



North Campus Chiller Plant



University of Idaho

**709 S Deakin St,
Moscow, ID 83844**

208-885-6246

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Alejandro Madrigal

Rachal Skyving

Clifton Brewer

Shelby West

This Report discusses the validation of the University of Idaho's North Campus Chiller Plant. Inventory and installation of sensors allowed for data to be collected and then implemented into a model to show the chiller plants performance under various operating conditions.

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Contact Information

Client

Email

Scott Smith.....scsmith@uidaho.edu

-Project Advisor

Dr. Steven Beyerlein, Ph.D.....sbeyer@uidaho.edu

Team Members

Alejandro Madrigal.....madr8506@vandals.uidaho.edu

Rachal Skyving.....skyv3870@vandals.uidaho.edu

Shelby West.....west2864@vandals.uidaho.edu

Cliff Brewer.....brew0066@vandals.uidaho.edu

Background

The University of Idaho utilizes a district energy system to distribute thermal energies for heating and cooling most of the buildings on campus. The cooling part is made up of three chiller plants. One of which is the North Campus Chiller Plant (NCCP). It utilizes absorption chilling and vapor compression cycles removing heat.

The NCCP began evolving in 1990 with a 90 TONR air cooled electric chiller. In the years following, a single effect and double effect absorber have been added, 600 TONR and 1200 TONR respectively, as well as a 1200 TONR electric centrifugal chiller. The NCCP should be able to produce 3000 TONR but has trouble providing more than 1600 TONR to campus.

Problem Definition

Throughout the evolution of the chiller plant, there has not been any comprehensive system analysis. By conducting a comprehensive system analysis we will be able to work toward improving the quality, productivity, and efficiency of the NCCP.

The goal of this project is to implement an automated control system and data collection system to analyze with. The purpose is to develop a working math model for the North Campus Chiller Plant, inventory existing instrumentation and specify additional instrumentation for complete system characterization, and demonstrate how to use system model along with available data to study different operating conditions.

Project Plan

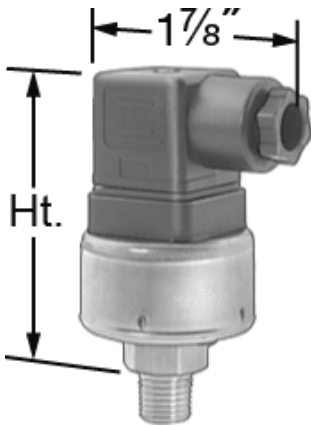
Our plan is to familiarize ourselves with the chiller process and the chiller plant. We will then inventory existing instrumentation and take note of additional instrumentation required. We will also work on a math model taking into account the different states of the chiller process. Once the instrumentation is all installed we will be able to use the data collected through our instrumentation and use the math model for validation. From there we can use a variety of data to analyze how the chiller plant is performing and identify limitations or weaknesses in the system.

Executive Summary

Many campuses, large buildings and other facilities utilize chilled water plants for the production and distribution into air handling units and other cooling equipment. The North Campus Chiller Plant is an integral component of the campus chilled water system. The purpose of the North Campus Chiller Plant project was to (1) develop and validate a working math model of the system, (2) inventory existing instrumentation and specify additional instrumentation for complete system characterization, and (3) demonstrate how to use the system model along with available data to study different operating conditions. The maintenance and operation of the NCCP has a significant impact on building energy use and the energy operating costs. Our intent was to work on improving quality, productivity, and efficiency by specifying the critical measurement points and implementing a data collection process that supports a mathematical modeling of the system. The project deliverables were as follows; a piping & instrumentation diagram that displays existing and added instrumentation throughout the system, a validated math model created in engineering equation solver (EES), and a Wikipedia page to show project learning.

Instrumentation

Pressure sensor



23 Total pressure sensors were added to the system, they have different pressure ranges based on their locations, 0-15 psi, 0-50 psi, 0-100 psi, and 0-200 psi. High pressure ranges are not needed before pumps because they normally operate near 3 to 5 psi, and higher pressure sensors are needed after pumps because of the pressure increase in the pump.

Figure 1: McMaster Carr Pressure sensor used in the NCCP

Onicon Flow Meter



The system only needed one additional flow meter, the company that we ordered it from makes all of the flow meters based on the application, so it took longer than the other sensors to order and have delivered. The range on the meter is 0-3200 gpm, which is more than enough for its location.

Figure 2: One of the many Onicon Flow meters used in the NCCP.

GE Enthalpy sensor



Four enthalpy sensors were installed in the plant, one above each of the three towers collecting data on the air coming out of each tower. and one collecting data on ambient air. The range on the enthalpy sensors is 0-100 BTU/lbm.

Figure 3: Image of one of the multiple enthalpy sensors used in the NCCP.

Creation of Math Model

The math is used to calculate and accurately show operating conditions of the NCCP at various points throughout the plant. This math model was developed using a first-law thermodynamic analysis.

Before beginning the E.E.S. code for the plant we first began by walking through the plant creating rough sketches on engineering paper of where the various states would be that would serve as locations to obtain flow properties that included: flow, temperature, and pressure, noting whether or not there was a sensor collecting that data or not. After noting what sensors were where we then began to create an inventory of sensors that need to specified and purchased (see above for installed inventory).

The first step we took to creating the model was creating a diagram that would easily identify the not only the machinery in the plant but also the state points that would be used to calculate the various parameters. A section of the diagram and legend is shown in figure #, # (for full diagram see ###). This section is isolates chiller 2 simplifying the complete loop that takes place on the condenser and evaporator sides of the chiller.

The diagram then uses three colors to denote the plant tags for each chiller; chiller two using light blue, chiller three using light green and chiller four using magenta. In addition to the plant tags the diagram also uses red boxes with numbers within to list the individual state points that correlate to individual chiller; chillers two and three going from 1-13 and chiller four from 1-6 and 9-14 (gap is due to it being a centrifugal chiller, electronically powered with no steam).

