About

Model name	ConstantTcondHeatPump
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Short description	Heat pump model with constant output temperature at the condenser.
Present use / development status	Used as component model for representing the heat pump defined in system configuration MENB-SC.

Classification

Domain	☐ electrical storage ☐ thermal storage ☒ energy conversion device ☐ other, please specify:
Intended application (including scale and resolution)	Used as part of the power-to-heat facility in system configuration MENB-SC, providing a coupling point between the electrical network and the thermal network. In this setup, its intended power consumption rating is 100 kW_{el}. The source for the evaporator is the thermal network's return line. The condenser's output is fed to the thermal storage tank. The model is intended for high-resolution technical simulations, e.g., implementing test case MENB-TC01.
Modelling of spatial aspects	☐ lumped (single device) ☒ discretized (single device) ☐ averaged (multiple devices) ☐ other, please specify:
	The model captures the thermodynamic processes of the heat pump's evaporator and condenser. Details about the hydraulics of the components are not considered.
Model dynamics	☐ static ☒ quasi-static ☐ dynamic ☐ other, please specify:
	The model equations assume quasi-static thermodynamic processes.
Model of computation	☒ time-continuous ☒ discrete-event ☐ state machine ☐ other, please specify:

	The mathematical representation of the model includes a first-order linear differential equation. Hence, the model is primarily intended for time-continuous simulations (using a numerical integrator), see Equation 11a. Alternatively, the model equations also include an (approximate) analytical solution that allows to use the model in a time-discrete simulation (e.g., in a simulation with fixed time-steps and without using a numerical integrator), see Equation 11b.
Functional representation	☒ explicit ☒ implicit ☐ other, please specify:
	Most model equations are explicit and can be directly used to calculate the system state through a sequence of simple calculations. However, the system dynamics is modelled implicitly with the help of a first-order linear differential equation (Equation 11a), which requires a numerical integrator to calculate the system state.

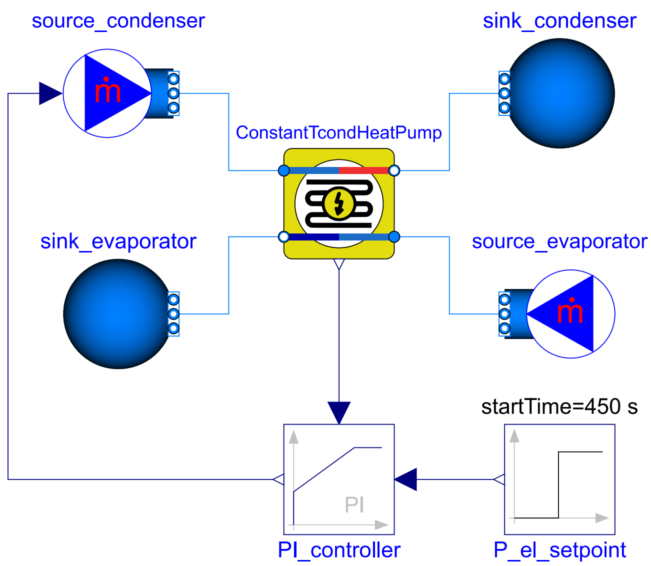
Mathematical Model

Input variables	• `mdot_cond_in` (float): mass flow at condenser inlet [kg/s] • `mdot_evap_in` (float): mass flow at evaporator inlet [kg/s] • `T_cond_in` (float): temperature of mass flow at condenser inlet [°C] • `T_evap_in` (float): temperature of mass flow at evaporator inlet [°C]
Output variables	• `mdot_cond_out` (float): mass flow at condenser outlet [kg/s] • `mdot_evap_out` (float): mass flow at evaporator outlet [kg/s] • `T_cond_out` (float): temperature of mass flow at condenser outlet [°C] • `T_evap_out` (float): temperature of mass flow at evaporator outlet [°C] • `P_effective` (float): electrical power consumption [kW_{el}]
Parameters	• `P_rated` (float): electrical power rating [kW_{el}] • `P_0` (float): electrical stand-by power consumption [kW_{el}] • `T_evap_min` (float): minimal evaporator outlet temperature [°C] • `T_cond_max` (float): maximum condenser outlet temperature [°C] • `T_cond_target` (float): condenser outlet temperature setpoint [°C] • `eta_sys` (float): ratio between work provided by the pump and available thermodynamic work [-] • `eta_comp` (float): compressor efficiency [-] • `lambda_comp` (float): compressor time constant [1/s]

