# Industrial Power Automation & Optimization


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Principal Data Scientist

Lineage Logistics

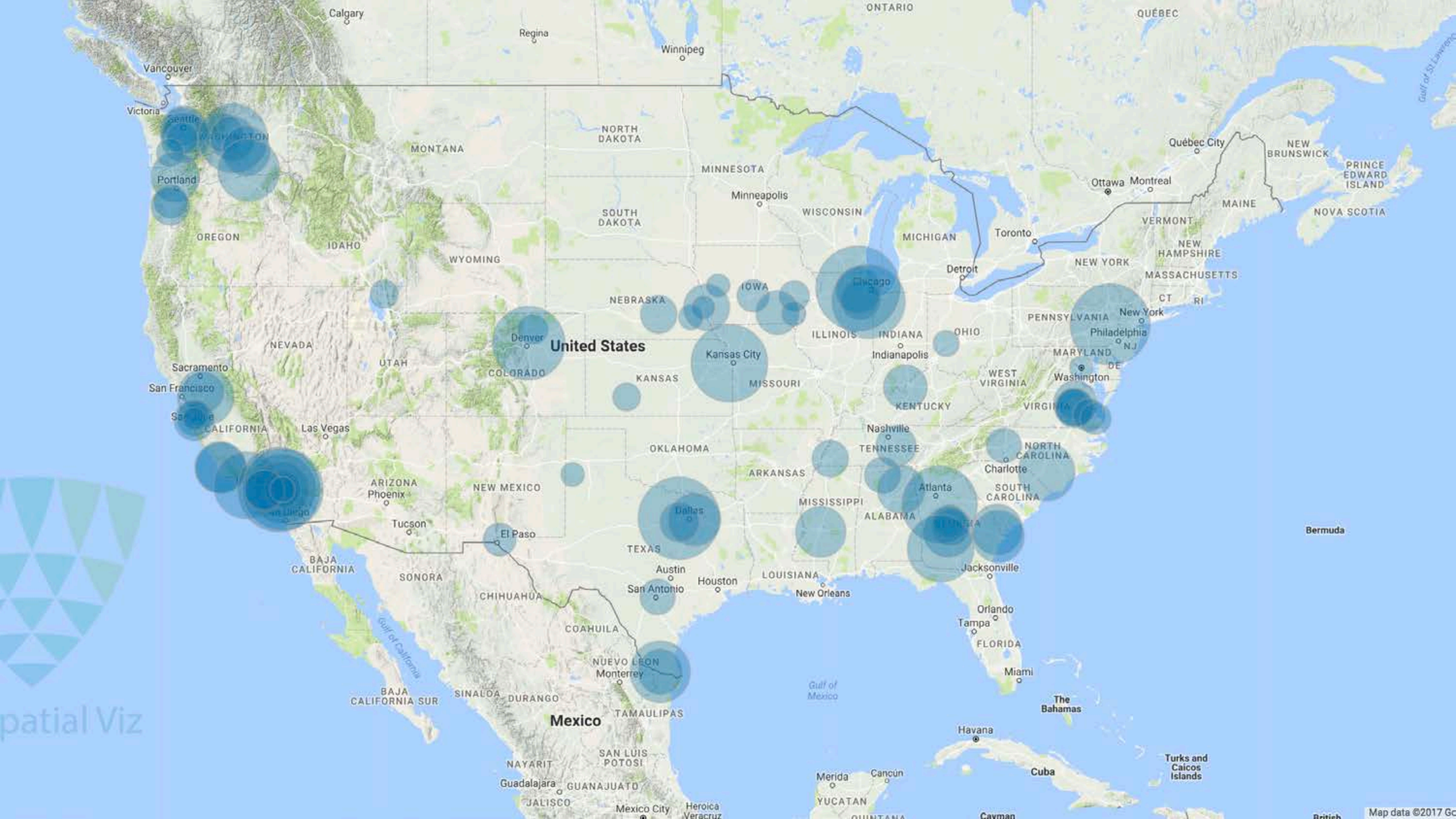
ETCC EMERGING TECHNOLOGIES COORDINATING COUNCIL



Lineage


0 °F


LLSS AMMONIA
BD AMMONIA



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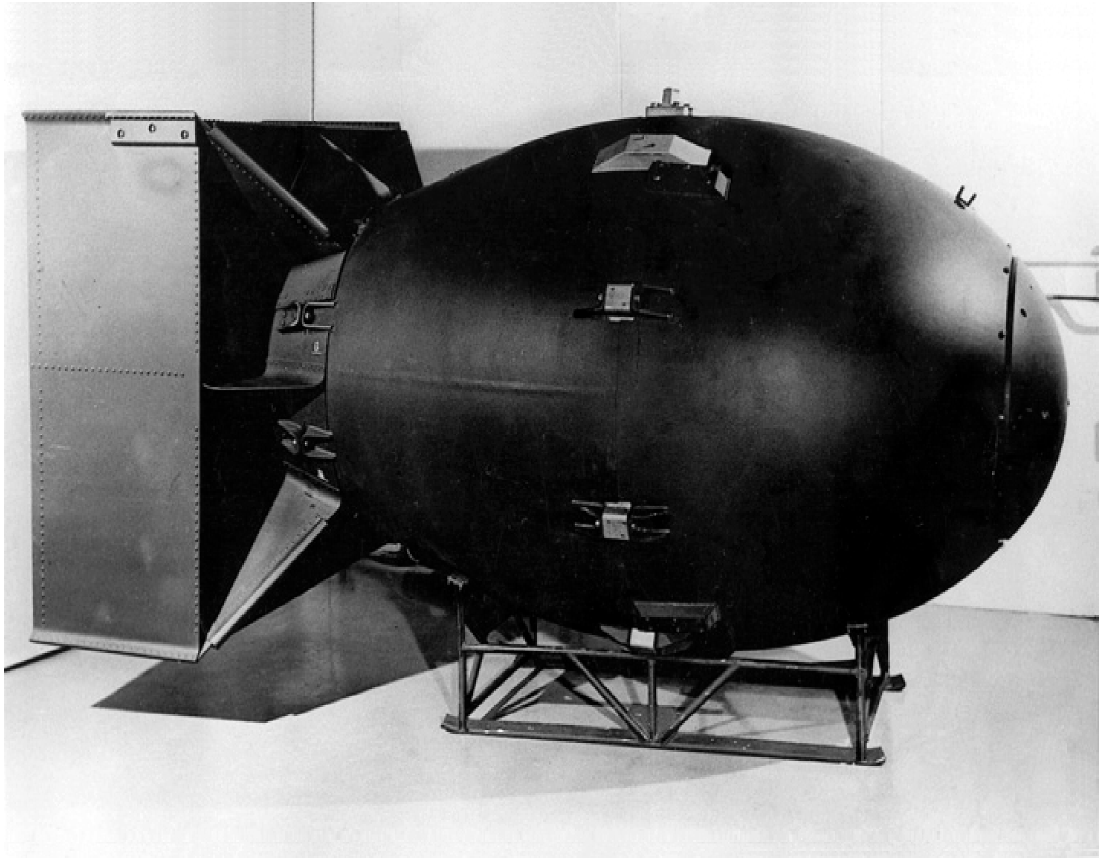
patial Viz
Map data ©2017 Go

