

# **MINLP of a Chiller System with Thermal Energy Storage**

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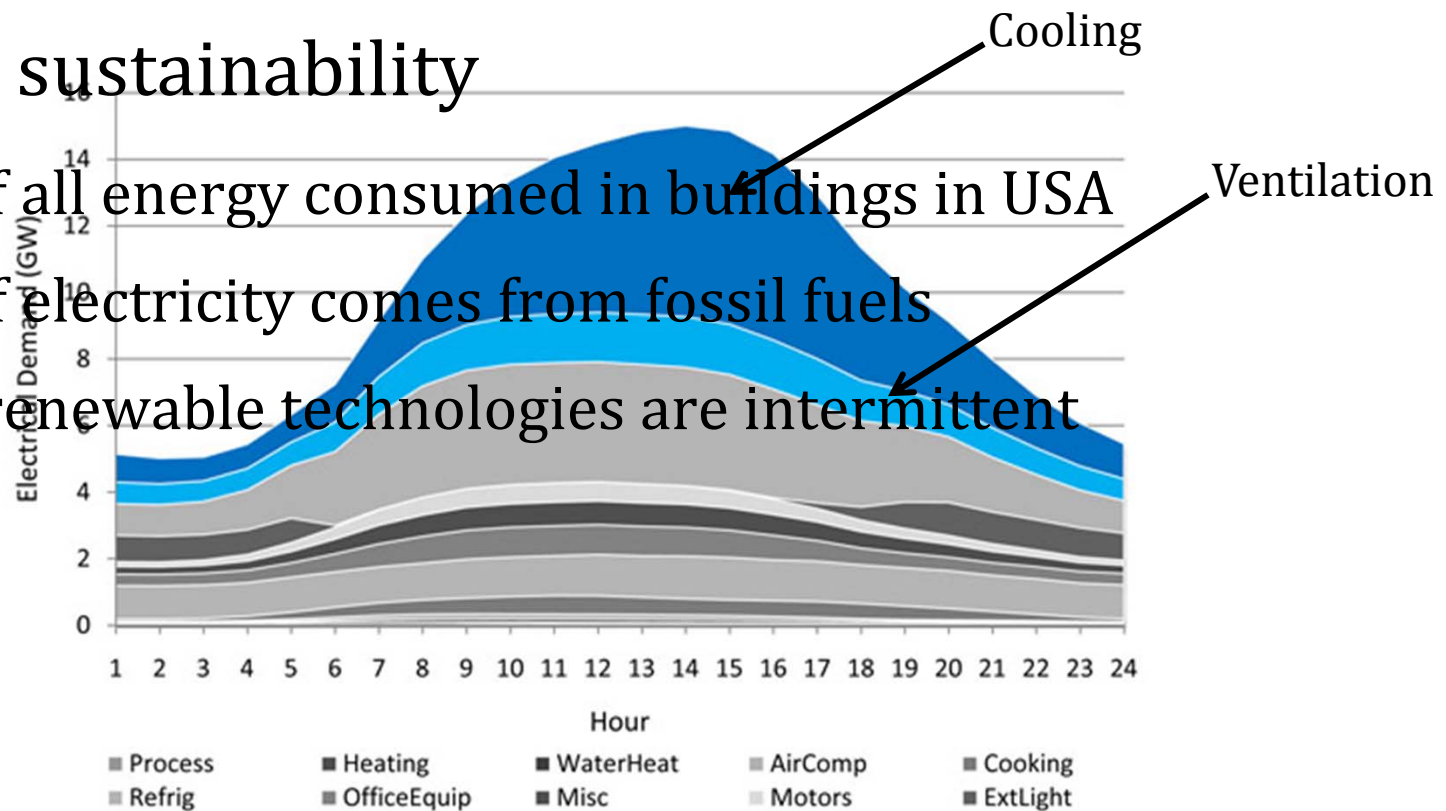
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# Motivations

