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DESIGNING SOLAR THERMAL SYSTEMS

Active Solar Thermal Energy in Buildings
Sizing the solar thermal system

Process

• Establish the Domestic Hot Water (DHW) Demand (+ space heating)

• Size the collector array

• Size the storage tank

• Size solar circuit (pipes, insulation, pumps)
Domestic Hot Water Demand

\[ Q_{DHW} = \frac{V \times C_p \times \Delta T}{3600} \] [kWh]

- \( Q_{DHW} \): Energy content of domestic hot water in kWh
- \( V \): Hot water consumption in litres (per day)
- \( C_p \): Specific heat capacity of water (4.2 kJ/litre K)
- \( \Delta T \): Temperature difference bet. DHW and cold water in K

<table>
<thead>
<tr>
<th>Level of DHW demand</th>
<th>Litres per day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>10-20 l</td>
</tr>
<tr>
<td>Medium</td>
<td>20-40 l</td>
</tr>
<tr>
<td>High</td>
<td>40-80 l</td>
</tr>
</tbody>
</table>

Demand for domestic hot water per day per person, at a temperature of 60 C (Recknagel et al., 2003)
## DHW Demand in large buildings

### DHW estimates according to VDI 2067, Source: Viessmann

<table>
<thead>
<tr>
<th>Consumption Type</th>
<th>Hot water requirement per day and person at a temperature of 60°C (L/t)</th>
<th>Hot water requirement $V_p$ litres/(d · person) (DHW temp. 45 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>From - To</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retirement home</td>
<td>45</td>
<td>30 - 65</td>
</tr>
<tr>
<td>Kitchen - breakfast</td>
<td>2</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Kitchen - noon/evening</td>
<td>5</td>
<td>4 - 8</td>
</tr>
<tr>
<td>Swimming pool - public/private</td>
<td>40/20</td>
<td></td>
</tr>
<tr>
<td>Sauna - public/private</td>
<td>70/35</td>
<td></td>
</tr>
<tr>
<td>Hospital</td>
<td>80</td>
<td>60 - 120</td>
</tr>
<tr>
<td>Sports facilities - total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sports facilities - showers</td>
<td>25</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Hotel (ⅠⅠ)</td>
<td>50</td>
<td>30 - 80</td>
</tr>
<tr>
<td>Hotel (ⅠⅠⅠⅠ)</td>
<td>80</td>
<td>80 - 150</td>
</tr>
<tr>
<td>Guest house, inn</td>
<td>30</td>
<td>20 - 50</td>
</tr>
<tr>
<td>Holiday house</td>
<td>40</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Camping site</td>
<td>20</td>
<td>15 - 35</td>
</tr>
<tr>
<td>Youth hostel, holiday hostel</td>
<td>20</td>
<td>15 - 30</td>
</tr>
<tr>
<td>Student hall of residence</td>
<td>25</td>
<td>15 - 60</td>
</tr>
</tbody>
</table>

*¹Empirical value: 30 to 50 litres/(d · person)

Source: Kingspan Solar
Sizing the solar storage tank

For small domestic systems
• The cylinder should be at least 2 x volume of DHW usage per day

For larger systems
• Use 50 l/m² of collector aperture area for preliminary design

More precise calculation taking into consideration temp of DHW at user point:

\[
V_{cyl} = \frac{2 \times V \times (T_h - T_c)}{(T_{dhw} - T_c)}
\]

\[
\begin{align*}
V_{cyl} & \quad \text{Minimum volume of cylinder (l)} \\
V & \quad \text{Domestic hot water demand per day (l)} \\
T_h & \quad \text{Temperature of hot water at outlet (°C)} \\
T_c & \quad \text{Temperature of cold water supply (°C)} \\
T_{dhw} & \quad \text{Temperature of stored water (°C)}
\end{align*}
\]
Energy Balance in a Solar Thermal System

\[ Q_{col} \quad \text{Solar irradiation at collector level} \]

\[ Q_{sol} \quad \text{Solar energy input} \]

\[ Q_{aux} \quad \text{Auxiliary heat input} \]

\[ Q_{DHW} \quad \text{DHW Heat Demand} \]

\[ \text{Back-up} \]
Indicators of solar thermal performance

\[ Solar \ fraction, SF = \frac{Q_{sol}}{Q_{aux} + Q_{sol}} \quad (\%) \]

\[ Specific \ load = \frac{litres \ of \ DHW \ usage}{m^2 \ of \ solar \ collector, \ per \ day} \quad (l/m^2\cdot\text{day}) \]

\[ Specific \ solar \ yield = \frac{Q_{sol}}{Collector \ Area} \quad (kWh/m^2\cdot\text{yr}) \]

\[ Solar \ System \ efficiency, SE = \frac{Q_{sol}}{Q_{col}} \quad (%) \]
Solar collector area – balancing solar fraction, efficiency and cost

