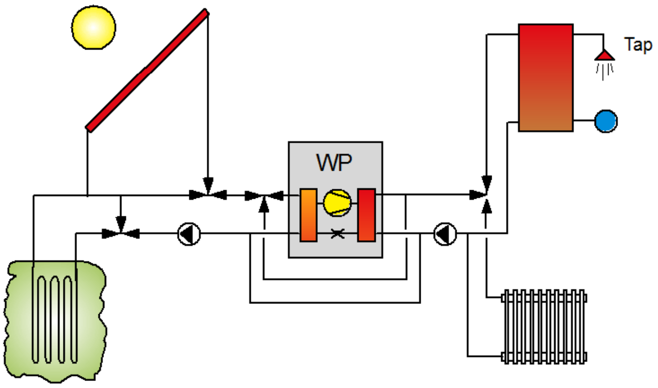
Optimization models for the combination of heat pumps with solar thermal in domestic applications



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Assigned by Netherlands Enterprise Agency (RVO)

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Basic questions:

1. What is the Energy Performance?
2. What are the advantages?
3. What are the costs?
4. How can they be fitted into an Energy Performance Standard ?

2

Archetype system

Features:

1. 20-40 GJ heating
2. 14 GJ DHW
3. ~ 2 x 20 m² roof
4. Zero energy ?

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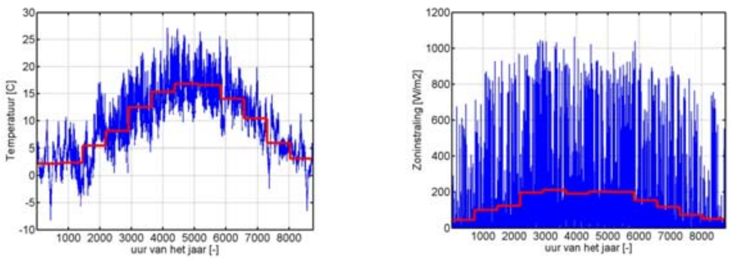
Calculation method: Hourly

1. Hourly method , 8760 sequential hours/year. Explicit time-integration $t_n \Rightarrow t_{n+1}$.



Hourly values of ambient temperature and solar radiation, as opposed to monthly average values (red line).

2. As simple as monthly values, more accurate.
3. Option to incorporate thermal capacities.
4. Conform : prEN15316-5

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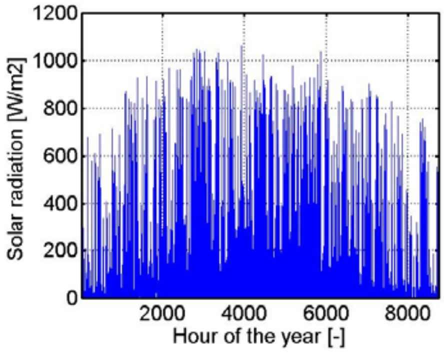
Weather-input according to NEN5060

1. On an hourly basis:

- Solar radiation: **G** [W/m²].
- Dry bulb temperature **T** [ºC].
- Relative humidity **RV** [%].
- Absolute moist contant **H** [gr/kg].
- Saturated vapour pressure **Ps** [Pa].
- Wind speed **U** [m/s].
- Wind direction **D** [grd]
- Could fraction **N** [%].
- Precipitation **R** [mm]
- Air enthalpy **h** [kJ/kg].



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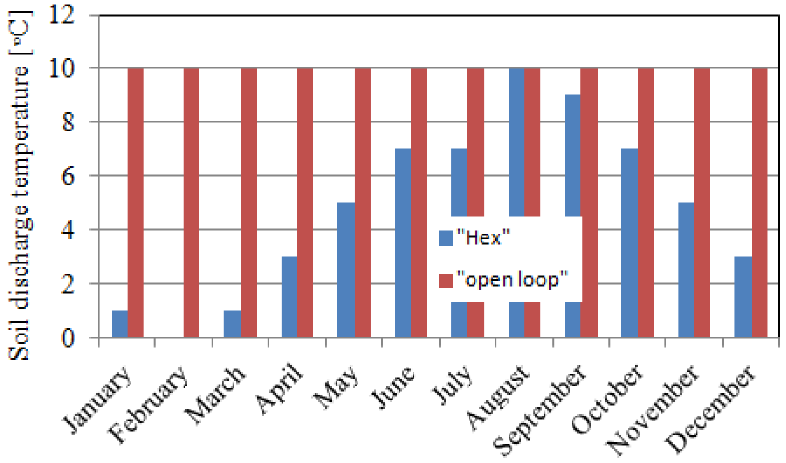
Soil temperature

