

Storage Tank A3s; an Example of Conceptual Modeling

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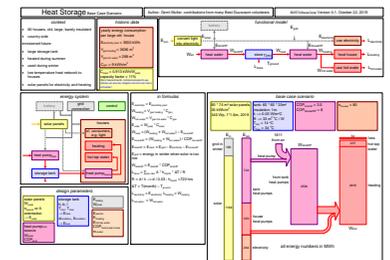
Abstract

A challenge for sustainable heating in the Netherlands is coping with the seasonal variations of heat demand and renewable supply. This presentation shows a set of conceptual models to explore how a large water tank in the ground may store heat in the summer to use it in the winter.

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context

- 80 houses, old, large, barely insulated
 - country side
- envisioned future:
- large storage tank
 - heated during summer
 - used during winter
 - low temperature heat network to houses
 - solar panels for electricity and heating

historic data

yearly energy consumption per large old house

$$E_{\text{electricity past}} = 3550 \text{ kWh}$$

$$V_{\text{gas heating}} = 3636 \text{ m}^3$$

$$V_{\text{gas hot water}} = 288 \text{ m}^3$$

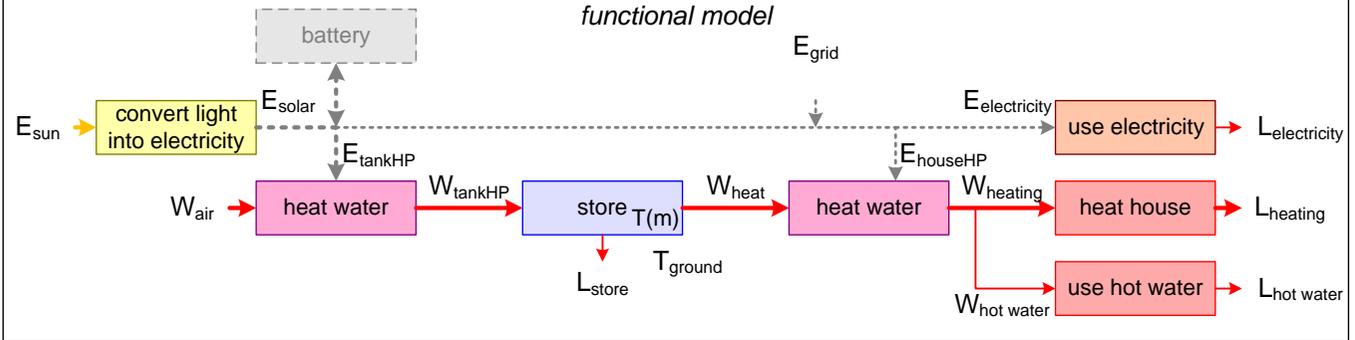
$$C_{\text{gas}} = 9 \text{ kWh/m}^3$$

$$C_{\text{solar}} = 0,913 \text{ kWh/W}_{\text{peak}}$$

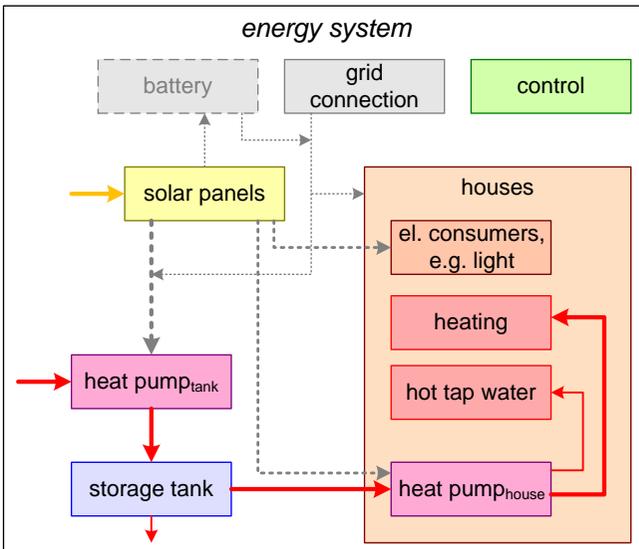
$$\text{capacity factor} = 11\%$$

<https://www.linkedin.com/pulse/waarom-wemoeten-en-kunnen-stoppen-met-het-van-hans-schneider/>

