SPF Solartechnik Prüfung Forschung

Institut für Solartechnik
HSR Hochschule für Technik Rapperswil
Oberseestrasse 10, CH-8640 Rapperswil
Tel. +41 55 222 48 21, Fax +41 55 222 48 44
www.solarenergy.ch

TRNSYS-Type 977
Compression Heat Pump with start losses and defrosting based on Curve-Fit of COP and condenser heat
V4.01

Michel Haller, Dani Carbonell 11.08.2017

Attention: reference temperature for COP and Power has been changed to average of inlet and outlet (instead of inlet for evaporator and outlet for condenser)

1 Introduction

This TRNSYS Type simulates a heat pump (typically air-water or water-water) with its COP calculated based on biquadratic curve fits that use the evaporator inlet temperature and the condenser outlet temperature as independent variables. The model follows to a large extent the basic concepts of the model by Wetter & Afjei (1996), with the difference that the bi-quadratic curve-fits are done for COP and heat output instead of electricity consumption and heat output. Defrosting losses of air-source heat pumps are assumed to be either already included in the curve fits, or they can be calculated based on the same approach of defrosting efficiency, relative humidity of the air, and air inlet temperature, as in the semi-physical heat pump model type 877. The reference temperature for COP and Power has been changed to average of inlet and outlet (instead of inlet for evaporator and outlet for condenser).

2 Parameters, Inputs and Outputs

2.1 Parameters

Nr.	short	explanation	unit	range
1-6	$c1-c6$	1st to 6th coefficient for bi-quadratic polynomial function for the condenser power	kW	[-inf;+inf]
7-12	$cop1-cop6$	1st to 6th coefficient for bi-quadratic polynomial function for the COP	-	[-inf;+inf]
13	τ_{start}	start time constant	s	[0;+inf]
14	τ_{stop}	stop time constant	s	[0;+inf]
15	$t_{evap,ice}$	temperature of ambient air (inlet) below which defrosting takes place	°C	[-inf;+inf]
16	$\eta_{defrost}$	Efficiency of defrosting	-	[0;1]
17	$P_{el,vent}$	electricity consumption of ventilator	kW	[0;+inf]
18	$P_{el,ctr}$	electricity consumption of controller	kW	[0;+inf]
19	$t_{evap,min}$	minimum temperature for evaporator outlet	°C	[-inf;+inf]
20	$t_{evap,max}$	maximum temperature for evaporator outlet	°C	[-inf;+inf]
21	$t_{cond,min}$	minimum temperature for condenser outlet	°C	[-inf;+inf]
22	$t_{cond,max}$	maximum temperature for condenser outlet	°C	[-inf;+inf]
23	cp_{evap}	specific heat of the evaporator heat source	kJ/kgK	[0;+inf]
24	cp_{cond}	specific heat of the condenser heat sink	kJ/kgK	[0;+inf]
25	τ_{error}	Number of hours heat pump stays on error (compressor and ventilator OFF) if it has been tried to run it with outlet temperature of the condenser above maximum or inlet temperature of the evaporator below minimum.	h	[0;+inf]
26	Mo_{loss}	heat loss and startup calculation mode: 0: no losses; 1: based on start and stop time constants; 2: based on thermal capacity and UA-value only during standby; 3: thermal cap. + UA-losses during standby	-	[0;3]

		AND during operation;		
27	C_{therm}	thermal capacity of the heat pump	kJ/K	[0;+inf]
28	UA_{loss}	UA-value for thermal losses of the heat pump	W/K	[0;+inf]

2.2 Inputs

Nr.	short	explanation	unit	range
1	$t_{evap,in}$	temperature of evaporator inlet	°C	[-inf;+inf]
2	$\dot{m}_{evap,in}$	mass flow rate of evaporator inlet	kg/h	[0;+inf]
3	$t_{cond,in}$	temperature of condenser inlet	°C	[-inf;+inf]
4	$\dot{m}_{cond,in}$	mass flow rate of condenser inlet	kg/h	[0;+inf]
5	$\gamma_{comp,ON}$	Control switch for turning heat pump (compressor / working fluid cycle) on	-	[0;1]
6	$RH_{evap,in}$	Relative humidity of air inlet	-	[0;1]
7	t_{room}	Temperature of the room for thermal loss calculation	°C	[-inf;+inf]
8	$frCond$	Factor for multiplication with Condensor heat output for modulating / inverter controlled heat pumps	-	[-inf;+inf]
9	$frCOP$	Factor for multiplication with COP for modulating / inverter controlled heat pumps	-	[-inf;+inf]

