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.

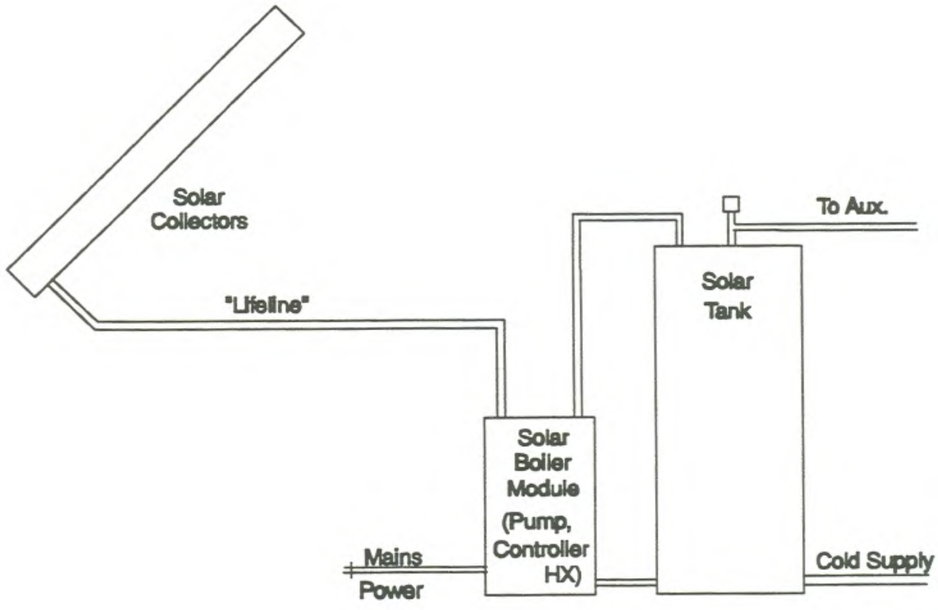

Figure 10-1. Canadian Base Case System Diagram.

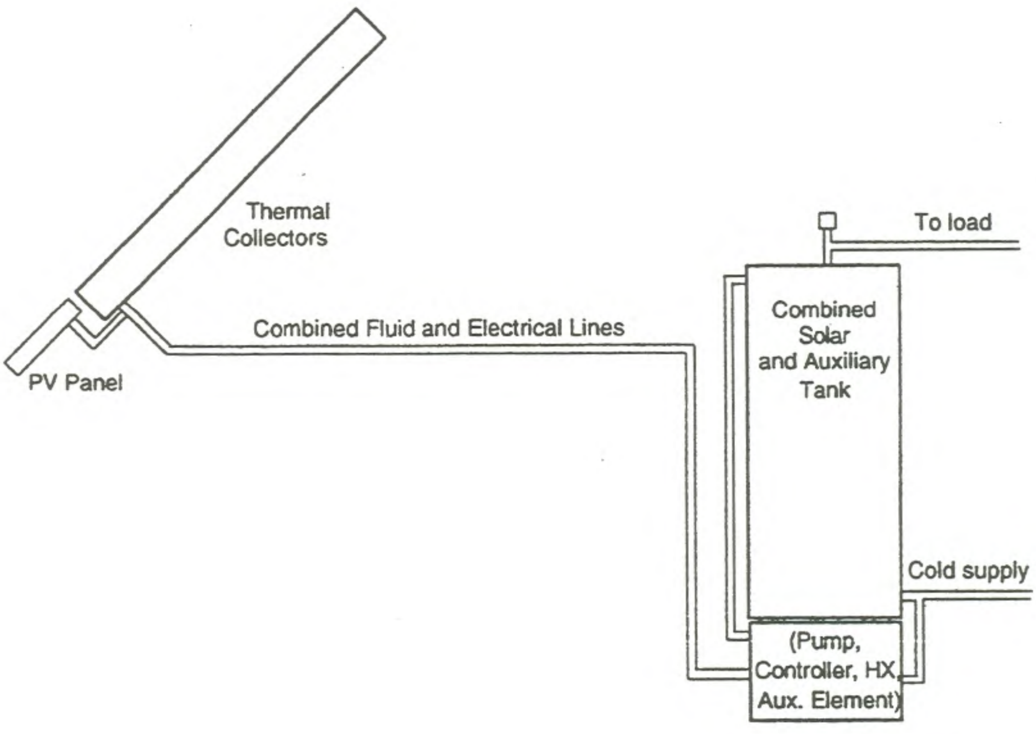

Figure 10-2. Canadian Dream System Diagram.