functional model



energy system



design parameters

solar panels W_{peak} n_{panels} or A orientation $\rightarrow E_{\text{solar}}$	storage tank h, b, l $T_{\text{min}}, T_{\text{max}}$ $\rightarrow E_{\text{tank}}$ $d_{\text{insulation}}, \lambda_{\text{insulation}}$ $\rightarrow E_{\text{loss}}$	Battery E_{battery} W_{peak}
heat pump_{tank} source W_{peak} COP_{tank}	House E_{electric} E_{heating} $E_{\text{hot tap water}}$ $\text{COP}_{\text{heat pump house}}$ n_{houses}	

in formulas

$$E_{\text{electricity}} = E_{\text{electricity past}}$$

$$W_{\text{heating}} = V_{\text{gas heating}} * C_{\text{gas}}$$

$$W_{\text{hot water}} = V_{\text{gas hot water}} * C_{\text{gas}}$$

$$E_{\text{solar}} = W_{\text{peak}} * C_{\text{solar}}$$

$$W_{\text{heat}} = (W_{\text{heating}} + W_{\text{hot water}}) - E_{\text{houseHP}}$$

$$E_{\text{houseHP}} = (W_{\text{heating}} + W_{\text{hot water}}) / \text{COP}_{\text{houseHP}}$$

$$E_{\text{tankHP}} = E_{\text{solar}} + E_{\text{grid}} - E_{\text{electricity}} - E_{\text{houseHP}}$$

$$E_{\text{grid}} = \text{energy in winter when solar is too low}$$

$$W_{\text{tankHP}} = E_{\text{tankHP}} * \text{COP}_{\text{tankHP}}$$

$$L_{\text{store}} = \sum_{\text{jan..dec}} A * h_{\text{month}} * \Delta T / R$$

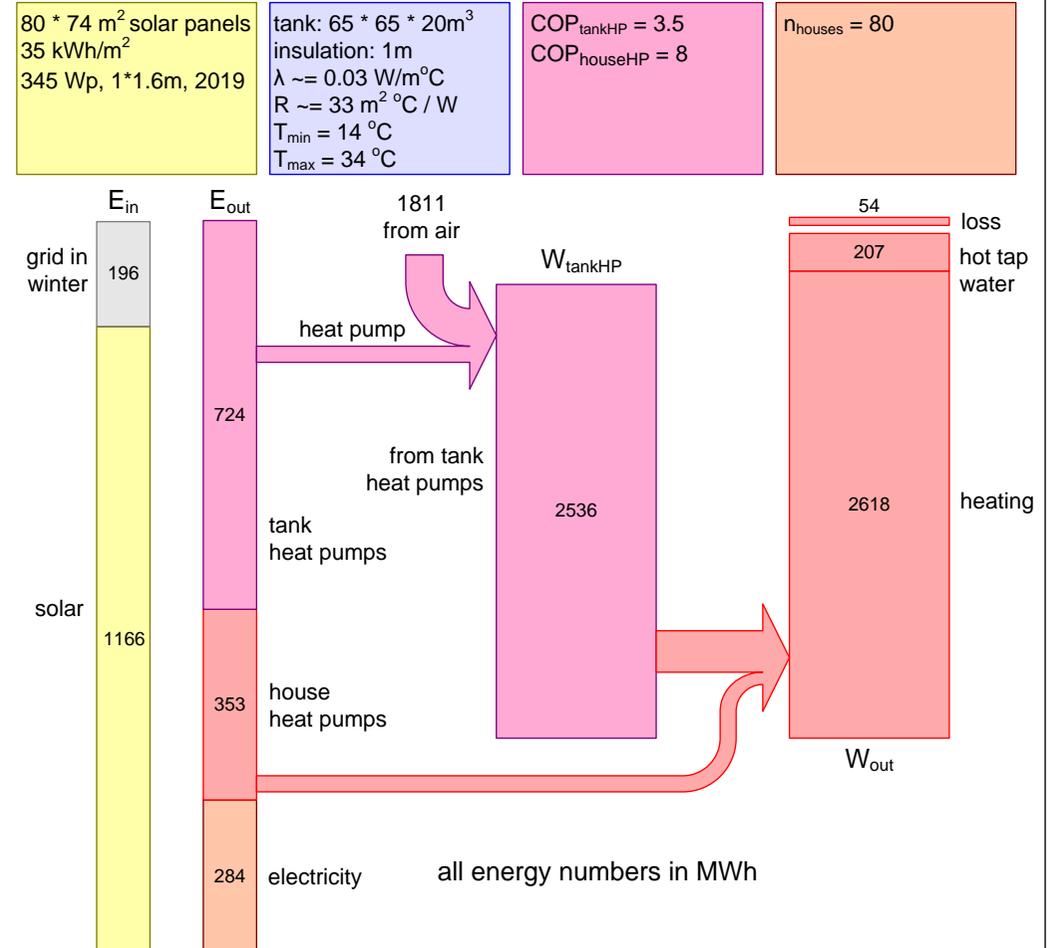
$$R = d / \lambda \approx d / 0.03 ; h_{\text{month}} = 720 \text{ hrs}$$

