4.1	12.17	3.6
Apr	16.97	9.4	17.06	11.7	14.94	8.6
May	20.40	16.0	18.73	18.2	17.17	13.9
June	21.98	19.9	20.90	23.7	19.43	19.2
July	23.28	23.3	21.47	26.7	17.74	22.7
Aug	19.99	22.1	18.86	25.6	16.61	22.7
Sep	14.59	17.4	13.72	21.3	13.32	19.6
Oct	9.47	12.3	8.77	14.7	9.36	14.3
Nov	5.45	3.3	4.47	7.8	5.31	8.6
Dec	3.71	-1.8	3.77	1.4	4.30	3.0
Year	13.51	9.7	12.71	12.8	12.06	11.4

Source: Atmospheric Environment Service, Environment Canada

B1.4. Energy Costs

The cost of competing conventional sources of energy is another important factor which directly impacts the market potential for residential solar water heaters. Table B1-3 presents Canadian energy prices as tabulated by Natural Resources Canada (NRCan). The prices are given for four geographic areas to account for regional variations: Atlantic Canada, Quebec, Ontario and the West. Provincial energy prices are averaged for the two regions representing more than one province, and energy prices are not given for those regions where a fuel is unavailable or rarely used.

Table B1-3 also includes estimates of what the fuel prices will be in the year 2010 based on departmental projections. Electricity prices are projected to increase by roughly 6% in real terms, and residential oil and natural gas prices to increase by 2% and 16%, respectively. This sharper increase in gas prices is attributed to the high cost of exploration and development of new gas sources, and recently depressed prices due to excess gas supply. It should be noted that all prices are given in dollars per output gigajoule, and that conversion efficiencies were assumed to be 100% for electricity and 50% for both oil and gas heating.

Table B1-3. Typical Canadian Energy Prices ($94/output GJ).

Fuel Type	Atlantic		Quebec		Ontario		West	
	1994	2010	1994	2010	1994	2010	1994	2010
Electricity	$18.30	$19.20	$16.23	$17.88	$20.65	$21.67	$14.27	$14.99
#2 Oil	$20.45	$20.02	$19.02	$19.46	$18.94	$19.62	-	-
Natural Gas	-	-	$17.03	$18.94	$11.54	$13.49	$10.42	$12.58

Note: Conversion efficiency of 50% applied to #2 oil and gas

These projected energy price increases, coupled with forecasted reductions in SDHW costs (shown in Figure B1-5), should significantly enhance the market potential for SDHW in Canada. A recent study by CANMET has shown that of the numerous solar end-use applications on the market today, residential water heating is among the most promising based on its potential energy contribution over the next 20 years. The study identifies a market potential of over 100,000 systems for Canada over this time period.

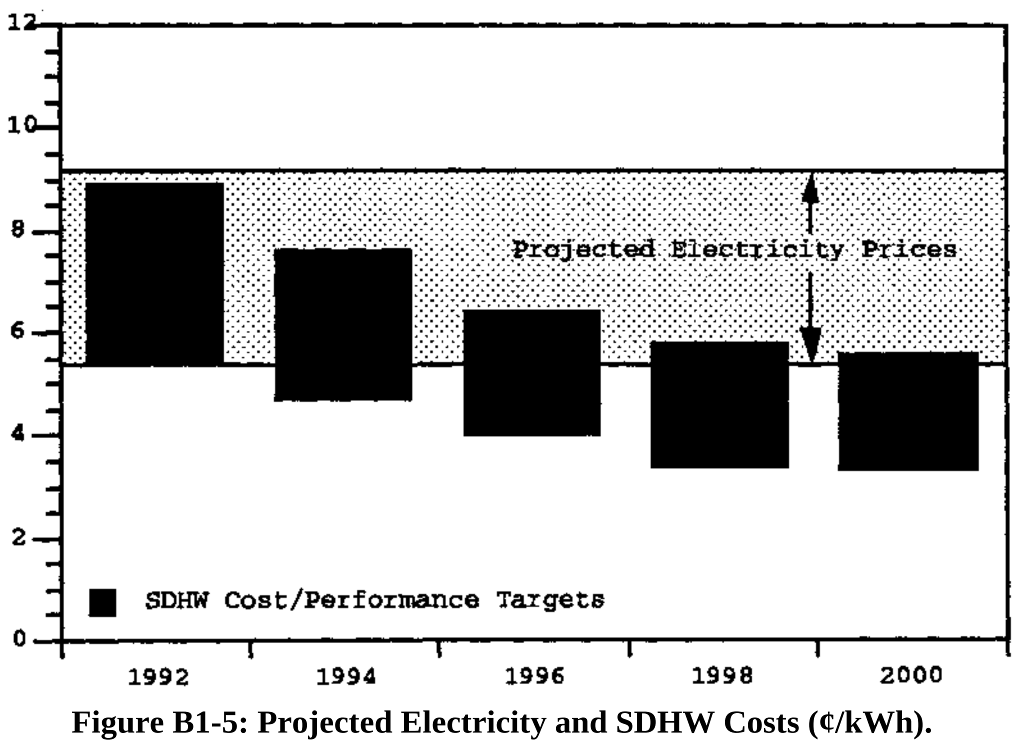

Figure B1-5: Projected Electricity and SDHW Costs (¢/kWh).