# 2800 TJ => 23 Fat Mans => $61MM/yr



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| | THERMAL WORK | | EFFICIENCY | | PRICE / kW |
| --- | --- | --- | --- | --- | --- |
| POWER COST = | $kW_T$ | * | $\frac{kW_E}{kW_T}$ | * | $\frac{\$}{kW_E}$ |

**Thermal Work**
- Doors
- LEDs

**Efficiency**
- VFDS
- Control Logic
- Voltage Regulation

**Price / kW**
- **SCHEDULE OPTIMIZATION**
- Rate Contracts
- Solar
- Energy Storage

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|---|---|---|---|---|---|
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- **Doors**
- LEDs

- VFDS
- Control Logic
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- SCHEDULE OPTIMIZATION
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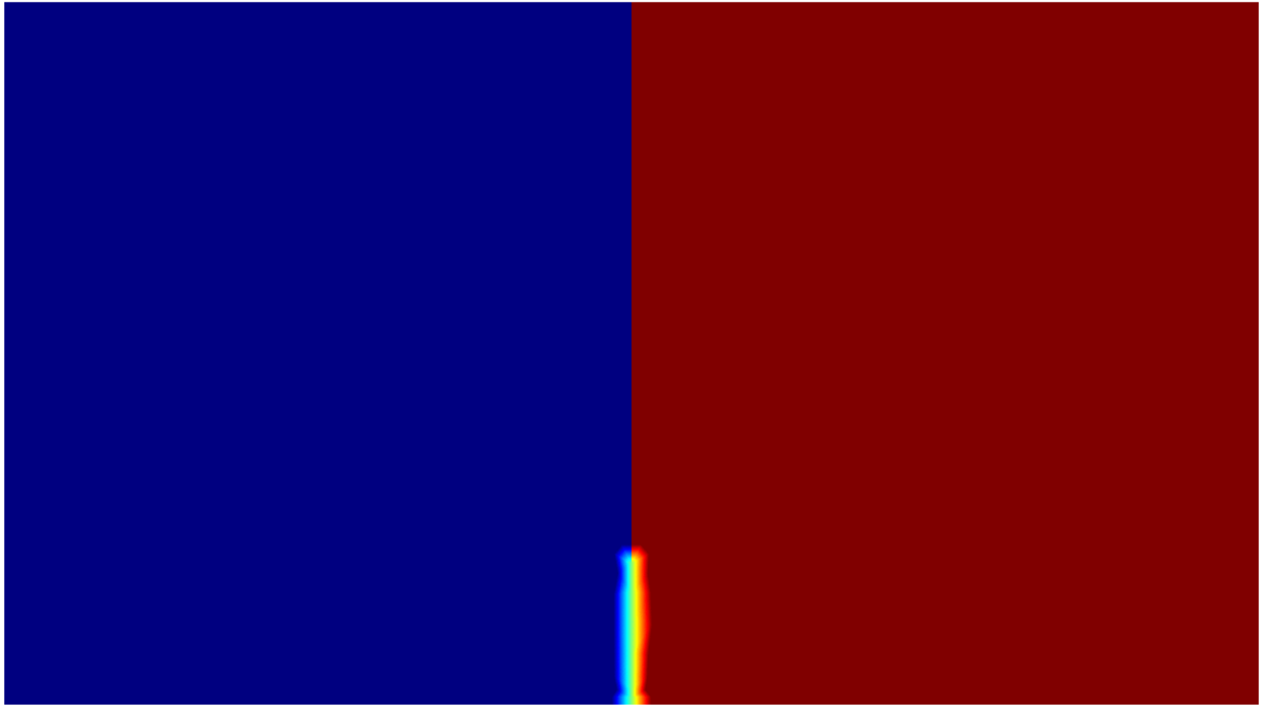
80 °F
0 °F
HYSTER



| | | Thermal Work | | Efficiency | | Price / kW |
|---|---|---|---|---|---|---|
| Power Cost | = | $kW_T$ | * | $\frac{kW_E}{kW_T}$ | * | $\frac{\$}{kW_E}$ |

- Doors
- LEDs

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- Control Logic
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- **SCHEDULE OPTIMIZATION**
- Rate contracts
- Solar
- Energy Storage

Weather

# Georgia Weather Forecast: Heat Wave, Storm Chances

Dangerous "feels like" temperatures expected Monday, with a week of temperatures in the 90s, according to the National Weather Service.

