Optimal operation of energy storage in buildings: The use of hot water system
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Agenda

- Project description
- Work done
- Model validation
- Further work
Project description

- Optimal operation of energy storage in buildings with focus on the optimization of an electrical water heating system.
- Objective is to minimize the energy cost of heating the water
- Main complications: Electricity price and future demand
- Goal: To propose, implement and compare different simple policies that result in near-optimal operation of the system.
Proposed policies

• Should be robust in some to-be-defines sense (e.g. must be feasible for at least 95% of the cases)
• Should result in significant savings compared to trivial solution
• Should be simple to implement in practice.
Process flow scheme

Dynamic model:

\[
\frac{dV}{dt} = q_{in} - q_{out}
\]

\[
\frac{dT}{dt} = \frac{1}{V} \left[ q_{in}(T_{in} - T) + \frac{Q}{\rho c_p} \right]
\]
Model assumptions

- $q_{hw}$ and $T_{hw}$ controlled directly by the consumer
- Perfect control when feasible

Perfect control:

$$T_{hw} = T_{hw,s} \quad \text{and} \quad q_{hw} = q_{hw,s}$$

else

$$T < T_{hw,s} \quad \text{and} \quad q_{hw} = q_{hw,s}$$
Model equation

\[ \frac{dx}{dt} = f(x, u, d) \]

Definition of the state, input and disturbance vectors.

\[ x = \begin{bmatrix} V \\ T \end{bmatrix}, u = \begin{bmatrix} Q \\ q_{in} \end{bmatrix}, d = \begin{bmatrix} q_{hw} \\ T_{hw,s} \\ T_{in} \\ p \end{bmatrix} \]
Model validation
PID controller

\[ p(t) = p + K_c(e(t) + \frac{1}{\tau_I} \int_0^t e(t) \, dt + \tau_D \frac{de(t)}{dt}) \]

\[ G(s) = K_p \left(1 + \frac{1}{\tau IS} + \tau DS\right) \]
Demand profile

- Randomly generated demand profiles from MATLAB script, qhw.
Electricity Price

- On-off peak price
- Time varying price
Implementing a switch
Price threshold, $p_B$

- Defining set-points for the temperature at the switch

$$T_{set} = \begin{cases} 
  T_{max} & \text{if } p > p_B \\
  T_{buffer} & \text{if } p \leq p_B 
\end{cases}$$

$$V_{set} = \begin{cases} 
  V_{max} & \text{if } p > p_B \\
  V_{max} & \text{if } p \leq p_B 
\end{cases}$$
Results

• Switching between set-points as the price is higher or lower than the price threshold $P_B$. 
Weekly average

- $P_B$ average from previous week
Average from previous day

(c) Friday

(d) Saturday
Average current day

• Comparing the total cost with different boundaries, also assuming the electricity price for the current day is known, and the average of this day can be used.
No boundary?

- The lowest price threshold resulted in the lowest cos, what are the result with no boundary?
No boundary?

- $T_{\text{start}} = 90 \, ^\circ\text{C}$, low total cost.
- $T_{\text{start}} = 65 \, ^\circ\text{C}$, higher total cost.
Cost function

- Original cost function:

\[ J(t) = \int_0^t p(t)Q(t)\,dt \]

- Implementing a penalty into the cost function:

\[ J = \int_{t_0}^{\infty} p(t)Q\,dt + \int_{t_0}^{\infty} p^\ast(T)Q_{\text{demand}}\,dt \]

\[ p^\ast(T) = \begin{cases} 0 & \text{if } T \geq T_{hw,s} \\ p_1 * (T_{hw,s} - T)^2 + p_2 * (T_{hw,s} - T) & \text{if } T < T_{hw,s} \end{cases} \]
Further work

- Optimization problem: $\min J(P_B, T_{buffer})$
- Decision variables: $P_B$ and $T_{buffer}$

Finding the optimal $P_B$ and $T_{buffer}$ which provides the lowest total cost.

Simulate for longer periods and generalizing the simulation

Find near optimal policies