Effects of Voltage Fluctuations on OSU Heat Flux Density

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Agenda

- Background – Why?

- Plan
  - Procedure
  - Voltage Measurement and Logging
  - Raw Data Collection

- Data Analysis

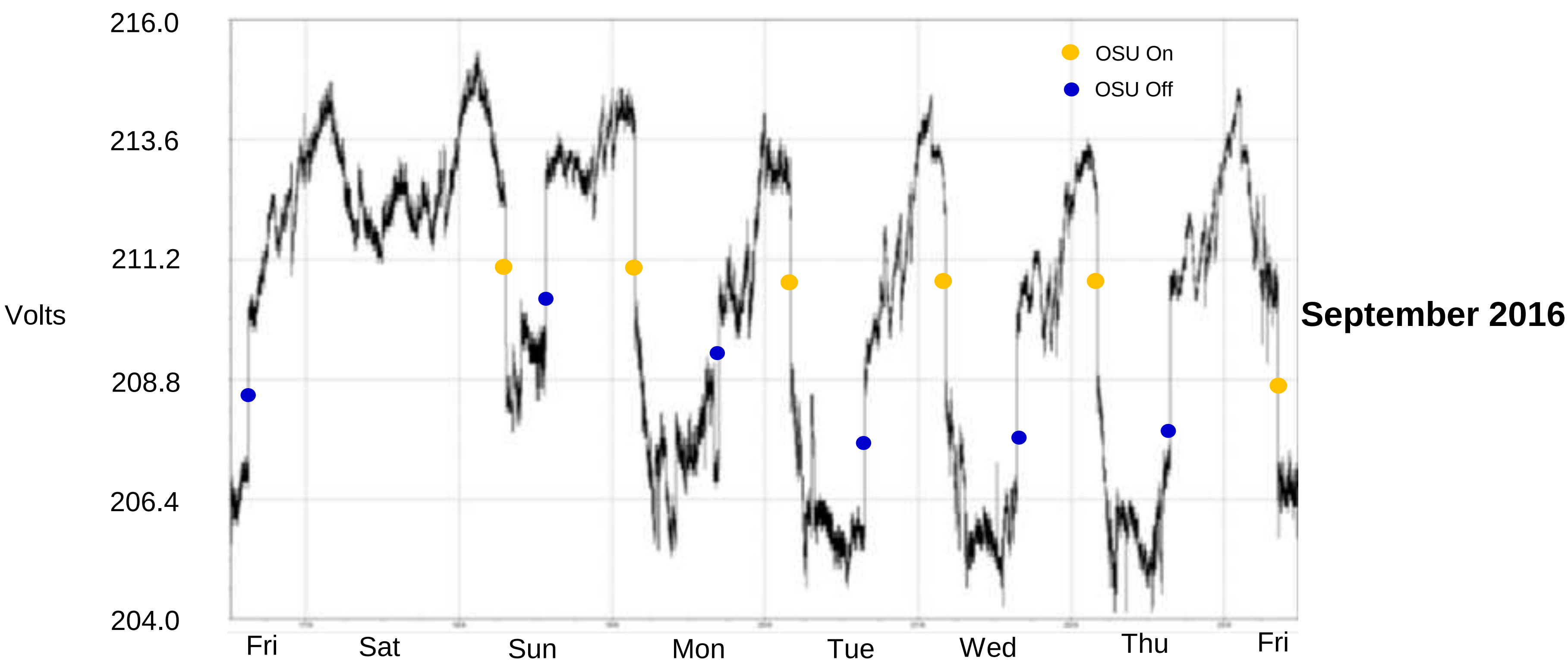
- Conclusion

- Recommendations

- Next Steps

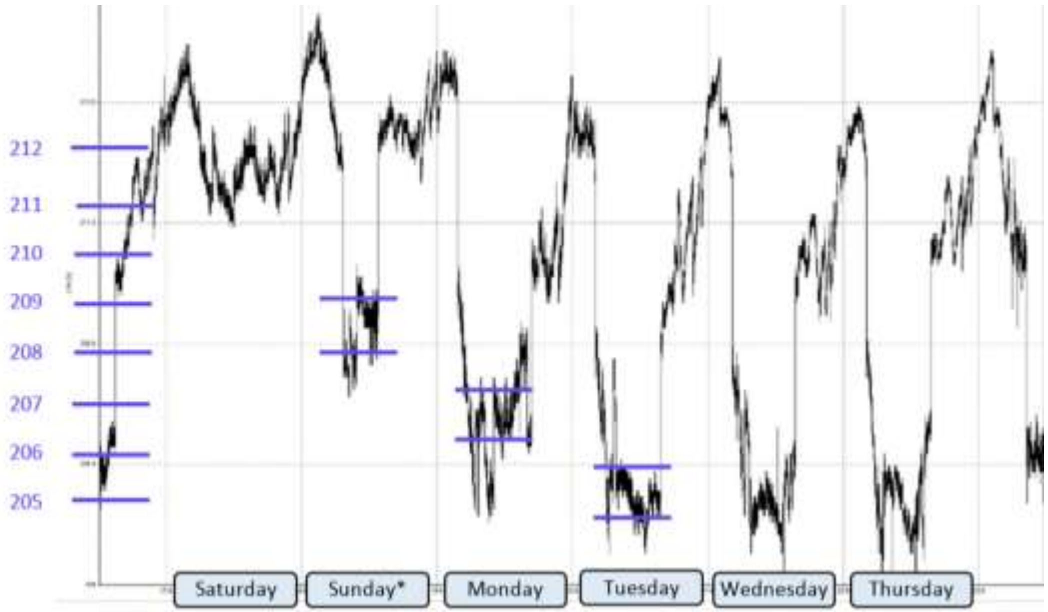
Background

- Notional relationship between Globar calibration power and time of day
- Specifications control heat flux but not voltage
- Initial voltage monitoring conducted indicated a dynamic supply voltage



Plan

- Record supply voltage and record heat flux over a range of voltages
- Use known supply profile to provide different voltage data points



September 2016

Target Voltage	
Supply	w/Loads
209	208
207	206
205	204

- Use lab equipment to introduce an additional ~1 volt drop
  - **Despatch** Oven Model RFD1-42-2E 34.5A max load - set to 500ºF
  - **Fischer Scientific** Isotemp Programmable Forced Draft Furnace - set to 600ºF
  - **Wabash** Heated Press Model G30H-18-BCLPX 26A max load - set to 320ºF
  - **Tetrahedron** Press Model SFP-13 28A max load - set to 510ºF