By Greg Hambrick (Patch National Staff) - July 17, 2016 4:18 pm ET

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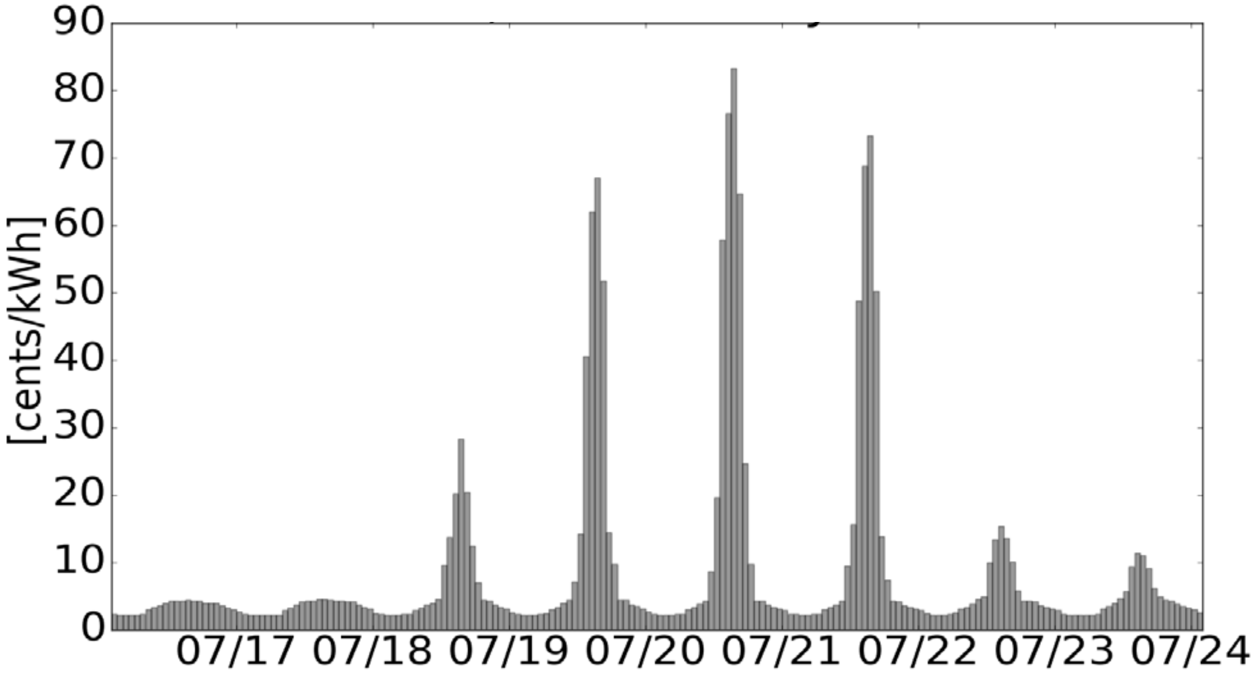
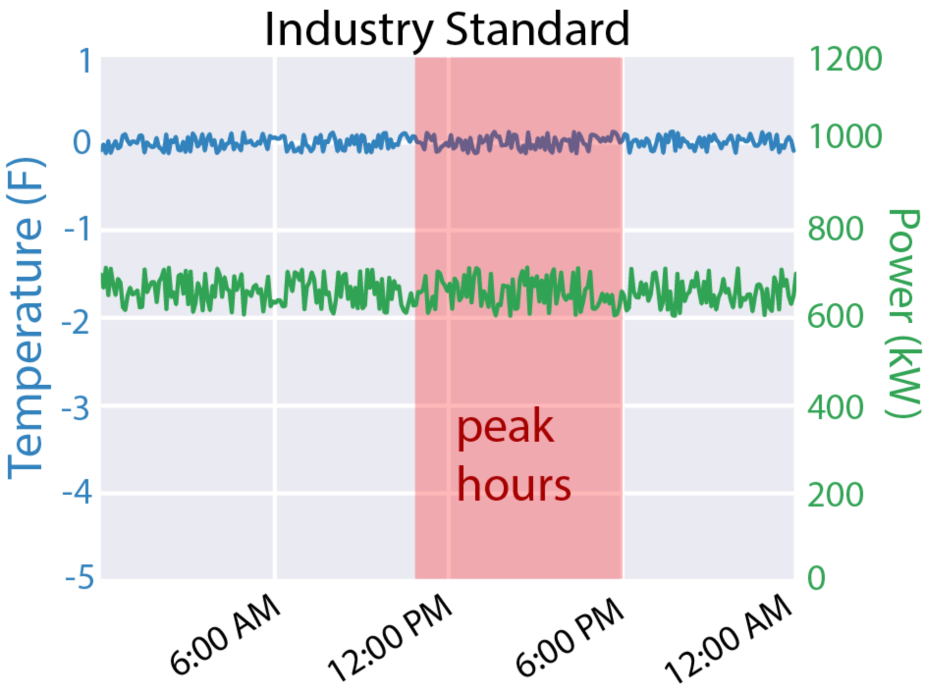
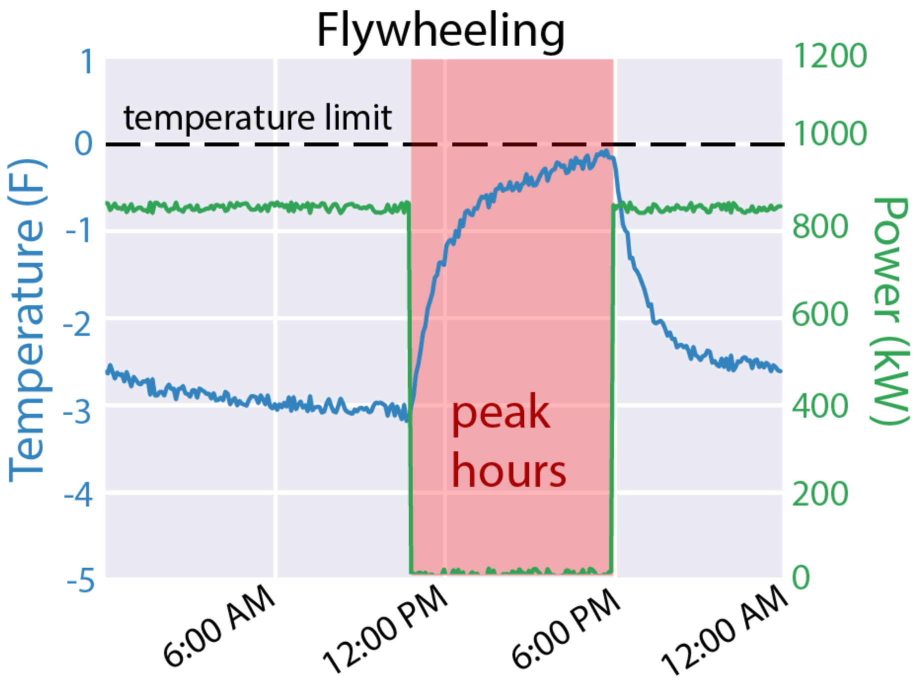
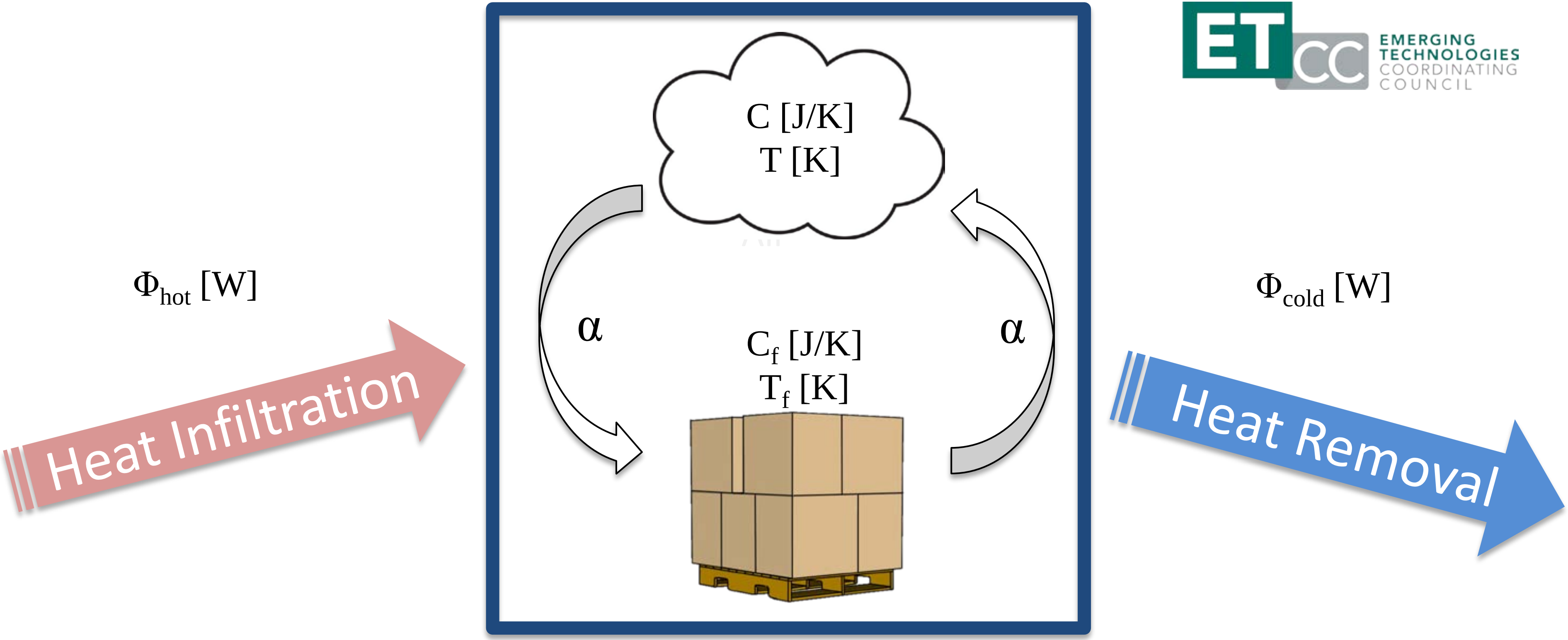



