DISTRIBUTED ENERGY PROGRAM **REPORT**

Performance Assessment Report for the Domain CHP System

November 2005

By
Burns & McDonnell Engineering

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Domain CHP System Performance Assessment Report

for the

Packaged Cooling, Heating and Power Research & Development Program

Submitted to

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PART 1

INTRODUCTION

Burns & McDonnell Engineering, Incorporated (Burns & McDonnell) prepared this Performance Assessment Report for Oak Ridge National Laboratory (ORNL) in support of Phase I of the Packaged Cooling, Heating and Power Systems (CHP) Program. The CHP Program is one component of the Department of Energy's (DOE) Energy Efficiency & Renewable Energy/Distributed Energy Resources Program, which has the goal of increasing the supply and use of clean energy resources and improving the reliability of the nation's energy systems. Specific objectives under the DOE program include:

1. Increase the amount of the nation's distributed power to 20 percent of new electricity capacity by 2010 to mitigate transmission and distribution constraints by increasing on-site power generation capacity.
2. Double the capacity of combined heat and power (CHP) systems in the nation by 2010 from the 1999 level of 46 GW to 92 GW to make use of thermal energy normally wasted in the generation of power.

The CHP program contributes to the accomplishment of these objectives through partnerships with industry to research, develop and demonstrate packaged/modular CHP systems. The CHP program is aimed at increasing the efficiency of commercially available distributed generation, heating, and cooling systems thereby reducing overall fuel demand and demand on the electric grid. Under this program, Burns & McDonnell, teaming with Solar Turbines, Broad Air Conditioning USA and Austin Energy developed a large-scale modular CHP system that is a showcase for the benefits of packaged CHP systems when compared to central generation systems. These benefits include:

- Improved fuel efficiency
- Reduced energy costs
- Improved power reliability
- Increased energy choices
- Reduced air emissions
- Increased energy security
- Reduced system installation time

Burns & McDonnell supports program objectives through the development of CHP projects nation-wide as well as through the publication of a series of research and development reports such as this one. This report presents a summary of the performance testing results for the month of May 2005 for the CHP system installed at the Domain Technology Park in Austin, Texas. It is the first of a series of performance assessment reports during an extended testing period and is meant to augment the performance assessment reports generated during the post-commissioning test phase. These results summarize the CHP system performance over a range of operating conditions. The report is divided into the following sections:

Part 1 Introduction
Part 2 Description of the Performance Tests
Part 3 Detailed Performance Testing Results
Part 4 Summary of Findings and Observations

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PART 2

DESCRIPTION OF PERFORMANCE TESTS

The testing and data collection methods for the Domain CHP project are based upon a combination of instrument measurements and calculations to determine and document the performance of the overall system as well as the performance of each of the major components: The Solar combustion turbine including inlet air cooling and the Broad absorption chiller (ABS). These testing methods were developed under the assumption that the turbine and the absorption chiller would be operated at full load. Due to site operational and contractual limitations for delivery of chilled water to the site's clients, the proposed tests were limited to those operating conditions with a chilled water supply temperature of 46 F and lower.

The specific testing methods and procedures and system performance standards for the CHP system installed at the Domain were developed in collaboration with ORNL and Austin Energy, the system owner/operator, and are documented in detail in a separate Task Report. Measurements and calculations for the CHP system auxiliary equipment are included in this assessment. Burns & McDonnell also included instrumentation and calculations for additional auxiliary equipment and their associated energy consumption values. This additional auxiliary equipment includes: the chilled water circulation pumps of the central chiller plant, the chilled water distribution pumps, the associated cooling tower fan energy required for the absorption chiller, and the associated cooling water (condenser water) pumps.

The performance period for this report is May 1 to June 3, 2005. System operation during this period was intermittent primarily due to the owner's decision to operate the system in a peaking mode rather than a base-loaded mode. Generally, the system was operated 5 days per week during the hottest time of day (1pm to 9pm) during which the chilling load and grid electricity prices were at a peak. It is anticipated that the system will continue to be operated in this fashion during each cooling season in Austin, approximately April through October. Subsequent reports will document the performance of the system during the remainder of the 2005 cooling season.

* * * *

PART 3

DETAILED PERFORMANCE TESTING RESULTS

MAY, 2005

Burns & McDonnell continued to evaluate the Domain CHP system performance from additional run time data during the extended testing period over the 2005 cooling season. We were assisted in this effort by Austin Energy who provided the minute by minute system data from the CHP system. Based on this data, the Turbine and Chiller Output graphs were developed. The resulting graphs of the May 2005 data are shown in this report, along with a summary of the results and any trends or significant correlations that were observed. During this testing period, the CHP system was operated during peak chilling load hours with the turbine at full load, and with the ABS chiller operating in a load-following mode to meet the variations in the Domain site chilling load.

COMBUSTION TURBINE PERFORMANCE VARIATION GRAPHS

The performance of the turbine was evaluated as shown in the following graphs. As shown in Figures 1-3, the combustion turbine remained at full load, and the chilled water flow also remained essentially constant, as the cooling load was also high during the peak hours of the day.