2.3 Outputs

Nr.	short	explanation	unit	range
1	$t_{evap,out}$	temperature of evaporator outlet	°C	[-inf;+inf]
2	$\dot{m}_{evap,out}$	mass flow rate of evaporator outlet	kg/h	[0;+inf]
3	$t_{cond,out}$	temperature of condenser outlet	°C	[-inf;+inf]
4	$\dot{m}_{cond,out}$	mass flow rate of condenser outlet	kg/h	[0;+inf]
5	$P_{el,comp}$	electric power consumption compressor	kW	[0;+inf]
6	$P_{el,tot}$	electric power consumption total (including controller and ventilation)	kW	[0;+inf]
7	$\dot{Q}_{evap}$	evaporator heat transfer	kW	[0;+inf]
8	$\dot{Q}_{cond}$	condenser heat transfer	kW	[0;+inf]
9	COP_{ss}	coefficient of performance in steady state, without start losses and without defrosting losses	-	[0;+inf]
10	$\dot{Q}_{loss}$	start losses (for Moloss 1) or heat losses to ambient (mode 2,3)	kW	[0;+inf]
11	$\dot{Q}_{defrost}$	defrosting losses	kW	[0;+inf]
12	$\gamma_{evap,lp}$	error low pressure in evaporator	-	[0;1]
13	$\gamma_{evap,hp}$	error high pressure in evaporator	-	[0;1]
14	$\gamma_{cond,lp}$	error low pressure in condenser	-	[0;1]
15	$\gamma_{cond,hp}$	error high pressure in condenser	-	[0;1]
16	$\dot{Q}_{cond,ss}$	steady state condenser power (before subtraction of losses to ambient and for defrosting)	kW	[0;+inf]
17	$\dot{Q}_{cap}$	heat exchange rate with thermal capacitance	kW	[0;+inf]

18	HpIsBlock	Boolean to know if the heat pump is block or not	-	[0,1]

3 Calculation

The steady state condenser power $\dot{Q}_{cond}$ of the heat pump and the COP are calculated as a function of the normalized inlet temperatures of the evaporator $\theta_{e,n,in}$ and the outlet temperature of the condenser $\theta_{c,n,out}$:

$$\dot{Q}_{cond,ss} = frCond \cdot \left[c1 + c2 \cdot \theta_{n,e,avg} + c3 \cdot \theta_{n,c,avg} + c4 \cdot \theta_{n,e,avg} \cdot \theta_{n,c,avg} + c5 \cdot \left(\theta_{n,e,avg}\right)^2 + c6 \cdot \left(\theta_{n,c,avg}\right)^2 \right]$$

$$COP_{ss} = frCOP \cdot \begin{bmatrix} cop1 + cop2 \cdot \theta_{n,e,avg} + cop3 \cdot \theta_{n,c,avg} + cop4 \cdot \theta_{n,e,avg} \cdot \theta_{n,c,avg} \\ + cop5 \cdot \left(\theta_{n,e,avg}\right)^2 + cop6 \cdot \left(\theta_{n,c,avg}\right)^2 \end{bmatrix}$$

with

$$\theta_{avg} = \frac{0.5 \cdot \left(t_{in}[°C] + t_{out}[°C]\right)}{273.15K}$$

because the outlet temperature of the condenser $t_{cond,out}$ is itself a function of $\dot{Q}_{cond}$ and the inlet temperature, it has to be found iteratively.

Defrosting losses

For cases where $t_{evap,in} < t_{evap,ice}$ losses are calculated as:

$$\dot{Q}_{loss,defrost} = \dot{m}_{evap} \cdot \left(x_{air,in} - x_{air,out}\right) \cdot h_{melt} / \eta_{defrost}$$

Where $x_{air,in}$ and $x_{air,out}$ are the inlet and outlet water vapor load of the air. The outlet water vapor load is calculated as the water vapor load that corresponds to saturated air at the outlet temperature $t_{evap,out}$ and is thus dependent also on the term $\dot{m}_{evap}$.

Mode 1 loss calculation

Start losses during a particular timestep are calculated as:

$$fr_{loss,start} = \frac{\tau_{start,loss}}{\tau_{timestep}} \cdot \left[\exp\left(-\frac{\tau_{on,n}}{\tau_{start}}\right) - \exp\left(-\frac{\tau_{on,n+1}}{\tau_{start}}\right) \right] \cdot \left[1 - \exp\left(-\frac{\tau_{off}}{\tau_{stop,loss}}\right) \right]$$

$$\dot{Q}_{loss,start} = fr_{loss,start} \cdot \left[\dot{Q}_{cond,ss} - \dot{Q}_{defrost} \right]$$

Where $\tau_{timestep}$ is the length of the timestep, $\tau_{on,n}$ is the time elapsed between start of the compressor and the beginning of the timestep, $\tau_{on,n+1} = \tau_{on,n} + \tau_{timestep}$ is the time elapsed at the end of the timestep, τ_{off} is the off-time before the heat pump is starting to operate again, and $\tau_{stop,loss}$ is the stop time constant.

