Physically Based Load Models (PBLM)

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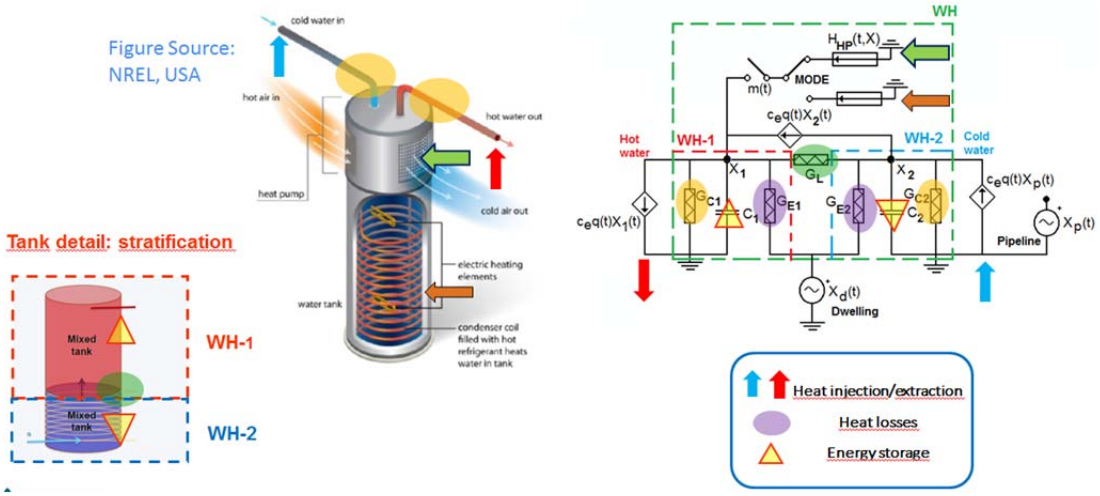
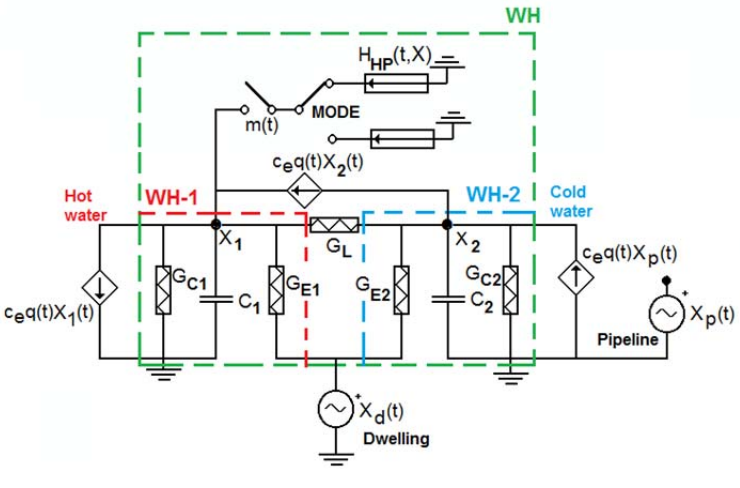
Model: Water Heater/Heat Pump Water Heater

1) Electrical-Thermal equivalent of thermal processes and energy conversion

a) Physical processes and coding



b) Electrical equivalent (simplified)



c) Brief explanation of model parameters and state variables

The model has several components:

Appliance: the PBLM model proposed for HPWH (or WH) is a thermal-electric equivalent, specifically a lumped RxCx network being fed by two heat (current) sources. The model takes into account the water storage capacity in the tank (C1, C2 parameters), heat losses (Gx), the heat losses due to inlets of cold water (a dependent current source in the model), outlets of hot water (again a dependent current source) and heat gains due to auxiliary resistor (H_R) or Heat Pump (H_{HP}) both current sources. The resistor and HP sources are selected by the user through the appliance menu of the load (MODE eco or boost).

Control mechanism m(t): which drives the demand (a thermostat in thermostatically controlled loads)

State variables: X_1 and X_2 are the temperature of the water inside the stratified tank of HPWH.

Customer service: q(t): water flow, i.e. the service of the load, in this case flow at a certain temperature level Xs (thermostat setpoint). This variable explains the energy requirements through specific heat c_e of water and inlet/outlet temperatures.

MODE (only in HPWH): the switch that drives the mode of use of the load (with an auxiliary resistor or the compressor).

Example of physical characteristics of the load:

CHARACTERISTICS OF HPWH ARISTON NUOS EVO

Characteristic	**Value**
Capacity (l), Energy Label	80l, A+
Rated Power of Heat Pump (W)	250 (avg)/ 350 (max)
Performance, COP (outdoor air at 7ºC)	2.55
Max. Heating time (h)	5h35m
Max. WH Temperature (ºC)	55 (only HP)/ 62
Auxiliary Resistor (W)	1200

PARAMETERS OF HPWH MODEL

Parameter	**Value**
Capacity C1=C2 (kJ/ºK)	150.5
Heat source H_{HP} (avg)/ H_R (J/s)	600/1200
GL (J/sºK)	60.6
GE1=GE2 (J/sºK)	0.26
GC1=GC2 (J/sºK)	0.15
Thermostat deadband (ºC)	55-50

d) State-Space Equations

- **State Space System (DX) = [A](X) + [B](U):**

The state-space representation for the model previously represented is:

$$\begin{pmatrix} DX_1(t) \\ DX_2(t) \end{pmatrix} = \begin{bmatrix} -\frac{G_L + G_{C1} + G_{E1} + c_e q(t)}{C_1} & \frac{1}{C_1} G_L \\ \frac{1}{C_2} G_L & -\frac{G_L + G_{C2} + G_{E2}}{C_2} \end{bmatrix} \begin{pmatrix} X_1(t) \\ X_2(t) \end{pmatrix} + \begin{bmatrix} \frac{1}{C_1} G_{e1} & 0 & \frac{1}{C_1} \\ \frac{1}{C_2} G_{e2} & \frac{c_e q(t)}{C_2} & 0 \end{bmatrix} \begin{pmatrix} X_d(t) \\ X_p(t) \\ H_{HP}(t) \end{pmatrix}$$

Where: