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

<table>
<thead>
<tr>
<th>Subject</th>
<th>Canada</th>
<th>Denmark</th>
<th>Germany</th>
<th>Spain</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-sponsors</td>
<td>EMR</td>
<td>Danish ISES Section</td>
<td>none</td>
<td>Junta del Andalucía</td>
<td>none</td>
</tr>
<tr>
<td>Description</td>
<td>Review of recent advancements and benefits to utilities</td>
<td>active solar heating systems market situation in various countries</td>
<td>active solar heating market, actual situation and trends in IEA countries</td>
<td>State renewable energy policy and market situation</td>
<td>Review of recent developments</td>
</tr>
</tbody>
</table>

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>
<thead>
<tr>
<th>Subject</th>
<th>Canada</th>
<th>Denmark</th>
<th>Germany</th>
<th>Netherlands</th>
<th>Switzerland</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collector</strong></td>
<td>flat plate</td>
<td>flat plate</td>
<td>flat plate</td>
<td>flat plate</td>
<td>flat plate</td>
<td>flat plate</td>
</tr>
<tr>
<td>Geometry</td>
<td>single</td>
<td>single</td>
<td>single</td>
<td>single</td>
<td>single</td>
<td>single</td>
</tr>
<tr>
<td>Covers</td>
<td>low iron glass</td>
<td>low iron glass</td>
<td>low iron glass</td>
<td>low iron glass</td>
<td>low iron glass</td>
<td>low iron glass</td>
</tr>
<tr>
<td><strong>Selective surface</strong></td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td><strong>Absorber material</strong></td>
<td>black nickel</td>
<td>black nickel</td>
<td>black chrome</td>
<td>black chrome</td>
<td>black nickel</td>
<td>black chrome</td>
</tr>
<tr>
<td><strong>Tube OD/fin width</strong></td>
<td>8/143 mm Sunstrip®</td>
<td>8/143 mm Sunstrip®</td>
<td>8/125 mm Sunstrip®</td>
<td>8/125 mm Sunstrip®</td>
<td>8/125 mm Sunstrip®</td>
<td>8/125 mm Sunstrip®</td>
</tr>
<tr>
<td><strong>Flow design</strong></td>
<td>serpentine</td>
<td>parallel</td>
<td>parallel</td>
<td>parallel</td>
<td>parallel</td>
<td>parallel</td>
</tr>
<tr>
<td><strong>Coolant</strong></td>
<td>glycol</td>
<td>glycol</td>
<td>glycol</td>
<td>glycol</td>
<td>glycol</td>
<td>glycol</td>
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<tr>
<td><strong>Heat exchanger</strong></td>
<td>aluminum</td>
<td>aluminum</td>
<td>aluminum</td>
<td>aluminum</td>
<td>aluminum</td>
<td>aluminum</td>
</tr>
<tr>
<td><strong>Efficiency curve nL/nLf</strong></td>
<td>0.645/0.95/0.0070</td>
<td>0.645/0.95/0.0070</td>
<td>0.645/0.95/0.0070</td>
<td>0.645/0.95/0.0070</td>
<td>0.645/0.95/0.0070</td>
<td>0.645/0.95/0.0070</td>
</tr>
<tr>
<td><strong>Heat capacity</strong></td>
<td>-5 KJ/K.m²</td>
<td>-5 KJ/K.m²</td>
<td>41 KJ/K.m²</td>
<td>41 KJ/K.m²</td>
<td>41 KJ/K.m²</td>
<td>41 KJ/K.m²</td>
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<td>pumps stops &gt; 95°C</td>
<td>pumps stops &gt; 95°C</td>
<td>pumps stops &gt; 95°C</td>
<td>pumps stops &gt; 95°C</td>
<td>pumps stops &gt; 95°C</td>
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<tr>
<td><strong>Piping</strong></td>
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<td>copper</td>
<td>copper</td>
<td>copper</td>
<td>copper</td>
<td>copper</td>
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<tr>
<td>Insulation material</td>
<td>none; PVC jacket</td>
<td>PUR foam 10 mm/13/15 mm/5 m</td>
<td>closed cell foam</td>
<td>closed cell foam</td>
<td>closed cell foam</td>
<td>closed cell foam</td>
</tr>
<tr>
<td>ID/OD/length one way</td>
<td>4.8/6.4 mm/15 m</td>
<td>16/18 mm/20 m</td>
<td>13/15 mm/20 m</td>
<td>13/15 mm/20 m</td>
<td>13/15 mm/10 m</td>
<td>16/18 mm/7.6 m</td>
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<td><strong>Solar storage &amp; HX</strong></td>
<td>0.6/1.5 m</td>
<td>0.50 m/1.60 m</td>
<td>0.620/1.47 m</td>