Internal variables	• `W_rated` (float): mechanical power rating [kW] • `W_0` (float): mechanical stand-by power consumption [kW] • `W_cond_max` (float): maximum mechanical work done in the condenser [kW] • `W_evap_max` (float): maximum mechanical work done in the evaporator [kW] • `W_max` (float): maximum mechanical work constraint [kW] • `W_requested` (float): requested mechanical work [kW] • `W_effective` (float): effective mechanical work [kW] • `Q_flow` (float): requested heat flow at the condenser [kW_{th}] • `T_cond_log` (float): logarithmic mean temperature of condenser [°C] • `T_evap_log` (float): logarithmic mean temperature of evaporator [°C] • `eta` (float): overall efficiency [-]
Internal constants	• `Cp` (float) = 4.180: specific heat capacity of water [kJ/(kg.K)]
	Governing equations
	1) `mdot_cond_out` = – `mdot_cond_in` 2) `mdot_evap_out` = – `mdot_evap_in` 3) `T_cond_log` = *logmean*(`T_cond_in`, `T_cond_out`) 4) `T_evap_log` = *logmean*(`T_evap_in`, `T_evap_out`) 5) `eta` = `eta_sys` / (1 – `T_evap_log` / `T_cond_log`) 6) `Q_flow` = (`T_cond_target` – `T_cond_in`) · \ · `Cp` · `mdot_cond_in` 7) `W_cond_max` = (`T_cond_max` – `T_cond_in`) · \ · `Cp` ·`mdot_cond_in` / `eta` 8) `W_evap_max` = (`T_evap_in` – `T_evap_min`) · \ · `Cp` · `mdot_evap_in` / (`eta` – 1) 9) `W_max` = \ = *max*(0, *min*(`W_evap_max`, `W_cond_max`, `W_rated`)) 10) `W_requested` = *clamp*(0, `Q_flow` / `eta`, `W_max`) 11) Alternative representation of system dynamics (a: linear differential equation, b: approximate solution for simulation step-size Δt): a) $\frac{d}{dt}$ `W_effective` = `lambda_comp` · \ · (`W_requested` – `W_effective`) b) `W_effective`(t + Δt) = \ = (1 – *exp*(–`lambda_comp` · Δt)) · `W_requested`(t) + \

	$+\ exp(-\mathtt{lambda\_comp} \cdot \Delta t) \cdot \mathtt{W\_effective}(t)$ 12) $\mathtt{P\_effective} = \mathtt{P\_0} + \mathtt{W\_effective} / \mathtt{eta\_comp}$ where • $logmean(\mathtt{x}, \mathtt{y}) = (\mathtt{x} - \mathtt{y}) / ln(\mathtt{x} / \mathtt{y})$ • $clamp(\mathtt{a}, \mathtt{x}, \mathtt{b}) = \begin{cases} \mathtt{x} \ldots \text{if } (\mathtt{x} > \mathtt{a}) \vee (\mathtt{x} < \mathtt{b}) \\ \mathtt{a} \ldots \text{if } (\mathtt{x} \le \mathtt{a}) \\ \mathtt{b} \ldots \text{if } (\mathtt{x} \ge \mathtt{b}) \end{cases}$
	Constitutive equations
	13) $\mathtt{W\_rated} = \mathtt{P\_rated} \cdot \mathtt{eta\_comp}$ 14) $\mathtt{W\_0} = \mathtt{P\_0} \cdot \mathtt{eta\_comp}$
Initial conditions	N/A
Boundary conditions	• $\mathtt{T\_evap\_log} < \mathtt{T\_cond\_log}$