After completion of the diagram we began the creation of the E.E.S. code by listing all of the plant tags throughout the system, and other inputs such as outside air temperature that must be manually inputted given operation conditions in order to run the model. The plant tags were then set equal to their corresponding state points in order to create an array

for properties of the fluids throughout each loop. The remaining known properties were then entered at each respected state point.

Once all of the properties were entered at each state point we then began using a first-law thermodynamic analysis to determine the heat exchange ranges throughout the condenser and evaporator sides of each chiller. After that a cooling tower performance analysis was done to determine to the determine the load going through the cooling tower but also dimensionless parameters to track cooling performance including COP_c and effectiveness, ϵ .

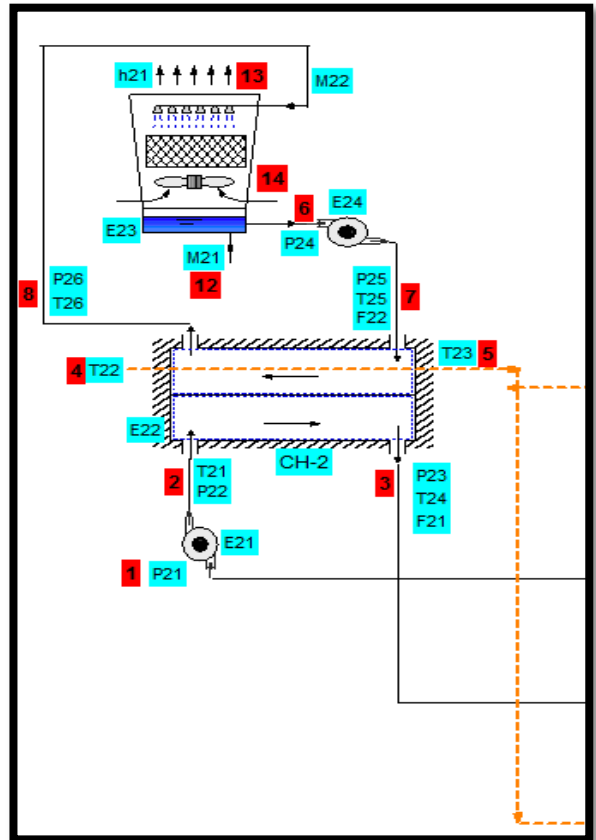


Figure 4: Section of the E.E.S. Diagram isolating the Chiller 2 loop.

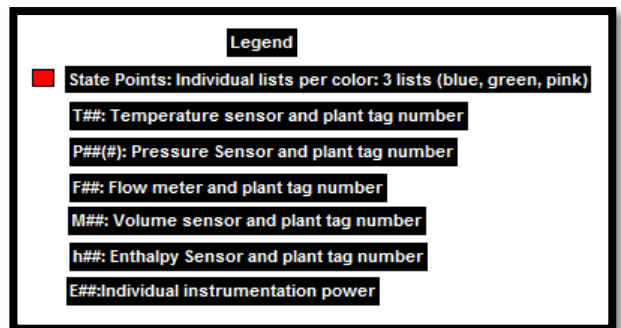


Figure 5: Legend to be used the the E.E.S. diagram

Validation

To validate our math model we compared our results to some manufacturer’s information with given operating conditions. Some of this information can be seen in figure 6 below. After calculating the cooling tower load and comparing it to the manufacturer’s we were able to determine that our code was properly working. In addition, we researched typical values for the the COPc of a single-effect absorber and found that our model was also correctly calculating this parameter for the various operating conditions.

Models VT1-825-P to 1355-S

Model Number	Nominal Tonnage ⁽¹⁾	Motor HP ⁽²⁾	Airflow (CFM)	Weights (lbs)			H	Connections ⁽⁴⁾		
				Operating ⁽³⁾	Shipping	Heaviest Section		Inlet	Outlet	Make-up
VT1-550-P	550	(2) 40	165,060	30,590	16,020	10,220	12'-11"	(2) 8"	12"	2"
VT1-580-P	680	(2) 40	163,100	32,150	17,580	10,220	14'-10"	(2) 8"	12"	2"
VT1-750-P	750	(2) 40	158,600	34,090	19,520	10,220	16'-3"	(2) 8"	12"	2"
VT1-800-Q	800	(2) 50	170,300	34,170	19,600	10,300	16'-3"	(2) 8"	12"	2"
VT1-830-R	830	(2) 60	180,500	34,410	19,840	10,540	16'-3"	(2) 8"	12"	2"
VT1-825-P	825	(3) 40	247,590	45,980	24,000	15,300	12'-11"	(3) 8"	(2) 10"	3"
VT1-921-Q	921	(3) 30	223,050	47,750	25,770	14,730	14'-10"	(3) 8"	(2) 10"	3"
VT1-1020-P	1,020	(3) 40	244,650	48,320	26,340	15,300	14'-10"	(3) 8"	(2) 10"	3"
VT1-1125-P	1,125	(3) 40	237,900	51,230	29,250	15,300	16'-3"	(3) 8"	(2) 10"	3"
VT1-1200-Q	1,200	(3) 50	255,450	51,350	29,370	15,420	16'-3"	(3) 8"	(2) 10"	3"
VT1-1245-R	1,245	(3) 60	270,750	51,710	29,730	15,780	16'-3"	(3) 8"	(2) 10"	3"
VT1-1335-S	1,335	(3) 75	290,550	51,770	29,790	15,840	16'-3"	(3) 8"	(2) 10"	3"

Figure 6 Manufacturer's data that was used to validate the heat rate released by the cooling tower.

Obtaining Input Data

As stated previously the math model had a number of inputs that were required for it to run. Unfortunately, there was no way to link the workbooks that contained the recorded data over the month to the model which left a lingering question that we have for ATS to see if in the future they could develop a way to integrate these two systems. This problem overcome by us as a team manually averaging the necessary data for each hour between 8:30 A.M. and 6:30 P.M. for two days that showed different outside conditions. The two days that were chosen were September 10, 2016 and September 12, 2016 for their hot and cold temperatures respectively. The newly averaged data was then put into tables corresponding to their time, day, and plant tag an example is shown below.