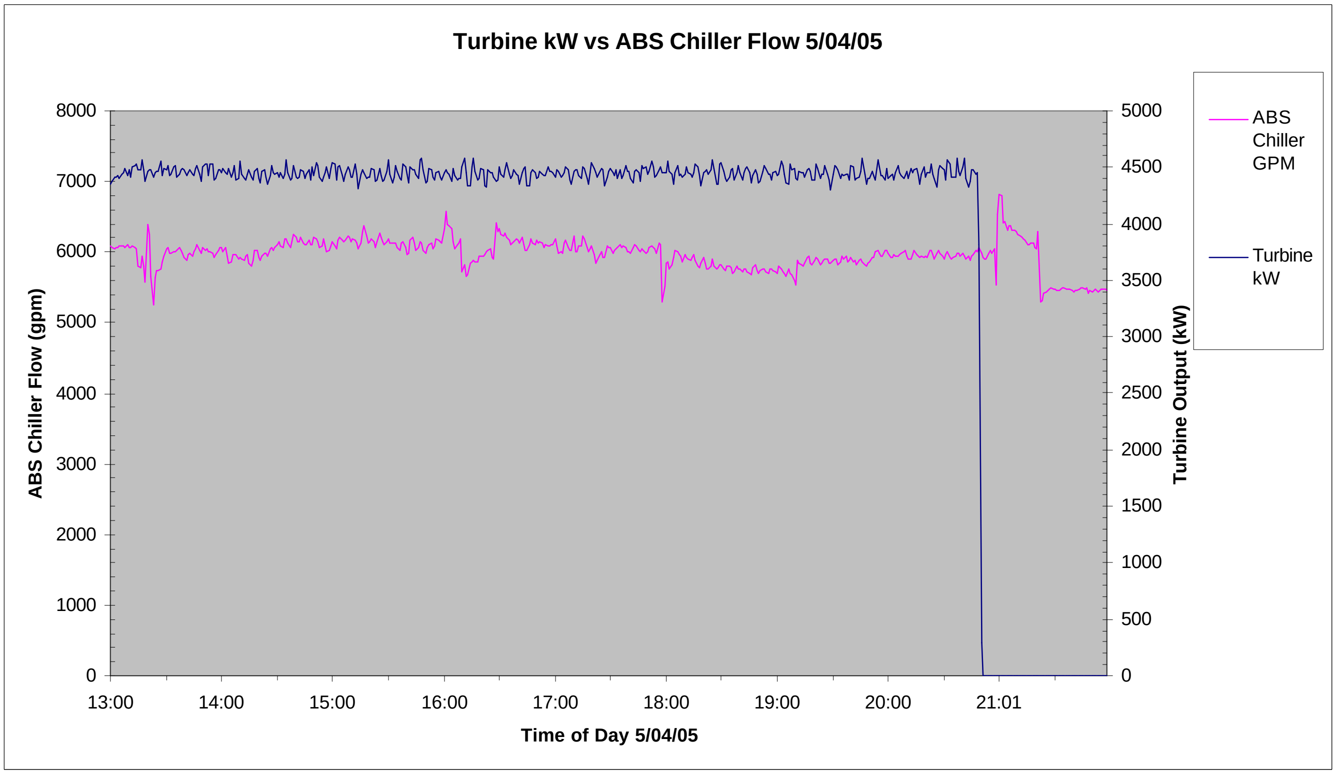

Figure 1 – Turbine kW output and ABS chilled water flow versus time of day 5/04/05

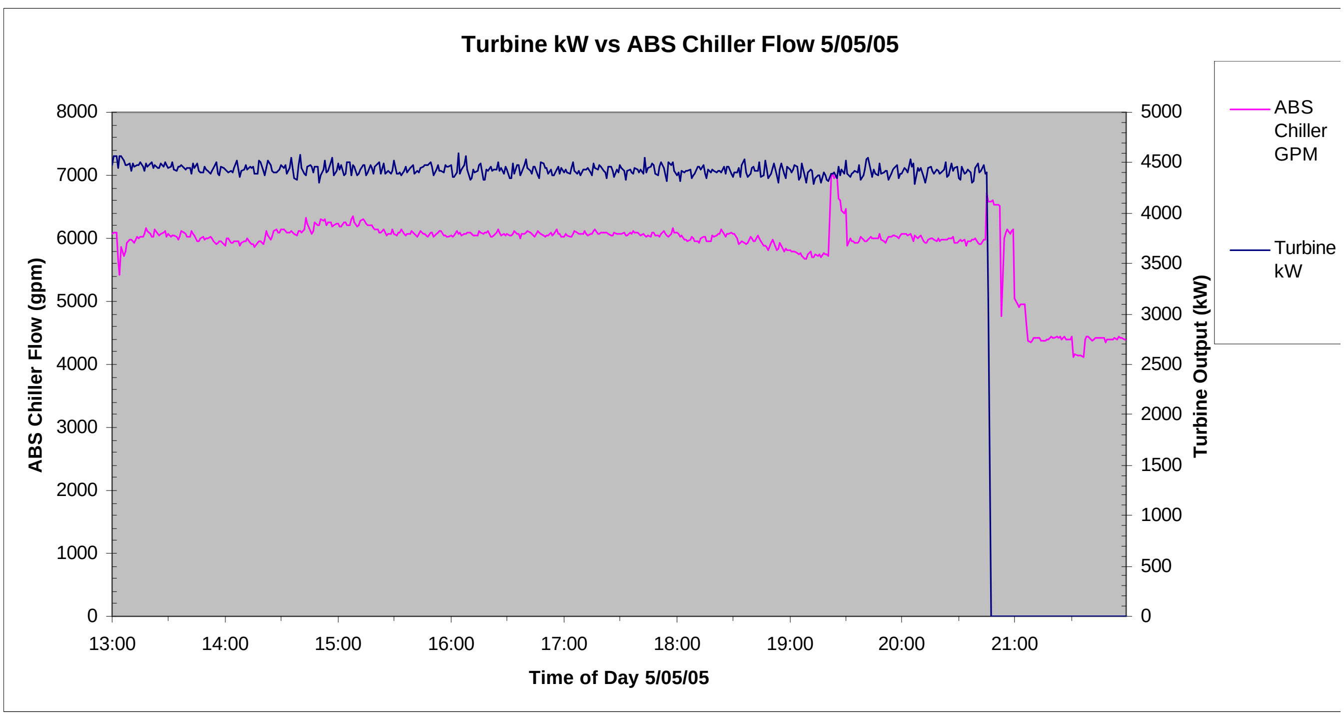

Figure 2 – Turbine kW output and ABS chilled water flow versus time of day 5/05/05

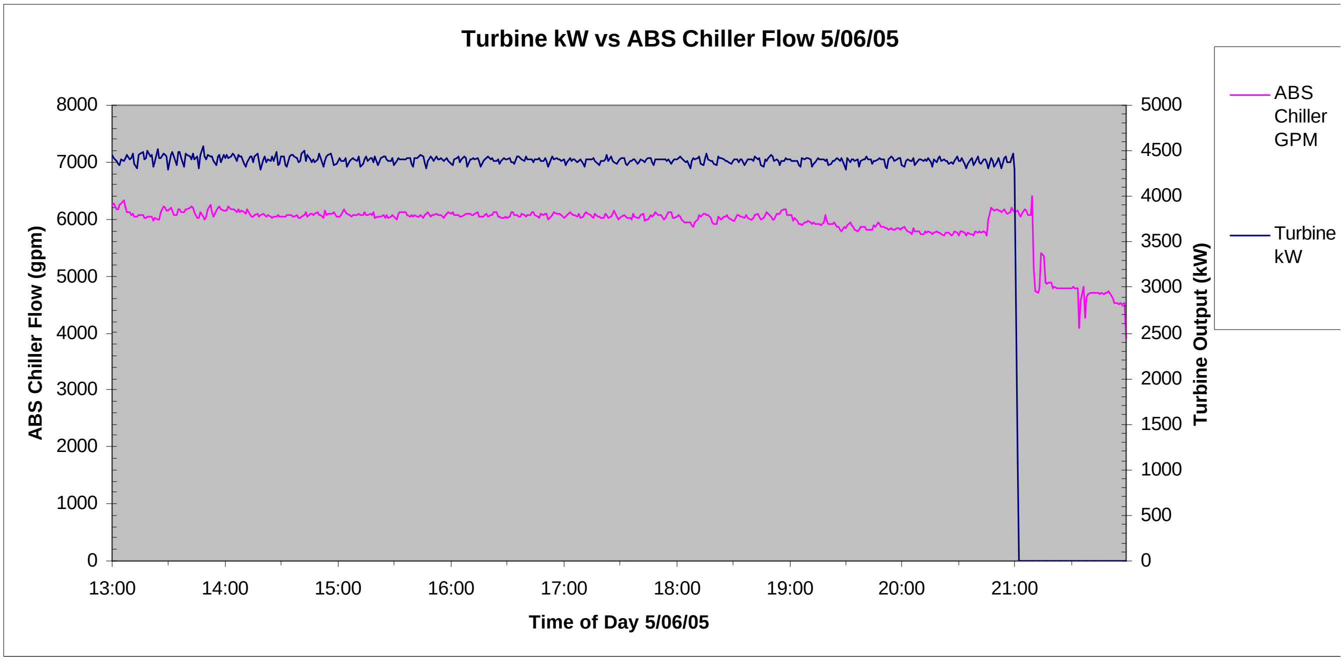

Figure 3 – Turbine kW output and ABS chilled water flow versus time of day 5/06/05

Figure 4-6 show that the inlet air temperature to the turbine, based on use of inlet air cooling, averaged 53-54ºF. Based on this essentially constant temperature, the turbine output remained essentially constant between 4400 kW and 4500 kW.

