One Lincoln Heat Recovery Measurements

The heat recovery measurements at One Lincoln consist of three temperature sensors; a supply water sensor directly connected to the data logger, and two BTU meter temperatures and a BTU flow meter connected to the data logger via MODBUS. The supply sensor had been providing readings that were reasonable in magnitude, but were resulting in excessively high heat transfer rates and FCE_{chp} > 100%.

The supply temperature data in Figure 1 appear reasonable in overall temperature (the supply for the unit should be nominally 180°F), however several unusual trends occur. The supply temperature was observed to increase when the CHP system was down, while the BTU temperature sensors (across the dump HX) decreased to ambient conditions.

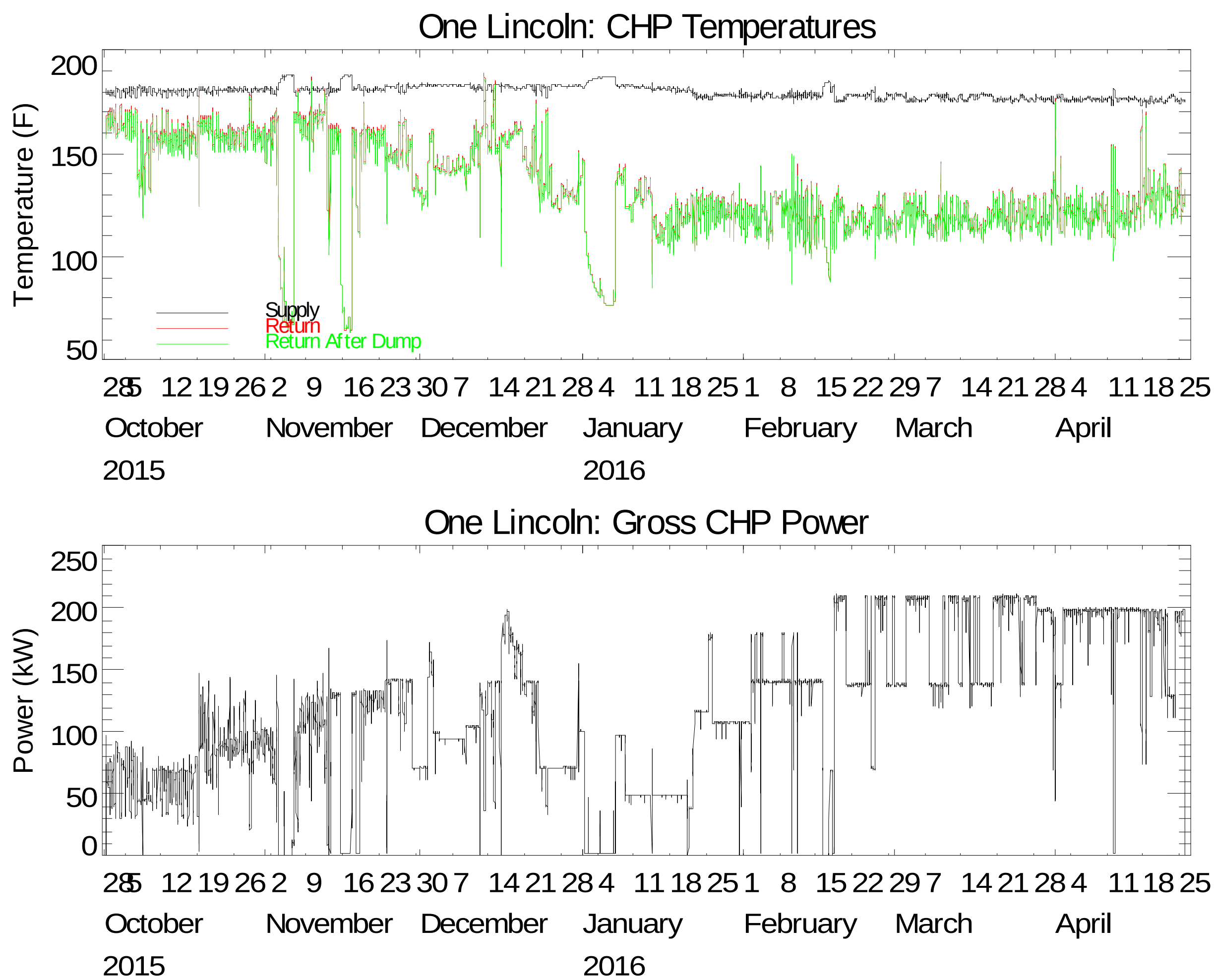


Figure 1. CHP Supply Temperature and Gross CHP Power

CHP efficiency calculated using these measurements regularly exceed 100%. A distinct change in the FCE calculation occurred on January 15, 2016.

