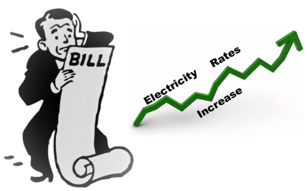
Optimizing Residential HVAC Thermostat to Minimize Electricity Cost

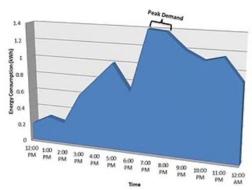
Adhithyan Sakthivelu and Mohamed Nijad

ENERGY 291

Introduction and Problem

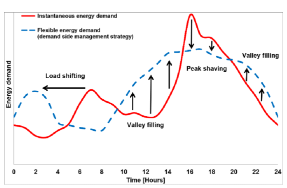
- Customers experience high electricity bills as a result of HVAC power (represents more than half the total load for residential)
- Peak load can translate into a sharp increase in aggregated power demand that can stress the power grid and electric utilities
- Optimization potential if customer's comfort range is increased





Approach

- Model house as a thermal storage unit to understand affect of heating and cooling energy to indoor set temperature
- Utilize the flexibility of controlling thermostat set temperature and its load profile to reduce cost, shift load, and reduce peak load



House Thermal Model

- House is modeled as a thermal storage unit

Heater equation

$$\frac{dQ_{heat}}{dt} = (T_{heater} - T_{indoor}) \times Mdot \times c$$

Cooler equation

$$\frac{dQ_{cool}}{dt} = (T_{indoor} - T_{cooler}) \times Mdot \times c$$

Thermal losses/gain of the houses

$$\frac{dQ_{losses}}{dt} = \frac{T_{indoor} - T_{out}}{R_{eq}}$$

House indoor temperature change

$$\frac{dT_{indoor}}{dt} = \frac{1}{M_{air} \times c}\left(\frac{dQ_{heat}}{dt} - \frac{dQ_{cool}}{dt} - \frac{dQ_{losses}}{dt}\right)$$

Model Structure

- Objective function: minimize cost function

$$\text{minimize} \sum_{t=1}^{24} cost_{(t)} \times (Q_{heat(t)} + Q_{cool(t)})$$

- Constraints:

$$T_{indoor(1,25)} = T_{set}\,{}^{o}C$$

$$T_{set} - \Delta T_{comfort} \leq T_{indoor(t)} \leq T_{set} + \Delta T_{comfort}\,{}^{o}C,\ \forall t$$

$$M_{air}c_{air}\big(T_{indoor(t+1)} - T_{indoor(t)}\big)Q_{heat(t)} - Q_{cool(t)} - \frac{T_{indoor(t)} - T_{out(t)}}{R_{eq}}\ \ joules/hr\ \forall t$$

$$Q_{heat(t)} \leq Mdot \times c \times \big(T_{heater(t)} - T_{indoor(t)}\big)\ joules/hr$$

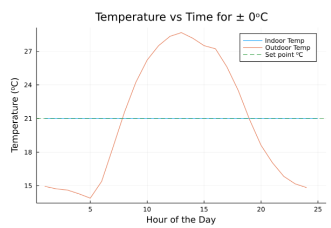
$$Q_{cool(t)} \leq Mdot \times c \times \big(T_{indoor(t)} - T_{cooler(t)}\big)\ joules/hr$$

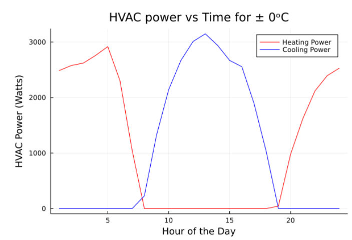
$$Q_{heat(t)} \times \gamma_{J2W} \leq \eta_{heat} \times P_{limit}\ \forall\, t$$

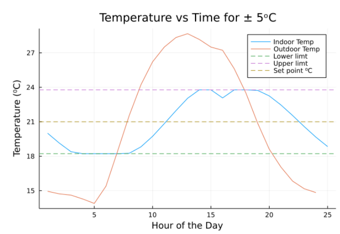
$$Q_{cool(t)} \times \gamma_{J2W} \leq \eta_{cool} \times P_{limit}\ \forall\, t$$

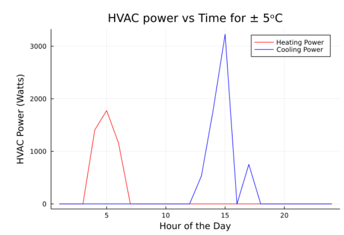
Results

- Cost minimization with and without comfort level: cost goes down from \$5.23 to \$1.23 per day!

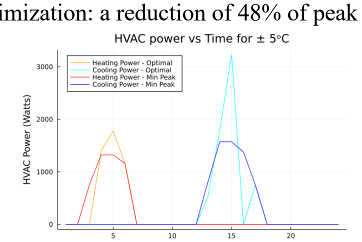






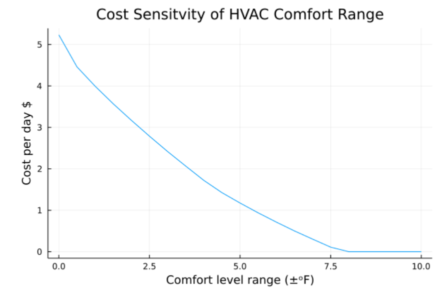


- Peak load minimization: a reduction of 48% of peak load (from 3200W to 1655W)



Sensitivity Analysis

- Sensitivity analysis quantifies the changes on the cost of electricity with respect to comfort level range



Conclusions

- A homeowner can reduce their daily electricity cost from \$5.23 to \$1.23 by relaxing set temperature by ±5 'F, which can translate to \$120 savings per month
- Peak load can be reduced by 48% by utilizing low power mode throughout a longer duration

Future Work

- Model can be used to optimize over a group of residential buildings for aggregate demand response
- Utilities can use model to introduce incentives for demand response programs for residential homes to reduce peak load during high peak periods
- The optimization model can by experimented into a thermostat controls device such as Goggle NEST

References and Acknowledgements

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[3] "House Thermal Model." MATLAB and Simulink, https://www.mathworks.com/help/simulink/slref/thermal-model-of-a-house.html.