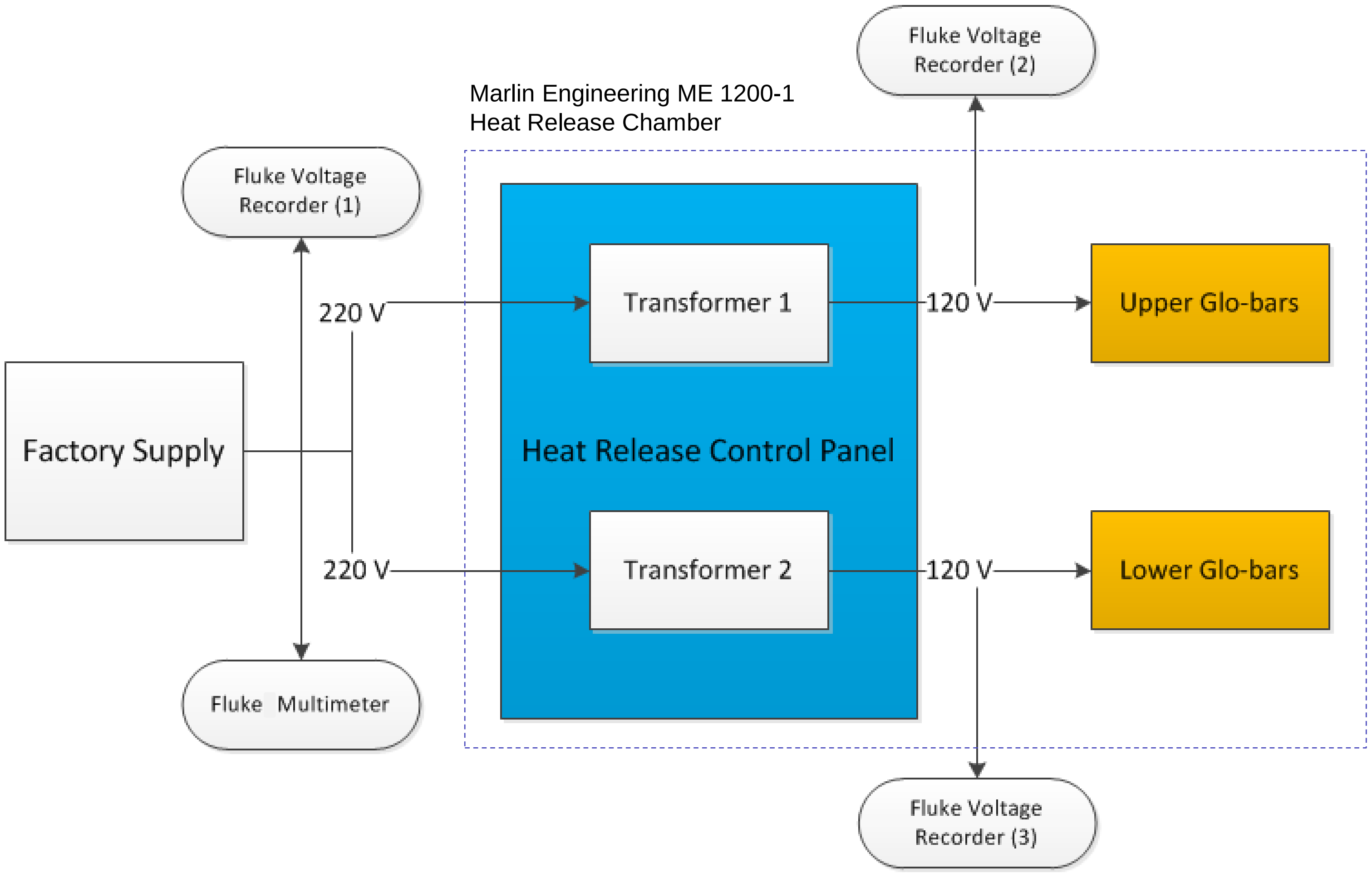
Procedure

1. At the beginning of each day, complete startup procedures and allow unit to stabilize for 2 hours.
2. Gather heat flux and environmental data at a given supply voltage value.
3. Engage laboratory loads and confirm voltage drop has occurred, then repeat step 2.
4. Disengage laboratory loads.
5. Monitor supply voltage and repeat steps 2-4 at varying voltage values over 3 days, Sunday-Tuesday.
6. At the end of each day, complete shutdown procedures.

*Additional details available at task group session.