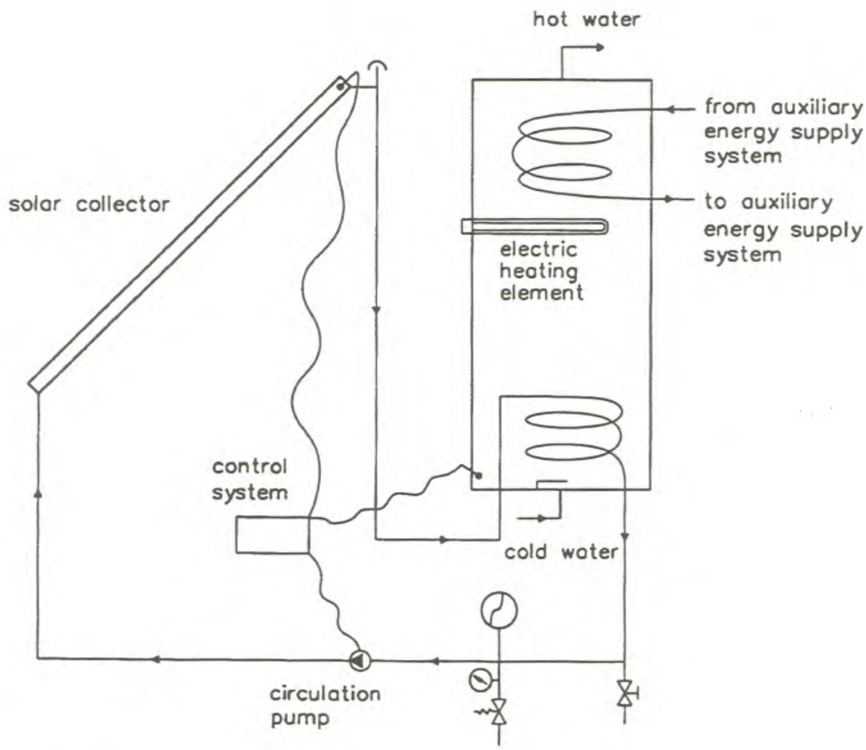

Figure 10-3. Danish Base Case System Diagram.

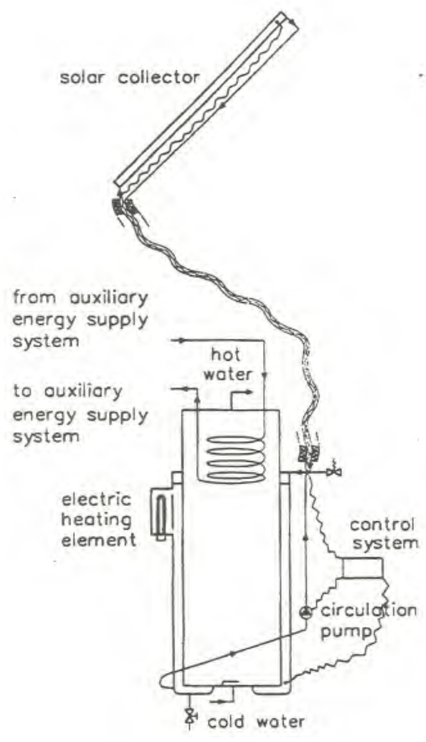

Figure 10-4. Danish Dream System Diagram.

