Introduction

This document describes the reference solar domestic hot water (SDHW) system for domestic hot water preparation in a multi-family house (MFH) in Austria. The system is modelled with TSol to calculate the fuel consumption and electric energy, as well as the substituted fuel provided by the SDHW system, which are needed to provide the required domestic hot water and space heating. Using this result the levelized costs of heat (LCOH) for the substituted fuel is calculated using Equation 1, with the reference costs for the investment of the system, installation costs, fuel and electricity costs.

Hydraulic Scheme of the System

<table>
<thead>
<tr>
<th>Key data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collector area (one collector)</td>
</tr>
<tr>
<td>Heat store volume</td>
</tr>
<tr>
<td>Location</td>
</tr>
<tr>
<td>Hemispherical irradiance on horizontal surface</td>
</tr>
<tr>
<td>Lifetime of system</td>
</tr>
</tbody>
</table>

Levelized Cost of Heat (LCoH)

| LCoH solar part without VAT                  | 0.0564 €/kWh |
| LCoH conventional part without VAT           | 0.0733 €/kWh |
| LCoH complete system without VAT             | 0.0707 €/kWh |
**Details of the system**

<table>
<thead>
<tr>
<th>Location</th>
<th>Austria, Graz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of system</td>
<td>Solar domestic hot water (SDHW) system</td>
</tr>
</tbody>
</table>

Weather data including:
- hemispherical irradiance on horizontal surface
- beam irradiance on horizontal surface
- diffuse irradiance on horizontal surface
- ambient temperature

in hourly values:

\[
\begin{align*}
\Sigma G_{\text{hem, hor}} &= 1126 \text{ kWh/(m}^2\text{ a)} \\
\Sigma G_{\text{beam, hor}} &= 482 \text{ kWh/(m}^2\text{ a)} \\
\Sigma G_{\text{diff, hor}} &= 644 \text{ kWh/m}^2\text{ a)} \\
T_{\text{amb, av}} &= 9.2 \ ^{\circ}\text{C}
\end{align*}
\]

Collector orientation:
- collector tilt angle to horizontal
- South deviation of collector
- ground reflectance
- resulting hemispherical irradiance on tilted surface

35 °
- south = 0°
0.2

\[
\Sigma G_{\text{hem, tilt}} = 1280 \text{ kWh/(m}^2\text{ a)}
\]

Load information including:
- heat demand space heating
- tapping profile

110.4 MWh/a [1]
42.53 MWh/a [1]

- tapping temperature
- average inlet temperature of cold water
- cold water inlet temperature amplitude

60°C
9.6 °C
0 K
### Hydraulic scheme of the system

<table>
<thead>
<tr>
<th>Collector information based on gross area</th>
<th>T*SOL Database Standard Flat-Plate Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of collectors</td>
<td>25</td>
</tr>
<tr>
<td>Collector area of one collector</td>
<td>2.0 m²</td>
</tr>
<tr>
<td>Maximum collector efficiency</td>
<td>0.8</td>
</tr>
<tr>
<td>Incidence angle modifier for direct irradiance $b_0$</td>
<td>0.88 (at 50°)</td>
</tr>
<tr>
<td>Incidence angle modifier for diffuse irradiance $K_d$</td>
<td>0.83</td>
</tr>
<tr>
<td>Linear heat loss coefficient $a_1$</td>
<td>3.69 W/(m²K)</td>
</tr>
<tr>
<td>2nd order heat loss coefficient $a_2$</td>
<td>0.007 W/(m²K²)</td>
</tr>
<tr>
<td>Effective heat capacity $c_{eff}$</td>
<td>6.0 kJ/(m³K)</td>
</tr>
</tbody>
</table>

**Heat store parameters**

<table>
<thead>
<tr>
<th></th>
<th>T*SOL Database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat store volume</td>
<td>4000 l</td>
</tr>
<tr>
<td>Auxiliary volume for DHW preparation</td>
<td>1600 l</td>
</tr>
<tr>
<td>Store inner diameter</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Rel. Height of solar inlet</td>
<td>0.4</td>
</tr>
<tr>
<td>Rel. Height of solar outlet</td>
<td>0.02</td>
</tr>
<tr>
<td>Rel. Height of auxiliary inlet</td>
<td>0.95</td>
</tr>
<tr>
<td>Rel. Height of auxiliary outlet</td>
<td>0.6</td>
</tr>
<tr>
<td>Rel. Height of sensor for collector loop</td>
<td>0.19</td>
</tr>
<tr>
<td>Rel. Height of sensor for auxiliary heating</td>
<td>0.75</td>
</tr>
<tr>
<td>Set temperature for DHW</td>
<td>60.0 °C +/− 3 K</td>
</tr>
<tr>
<td>Overall heat loss capacity rate of store</td>
<td>7.7 W/K</td>
</tr>
<tr>
<td>Effective vertical conductivity</td>
<td>1.2 W/(mK)</td>
</tr>
<tr>
<td>Heat transfer capacity rate of solar loop HX $(kA)_{WT,Sol} = 4000$ [W/K]</td>
<td></td>
</tr>
<tr>
<td>Heat transfer capacity rate of auxiliary loop HX $(kA)_{WT,Aux} = 4000$ [W/K]</td>
<td></td>
</tr>
<tr>
<td>Volume solar loop HX (Heat eXchanger)</td>
<td>-</td>
</tr>
<tr>
<td>Volume auxiliary loop HX</td>
<td>-</td>
</tr>
<tr>
<td>Maximum heat store temperature</td>
<td>90 °C</td>
</tr>
<tr>
<td>Ambient temperature of heat store</td>
<td>15 °C</td>
</tr>
</tbody>
</table>