<td>0.610/0.96 m</td>
<td>0.610/1.40 m</td>
<td>0.590/1.40 m</td>
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<td>Diameter/height</td>
<td>273 t</td>
<td>295 t</td>
<td>400 t</td>
<td>500 t</td>
<td>389 t</td>
<td>389 t</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>glass-lined steel</td>
<td>St 37-2 steel</td>
<td>enameled steel</td>
<td>stainless steel</td>
<td>glass-lined steel</td>
<td>glass-lined steel</td>
</tr>
<tr>
<td><strong>Material</strong></td>
<td>side arm</td>
<td>bottom helix</td>
<td>bottom finned tube</td>
<td>bottom helix</td>
<td>bottom helix</td>
<td>bottom helix</td>
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<tr>
<td><strong>Heat exchanger</strong></td>
<td>150-380 W/K</td>
<td>180 W/K</td>
<td>300 W/K</td>
<td>300 W/K</td>
<td>200 W/K</td>
<td>200 W/K</td>
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<td>50 mm fiberglass</td>
<td>50 mm PUR foam</td>
<td>100 mm PUR foam</td>
<td>80 mm PUR foam</td>
<td>100 mm PUR</td>
<td>51 mm fiberglass</td>
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<td>Subject</td>
<td>Canada</td>
<td>Denmark</td>
<td>Germany</td>
<td>Netherlands</td>
<td>Switzerland</td>
<td>United States</td>
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<tr>
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<td>--------------------------</td>
<td>---------------------------</td>
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<tr>
<td>Auxiliary</td>
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<td></td>
<td></td>
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<tr>
<td>Tank dimensions</td>
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<td>none</td>
<td>none</td>
<td>0.50/1.40 m</td>
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<td>Volume</td>
<td>273 (182) ℓ</td>
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<td></td>
<td></td>
<td>189 ℓ</td>
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<tr>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Insulation</td>
<td>50 mm fiberglass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51 mm fiberglass</td>
</tr>
<tr>
<td>Power</td>
<td>2 x 4.5 kW U-tubes</td>
<td>~300 W/K/1000W</td>
<td>500 W/K</td>
<td>20-30 kW</td>
<td>3 kW</td>
<td>2 x 4.5 kW U-tubes</td>
</tr>
<tr>
<td>Location</td>
<td>20 cm from bottom</td>
<td>HX spiral top heating element top</td>
<td>HX spiral top finned tube</td>
<td>adjacent separate</td>
<td>middle</td>
<td>35 cm from top</td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow rates</td>
<td>0.4 to 1.3 ℓ/min</td>
<td>4 ℓ/min</td>
<td>4 ℓ/min</td>
<td>4 ℓ/min</td>
<td>~6 ℓ/min</td>
<td>6 ℓ/min/4 ℓ/min</td>
</tr>
<tr>
<td>Power</td>
<td>120 W</td>
<td>30 W</td>
<td>55 W</td>
<td>30 W</td>
<td>60 W</td>
<td>30 W/60 W</td>
</tr>
<tr>
<td>Load</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>300 ℓ/day at 50°C</td>
<td>200 ℓ/day at 45°C</td>
<td>250 ℓ/day at 45°C</td>
<td>110 ℓ/day at 65°C</td>
<td>220 ℓ/day at 50°C</td>
<td>265 ℓ/day at 55°C</td>
</tr>
<tr>
<td>Cold water inlet</td>
<td>10°C</td>
<td>10°C</td>
<td>11°C (5 - 17°C)</td>
<td>15°C</td>
<td>10°C</td>
<td>17°C</td>
</tr>
<tr>
<td>Draw profile</td>
<td>4 equal draws at 8, 12, 16, and 19:00</td>
<td>4 equal draws at 8, 12, 18, and 20:00</td>
<td>f-chart profile</td>
<td>5 equal draws at 7, 8, 13, 18, and 19:00</td>
<td>3 equal draws at 8, 13, 17:30</td>
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<tr>
<td>Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>differential</td>
<td>differential</td>
<td>differential</td>
<td>differential</td>
<td>differential</td>
<td>differential</td>
</tr>
<tr>
<td>On/off ∆T</td>
<td>10/2 K</td>
<td>10/2 K</td>
<td>5/2 K</td>
<td>10/2 K</td>
<td>8/4 K</td>
<td>2.8/0 K</td>
</tr>
</tbody>
</table>
Table 10-2. Dream System Description.