Max. collector yield

Optimised for solar contribution and cost

Maximum heat demand coverage

Source: Kingspan Solar
Sizing the collector area - First approximation

\[ \text{Collector area} = \frac{Q_{DHW}}{Q_{col}} \times SF \times SE \]

- \( Q_{DHW} \): Heating requirement (kWh/yr)
- \( SF \): Solar fraction (%)
- \( SE \): Average solar system efficiency (%)
- \( Q_{col} \): Solar irradiation incident on solar collector (kWh/m\(^2\), yr)
- \( Q_{col} = G \times \text{inclination: orientation correction factor} \)
- \( G \): Solar irradiation on a horizontal surface (kWh/m\(^2\), yr)
Sizing the collector area - First approximation

Example

Project:
• 4 persons @ 50 l/person (required at 45 °C at user point)
• Roof pitch = 35°, cold water 10 °C
• Solar fraction required = 60%

Heating demand:
• DHW energy content = 4 x 50 l x 365 d/yr x 4.2 kJ/l·K x 40 K /3600
  = 3407 kWh/yr
• Distribution losses + storage losses = 30%
• Total heat demand = 4867 kWh

Approximate Sizing:
• Collector area = (4867 kWh x 60%) / (1720 kWh/m², yr x 115%) = 1.48 m²
  Typical nearest solar collector has an aperture area of 2 m².
• Cylinder = 2 m² x 50 l/m² = 200 litres
Sizing collector area for larger systems

<table>
<thead>
<tr>
<th>Specific load (l/m²·d)</th>
<th>30</th>
<th>45</th>
<th>70</th>
<th>100</th>
<th>140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Fraction</td>
<td>55%</td>
<td>46%</td>
<td>38%</td>
<td>32%</td>
<td>27%</td>
</tr>
<tr>
<td>Annual specific yield</td>
<td>390</td>
<td>475</td>
<td>550</td>
<td>615</td>
<td>675</td>
</tr>
</tbody>
</table>

**Example**

Apartment block with 30 occupants, 30 l/person @60 C per day = 900 l/day

**Heating demand:**

HW preparation = 900 l x 365 day/yr x 4.2 kJ/l·K x 50 K /3600 = 19,162.5 kWh/yr

Circulation losses + storage losses = 40%

Total heat demand = 26,828 kWh

**Sizing collector:**

Specific yield in good location, solar fraction 35% = 615 kWh/m²·a

Collector area = 44 m²

**Sizing storage tank:**

44 m² col x 50 l/m² col = 2200 l

*Source: Solarpraxis, 2002*
Heat losses from pipes

\[ \dot{Q}_\text{pipe} = \frac{2 \pi \lambda \Delta \theta}{\ln\left(\frac{D_{\text{wd}}}{D_{\text{pipe}}}\right)} \text{ (W/m)} \]

\( \lambda \): thermal conductivity of the insulating material (e.g. 0.04 W/m·K)

\( D_{\text{wd}} \): outside dimension of the insulated pipe (e.g., 54 mm)

\( D_{\text{pipe}} \): outside diameter of the pipe (e.g., 18 mm)

"\( \Delta \theta \)“: temperature difference between pipe & outside air (e.g., 30 K)

Q1: Calculate the heat loss from solar circuit with 20 m of insulated pipe (see conditions above) based on 2000 hours of operation per year: ________ ?
Heat losses from storage tanks

Specific heat loss from storage tank, \( \dot{Q}_{st} = k \times A \times \Delta \theta \)

- **k**: heat transfer coefficient (W/m\(^2\)·K)
- **A**: heat transfer surface area of the tank (m\(^2\))
  (kA value is often given by tank manufacturers in W/K.)
- **\( \Delta \theta \)**: temperature difference between tank & surroundings (K)