Over 10,000 of these systems are expected to be in place by the year 2000, mainly as back-up to existing electric water heaters. The market is expected to be greatest in provinces with a high residential demand for electricity or high cost, namely Ontario, followed by Quebec and Nova Scotia as shown in Figure B 1-6. The market in the remaining provinces is comparatively smaller, due mainly to the availability of low-cost natural gas or hydro-electricity.

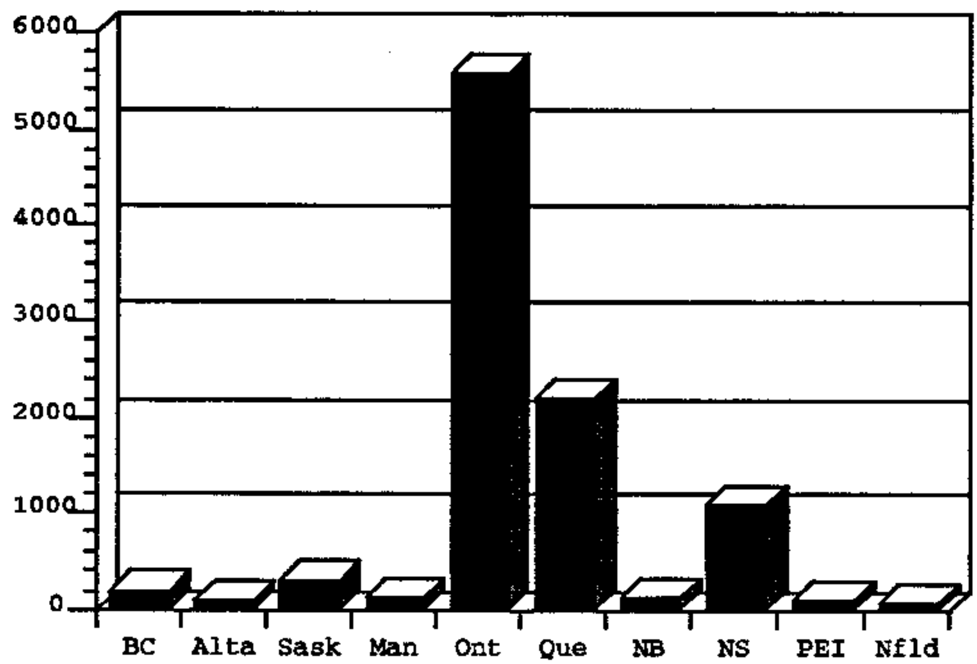

Figure B1-6. Projected SDHW Installations in Canada by Province in Year 2000.

B 1.5. S-2000 Program

The market projections shown above comprise the goals of NRCan/CANMET's S-2000 program. Administered by CANMET's Alternative Energy Division, S-2000 is a multi-faceted program which supports the R&D needed to realize technology cost/performance improvements, and market development initiatives to introduce solar water heaters to electric utilities and homeowners. These include workshops for utility officials, and pilot projects with electric utilities to finance, install, and monitor SDHW systems. Specific S-2000 program goals include:

- Peak load reduction, cost-effective energy savings and environmental improvements through the installation of residential solar water heaters.

- The transfer of information on SDHW technology and performance to utilities and other technology users.

- Promoting the development of the SDHW industry, fostering cost and performance improvements, and helping to ensure high reliability and service standards for equipment.

CANMET, Nova Scotia Sustainable Economic Development and Thermo Dynamics Ltd. of Halifax are currently cooperating in a field trial to evaluate the aggregate energy, demand and economic benefits of Canadian SDHW technology in 60 homes in one Nova Scotia community. Based on results to date, it is estimated that the solar systems being demonstrated will reduce the amount of energy consumed for water heating by about half in a typical NS household, representing savings of $275 in annual energy costs. B.C. Hydro and West Kootenay Power have installed eight systems throughout British Columbia, and Hydro Quebec is close to completing a pilot project to evaluate multi-family residential systems in the Montreal area. BC Hydro is now considering a larger scale program targeted at the non-integrated areas in its service region, and Hydro Quebec is assessing SDHW for new single-family residential construction.

More recent S-2000 developments include the initiation of pilot projects with two separate municipal electric utilities in Ontario, the largest potential Canadian market. In cooperation with CANMET, Guelph Hydro is in the process of installing 100 SDHW systems and low level monitoring hardware in its service area to evaluate load-side benefits, customer savings, and program take-up when long-term, low-interest fmancing is offered. London Hydro, on its own initiative, has also conducted a study of a SDHW rental program for its customers with very favorable results. More recently, the utility has joined forces with the S-2000 program to implement a pilot project geared towards validating its feasibility study results. The primary objective of this work is to convince its regulatory board of the benefits of a full-scale SDHW system rental program based on its existing marketing and distribution channels.

B2. DENMARK

B2.1. Introduction

In the period prior to the beginning of the Task 14 project in 1989, only a few hundred solar water heating systems were installed yearly in Denmark, and only 5 Danish solar collector manufacturers marketed solar heating systems.

During the progress of the Task 14 project, the number of solar water heating systems installed yearly and the number of solar collector manufacturers have both increased markedly in Denmark. In 1993, 18 different Danish companies marketed solar heating systems and approximately 2,500 solar heating systems, with a total solar collector area of 25,000 m^2, were installed in Denmark.