Testing

Model Validation	
Narrative	The operation of the heat pump is simulated for 900 seconds with mass flows of constant temperature going into the evaporator and the condenser. A PI controller governs the heat pump's power consumption by controlling the mass flow at the condenser inlet. The simulation starts with the heat pump in steady state operation. After 450 seconds, the power consumption setpoint of the PI controller changes, resulting in a dynamic response of the heat pump, which settles back to steady state operation within a short period.
Test system configuration	Figure 1 shows a graphical representation of the test system (implemented with Modelica). It comprises the heat pump model itself, two ideal mass flow sources and two ideal mass flow sinks (for the evaporator loop and the condenser loop) as well as a PI controller. The test system is simulated for 900 seconds.  Figure 1: Graphical overview of the test system (implemented with Modelica)

Inputs and parameters	Parameters of heat pump model:
	• `P_rated` = 50 kW_{el}
	• `P_0` = 0.3 kW_{el}
	• `T_evap_min` = 20 °C
	• `T_cond_max` = 85 °C
	• `T_cond_target` = 75 °C
	• `eta_sys` = 0.5
	• `eta_comp` = 0.7
	• `lambda_comp` = 0.2 s^{-1}
	
	Parameters of ideal mass flow sources/sinks:
	• `source_evaporator`
	  ○ temperature: 30 °C
	  ○ mass flow: 3.5 kg/s
	• `source_condenser`
	  ○ temperature: 60 °C
	  ○ mass flow: controlled by PI controller
	• `sink_evaporator`
	  ○ temperature: 20 °C
	• `sink_condenser`
	  ○ temperature: 50 °C
	
	PI controller
	• `k` (float) = 1e-3: gain of the PI controller
	• `Ti` (float) = 1s: time constant of integrator block
	• `yMax` (float) = 3 kg/s: upper limit of output
	• `yMin` (float) = 0 kg/s: lower limit of output
	
	The PI controller setpoint is the only exogenous input to the test system:
	$\texttt{PI\_setpoint} = \begin{cases} 25\ kW_{el} & \text{for } t \in [0,450) \\ 50\ kW_{el} & \text{for } t \in [0,900] \end{cases}$

Control function	The PI controller is modelled according to chapter 3 of reference [1].
Initial system state	The simulation starts with the heat pump close to steady state operation: • `mdot_cond_in` = 3.5 kg/s • `mdot_evap_in` = 1.2 kg/s • `T_cond_in` = 60 °C • `T_evap_in` = 30 °C • `T_cond_out` = 75 °C • `T_evap_out` = 26 °C • `P_effective` = 25 kW_{el}
Temporal resolution	The simulation of the heat pump model requires a numerical integrator. The simulation step size should be chosen accordingly. For the results reported below, the DASSL solver has been used with a tolerance of 1e-4.
Evolution of system state	The simulation starts with the heat pump in steady state operation. After 450 seconds, the power consumption setpoint of the PI controller

<table>
<tr><td></td><td>changes, resulting in a dynamic response of the heat pump, which settles back to steady state operation within a short period.</td></tr>
<tr><td>Expected results</td><td>Figure 1 shows the most relevant results from the simulation of the test setup. The results are also attached as dataset in file “MENB_heat_pump_test.zip”.

The results reported here have been produced with an implementation of the heat pump model and the test system in Dymola/Modelica. Dymola’s DASSL solver has been used with a tolerance of 1e-4.