<table>
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<tr>
<th>Subject</th>
<th>Canada</th>
<th>Denmark</th>
<th>Germany</th>
<th>Netherlands</th>
<th>Switzerland</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Justification for choice</td>
<td>Lower power pump, more efficient glazing and absorber, more uniform sidearm flow, lower cost PV panel and pump are used.</td>
<td>Low flow and drainback reduce costs and increase performance.</td>
<td>Low-flow, high-performance collector, advanced storage design, and Life-Line® piping are used.</td>
<td>Low flow as well as other improvements are used to reduce costs and improve performance.</td>
<td>Components are system-optimized and system is designed for ease of installation.</td>
<td>Modifications are made to improve performance and lower the cost of a system that already has high performance.</td>
</tr>
<tr>
<td>Collector geometry</td>
<td>flat plate double</td>
<td>flat plate single</td>
<td>flat plate single</td>
<td>flat plate single</td>
<td>flat plate single</td>
<td>flat plate single</td>
</tr>
<tr>
<td>Collector covers</td>
<td>low-iron glass/PTFE</td>
<td>low-iron glass</td>
<td>low-iron glass</td>
<td>low-iron glass</td>
<td>low-iron glass</td>
<td>low-iron glass</td>
</tr>
<tr>
<td>Collector Transmittance α/C</td>
<td>0.88</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Collector Absorber material</td>
<td>Cu alloy</td>
<td>Cu alloy</td>
<td>Cu alloy</td>
<td>Cu</td>
<td>Cu</td>
<td>stainless steel</td>
</tr>
<tr>
<td>Collector Selective surface</td>
<td>sputtered carbide</td>
<td>sputtered carbide</td>
<td>sputtered material</td>
<td>black chrome</td>
<td>black chrome</td>
<td>chemical treatment</td>
</tr>
<tr>
<td>Collector m/C</td>
<td>0.95/0.05</td>
<td>0.95/0.05</td>
<td>0.95/0.05</td>
<td>0.95/0.08</td>
<td>0.95/0.08</td>
<td>0.95/0.11</td>
</tr>
<tr>
<td>Collector Tube OD/fins width</td>
<td>8/125 mm Sunstrip® parallel</td>
<td>10/143 mm Sunstrip® parallel</td>
<td>10/143 mm copper</td>
<td>5/137 mm copper</td>
<td>10/100 mm</td>
<td>114 mm cylinder</td>
</tr>
<tr>
<td>Collector Flow design</td>
<td>25/25 mm</td>
<td>50/15 mm</td>
<td>50/15 mm</td>
<td>25/25 mm</td>
<td>50/15 mm</td>
<td>25/25 mm</td>
</tr>
<tr>
<td>Collector Insulation material</td>
<td>isocyanurate</td>
<td>isocyanurate</td>
<td>ethylene glycol</td>
<td>PUR</td>
<td>PUR</td>
<td>ETC with reflector</td>
</tr>
<tr>
<td>Collector Back/edge insulation</td>
<td>2.58 m x 2</td>
<td>3.00 m²</td>
<td>ethylene glycol</td>
<td>PUR</td>
<td>PUR</td>
<td>126 mm diam. tube</td>
</tr>
<tr>
<td>Collector Length/width/height</td>
