Physically Based Load Models (PBLM)

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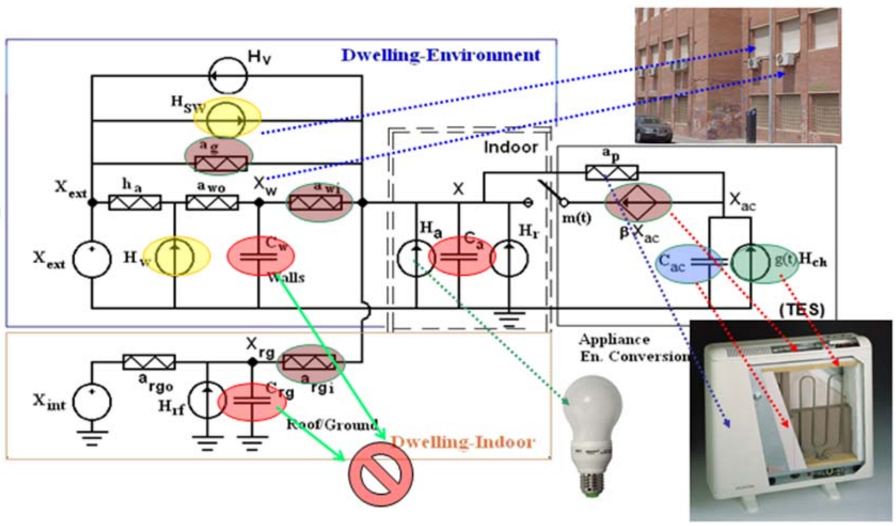
Model: Space Heating/Air Conditioning

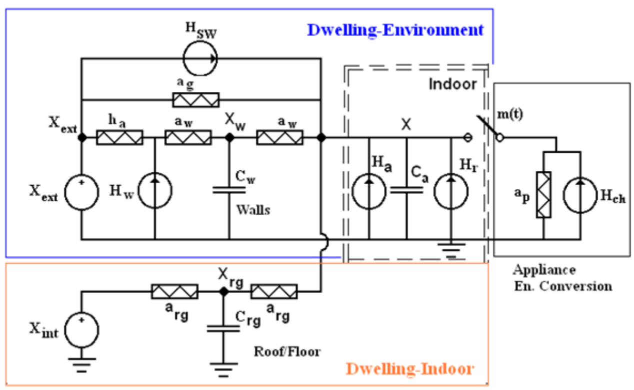
1) **Electrical-Thermal equivalent of thermal processes and energy conversion**

a) **Physical processes and coding**

Dwelling characteristics: storage and heat transfer
Weather: Solar radiation, external temperature
Load/appliance: energy conversion and storage



b) **Electrical equivalent (simplified)**



c) **Brief explanation of model parameters and state variables**

The model has several components:

- The energy conversion of the appliance, i.e. electric power is converted into heat (space heating), "cold" (air conditioning), or hot water (WH). This is represented in fig. by an intensity source (H_{ch}).

- According to a state variable (indoor or water temperature) the control mechanism m(t) decides if the load demands more or less power, i.e. a thermostat in some loads. In our case driven by X(t).
- The dwelling/environment model, i.e. a model that represents heat losses, through walls (h_a, a_w), the floor (a_{rg}), windows (a_g); as well as heat gains, solar radiation (H_{sw}), internal gains due to inhabitants/residents (H_r) or appliances (H_a) running inside the dwelling, such as lighting, TV, fridges, etc. The model takes into account heat storage from the specific heat of walls (C_w), roof/ground (C_{rg}) or air mass (C_a).
- The state variables (system output) are usually temperatures: Internal/indoor (X), walls (X_w) and roof/ground (X_{rg}).
- System inputs: external temperature (X_{ext}) and heat sources: load conversion (H_{ch}), heat gains by radiation (H_{sw}, H_w) or the work of other loads (H_a).