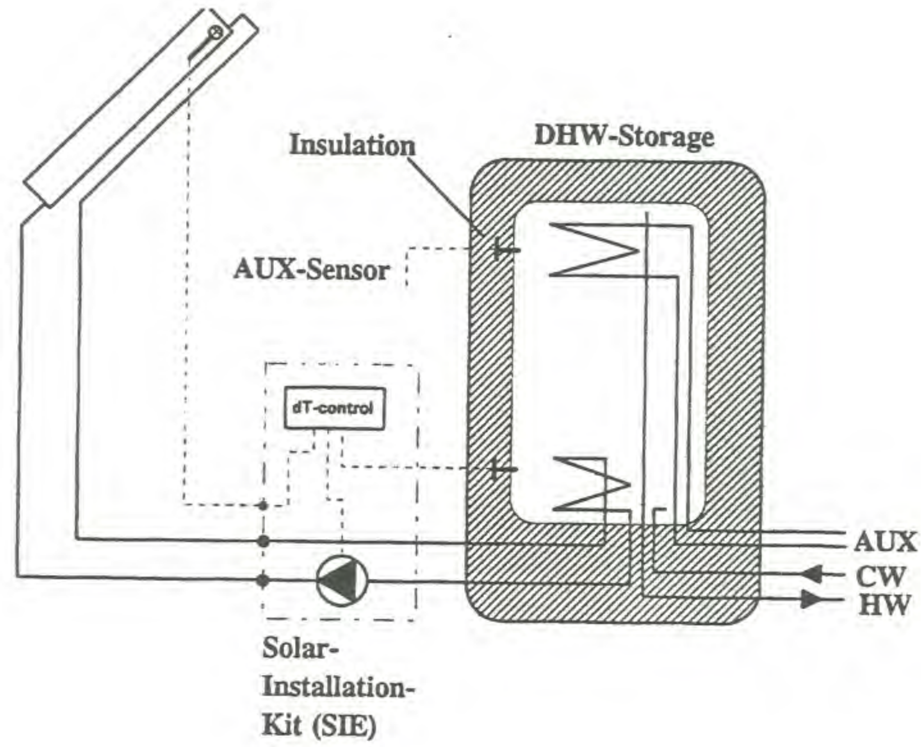

Figure 10-5. German Base Case System Diagram.

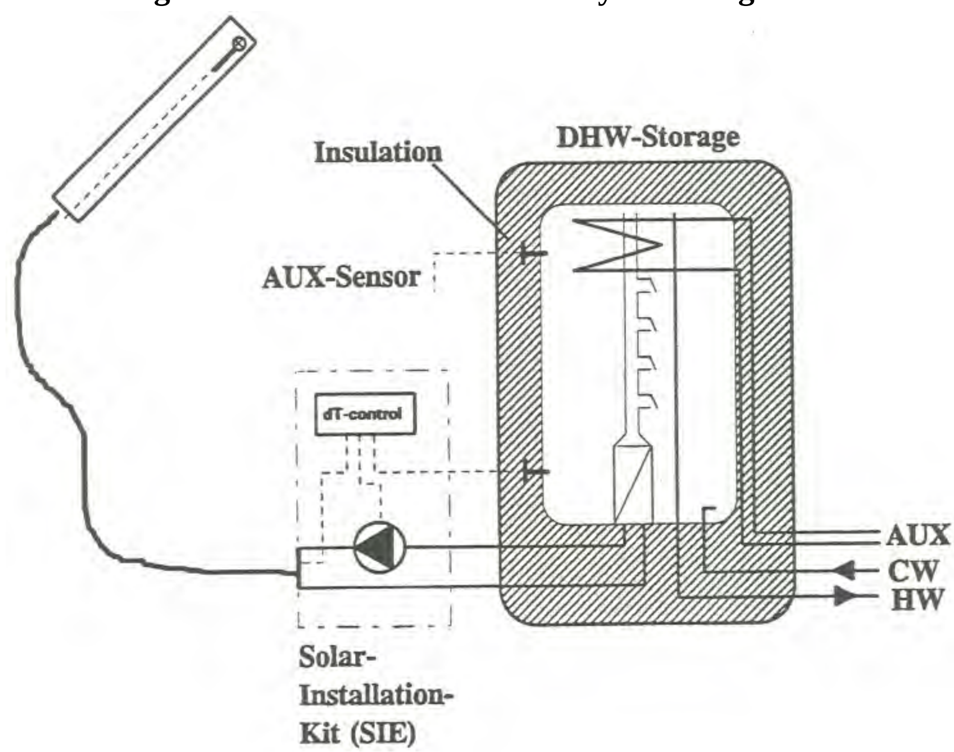

Figure 10-6. German Dream System Diagram.

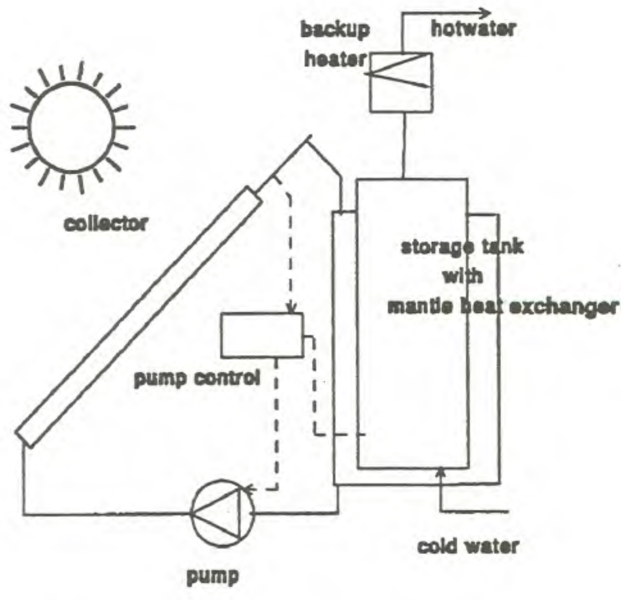

Figure 10-7. The Netherlands Base Case System Diagram.