Q2: Calculate the heat loss of a storage tank with a kA value of 1.6 W/K, in which hot water is stored at an average temperature of 50 C in a utility room at 20 C average temperature: _____ ?
Design/simulation software
Efficiency curve against a coefficient integrating temperature difference and solar irradiance (one single curve per collector). Source: AEE INTEC
Designing collector field

Lowest solar noon angle (21st December) = 90° - latitude - 23.5°

In Yerevan: $\varepsilon = 26.5°$; $\alpha = 35°$

Flat plate collector example: $L = 2.1$ m, $H = 1.2$ m

$D = 1.97 \times L = 4.14$ m

\[ H = L \times \sin \alpha \text{ (m)} \]

\[ D = \frac{L \times \sin[180 - (\alpha + \varepsilon)]}{\sin \varepsilon} \text{ (m)} \]

Source: AEE Intec, 2004
Collector array layout
Small systems

Source: Solarpraxis, 2002
Collector array layout - Large systems

Advantageous hydraulics

Disadvantageous hydraulics
Collector array layout - Large systems

Advantageous hydraulics
Assembly of Sensors
Positioning of Sensors in Collector Bank

Immerged Bushing (Preferable)

Surface Bushing (Less Convenient)

Hot

Cold
Pressure Loss, Flow Rate and Pipe Diameter in Solar Circuit

Volumetric flow rate, \( \dot{m} = \frac{Q \dot{sol}}{C_{gw} \times \Delta \theta} \)

Q: usable thermal output converted by the collector (W/m²)
C_{gw}: specific heat capacity of the solar liquid, e.g., 1.03 Wh/kg·K
\( \Delta \theta \): temp. difference between feed & return flows, e.g., 10 K

Solar circuit pipe diameter, \( D (mm) = \sqrt{\frac{4 \dot{m}}{\pi v}} \)

v: flow speed, target of 0.7 m/s
Example

Irradiance = 800 W/m²
Collector efficiency = 50%
Collector area = 6 m²

\[ \dot{m} = \frac{(800 \, W/m^2 \times 50\%)}{(1.03 \, Wh/kg\cdot K \times 10 \, K)} = 39 \, kg/m^2h = 40 \, l/h\cdot m^2 \]

\[ D = \sqrt{\left[\frac{4 \times (6 \, m^2 \times 40 \, l/h\cdot m^2)}{(0.7 \, m/s)}\right]/\pi} \]

= 11.01 mm

→ nearest standard copper pipe Cu 15 x 1 DN12 with a 13 mm internal diameter
Collector flow rate - high versus low

<table>
<thead>
<tr>
<th></th>
<th>Range of specific mass flow rate (kg/m².hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-flow</td>
<td>5-20</td>
</tr>
<tr>
<td>High-flow</td>
<td>21-70</td>
</tr>
</tbody>
</table>

Comparison of mass flow rates for high and low-flow solar systems
Source: AEE INTEC

Benefits of low-flow:
• Smaller pipe diameters
• Longer collector series (up to 80 m²), less pipework
• Reduced pipe heat losses
• Lower capital cost
• Lower running cost
• Reduced frequency of auxiliary heating
Pressure Loss in Collectors

Example of pressure loss for 5 glazed flat plate collectors.
Pressure Loss in Piping

Pipe network characteristics for copper, 35% glycol, 65% water, 50°C.
Pressure Loss Due to Accessories and Other Components
Sizing of Pumps

\[ \Delta p_{\text{tot}} = \Delta p_{\text{collector}} + \Delta p_{\text{solar circuit}} + \Delta p_{\text{heat exchanger}} \]
Sizing of Heat Exchangers
Sizing of Expansion Chamber

\[ V_u = \text{Effective volume of expansion chamber} \]

\[ V_u = (V_e + V_{vap} + V_r) \times C_p \]

\[ V_e = \text{expansion volume} = V_t \times C_e \]

\[ V_{vap} = \text{volume due to steam formation} \]

\[ V_r = \text{spare volume} \]

\[ C_e = \text{Expansion coefficient} \]

\[ V_t = \text{Total fluid volume} \]

\[ C_p = \frac{P_M + 1}{P_M - P_m} \]

\[ P_M = \text{maximum pressure} \]

\[ P_m = \text{minimum pressure} \]

\[ P_{VS} = \text{PVS x 0.9} \]

\[ P_{VS} = \text{calibrated pressure of safety valve} \]
Active Solar Thermal Energy in Buildings