Example of physical characteristics of a dwelling:

Room characteristics	**Main physical parameters**	
Location: Murcia (Spain)	External walls:	K = 1.35 W/(m^2.ºC)
Sector: residential		Weight = 243 kg/m^2
Room's volume: 50 m^3		Thermal capacity = 2192 kJ/ºC
External walls: 12.5 m^2	Internal walls:	K = 2.25 W/(m^2.ºC)
Glazed area: 2.5 m^2		Weight = 96 kg/m^2
Internal walls: 32.5 m^2		Thermal capacity = 2870 kJ/ºC
External orientation: Southwest	Ceiling and floor:	K = 1.99 W/(m^2.ºC)
Internal loads: just 2 x 100W incandescent lamps		Weight = 493 kg/m^2
Device parameters		Thermal capacity = 12304 kJ/ºC
Rated power: 1300 W	Room:	Internal capacity = 1358 kJ/ºC
Nominal COP: 2.8	Windows:	K = 5 W/(m^2.ºC)

d) State-Space Equations

- **First equation: Capacitor Cw (C1 in Matlab):**

$$\frac{dX_w}{dt} = -\frac{(X_w - X_{ext} - h_a H_w)}{C_w(h_a + a_{w0})} - \frac{(X_w - X)}{C_w a_{wi}}$$

- **Second equation: Capacitor Ca (C2):**

$$\frac{dX}{dt} = -\frac{(X - X_{ext})}{C_a(a_g)} - \frac{(X - X_w)}{C_a a_{wi}} - \frac{(X - X_{rg})}{C_a a_{rgi}} + \frac{(H_{sw} + H_a + H_r + H_{ch} - H_v)}{C_a}$$

- **Third equation: Capacitor Crg (C3):**

$$\frac{dX_{rg}}{dt} = -\frac{(X_{rg} - X_{\mathrm{int}})}{C_{rg}(a_{rg0})} - \frac{(X_{rg} - X)}{C_{rg} a_{rgi}} + \frac{(H_{rf})}{C_{rg}}$$

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

$$\begin{pmatrix} DX_w \\ DX \\ DX_{rg} \end{pmatrix} = \begin{bmatrix} -\frac{1}{C_w}\left[\frac{1}{(h_a + a_{w0})} + \frac{1}{a_{wi}}\right] & +\frac{1}{C_w a_{wi}} & 0 \\ \frac{1}{C_a a_{wi}} & -\frac{1}{C_a}\left[\frac{1}{a_g} + \frac{1}{a_{wi}} + \frac{1}{a_{rgi}}\right] & \frac{1}{C_a a_{rgi}} \\ 0 & \frac{1}{C_{rg} a_{rgi}} & -\frac{1}{C_{rg}}\left[\frac{1}{a_{rg0}} + \frac{1}{a_{rgi}}\right] \end{bmatrix} \begin{pmatrix} X_w \\ X \\ X_{rg} \end{pmatrix} +$$

$$+ \begin{bmatrix} \frac{1}{C_w(h_a + a_{w0})} & 0 & \frac{h_a}{C_w(h_a + a_{w0})} & 0 & 0 \\ \frac{1}{C_a a_g} & 0 & 0 & \frac{1}{C_a} & \frac{1}{C_a} \\ 0 & \frac{1}{C_{rg} a_{rg0}} & 0 & 0 & 0 \end{bmatrix} \begin{pmatrix} X_{ext} \\ X_{\mathrm{int}} \\ H_w \\ H_{sw} - H_v \\ H_a + H_r + H_{ch} \end{pmatrix}$$

- **State Space System (Y) = [C](X) + [D](U)**

$$\begin{pmatrix} X_w \\ X \\ X_{rg} \\ I_{rgi} \\ I_{wi} \end{pmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & \frac{1}{a_{rgi}} & -\frac{1}{a_{rgi}} \\ -\frac{1}{a_{wi}} & \frac{1}{a_{wi}} & 0 \end{bmatrix} \begin{pmatrix} X_w \\ X \\ X_{rg} \end{pmatrix} + + \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{pmatrix} X_{ext} \\ X_{\mathrm{int}} \\ H_w \\ H_{sw} - H_v \\ H_a + H_r + H_{ch} \end{pmatrix}$$