1. Medium temperature (@ evaporator) according to NEN 7120, appendix Q



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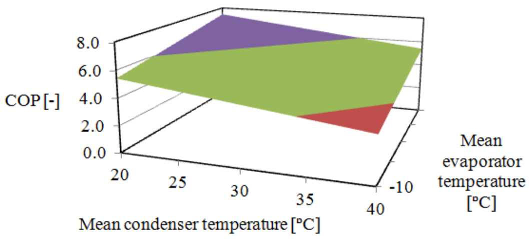
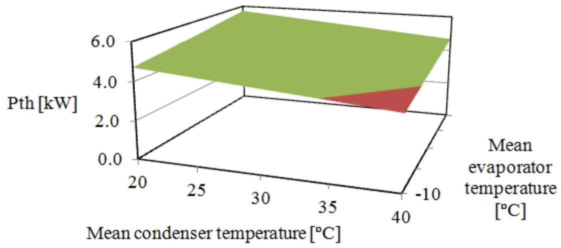
Heat Pump- Performance

1. COP and Power, bilinearly depending on evaporator and condenser temperatures





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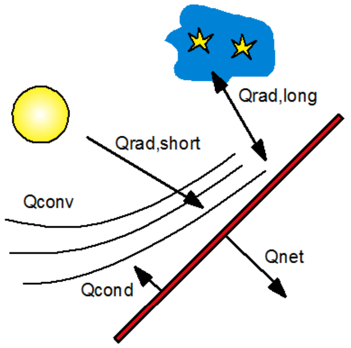
Ambient heat exchanger (solar collector)



$$\dot{Q} = \eta_0 G - c_1 (T_m - T_a) - c_2 (T_m - T_a)|T_m - T_a| + c_3 u (T_m - T_a) + c_4 (E_L - \sigma T_m^4) - c_5 \frac{dT_m}{dt}$$
$$- c_6 u G + c_7 (2.8 - 3.0 u)(v_a - v_{sat}(T_m)) + c_8 (\sigma T_b^4 - \sigma T_a^4) + c_9 m_{wat} C_{p,wat} (T_{wat} - T_m)$$

Ref. Bunea, 2015 conform EN12975

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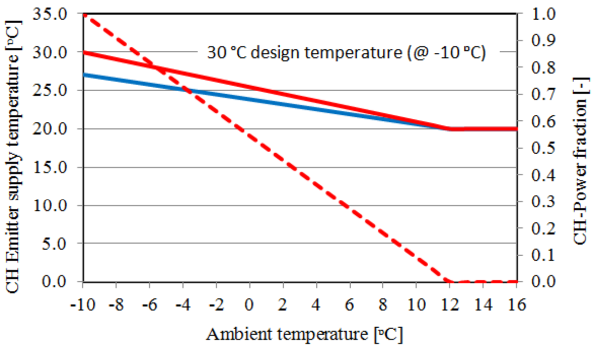
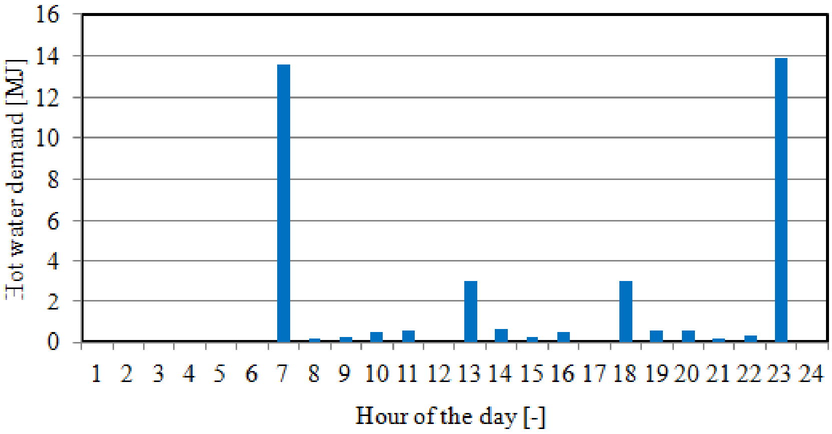
Heating (H) demand