Initial Globar Power Setting Were Not Changed During Data Collection

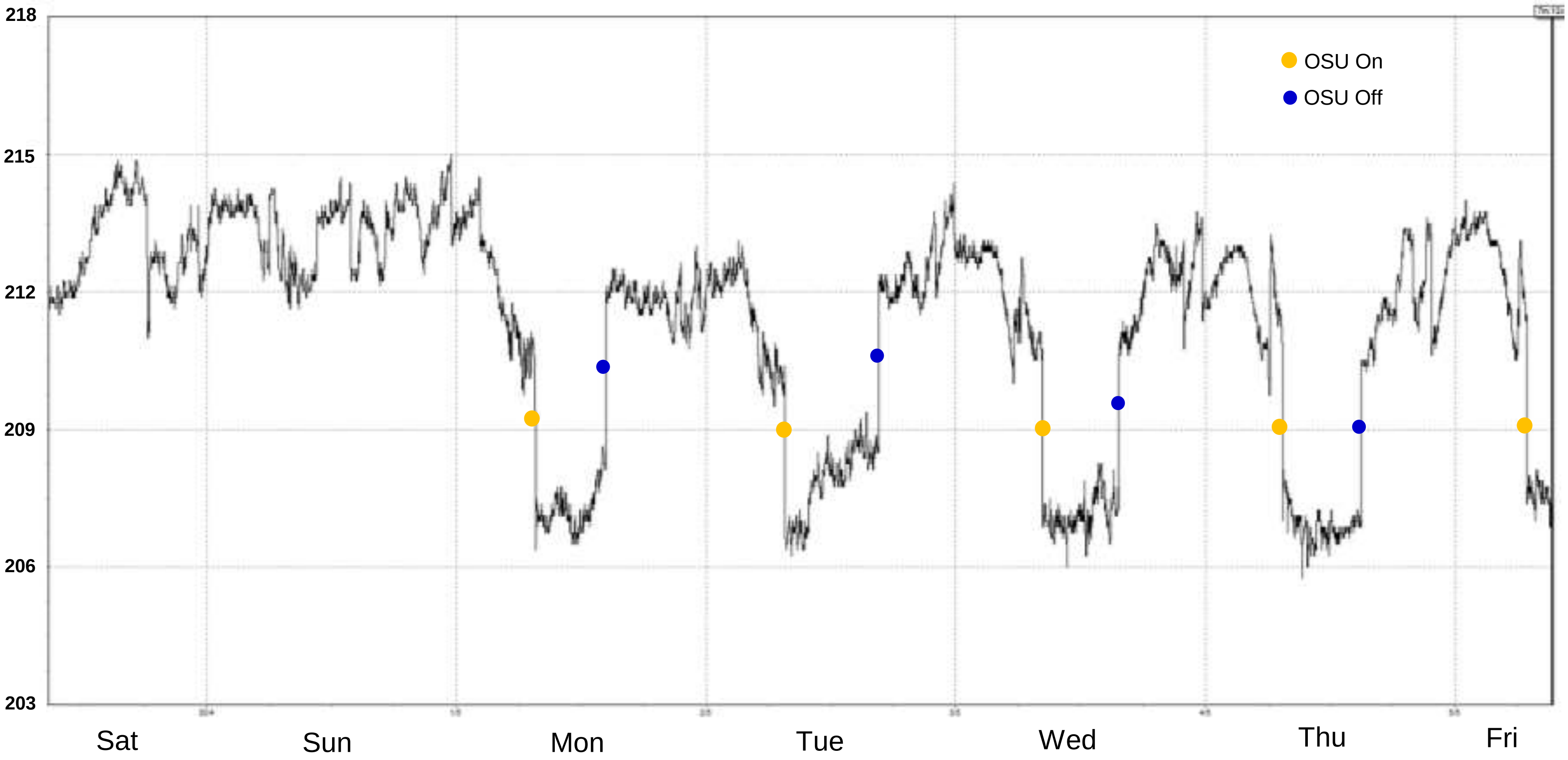
Voltage Measurement and Logging



Fluke True RMS Multimeter - Model 87 (Qty 1)

