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.

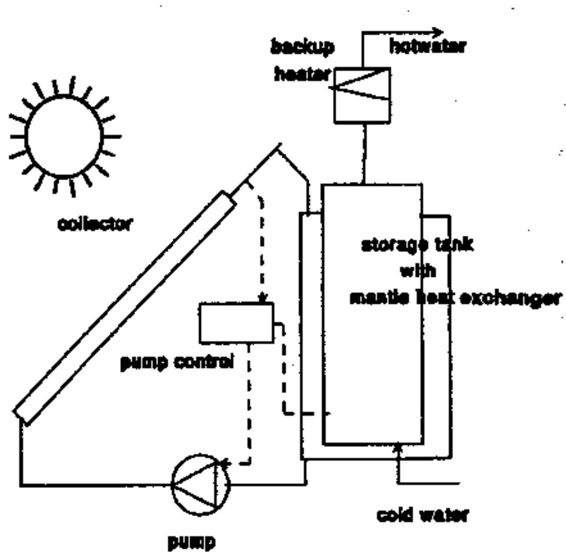

Figure A4-1. The Netherlands Base Case System Diagram.

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.

Sunstrip® absorber is mounted in a parallel configuration. The optical properties are α 0.84 and ε 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.

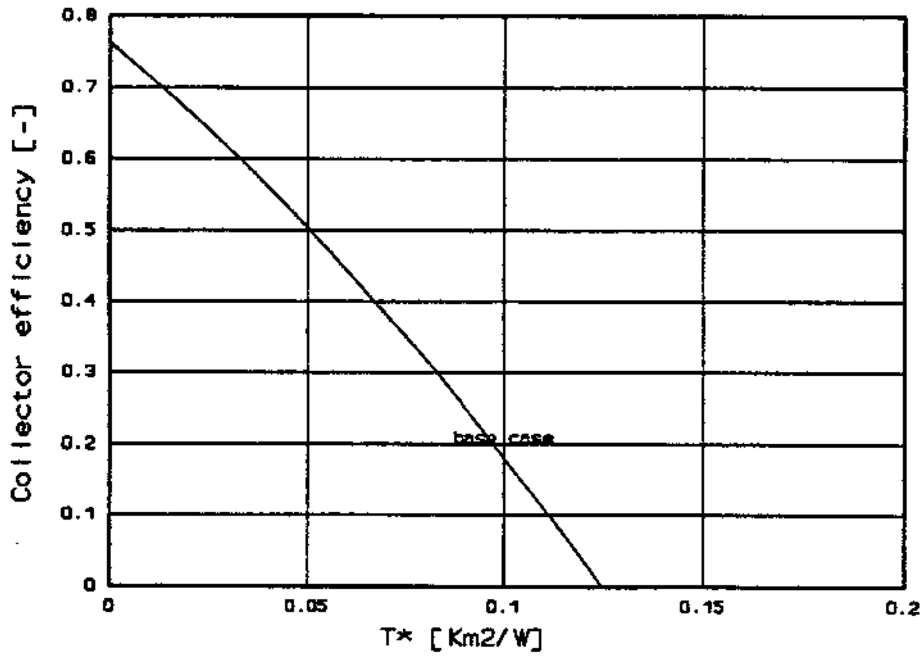

Figure A4-2. Base Case System Collector Efficiency Curve.

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. [illegible] 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.

A4.2.2.2. Collector cover material.
The collector cover consist of 3.2 mm low-iron, tempered glass, produced by AFG, USA.

A4.2.2.3. Absorber material. The
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.

A4.2.2.4. Absorber fin/flow design.
The distance between the tubes of the serpentine configuration is 100 mm. Each absorber consists of 4 equal absorber plates, which are interconnected.

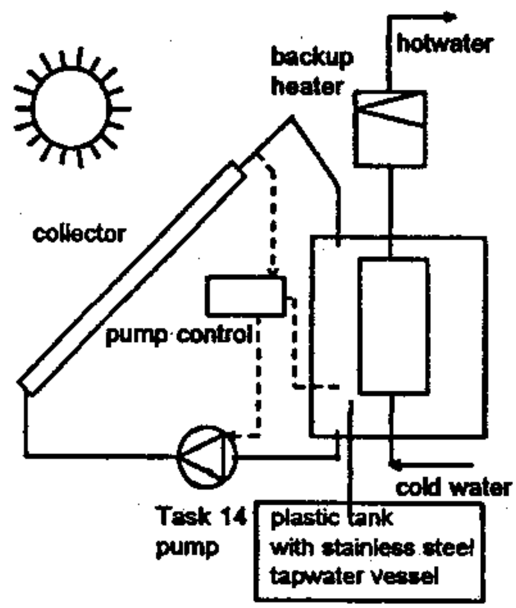

Figure A4-3. The Netherlands Dream System Diagram.