<td>3.17 m²</td>
<td>3.17 m²</td>
<td>ethylene glycol</td>
<td>PUR</td>
<td>PUR</td>
<td>SK glass</td>
</tr>
<tr>
<td>Collector Aperture area x #</td>
<td>2.58 m² x 2</td>
<td>3.00 m²</td>
<td>ethylene glycol</td>
<td>PUR</td>
<td>PUR</td>
<td>0.91</td>
</tr>
<tr>
<td>Collector Gross area x #</td>
<td>2.72 m² x 2</td>
<td>3.17 m²</td>
<td>ethylene glycol</td>
<td>PUR</td>
<td>PUR</td>
<td>stainless steel</td>
</tr>
<tr>
<td>Collector efficiency curve η/α</td>
<td>0.756/2.91/0.0024</td>
<td>0.756/4.62/0.013</td>
<td>0.83/3.7/0.07</td>
<td>6.8 kJ/K-m³ with fluid oversize expansion tank and pump stops &gt; 90°C</td>
<td>6.8 kJ/K-m³ with fluid oversize expansion tank and pump stops &gt; 90°C</td>
<td>149 m²</td>
</tr>
<tr>
<td>Heat Capacity</td>
<td>–1 kJ/K-m³</td>
<td>–1 kJ/K-m³</td>
<td>–1 kJ/K-m³</td>
<td>–1 kJ/K-m³</td>
<td>–1 kJ/K-m³</td>
<td>–1 kJ/K-m³</td>
</tr>
<tr>
<td>Overheat protection</td>
<td>pump stops &gt; 90°C</td>
<td>pump stops &gt; 90°C</td>
<td>pump stops &gt; 90°C</td>
<td>pump stops &gt; 90°C</td>
<td>pump stops &gt; 90°C</td>
<td>pump stops &gt; 90°C</td>
</tr>
<tr>
<td>Piping</td>
<td>nylon or PTFE</td>
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<td>silicon rubber</td>
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<td>Piping Insulation material</td>
<td>fiberglass</td>
<td>14 mm trocellen</td>
<td>closed cell foam</td>
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<td>9 mm polyethelene</td>
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<td>7/9 mm/15 m</td>
<td>10/18 mm and 8/18 mm/5 m</td>
<td>5/9 mm/20 m</td>
<td>8/10 mm/3.5 mm</td>
<td>10/20 mm/13.75 mm</td>
<td>16/20 mm/8 m</td>
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<td>Switzerland</td>
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<td>---------</td>
<td>-------------</td>
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<td>Solar storage &amp; HX</td>
<td>0.6/1.5 m³</td>
<td>0.5/0.148 m³</td>
<td>0.5/0.147 m³</td>
<td>0.54/0.187 m³</td>
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<td>Diameter/diameter</td>
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<td>300 mm</td>
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<td>Volume</td>
<td>430 L</td>
<td>384 L</td>
<td>151 L</td>
<td>114 L</td>
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<td>600-700 W/K</td>
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<td>1.4 m³/min</td>
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Table 10.2 (cont.), Dream System Description.
Table 10-3. Costs, Performance, and Comparisons.