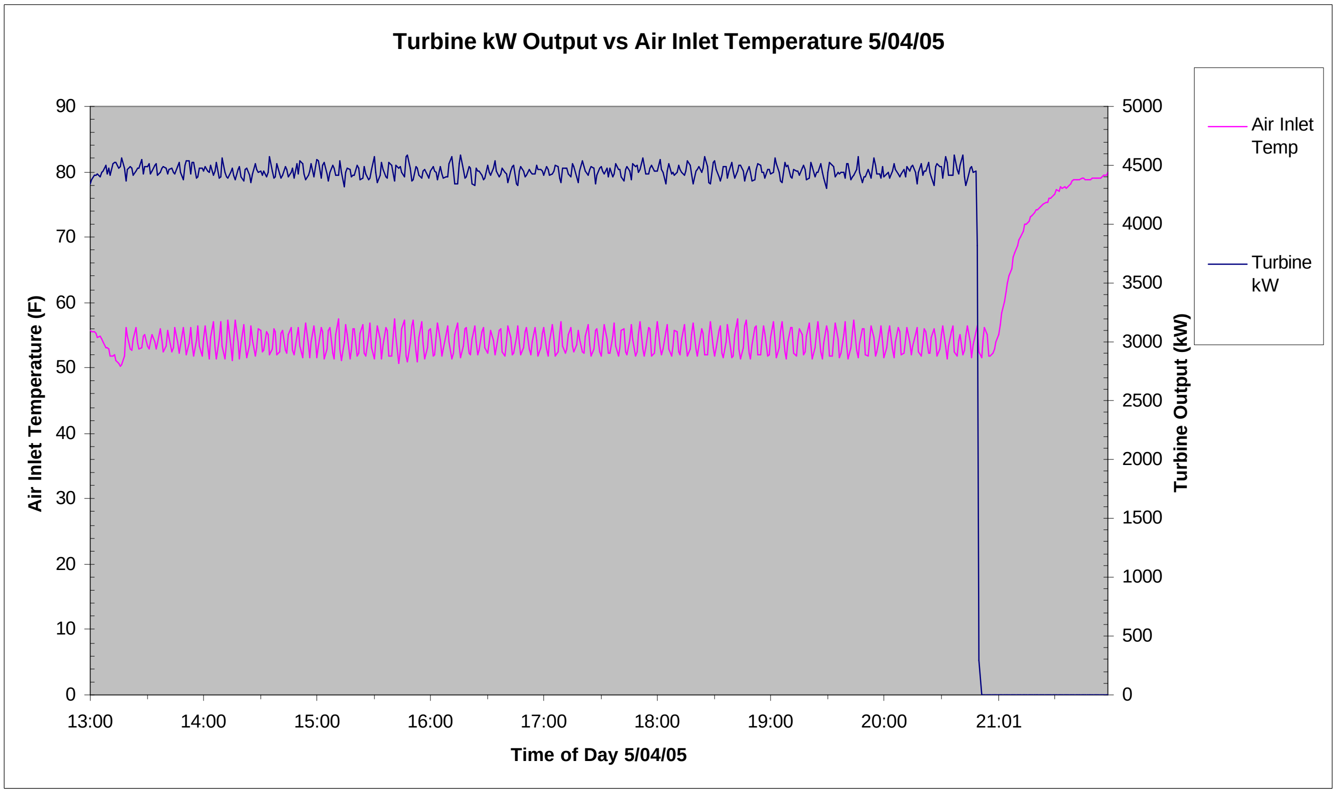

Figure 4 – Turbine kW output and inlet air temperature versus time of day 5/04/05

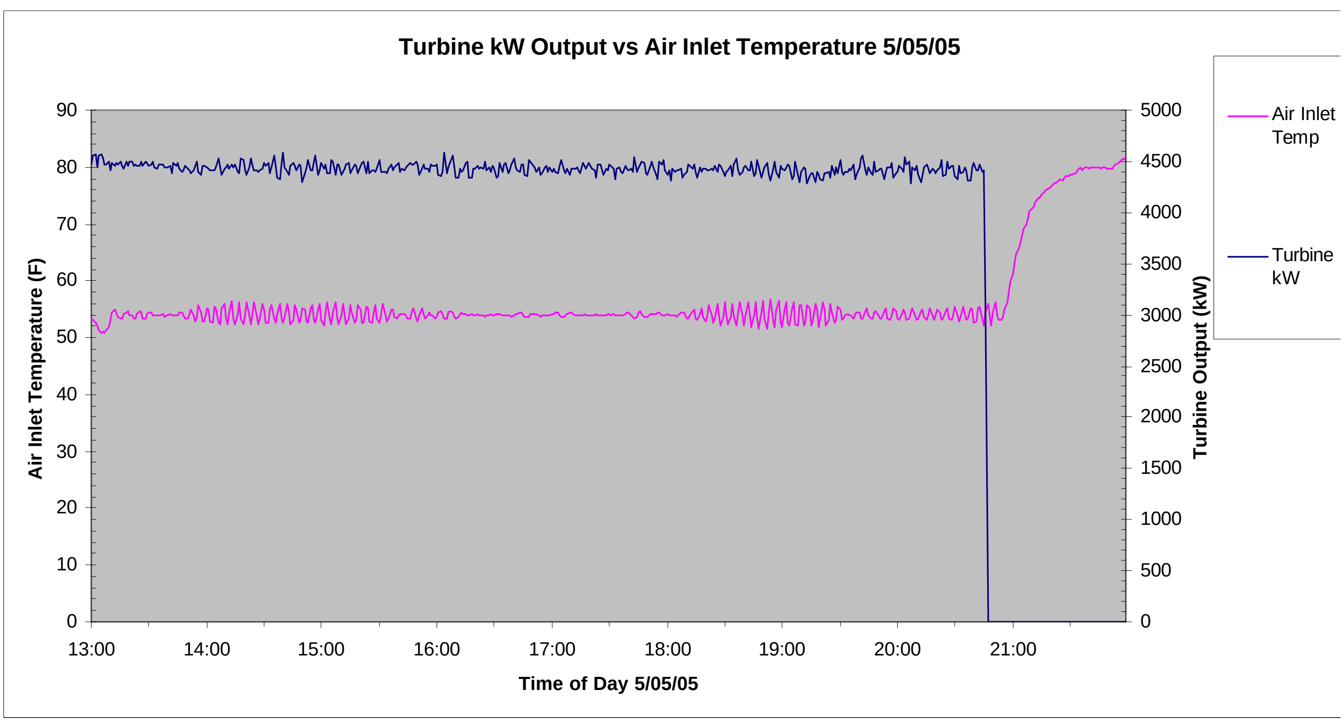

Figure 5 – Turbine kW output and inlet air temperature versus time of day 5/05/05