T_23	DAY	SEPTEMBER 10, 2016 (HOT)	SEPTEMBER 12, 2016 (COLD)
TIME (24 HR)			
	8:30	190.9032857	190.1372857
	10:30	193.2237143	191.9943333
	12:30	196.2222857	193.3331429
	14:30	197.5578571	194.0118333
	16:30	198.5647143	194.1393333
	18:30	197.7767143	193.0413333

Figure 7: An example of the averaging tables that were used to input data into the math model. This particular table corresponds to the plant tag T_23.

After all of these tables were created we then inserted all the required inputs for the model and ran the model 12 times, 6 times for each day at the designated times. After completion of this we then

obtained the results required to graphically display our results and see how the system behaved dependent upon outside conditions.

Results

After running our math model for the Chiller 2, the 600-ton single effect absorber we were saw results that correlated with the operating conditions for that given day. We tended to see the best performance from the chiller with the outside air relatively cool and with a low humidity ratio which should be expected given their influences upon determining the the COPc of the chiller. Four plots are shown below, two displaying the relationship between time, outside air temperature, and heat transfer rate through the cooling tower for the chiller 2 loop for their given day and the other two plots displaying the relationship between time, outside air temperature, and COPc of the chiller for their given day.

COPc Plots

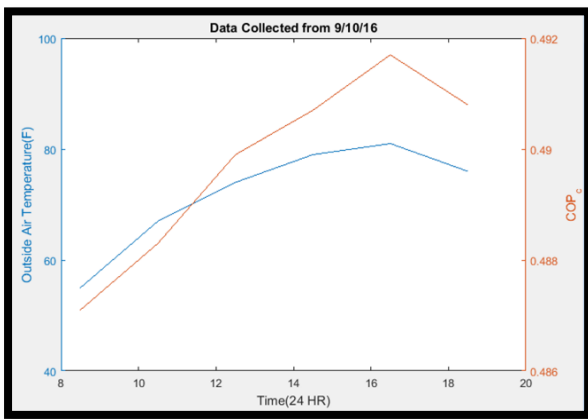


Figure 7: COPc plot for 9/10/16 from 8:30 A.M. to 6:30 P.M.

Cooling Tower Load Plots

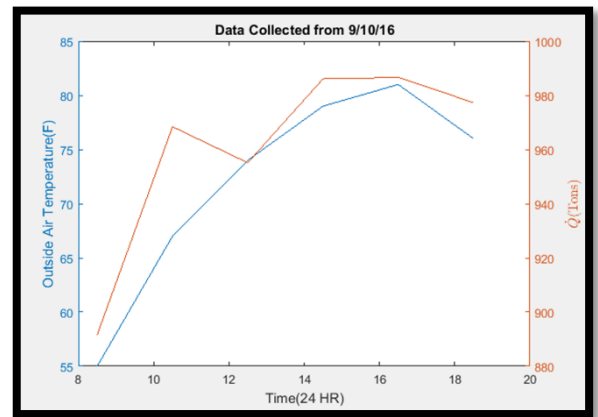


Figure 8: Cooling tower Load plot for 9/10/16 from 8:30 A.M. to 6:30 P.M.

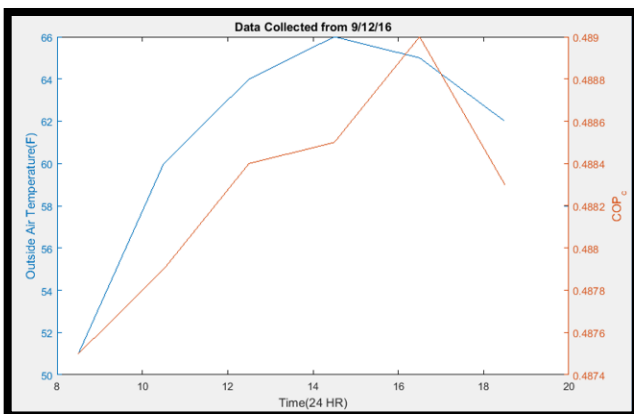


Figure 9: COPc plot for 9/12/16 from 8:30 A.M. to 6:30 P.M.