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<td>Latitude °</td>
<td>Toronto</td>
<td>Copenhagen</td>
<td>Hannover</td>
<td>DeBilt</td>
<td>Kloten 1986</td>
<td>Sacramento, CA</td>
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<td>collector aperture GJ/m²-yr</td>
<td>45</td>
<td>45</td>
<td>38</td>
<td>45</td>
<td>45</td>
<td>38.5</td>
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<td>Radioactivity *</td>
<td>5.48</td>
<td>4.262</td>
<td>3.808</td>
<td>3.989</td>
<td>8.6 (-1 to 19)</td>
<td>16 (-7 to 24)</td>
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<td>Monthly average daytime temperature °C</td>
<td>9 (6-22)</td>
<td>8.1</td>
<td>8.7 (0 to 17)</td>
<td>9.5 (2 to 18)</td>
<td>1.86 Df/594</td>
<td>1.437 Fr/194</td>
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<tr>
<td>Operating and maintenance $/yr</td>
<td>&lt; 10</td>
<td>15-22</td>
<td>51-131</td>
<td>17</td>
<td>84-150</td>
<td>10</td>
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<td>Base Case performance</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aperture m² (x number)</td>
<td>2.835 (x 2)</td>
<td>4.38 (x 1)</td>
<td>6.35 (x 1)</td>
<td>2.83 (x 1)</td>
<td>1.74 (x 4)</td>
<td>2.56 (x 1)</td>
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<td>Thermal (Q_m - Q_w) GJ/yr</td>
<td>8.7</td>
<td>5.07</td>
<td>6.55</td>
<td>3.70</td>
<td>7.2</td>
<td>7.05</td>
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<td>Reliability and Durability</td>
<td>good to excellent</td>
<td>no problems</td>
<td>excellent</td>
<td>no significant problems</td>
<td>same as ordinary water heaters</td>
<td>excellent</td>
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<tr>
<td>Dream System cost (1993 US$)</td>
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<td></td>
<td></td>
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<td>Components</td>
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<td>Collector</td>
<td>530</td>
<td>490</td>
<td>1428</td>
<td>550</td>
<td>853</td>
<td>650 integral + 250</td>
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<td>Solar storage</td>
<td>175</td>
<td>552</td>
<td>1095</td>
<td>385</td>
<td>800</td>
<td>125</td>
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<td>Pump/controls</td>
<td>100</td>
<td>163</td>
<td>570</td>
<td>145</td>
<td>300</td>
<td>125</td>
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<td>Piping/fitting</td>
<td>175</td>
<td>120</td>
<td>100</td>
<td>100</td>
<td>280</td>
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<td>Fluids/other</td>
<td>205</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>233</td>
<td>50</td>
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<td>Installation materials and labor</td>
<td>260</td>
<td>567</td>
<td>2200</td>
<td>360</td>
<td>2000</td>
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<td>Total*</td>
<td>1445</td>
<td>1892</td>
<td>5393</td>
<td>1540</td>
<td>4466</td>
<td>1510</td>
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<td>Operating and maintenance</td>
<td>&lt; 5</td>
<td>15</td>
<td>37-117</td>
<td>11</td>
<td>74-140</td>
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</table>

