Modelling the Drake Landing Solar Community with TRNSYS 17 and estimating its potential under Helsinki conditions

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Outline

Goals
1. Make model of DLSC;
2. Localise it to Helsinki;
3. Make modifications in order to maximise solar frac (or REF).

Some definitions
Solar fraction = Solar energy / total energy demand → gas boilers
Renewable energy fraction (REF) = (Solar + ground energy) / total energy demand → heat pump
Drake Landing Solar Community (DLSC)

- 52 single family detached houses
- 798 solar collectors
- Borehole thermal energy storage (BTES): 144 boreholes
- Short-term thermal storage (STTS) water tanks: 2 x 120 m³

How it works

Modes of operation
- Sunny summer (charging): Heat flow from solar collectors to boreholes
- Dark winter (discharging): Heat flow from boreholes to district heating loop
- Other: Mix of both charging and discharging
Modelling the DLSC

- Solar collector model:
  Same performance equation to that of the DLSC (inc. transmission losses)
- Simplified house model:
  Obtained a similar heating demand as in the DLSC: approx. 100 kWh / (m² year)
- Borehole model:
  Used the same configuration and soil properties as those in the DLSC
- STTS tanks:
  Merged the tanks to a single unit and obtained similar heat losses

Simulation vs. Official DLSC results

Energy balance around the STTS tanks

Differences in results due to:
- System changes made throughout the years in DLSC; not inc. in model
- Simplifications had to be made

1st July 2007 → 30th June 2011
Relocalise to Helsinki

Soil properties DLSC Helsinki

<table>
<thead>
<tr>
<th>Property</th>
<th>DLSC</th>
<th>Helsinki</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\lambda) [W/(m K)]</td>
<td>1.37</td>
<td>3.5</td>
</tr>
<tr>
<td>(\rho C) [MJ/(m^3 K)]</td>
<td>3.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Untouched ground temp. [°C]</td>
<td>4</td>
<td>5.6</td>
</tr>
</tbody>
</table>

How to improve Helsinki results

First, understand which parameters are key...

Environment-side
- Solar radiation
- Soil properties
- Outdoor temperature

Demand-side
- Heating demand (insulating the houses)
- Lowering the water supply setpoint temperature
- Further insulating the STTS tanks

... then, by how much they affect the results!
Environment-side

- Solar radiation has the largest impact: importance to maximise use of solar heat

Demand-side

- The passive standard considerably increases the solar fraction
- Lowering the water supply setpoint further improves the solar fraction (despite lower ground temperatures)
Replacing the gas boilers with a heat pump – Schematic representation

Differences with previous model:
- No more gas boilers
- Unmerged STTS tanks
- Heat pump placed between both tanks

Note:
There exists many alternative configurations and design options

Solar fraction (Gas boilers) vs. Renewable Energy Fraction (Heat pump)

Case 3

- For high solar collector areas (e.g. 100%), solar storage gives the highest level of grid energy independence.
- For low solar collector areas (e.g. 25%), solar storage combined with ground energy retrieval gives the highest level of grid energy independence.

⚠️ Due to max. evaporator temp. of heat pump (26°C), REF is limited as solar area increases

⚠️ Note: Non-solar frac. = Gas; Non-renewable frac. = Electricity
Further work

Finer tuning model
- Added shading to the houses, preventing summer overheating
- Included system downtime
- Reduced energy imbalances (from ~3 to <1%)
- Run all simulations with ‘finer-tuning’ model
- Run simulations with different heat pumps (higher evaporator temperatures)
- Run simulations in several locations worldwide (e.g. China, Spain, Ireland)

Conclusions (so far)

- High solar frac. and REF achievable in Southern Finland (despite low solar radiation levels in winter and mediocre soil properties)
- Higher levels of insulation in Helsinki means that higher initial investment costs are required (~€2.7 million to rebuild the DLSC (ex. houses) in North America today)
- If such high solar frac. / REF levels can be achieved at 60°N, this means that there is a huge potential for solar & ground source space heating across the globe!
Thank you for listening!

Questions?

Official results

- 97% solar fraction in 5th year
- Associated electricity consumption per household = 1085 kWh/ year (equiv. to 3 iPhones; “The cloud begins with coal”)

- 5 years to fully charge the ground
- Borehole temperature does not exceed 80°C
- Estimated design life: 50 years
**Costs**

Costs if reconstructed in North-America

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (CAD$ 2006-07)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Collectors</td>
<td>710,000</td>
</tr>
<tr>
<td>Installation of Solar Collectors</td>
<td>350,000</td>
</tr>
<tr>
<td>Seasonal Storage Borehole Field</td>
<td>620,000</td>
</tr>
<tr>
<td>District Heating &amp; Solar Collection Loops</td>
<td>1,025,000</td>
</tr>
<tr>
<td>Energy Centre including STTS Tasks</td>
<td>600,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3,385,000</strong></td>
</tr>
</tbody>
</table>

If on-site flooding led to increased costs for the project, which is not included above.

