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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

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Drake Landing Solar Community (DLSC)

50.7° N, 114.0° W

- 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 m^3

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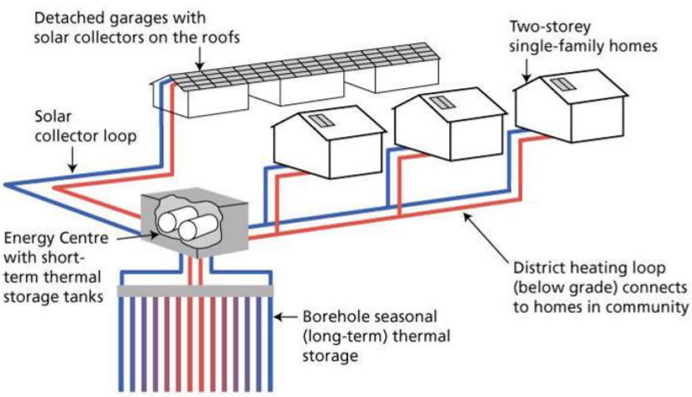
How it works



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

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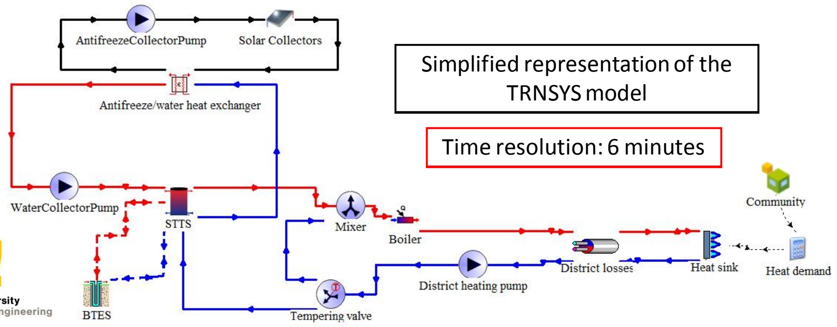
Modelling the DLSC

- 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 / (m^2 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



Simplified representation of the TRNSYS model

Time resolution: 6 minutes

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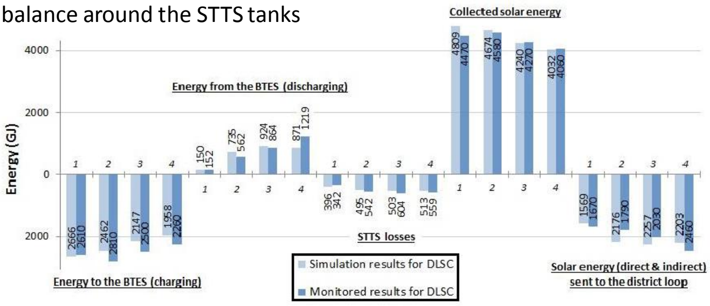
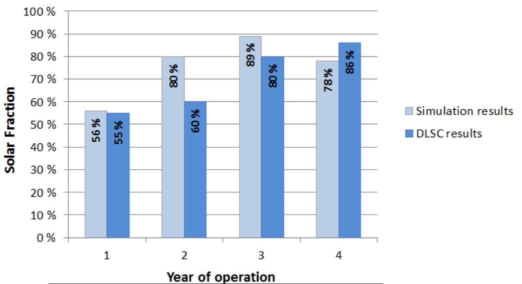
Simulation vs. Official DLSC results

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

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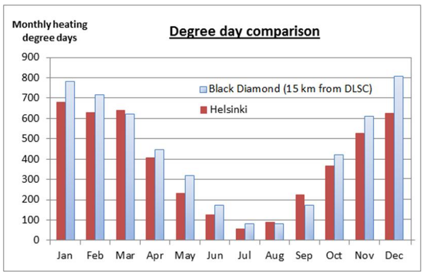
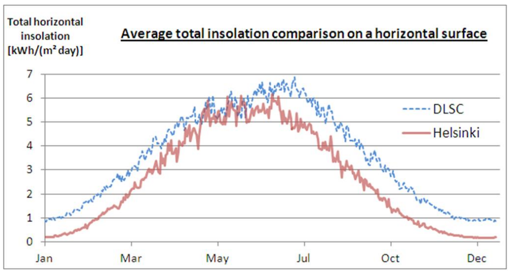
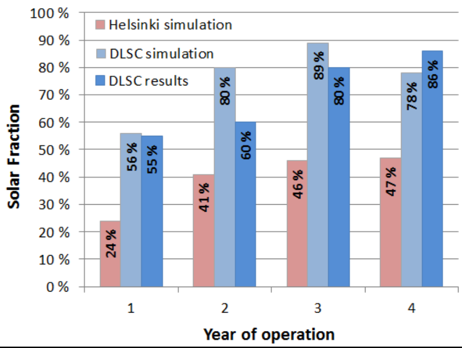
Relocalise to Helsinki