1. Distribution over a year, according to degree-hours (ambient temperature).
2. Maximum heating system temperatures according to NEN 7120

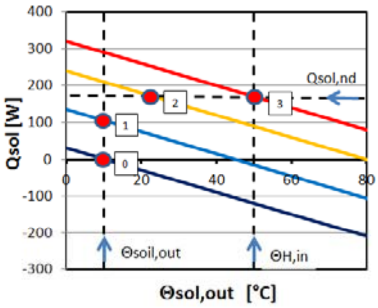


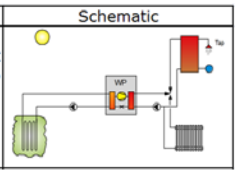
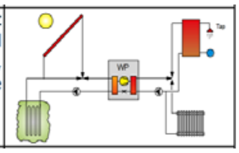
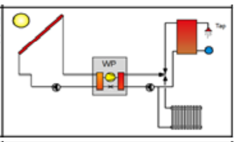
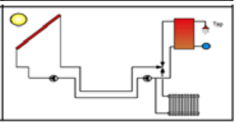
DHW-heating (W)

1. Draw-profile #4 (49 draws), recalculated to hourly values.



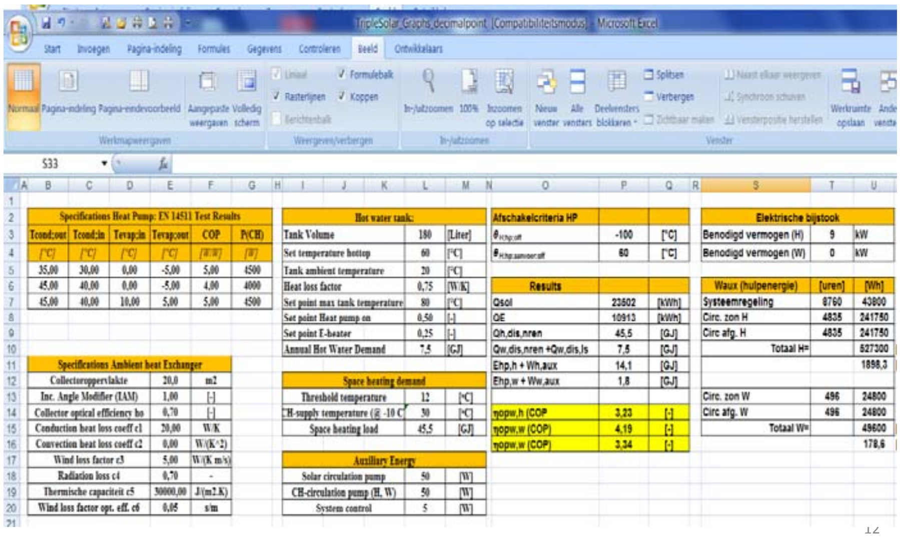
System Control



Mode	Description	Schematic
"0"	Collector not in operation. No- or negative power at temperatures equal to ground source.	
"1"	Collector positive- but insufficient power at ground source tempera--ture, sup-port from ground source needed.	
"2"	Collector can provide neces-sary power, but not at required space heating- or DHW temperature.	
"3"	Collector can provide neces-sary power at spacing or DHW-temperature (bypass).	

XLS-calculation tool

1. Cockpit (input/output)



Specifications Heat Pump: EN 14511 Test Results					
Tcond;out	Tcond;in	Tevap;in	Tevap;out	COP	P(CH)
[°C]	[°C]	[°C]	[°C]	[W/W]	[W]
35,00	30,00	0,00	-5,00	5,00	4500
45,00	40,00	0,00	-5,00	4,00	4000
45,00	40,00	10,00	5,00	5,00	4500