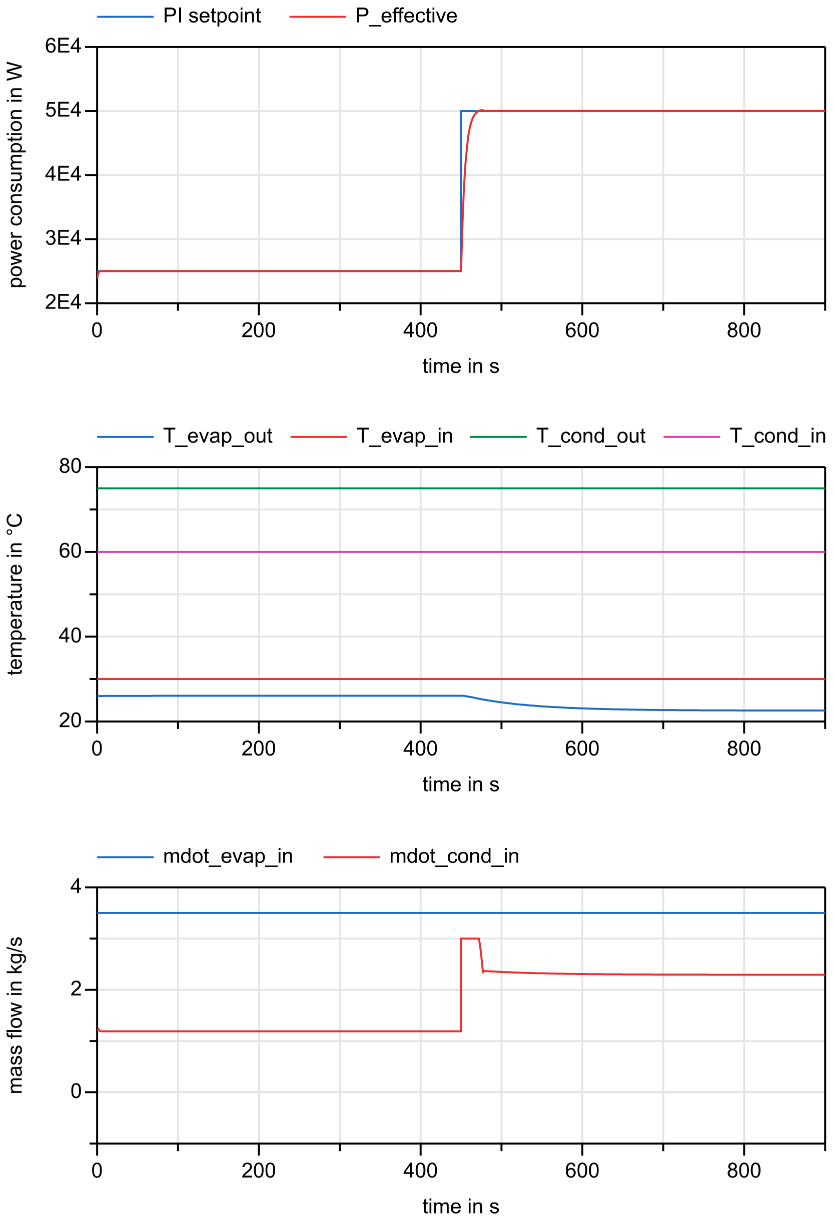


Figure 2: Expected results for the power consumption (top), temperature (middle) and mass flows (bottom).</td></tr>
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Model harmonization	
Narrative	See model validation test setup.
Test system configuration	See model validation test setup.
Inputs and parameters	See model validation test setup.

Control function	See model validation test setup.
Initial system state	See model validation test setup.
Temporal resolution	See model validation test setup.
Evolution of system state	See model validation test setup.
Expected results	• electrical energy consumed: 9.24 kWh • thermal energy withdrawn from the evaporator mass flow: 77.4 MJ • thermal energy supplied to the condenser mass flow: 121.58 MJ

Additional Information

Reference implementation	Modelica and Python implementations of this model are available online: https://github.com/ERIGrid2/benchmark-model-multi-energy-networks
Similar / related models	-
Related publications	[1] Åström K.J., and Hägglund T.: *PID Controllers: Theory, Design, and Tuning.* Instrument Society of America, 2nd edition, 1995
Intellectual property	This model is released under a BSD-3-Clause License.