Soil properties	DLSC	Helsinki
λ [W / (m K)]	1.37	3.5
ρC [MJ / (m³ K)]	3.2	2.2
Untouched ground temperature [°C]	4	5.6



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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!

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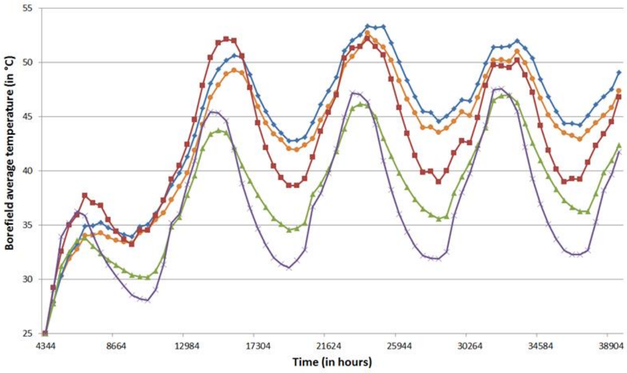
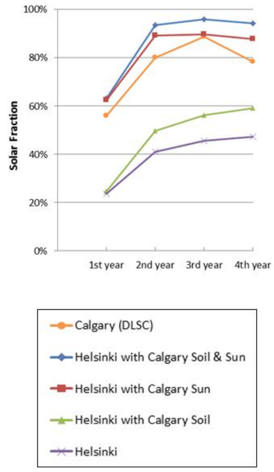
Environment-side





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

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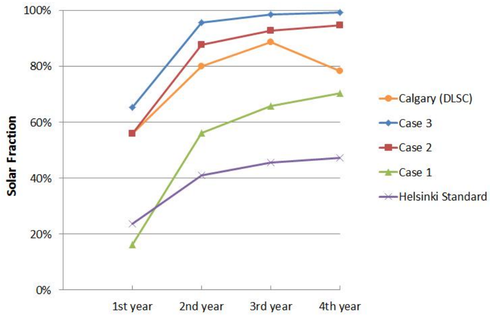
Demand-side

	Helsinki - Standard	Case 1	Case 2	Case 3	Calgary (DLSC)
Standard houses (like in the DLSC)	✓				✓
Passive houses (including internal heat gains)		✓	✓	✓	
Lower water supply setpoint temperature			✓	✓	
Additional insulation in the STTS tanks and district heating network				✓	



- The passive standard considerably increases the solar fraction
- Lowering the water supply setpoint further improves the solar fraction (despite lower ground temperatures)

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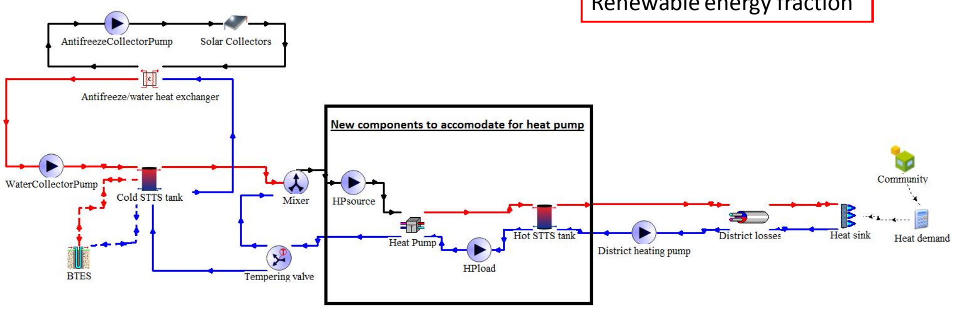
Replacing the gas boilers with a heat pump – Schematic representation

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

Index of performance:
Renewable energy fraction



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Note:
There exists many alternative configurations and design options