$$\Delta T = T(\text{month}) - T_{\text{ground}}$$

$$L_{\text{electricity}} = E_{\text{electricity}}, L_{\text{heating}} = W_{\text{heating}}$$

$$L_{\text{hot water}} = W_{\text{hot water}}$$

base case scenario



2 bad insulation scenario

- 0.1m insulation *i.s.o.* 1m
- consequences
- $W_{loss} = 561\text{MWh}$ *i.s.o.* 54 MWh
- $80 * 84 \text{ m}^2$ solar panels *i.s.o.* $80 * 72 \text{ m}^2$

3 low tank temperature scenario

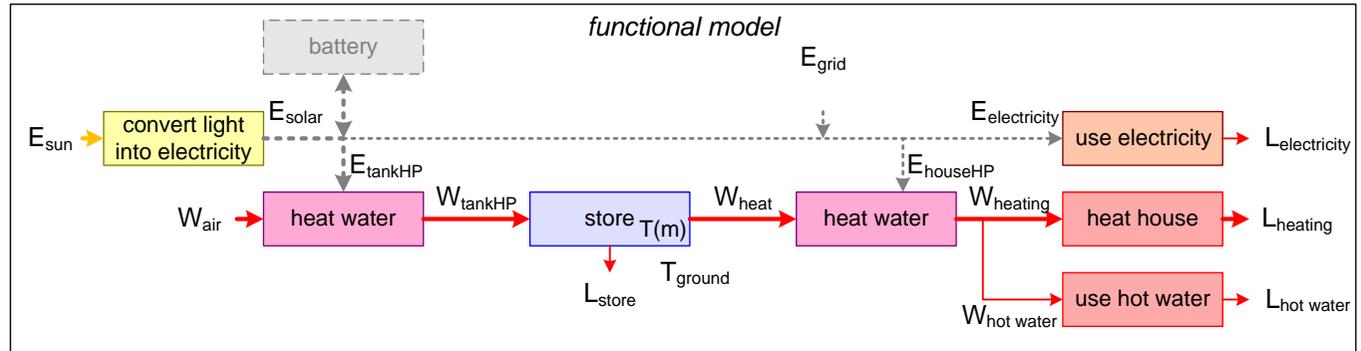
- $T_{min} = 8^\circ\text{C}$, $T_{max} = 25^\circ\text{C}$ *i.s.o.* 14..34°C
- consequences
- $b, l = 72 \text{ m}$ *i.s.o.* 65 m
- less loss in pipes of heat network (not modeled)

4 medium size tank scenario

- $b, l = 59 \text{ m}$ *i.s.o.* 65 m
- consequences
- $T_{min} = 12^\circ\text{C}$, $T_{max} = 36^\circ\text{C}$ *i.s.o.* 14..34°C
- less capacity for extreme winters