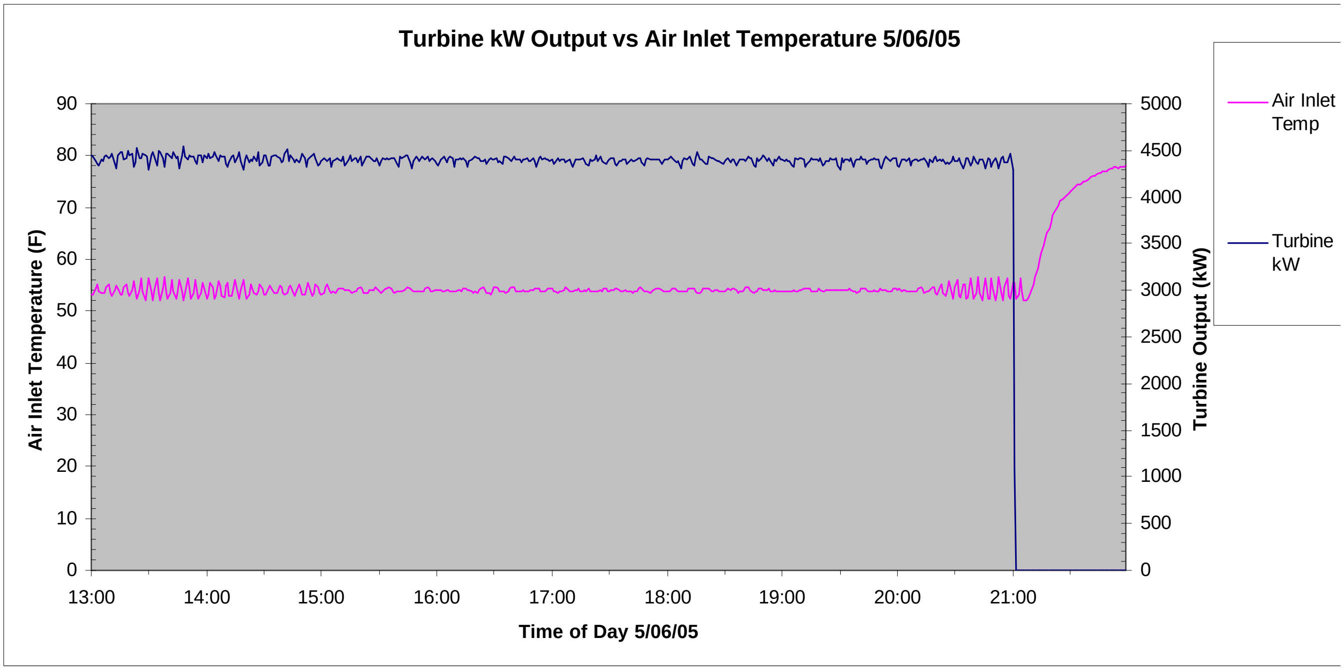

Figure 6 – Turbine kW output and inlet air temperature versus time of day 5/06/05

Figures 7-9 show that with the turbine at a constant load of about 4500 kW, the ABS chiller tons remained consistently high until 6:00 p.m (18:00) and then decreased. These followed typical daily patterns for summer days. The data on May 4th shows more unexpected variation in chiller load than normal.