TYPICAL SYSTEM CONFIGURATIONS
**Solar water heater configuration 1**

<table>
<thead>
<tr>
<th>Description</th>
<th>Twin coil cylinder, solar heating and auxiliary heating take place in the same tank.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical applications</td>
<td>Most common configuration in single houses applications</td>
</tr>
</tbody>
</table>
| Pros | Lower footprint  
| | Lower capital cost  
| | Less installation cost  
| | Lower A/V  |
| Cons | Higher water t°  
| | → higher storage losses  
| | Typically less solar storage volume  |
| Notes | Auxiliary heating coil & boiler can be replaced with immersion heater |
## Solar water heater configuration 2

### Description
Solar cylinder & separate auxiliary heating cylinder.

### Typical applications
More typical of larger installations (multi-family or non-residential).

### Pros
- Higher solar storage volume
- Higher solar collector efficiency

### Cons
- Larger footprint
- Larger A/V → higher storage losses
- Higher capital cost

### Notes
Also appropriate in retrofit where existing cylinder is suitable
**Solar water heater configuration 3**

<table>
<thead>
<tr>
<th>Description</th>
<th>Single coil cylinder for solar heating, auxiliary heating instantaneous through e.g. combi-boiler or external plate heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical applications</td>
<td>Typically with gas combi-boilers in domestic situations</td>
</tr>
</tbody>
</table>
| Pros | Less storage heat loss  
Smaller cylinder  
Lower capital cost  
Better stratification |
| Cons | Limited hot water draw rates |
| Notes | Boiler output to regulate according to incoming water temperature |
**Solar combisystem configuration 1**

<table>
<thead>
<tr>
<th>Description</th>
<th>Tank in tank cylinder. Outer tank acts as thermal buffer with heating water. Internal tank storing hot water cylinder and heated by surrounding heating water. Three port valve regulates direction of UFH return to buffer (solar input) or to the boiler (auxiliary heating).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical applications</strong></td>
<td>Typical of solar combisystems operating with underfloor heating (UFH)</td>
</tr>
<tr>
<td><strong>Pros</strong></td>
<td>Lower operating temperature of UFH increases the solar system efficiency. Lower footprint Lower capital cost</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td>Limited choice in tank sizes (generally up to 1000 litres) Surplus of solar heat during the summer</td>
</tr>
<tr>
<td><strong>Notes:</strong></td>
<td>Internal tank can be replaced with internal heat exchanger (coil type) to heat DHW</td>
</tr>
</tbody>
</table>
Solar combisystem
Solar combisystem configuration 2

<table>
<thead>
<tr>
<th>Description</th>
<th>Separate hot water cylinder and buffer tank for space heating. Three port valve directs solar heat to HW cylinder or buffer tank depending on demand (normally priority to HW) and temperature regime.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical applications</td>
<td>Typical of solar combisystems operating with radiators or fan coils.</td>
</tr>
<tr>
<td>Pros</td>
<td>Large choice of tank sizes More scope to optimise temperature regime in solar circuit</td>
</tr>
<tr>
<td>Cons</td>
<td>Higher capital cost Bigger footprint More complex regulation Surplus of solar heat during the summer</td>
</tr>
</tbody>
</table>
| Notes: | }
### Solar combisystem configuration 3

**Description**
Solar combisystem with swimming pool heating

<table>
<thead>
<tr>
<th>Typical applications</th>
<th>Individual house with swimming pool</th>
</tr>
</thead>
</table>
| **Pros**             | Excess summer solar heat used to heat pool water  
                       | Low extra installation cost compared to regular combi |
| **Cons**             |                                      |
| **Notes:**           | Example of internal heat exchanger (coil type) to heat DHW |
### Large solar thermal configuration 1

#### Description
Central solar buffer tank with circulation loop (one pipe) supplying solar heat to individual units. Individual auxiliary heating in each apartment.

#### Typical applications
Apartment blocks

#### Pros
- Auxiliary heating at point of use → lower circulation t ° & losses
- Individual fuel supply (energy metering optional)
- Less equipment in shared ownership

#### Cons
- Higher capital investment
- Higher fire hazard (fuel distribution to each unit)

#### Notes:
DHW can be pre-heated by accumulation in a cylinder or instantaneously through a plate heat exchanger.
### Large solar thermal configuration 2

**Description**
Central solar storage tank with circulation loop distributing hot water to individual units. Central auxiliary heating.