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.

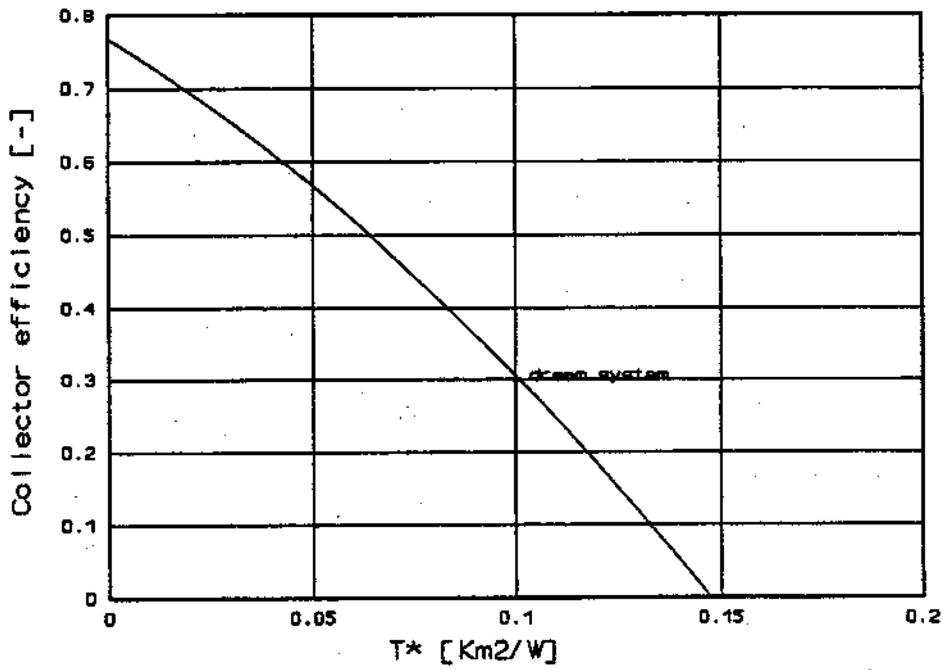

Figure A4-4. The Netherlands Dream System Collector Efficiency Curve.

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.