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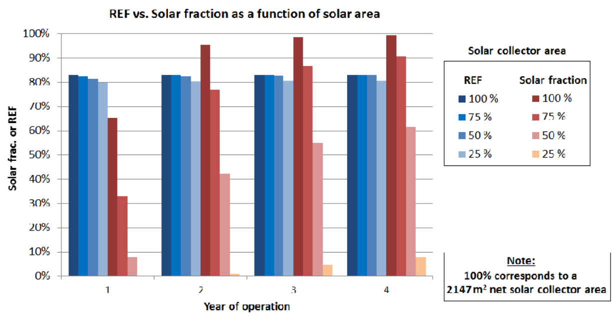
Solar fraction (Gas boilers) vs. Renewable Energy Fraction (Heat pump)

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

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

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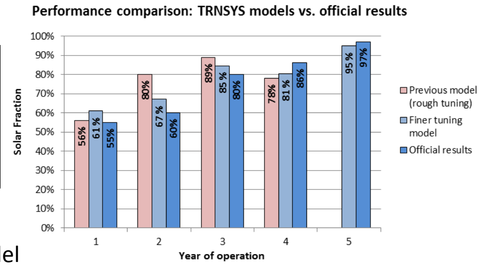
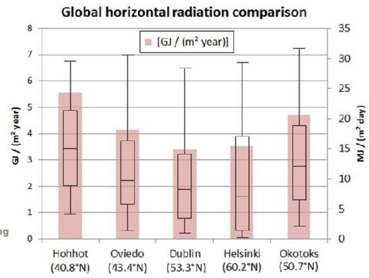
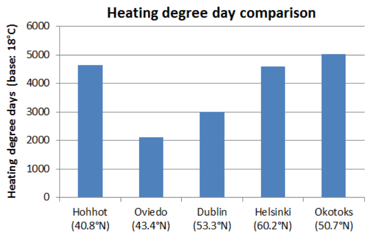
Further work

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)





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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 (exc. 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!

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Thank you for listening!

Questions?

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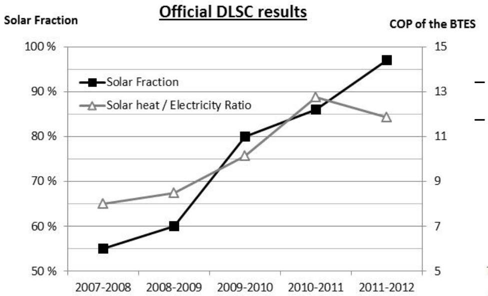
Official results

DLSC results



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

- 97% solar fraction in 5th year
- Associated electricity consumption per household = 1085 kWh / year

(equiv. to 3 iPhones; ”The cloud begins with coal”)

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Costs

Costs if reconstructed in North-America

Item	Cost (CAD$ 2005-07)
Solar Collectors	710,000
Installation of Solar Collectors	430,000
Seasonal Storage Borehole Field	620,000
District Heating & Solar Collection Loops	1,025,000
Energy Centre including STTS Tanks	600,000
Total	3,385,000

~ € 2.6 M (2012)

- If annual and operating costs as well as the replacement of most of the solar collectors, the unit cost of solar energy over 40 years is estimated at **0.17 CAD$/kWh (~0.13 €/kWh)**
- Today, Drake Landing inhabitants pay a fixed charge of 60 CAD$/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

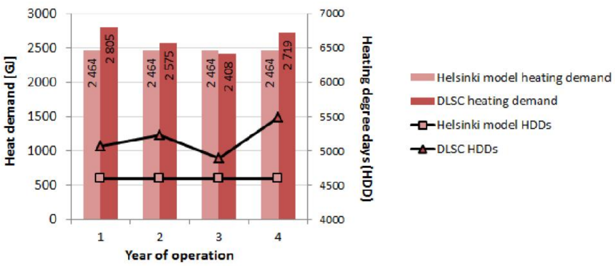
Weather data used for **Okotoks** was in fact Calgary data.

Source: Canadian weather energy and engineering data sets (CWEEDS files). [Online] [Cited: 19/12/12.] ftp://arcdm20.tor.ec.gc.ca/pub/dist/climate/CWEC/ENGLISH/CWEEDS%20documentation_Release9.txt.

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

Source: *Development of weighting factors for climate variables for selecting the energy reference year according to the EN ISO 15927-4 standard.* **T. Kalamees, K. Jylhä, H. Tietäväinen, J. Jokisalo, S. Ilomets, R. Hyvönen, and S. Saku.** Vols. Energy and Buildings 47 (2012) 53–60.