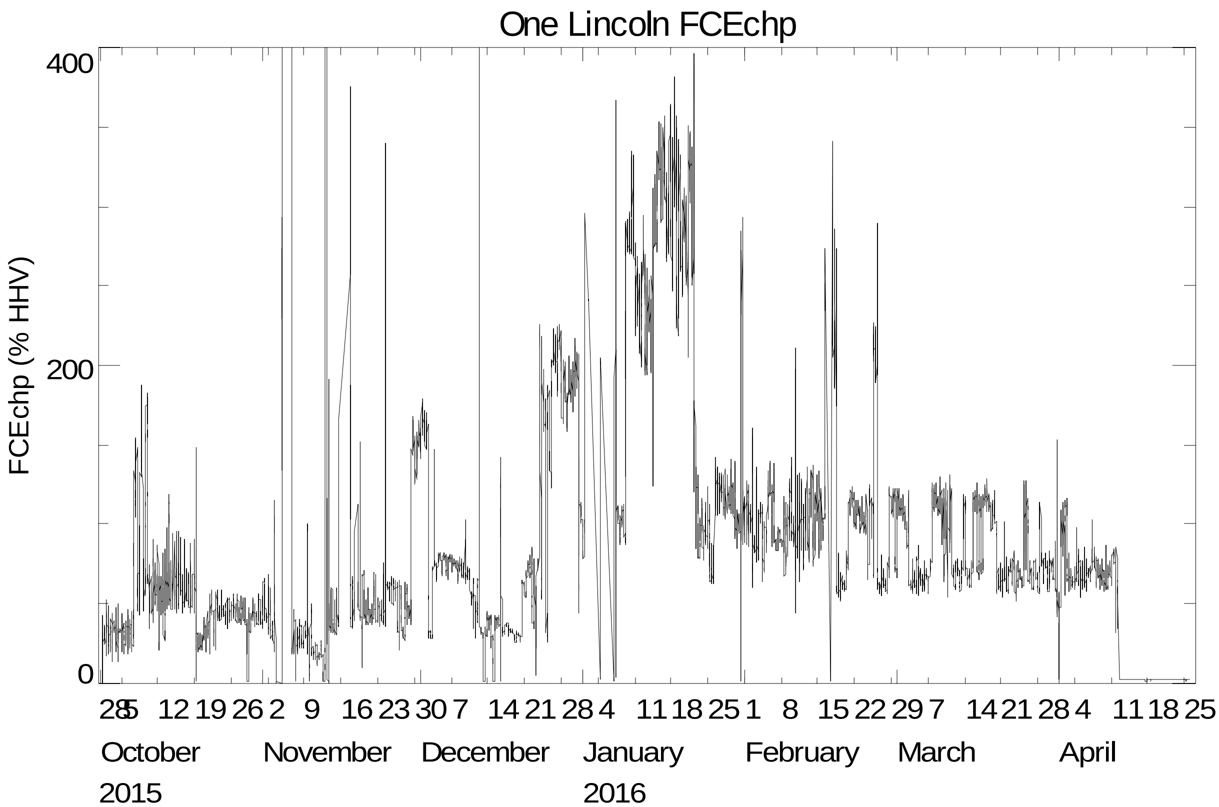
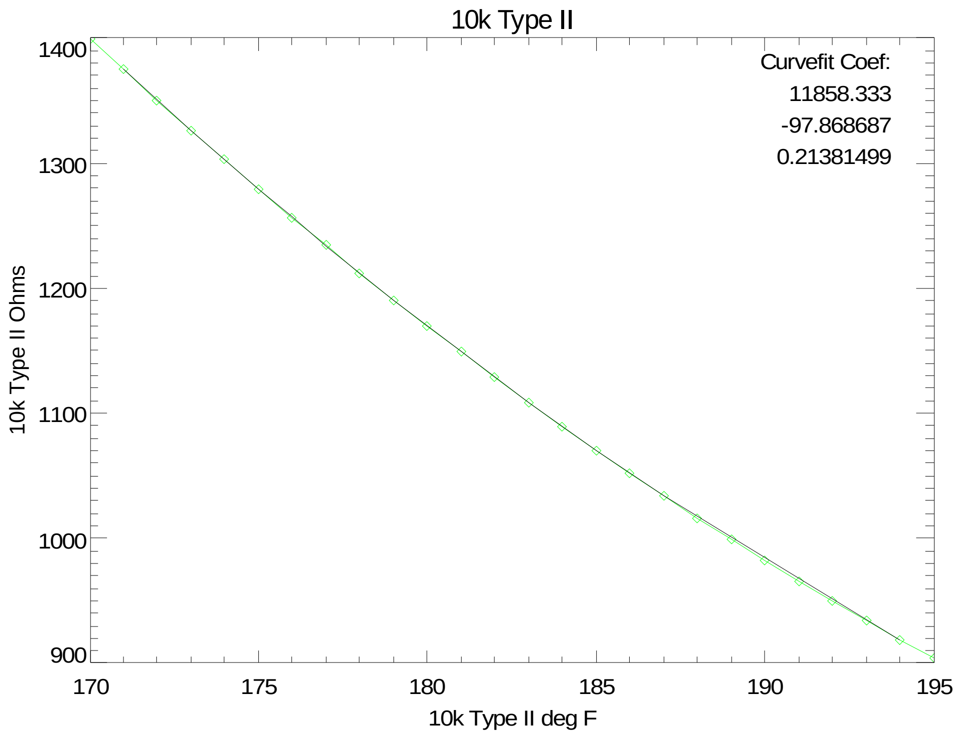