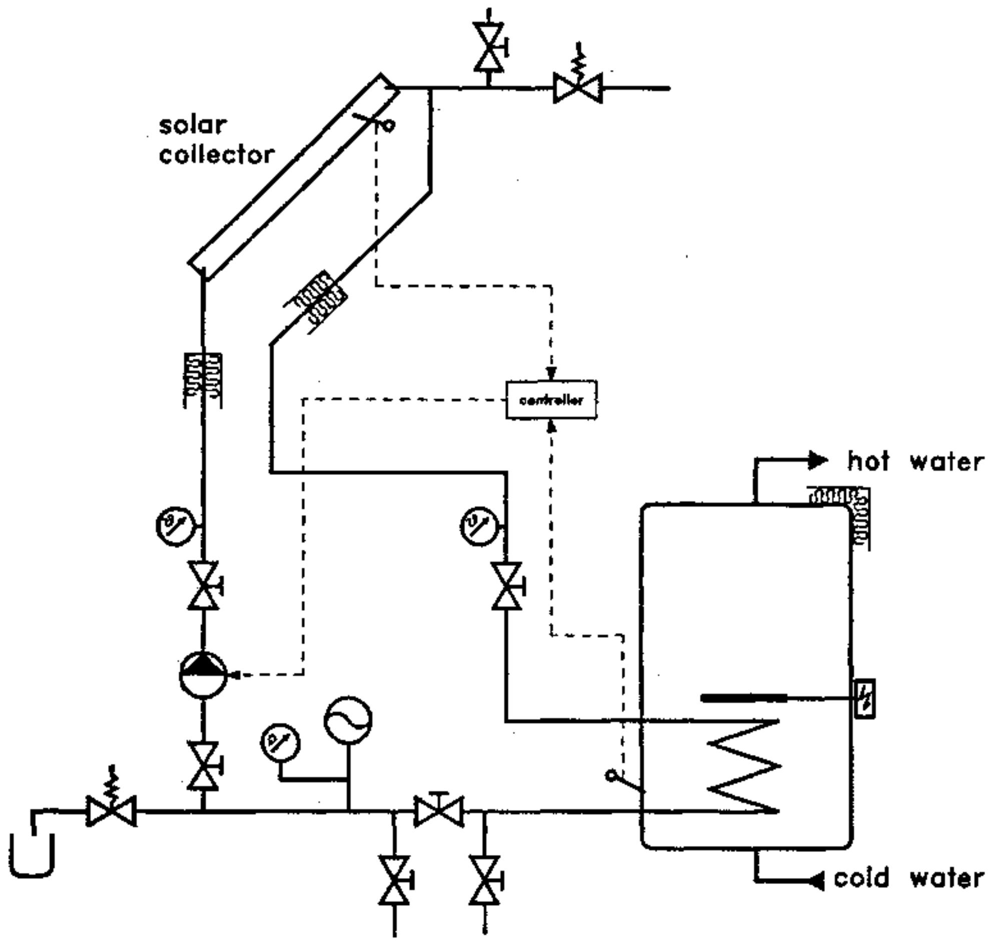

Figure A5-1. Common Domestic Hot Water System in Switzerland.

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 $\tau = 0.91$.

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.

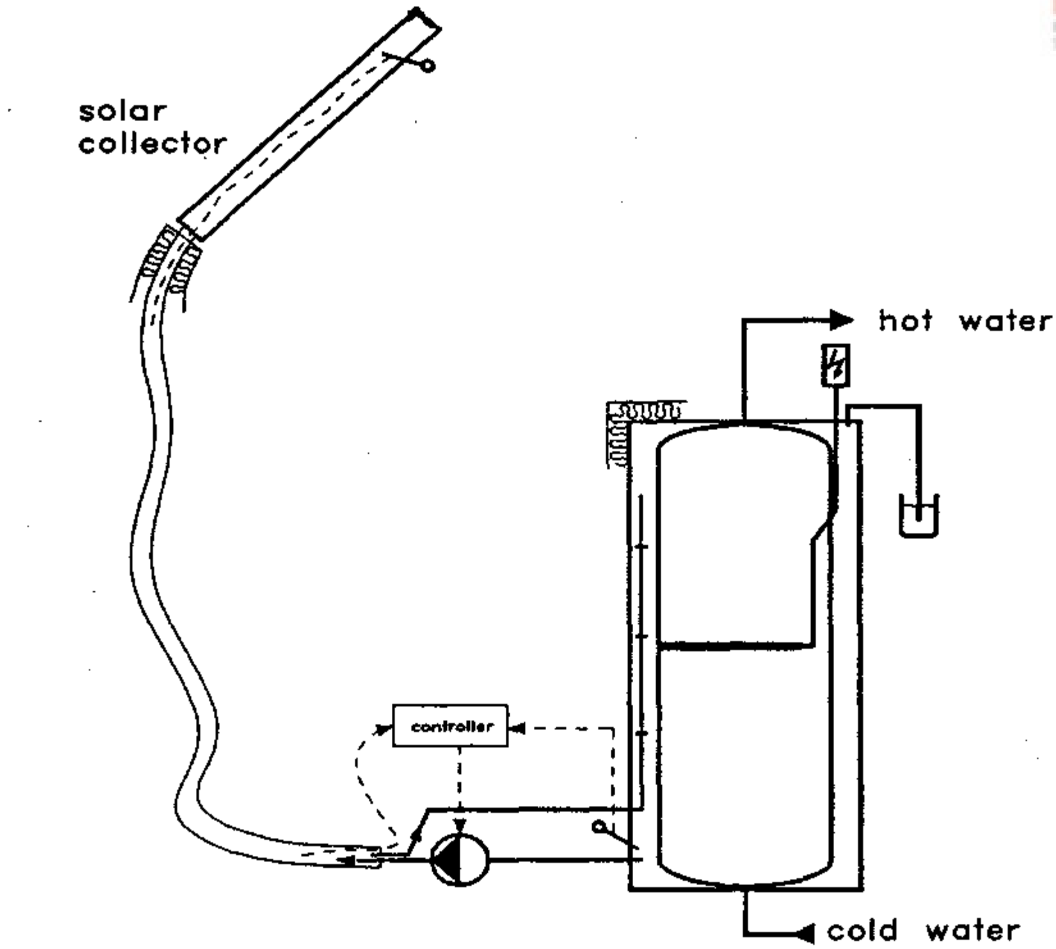

Figure A5-2. Swiss Dream System SOLKIT ®.

<u>A5.2.2. Collector</u>

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

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.

[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

A6.1.1. System Diagram and Description of Operating Modes 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.