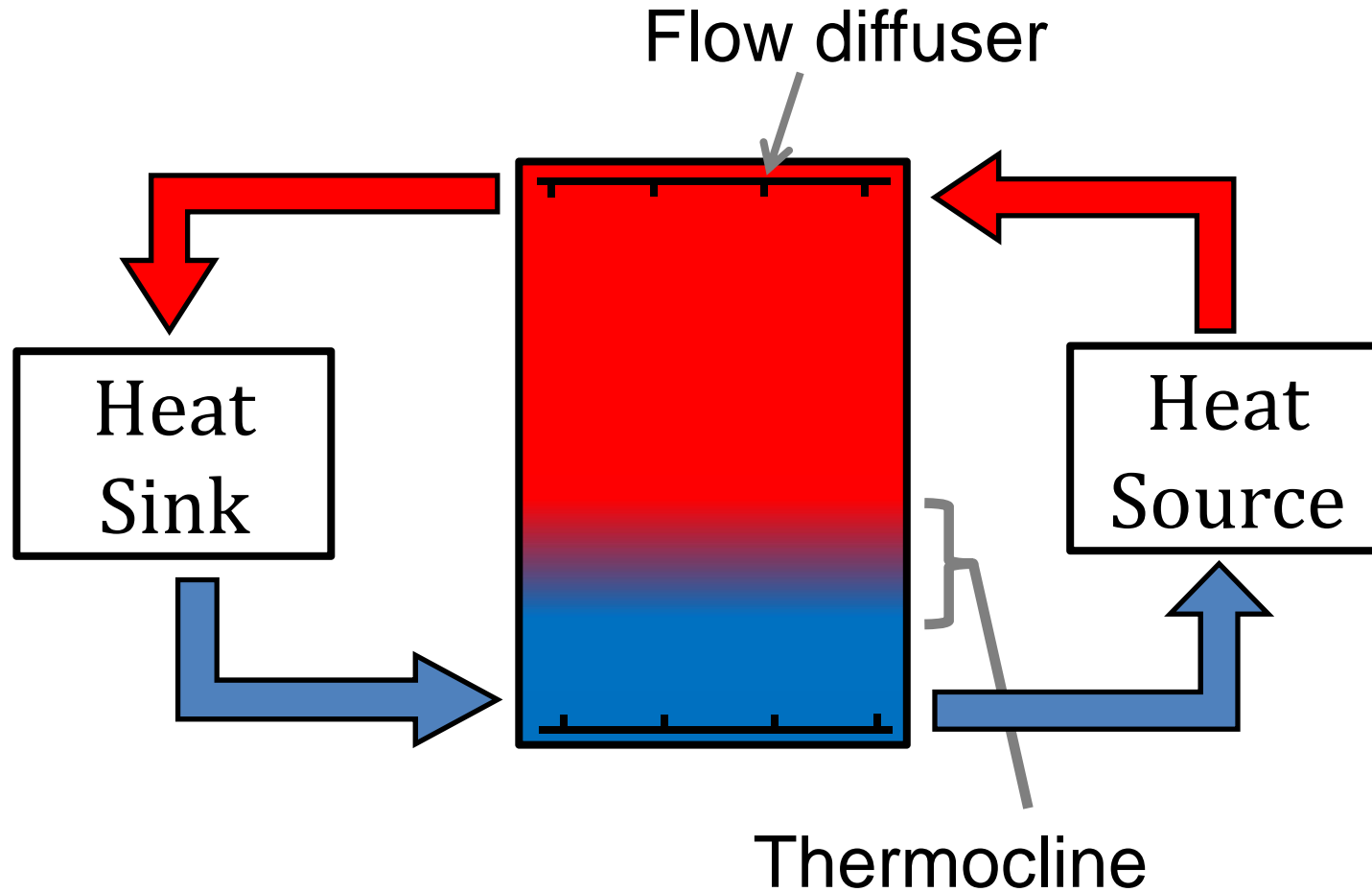
- Peak demand
- Low utilization → high cost

