Load shifting for HVACR systems using automated demand response and interpolative pre-cooling

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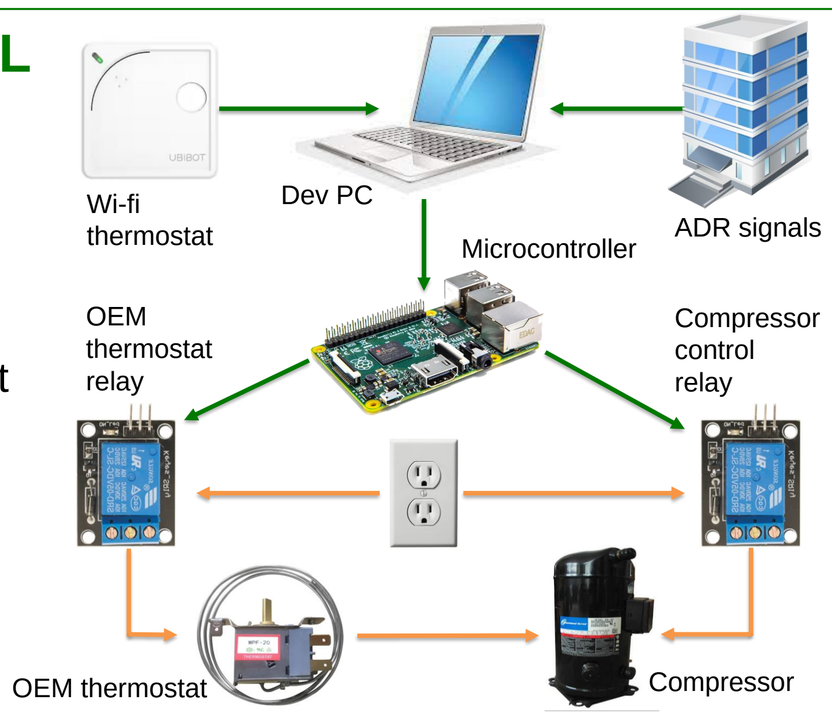
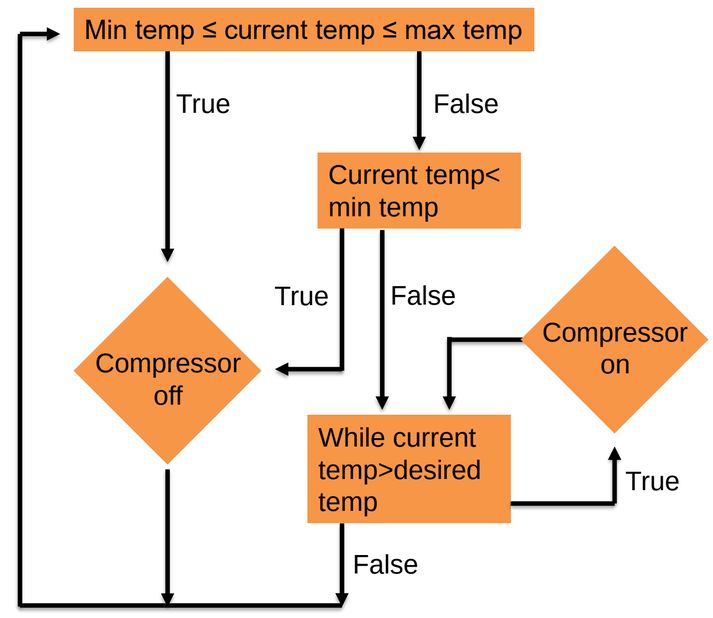
SYSTEM TOPOLOGY AND CONTROL

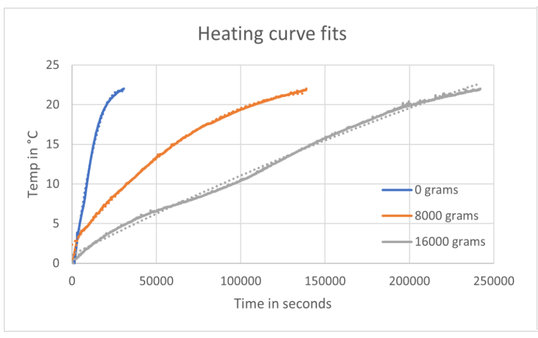
Grid Fruit is a software as service provider which seeks to save commercial refrigeration clients money by using automated demand response (ADR) to perform load shifting. To show product viability, a demonstration platform was constructed which responds to event signals sent via the OpenADR protocol. Using the received signals, the system calculates the optimal compressor operation schedule to minimize power usage during ADR events.