Specifications Ambient heat Exchanger		
Collectoroppervlakte	20,0	m2
Inc. Angle Modifier (IAM)	1,00	[-]
Collector optical efficiency ho	0,70	[-]
Conduction heat loss coeff c1	20,00	W/K
Convection heat loss coeff c2	0,00	W/(K^2)
Wind loss factor c3	5,00	W/(K m/s)
Radiation loss c4	0,70	-
Thermische capaciteit c5	30000,00	J/(m2.K)
Wind loss factor opt. eff. c6	0,05	s/m

Hot water tank:		
Tank Volume	180	[Liter]
Set temperature hottop	60	[°C]
Tank ambient temperature	20	[°C]
Heat loss factor	0,75	[W/K]
Set point max tank temperature	80	[°C]
Set point Heat pump on	0,50	[-]
Set point E-heater	0,25	[-]
Annual Hot Water Demand	7,5	[GJ]

Space heating demand		
Threshold temperature	12	[°C]
CH-supply temperature (@ -10 C	30	[°C]
Space heating load	45,5	[GJ]

Auxiliary Energy		
Solar circulation pump	50	[W]
CH-circulation pump (H, W)	50	[W]
System control	5	[W]

Afschakelcriteria HP		
$\theta_{H,hp;off}$	-100	[°C]
$\theta_{H,hp;samoer;off}$	60	[°C]

Results		
Qsol	23602	[kWh]
QE	10913	[kWh]
Qh,dis,nren	45,5	[GJ]
Qw,dis,nren +Qw,dis,ls	7,5	[GJ]
Ehp,h + Wh,aux	14,1	[GJ]
Ehp,w + Ww,aux	1,8	[GJ]
ηopw,h (COP	3,23	[-]
ηopw,w (COP)	4,19	[-]
ηopw,w (COP)	3,34	[-]

Elektrische bijstook		
Benodigd vermogen (H)	9	kW
Benodigd vermogen (W)	0	kW

Waux (hulpenergie)	[uren]	[Wh]
Systeemregeling	8760	43800
Circ. zon H	4835	241750
Circ afg. H	4835	241750
Totaal H=		527300
		1898,3
Circ. zon W	496	24800
Circ afg. W	496	24800
Totaal W=		49600
		178,6

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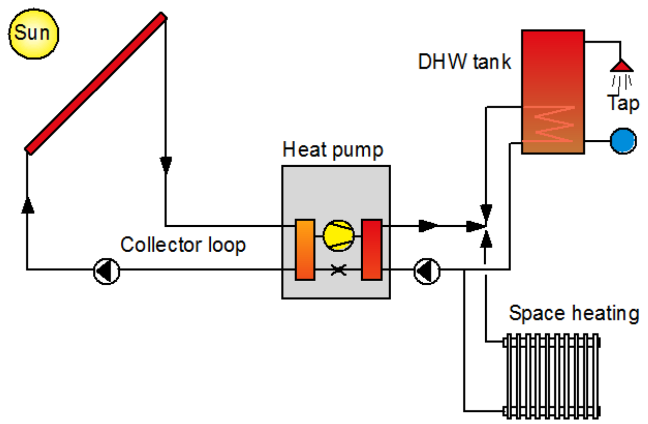
Sample system



Serial system: Ambient heat exchanger as single source for a heat pump, providing heating (H) and DHW (W)

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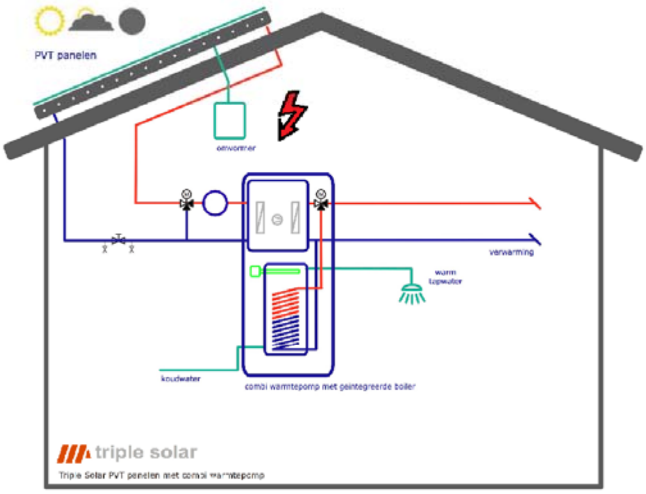
Sample system