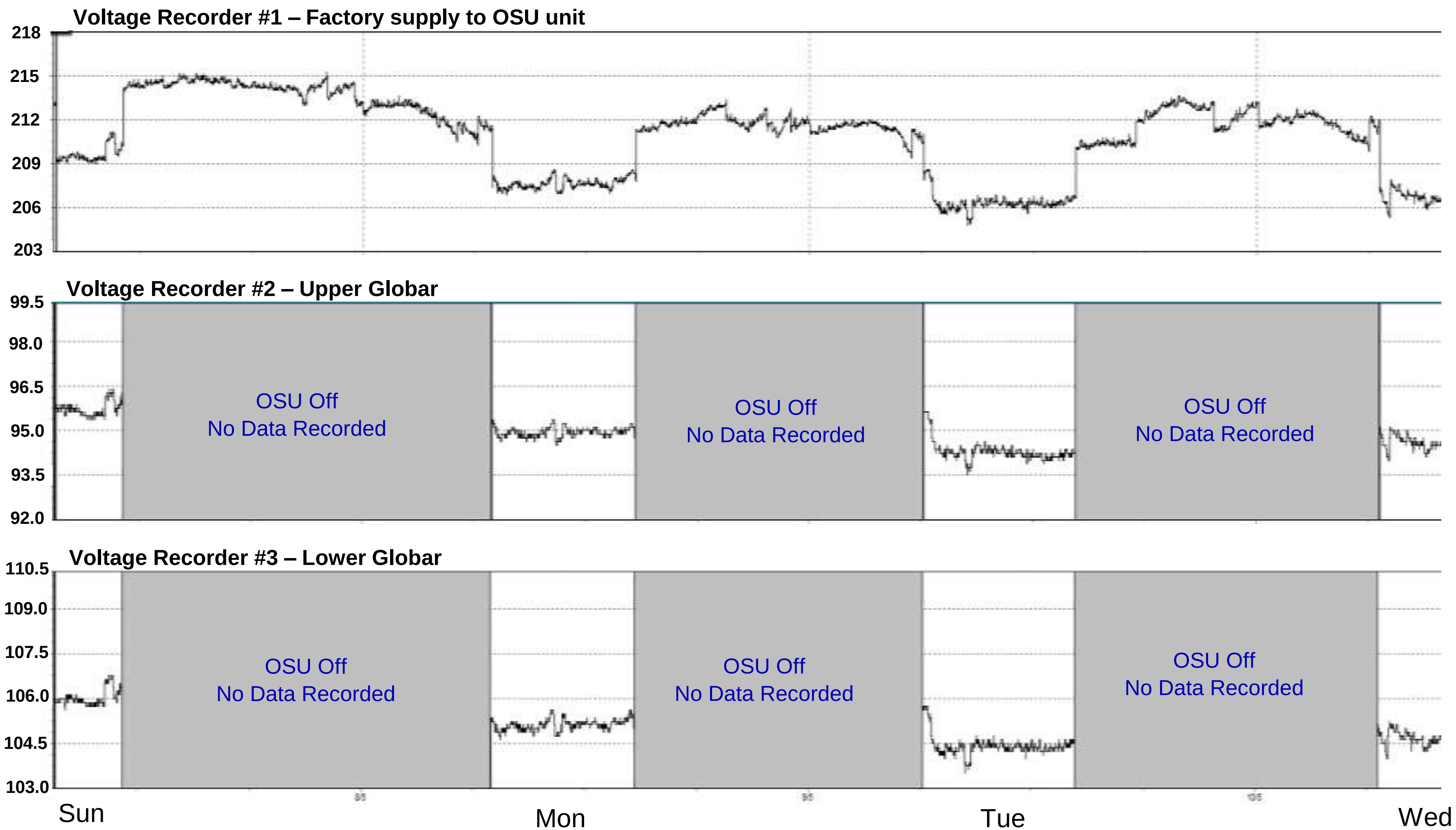
Fluke Voltage Quality Recorder - Model VR 1710 (Qty 3)

Verification of Supply Voltage Behavior



'Natural' Voltage Collected the Week Prior to Data Collection

Actual Supply Voltage Behavior (Data Gathering)