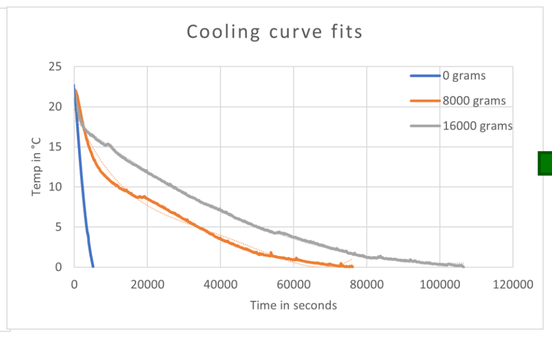




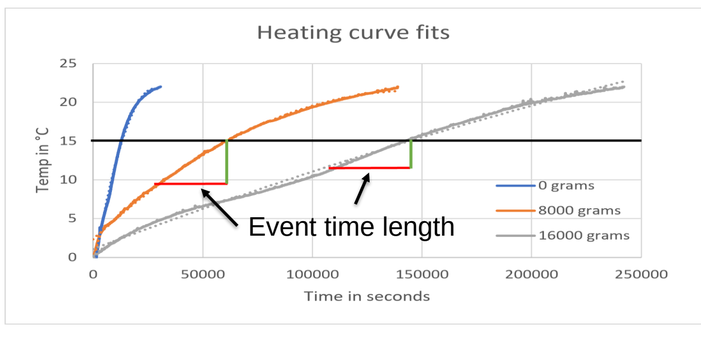
INTERPOLATIVE PRE-COOLING METHODOLOGY

To minimize energy cost, it is desirable to reduce or eliminate power consumption during high price periods. This can be done by reducing the temperature of the refrigerator and its contents before the event, allowing the system to warm up over the course of the high price period without exceeding the allowable max temperature. A series of simple tests allow users to determine the heating and cooling curves of their system under various levels of loading. Using these curves, the optimal time to begin pre-cooling that maximizes savings can be calculated.

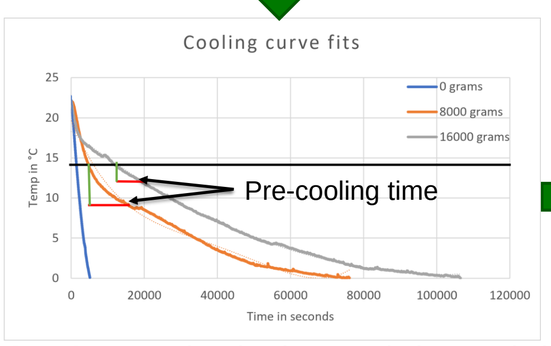




Step 1. Obtain heating and cooling equations by cooling and heating different loads continuously from 0° C to 22° C. Curve fit to desired accuracy



Step 2. Given the time length of the high price period, determine the temperature to be pre-cooled to by back calculating from maximum temperature with the curve fitted heating equations.



Step 3. Determine the time needed to reach the pre-cooling temperature by finding the time differential between the current temperature and precooling temperature from step 2.

Linear Interpolation Formula

$$Y = Y_0 + (X - X_0) \times \frac{Y_1 - Y_0}{X_1 - X_0}$$

Step 4. Using the required cooling times obtained from the two nearest curves in terms of mass (one of less mass than actual, one of greater mass), linearly interpolate between the two times to find the cooling time for the actual load.

Y = interpolated cooling time in seconds
X = current load mass in grams
$Y_{0,1}$ = cooling times for lower and upper mass curves
$X_{0,1}$ = Load masses used during recording of upper and lower curves

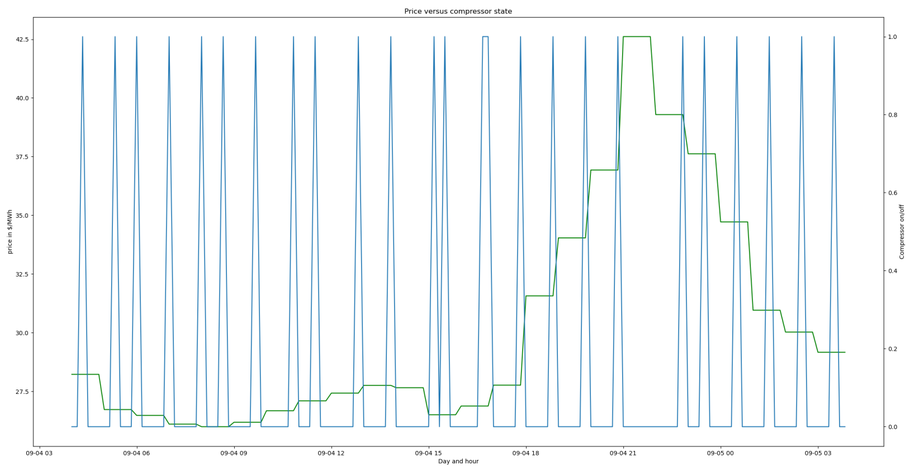
CONCLUSIONS: SYSTEM PERFORMANCE AND ESTIMATED MONETARY SAVINGS

- To estimate possible savings, mixed integer programming was used to determine daily compressor operation schedules that minimized energy cost in response to day-ahead LMP.
- This process was carried out using a year of hourly historical LMP data from PJM, with an individual optimization being performed for each day.
- Baseline performance was simulated using real-world power consumption profiles obtained from the test system under thermostatic operation.

$$min \sum_{j=1}^{365} \sum_{i=1}^{24 \times \frac{3600}{SCT}} LMP[i] \times P[i] \times \frac{SCT}{3600}$$

Subject to

$$P[i] == 0 \gg T8k[i] == T[i] + 0.0004 \times SCT$$
$$P[i] == 1 \gg T8k[i] == T[i] - 0.0016 \times SCT$$
$$P[i] == 0 \gg T16k[i] == T[i] + 0.0002 \times SCT$$
$$P[i] == 1 \gg T16k[i] == T[i] - 0.0013 \times SCT$$
$$T[i+1] == T8k[i] + (Lmass - 8000) \times \frac{T16k[i] - T8k[i]}{8000}$$
$$T[i] \geq 2.22° C \;\&\; T[i] \leq 4.44° C$$
$$T[0] == 3.33° C$$



	Baseline Performance	Day-ahead optimized	DA Optimized schedule with RT prices	Difference between baseline and DA schedule with RT prices
Yearly cost ($)	3.53	2.87	2.97	-15.86%
Yearly energy use (kWh)	57.78	49.23	49.23	-14.79%
Median daily cost ($)	0.0083	0.0071	0.0069	-16.87%