Figure 2. CHP Efficiency (FCEchp) Calculated from Field Measurements

The observed pattern in the supply temperature data (increasing when temperatures should decrease), leads us to believe that the sensor used was not the expected 10k Type II Thermistor (which decreases resistance with increasing temperature), but rather a 1000 Ohm Balco RTD (which has a positive relation of resistance with temperature). The temperature data for the supply sensor was converted back to ohms using a curve-fit of the published temperature/resistance relation for a 10k Type II thermistor, and then converted from ohms to degrees Fahrenheit using the published temperature/resistance relation for a Balco RTD.

$$\text{Thermistor °F to Ohms} = C_{thermistor}(0) + C_{thermistor}(1)\times°F + C_{thermistor}(2)\times°F^2$$

$$\text{Ohms to RTD °F} = C_{Balco\ RTD}(0) + C_{Balco\ RTD}(1)\times Ohms + C_{Balco\ RTD}(2)\times Ohms^2$$



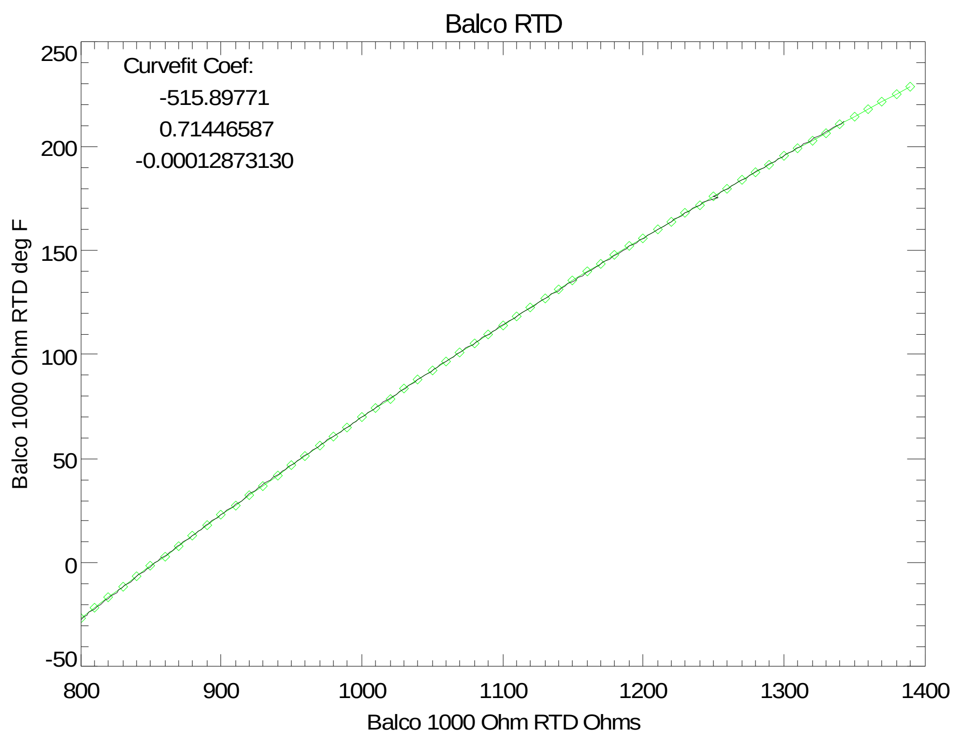


Figure 3. Resistance / Temperature Curves for Balco RTD and 10k Type II Thermistor