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

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- Mr. Simon Furbo
- Mr. Emanuel Brender

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- Dr. Michael Mack
- Dr. Klaus Vanoli
- Mr. Uwe Viertel

Netherlands
- Mr. Teun P. Bokhoven
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- Mr. Jeroen van der Linden

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- Ms. Carmen Granados

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Switzerland
- Mr. Ueli Frei
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- Dr. William Duff
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<th>Facsimile</th>
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<tbody>
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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 A1-1.

![Figure A1-1. Canadian Base Case System Diagram.](image)

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.

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.

A1.1.1.2. Collector cover material. The cover is pebble-surface, low-iron glass.

A1.1.1.3. 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 $\text{dT/G}$ only to 0.10, for an actual collector.

$$\eta = 0.645 \cdot (3.93 + 0.0070 \cdot \text{dT/G})$$

A1.1.2. Piping Runs

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

A1.1.2.2. Insulation material. The pipe insulation material is non-hygroscopic fiberglass.
of a 6.4 mm outside diameter (OD) (4.8 mm inside diameter (ID)) supply tube wrapped in insulation and paralleled with the 6.4 mm OD return tube and the two sensor feed wires. The whole bundle is wrapped in another layer of insulation, plus an outer PVC environmental jacket.

A1.1.3. Solar Storage and Heat Exchanger

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

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

A1.1.3.3. Heat exchanger specifications. The heat exchanger has a rating of 380 W/K. For the current heat exchanger the UA value varies from 100 to 300 W/K as the sidearm flow rate varies.

A1.1.4. Auxiliary

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

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

A1.1.5. Pump

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

A1.1.6. Load

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

A1.1.7. Controls

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

A1.1.7.2. Operating modes.

The pump is off if the collector is cooler than the tank bottom, or if the solar tank is over temperature.
The pump is on if the collector is warmer than the tank bottom, and the tank is not over temperature.

A1.2. Dream System Description

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

• The pump is powered by a 5 W PV panel.

• The collectors have a light-weight absorber design with narrow, small-bore, fm tubes connected in parallel, and a PTFE convection bather (inner glazing).

• The tubing in the Life-Line® lines is polymeric rather than copper.

• The pump/heat exchanger module is below the solar tank to maximize the flow in the sidearm thermosyphon near the end of a charge cycle.

• The pump is much smaller, cheaper, and more efficient.

• The auxiliary electric element is installed in the outlet header of the heat exchanger, and the auxiliary storage shares the solar tank, which is larger. See Figure A1-2.

Figure A1-2. Canadian Dream System Diagram.
Operating Modes:

Pump off, due to:

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

Pump on, due to:

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

Auxiliary:

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

A1.2.1. Collector

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

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

A1.2.1.3. Absorber material. 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 fin 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):
η = 0.765 - (2.91 + 0.0024*\(dT\)) * \(dT/G\).

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\(^2\)K, 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.

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. The auxiliary element will be 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 m²) $658
Solar Storage(s) (273 ℓ) $187
Overheat and Overpressure Prevention - with tank
Auxiliary Storage - N/A
Auxiliary - N/A
Fluids Other Than Water
Heat exchanger(s)
Pump(s): Procon 1521 + 120 W GE motor ($190)
Controller: Heliotrope DTT84 ($100)

$635
A1.4.2. Installation Cost

$260

A1.4.3. Operating and Maintenance Costs

N/A

A1.5. Performance of the Base Case System


<table>
<thead>
<tr>
<th>Location for Simulation:</th>
<th>Toronto</th>
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</thead>
<tbody>
<tr>
<td>Latitude:</td>
<td>43 °</td>
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<tr>
<td>Collector slope:</td>
<td>45 °</td>
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<tr>
<td>Collector Aperture Area:</td>
<td>5.67 m²</td>
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Table A1-1. Thermal Performance of Canadian Base Case System.

<table>
<thead>
<tr>
<th>Month</th>
<th>Radiation on the Collector, MJ/m²/day</th>
<th>Daytime Ambient Temperature °C</th>
<th>Daily Solar Contribution, MJ/m²/day</th>
<th>Auxiliary Required, MJ/m²/day</th>
<th>Total DHW Load, MJ/m²/day</th>
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<td>8.3</td>
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</table>

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.

A1.6.1. Component Costs

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

A1.6.2. Installation Cost

$260

A1.6.3. Operating and Maintenance Costs

N/A

A1.7. Performance of the Dream System


Location for Simulation: Toronto
Latitude: 43°
Collector slope: 45°
Collector Aperture Area: 5.15 m²
Table A1-2. Thermal Performance of Canadian Dream System.