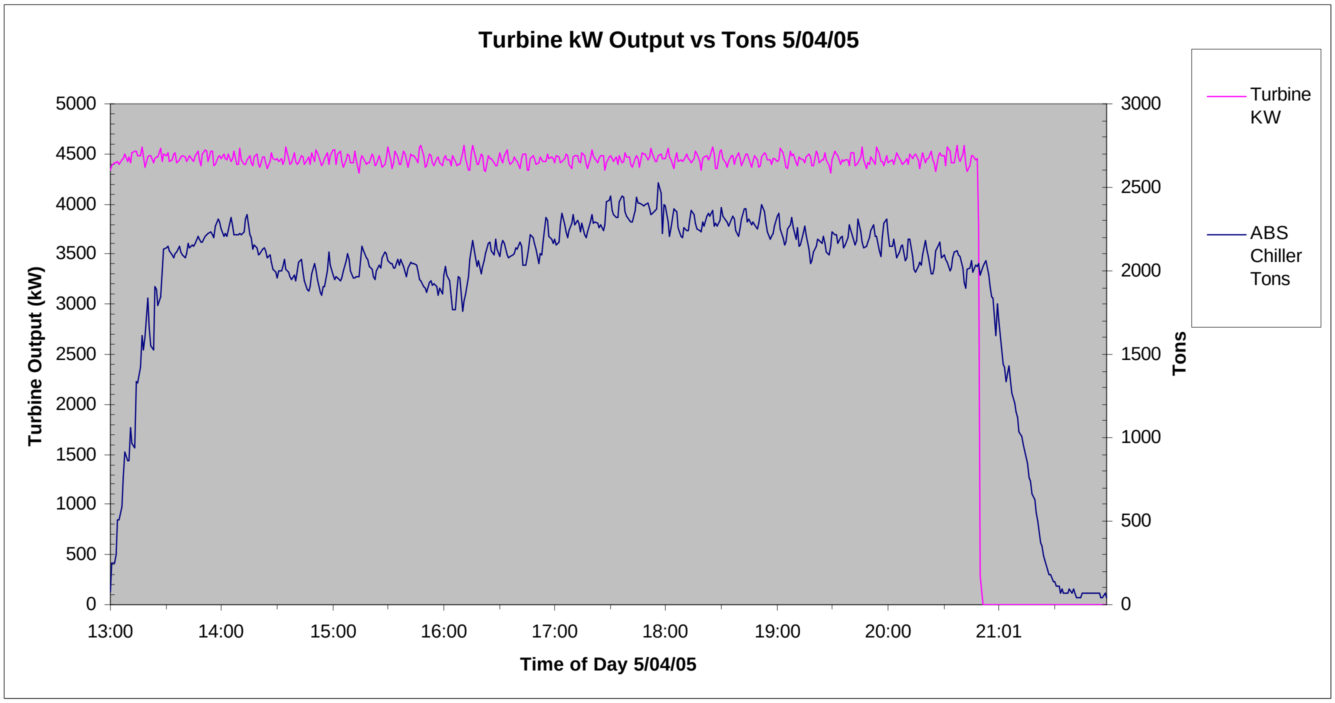

Figure 7 – Turbine kW output and ABS tons versus time of day 5/04/05

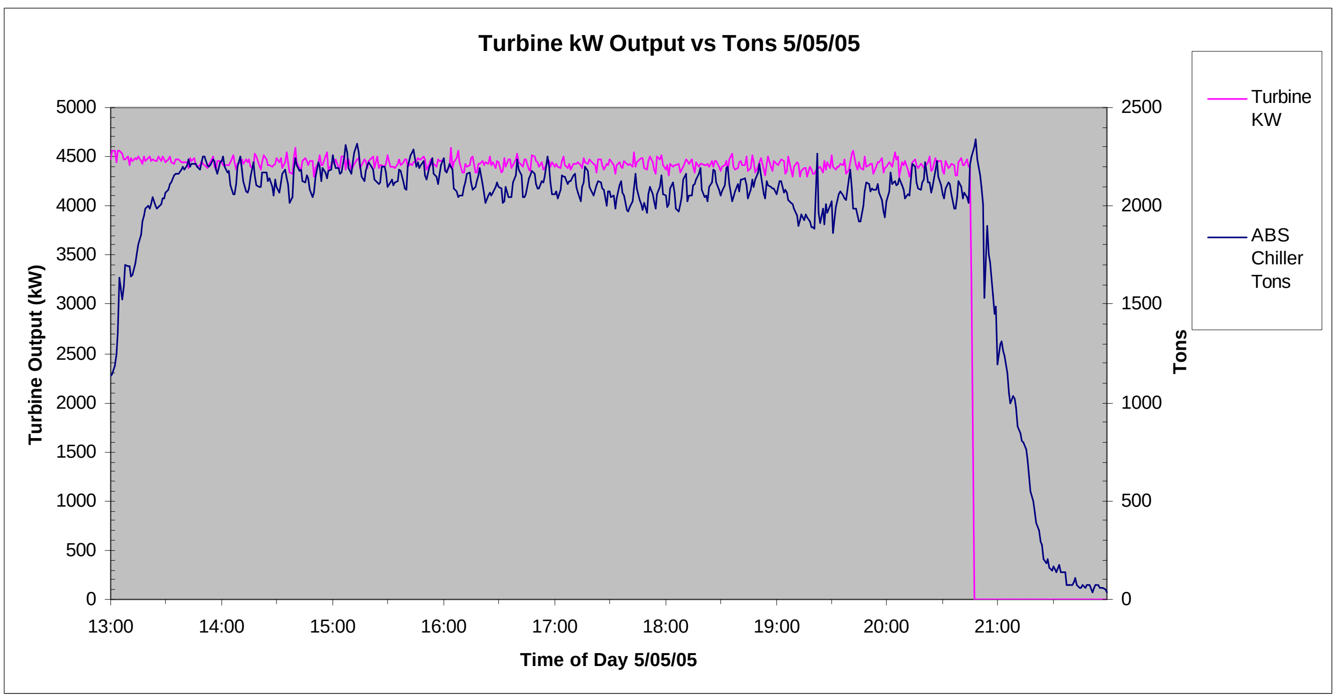

Figure 8 – Turbine kW output and ABS tons versus time of day 5/05/05

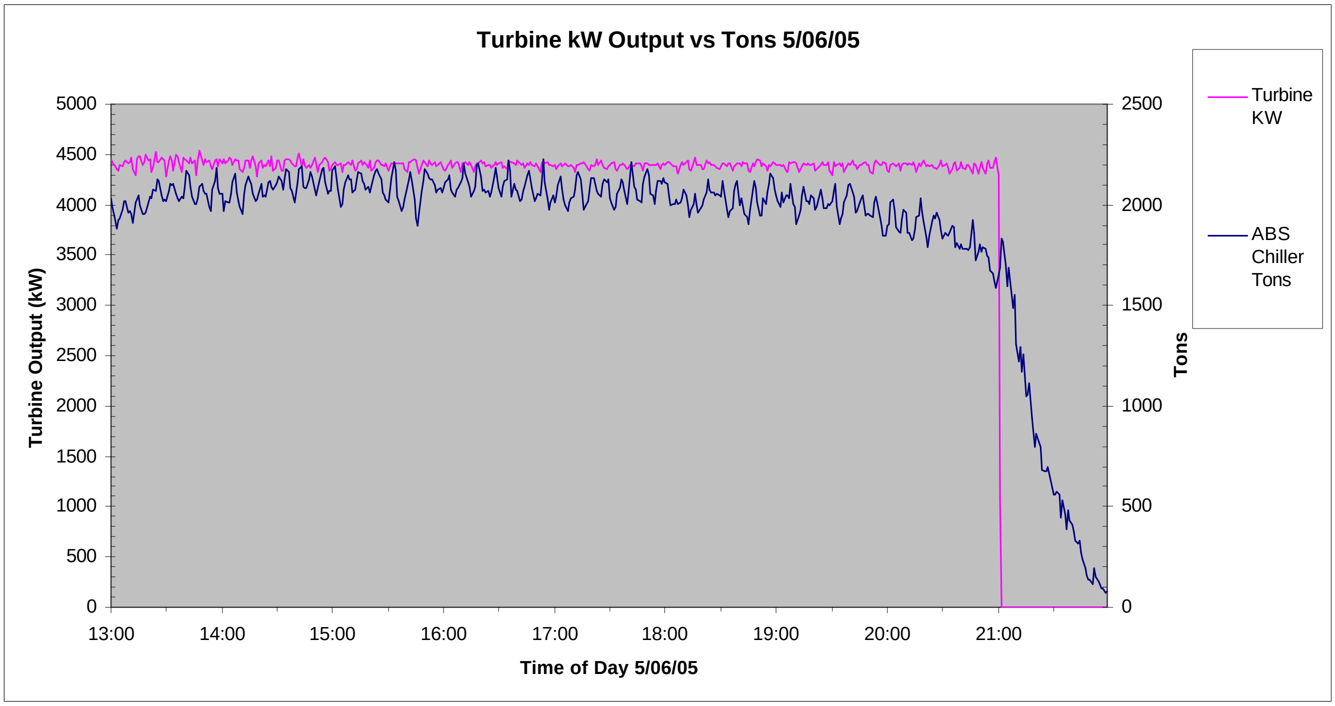

Figure 9 – Turbine kW output and ABS tons versus time of day 5/06/05

Figures 10-12 show data on the variation in ABS chiller tons versus turbine exhaust temperature. Since the turbine was run at essentially full load, the exhaust temperature did not show any significant variations. The ABS tons did show some variations within a band of approximately 150-200 tons. This is probably attributable to the lag between the chiller controls to change tons, and the actual time it took for the ABS chiller to respond to the change. During this time period the diverter damper position varied from 51% to 100% open to the ABS chiller.