The solar water heating market includes a combination of large and small systems.

B2.2. Country Information

The most commonly used energy sources in Denmark are oil, natural gas, and electricity.

The energy prices in US $ are as follows:

- Electricity approx. 0.15US$/kWh
- Natural gas approx. 0.65US$/m3
- Oil approx. 0.64US$/liter

The use of renewable energy in Denmark is supported by the government, which supports the use of biomass (straw, trees etc.), wind energy, and solar energy. The government's aim is to encourage the use of clean energy sources. Some of the most important initiatives are:

- Tax on conventional energy sources
- Tax on CO_2 emissions
- Implementation of the Energy Plan 2000, aiming for an 80% reduction of CO2 emissions
- Tax on consumption of water to protect the environment and improve the quality of water

The combined electrical energy production with biomass is the most accentuated.

In order to decrease the total use of energy in Denmark, regulations have been implemented. The most important one is the building code BR 94, which calls for increasing insulation, making houses air-tight, and decreasing window area.

The primary consumers of solar energy in Denmark are private households and institutions such as schools, homes for elderly people, etc. In Denmark, solar energy is an attractive solution in the long run, and Danish consumers are often concerned with both the economic and the environmental implications of buying a solar heating system.

There still exists a large, potential, untapped market in Denmark. The total market potential is estimated at about one million households and is expected to continue increasing.

The weather data used for determining dimensions of solar heating systems in Denmark are obtained from the Danish Test Reference Year. The monthly horizontal radiation and average outside temperatures for this year are shown in Table B2-1.

Table B2-1. Weather Data From the Danish Test Reference Year.

Month	Monthly horizontal radiation	Average outside temperature
January	47 MJ/m²	- 0.6°C
February	119 -	- 1.1°C
March	212 -	2.6°C
April	428 -	6.6°C
May	562 -	10.6°C
June	670 -	15.7°C
July	580 -	16.4°C
August	486 -	16.7°C
September	299 -	13.7°C
October	158 -	9.2°C
November	68 -	5.0°C
December	43 -	1.7°C
Total	3665 MJ/m²	8.1°C

A hot water consumption figure of 200 ℓ/ day heated from 10°C to 45°C was used to test marketed DHW solar heating systems and to calculate consumer benefits from state subsidies for these systems. The test draw pattern was 50 Q each at 8:00 a.m., noon, 6:00 p.m. and 8:00 p.m.

The Danish government supports the use of domestic solar water heating systems by insuring that every DHW solar heating system installed in Denmark is state-subsidized as long as the system type is approved by the Danish Solar Energy Testing Laboratory at the Danish Technological Institute. Before a system type is approved, the solar collector, heat storage, and sometimes the entire system are tested. The efficiency of the solar collector is measured in an outdoor solar simulator test facility, and the thermal characteristics of the heat storage are measured in an indoor heat storage test facility. In addition, the yearly thermal performance of the system is determined by use of a computer program. Weather data from the Danish Test Reference Year and the above-mentioned standard hot water consumption figure are used as assumptions for the calculations.

The state subsidy until June 1990 was 30% of the consumer price of the system. Since June 1990, the state subsidy for a marketed solar water heating system has been determined by the equation:

$$\text{State-subsidy} = (Q_{net} + Q1) \times 5 \text{ DKK}$$

where $Q_{net} = Q_{gross} - Q_{pump} - Q_{sup,s} - Q_{sup,w}$.

Q_{net} = calculated yearly net solar energy use of the system, kWh/year.

Q1 = difference in heat loss between the solar heating system and the conventional hot water tank.

Q1 is found from:
110 kWh/year for solar heating systems with a built-in electric heating element.
190 kWh/year for solar heating systems with a built-in heat exchanger spiral.
300 kWh/year for solar heating systems with both a built-in electric heating element and a built-in heat exchanger spiral.

Q_{gross} = hot water energy consumption tapped from the system, kWh/year.

Q_{pump} = yearly energy consumption for the system's circulation pump, kWh/year.

$Q_{sup,s}$ = energy consumption for the electric heating element in the summer, kWh/year.

$Q_{sup,w}$ = energy consumption for the heat exchanger spiral in the winter, kWh/year.

A typical DHW solar heating system has a solar collector area of about 4-6 m^2 and a hot water tank of approximately 200-300 ℓ. The yearly solar fraction of a typical Danish marketed solar heating system is approximately 60%. The system's cost-inclusive VAT is about 25,000-40,000 DKK. The state subsidy varies from approximately 7,000-11,000 DKK.

The typical DHW solar heating system in Denmark is based on a hot water tank installed with an auxiliary energy supply system, or systems. An electric heating element and/or a heat exchanger spiral is commonly built into the top of the hot water tank. The heat storage of the solar heating system and the auxiliary energy system use the same tank.