Standard house case:



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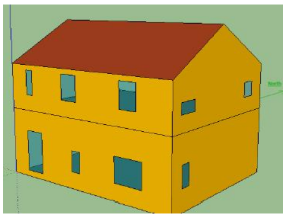
Standard and Passive house models

House models (52 houses assumed identical)

	Passive	Standard
U-value for walls, floor, ceiling, roof	0.08 W / (m^2 K)	0.21 W / (m^2 K)
U-value for front and back doors	0.2 W / (m^2 K)	Modelled as a window
U-value for windows	0.7 W / (m^2 K)	1 W / (m^2 K)
G-value for windows	50.1 %	32.8%
Glazed area / floor area	15%	7.5%
Floor area	142.5 m^2	142.5 m^2
Internal gains (see below for details)	2.7 W / m^2	
Air change rate	0.5 vol / hr	0.5 vol / hr
Heat recovery efficiency	80 %	69 %
House heating setpoint	20°C	20.3°C

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



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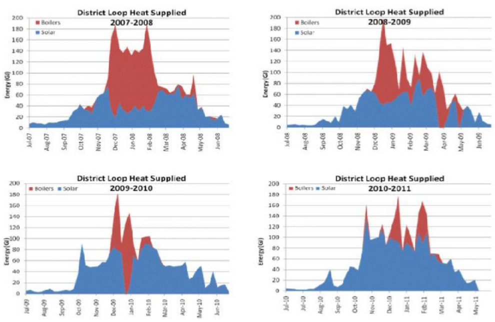
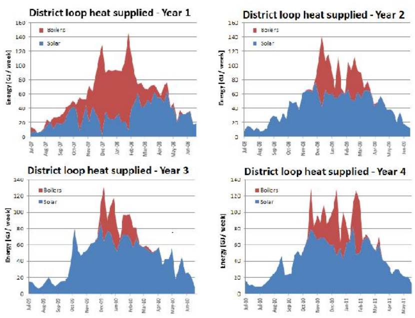
Heat demand profile comparison (Standard case)

Official DLSC heating demand profile



Simulated heating demand profile



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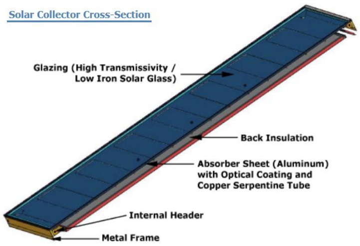
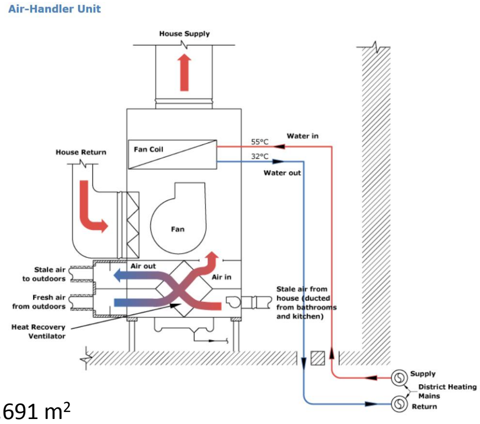
Solar thermal collectors and air-handler / heat recovery units

Solar collectors (space heating)



Air-Handler and heat recovery unit



- 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

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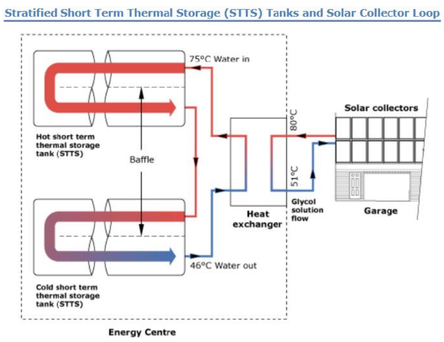
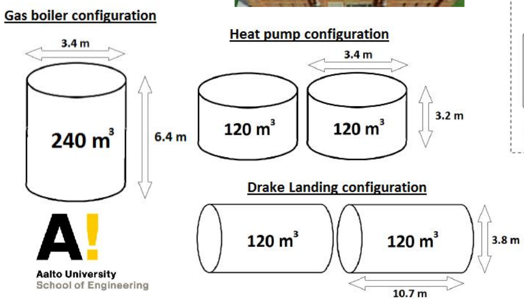
Short-term thermal storage (STTS) tanks

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





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Model parameters (tanks outdoors)