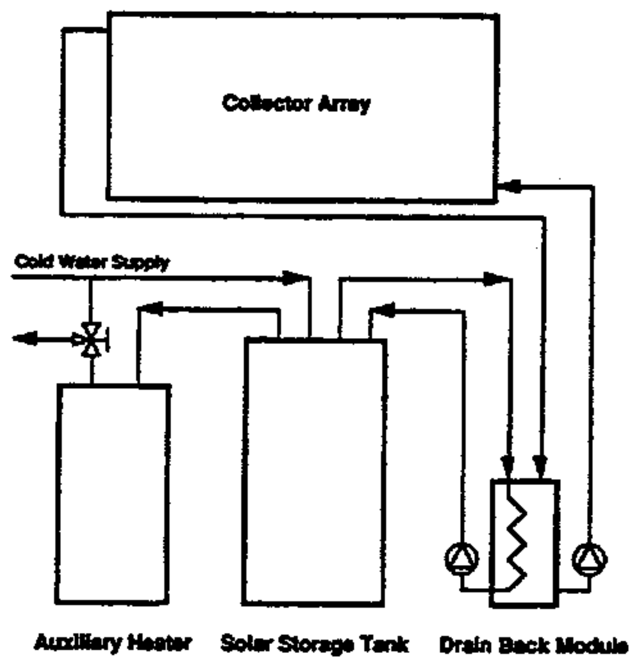

Figure A6-1. United States Base Case System for Freezing Climates.

A6.1.2. Collector

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.

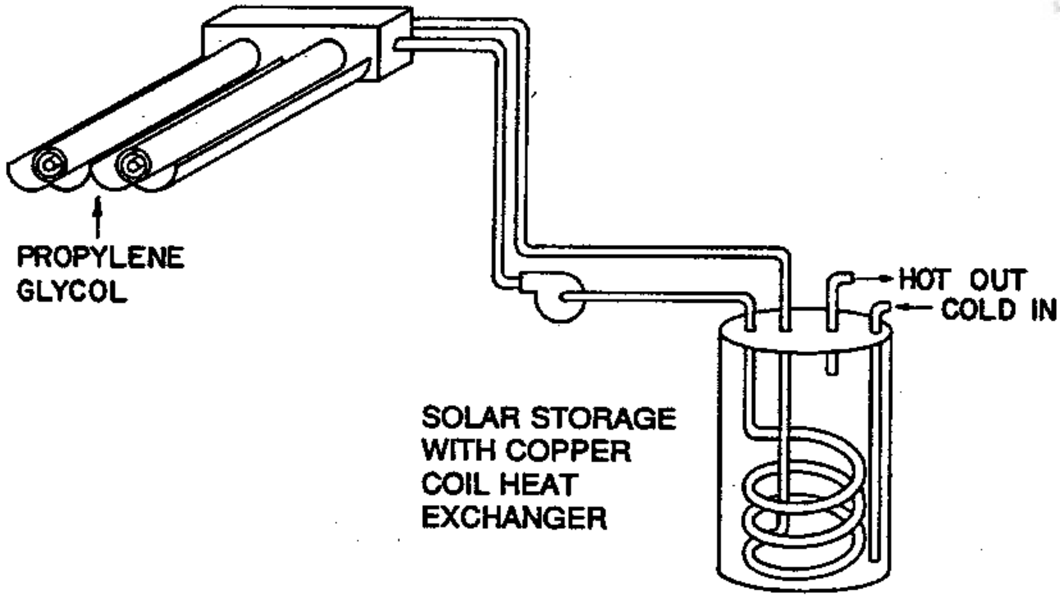

Figure A6-2. United States Dream System for Freezing Climates.

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	$0.0189\ m^3 \times 2$	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

A6.4.2. Typical Installation Costs $300

A6.4.3. Annual Operating and Maintenance Costs $10

A6.5. Performance of the Base Case System

A6.5.1. Thermal Performance The thermal performance of the system is 7.05 GJ per year.

Location or basis	Sacramento, California
Latitude	38.5°
Collector slope	28.5°

A6.5.2. Reliability and Durability According to experience thus far, the reliability and durability has been excellent.

A6.6. Costs of the Dream System (1993 US$)

A6.6.1. Component Costs

Collector	$650
Solar Storage	integral + $250
Pump/Controls	$125
Solar Energy System Piping/Fittings	$125
Fluids/Overheat and Over-pressure Prevention/Other	$50

A6.6.2. Typical Installation Costs $300

A6.6.3. Annual Operating and Maintenance Costs $10

A6.7. Performance of the Dream System

A6.7.1. Thermal Performance The thermal performance of the system is 8.51 GJ per year.

Location or basis	Sacramento, California
Latitude	38.5°
Collector slope	28.5°

A6.7.2. Reliability and Durability 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

INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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.