Industry Standard
1
0
-1
-2
-3
-4
-5
Temperature (F)
1200
1000
800
600
400
200
0
Power (kW)
peak hours
6:00 AM
12:00 PM
6:00 PM
12:00 AM


Flywheeling
temperature limit
1
0
-1
-2
-3
-4
-5
Temperature (F)
1200
1000
800
600
400
200
0
Power (kW)
peak hours
6:00 AM
12:00 PM
6:00 PM
12:00 AM



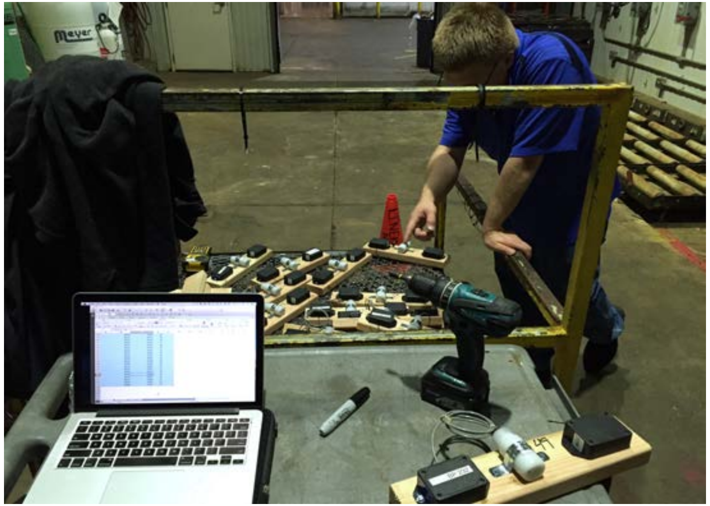

$$C_f \frac{\mathrm{d}T_f}{\mathrm{d}t} = -\alpha(T_f(t) - T(t))$$

$$C \frac{\mathrm{d}T}{\mathrm{d}t} = \alpha(T_f(t) - T(t)) + \Phi$$

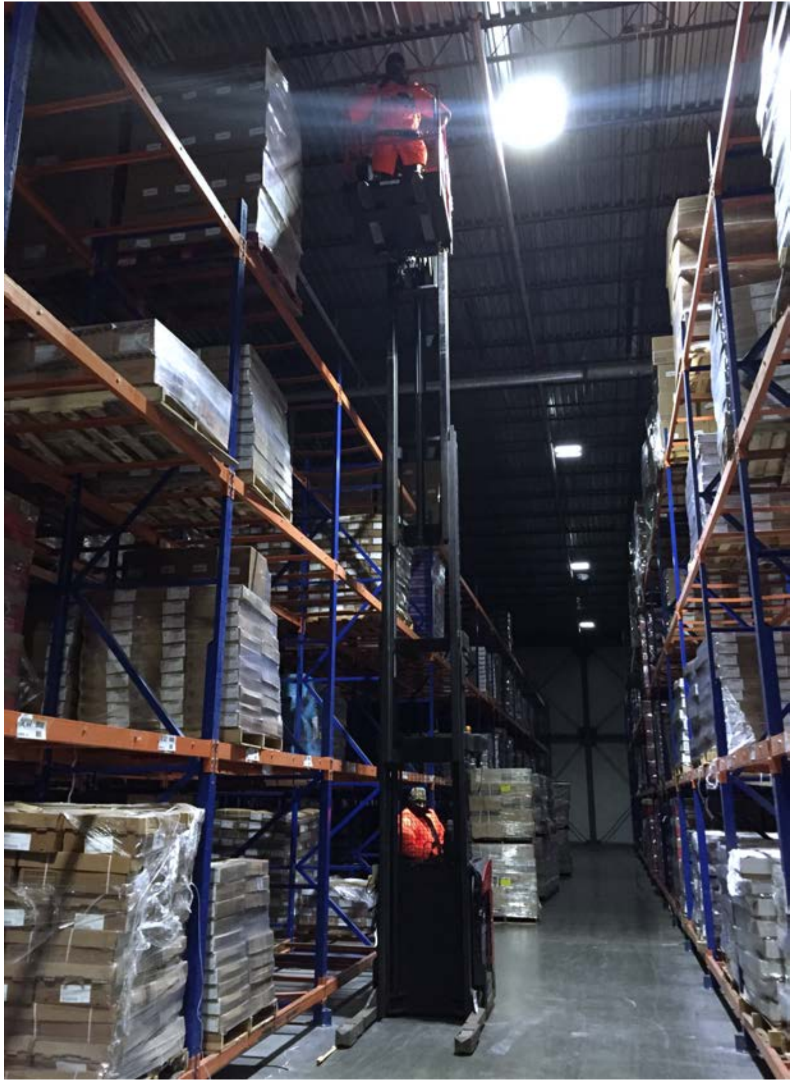
$$\Rightarrow$$

$$T(t) = A + mt + Be^{-t/\tau}$$

$$T_f(t) = A_f + mt + B_f e^{-t/\tau}$$







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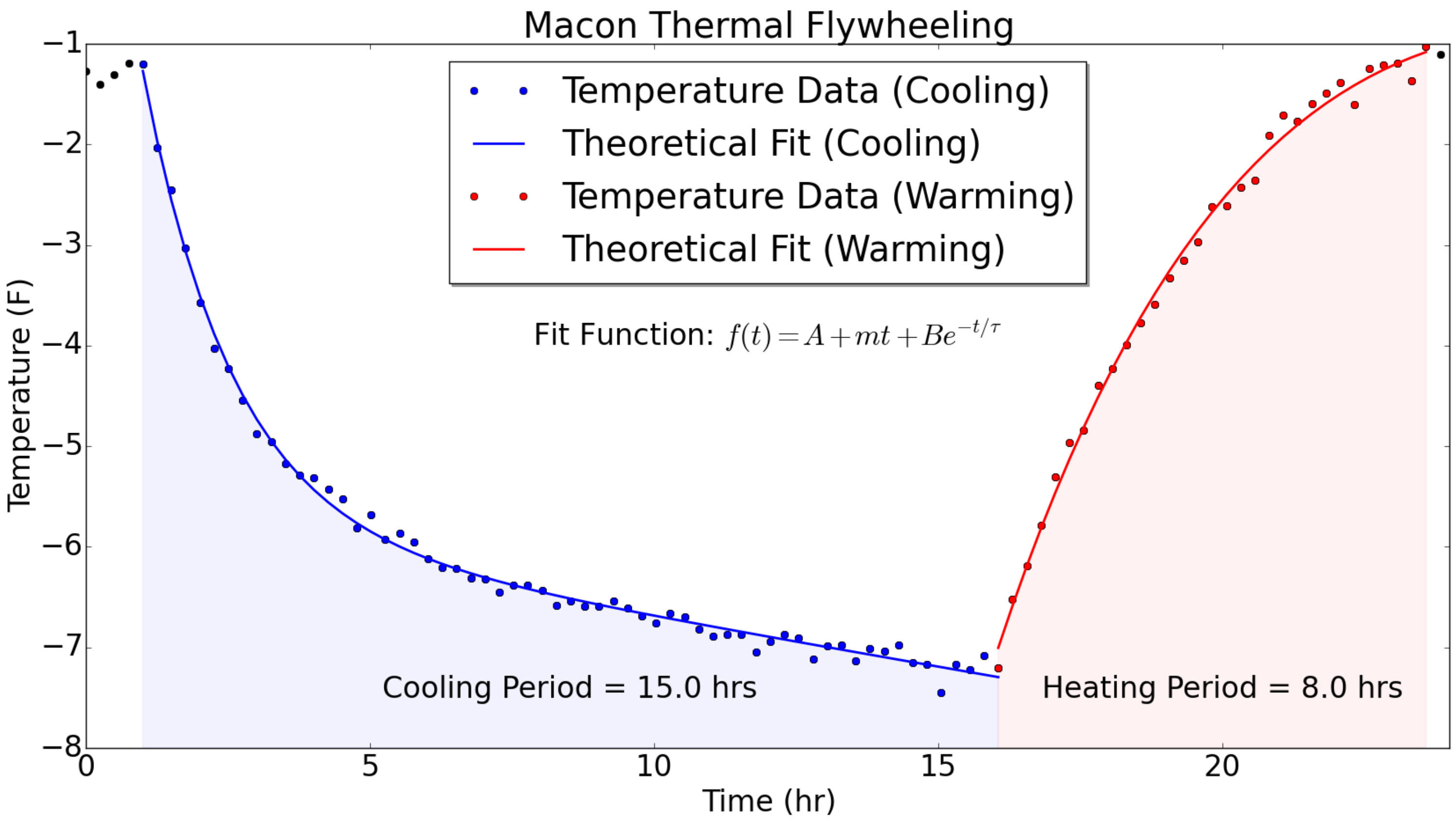

Macon Thermal Flywheeling
Temperature Data (Cooling)
Theoretical Fit (Cooling)
Temperature Data (Warming)
Theoretical Fit (Warming)
Fit Function: $f(t) = A + mt + Be^{-t/\tau}$
Cooling Period = 15.0 hrs
Heating Period = 8.0 hrs
Temperature (F)
Time (hr)
−1
−2
−3
−4
−5
−6
−7
−8
0
5
10
15
20