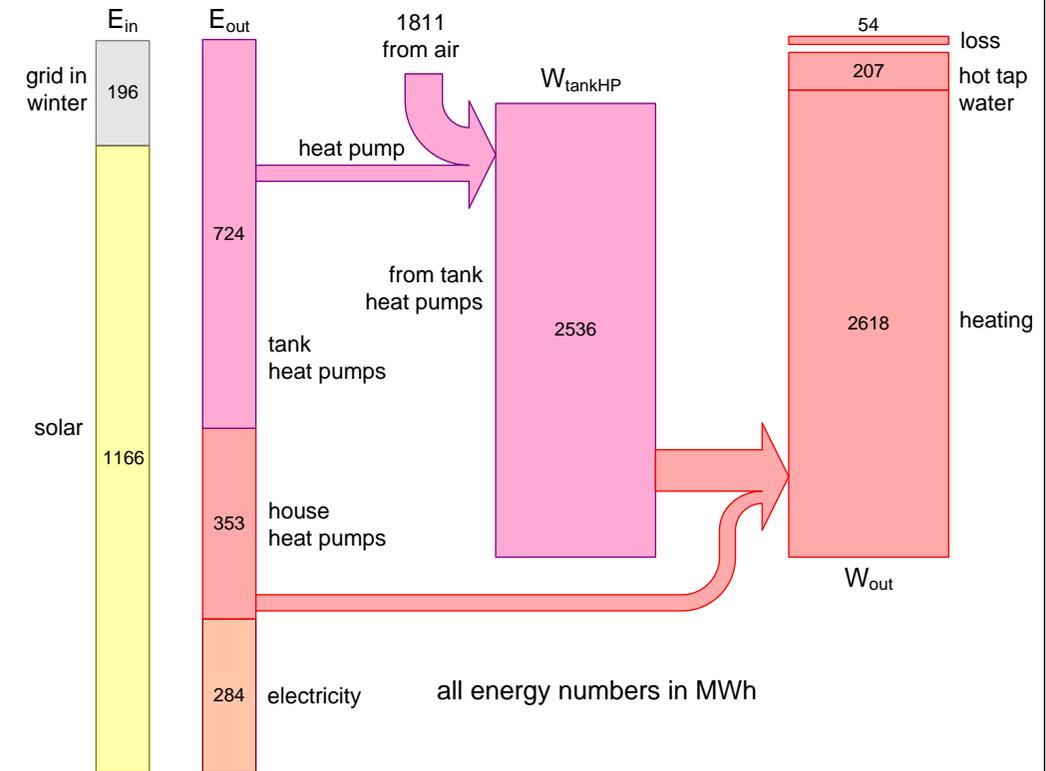
5 small tank scenario

- $b, l = 51 \text{ m}$ *i.s.o.* 65 m
- consequences
- $T_{min} = 10^\circ\text{C}$, $T_{max} = 43^\circ\text{C}$ *i.s.o.* 14..34°C
- less capacity for extreme winters



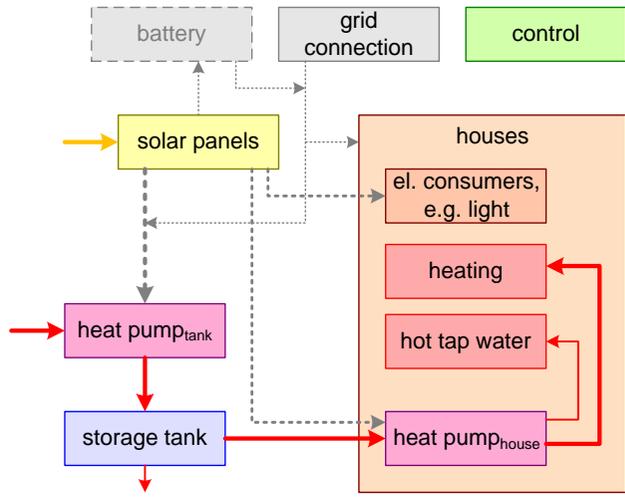
base case scenario

- 80 * 74 m² solar panels
35 kWh/m²
345 Wp, 1*1.6m, 2019
- tank: 65 * 65 * 20m³
insulation: 1m
 $\lambda \sim 0.03 \text{ W/m}^\circ\text{C}$
 $R \sim 33 \text{ m}^2 \text{ }^\circ\text{C} / \text{W}$
 $T_{min} = 14^\circ\text{C}$
 $T_{max} = 34^\circ\text{C}$
- $\text{COP}_{\text{tankHP}} = 3.5$
 $\text{COP}_{\text{houseHP}} = 8$
- $n_{\text{houses}} = 80$