Figure 4 displays the impact of recalculating the temperature based on measured resistance. The new calculated supply temperature is shown in **blue**. Calculated temperature data prior to January 15, 2015 now shows a decrease when the CHP is off, however the new supply temperature during CHP operation is lower than the temperature returning to the unit (not possible). After January 15, 2016 the calculated supply temperature has reasonable temperature range, and is consistently higher than the two return temperatures measured by the BTU meter. It is unclear what sensor was used before January 15, or if that sensor worked properly, but this data is irreconcilable.

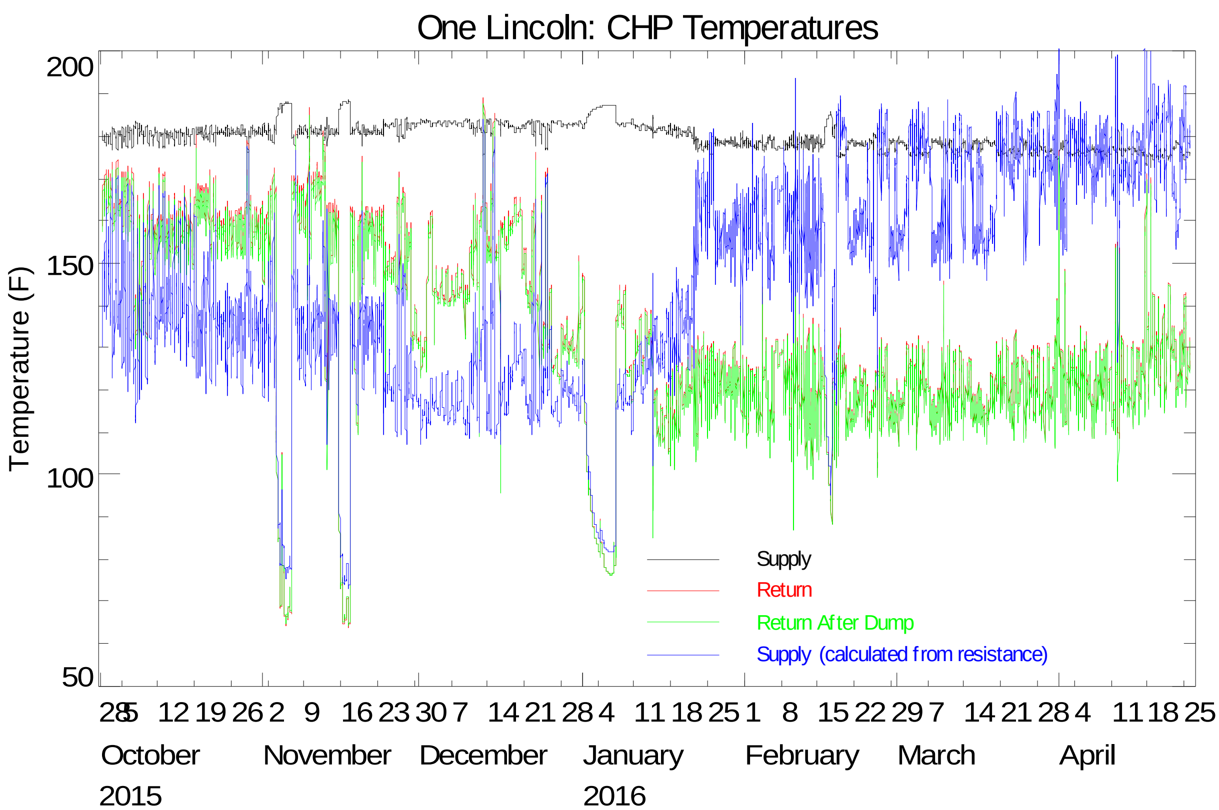


Figure 4. CHP Loop Temperatures with Calculated Supply Temperature

Using the new calculated supply temperature the CHP efficiency was calculated. Because the supply temperature was lower than the return temperatures prior to January 15, 2016, no heat recovery can be calculated for that period, and the CHP efficiency (FCE_{chp}) is equal to the electrical efficiency (FCE_{elec}). After January 15, 2016, the calculated CHP efficiency is below 100%, but still much higher than the rating.