Prior to the beginning of the Task 14 project, all Danish marketed solar heating systems were based on the same design, a hot water tank with a built-in heat exchanger spiral situated at the bottom of the tank. The solar collector fluid is circulated through the heat exchanger spiral with a volume flow rate of about 1 ℓ/minute per m

B2.3. Utilization of Knowledge Developed in the Task

The work of the Task 14 project has strongly influenced the development of Danish DHW solar heating systems. In January 1992, a workshop on the market situation for active solar heating systems was organized by the Danish ISES Section in Lyngby in conjunction with an expert meeting. Presentations on the market situation in 7 countries were provided by: Teun P. Bokhoven of Solar Systems, b.v. for the Netherlands; Pierre Bremer of Sede SA, for Switzerland; Michael Mack of ISFH Hannover, for Germany; Peter Allen of Thermo Dynamics Ltd, for Canada; Svend Erik Mikkelsen of CowiConsult, for Denmark; Göran Hulima& of Andersen & Hultmark, for Sweden; and Emanuel Brender of Batec A/S, for Denmark. The workshop was a great inspiration for the 35 participants, mainly Danish solar collector manufactures and consultants. Most Danish work in the Task 14 project has been concentrated on low-flow systems and drainback systems.

In 1989, a low-flow system was first introduced to the Danish market by one Danish producer. This low-flow system consisted of a hot water tank with a mantle welded around a portion of the tank's surface. The solar collector fluid was circulated through the mantle.

The number of solar heating systems installed annually and the sale of Danish low-flow systems have increased rapidly since the inception of the project. See Figure B2-1.

Today, two manufacturers are marketing low-flow systems, and an additional company is developing a low-flow system.

Recently, several Danish companies have begun development of DHW solar heating systems based on both the low-flow and the drainback principles. Their work is strongly influenced by the work carried out within the Task 14 project. Some of the systems are currently being tested at the Thermal Insulation Laboratory. Others will be tested in the future. In this way, the testing experience gained from the Task 14 project will be utilized as well.

B2.4. Cost/Performance Improvement

It is expected that the cost/performance ratios for DHW systems based on the low-flow and drainback principles will be about 35% better than the cost/performance ratios for traditional Danish solar DHW systems.

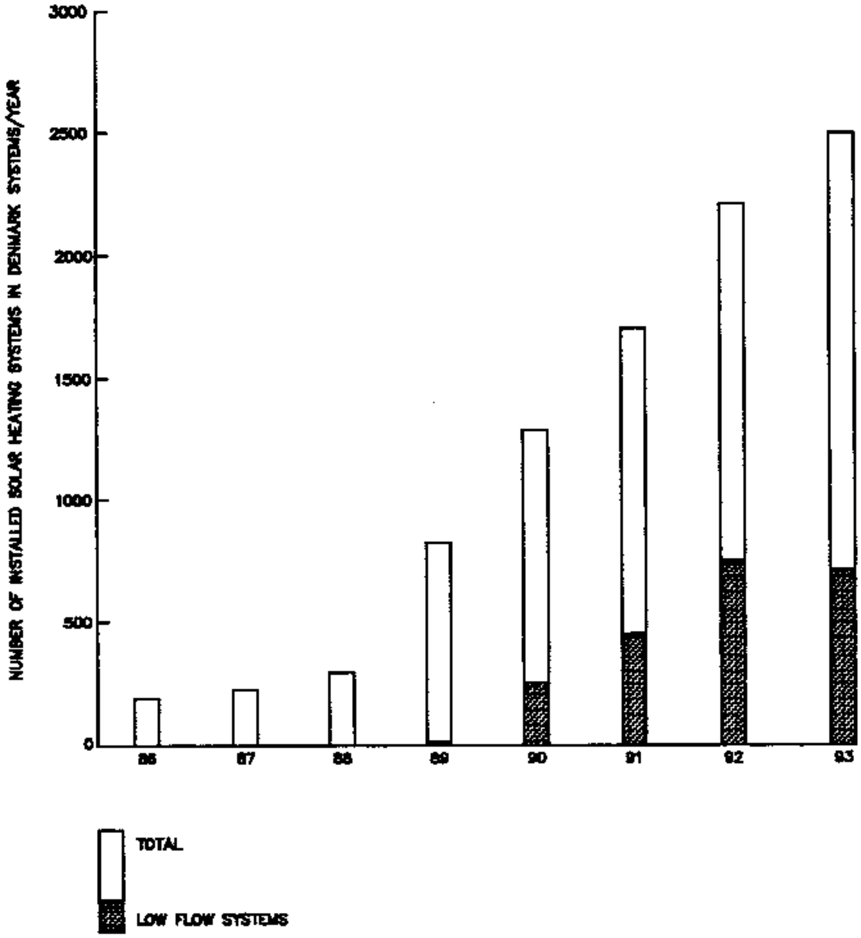

Figure B2-1. Number of Installed Solar Heating Systems in Denmark.

B3. GERMANY

B3.1. Introduction

In Germany, the market for SDHW systems was greatly influenced by political promotion and the oil crises of 1973/74 and 1978/79. Between 1974 and 1979, the market for solar domestic hot water systems started to boom, resulting in –40,000 m^2 of installed collector area by 1979. In 1980, there was a total of –120,000 m^2 of collector area installed. Between 1981 and 1987, the solar market dropped to between 15,000 and 25,000 m^2, but it significantly rebounded after mid-1986 because of the public's growing ecological awareness. Since then, the question of energy resources has become more and more a political issue with the onset of governmental subsidy programs in 1986 and 1989.

Sales of SDHW systems have increased in Germany since 1980, as shown in Table B3-1, with an approximate share of 15-20 percent for vacuum collectors.

Table B3-1. SDHW - Sales Development.