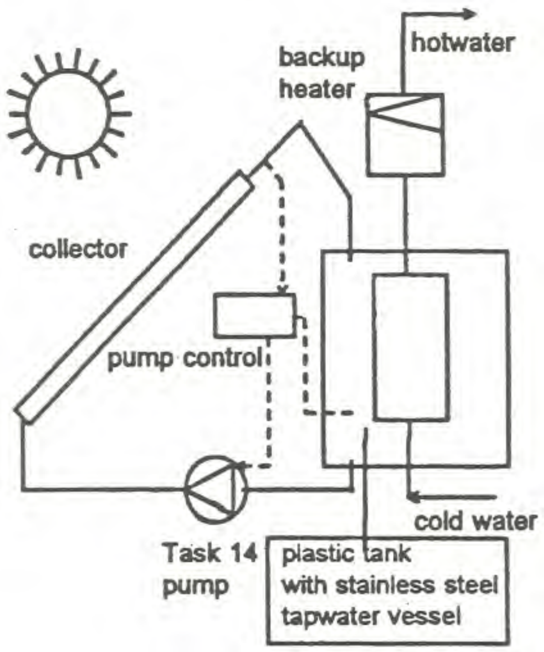

Figure 10-8. The Netherlands Dream System Diagram.

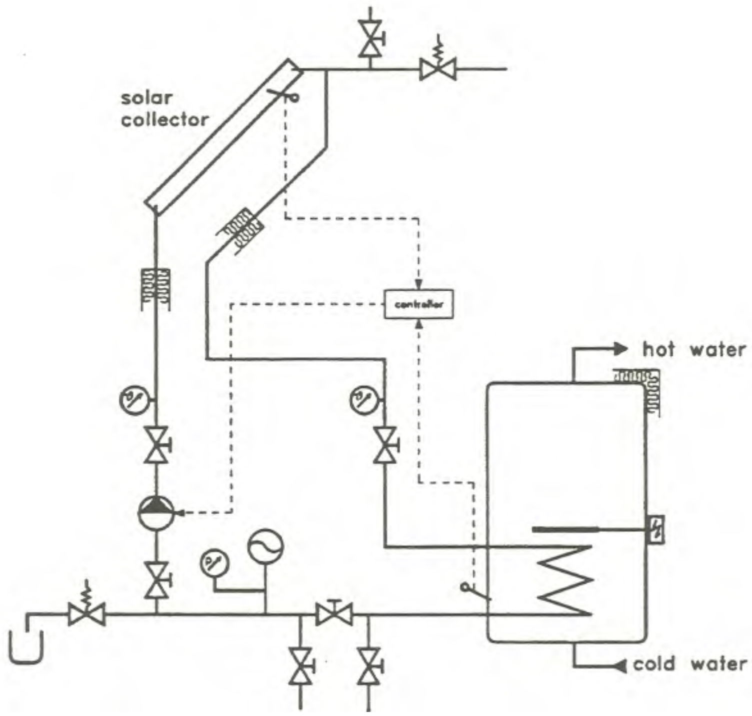

Figure 10-9. Common Domestic Hot Water System in Switzerland.

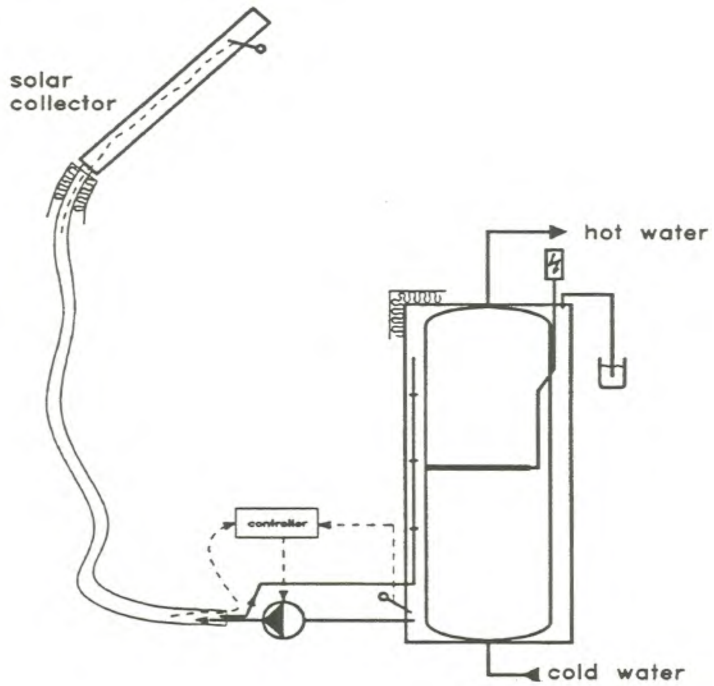

Figure 10-10. Swiss Dream System SOLKIT®.