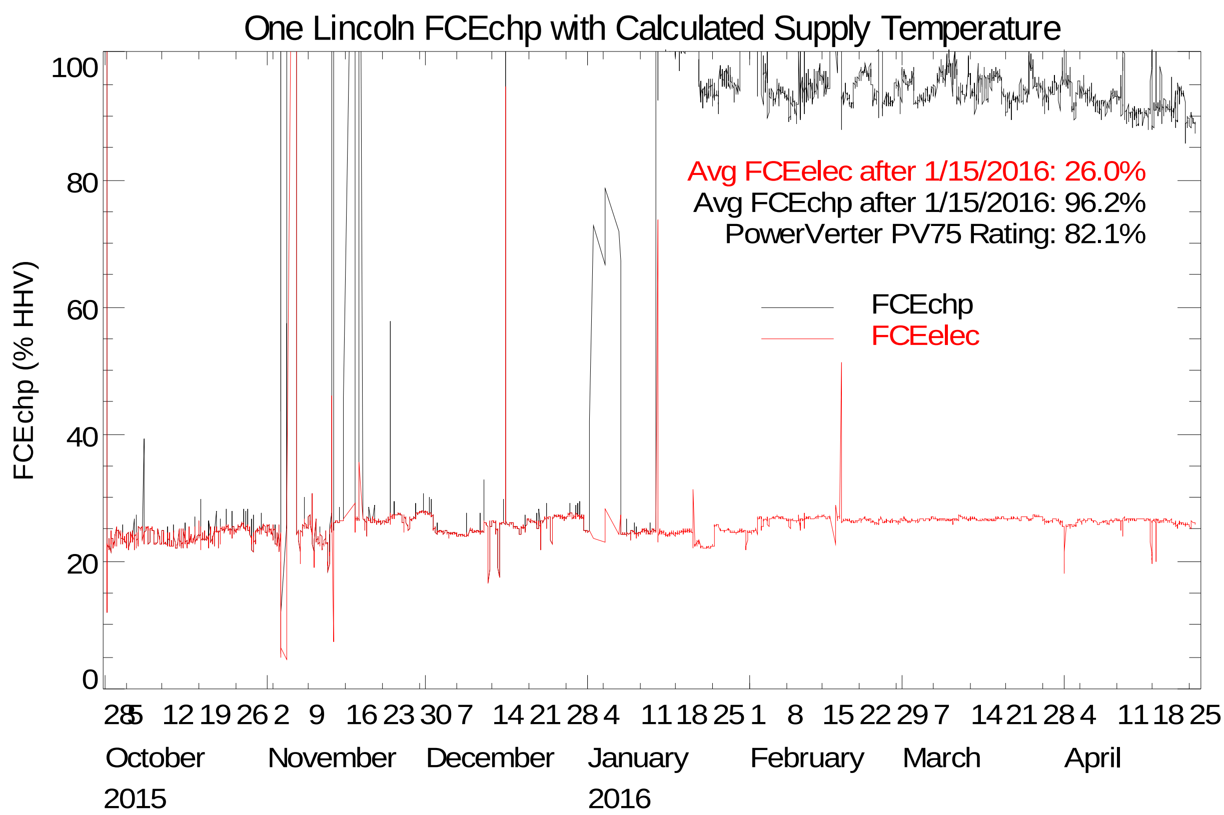


Figure 5. FCE_{chp} Using Calculated Supply Temperature

Since the system is not rejecting heat at this time, with no observable temperature difference across the dump radiator HX (THW2 – THW3), the entirety of the heat produced by the engine is useful heat, and the FCE_{chp} should match the rating. Table 1 displays that even after the temperature correction, the measured heat recovered is 20% higher than expected, and thermal efficiency (FCE_{therm}) is 14% higher than expected.