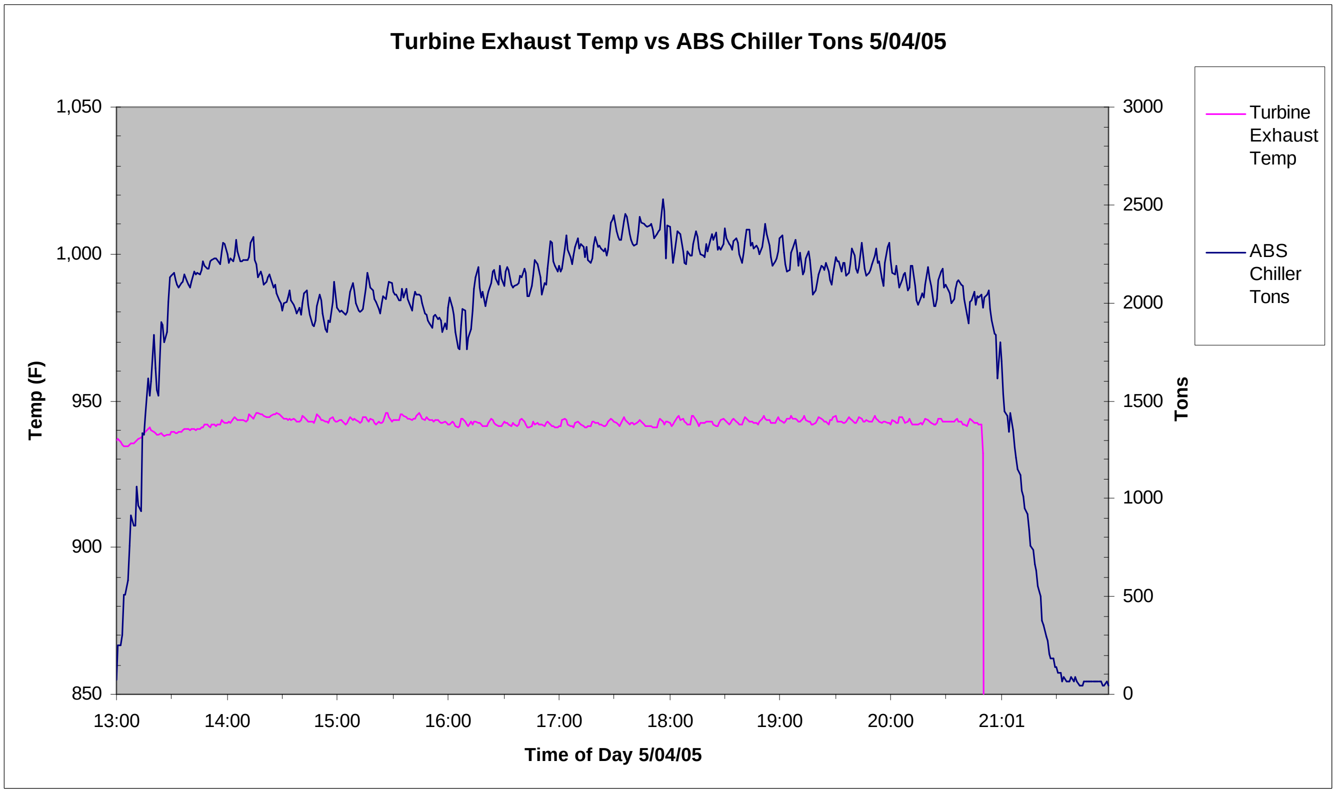

Figure 10 – Turbine exhaust temperature and ABS tons versus time of day 05/04/05

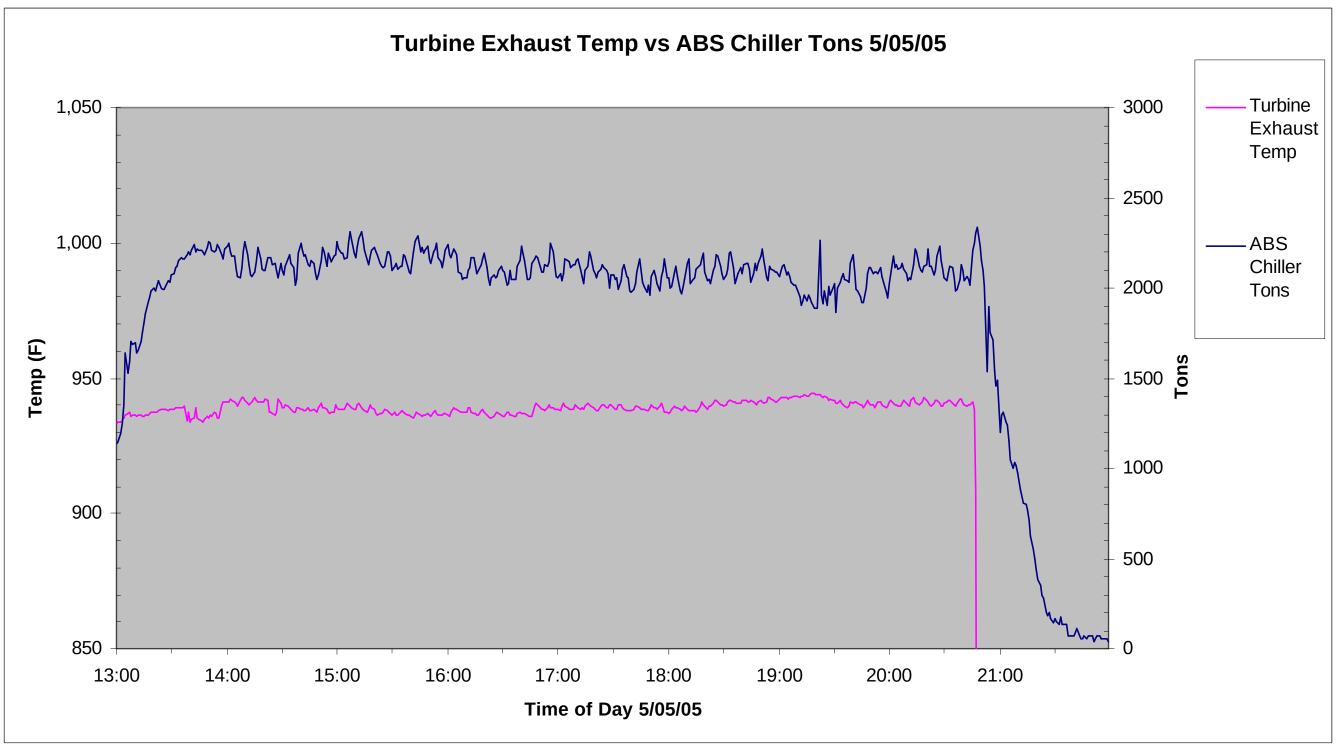

Figure 11 – Turbine exhaust temperature and ABS tons versus time of day 05/05/05

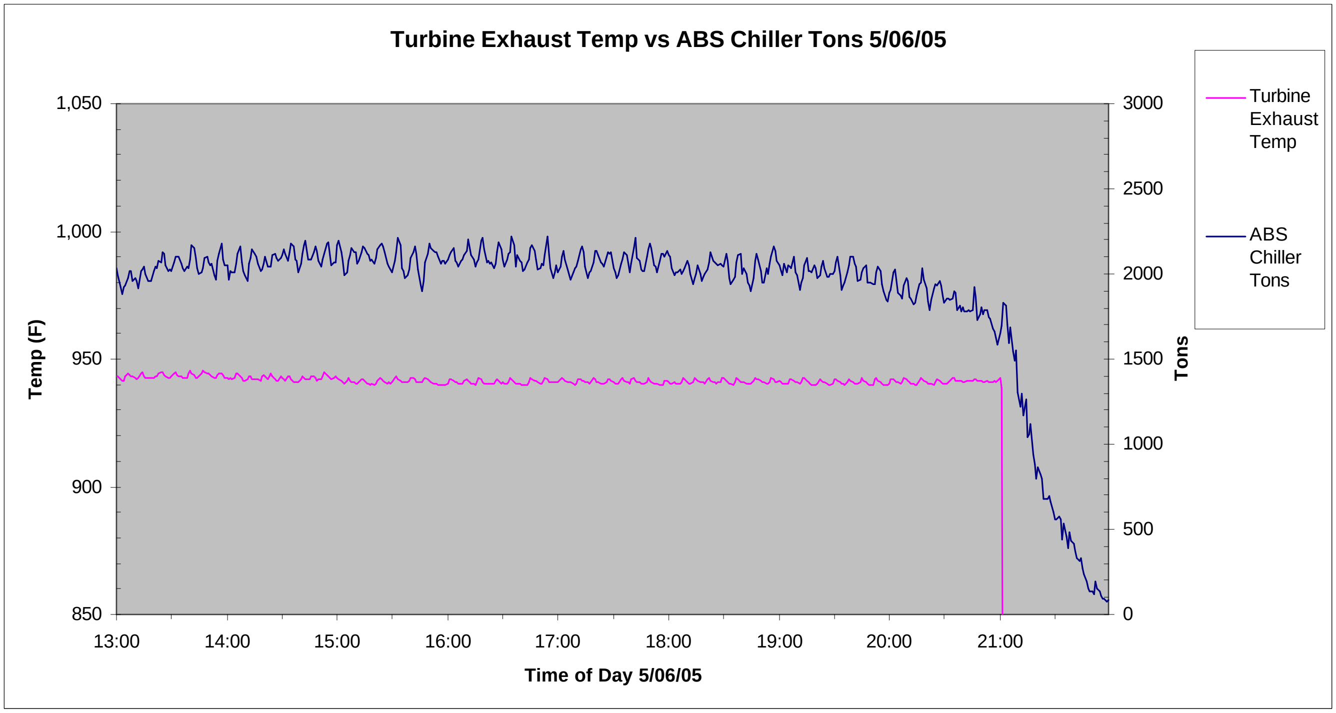

Figure12 – Turbine exhaust temperature and ABS tons versus time of day 05/06/05

Figures 13-15 show that with a constant inlet air temperature to the turbine, based on inlet air cooling, the turbine exhaust temperature with the turbine at full load does not change. The data from the fourth of May did show about a 6ºF variation in inlet air temperature over the entire run period, which was not observed on the next two days.