- Energy sustainability

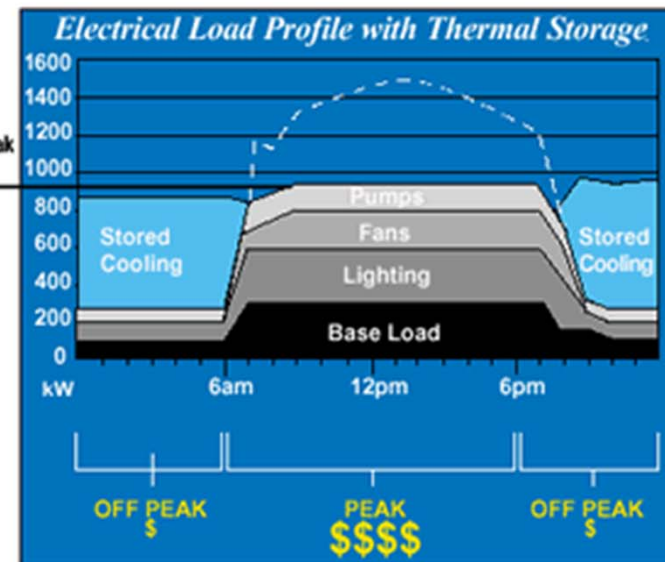
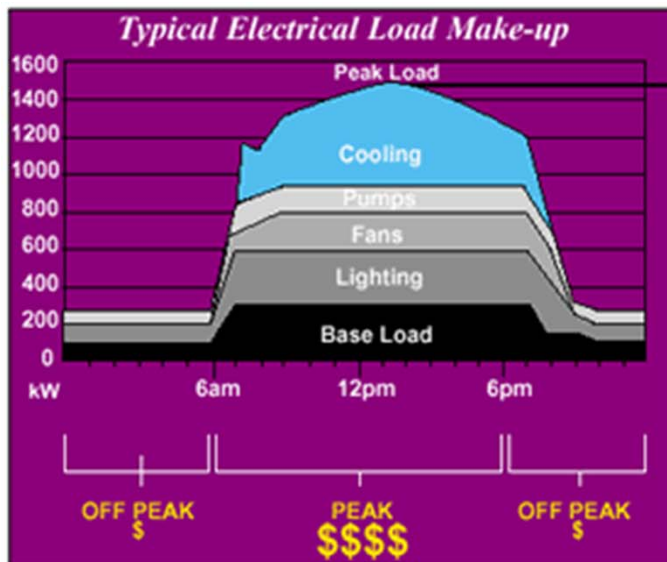
- 40% of all energy consumed in buildings in USA
- 70% of electricity comes from fossil fuels
- Many renewable technologies are intermittent