Mode 2 and 3 loss and thermal capacity calculation

It is assumed that thermal capacitance of the heat pump can be represented with one thermal node, whose temperature is at the same time the supply temperature. The node temperature t_{out} is dependent on time t and can be calculated by an exponential approach:

$$t_{out}(t) = t_{\inf} - (t_{\inf} - t_{out,t_0}) \cdot EXP(-G_1 \cdot \Delta\tau)$$

The average outlet temperature over one timestep Δt is:

$$t_{cond,out} = t_{\inf} + \frac{(t_{\inf} - t_{out,t_0}) \cdot (EXP(-G_1 \cdot \Delta\tau) - 1)}{G_1 \cdot \Delta\tau}$$

With $t_{\inf}$ (temperature after an infinite time), G_1, and G_2:

$$t_{\inf} = G_2 / G_1$$

$$G_1 = \frac{UA + \dot{C}_{flow}}{C}$$

$$G_2 = \frac{\dot{Q}_{gen} + UA_{loss} \cdot t_{room} + \dot{C}_{flow} \cdot t_{in}}{C}$$

$\dot{Q}_{gen}$ is the steady state heating power of the heat pump after subtraction of the defrosting losses, $\dot{C}_{flow} = \dot{m}_{cond} \cdot cp_{cond}$ is the capacity flow rate, and t_{in} the return temperature. Heat losses, outlet heating power, and the heat charged to or released from the thermal capacitance are:

$$\dot{Q}_{loss} = UA_{loss} \cdot \left(t_{cond,out} - t_{room}\right)$$

$$\dot{Q}_{cap} = \dot{C}_{flow} \cdot \left(t_{cond,out} - t_{room}\right)$$

$$\dot{Q}_{cap} = \dot{Q}_{cond,ss} - \dot{Q}_{cond} - \dot{Q}_{loss,defrost} - \dot{Q}_{loss}$$

Final outputs

The other outputs are calculated as:

$$\dot{Q}_{evap} = \dot{Q}_{cond,ss} \cdot \left(COP_{ss} - 1\right) / COP_{ss}$$

$$\dot{Q}_{cond} = \dot{Q}_{cond,ss} - \dot{Q}_{loss} - \dot{Q}_{loss,defrost} - \dot{Q}_{cap}$$

$$P_{el} = \frac{\dot{Q}_{cond,ss}}{COP_{ss}}$$

$$t_{evap,out} = t_{evap,in} - \dot{Q}_{evap} / \left(\dot{m}_{evap} \cdot cp_{evap}\right)$$

$$t_{cond,out} = t_{cond,in} + \dot{Q}_{cond} / \left(\dot{m}_{cond} \cdot cp_{cond}\right)$$

Literature

Wetter, M. & Afjei, T., 1996. *TRNSYS TYPE 410 - Kompressionswärmepumpe inklusiv Frost- und Taktverluste - Modellbeschreibung und Implementation in TRNSYS*. Zentralschweizerisches Technikum Luzern.

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Change-Log

11.08.2017, V401

(MH) corrected description of params 19 + 20 from “evaporator inlet” to “evaporator outlet”

30.06.2016, V401

(DC) corrected error in calculation of average temperature of the evaporator

(DC) new output “heat pump is blocked”

(DC) heat pump loss mode 0 threw an error – this has been corrected

26.11.2015, V400

(MH) introduced factors frCond and frCOP for multiplication of condensing power and COP for inverter controlled heat pumps

28.07.2015, V301

(MH) corrected erroneous conversions between kW an W.

09.06.2015, V300

The reference temperature for COP and Power has been changed to average of inlet and outlet (instead of inlet for evaporator and outlet for condenser).

02.06.2015, V200

Renamed Parameter 19 to 22; M. Granzotto;

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Appendix A: Fitting physical heat pump model curves of Type 976 with Type 977

This description is based on versions before V300, since then, the average temperature of inlet and outlet is the reference, not the condenser outlet or evaporator inlet…

The physical heat pump model Type 976 can be fitted with this model 977 in order to get a model with almost exactly the same output, but way faster calculation time. However, in comparison to Type 976, this type is not able to:

- simulate heat pumps with more than one heat source / more than one evaporator
- simulate heat pumps with desuperheating
- simulate the effect of changes of flowrate on the evaporator or condenser side on the effectiveness of the heat exchange

It is able to simulate quite close to the calculation of Type 976:

- defrosting losses dependent on ambient air temperature and relative humidity
- start-losses