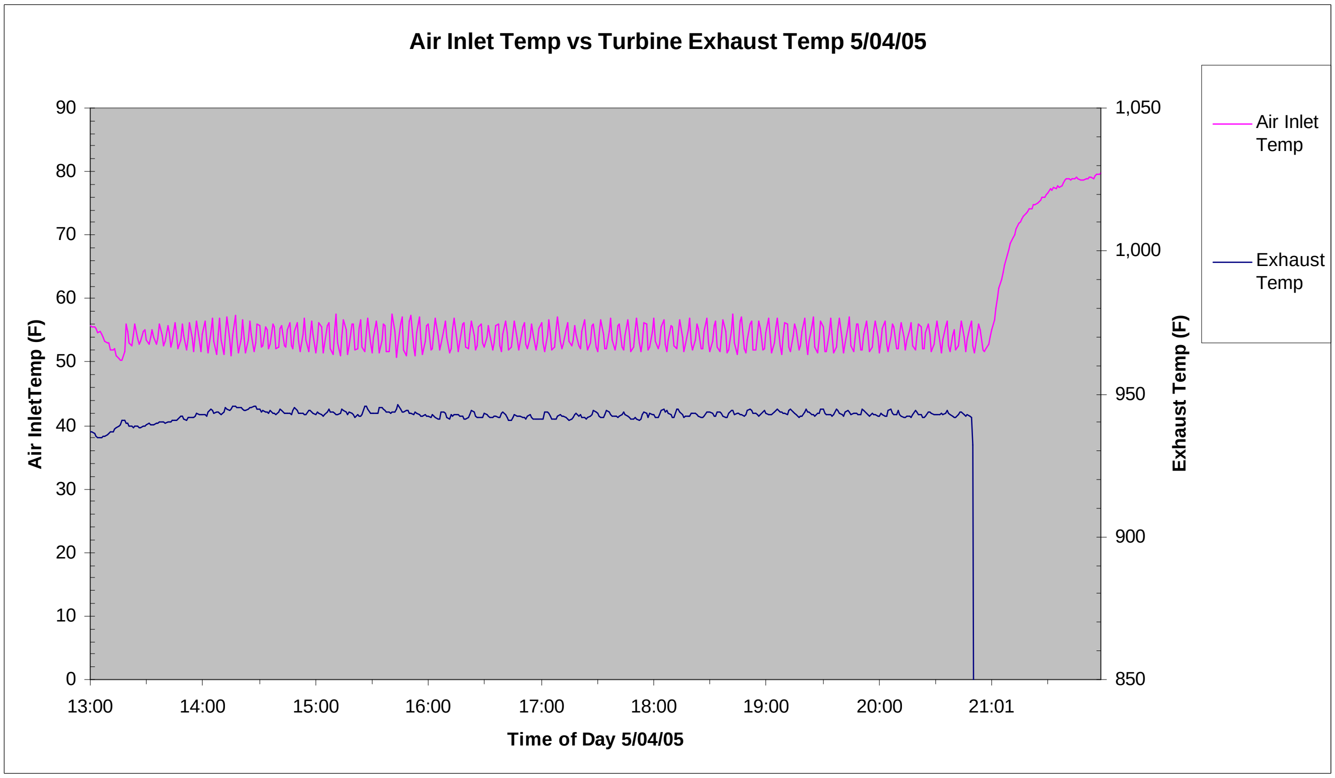

Figure 13 – Turbine inlet air and turbine exhaust temperatures versus time of day 5/04/05

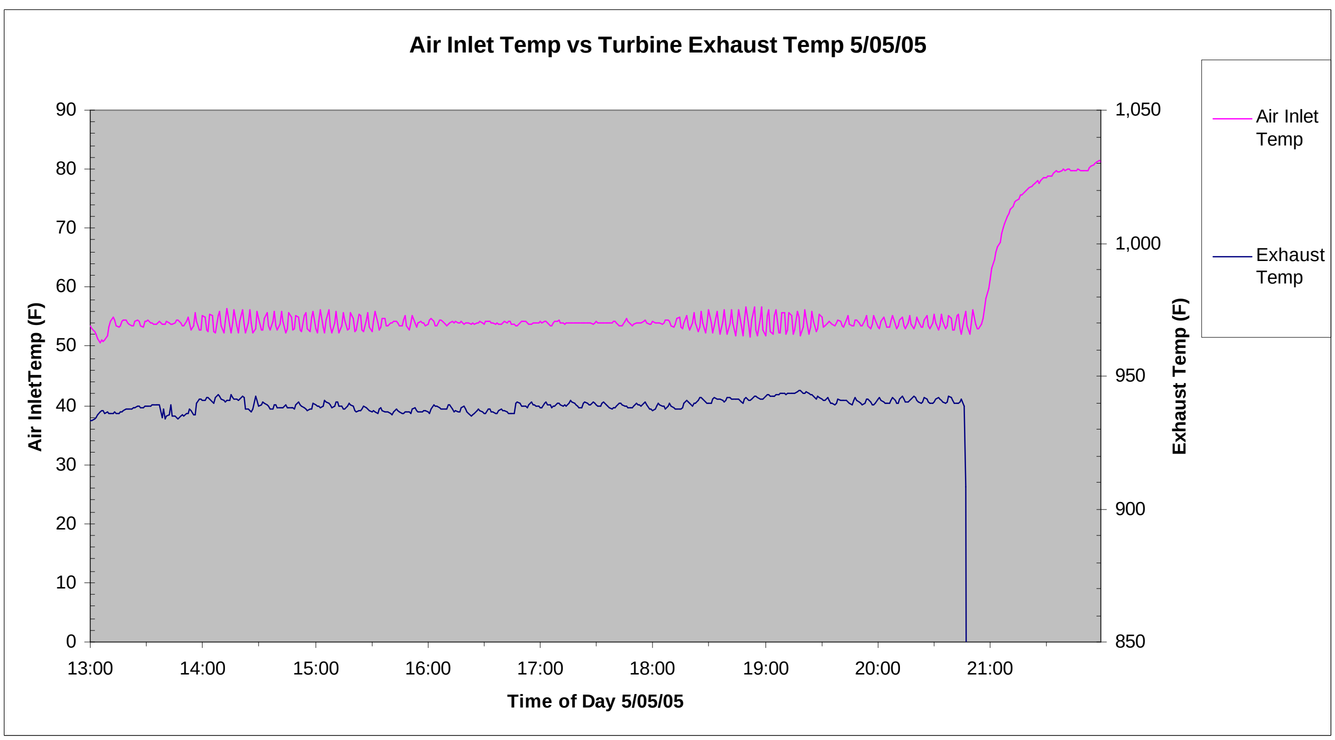

Figure 14 – Turbine inlet air and turbine exhaust temperatures versus time of day 5/05/05