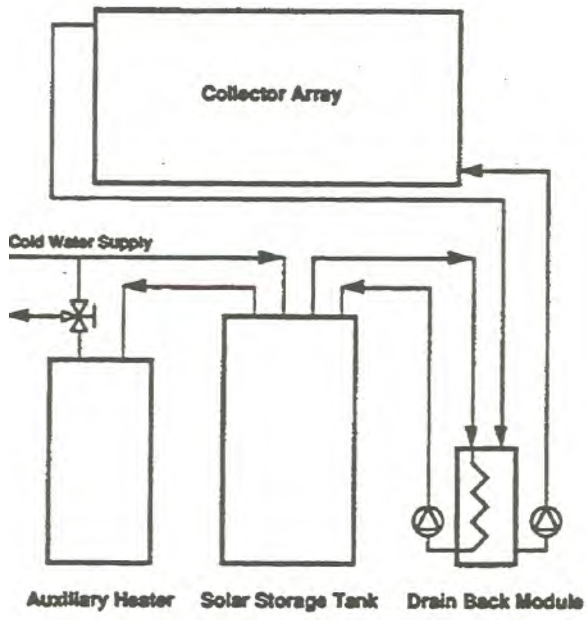

Figure 10-11. United States Base Case System for Freezing Climates.

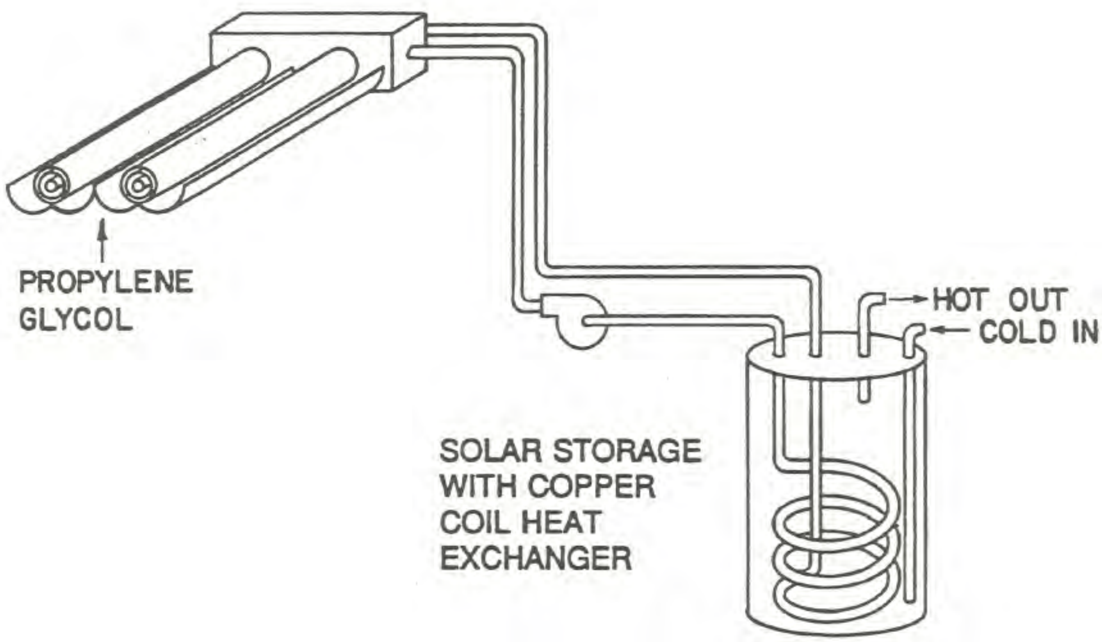

Figure 10-12. United States Dream System for Freezing Climates.

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 dimensions	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 m^2 (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.