**Typical applications**
Hotels, hospitals, nursing homes, etc.

**Pros**
- Central heating plant
- Simpler plumbing
- Lower capital investment
- Lower fire hazard (no individual fuel supply)

**Cons**
- Not suitable for energy metering
- Higher circulation losses

**Notes:**

---

[Image of diagram]
### Large solar thermal configuration 3

<table>
<thead>
<tr>
<th>Description</th>
<th>Central buffer tank with auxiliary heating with two-pipe network distributing heat to individual units for hot water and space heating.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical applications</td>
<td>Apartment blocks, terraced houses, etc.</td>
</tr>
</tbody>
</table>
| Pros | Very suitable for energy metering  
Higher solar fraction of total heat demand possible |
| Cons | Large solar system  
Higher footprint in plant room |
| Notes: | This system is essentially similar to a solar-assisted district heating network |
Pool Heating
Hot Household Water and Pool Heating
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INSTALLATION & COMMISSIONING
Mounting Solar Collectors
Roof integrated

Source: Solaris

Source: Schuco

Source: Carey Glass Solar
Mounting Solar Collectors On-roof

Source: Viessmann
Flat roof Installation

Source: Zen Renewables

Rosette to prevent water dripping into the house

Bituminous felt

Feed and Return of the collector

Sensor cable protection pipe

Source: Shüco
Mounting Solar Collectors
Façade mounted

Source: Shüco

Source: Conness
Mounting Solar Collectors
Ground mounted

Source: Kedco

Source: Conness
Commissioning

Flushing and purging

Standard flushing system. Source: Bosch/Buderus.
Commissioning

Set frost protection level
Heating design temperature = -11.1°C (RETScreen).
• Record low temperature = -28°C (Wikipedia)
• Mix anti-freeze at manufacturer’s recommended concentration.
• Check mix concentration with reflectometer at start-up and every two years.
• Antifreeze should be environmentally friendly, suitable for range of operating temperatures & provide corrosion protection.

Set Operating Pressure
• Operating pressure > 0.7 bar + static pressure
• Static pressure = 0.1 bar/m of height difference between highest (collector) and lowest (tank) points in the loop
Commissioning

Set flow rate

- Adjust when system is cold. Set fixed volumetric flow rate according to collector manufacturer’s instructions (table below).
- Adjust with pump speed switch & flow regulator.
- Alternatively, use variable speed pump regulating according to operating conditions.

Example of flow measure & regulation system. Source: Viessmann

<table>
<thead>
<tr>
<th>No. of collectors</th>
<th>gpm (l/min)</th>
<th>No. of collectors</th>
<th>gpm (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.22 (1)</td>
<td>11</td>
<td>2.4 (8 - 11)</td>
</tr>
<tr>
<td>2</td>
<td>0.44 (1.5 - 2)</td>
<td>12</td>
<td>2.64</td>
</tr>
<tr>
<td>3</td>
<td>0.66 (2.5 - 3)</td>
<td>13</td>
<td>2.96 (11 - 13)</td>
</tr>
<tr>
<td>4</td>
<td>0.88 (3 - 4)</td>
<td>14</td>
<td>3 (12 - 14)</td>
</tr>
<tr>
<td>5</td>
<td>1.1 (4 - 5)</td>
<td>15</td>
<td>3.3 (13 - 14)</td>
</tr>
<tr>
<td>6</td>
<td>1.32 (5 - 6)</td>
<td>16</td>
<td>3.5 (13 - 16)</td>
</tr>
<tr>
<td>7</td>
<td>1.54 (6 - 7)</td>
<td>17</td>
<td>4 (15 - 18)</td>
</tr>
<tr>
<td>8</td>
<td>1.76 (7 - 8)</td>
<td>18</td>
<td>4 (15 - 18)</td>
</tr>
<tr>
<td>9</td>
<td>1.98 (8 - 9)</td>
<td>19</td>
<td>4.5 (16 - 19)</td>
</tr>
<tr>
<td>10</td>
<td>2.2 (8 - 10)</td>
<td>20</td>
<td>4.5 (17 - 20)</td>
</tr>
</tbody>
</table>
Active Solar Thermal Energy in Buildings

FINANCIAL ANALYSIS OF PROJECTS
Lifecycle cost analysis

• **Costs**
  – Up-front capital cost (e.g. design & engineering), equipment, installation, civil works, electrical works, etc.)
  – Other costs: financing, maintenance, end-of-life, etc.
  – **Consider costs inflation**