Year	SDHW-sales/m^2-collector area
1989	30,000
1990	~70,000
1991	120,000
1992	~100,000
1993	~100,000

- Total system costs:
  1,200 - 1,500 US$/$m^2$ (FPC)
  –2,300 US$/$m^2$ (ETC)

- Today's installation costs:
  –400 US$/m2

- Average system size: 6-7 m2

- Home-owner installed systems: –40%, decreasing slightly since 1992.

By 1993, there were approximately 6 manufacturers of SDHW systems in Germany and about 5 companies selling systems with imported collectors.

B3.2. Country Information

- Population — 80.7 million
- Area — 357,000 km^2
- Private residences — 33.7 million
- One-family houses — 7.7 million[2]
- Two-family houses — 2.6 million[2]
- Three-family houses and larger — 2.1 million[2]
- Average hot water usage

- Typical demand temperature 45°C
- Residential electric DHW installations 26.6%
  price[3] 0.175 US$/kWh[4]
- Residential gas DHW installations 38.6%
  price[3] 0.036 US$/kWh[4]
- Residential oil DHW installations 29.5%
  price[3] 0.031 US$/kWh[4]
- Residential district heating DHW inst. 4.5%
  price[3] 0.047 US$/kWh[4]
- Residential solar DHW installations –100,000 systems

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1 BMWi, Energiedaten 92/93, Table 1
2 Germany before unification in 1990
3 Typical household consumption price, without infrastructure and connection to grids
4 BMWi, Energiedaten 92/93, Table 24

B3.2.1. Government Policies A national law, in effect between 1986 and 1991, which called for income tax deductions for energy saving investments in one- and two-family houses. Depending on an individual's income tax rate, this added up to a governmental subsidy of 20-30 percent of SDHW system costs.

B3.2.2. State and Utility Programs

- In 1994:

  The national program for residential solar DHW systems offers a subsidy of 147 US$/m^2 collector area up to 882 US$ per system. Due to a limited budget, the program collapsed after the first month of operation.

- There has been a regional state subsidy since 1989 with different rates of subsidy decreasing again since 1992. In some counties, the subsidy for solar systems has as much as 65 percent of the solar invested costs. In such cases, the budget has been strictly limited so that the governmental budget corresponds directly to the size of the SDHW market in that county. Now that the main pilot and demonstration program for SDHW systems is history, the county subsidy is in the range of 0-25 percent of the solar investment costs. The year 1992 had the year with the highest regional coverage of subsidy programs at an average level of 25-30 percent subsidy.

- There were a few regional utility programs.

- Every year the German SDHW Manufacturers Society (DFS) calls for a 48 million US$ (0.6 US$ per capita) governmental subsidy program and re-introduction of the income-tax deduction program.

B3.2.3. Regulations

- All DHW systems with more than 400 9 storage volume without regard to the energy source must undergo Legionnaires Disease prevention cycle by the national board of sanitary engineering. The whole system must be heated to 60°C once a day.

- The national board of sanitary engineering and the technical supervision council (TUV) stipulates some common safety regulations regarding the operation of DHW systems.

Table B3-2. Climatic Data for Germany.

		Greifswald 54.1°N	Emden 53.4°N	Hannover 52.5°N	Dresden 51.5°N	München 48.1°N	Friedrichshafen 47.7°N	
JAN	G_{av}	**0.50**	**0.70**	**0.57**	**0.70**	**1.07**	**1.10**	kWh/m^2
	T_{av}	-1.0	0.8	0.1	-1.2	-2.3	-1.0	°C
FEB	G_{av}	**1.10**	**1.30**	**1.13**	**1.30**	**1.83**	**1.80**	kWh/m^2
	T_{av}	-0.6	1.1	1.3	-0.7	-0.8	0.2	°C
MAR	G_{av}	**2.25**	**2.20**	**2.22**	**2.40**	**2.69**	**3.10**	kWh/m^2
	T_{av}	2.4	3.7	4.0	3.2	2.9	4.1	°C
APR	G_{av}	**3.60**	**3.60**	**3.44**	**3.60**	**4.11**	**4.50**	kWh/m^2
	T_{av}	7.1	7.4	7.8	8.2	6.9	8.6	°C
MAY	G_{av}	**4.50**	**4.50**	**4.54**	**4.60**	**5.07**	**5.50**	kWh/m^2
	T_{av}	12.3	11.4	12.8	13.0	12.0	13.2	°C
JUN	G_{av}	**5.50**	**5.50**	**5.20**	**4.80**	**5.39**	**5.70**	kWh/m^2
	T_{av}	16.1	14.7	15.7	16.5	15.1	16.7	°C
JUL	G_{av}	**5.00**	**4.50**	**4.66**	**4.40**	**5.46**	**6.00**	kWh/m^2
	T_{av}	18.1	16.6	17.2	18.1	17.0	18.4	°C
AUG	G_{av}	**4.50**	**4.50**	**4.17**	**4.00**	**4.60**	**4.80**	kWh/m^2
	T_{av}	17.7	16.6	16.4	17.8	16.1	17.6	°C
SEP	G_{av}	**3.00**	**3.60**	**2.77**	**3.00**	**3.70**	**4.00**	kWh/m^2
	T_{av}	14.4	13.8	13.5	14.4	12.6	14.3	°C
OCT	G_{av}	**1.70**	**1.50**	**1.48**	**1.90**	**2.23**	**2.50**	kWh/m^2
	T_{av}	9.2	9.6	8.9	9.1	7.6	8.9	°C
NOV	G_{av}	**0.6**	**0.70**	**0.67**	**0.80**	**1.18**	**1.20**	kWh/m^2
	T_{av}	4.5	5.4	4.5	4.3	2.4	4.2	°C
DEC	G_{av}	**0.4**	**0.40**	**0.41**	**0.50**	**0.83**	**1.00**	kWh/m^2
	T_{av}	1.0	2.5	1.9	0.4	-0.9	0.5	°C
ann	G_{av}	**996**	**988**	**953**	**976**	**1163**	**1258**	kWh/m^{2}a
	T_{av}	8.5	8.7	8.7	8.6	7.4	8.9	°C