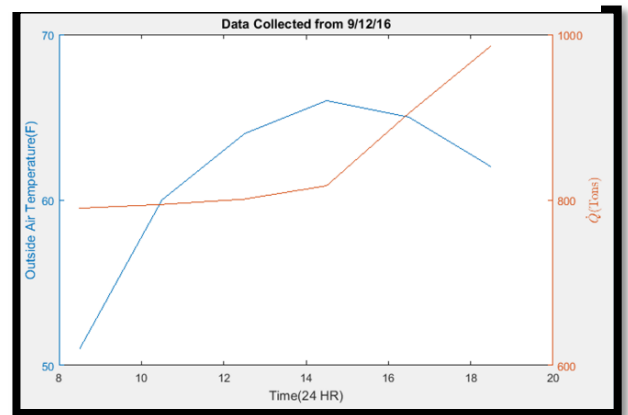
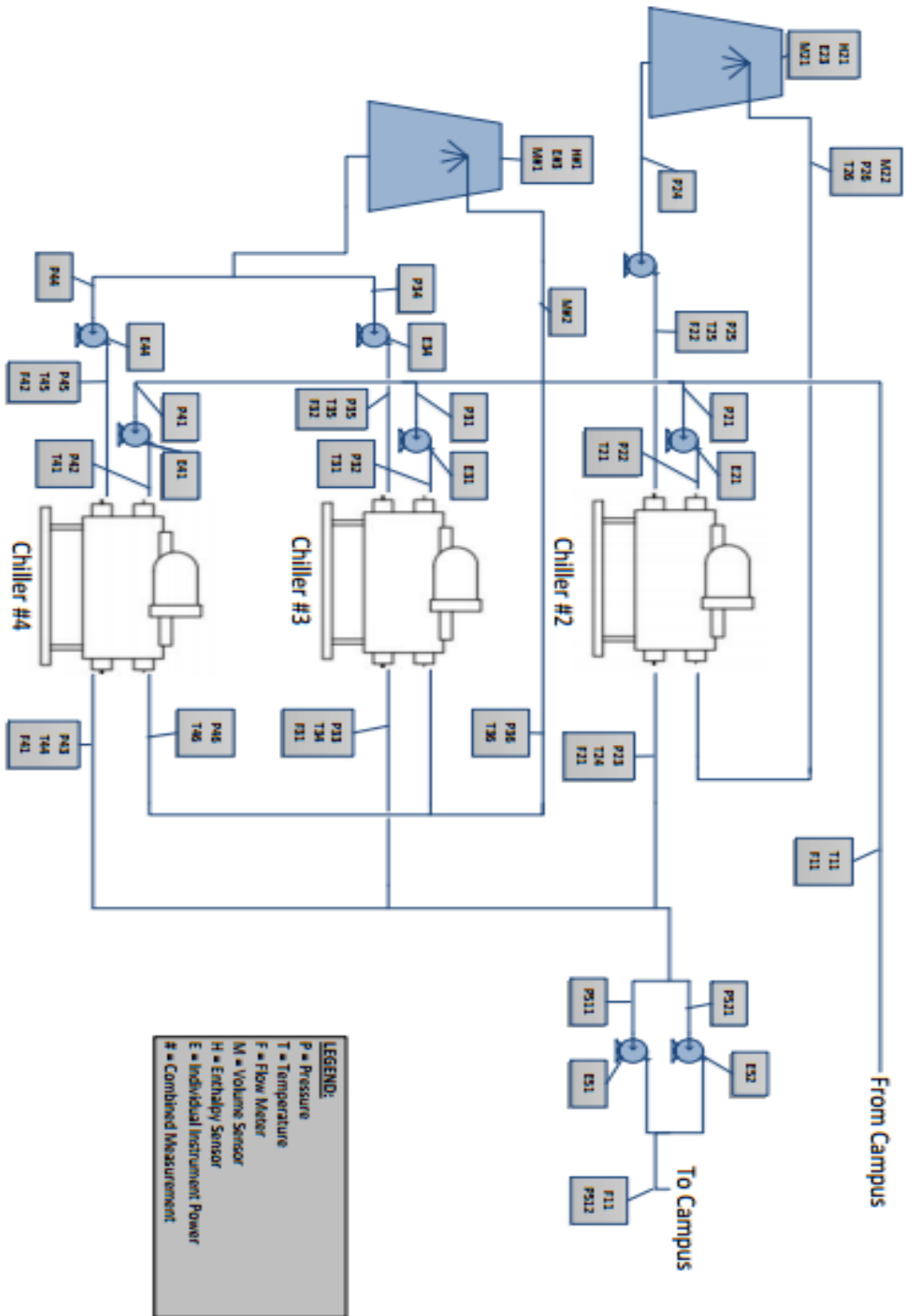
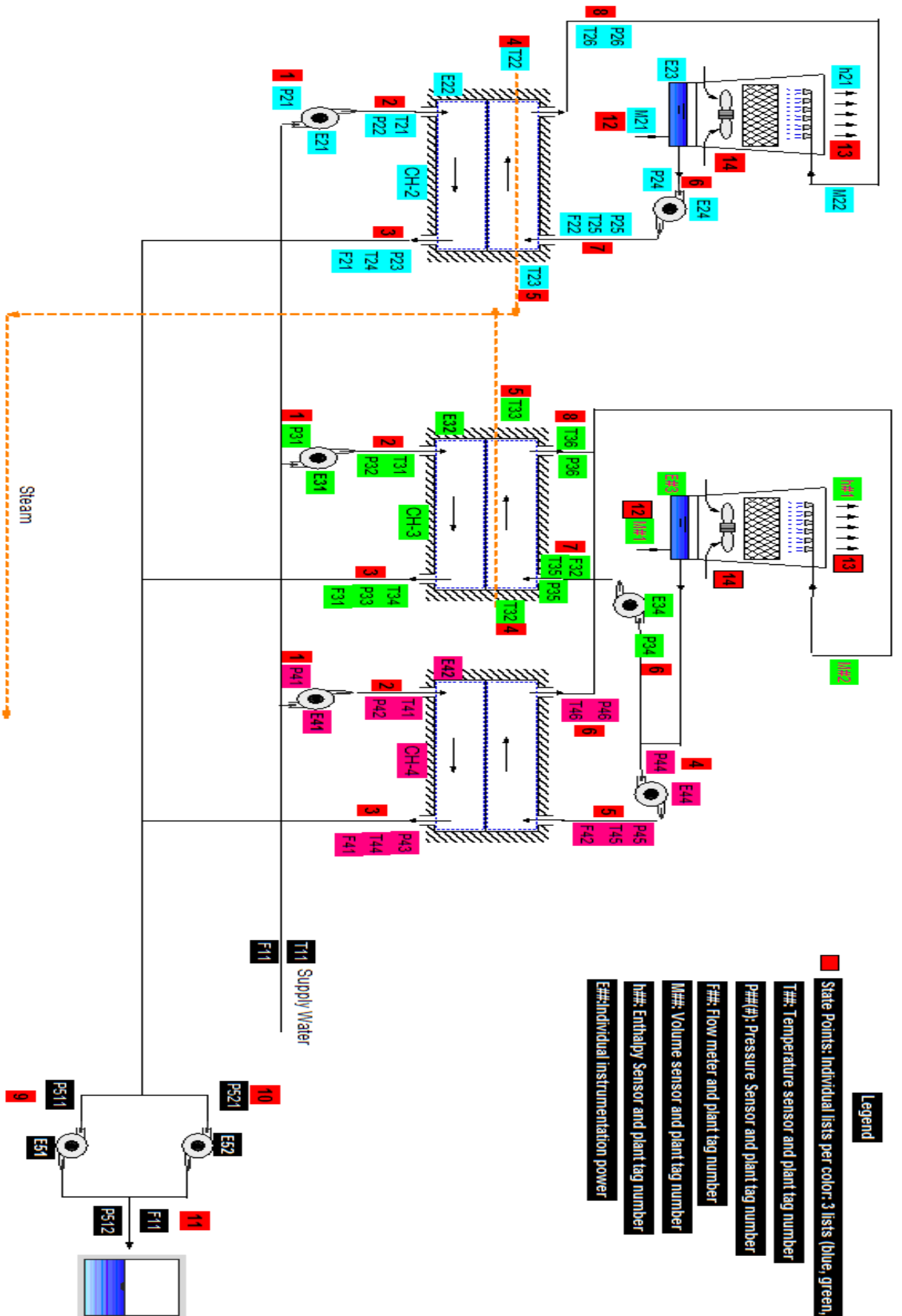