scenarios		1	2	3	4	5
		base case	bad insulation	low temp	medium tank	small tank
Oct 17, 09:21						
T start January		25	25	17	25	28
T high		40	40	30	40	45
T low		10	10	5	10	15
desired capacity	MWh	3000	3000	3000	2400	1800
d	m	1	0,1	1	1	1
solar area per house	m2	74	84	74	74	74
h	m	20	20	20	20	20
old large house/average house		3	3	3	3	3
#houses per block		80	80	80	80	80
Eelectricity	MWh	284	284	284	284	284
EhouseHeatPumps	MWh	353	353	353	353	353
Esolar	MWh	1166	1323	1166	1166	1166
Egrid	MWh	196	177	196	196	196
EtankHeatumps	MWh	724	863	724	724	724
Wheating	MWh	2618	2618	2618	2618	2618
WhotWater	MWh	207	207	207	207	207
Wloss	MWh	54	561	31	45	42
WfromHeatPumps	MWh	2536	3021	2536	2536	2536
WfromAir	MWh	1811	2158	1811	1811	1811
TminActual	oC	14	14	8	12	10
TmaxActual	oC	34	35	25	36	43
DTjan	oC	0,1	-0,1	0,3	0,2	0,4
b, l	m	65	65	72	59	51

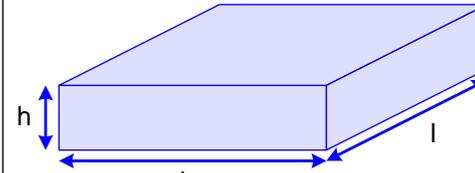
energy system



design parameters

<p>solar panels W_{peak} n_{panels} OR A orientation → E_{solar}</p>	<p>$E_{battery}$ W_{peak}</p>
<p>heat pump_{tank} source W_{peak} COP_{tank}</p>	<p>$E_{electric}$ $E_{heating}$ $E_{hot\ tap\ water}$ $COP_{heat\ pump\ house}$ n_{houses}</p>
<p>storage tank h, b, l T_{min}, T_{max} → E_{tank} $d_{insulation}, \lambda_{insulation}$ → E_{loss}</p>	

storage tank



$$V = h * b * l$$

$$A = 2 * (h * b + h * l + b * l)$$

$$E_{stored} = V * (T_{high} - T_{low}) * C_{water}$$

$$C_{water} = 4.2 \text{ kJ/kg/}^\circ\text{C} = 4.2 \text{ MJ/m}^3/\text{}^\circ\text{C}$$

$$= 1.17 \text{ kWh/m}^3/\text{}^\circ\text{C}$$

example with numbers

$$h = 25\text{m}, b = 100\text{m}, l = 100\text{m}$$

$$V = 25 * 100 * 100 = 0.25 * 10^6 \text{ m}^3$$

$$A = 30 * 10^3 \text{ m}^2$$

$$T_{high} = 80 \text{ }^\circ\text{C}$$

$$T_{low} = 10 \text{ }^\circ\text{C}$$

$$E_{stored} = 0.25 * 10^6 * 70 * 4.2 * 10^6 \text{ J}$$

$$\sim 74 * 10^{12} \text{ J} \sim 20 * 10^3 \text{ MWh}$$

heat loss

$$Q = A * h * \Delta T / R \text{ (a)}$$

h = duration in hours

$$R = d / \lambda \text{ (b)}$$

$$\lambda \sim 0.03 \text{ W/m}^\circ\text{C} \text{ (c)}$$

a <http://www.joostdevree.nl/shtmls/warmtestroom.shtml>
 b <http://www.joostdevree.nl/shtmls/r-waarde.shtml>
 c <http://www.ekbuwadvies.nl/tabellen/lambdamaterialen.asp>