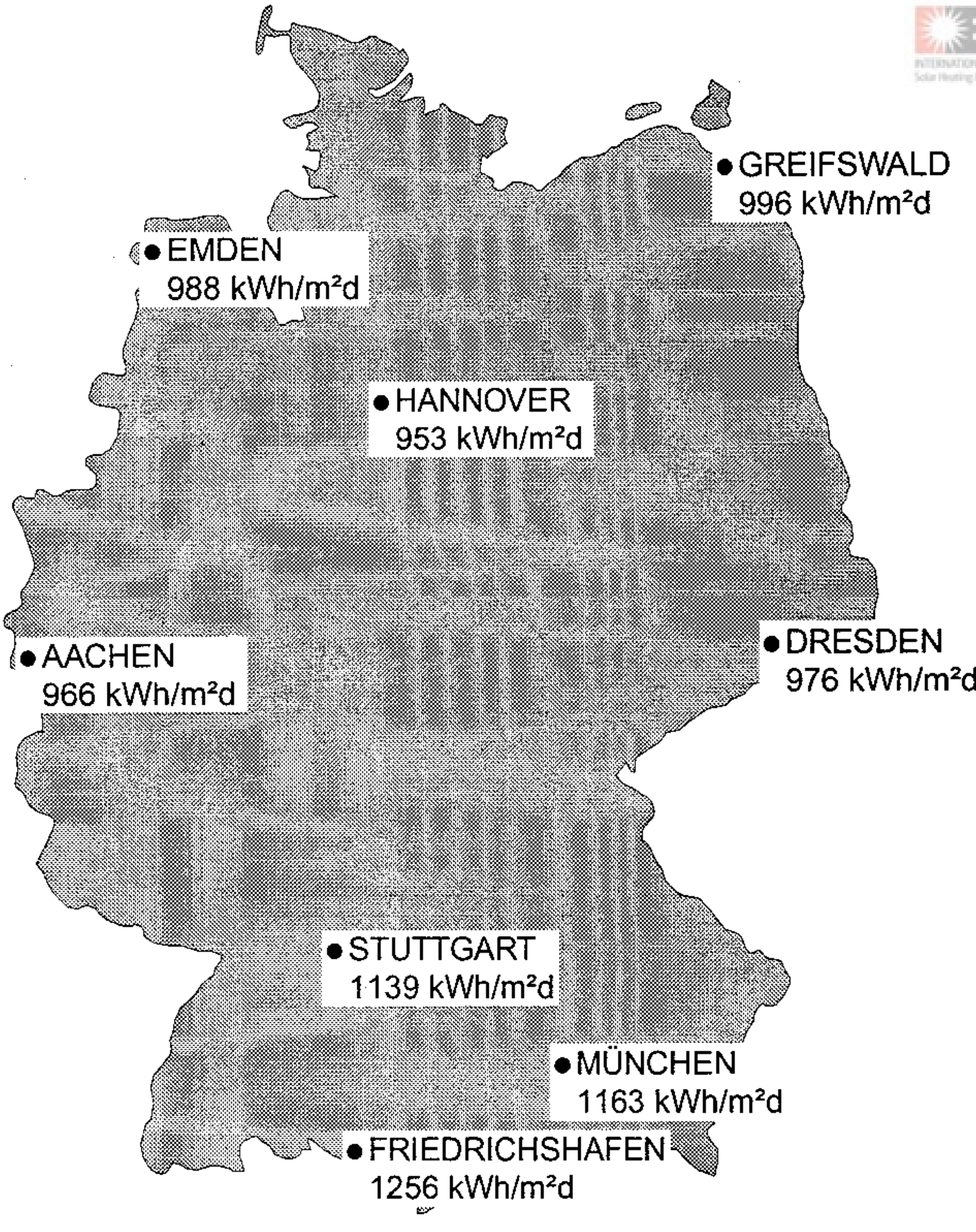

Figure B3-1. Climatic Map for Germany.

B4. THE NETHERLANDS

B4.1. Introduction

The solar domestic hot water market in the Netherlands has been growing since 1990. This market growth can be explained by three major factors:

a. The Dutch government announced a clear target for the numbers of solar DHW systems to be installed by the year 2010. In order to meet this target, a market stimulation program has been started which includes subsidies and advertising campaigns aimed at public awareness.

b. Utility companies are actively involved in a larger scale introduction of solar systems by innovative lease and rental programs as part of their role in environmental action programs.

c. The solar industry committed itself to invest in further research and development in order to bring down the price levels of the installed product to avoid subsidy-dependence.