Table 1. Comparing Measured to Rated FCE – January 15, 2016 - Present

	Measured	Rated	HR Correction Req.
FCEelec (%HHV)	26%	26%	
FCEtherm (%HHV)	70%	56%	0.80
Fuel Input (%HHV)	100%	100%	
FCEchp (%HHV)	96%	82%	

FCE_{elec} = Electric Output / Fuel Input
FCE_{therm} = Thermal Output / Fuel Input, also FCE_{therm} = FCE_{chp} - FCE_{elec}
FCE_{CHP} = (Electrical + Thermal Output) / Fuel Input

The heat recovery data from January 15, 2016 to May 6, 2016 is adjusted downward by this ratio of 0.8 to match the system rating. On May 6, 2016 CDH replaced the BALCO RTD with a proper 10k Type II thermistor. After this date, heat transfer is calculated using the measured temperature with no adjustments.

Figure 6. New 10k Type II Thermistor

Also, the heat recovery flow meter has failed on April 12, 2016. Recent operation has indicated a heat recovery flow that averages 65 GPM. Missing data are replaced with this value.

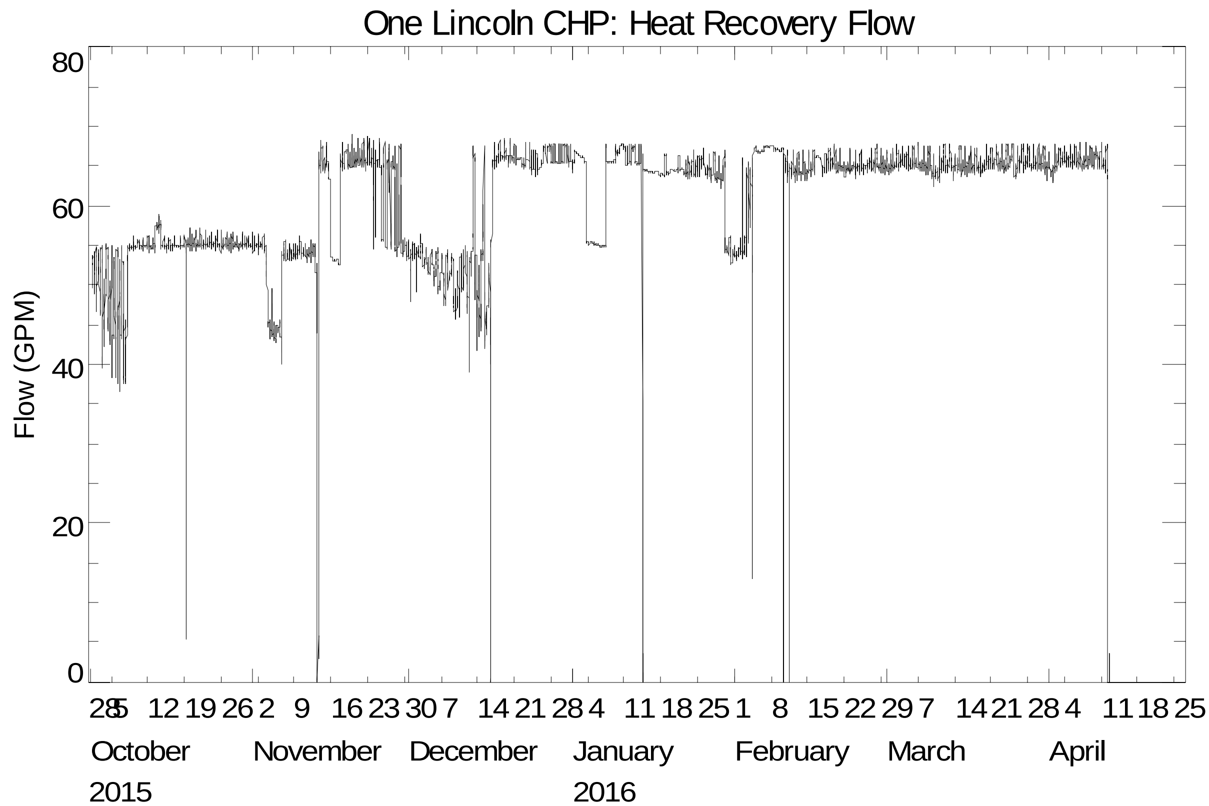


Figure 7. Heat Recovery Flow Measurement

Use of a constant 65 GPM flow has resulted in some issues during late April and early May 2016, where system flow began to vary when loads were satisfied. Figure 8 displays two trends of heat recovery with system power observed. Data for the upper trend are where actual system flows were reduced, however the heat recovery calculation uses the fixed 65 GPM. The lower trend is the trend at 65 GPM, which agrees well with normalized rating for the unit of 6.49 MBtu/kWh. Data during the upper trend are corrected by multiplying the ratio of the two trendlines. Note that during this operation the system was not rejecting any heat.