Figure 10: Cooling tower load plot for 9/12/16 from 8:30 A.M. to 6:30 P.M.

Future Work and Conclusion

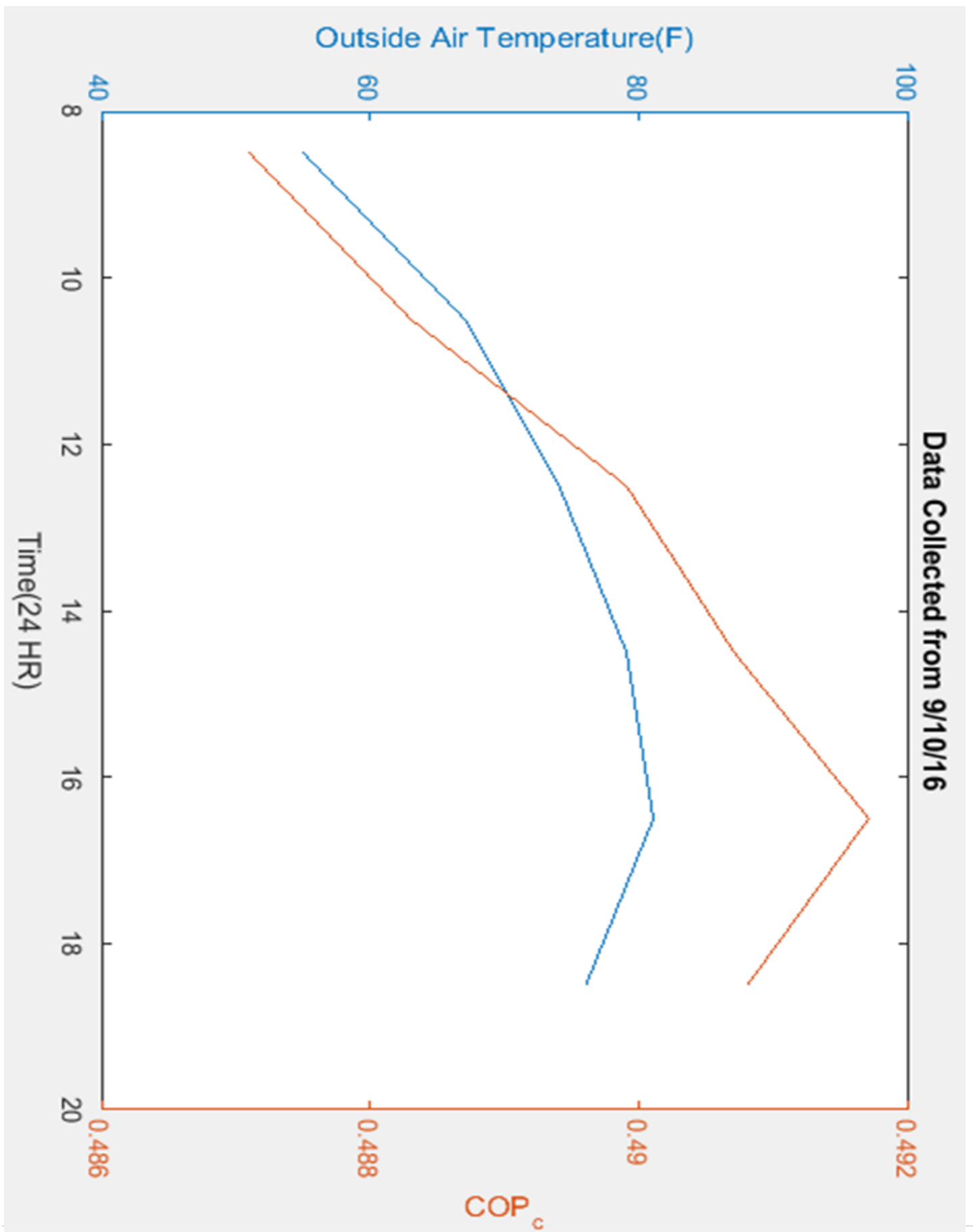
Throughout our work with the North Campus Chiller Plant we have had many positive gains. We developed and validated a working math model of chiller systems 2 and 3, created a line drawing of the system showing all the existing and additional sensors with P&ID software (Vizio), and also demonstrated the use of the math model by implementing collected data from the system. These accomplishments can be utilized by future engineering students working with the North Campus Chiller Plant. Future capstone students can use the system model along with available data collected from instrumentation to study the various operating conditions of the plant. Through study of these operating conditions, bottlenecks can be found and changes can be made to make the system more efficient and cost effective. Throughout the duration of this project we met all of our project deadlines in order to satisfy the client as well as the instructor. The advancements made over the course of our capstone design project can be utilized by the steam plant as needed. Also, our materials may be used for future capstone projects. The system model can benefit in reduced operating costs and overall plant efficiency.