STTS heat losses: 1.6 W/(m^2 K)
Losses with additional insulation: 0.3 W/(m^2 K)

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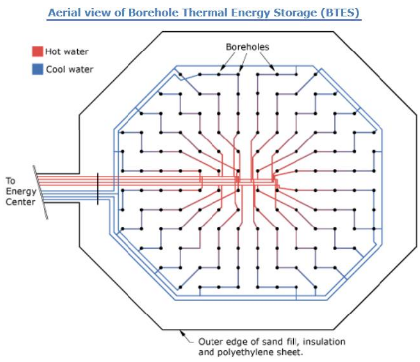
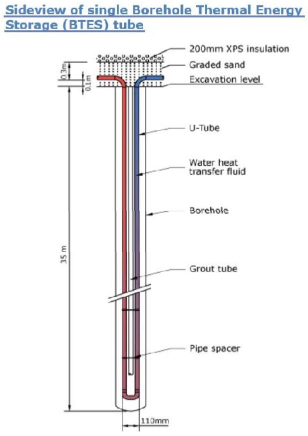
Borehole thermal energy storage (BTES)

- 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

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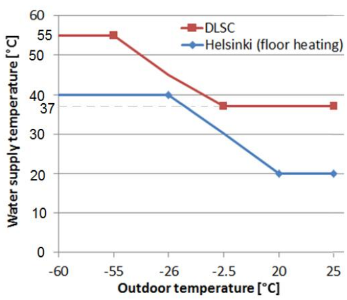
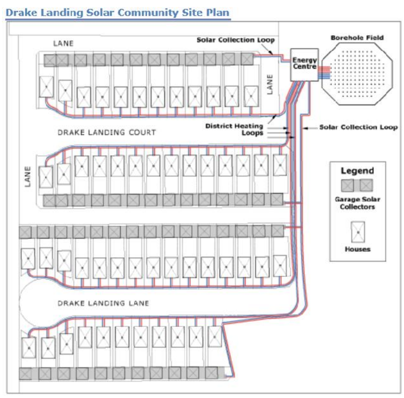
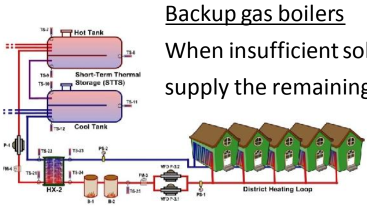
District heating network and water supply temperature

- 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

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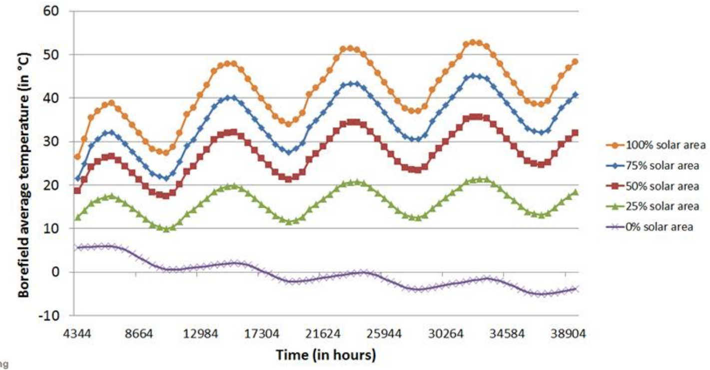
Heat pump model

All heating energy must pass by the heat pump

$$REF = \frac{Renewable\ energy}{Total\ energy} = \frac{evaporator}{evaporator + compressor} = \frac{condenser - compressor}{condenser} = \boxed{1 - \frac{1}{COP}}$$

Ground temperature (all cases below comply with case 3)



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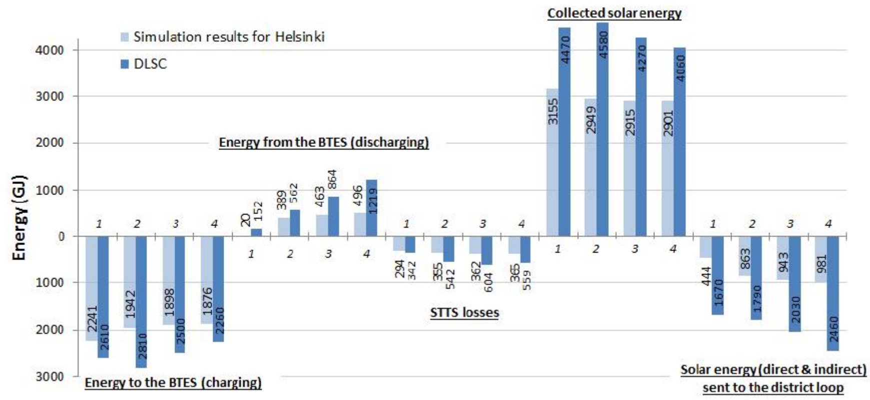
Helsinki simulation vs. Official DLSC results