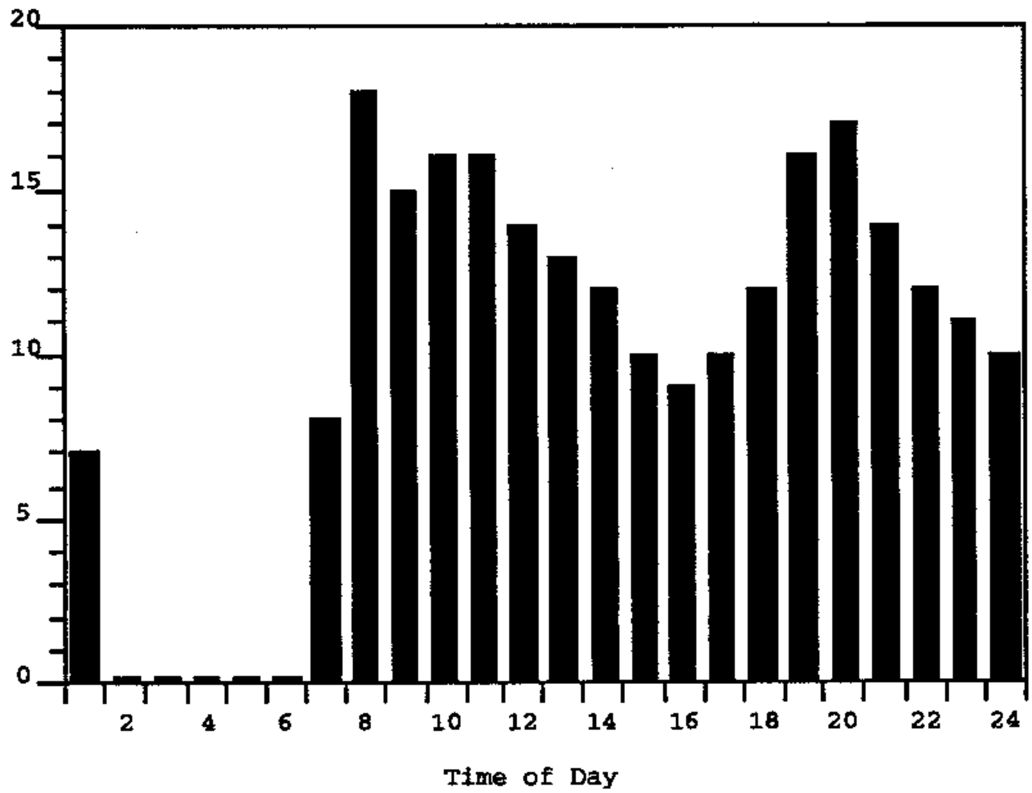

Figure B1-1. Hot Water Usage for a Typical Canadian Household (ℓ/hr).

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.

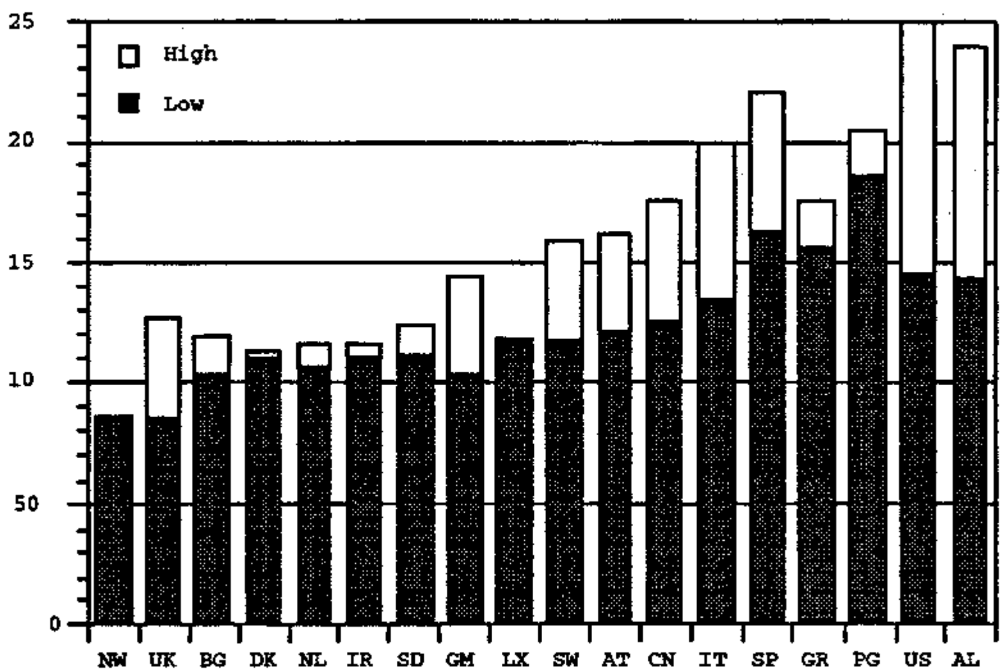

Figure B1-2. Average Daily Radiation on Surface at Tilt = Latitude for Various lEA Member Countries (MJ/m2-day).