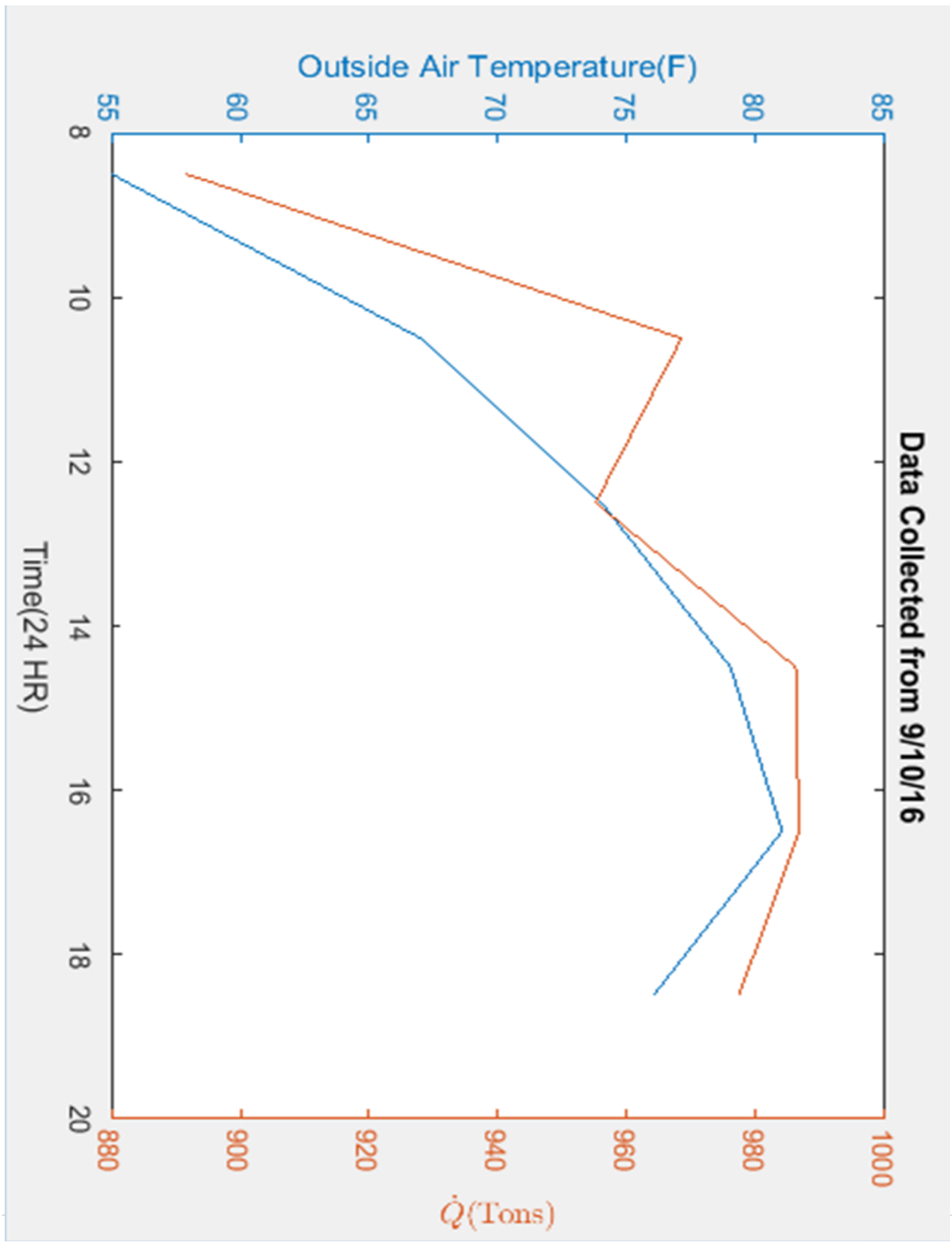


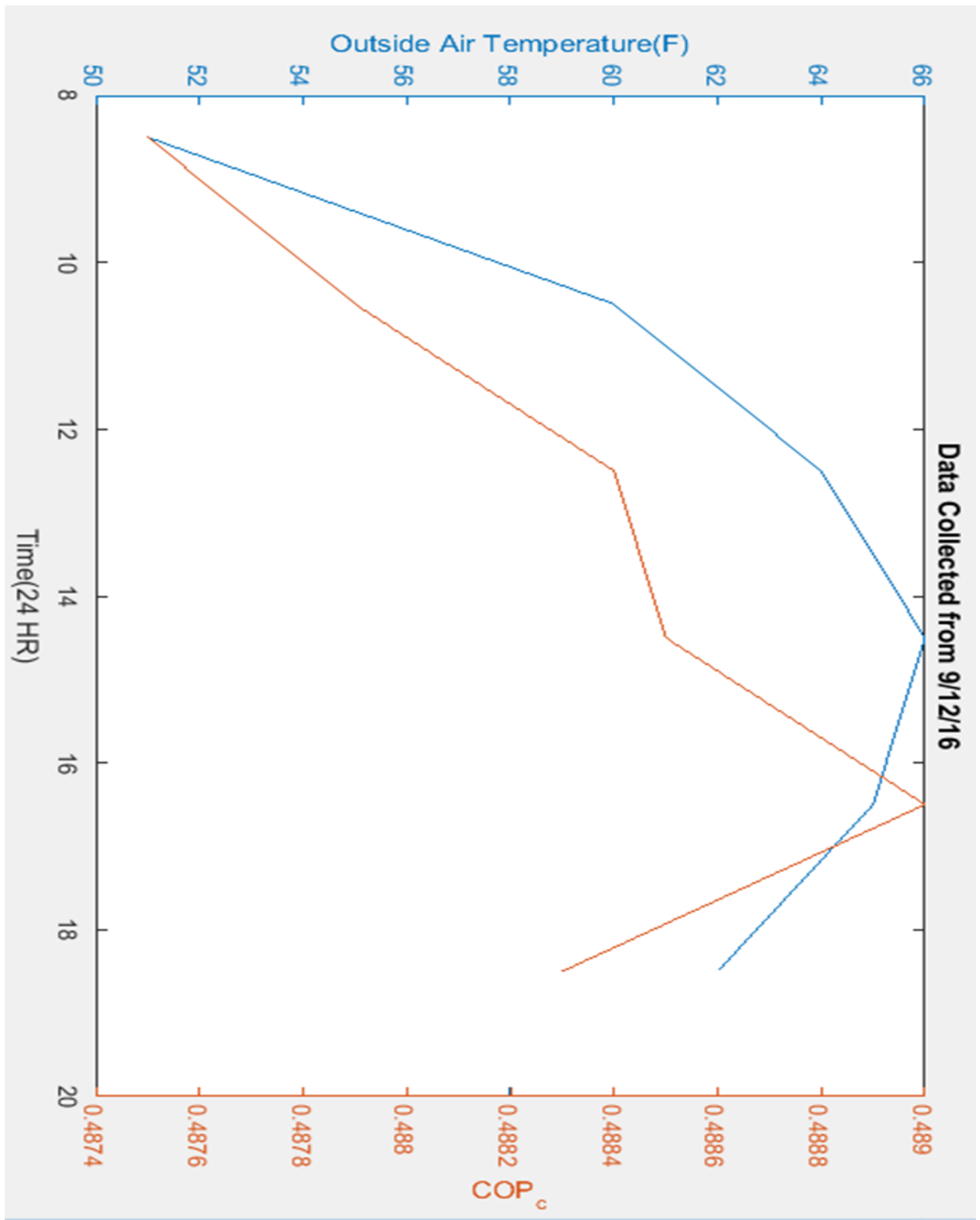


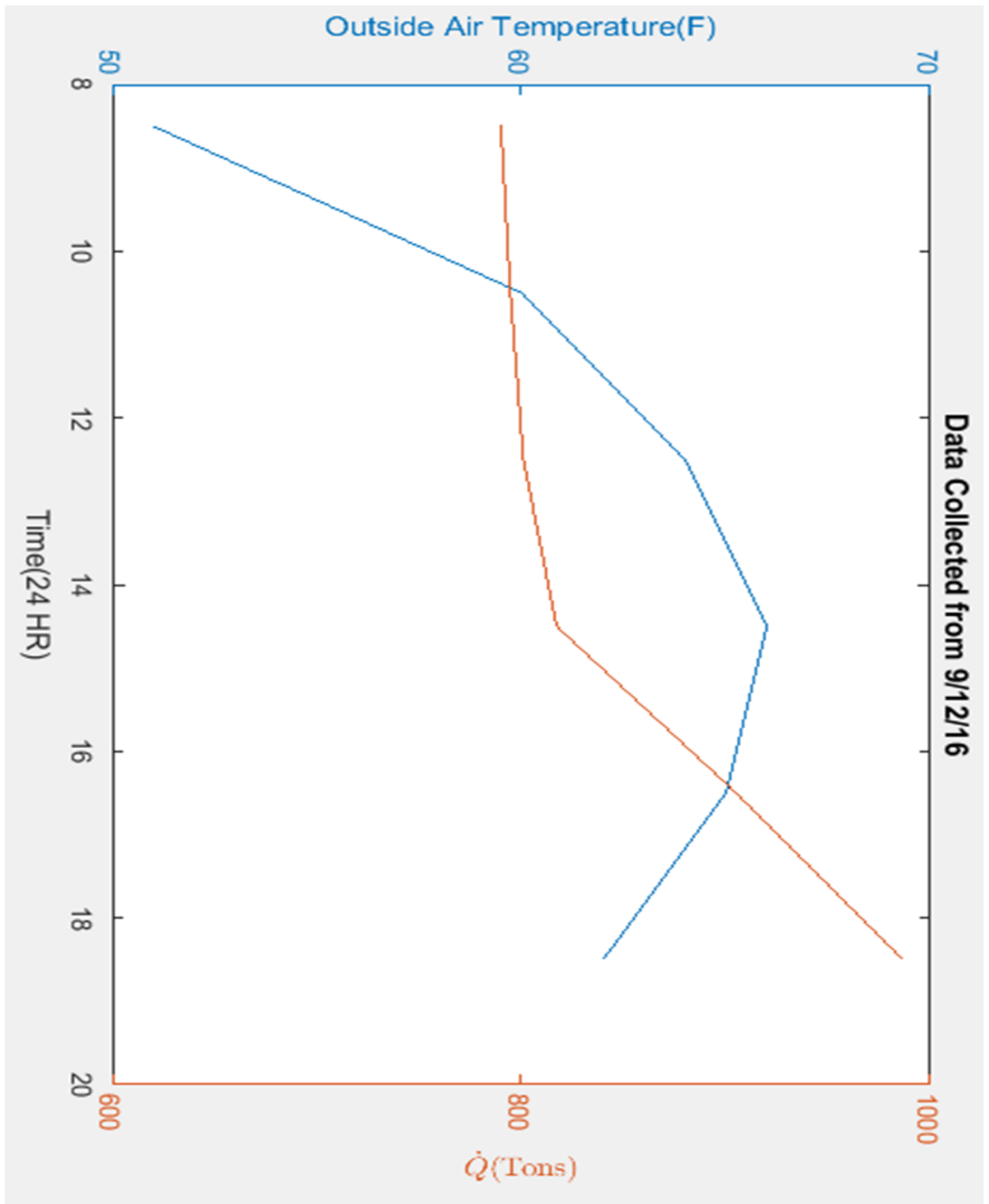
Legend

- State Points: Individual lists per color: 3 lists (blue, green, pink)
- T##: Temperature sensor and plant tag number
- P##(#): Pressure Sensor and plant tag number
- F##: Flow meter and plant tag number
- M##: Volume sensor and plant tag number
- h##: Enthalpy Sensor and plant tag number
- E##: Individual instrumentation power









User's Manual

The following gives step by step instructions on how to use the math model in order to determine the various parameters and heat exchange rates:

- 1) Choose a day to investigate.
- 2) Take the various workbooks and cut and paste all of the information for only that day into a blank excel workbook.
- 3) The data from the following books are required when completing step 2. **Condenser Side:** T_22, T_23, P_24, T_26, F_22, P_26, H_21, H_11, T_amb, Phi_amb, P_atm. **Evaporator Side:** P_21, P_22, P_23, P_511, P_521, P_512.
- 4) With the new workbooks containing only the data for the desired day the user must then decide upon a a range of times and then average the values for that time. For example for 8:30 A.M. average all of the values between 8 A.M. and 9 A.M. Repeat till the end of your time range. When conducting this we decided on a range of 8:30 A.M. to 6:30 P.M. as shown below.