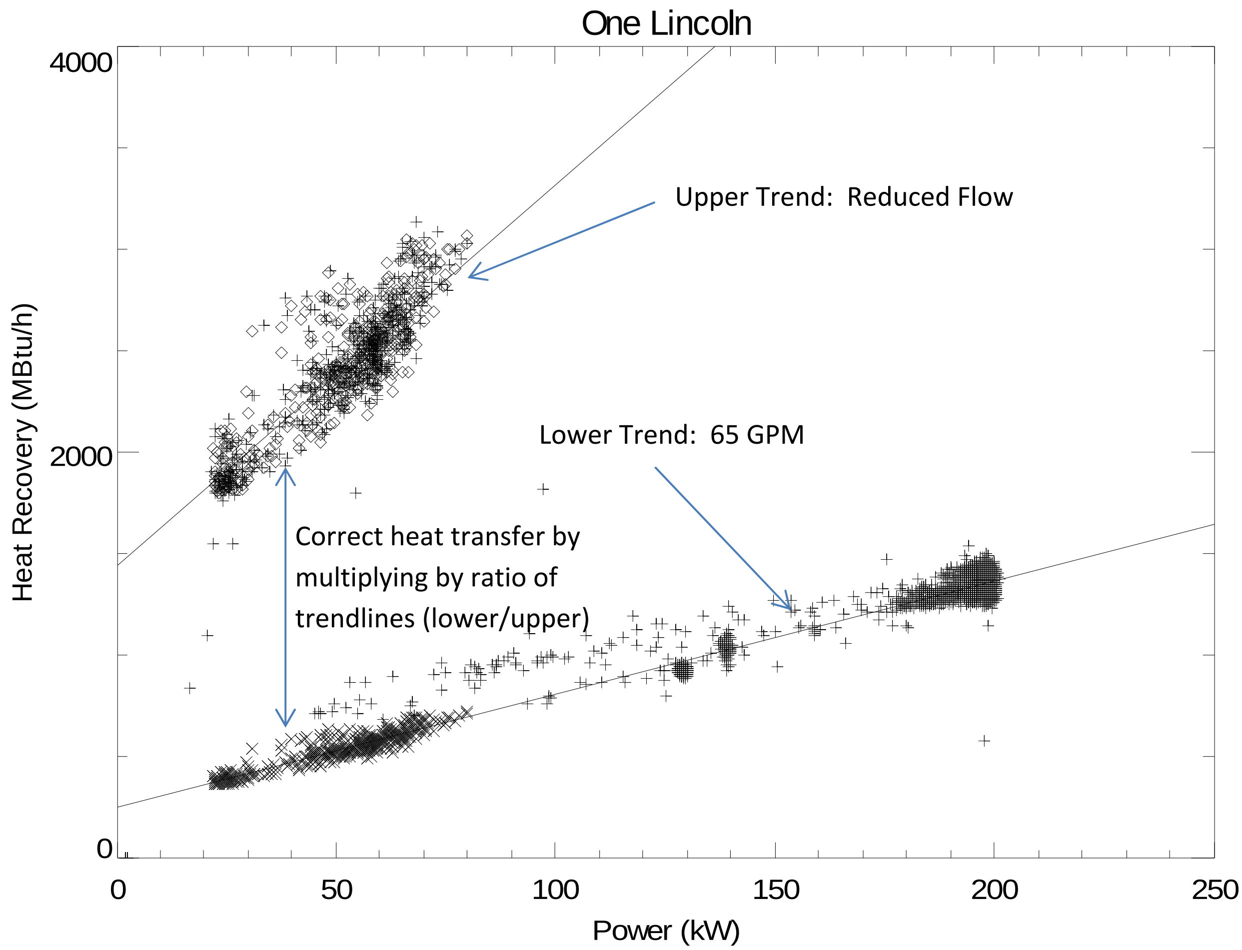


Figure 8. Heat Recovery Variation with System Power Showing Period of Reduced Flow during Flow meter Failure