# Objective = Minimize Cost

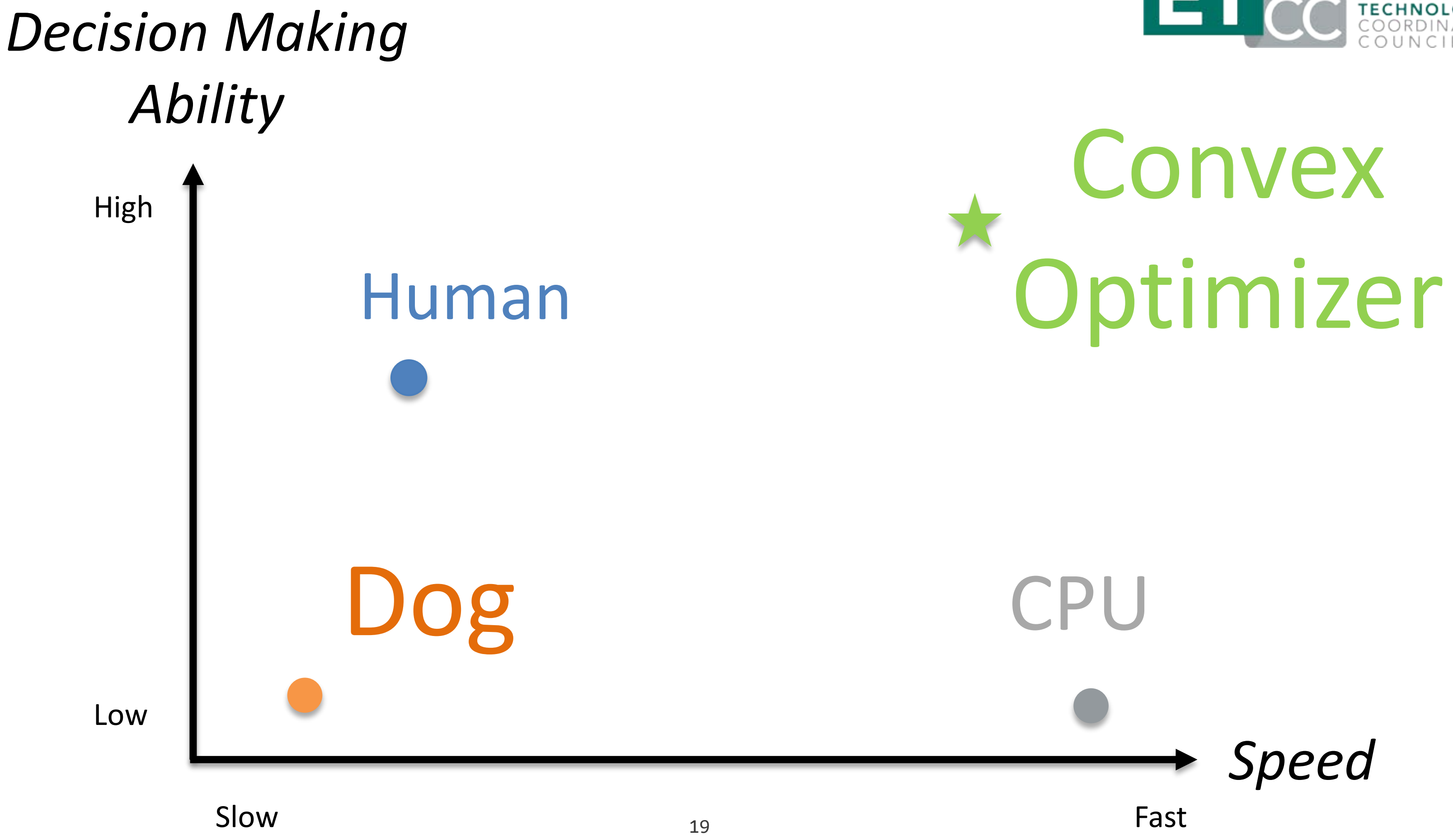
Usage Rates

Demand Rates

Warehouse Properties

Environmental Conditions

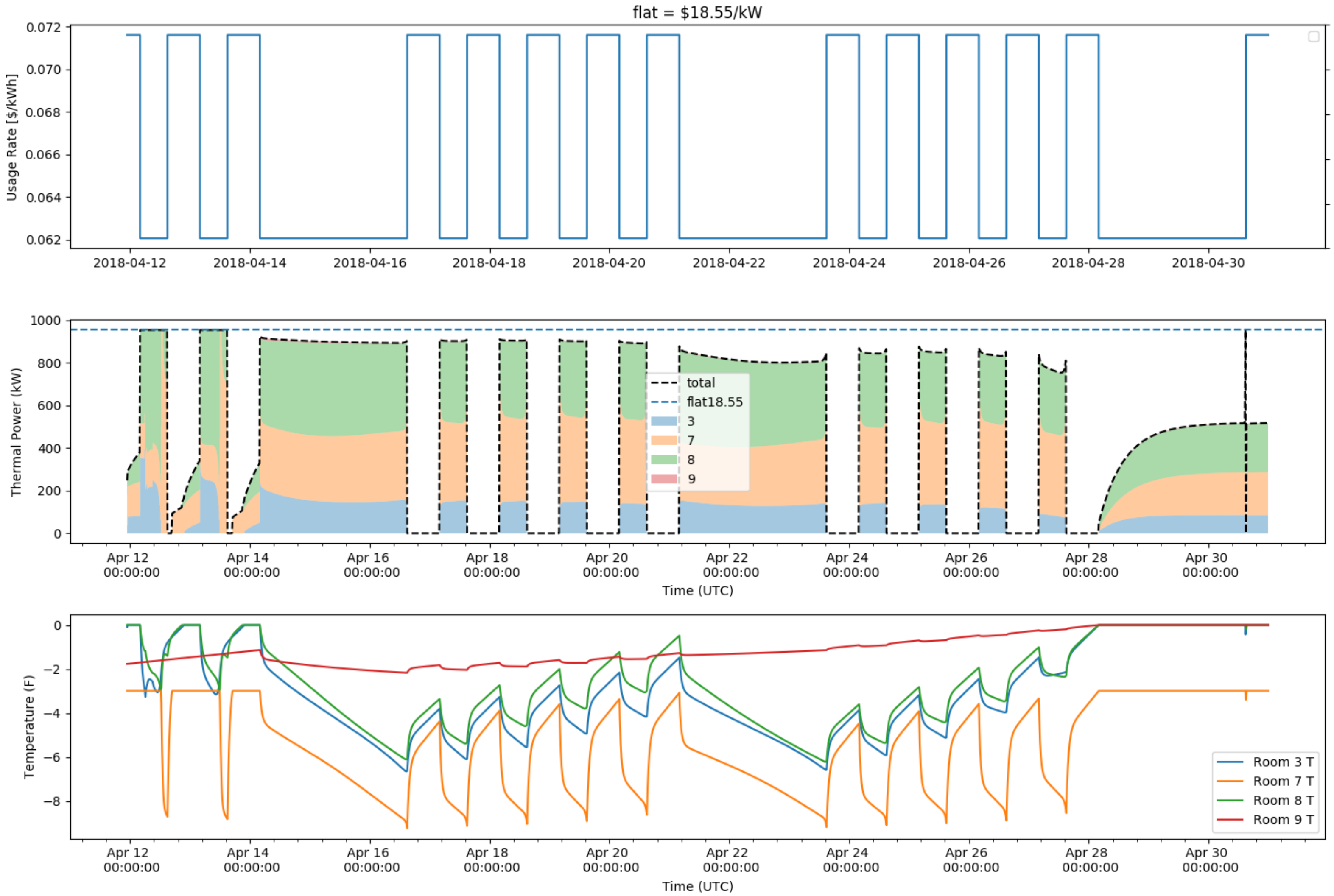
Cooling Schedule

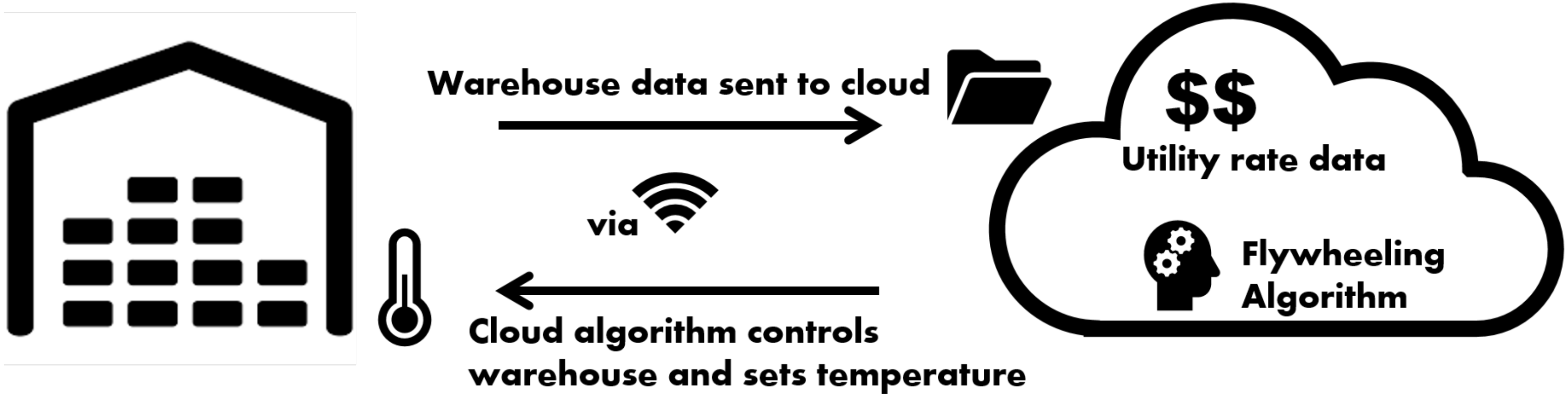

Decision Making Ability
High
Low
Human
Convex Optimizer
Dog
CPU
Speed
Slow
Fast

# Convex Formulation

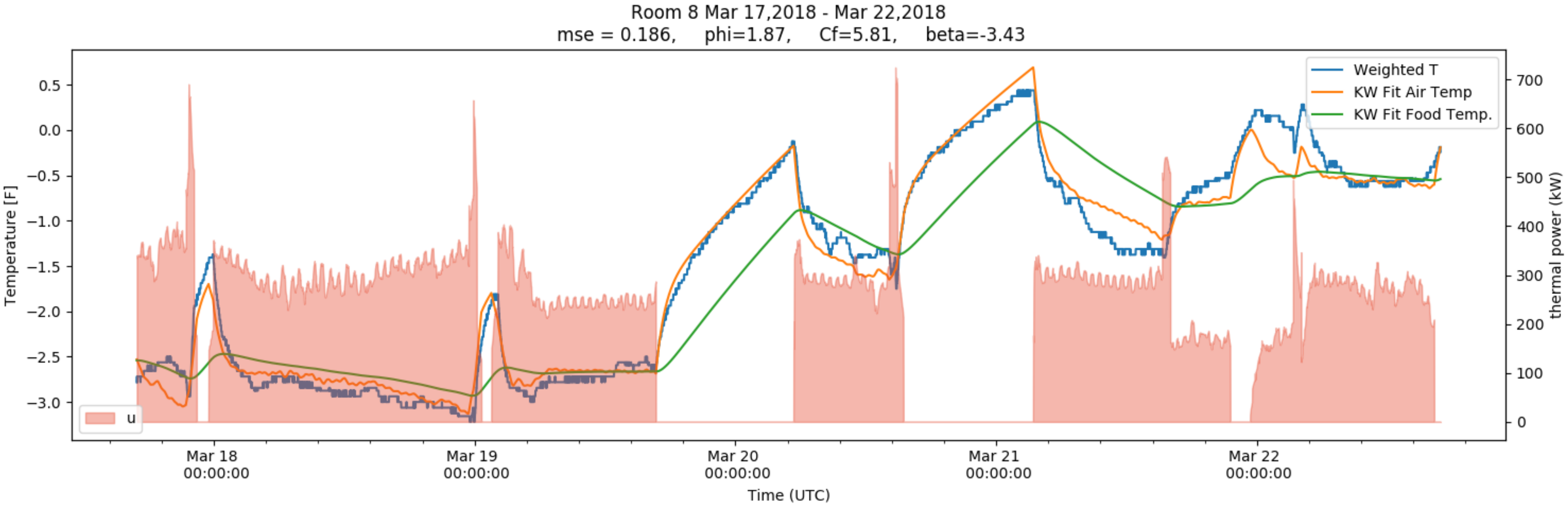
$$
\begin{aligned}
\text{minimize} \quad & c^T X + k_d max(X) \\
\text{subject to} \quad & 0 \leq X \leq M \\
& C_f \left(T_f(t+1) - T_f(t)\right) = \alpha \left(T_w(t) - T_f(t)\right) \\