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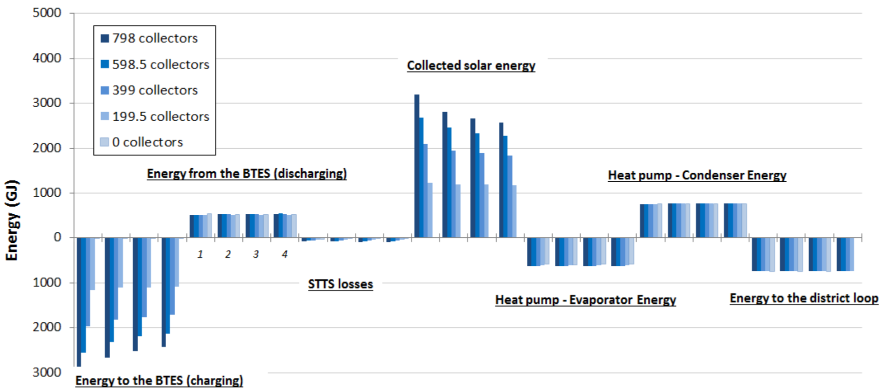
Heat pump model (all highly insulated)



- 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)

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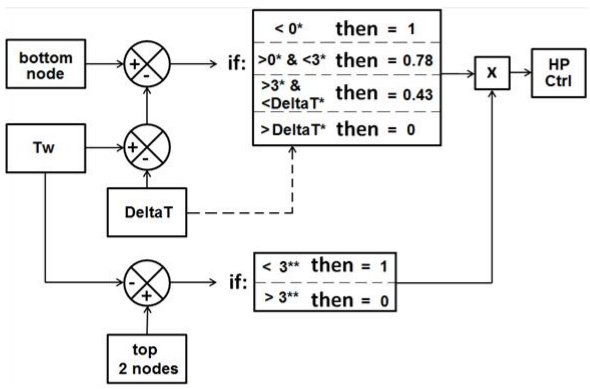
Heat pump controls



- Bottom node: temperature of the node at the bottom of the hot STTS tank [°C]
- Tw: Required water supply temperature [°C] (dependant on the outdoor temperature and the distribution losses in the district heating network)
- DeltaT: expected water temperature drop through heating the community [°C] (dependant 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 Ctrl: Heat pump control (0: Off; 1: On at maximum regime)
- *: deadband of 0.5 °C
- **: deadband of 2 °C

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Heat pump statistics (25% solar area case)

Temperature target

Too cool		too warm	
2141	steps off target	159879	steps off target
<1 degree off target	1733 time steps	<1 degree off target	11185 time steps
>1 but < 2 degrees off target	271 time steps	>1 but < 2 degrees off targe	69815 time steps
>2 but < 3 degrees off target	118 time steps	>2 but < 3 degrees off targe	68120 time steps
>3 but < 5 degrees off target	19 time steps	>3 but < 5 degrees off targe	9928 time steps
>5 but < 10 degrees off targe	0 time steps	>5 but < 10 degrees off targ	746 time steps

140	max consecutive time steps when Tsupply < Tw
3309	max consecutive time steps when Tsupply > Tw

HP is on for	65031 time steps
Max time ON	302 time steps
Average time ON	36.5 time steps
Median time ON	23 time steps

HP maximum flow on for	3643 time steps
HP medium flow on for	60920 time steps
HP minimum flow on for	468 time steps

Energy target

Too little energy		too much energy	
60208	steps off target	99940	steps off target
<=0.01% off target	58186 time steps	<=0.01% off target	70428 time steps
>0.01% and <=0.1% off target	1405 time steps	>0.01% and <=0.1% off targ	28212 time steps
>0.1% and <=1% off target	482 time steps	>0.1% and <=1% off target	1200 time steps
>1% and <=2% off target	42 time steps	>1% and <=2% off target	44 time steps
>2% and <=5% off target	53 time steps	>2% and <=5% off target	28 time steps

HP ON/OFF cycles	1551

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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

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