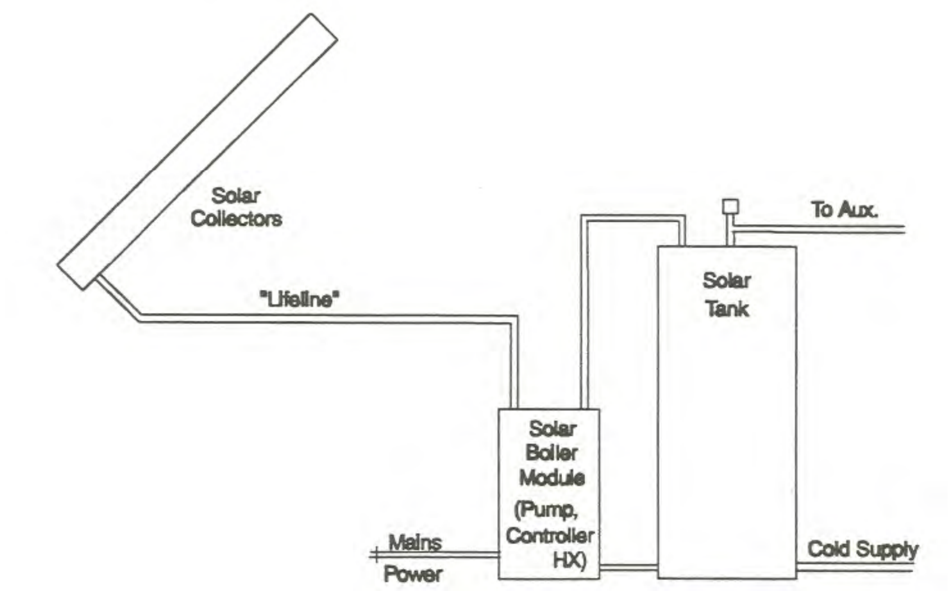

Figure A1-1. Canadian Base Case System Diagram.

<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.

A1.1.2.3. Configuration, dimensions, and specifications.

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.

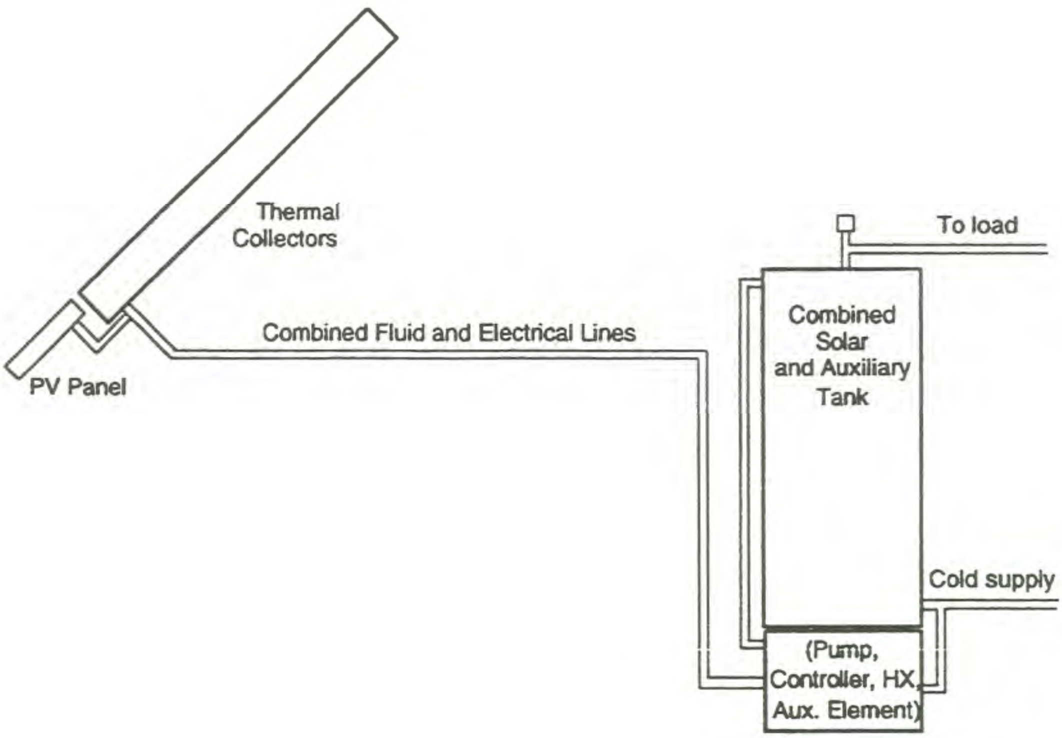

Figure A1-2. Canadian Dream System Diagram.