P_512	DAY	SEPTEMBER 10, 2016 (HOT)	SEPTEMBER 12, 2016 (COLD)
TIME (24 HR)			
8:30		79.88238333	81.06731667
10:30		80.9856	81.90495
12:30		82.56891667	82.80386667
14:30		83.07965	83.27375
16:30		83.52911667	83.39633333
18:30		82.78341667	83.1205

- 5) Open the code in E.E.S and enter in all of the required data at the top of the code the required parameters will have a comment next to the them saying “Input from ATS”

```
"Inputs via Excel Sheet"
"Outside properties"
P_atm=29.97 [psia] "Input from ATS"
T_amb= 57.114 [F] "Input from ATS"
phi_amb= 0.20 "Input from ATS "
h11= 19.48654286 [Btu/lb_m] "Input from ATS"

"Evaporator Loop Inputs"
P21= 83.26783333 [psi] "Input from ATS System"
T_21= 52.5 [F] "Input from ATS System"
P_22= 82.52823333 [psi] "Input from ATS System"
P_23= 30.99405 [psi] "Input from ATS System"
T_24= 44.3 [F] "Constant value for both days Input from ATS System"
P511= 82.23185 [psi] "Input from ATS"
P521= 99.76058333 [psi] "Input from ATS"
P512= 128.6237143 [psi] "Input from ATS"

"Condenser Loop Inputs"
T22= 275 [F] "Input from ATS System"
T23= 190.2467143 [F] "Input from ATS System"
P24= 12.86052857 [psi] "Input from ATS System"
P25=50.1991 [psi] "Constant value for both days Input from ATS System"
T25= 83 [F] " Constant value for both days Input from ATS System"
F22=1409 [gpm]*convert (gpm,ft^3/s) "Input from ATS"
P26= 12.48832857 [psi] "Input from ATS"
T26= 95 [F] "Input from ATS"
h21=19.156 [Btu/lb_m] "Input from ATS"
```

The number of times the code will have to be run all depends upon the number of time increments in the chosen range. So referring back to step 4 for our chosen range we had to run the code 6 times.

- 6) After each time the code is ran the user must then go into the “Key Variables” section and record the performance parameters in a new excel book. The section is shown below:

Main	Key Variables
$\dot{Q}_{CH2,EVAP}$	$= 1322$ [Btu/s] {396.6 [tons]} <i>Heat exchange rate through the evaporator of CH-2</i>
$\dot{Q}_{CH2,COND}$	$= -2339$ [Btu/s] {-701.6 [tons]} <i>Heat exchange rate through the condenser of CH-2</i>
$\dot{Q}_{load,CT2}$	$= 2261$ [Btu/s] {678.3 [tons]} <i>CT-2 Load</i>
$\dot{Q}_{CT,2}$	$= -140.4$ [Btu/s] {-42.13 [Tons]} <i>Heat transfer rate of the air through CT-2</i>
SHR_{CT2}	$= 0.06684$ <i>Sensible Heat Ratio of CT-2</i>
ϵ_{21}	$= -0.007589$ <i>CT-2 effectiveness (heat)</i>
ϵ_{22}	$= 0.1134$ <i>CT-2 effectiveness (mass)</i>
$COP_{c,2}$	$= 0.4916$ <i>COP_c rating of CH-2</i>

- 7) After the data is analyzed it can be input into the Matlab code to generate plots of the given performance parameters. The Plots are 2 dimensional 3 axis plots. One plot displays outside

air temperature and the chiller tower load vs. time and the other plot displays outside air temperature and COPc vs. time.

```
Matlab_Plot.m × +
1 - figure (1)
2 - x=Data(:,1)
3 - y1=Data(:,2)
4 - y2=Data(:,4)
5 - [AX,H1,H2] = plotyy(x,y1,x,y2,'plot');
6 - title('Data Collected from 9/10/16')
7 - xlabel('Time(24 HR)')
8 - ylabel(AX(2), '$\dot{Q}$ (Tons)', 'Interpreter','latex')
9 - ylabel(AX(1), 'Outside Air Temperature(F)')
10
11 - hold on
12 - figure (2)
13 - x2=Data(:,1)
14 - y3=Data(:,2)
15 - y4=Data(:,3)
16 - [AX,H1,H2] = plotyy(x2,y3,x2,y4,'plot');
17 - title('Data Collected from 9/10/16')
18 - xlabel('Time(24 HR)')
19 - ylabel(AX(2), 'COP_c')
20 - ylabel(AX(1), 'Outside Air Temperature(F)')
21
```

Sensitivity Analysis

A sensitivity analysis was conducted to find out what readings affect our COPc measurement to see the greatest sources of error. We looked through the sensors' spec sheet to find out the accuracy of each instrument. Given its accuracy and maximum operating range we were able to find out how far off our measurements could be. We figured out that the maximum error that we could see in the COPc measurement is 34%. The main sources of error are T21 and T24, they make up the biggest portion of the possible error.

Sensor	COPc	Delta	Accuracy	Max Range	Max Error	% Contribution	Total Error %
Original	0.4916	0	0	0	0	0	34.27583401
P22	0.4916	0	0.0015	200	0.3	0	
P23	0.4915	1E-04	0.0015	200	0.3	0.059347181	
T21	0.6091	0.1175	0.005	400	2	69.73293769	
T22	0.491	0.0006	0.005	500	2.5	0.356083086	
T23	0.4919	0.0003	0.005	140	0.7	0.178041543	
T24	0.4502	0.0414	0.005	140	0.7	24.56973294	
F21	0.5002	0.0086	0.01	2000	20	5.103857567	
Total:		0.1685					