**Solar thermal controller and hydraulic piping**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total pipe length of collector loop</td>
<td>23 m</td>
</tr>
<tr>
<td>Inner diameter of collector loop pipe</td>
<td>15 mm</td>
</tr>
<tr>
<td>Mass flow collector loop</td>
<td>40 kg/(m³h), constant</td>
</tr>
<tr>
<td>Temperature difference collector start-up</td>
<td>8 K</td>
</tr>
</tbody>
</table>
Temperature difference collector shut-off | 3 K
Electric power of solar thermal controller | 3 W
Operating hours of solar thermal controller per year | 8760 h
Electric consumption of controller per year | 26.3 kWh
Electric power of solar loop pump | 25 W
Operating hours of solar loop pump | 2760 h
Electric consumption of solar loop pump per year | 69 kWh

**Conventional back up system**
Type of auxiliary heating | Oil boiler
Boiler capacity | 52 kW
Mass flow | -
Efficiency factor of boiler | 0.85
Electric power of controller | 3 W
Operating hours of controller per year | 8760
Electric consumption of controller per year | 26.3 kWh
Electric power of pump | 12 W
Operating hours of pump (aux. Heating + space heating) | 4190 h
Electric consumption of pump per year | 50.3 kWh

**Investment costs conventional part**
Overall investment costs | 18500 €

**Investment costs solar thermal system**
Solar thermal collector, heat store, solar thermal controller solar thermal hydraulic components | 25150 € [2]
Installation | 6300 € [2]
Credit conventional heat store and share of installation | -4710 € [2]
Overall investment costs solar thermal part I₀ | 26740 €

**Operation costs conventional part per year**
Heat demand hot water | 19790 kWh/a
Fuel demand hot water | 23282 kWh/a
Heat demand space heating | 110400 kWh/a
Fuel demand space heating | 129882 kWh/a
Fuel demand hot water + space heating E₁ | 153165 kWh/a
Cost per kwh fuel (oil) | 0.066 €/kWh [3]
Fuel costs | 10109 €/a
Electricity demand | 76.56 kWh/a
Cost per kwh electric energy | 0.17 € [4]
Electricity costs | 13 €/a
Maintenance costs | 370 €/a
Yearly operation and maintenance cost conventional part C₇ | 10492 €

**Operation costs solar part per year**
Electricity demand | 95.3 kWh/a
Cost per kwh electric energy | 0.17 € [4]
Electricity costs | 16.2 €/a
Maintenance costs ($I_0 \times 2\%$) | 535 €/a  
---|---  
Yearly operation and maintenance cost solar part $C_t$ | 551 €/a  
Fractional energy savings with credit for 1600L-store, $UA=6.4$ W/K | 55.2 %  
Saved final energy (year t) $E_t$ | 28732 kWh  
Type of incentives | None  
Amount of incentives | 0 €  
Lifetime of system | 25 year  
Discount rate $r$ | 0 %  
Inflation rate | 0 %  
Corporate tax rate $TR$ | 0 %  
Asset depreciation (year t) $dep_t$ | 0 €  
Subsidies and incentives (year t) $S_t$ (considered in $I_0$) | 0 €  
Residual value $RV$ | 0 €  
Discount rate $r$ | 0 %  
VAT rate | 20 %  
LCOH solar part without VAT | 0.0564 €/kWh  
LCOH conventional part without VAT | 0.0733 €/kWh  
LCOH complete system without VAT | 0.0707 €/kWh  

Calculation of levelized cost LCOH [5,6]:

$$LCOH = {I_0 + \sum_{t=0}^{T} \frac{C_t(1-TR)-DEP_t \cdot TR - S_t - RV}{(1+r)^t} \over \sum_{t=1}^{T} \frac{E_t}{(1+r)^t}}$$

Where:

- $LCOH$: Levelized cost of heat in €/kWh
- $I_0$: Initial investment in €
- $C_t$: Operation and maintenance costs (year t) in €
- $TR$: Corporate tax rate in %
- $DEP_t$: Asset depreciation (year t) in €
- $S_t$: Subsidies and incentives (year t) in €
- $RV$: Residual value in €
- $S_t$: Saved final energy (year t)/Fuel demand in kWh
- $r$: Discount rate in %
- $T$: Period of analysis in year

Annex: Comparison to figures published in Solar Heat Worldwide

To compare the above presented LCOH based on the saved final energy with the LCOH$_{SHWW}$ presented in Solar Heat Worldwide based on the collector yield ($I_0$ without considering the conventional part, $C_t$: 0.5% of $I_0$, $E_t$ solar collector yield, $r$: 3%, $T$: 25 years) the following table is presented:

| Collector yield (year t) $E_t$ | 24760 kWh  
| LCOH$_{SHWW}$ solar part without VAT | 0.0793 €/kWh$_{th}$ |
References

[1] AEE INTEC