These three interrelated factors are defined in a "three-party-agreement." The objective of the agreement is to reduce the price of SDHW systems by 1998 to a level at which market mechanisms, without subsidy involvement of any kind, will guarantee a substantial amount of solar systems in the hot-water market.

One way in which the research institutes and industry work together towards a better price/performance ratio is through implementing the low-flow/matched-flow principles. The overall objective is to work towards a 40 percent improvement in price/performance by 1998, as compared to 1991. This must be accomplished by the research and development of cheaper systems, while maintaining the performance and quality standards, as well as higher market volumes with subsequently lower prices. Moreover, the subsidy system will change in 1994 towards a subsidy-on-performance, instead of one based on collector area.

B4.2. Country Information

B4.2.1. Statistical Information

Population 1993:	15.5 million
Percent of private homes:	Approximately 60%
Percent of rental homes:	Approximately 40%
Average daily hot water demand:	110 ℓ/65°C
Yearly DHW market:	350,000 systems
Number of solar manufacturers:	6
Current back-up energy source:	Over 75% natural gas
Latitude:	52 N

Average hours of sun/yr:	1,500
Average hours of sun/day:	4.2
Total solar radiation (horiz):	3.9 GJ/m2
Climate:	Mild Summer/Cold Winter
Energy Prices:	
Natural Gas (including VAT):	$0.26/m3
Electricity (including VAT):	$0.12/KWh

B4.2.2. System-Related Conditions Domestic hot water production, both traditional and solar system-generated, must comply with water authority regulations as formulated the in the Dutch working documents from VEWIN (an association of water authorities in the Netherlands).

The current regulation, VEWIN WB 4.4b, states the following:

"Hot water units using indirect heating sources must use a double-walled heat exchanger between the heat transfer medium and the drinking water."

and:

"It is prohibited to use a heat transfer medium in the double-walled heat exchanger which is toxic. If a fluid is used as a heat transfer medium, it must be either drinking water or a fluid with a non-toxic ATA certification, which states that it is allowed to be used for this purpose."

In practice, this implies that only low- or no-pressure water drainback systems are allowed. Regulations concerning the use of antifreeze additives may change in the future. All solar DHW systems must be supplied with the following directions:

WARNING:
USE ONLY DRINKING WATER TO FILL THE SYSTEM.
NO chemicals or any other fluids may be added to the drinking water.
The filling hose must be disconnected after each filling procedure.
DEFERRING FROM THIS REGULATION CAN, WHEN A DEFECT OCCURS, CONTAMINATE THE DRINKING WATER AND CAUSE A HEALTH HAZARD.

B4.3. Utilization of Knowledge Developed in the Task

The results of the work in Task 14 has been implemented to produce a number of improvements in solar DHW systems.

B4.3.1. Absorber Based on the work of K.G.T. Hollands et al., a new absorber has been developed to meet both low-flow and high-flow conditions. A number of test units have been examined. The one determined to be best was a serpentine copper absorber with 8 mm tubing and 100 fins.

B4.3.2. Load Profiles/Tank Design A discussion on the effect of the load profile and the rationale for stratification in the tank led to a few modifications in the tank design. However, it is believed that both mantle and helix heat exchangers can perform equally well, provided they are designed properly. The work in the Task has greatly improved knowledge in this area.

B4.3.3. Pump/Control The pump defined in the dream system is modeled after the Canadian pump, which is not yet on the market. Some systems use other small pumps which were tested as part of the Task work. A control strategy has not been implemented yet. Due to the high costs, PV power is not yet cost effective under Dutch conditions.

B4.3.4. Flexible Piping Strong interest has created a demand for flexible piping. The present problems of low supply and high prices are expected to be overcome shortly.

B4.4. Cost/Performance Improvement as a Result of Task Work

The cost/performance ratio of solar DHW systems, as indicated in Chapter 8, has decreased approximately 20 percent as a result of the implementation of low-flow principles and use of special components. Another 15 percent price reduction is expected from larger production volumes. These price reductions are a necessary condition for further market penetration of solar DHW systems in the Netherlands.

B5. SWITZERLAND

B5.1. Introduction

The market for thermal solar energy systems in Switzerland is very small. In 1993 just 1,000 systems (hot water, space heating and industrial applications) were built.

The common difficulties are a poor economic situation, high and rapidly changing interest rates and very low energy prices.

B5.2. Country Information

The most commonly used energy sources are:

For domestic hot water	electricity, oil and natural gas
For space heating	oil, natural gas and electricity

The energy prices in US$ are as follows:

Oil	10 US $/GJ
Natural Gas	12 US$/GJ
Electricity, night-time	40 US$/GJ
Electricity, daytime	80 US $/GJ

The use of renewable energy is supported by some Canton governments and also by the federal government. The federal program called "Energy 2000," has a very broad program to reduce energy needs in general. The thermal solar energy program includes a subsidy for domestic hot water installations in multiple family houses with more than 5 apartments. The subsidy is 200 US$ per square meter of collector area. In the field of small domestic hot water systems the development of a new low-flow system called SOLKIT (Swiss Dream System see Section A5) was financed by this program.