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. [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
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 m^2 @ \$100/m^2)		\$530
Solar Storage(s)		\$175
Overheat and Overpressure Prevention	- (with tank)	
Auxiliary Storage	- Part of solar tank.	
Auxiliary (integral with HX assembly)	- \$ 20	
Module housing/frame	- \$ 50	
Fluids Other Than Water	- \$ 15	
Heat exchanger(s)	- \$ 70	\$305
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 m^2

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.

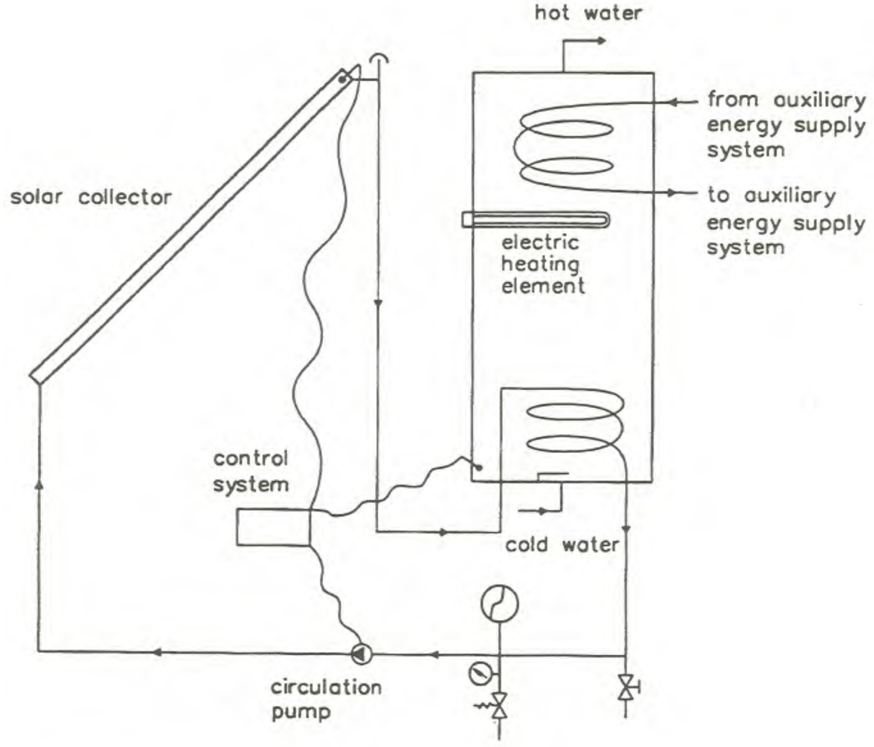

Figure A2-1. Danish Base Case System Diagram.

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.

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.

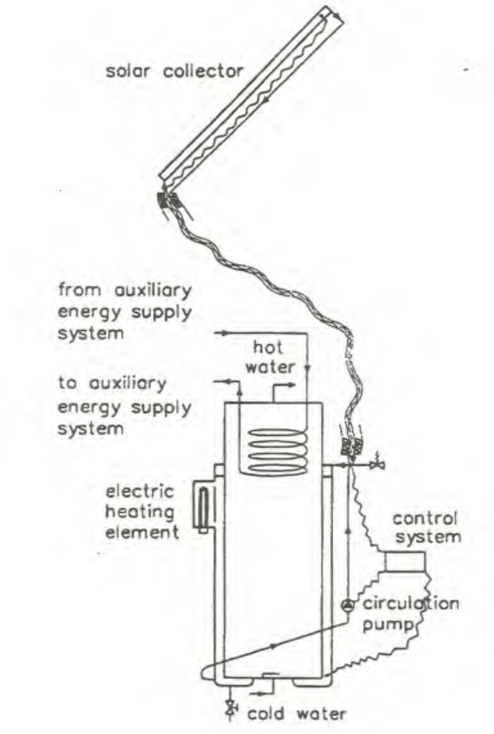

Figure A2-2. Danish Dream System Diagram.

A2.2.2. Collector

A2.2.2.1. Collector geometry.

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 fin/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.