Voltage Supply Changes Transfer Directly to the Globars

Raw Data Collection

LINE VOLTAGE VS. RADIATED HEAT FLUX - DATA COLLECTION LOG																					
Metadata						*Variable*				*Constants*							*Output*				
Data Tags						Voltage (V)				Controller Settings		Ambient Conditions		Air Pressure (mmHg)			Flux (W/cm^2)				
Data Point	Run #	Load?	Day	Date	Test Time	Target Voltage	Initial Voltage	Final Voltage	Average Voltage	Upper Bars	Lower Bars	Temp (°F)	Humidity (%RH)	Initial Pressure	Final Pressure		Center Heat Flux[#]	Top Right Flux	Top Left Flux	Bottom Right Flux	Bottom Left Flux
V_0	1	No	Sunday	5/7/2017	9:43am	209.0	209.2	209.2	209.328	52.8	64.7	71.2	36	203	201		3.56	3.56	3.72	3.54	3.66
	2				9:54am		209.2	209.4	209.297	52.8	64.7	71.4	35	202	203		3.56	3.58	3.73	3.53	3.66
	3				9:59am		209.3	209.5	209.359	52.8	64.7	71.3	35	200	202		3.56	3.58	3.70	3.53	3.67
	4				10:07am		209.1	209.1	209.250	52.8	64.7	71.4	35	203	202		3.55	3.59	3.71	3.53	3.67
	5	No			10:14am	211.0	210.5	210.6	210.609	52.8	64.7	71.4	35	200	203		3.59	3.63	3.76	3.58	3.70
	6				10:21am		210.6	210.8	210.719	52.8	64.7	71.5	35	201	200		3.59	3.63	3.77	3.58	3.72
	7				10:28am		210.9	210.7	210.969	52.8	64.7	71.5	35	200	200		3.60	3.62	3.76	3.58	3.70
	8	Yes			10:44am	210.0	209.6	209.6	209.672	52.8	64.7	71.7	34	201	200		3.57	3.59	3.74	3.56	3.68
	9				10:52am		210.0	210.0	209.906	52.8	64.7	72.0	34	201	203		3.57	3.62	3.75	3.56	3.68
	10				11:00am		210.1	210.1	210.219	52.8	64.7	72.1	34	202	203		3.58	3.62	3.75	3.56	3.70
V_2	1	No	Monday	5/8/2017	9:50am	208.0	207.6	207.8	207.563	52.8	64.7	68.7	38	200	203		3.54	3.55	3.70	3.52	3.65
	2				9:59am		207.7	207.9	207.844	52.8	64.7	68.8	38	202	202		3.53	3.56	3.69	3.50	3.65
	3				10:10am		208.3	208.5	208.406	52.8	64.7	68.7	38	203	203		3.56	3.59	3.71	3.53	3.67
V_3	1	Yes	Monday	5/8/2017	10:25am	207.0	207.1	206.9	207.063	52.8	64.7	68.9	38	200	202		3.51	3.52	3.66	3.48	3.63
	2				10:32am		207.1	207.2	207.047	52.8	64.7	69.0	38	201	201		3.51	3.53	3.65	3.46	3.60
	3				10:39am		207.0	207.7	207.125	52.8	64.7	68.9	38	201	203		3.50	3.53	3.66	3.48	3.62
V_4	1	No	Tuesday	5/9/2017	8:02am	206.0	206.0	206.4	205.953	52.8	64.7	66.8	47	200	200		3.45	3.49	3.61	3.43	3.57
	2				8:09am		206.6	206.2	206.438	52.8	64.7	67.3	46	203	201		3.46	3.50	3.65	3.43	3.56
	3				8:16am		206.3	206.4	206.156	52.8	64.7	67.5	46	201	201		3.46	3.49	3.64	3.43	3.56
V_5	1	Yes	Tuesday	5/9/2017	8:24am	205.0	205.5	205.0	205.531	52.8	64.7	67.8	46	202	200		3.44	3.46	3.58	3.39	3.51
	2				8:31am		205.2	204.7	205.172	52.8	64.7	68.0	45	200	202		3.42	3.45	3.59	3.39	3.53
	3				8:38am		205.1	205.4	205.156	52.8	64.7	68.3	45	202	202		3.42	3.44	3.58	3.40	3.51

[#]Note: Center Heat Flux is an average of three readings. Corner values are a single reading.