PVT Co-generation of electricity and thermal energy

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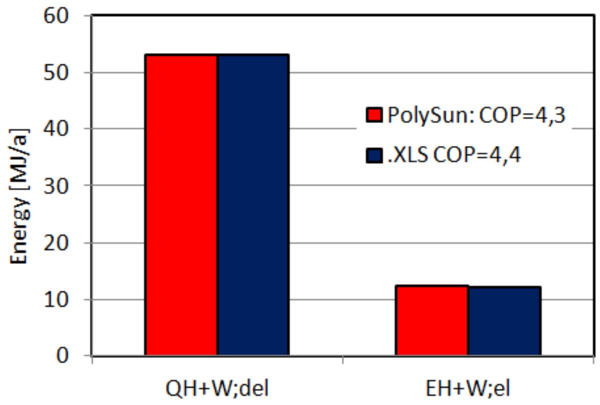
Validation with PolySum



System performance, assuming: 25 m^2 collector orientated south, 5 kW heat pump, 40 GJ annual heating load, 13 GJ annual hot water demand, Dutch reference year.

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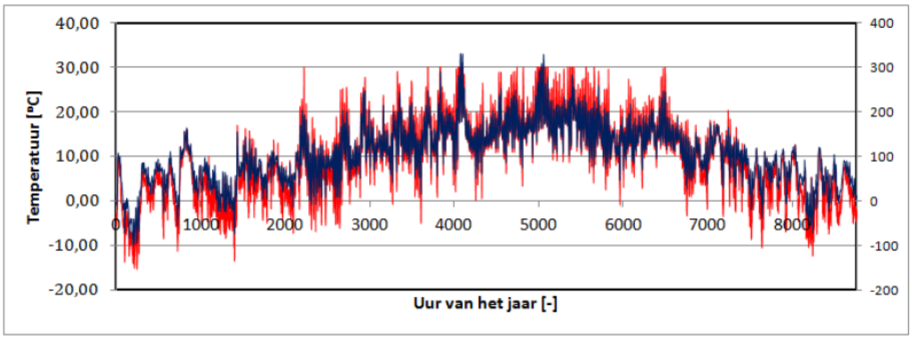
Insight in collector temperatures



Sample system. The red line give the mean temperature of the collector. The blue solid line is the ambient air temperature.

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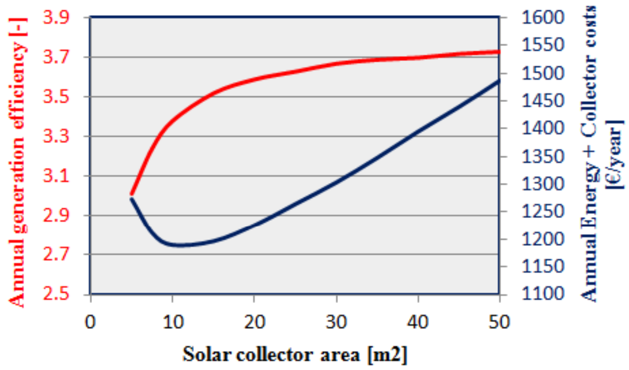
Marginal system performance and costs

Assuming:

- A particular (6 kW) heat pump and constant load (H: 40 GJ and DHW: 13 GJ)
- 25 ct/kWh electricity costs; 100 €/m^2 collector costs and 10% annual amortization)



Sample system: The red line indicates annual generation efficiency; The blue line the annual electricity + collector depreciation costs

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Declaration of comformity

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Conclusions

1. For The Netherlands: Small is Beautiful !

2. Economical optimal size, for typically Dutch conditions:
   a) Small heat pump < 5 kW
   b) Small DHW-tank < 200 litre
   c) Ambient collector < 10-20 m^2

3. Costs-competitiveness to be determined

4. First declaration of conformity now underway

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Further issues

1. Improve model by integration of single-node thermal building capacity (easy due to hourly time stepping)

2. Evaluate costs-effectiveness

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Thanks!

More information:

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Poll:

1. The best (most costs effective, quiet) exchanger of ambient heat is:

   ❍Uncovered, roof integrated collector ❍ BTES ❍ Fan-coil

2. For large scale implementation, heat pumps will be the heat generator in the built environment, in combination with district :

   ❍ Electricity (exclusively) ❍ Heat + electricity

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