Today, Drake Landing inhabitants pay a fixed charge of 60 CAD$/month ± their consumption in comparison to the community’s average consumption.

Note: On-site flooding led to increased costs for the project, which is not included above.

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**Weather data**

Weather data used for **Okotoks** was in fact Calgary data.

Source: Canadian weather energy and engineering data sets (CWEEDS files). [Online] [Cited: 19/12/12.]

Weather data used for **Helsinki** was in fact Vantaa data.

Standard and Passive house models

House models (52 houses assumed identical)

<table>
<thead>
<tr>
<th></th>
<th>Passive</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-value for walls, floor, ceiling, roof</td>
<td>0.09 W / (m² K)</td>
<td>0.21 W / (m² K)</td>
</tr>
<tr>
<td>U-value for front and back doors</td>
<td>0.2 W / (m² K)</td>
<td>Modelled as a window</td>
</tr>
<tr>
<td>U-value for windows</td>
<td>0.7 W / (m² K)</td>
<td>1 W / (m² K)</td>
</tr>
<tr>
<td>G-value for windows</td>
<td>60.1 %</td>
<td>32.8 %</td>
</tr>
<tr>
<td>Glazed area / floor area</td>
<td>15%</td>
<td>7.5%</td>
</tr>
<tr>
<td>Floor area</td>
<td>142.5 m²</td>
<td>142.5 m²</td>
</tr>
<tr>
<td>Internal gains (see below for details)</td>
<td>2.7 W / m²</td>
<td></td>
</tr>
<tr>
<td>Air change rate</td>
<td>0.5 vól / hr</td>
<td>0.5 vól / hr</td>
</tr>
<tr>
<td>Heat recovery efficiency</td>
<td>80 %</td>
<td>69 %</td>
</tr>
<tr>
<td>House heating setpoint</td>
<td>20°C</td>
<td>20.3°C</td>
</tr>
</tbody>
</table>

Internal gains for Passive standard comply to D3 (2012) code of Finland’s National building regulations

Heat demand profile comparison (Standard case)

Official DLSC heating demand profile

Simulated heating demand profile
Solar thermal collectors and air-handler / heat recovery units

Solar collectors (space heating)

- Serpentine copper tubing fixed to aluminium absorber
- Tilt: 45°; Azimuth: South
- Gross area: 2.873 m$^2$, Net aperture area: 2.691 m$^2$
  - Variable speed pump, design flow rate: 1.2 L/min
  - All collectors connected in parallel

Air-Handler and heat recovery unit

- Situated in the Energy Centre
- Volume: 2 x 120 m$^3$
- Max. temperature difference across each tank: 15°C

Short-term thermal storage (STTS) tanks

- Gas boiler configuration
- Heat pump configuration
- Drake Landing configuration

Model parameters (tanks outdoors)

STTS heat losses: 1.6 W/(m$^2$ K)
Losses with additional insulation: 0.3 W/(m$^2$ K)
Borehole thermal energy storage (BTES)

- Charging: Hot flow sent to centre and cold water recovered from outer edges
- Discharging: Cold flow sent to outer end and hot water recovered from the centre

- Maximum heat always kept in the centre
- 144 boreholes, each 35m deep
- Connected in 24 parallel strings each containing 6 boreholes in series

District heating network and water supply temperature

- Heat transfer from the STTS tanks to the homes
- District loop exclusively supplies heat to the 52 DLSC houses

Backup gas boilers

When insufficient solar energy: two gas boilers (469 + 353 kW) supply the remaining heat
All heating energy must pass by the heat pump

\[ \text{REF} = \frac{\text{Renewable energy}}{\text{Total energy}} = \frac{\text{evaporator}}{\text{evaporator} + \text{compressor}} = \frac{\text{condenser} - \text{compressor}}{\text{condenser}} = 1 - \frac{1}{\text{COP}} \]

Ground temperature (all cases below comply with case 3)

Helsinki simulation vs. Official DLSC results
Poor BTES efficiency with large collector area
- Poor use of collected solar energy
- Equal amount heat discharged from ground – independent of solar area (due to max. Evaporator temperature of 26°C)

Heat pump controls
- Bottom node: temperature of the node at the bottom of the hot STTS tank [°C]
- Tw: Required water supply temperature [°C] (dependent on the outdoor temperature and the distribution losses in the district heating network)
- DeltaT: expected water temperature drop through heating the community [°C] (dependent on the water supply temperature that arrives in the homes)
- Top 2 nodes: average temperature of these nodes in the hot STTS tank [°C]
- HP CH: Heat pump control (0: Off; 1: On at maximum regime)
- °: deadband of 0.5 °C
- °°: deadband of 2 °C
Heat pump statistics (25% solar area case)

Nominal heat capacity: 125 kW total (divided into 15 heat pumps)
Nominal flow rate: 6 L/s total (divided into 15 heat pumps)

Heat pump used in model: TRANE WPWD 024