<table>
<thead>
<tr>
<th></th>
<th>Radiation on the Collector, MJ/m²/day</th>
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<th>Auxiliary Required, MJ/m²/day</th>
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<td>9</td>
<td>6.9</td>
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</tr>
</tbody>
</table>

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.

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 m². 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.

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 m², is calculated by:

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

where \( T^* = \left(\frac{T_{\text{coll,in}} + T_{\text{coll,out}}}{2} - T_{\text{amb}}\right) / G \)

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 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.
A2.2. Dream System Description

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

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

Figure A2-2. Danish Dream System Diagram.

A2.2.2. Collector

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

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

A2.2.1.3. Absorber material. The absorber consists of Sunstrip® tube plates with a black nickel selective surface. The tubes are made of copper and the plates of aluminum.
A2.2.2.4. Absorber fins/flow design. The Sunstrip® tube plate dimensions are 0.5 mm x 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. The collector design makes it possible to drain the absorber 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 m², is calculated by:

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

where

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

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

A2.2.3.1. Piping material. A new flexible tubing has been developed. The piping material consists 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.

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.

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
A2.5. 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

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector</td>
<td>490 US$</td>
</tr>
<tr>
<td>Solar storage</td>
<td>552 US$</td>
</tr>
<tr>
<td>Pump/controls</td>
<td>163 US$</td>
</tr>
<tr>
<td>Piping/fittings</td>
<td>120 US$</td>
</tr>
<tr>
<td>Fluids/other</td>
<td>0 US$</td>
</tr>
<tr>
<td>Total system components</td>
<td>1325 US$</td>
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</tbody>
</table>
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

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 m²), 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
  - 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, $\alpha = 0.96 \pm 0.02$, $\varepsilon = 0.11 \pm 0.02$

• 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

\[
\eta = 0.802 - 3.69 \cdot \frac{\Delta T}{I} - 0.007 \cdot \frac{\Delta T^2}{I}, \quad \Delta T = \frac{T_{col,\text{out}} + T_{col,\text{in}} - T_{amb}}{2}
\]

• Overheat Protection

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

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

* Material Cu
* Dimensions 18 x 1 mm
• Insulation

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

• Specifications

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

A3.1.4. Solar Storage and Heat Exchanger

• 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 \( \lambda = 0.04 \) 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
Charging Strategy

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

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

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

Data

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

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

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

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

A3.1.7. Load

• Specifications

The load is chosen according to German standards for average demand. Performance calculations will be based on today’s standard demand for 5 persons.
Demand per 5-Person-Household

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

A3.1.8. Controls

Specifications

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

Operation Mode

\[ \Delta T = 5K \]
\[ \Delta T = 2K \]
\[ T_{STO, max} = 95°C \]

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

A3.2. Dream System Description

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

• Easy and inexpensive installation

The one-module, flat-plate collector is connected to Flextube® Swiss lifeline-design and may be installed in or on the roof. On-roof installation is suggested for easy and cheap retrofitting. The premanufactured Solar-Installation-Kit (SIE), as an interface between the Flextube® and storage, integrates all peripheral components such as the circulation pump, control-box, expansion vessel and safety devices. SIE is easily attached to the storage connection pipes that are brought to the front of the tank and mounted on an installation bracket as shown in Figure A3-3.
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 m², 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

\[
\eta = 0.83 - 3.7 \frac{\Delta I}{I} - 0.07 \frac{\Delta I^2}{I}, \quad \Delta T = \frac{T_{col} + T_{col'} - T_{amb}}{2}
\]

• 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\text{i} = 5 mm, d\text{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.

• 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 $\lambda = 0.04$ 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
* Δ$T_{log}$: 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
* $A_{HX}, A_{aux}$: 1 m²

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

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

* Volume Flow: 60-120 ℓ/h
* Maximum Head: 20 m
* Elt. Power: Not exceeding 33 W
* $\eta_{hydrodynamic}$: 20 percent
In Task 14, promising work in pump development is currently being conducted by Antony Caffell of Canada, Ueli Frey of Switzerland, and Klaus Lorenz of Sweden, in order to meet these specifications.