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.

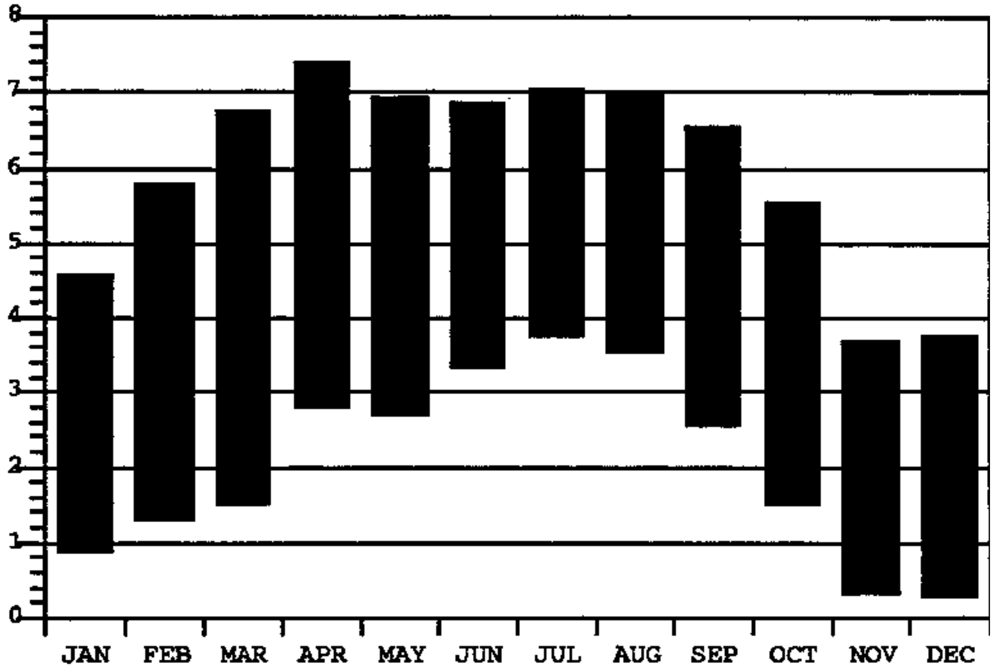

Figure B1-4: Solar Resource for Toronto at Tilt = Latitude (kWh/m2/day).

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/m²-d	Temp °C	Hor Rad MJ/m²-d	Temp °C	Hor Rad MJ/m²-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.

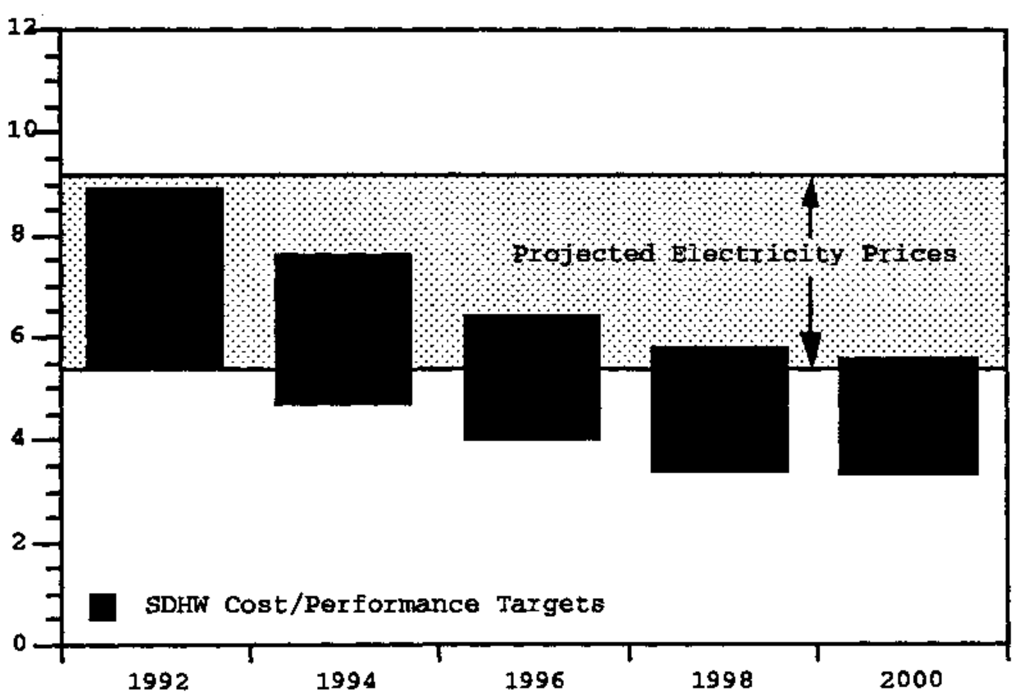

Figure B1-5: Projected Electricity and SDHW Costs (¢/kWh).