# Thermal Energy Storage (TES)



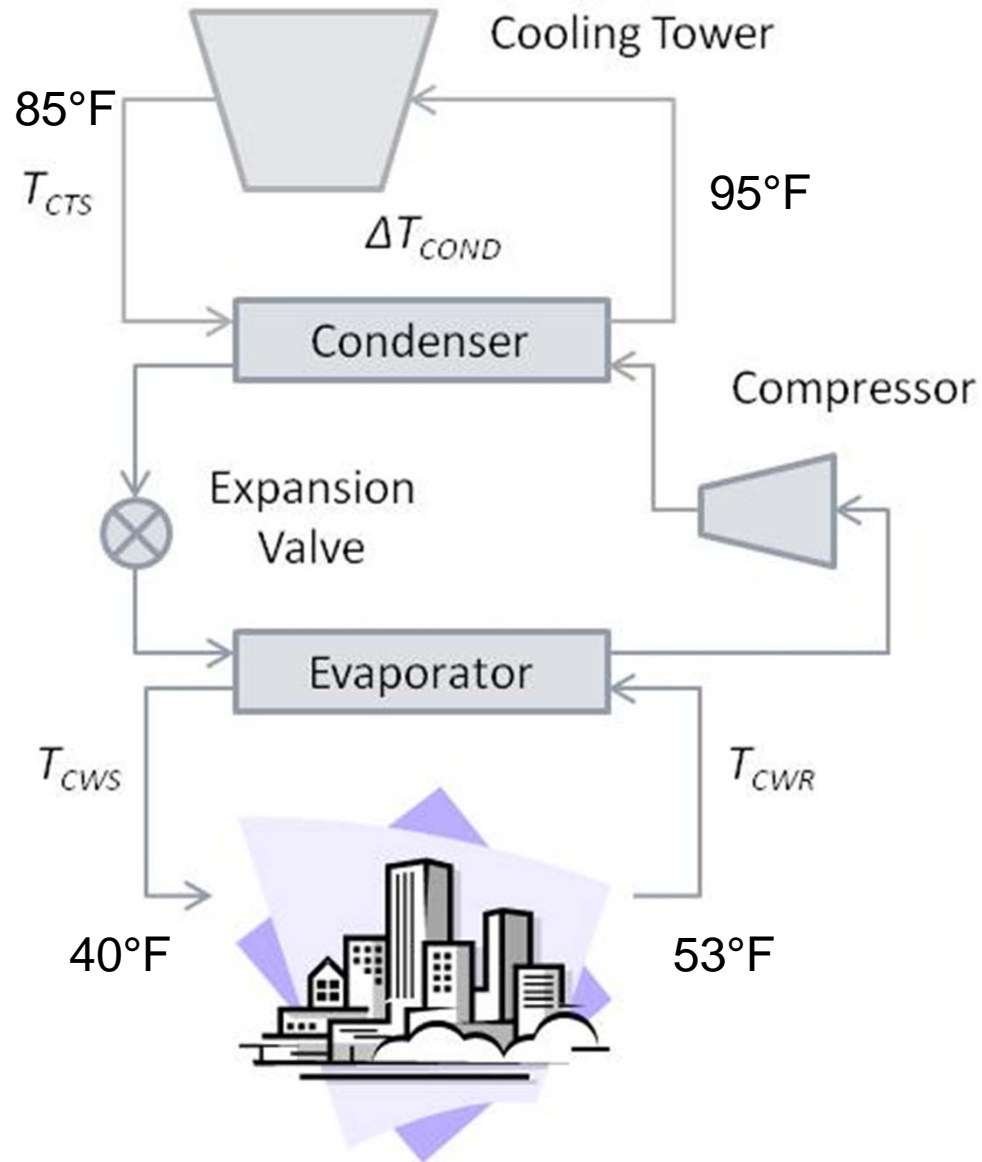
# Thermal Energy Storage (TES)