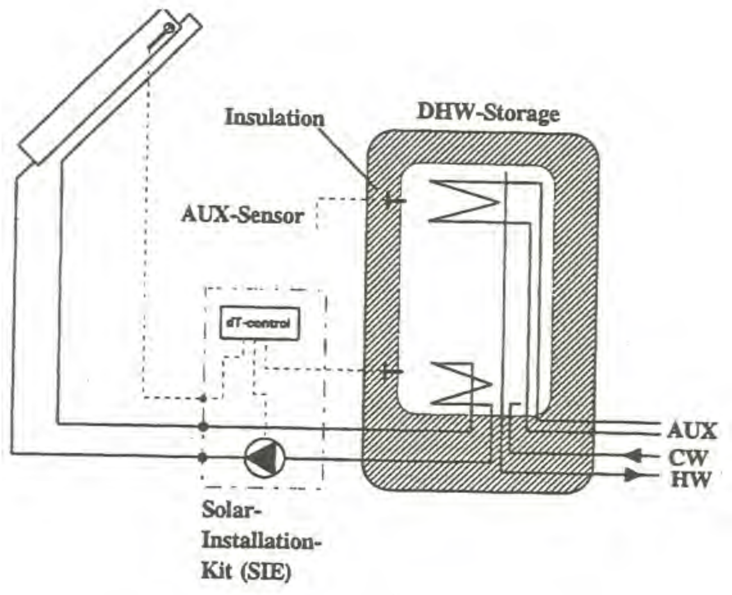

Figure A3-1. German Base Case System Diagram.

- 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.

<u>A3.1.3. Piping</u> 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)

<u>A3.1.8. Controls</u>

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

<u>A3.1.9. Rationale for Choice of Base Case</u> 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

<u>A3.2.1. Scheme and Operation Mode</u> 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.

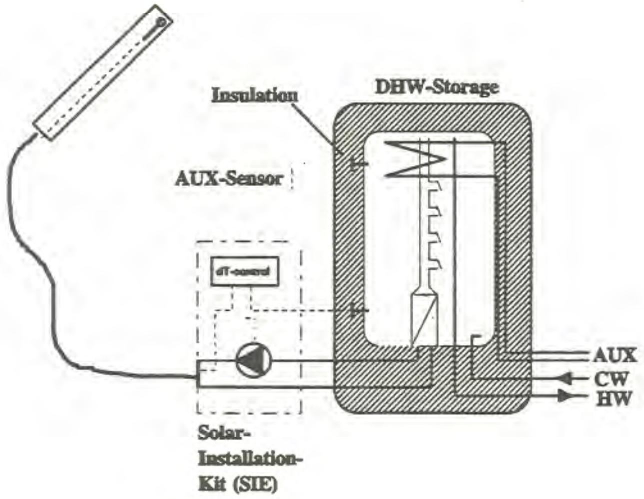

Figure A3-2. German Dream System Diagram.

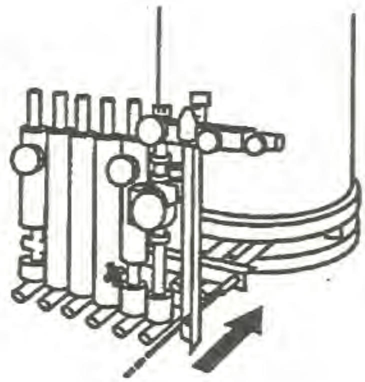

Figure A3-3. Storage-Installation-Kit and Bracket.

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, $\alpha = 0.95$, $\varepsilon = 0.08$
  * 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.

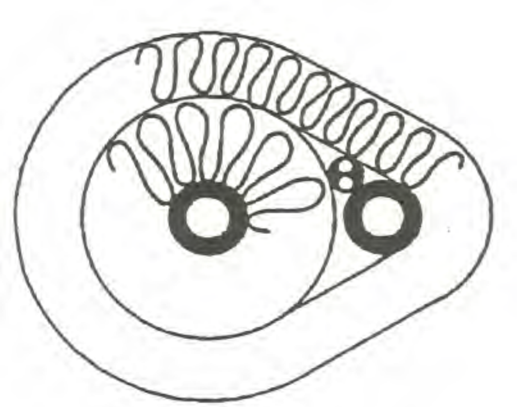

Figure A3-5. Flextube® System.

- 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}, A_{ux}	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, Uel Frey of Switzerland, and Klaus Lorenz of Sweden, in order to meet these specifications.

<u>A3.2.7. Load</u>

• 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)

<u>A3.2.8. Controls</u>

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^{2}d	kWh/m^{2}d	MJ/m^{2}d	kWh/m^{2}d	MJ/m^{2}d	kWh/m^{2}d	%
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**	**1057.9**	**1292.4**	**359.0**	**1091.9**	**303.3**	**50.76**
	MJ/m^{2}yr	kWh/m^{2}yr	MJ/m^{2}yr	kWh/m^{2}yr	MJ/m^{2}yr	kWh/m^{2}yr	%

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

	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		Q102		Q332		SF
	MJ/m²d	kWh/m²d	MJ/m²d	kWh/m²d	MJ/m²d	kWh/m²d	%
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 %