• **Revenues**
  – Heating fuel substituted (useful solar heat/boiler efficiency)
  – Subsidies
  – Residual value (e.g. scrap metal, potential future revenues, etc.)
  – **Consider energy inflation rate**
Discounted cash flow

- Future cash flows are discounted to present value (time value of money)
- Net Present Value (NPV): total present value of a time series of cash flows.
  \[ NPV = \sum_{t=0}^{N} \frac{C_t}{(1 + r)^t} = 0 \]
  - \( t \) - time of the cash flow
  - \( r \) - discount rate
  - \( C_t \) - net cash flow at time \( t \)

*If NPV > 0, then project worth doing.*

- Internal rate of return (IRR): yield on investment (%) – it’s the \( i \) that makes \( NPV = 0 \).
  *If IRR > \( i \) then project worth doing.*

*More info on whole life cycle cost http://www.wlcf.org.uk*
Life-Cycle Analysis

• **Costs**
  – Investment
    • Up to 10 m²: 700 - 1000 €/m²
    • From 10 m² to 50 m²: 600 - 800 €/m²
    • > 50 m²: 500 - 750 €/m²
  – Maintenance: 0.5-1% per year

• **Revenue**
  – Energy saving
    • Natural gas: €0.29/m³
    • Electricity: €0.15/kWh
  – CO₂ tax: €30/tCO₂ (in Ireland)
Discounted Cash Flow Analysis with RETSCreen

Hotel, 70 bedrooms with occupancy rate of 70%

Estimated DHW demand: 3700 l/d at 60 °C

43 m² quality flat plate collector, at 35° tilt & azimuth 0°

2000 litres storage tank

Auxiliary heating: gas boiler, 80% seasonal efficiency

Solar fraction = 43%

Result of the discounted cash flow analysis:

- Internal rate of return = 3% on equity
- Simple payback = 29 years
- Equity payback = 20 years
- Net Present Value = -5,435 €
Active Solar Thermal Energy in Buildings

APPLICATIONS IN ARMENIA
## Potential solar market segments in Armenia

<table>
<thead>
<tr>
<th>Market Segment</th>
<th>Potential Clients</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOCAL MARKET</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>Residential Housing / Summer Homes (net-metering or off-grid applications)</td>
</tr>
<tr>
<td>Recreation and Tourism</td>
<td>Hotels / Motels / Cottages / Resorts and Camps (off-grid applications)</td>
</tr>
<tr>
<td>Health Care</td>
<td>Hospitals / Clinics (back-up power supply)</td>
</tr>
<tr>
<td>Military/Defense</td>
<td>Military Bases (back-up, autonomous supply)</td>
</tr>
<tr>
<td>International</td>
<td></td>
</tr>
<tr>
<td>Organizations</td>
<td>Embassies / Foreign companies (back-up power)</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Farms / Rural Communities (PV irrigation, lighting)</td>
</tr>
<tr>
<td>Communication</td>
<td>Communication equipment (off-grid, back-up applications)</td>
</tr>
<tr>
<td>Entertainment</td>
<td>Cafes/Restaurants/Advertisement (off-grid and back-up power supply)</td>
</tr>
<tr>
<td>Grid-connected plants</td>
<td>Private and foreign investors (turn-key projects)</td>
</tr>
<tr>
<td>EXPORT MARKETS</td>
<td></td>
</tr>
<tr>
<td>Private and non-</td>
<td>Direct sales to privates or distributors (PV modules, other &quot;chain&quot; products)</td>
</tr>
</tbody>
</table>

### Barriers to deployment:

- Initial investment cost
- Subsidised conventional energy sources
- Highly developed energy supply infrastructure
- No supportive energy policy framework
Armenian Case Studies

Fig 1. Vahagani project (near Yerevan)

Fig 2. Northern Ave, Yerevan

Fig 3. Red Cross Rehabilitation Centre, Yerevan

Addiction Clinic, Yerevan
Armenian Case Studies

Fig 1: 70 m² in multi-family building in Yerevan.

Fig 2: 60 m² solar water heating at Vasgenian theological seminary (Sevan).

Fig 3: Domestic solar water & pool heating, Nork-Marash.
Solar thermal (foreground) and solar PV systems (background) installed on the roof of the American University of Armenia
Further References