# Traditional Chiller System

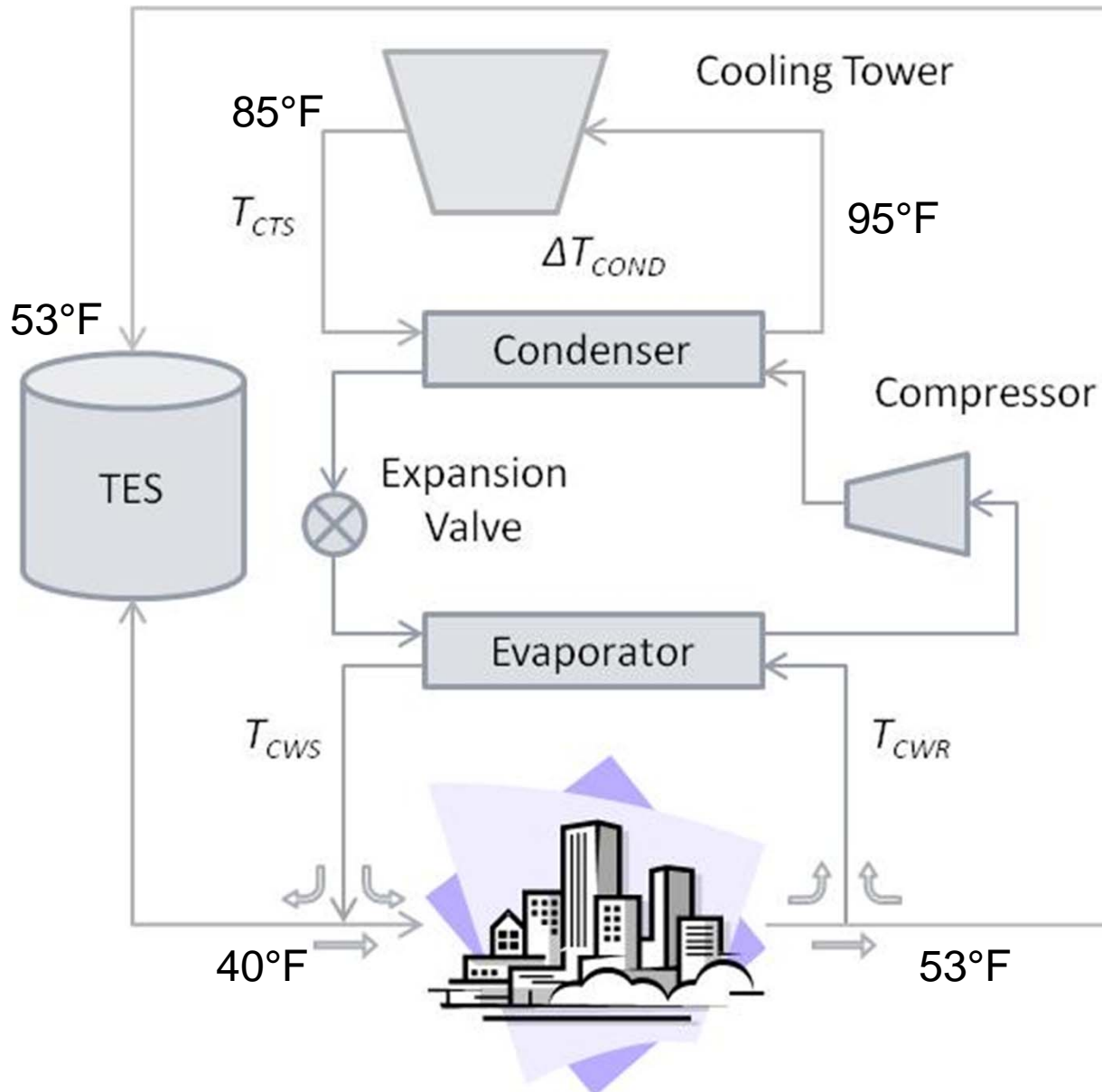
Efficiency affected by:

- $T_{CTS}$
- $T_{CWS}$
- Part-load Ratio (PLR)



40°F = 4.4°C  
53°F = 11.7°C  
85°F = 29.4°C  
95°F = 35°C

# Chiller-TES System



$40^{\circ}\text{F} = 4.4^{\circ}\text{C}$   
 $53^{\circ}\text{F} = 11.7^{\circ}\text{C}$   
 $85^{\circ}\text{F} = 29.4^{\circ}\text{C}$   
 $95^{\circ}\text{F} = 35^{\circ}\text{C}$