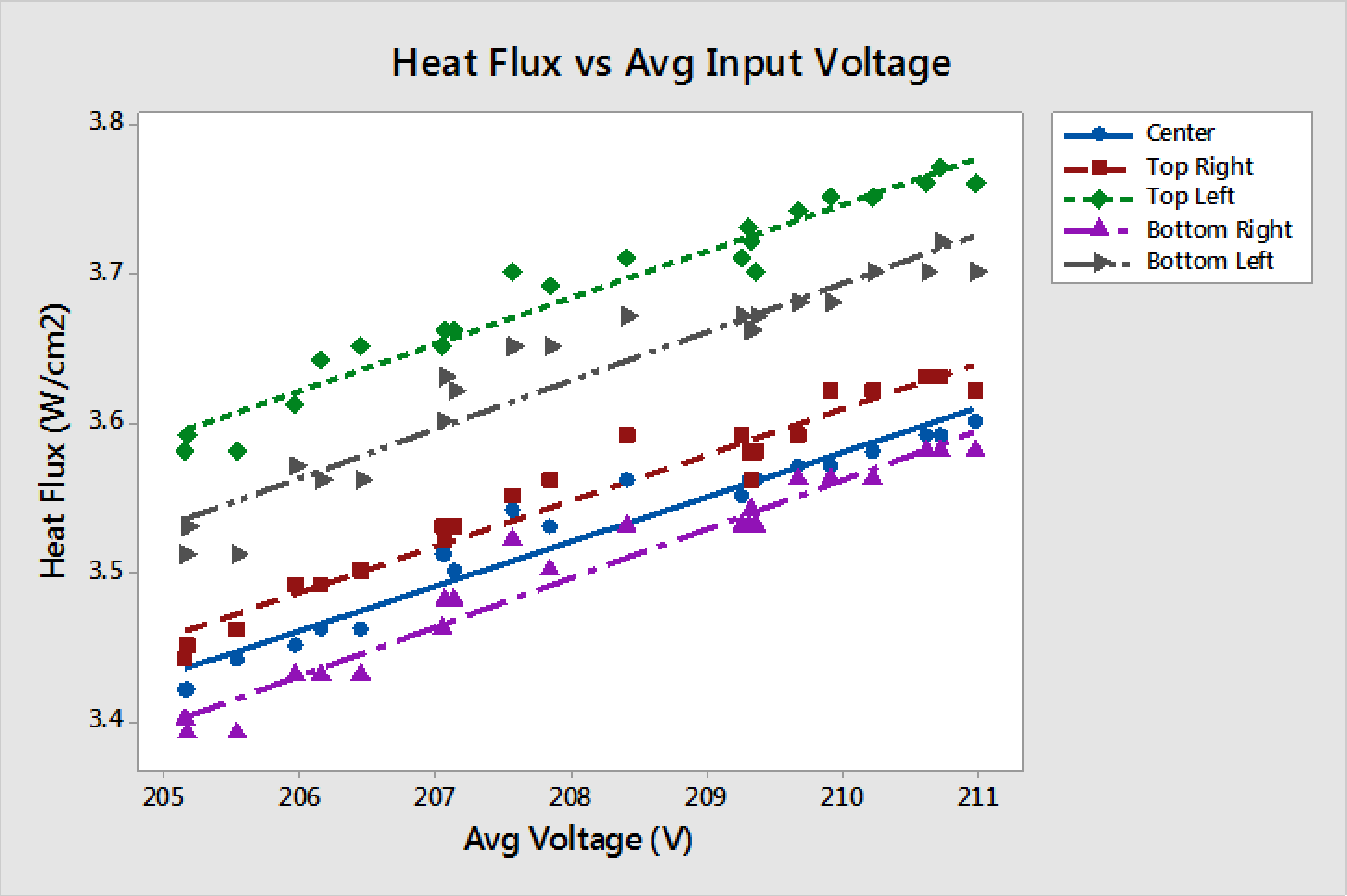
*Note: Despatch Circulation Oven used for load; once set temp reached, load drawn cycled to keep at set point. This caused ~0.8V fluctuation in the supply voltage for the runs noted above.

Center Heat Flux Varied from 3.42 to 3.60 W/cm^2 over a 6 Volt Supply Range

Specified range is 3.45 to 3.55 W/cm^2

Data Analysis

- Input Voltage vs. Heat Flux
  - Same general behavior for all flux measurement positions
    - Slope of lines approx. equivalent -> use Center Heat Flux as representative (avg. values preferred over single point values)



Data Analysis

- Input Voltage vs. Heat Flux
  - Regression model(s) for “Avg Center Heat Flux”
    - **“Best fit” for Avg Center Heat Flux includes predictors:**

      Average Voltage, Temperature, Humidity

- Heat flux changes linearly with voltage
  - 1V change results in 0.024 to 0.033 W/cm2 in radiated heat flux (center)

- 220 V supply voltage change needs to be controlled to within at most ± 1.5 V to remain within specification after calibrating to 3.50 W/cm^2