& C \left(T_w(t+1) - T_w(t)\right) = \alpha \left(T_f(t) - T_w(t)\right) + \Phi_{hot}(t) - \Phi_{cold}(t) \\
& \Phi_{hot}(t) = (k_1 + k_2 d(t))(T_o(t) - T_w(t)) + k_3 X(t) \\
& \Phi_{cold}(t) = k_4 X(t) \left(\frac{T_w}{T_o(t) - T_w(t)}\right) \\
& T_w \leq 0
\end{aligned}
$$

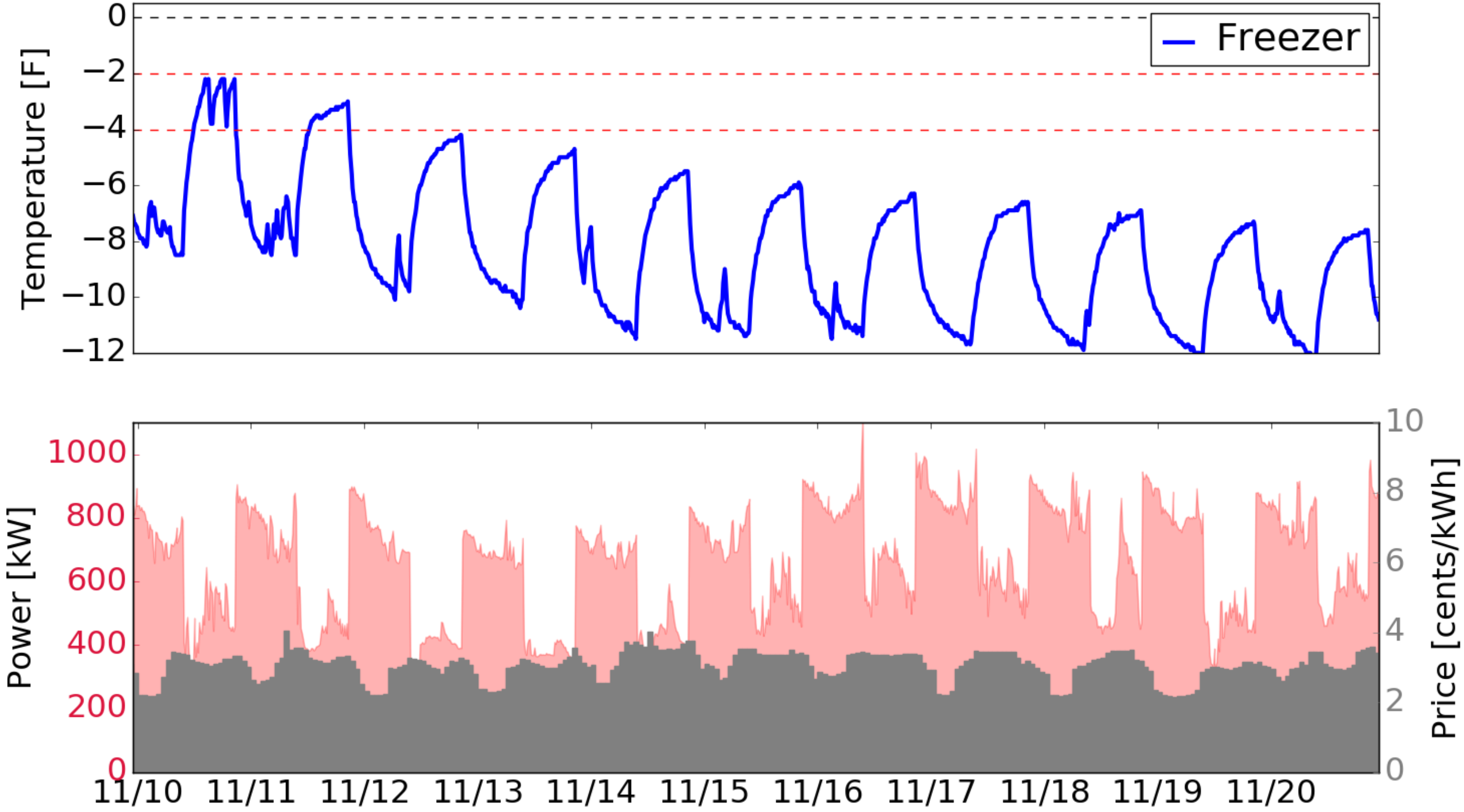
```python
#initial air temperature [F]
T0 = -2
#initial food temperature [F]
Tf0 = T0
#min/max temperature constraint [F]
Tmin = -20
Tmax = 0
# air and food temp versus time
T = cvx.Variable(hrs + 1)
Tf = cvx.Variable(hrs + 1)

# power consumption vs. time
x = cvx.Variable(hrs)

#define objective function
cost = cvx.sum_entries(cvx.mul_elemwise(p,x) + cvx.max(x)*D
objective = cvx.Minimize(cost)

# prepare a list of all the constraints
constraints = [T <= Tmax, T >= Tmin, T[0] == T0, Tf[0] == Tf0, x <= 100, x >= 0]

# Temperature trace must obey thermal differential equation
for t in range(hrs):
    constraints.append(Cf * (Tf[t + 1] - Tf[t]) == -alpha * (Tf[t] - T[t]))
    constraints.append((T[t + 1] - T[t])== (alpha * (Tf[t] - T[t]) - beta * x[t] + phi_h[t])

prob = cvx.Problem(objective, constraints)
prob.solve()
```