# Chiller & Building Models

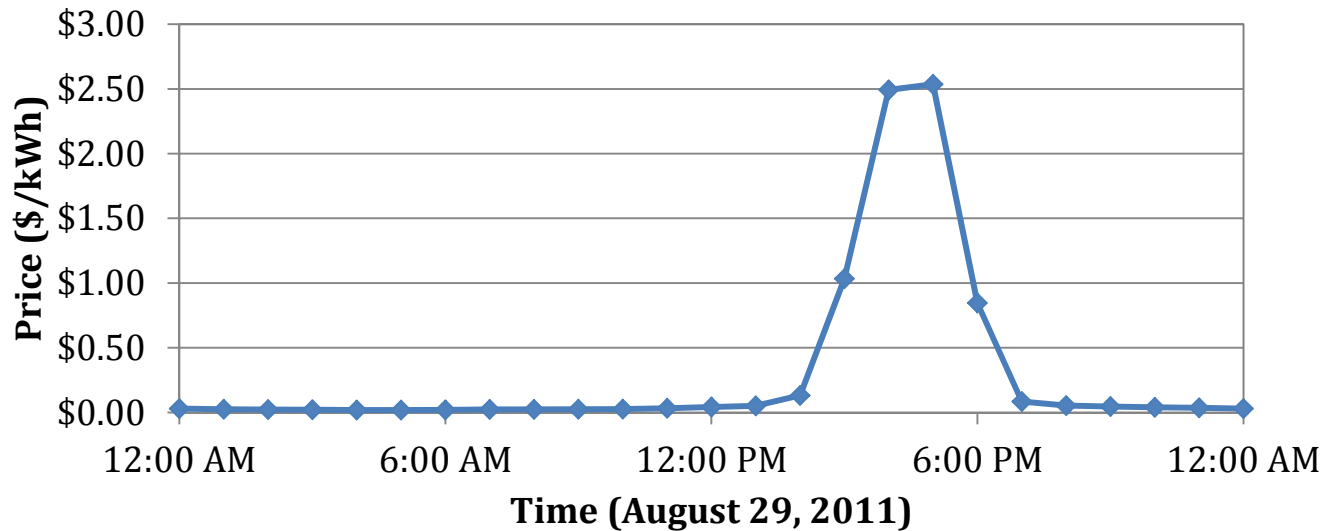
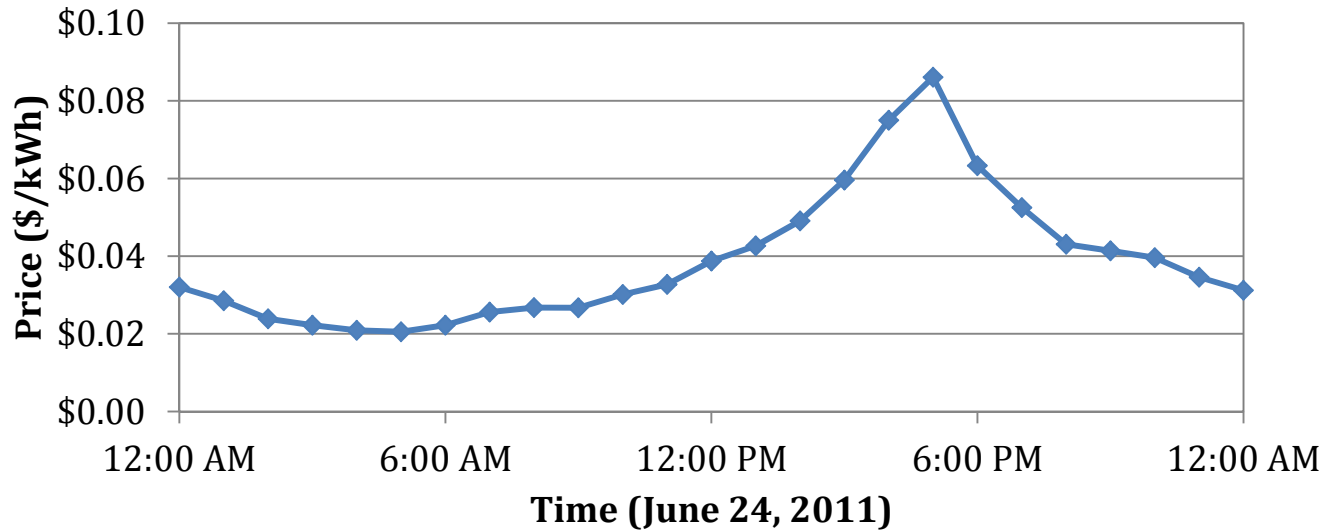
## ■ Chiller Models:

- Empirical, nonlinear, steady-state model
- Time constants → ~5 minutes

## ■ Building Models:

- Linear dynamic models
- 2011 Austin, TX weather data
- Time constants → hours

# Day-ahead Settling Point Price (SPP)



# Problem Formulation (MINLP)

$$J = \int_0^{t_f} c_{elec}(t) \sum_i P_{chiller,i}(t) dt$$

Subject to:

$$\sum_i y_i L_{chiller,i} = L_{building} - TES$$

$$P_{chiller,i} = y_i f(L_{chiller,i}, WBT) \quad f \text{ is nonlinear}$$

$$\frac{dE_{TES}}{dt} = -TES$$

$$0 \leq E_{TES} \leq 8000$$

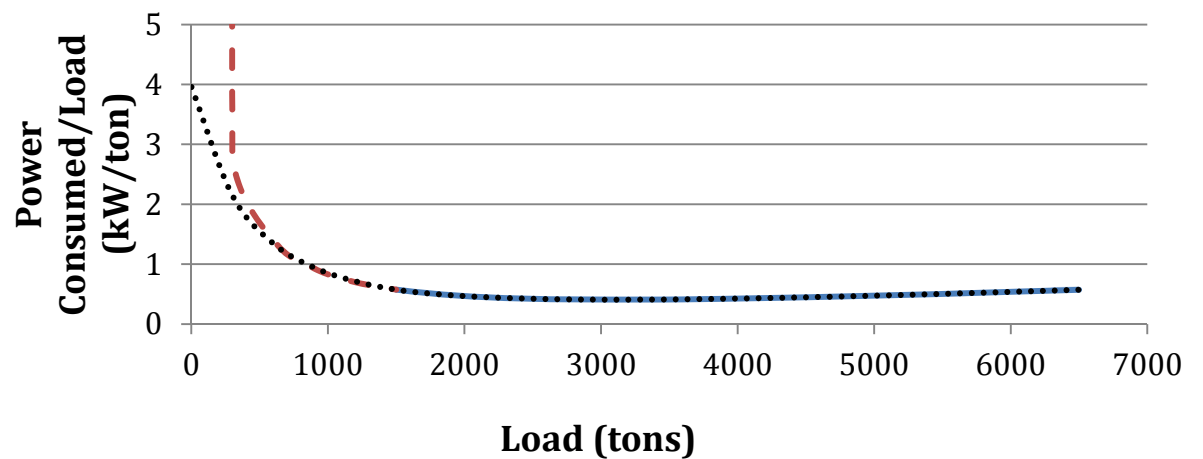
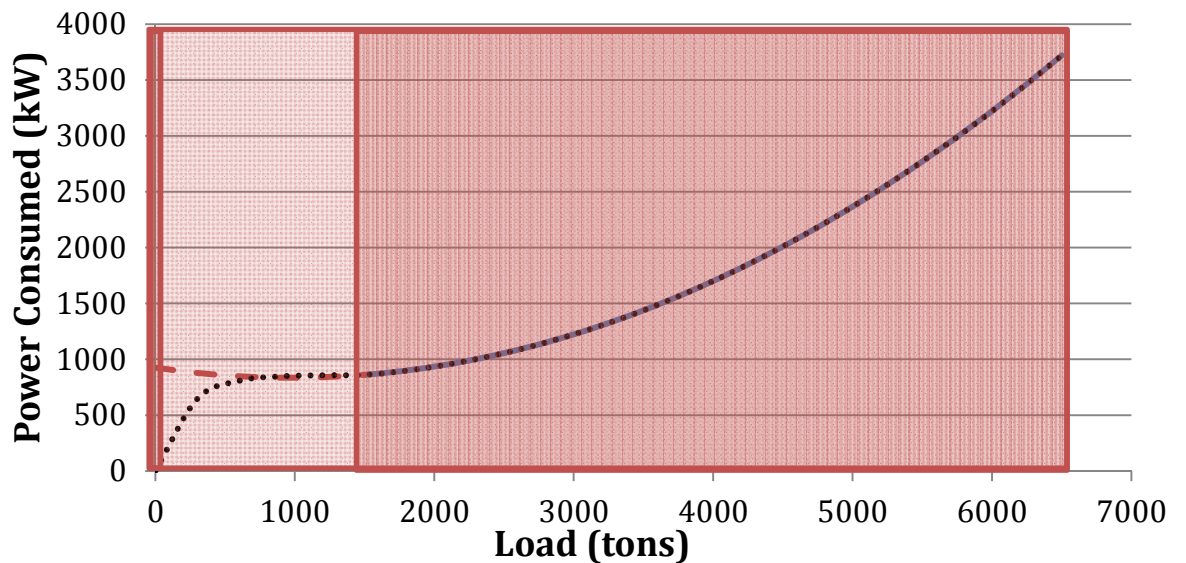
$$-2000 \leq TES \leq 2000$$

$$175 \leq L_{chiller,i} \leq 1312$$

$$y_i \in 0,1$$

# Relaxing Binary Constraints

- Mixed integer problem doubles # variables
- Branch and bound technique significantly increases computation time
- Continuous formulation?