A3.2.7. Load

• Specifications

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

* Current Standard Demand per 5-Person-Household

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

* Recommended Standard Demand per 5-Person-Household

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

A3.2.8. Controls

Specifications

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

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

Operation Mode

\[
\begin{align*}
\Delta T_{on} & = 8 \text{K} \\
\Delta T_{off} & = 3 \text{K} \\
T_{STO, max} & = 95 \text{°C}
\end{align*}
\]
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

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector and installation-kit</td>
<td>1,680 $</td>
</tr>
<tr>
<td>Storage and both heat exchangers</td>
<td>1,453 $</td>
</tr>
<tr>
<td>Solar installation kit, control, pump</td>
<td>625 $</td>
</tr>
<tr>
<td>Piping, insulated</td>
<td>300 $</td>
</tr>
<tr>
<td><strong>Total component costs</strong></td>
<td><strong>4,058 $</strong></td>
</tr>
</tbody>
</table>

#### 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/m²-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.

<table>
<thead>
<tr>
<th>Month</th>
<th>H100 MJ/m²d</th>
<th>kWh/m²d</th>
<th>Q102 MJ/m²d</th>
<th>kWh/m²d</th>
<th>Q332 MJ/m²d</th>
<th>kWh/m²d</th>
<th>SF %</th>
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<tbody>
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<td>359.0</td>
<td>1091.9</td>
<td>303.3</td>
<td>50.76</td>
</tr>
</tbody>
</table>

MJ/m²yr kWh/m²yr MJ/m²yr kWh/m²yr MJ/m²yr kWh/m²yr %
Table A3-2. Annual Values for Friedrichshafen, the Location With the Highest Annual Solar Insolation in Germany (4523 MJ/m²·yr; 1256.4 kWh/m²·yr).

<table>
<thead>
<tr>
<th></th>
<th>H100 (MJ/m²·a)</th>
<th>Q102 (MJ/m²·a)</th>
<th>Q332 (MJ/m²·a)</th>
<th>Q332 (kWh/m²·a)</th>
<th>SF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ann</td>
<td>5212.4</td>
<td>1447.9</td>
<td>1742.4</td>
<td>484.0</td>
<td>1460.5</td>
</tr>
</tbody>
</table>

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/m²-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
* Tcw-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.

<table>
<thead>
<tr>
<th></th>
<th>H100</th>
<th>Q102</th>
<th>Q332</th>
<th>SF</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MJ/m²d</td>
<td>kWh/m²d</td>
<td>MJ/m²d</td>
<td>kWh/m²d</td>
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<tr>
<td>Jan</td>
<td>2.9</td>
<td>0.81</td>
<td>1.4</td>
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<tr>
<td>Feb</td>
<td>5.9</td>
<td>1.63</td>
<td>3.1</td>
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<tr>
<td>Mar</td>
<td>9.7</td>
<td>2.70</td>
<td>4.9</td>
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<tr>
<td>Apr</td>
<td>13.1</td>
<td>3.63</td>
<td>5.9</td>
<td>1.64</td>
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<tr>
<td>May</td>
<td>15.8</td>
<td>4.39</td>
<td>6.3</td>
<td>1.75</td>
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<tr>
<td>Jun</td>
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<td>5.06</td>
<td>6.7</td>
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<tr>
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<td>4.39</td>
<td>5.9</td>
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<tr>
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<td>4.37</td>
<td>6.0</td>
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<tr>
<td>Sep</td>
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<td>3.18</td>
<td>4.8</td>
<td>1.33</td>
</tr>
<tr>
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<td>0.58</td>
<td>0.8</td>
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<tr>
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</tr>
<tr>
<td>MJ/m²yr</td>
<td>kWh/m²yr</td>
<td>MJ/m²yr</td>
<td>kWh/m²yr</td>
<td>MJ/m²yr</td>
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