The weather data used mostly are based on 3 typical meteorological regions:

Kloten	Low lands
Davos	Alps
Locarno	Southern

Table B5-1. Switzerland Weather Data.

Month	KLOTEN Total yearly horizontal radiation	KLOTEN Average ambient temperature	DAVOS Total yearly horizontal radiation	DAVOS Average ambient temperature	LOCARNO Total yearly horizontal radiation	LOCARNO Average ambient temperature
1	94	-1.3	169	-5.0	163	2.8
2	167	1	238	-4.2	215	4.5
3	301	4.3	410	-2.4	377	7.6
4	450	8.7	536	1.7	490	11.5
5	565	13.7	616	6.9	600	14.9
6	613	16.4	624	9.7	702	18.2
7	646	18.6	665	12	720	21.0
8	525	17.4	552	11.8	571	20.4
9	387	13.9	441	8.7	408	17.3
10	229	8.6	338	4.1	321	12.3
11	107	3.3	178	-1.0	166	6.7
12	77	-1.2	155	-5.2	161	3.5
Total	4162	8.6	4925	3.1	5004	11.7

Hot water consumption is indicated by a "SIA"-standard (SIA: Schweizerischer Ingenieur- und Architekten-Verein):

58 ℓ per person per day heated from 10 to 55°C, or approximately 2.5 kWh per person per day.

B6. UNITED STATES

B6.1. Introduction

The United States solar industry peaked in 1985, when over 200 collector manufacturers existed and thousands of systems were being installed each month. From 1985 to 1989, the industry declined to 12 manufacturers installing 3,500 solar domestic hot water systems per *year.*

Since the beginning of Task 14, the number of manufacturers has not increased. Approximately 12 companies are currently marketing solar systems, which are being installed at a rate of 4,500 per year.

B6.2. Country Information

United States weather data is provided in Table B6-1. Four locations were chosen to typify the range of weather types throughout the country.

Table B6-1. United States Weather Data.

Latitude	Sacramento, CA (38.5°)		Miami, FL (25.8°)		Phoenix, AZ (33.4°)		New York, NY (40.8°)	
	Radiation on the Horizontal, $MJ/m^2/day$	Daytime Ambient Temperature °C	Radiation on the Horizontal, $MJ/m^2/day$	Daytime Ambient Temperature °C	Radiation on the Horizontal, $MJ/m^2/day$	Daytime Ambient Temperature °C	Radiation on the Horizontal, $MJ/m^2/day$	Daytime Ambient Temperature °C
Jan	6.8	7	12.0	19	11.6	10	5.7	0
Feb	10.7	10	14.9	19	15.6	13	8.2	1
Mar	16.6	12	18.2	21	20.6	15	11.8	5
Apr	22.7	15	21.1	23	26.7	19	15.5	11
May	27.6	18	20.9	25	30.4	24	18.6	17
Jun	30.5	21	19.4	27	31.1	29	19.4	22
Jul	30.5	24	20.0	27	28.2	32	19.2	25
Aug	26.9	23	18.5	28	26.0	31	16.8	24
Sep	21.6	22	16.5	27	22.9	28	13.8	20
Oct	14.9	17	14.8	25	17.9	22	10.2	15
Nov	8.9	12	12.7	22	13.1	15	6.0	9
Dec	6.1	8	11.6	20	10.6	11	4.6	2
Ann	7497	16	6104	24	7755	21	4565	13

Hot water consumption in Sacramento is 255 ℓ/day. However, U.S. testing is based on three equal draws totaling 375 ℓ/day, drawn at 8:00 a.m., noon, and 5:00 p.m.

The U.S. government provides no subsidies or tax credits for solar DHW use, although some states do provide tax credits.

Most areas of the U.S. require some form of testing of solar equipment. This testing is either a collector test (ASHRAE 93), a system test (ASHRAE 95), or system-modeled performance by the Solar Rating and Certification Corporation (SRCC 0G-300). The two U.S. certification groups are SRCC and the Florida Solar Energy Center (FSEC).

State tax credits do not require any specific performance level. However, the Sacramento Municipal Utility District (SMUD) rebate in that California city is performance-based.

The typical DHW system in Sacramento consists of a four-square-meter collector and a 300 ℓ tank. The yearly solar fraction of this type of system is 65 percent and the cost is 2,950 US$. SMUD will rebate $800 to the purchaser, leaving a net cost to the purchaser of $2,150.

Sacramento systems are typically of closed-loop design employing either a mantle heat exchanger or a wrap-around heat exchanger on the storage tank. The U.S. requires a double-walled, vented heat exchanger, eliminating in-tank exchangers.

Most systems now installed are two-tank systems, since single-tank system elements only heat the top 130 liters of the tank, which doesn't supply sufficient hot water on cloudy days.

B6.3. Utilization of Knowledge Developed in the Task

The work of Task 14 has not yet been utilized by U.S. manufacturers. However, some manufacturers are considering Life-Line^{s} piping, some aspects of low-flow design, and pumping variations. These manufacturers are waiting for more long-term exposure to these techniques before they make a firm commitment such changes. Since the beginning of Task 14, the number of installations has increased. However, low-flow design has not produced any of this increase.

B6.4. Cost Performance Improvement

It is expected that the work being done on heat exchanger development, low-flow piping, and a new low-flow pump will increase performance and lower costs by 25 percent.

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