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.

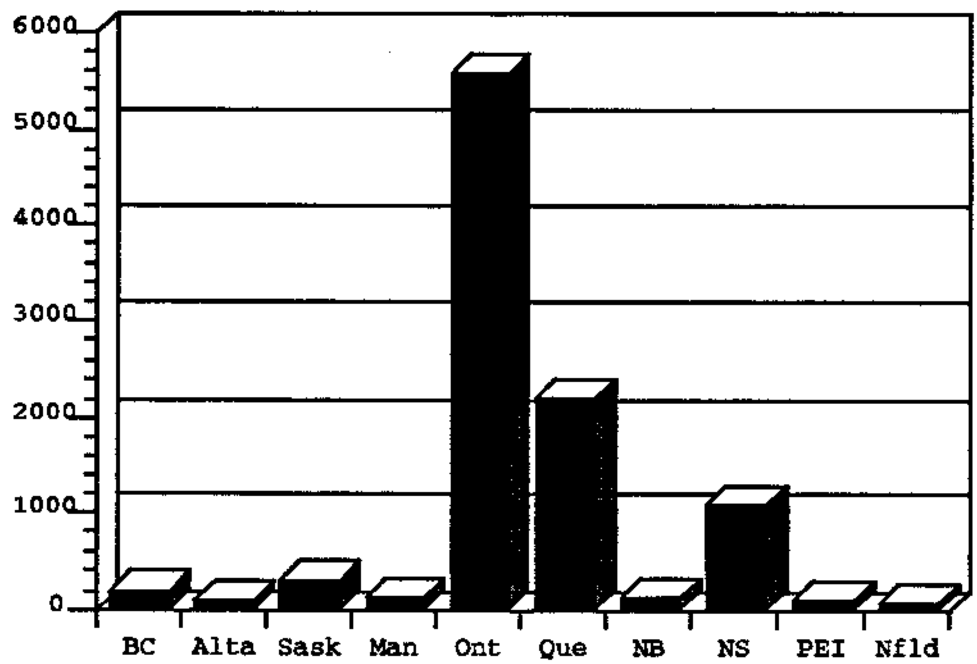

Figure B1-6. Projected SDHW Installations in Canada by Province in Year 2000.

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^2

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.

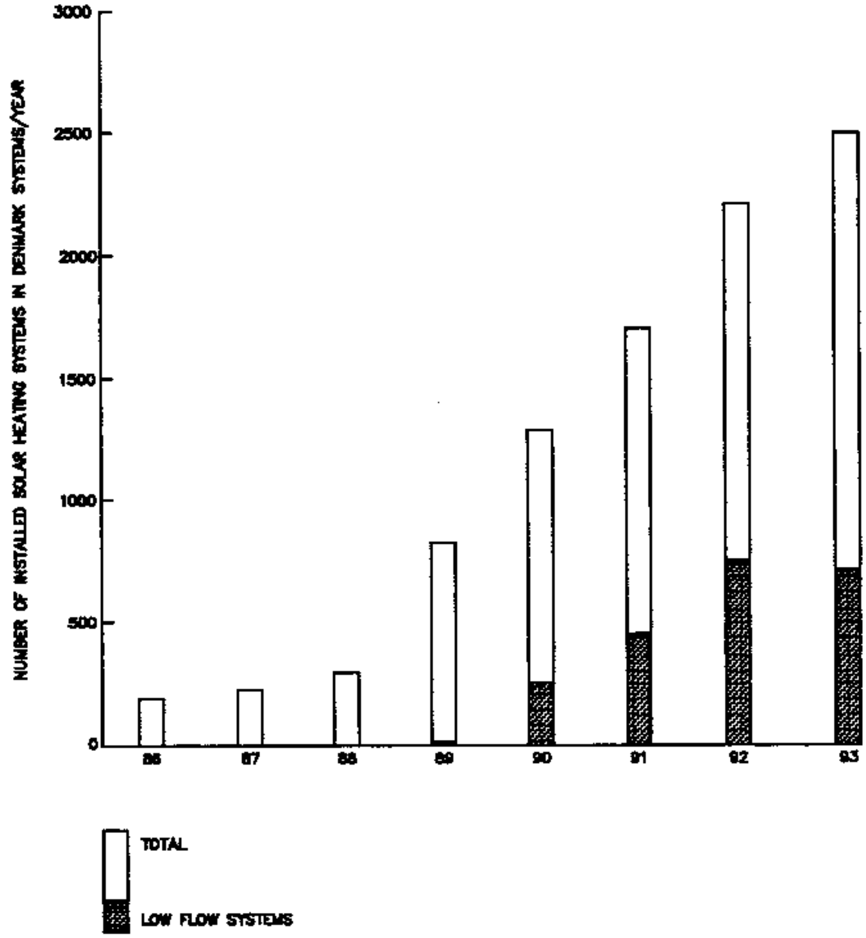

Figure B2-1. Number of Installed Solar Heating Systems in Denmark.