# Problem Formulation (Relaxed)

$$J = \min \sum_{i=1}^{24} \left[ c_{elec,i} \left( P_{chiller1,i} + P_{chiller2,i} \right) \right]$$

Subject to:

$$L_{chiller1,i} + L_{chiller2,i} = L_{building,i} - TES_i$$

$$P_{chiller1,i} = f \left( L_{chiller1,i}, WBT_i \right) \quad f \text{ is nonlinear}$$

$$P_{chiller2,i} = f \left( L_{chiller2,i}, WBT_i \right)$$

$$E_{TES,i} = E_{TES,i-1} - TES_i$$

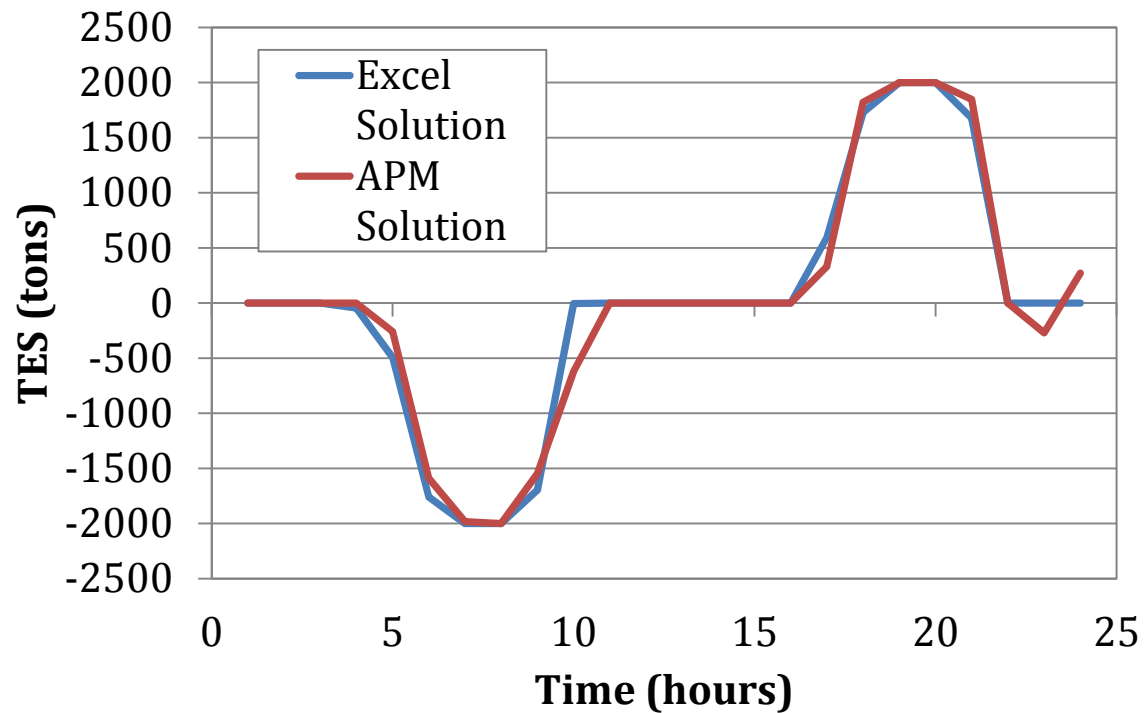
$$0 \leq E_{TES,i} \leq 8000$$

$$-2000 \leq TES_i \leq 2000$$

Solved using SQP  
algorithm

# Results

	<b>BONMIN</b>	<b>BONMIN2</b>	<b>Excel</b>	<b>APM</b>	<b>Matlab</b>
<b>Value (\$/day)</b>	\$ 807.53	\$ 803.00	\$ 801.93	\$ 802.89	\$ 802.13
<b>Time (min)</b>	11.56	-	58.376	897.6	0.108256



# Conclusions

- Relaxed formulation appears adequate
- Ease of implementation (easiest to hardest)
  - Excel
  - Matlab
  - APMonitor
  - GAMS