Conclusion / Recommendation

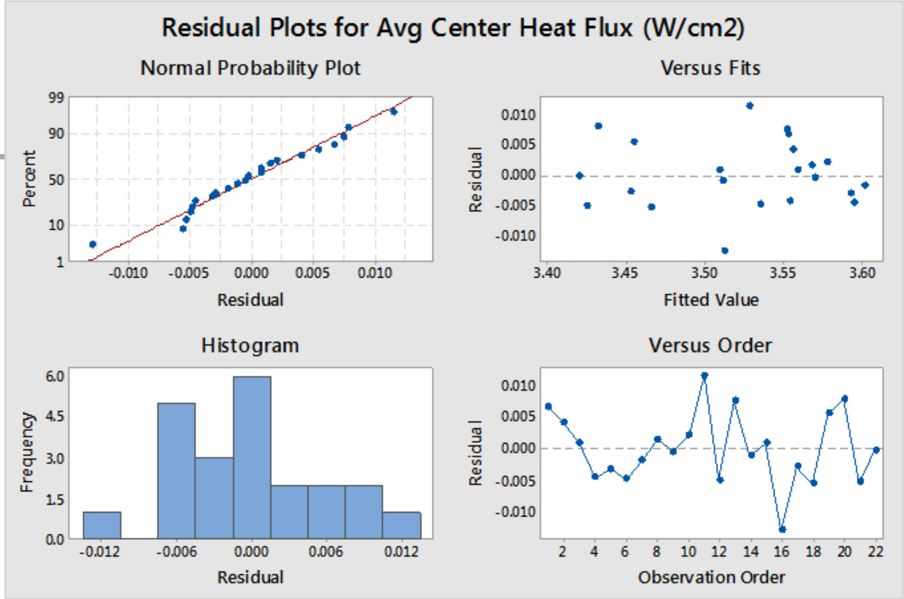
- Conclusion
  - Post-calibration changes in supply voltage affect radiated heat flux
  - For initial center heat flux value of 3.5 W/cm^2 to remain within specification, OSU supply voltage needs to be regulated to within at most ± 1.5 V
- Recommendation
  - Heat release specifications should include voltage conditioning to reduce inter-lab and intra-lab variation
  - Voltage conditioning options
    - 15 kVA Single Phase Power Conditioner (~$11k)
      - May sufficiently isolate from ‘natural’ variation, but may still be susceptible to large local load cycling
    - 15 kVA Single Phase UPS (~$15k)
      - Provides tighter voltage regulation than the Power Conditioner and immune to intra-day power swings
      - Yearly maintenance required, batteries require replacement every 5-10 years.

Next Steps

- Investigating voltage monitoring at Boeing Seattle and Boeing SC sites
- Working group proposal to monitor supply voltages over 1 week period
- Breakout Group Discussion Topics
  - Discuss approaches to control voltage - further experimentation
    - Review / establish recommended level of voltage control
    - Implement voltage conditioning prior to further HR2 work (ex. DOE repeat)
    - Discuss need to define voltage control in OSU / HR2 handbook / workbook
  - Discuss temperature and humidity affect on heat flux and further action
  - Discuss how to characterize heat flux changes on heat release results

To share at task group meeting

Data Analysis



- Input Voltage vs. Heat Flux
  - Regression model(s) for "Avg Center Heat Flux"
    - **"Best fit" for Avg Center Heat Flux includes predictors:**

      Average Voltage, Temperature, Humidity

Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.070660	99.06%	0.070660	0.023553	630.71	0.000
Avg Voltage (V)	1	0.067353	94.42%	0.008092	0.008092	216.69	0.000
Temp (F)	1	0.000382	0.54%	0.001876	0.001876	50.24	0.000
Humidity (%RH)	1	0.002924	4.10%	0.002924	0.002924	78.30	0.000
Error	18	0.000672	0.94%	0.000672	0.000037		
Total	21	0.071332	100.00%				

Model Summary

S	R-sq	R^2(adj)	PRESS	R^2(pred)
0.0061110	**99.06%**	98.90%	0.0010233	98.57%

Coefficients

Term	Coef	SE Coef	95% CI	T-Value	P-Value	VIF
Constant	-1.067	0.362	(-1.827, -0.307)	-2.95	0.009	
Avg Voltage (V)	0.02843	0.00193	(0.02437, 0.03249)	14.72	0.000	7.59
Temp (F)	-0.01538	0.00217	(-0.01994, -0.01082)	-7.09	0.000	8.46
Humidity (%RH)	-0.006556	0.000741	(-0.008113, -0.005000)	-8.85	0.000	6.86

Regression Equation

Avg Center Heat Flux (W/cm2) = -1.067 + 0.02843 Avg Voltage (V) - 0.01538 Temp (F)- 0.006556 Humidity (%RH)