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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²
	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/m²a
	T_{av}	8.5	8.7	8.7	8.6	7.4	8.9	°C

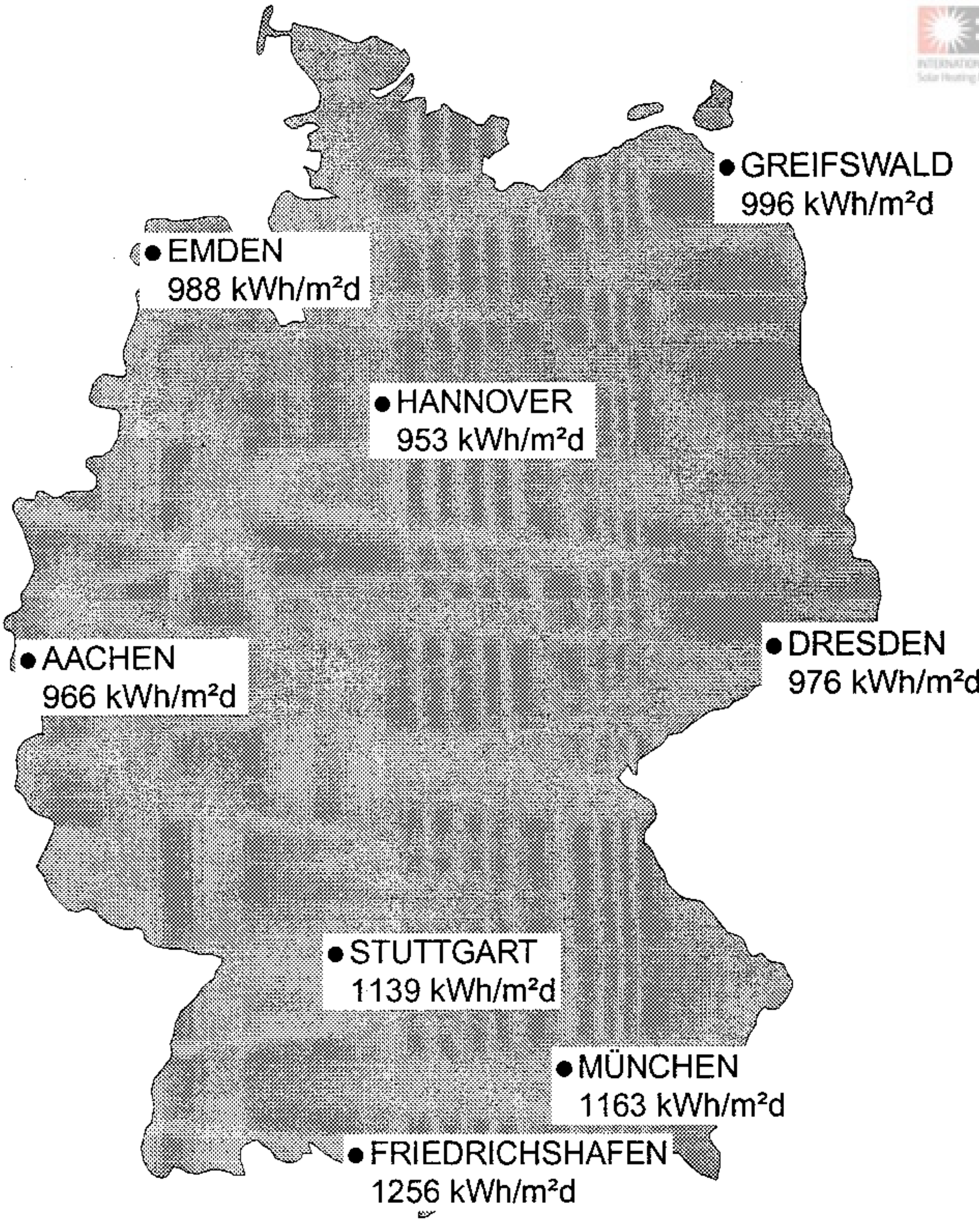

Figure B3-1. Climatic Map for Germany.

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/m²/day	Daytime Ambient Temperature °C	Radiation on the Horizontal, MJ/m²/day	Daytime Ambient Temperature °C	Radiation on the Horizontal, MJ/m²/day	Daytime Ambient Temperature °C	Radiation on the Horizontal, MJ/m²/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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