flat = $18.55/kW
Usage Rate [$/kWh]
0.072
0.070
0.068
0.066
0.064
0.062
1.0
0.8
0.6
0.4
0.2
0.0
2018-04-12
2018-04-14
2018-04-16
2018-04-18
2018-04-20
2018-04-22
2018-04-24
2018-04-26
2018-04-28
2018-04-30
Thermal Power (kW)
1000
800
600
400
200
0
total
flat18.55
3
7
8
9
Apr 12 00:00:00
Apr 14 00:00:00
Apr 16 00:00:00
Apr 18 00:00:00
Apr 20 00:00:00
Apr 22 00:00:00
Apr 24 00:00:00
Apr 26 00:00:00
Apr 28 00:00:00
Apr 30 00:00:00
Time (UTC)
Temperature (F)
0
−2
−4
−6
−8
Room 3 T
Room 7 T
Room 8 T
Room 9 T
Apr 12 00:00:00
Apr 14 00:00:00
Apr 16 00:00:00
Apr 18 00:00:00
Apr 20 00:00:00
Apr 22 00:00:00
Apr 24 00:00:00
Apr 26 00:00:00
Apr 28 00:00:00
Apr 30 00:00:00
Time (UTC)


Warehouse data sent to cloud
via
Cloud algorithm controls
warehouse and sets temperature
$$
Utility rate data
Flywheeling
Algorithm

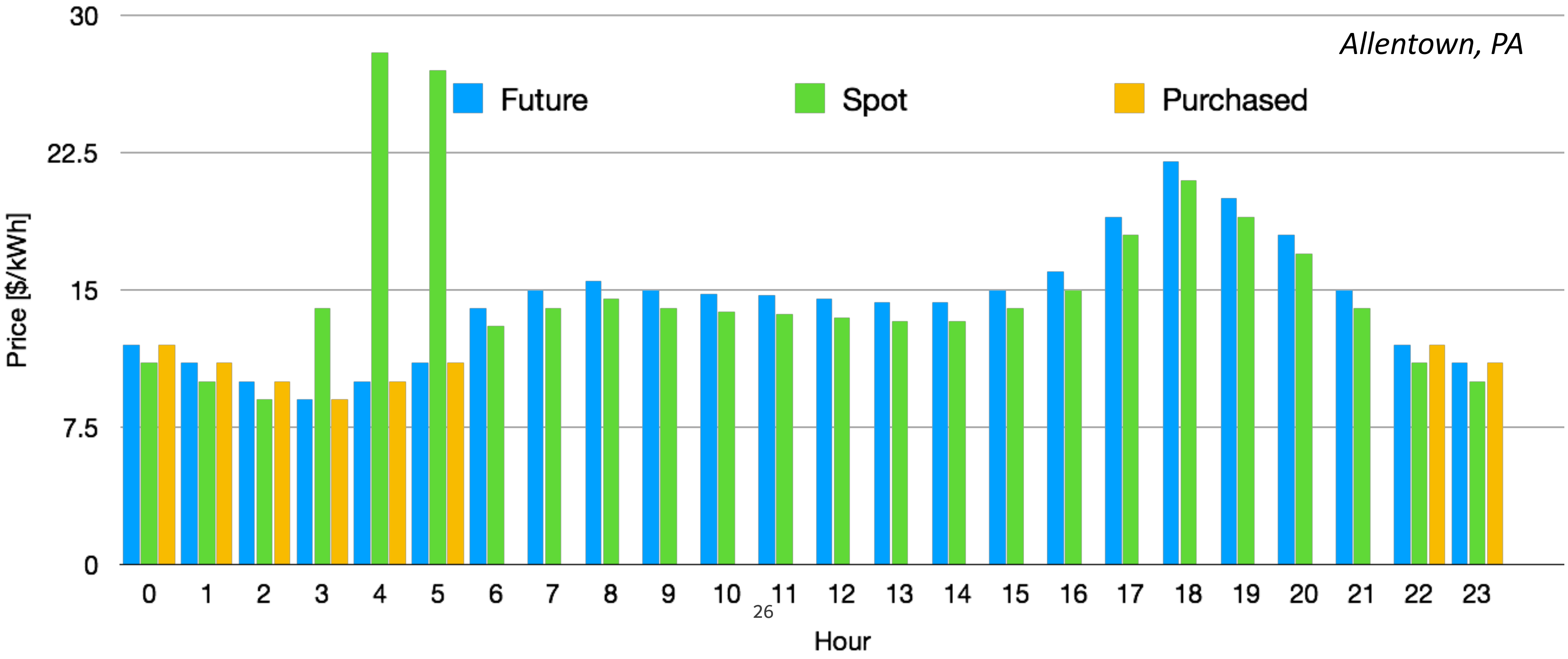
# *Theory vs. Experiment*





Temperature [F]
0
−2
−4
−6
−8
−10
−12
Freezer
Power [kW]
1000
800
600
400
200
0
Price [cents/kWh]
10
8
6
4
2
0
11/10
11/11
11/12
11/13
11/14
11/15
11/16
11/17
11/18
11/19
11/20

# Power as a Profit Center



# *Highlights*

- Industrial equipment can safely receive setpoints from the cloud
- Optimization algorithms can find optimum equipment setpoints
- US food supply is the largest & cheapest battery in the world

- Schedule optimization has reduced cooling costs ~40%
- Technique can modified to achieve *any* objective:
    - Match solar production (ZNE)
    - Demand Response events
    - Operate equipment at most efficient state

# *Thank you*

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