example with numbers

$$A = 30 * 10^3 \text{ m}^2$$

$$\Delta T = 70 \text{ }^\circ\text{C}$$

$$d = 1\text{m}$$

$$R = 33 \text{ m}^2 \text{ }^\circ\text{C W}^{-1}$$

$$Q_{1hr} = 30 * 10^3 * 70 / 33 \sim 63 \text{ kWh}$$

$$Q_{24hr} \sim 1.5 \text{ MWh}$$

$$Q_{1month} \sim 46 \text{ MWh}$$

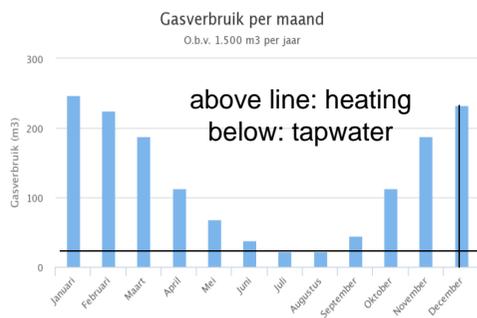
heat demand per year per typical house

gas consumption = 1500 m³/year/house

1 m³ gas = 9 kWh

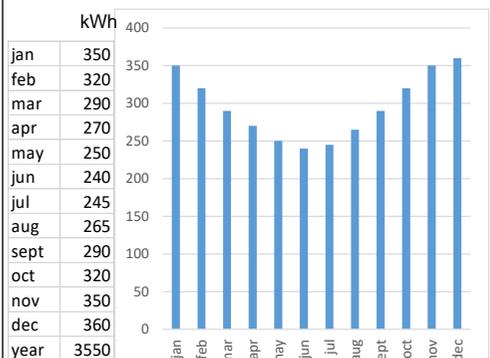
$E_{heating+tapwater} = 13.5 \text{ MWh/year/house}$

typical gas consumption per month



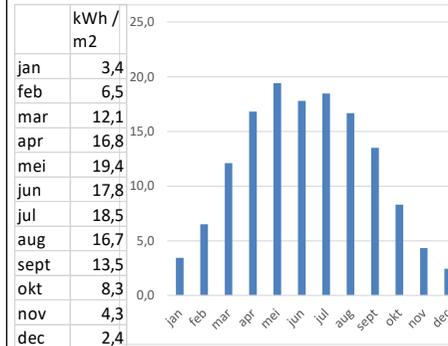
<https://www.energiesite.nl/veelgestelde-vragen/wat-is-een-gemiddeld-gasverbruik/>

typical electricity consumption per month



Gerrit's thumb, based on average family energiesite.nl

typical solar production per month



5 year average of solar panels at Notenboom 6, Best kWh/m2 for 245 Wp panels facing South East @ ~40 degrees

Assessment Criteria

PESTEL

- Political
- Economic
- Social
- Technical
- Environmental
- Legal

Political

- social acceptance
- fit with regional and national politics
- reputation risk

Economic

- CAPEX
- OPEX
- time to deployment
- life time
- risks
- viable business model

Social

- affordable for all
- participation by all
- disruption of deployment
- side effects (e.g.noise)

Technical

- readiness level
- complexity
- competence level
- effectiveness/ performance
- robustness

Environmental

- foot print
- impact on flora and fauna

Legal

- fits in current legislation

Concepts that need assessment

solar

PV panel type TEc

heat collectors TEc

trackers TEc

inverters TEc

payment Ec

governance, owner PEcSL

location PSEn

battery

type TEc

location PSEn

electric network

measuring Ec

payment Ec

governance, owner PEcSL

tank heat pump

type TEc

source TEc

location PSEn

storage tank

insulation TEc

shape TEc

construction TEc

location PSEn

heat network

type TEc

measuring Ec

payment Ec

governance, owner PEcSL

in-house heat equipment

heat pump type TEc

local tank TEc

control

energy management TEc

handling extremes TEc

maintenance TEc