In order to get from the physical model output to the input of Type 977, the physical model needs to be parameterized and a performance map needs to be "simulated" by supplying a range of condenser and evaporator inlet temperature. Relative humidity should be set to a high value (e.g. 0.9) and start losses to zero (tau_start = 0.0000001) for this purpose. The following model output need to loaded into the Excel-File "Type977_parameter_fit.xlsm":

TIME	Tamb	TairOut	TcondIn	TcondOut
PelComp	PelTot	Pevap_kW	Pbrine_kW	Pdesup_kW
Pcond_kW	Ploss_defrost_kW	Ploss_start_kW		

Then, the following paramters in the Worksheet "Fit" are set equal to the paramaters of Type 976:

tevap_min	tevap_max	tcond_min	tcond_max	cp_evap
cp_cond	eta_defrost	Mfr_evap_in	Mfr_cond_in	RH_evap_in

Then, after enabling macros, first the steady state COP and the condenser power are fitted each without taking into account defrosting losses or start losses (parameters c1 to c6 for condenser power and cop1 to cop6 for COPss). If this fit is satisfactory (watch RMSE and min. and max. deviations in RED), the air inlet temperature below which defrosting takes place "TevapIce" is adapted in order to reduce the deviations between the final COP value of the simplified model and the final COP value of Type 976 model.

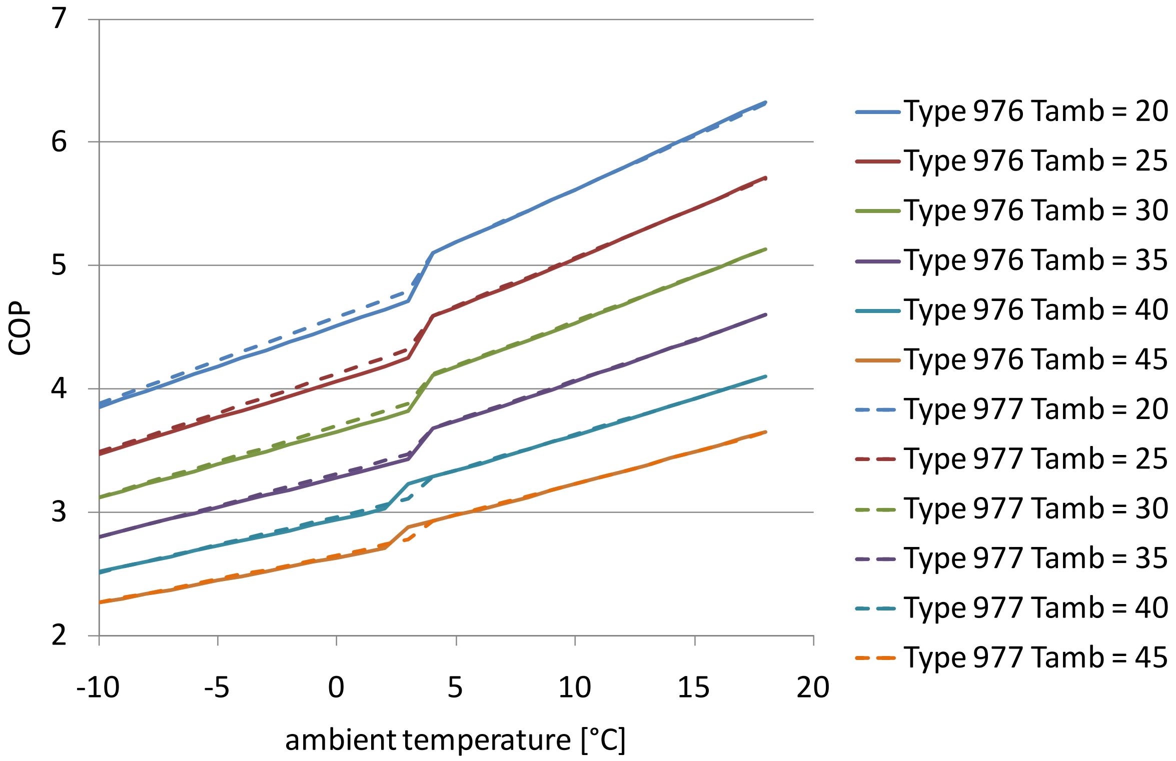

Figure 1: comparison of Type 977 output with Type 976 output for an air source heat pump. Parameters c1-c6 and cop1-cop6 of Type 977 fitted to the Output of Type 976 with the Excel-Tool.

Comparison of calculation time with two heat pumps in Task 32 reference deck:

	Type 976	Type 977
Total calculation time (min)	57	17
inside heat pump type (min)	42	0.03