Optimization of energy storage in buildings based on self-optimizing control

Vegard Skogstad

Supervisors: Sigurd Skogestad & Vinicius de Oliveira

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The system

\[ \frac{dV}{dt} = q_{in} - q_{out} \] (1)

\[ \frac{dT}{dt} = \frac{1}{V} \left( q_{in} \left(T_{cw} - T\right) + Q - Q_{loss} \right) \rho c_p \] (2)

\[ \frac{dJ}{dt} = pQ + p^*Q_{demand} \] (3)
The system

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\frac{dT}{dt} = \frac{1}{V} \left( q_{in}(T_{cw} - T) + \frac{Q - Q_{loss}}{\rho c_p} \right)
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\frac{dJ}{dt} = pQ + p^* Q_{demand}
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Find empirical rules for hot water tank heating by comparing with optimized solution of the system
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Electricity market

- Prices vary with demand
- Demand depends on time of day, location, weather conditions and time of year
- The varying price means there are possible environmental and monetary savings to optimal operation
Possible advantages

How does this save us money?

• We want to use the storage capabilities of the hot water tank to buy electricity when price is low and use the stored energy when price is high.

How does this make the world a better place?

• Renewable energy sources will be more profitable.
• Peak demand will decrease.
Possible advantages

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How does this make the world a better place?

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Milestones

- Model the system in Simulink and Matlab.
- Find optimal set points for the free variable, $T_s$.
- Compare different procedures with the optimal solution. Try to propose heuristic rules from these.
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\[ \text{Cold water} \quad T_{cw} \quad [K] \quad q_{in} \quad [m^3/s] \]

\[ \text{Electric heater} \quad Q \quad [W] \]

\[ \frac{dT}{dt} = \frac{1}{V} \left( q_{in} (T_{cw} - T) + Q - Q_{loss} \right) \quad (5) \]

\[ \frac{dJ}{dt} = pQ + p^*Q_{demand} \quad (6) \]
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Simulink model
The volume set point for the tank should at optimal operation ensure this behavior:

1. Manipulate $q_{in}$ to keep $V = V_{max}$ while $T > T_{hw,s}$
2. Set $q_{in} = 0$ while $T = T_{hw,s}$ and $V > V_{min}$
3. Manipulate $q_{in}$ to keep $V = V_{min}$ while $T < T_{hw,s}$
Volume set point

- if $T \leq T_{hw,s}$: $V_s = V_{min}$
- else $V_s = V_{max}$
Simulink model with switch
Matlab input

Disturbances:

• The demand profile, $q_{out}$ are generated in Matlab, using a script written by Vinicius.
• The price profile, $p$, are taken from Nordpols hourly database.
• The cold water temperature, $T_{cw}$, and the hot water set point, $T_{hw,s}$, are both assumed constant.

Optimized variable:

• Temperature set point, $T_s$. 
Our goal is to minimize the cost function $J$ by changing the temperature set point.

Optimization

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## Brute force optimization

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<td>Always finds correct solution</td>
<td>Inefficient</td>
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<td>Reliable</td>
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- With large sets of temperature set points. Brute force optimization does not calculate the solution within a reasonable time frame.
- Generating to large matrices containing temperature set points might cause Matlab to shut down.
- The main issue is that each simulation takes a long time
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System behavior

Model implementation
Use a method of optimization that does not require simulation.
Conclusions

- Both environmental and economical advantages to hot water energy storage.
- The optimal way of achieving this is not yet determined.