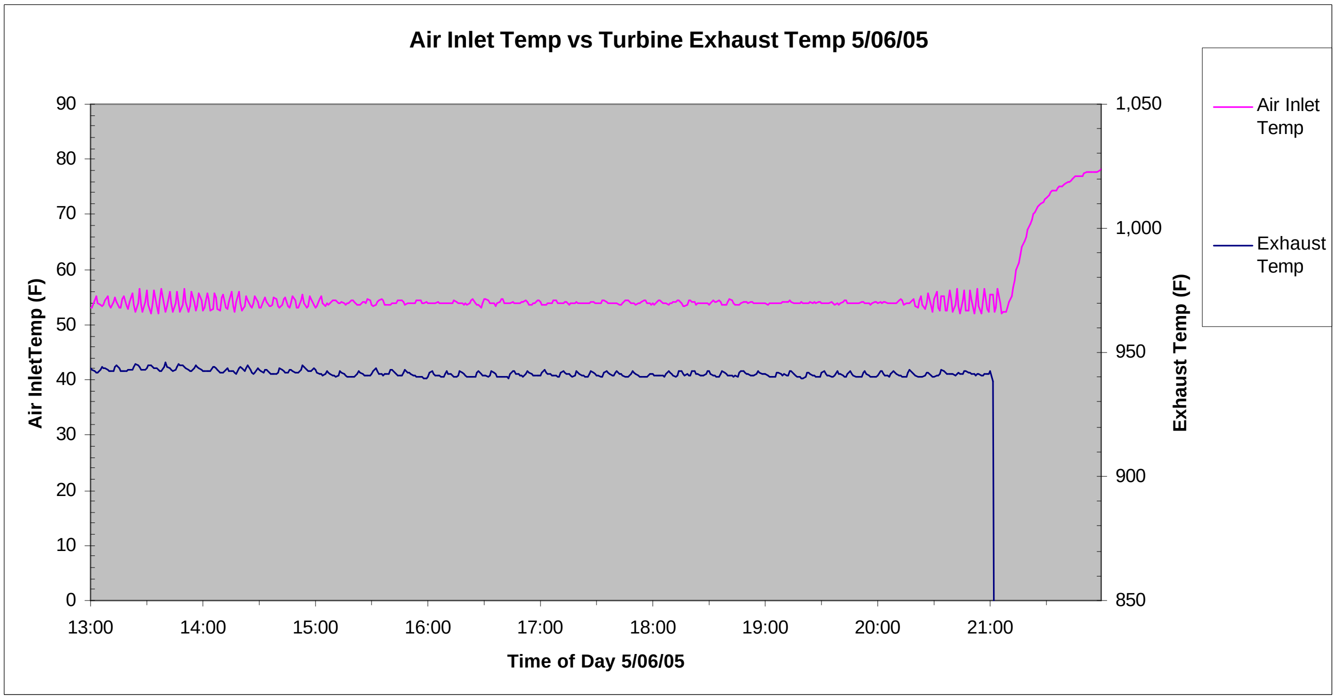

Figure 15 – Turbine inlet air and turbine exhaust temperatures versus time of day 5/06/05

Figures 16-18 show the correlation between the chilled water gpm and the resulting tons for the ABS chiller. Assuming a relatively constant delta T, there should be a direct correlation between the chilled water gpm and the tons. The graphs generally show this, but the first day seemed to show less coordination than the other two days.

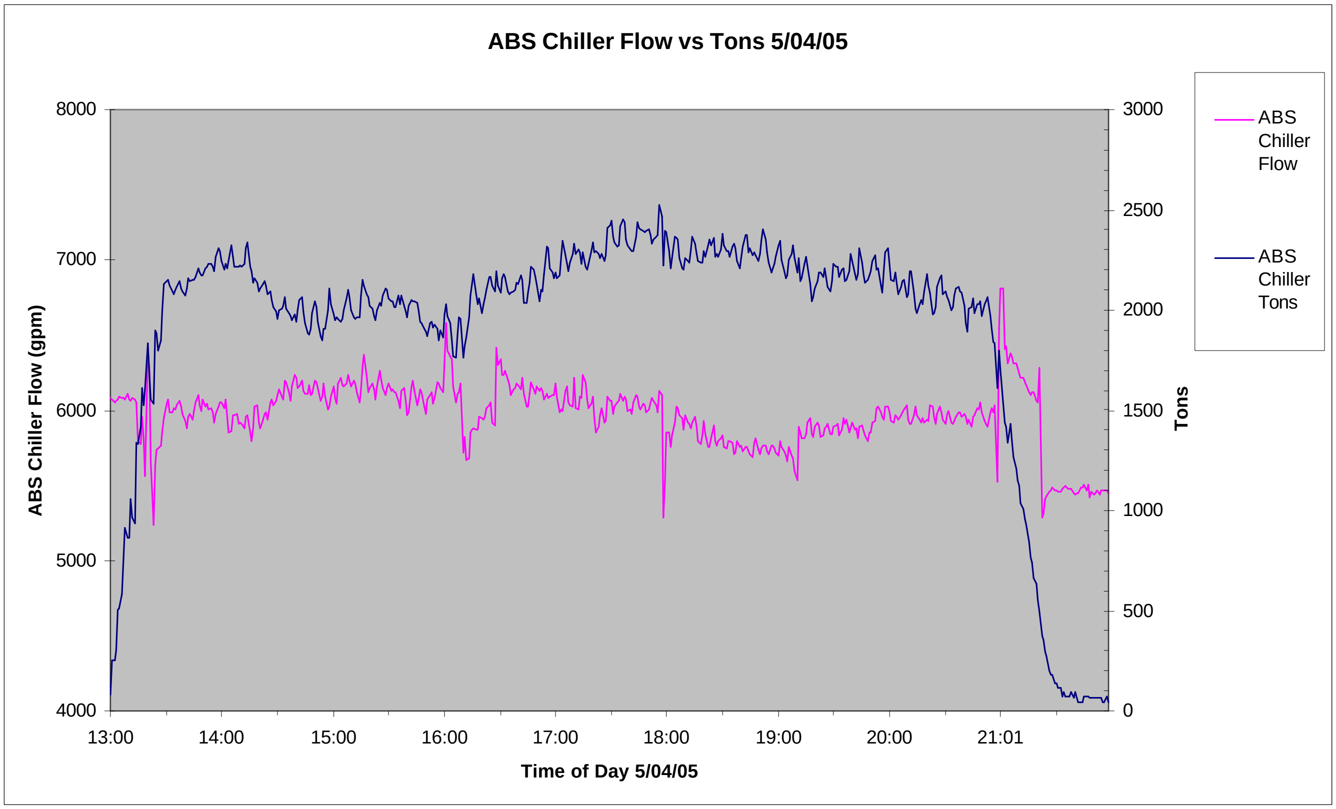

Figure 16 – ABS chilled water flow (gpm) and ABS tons versus time of day 05/04/05

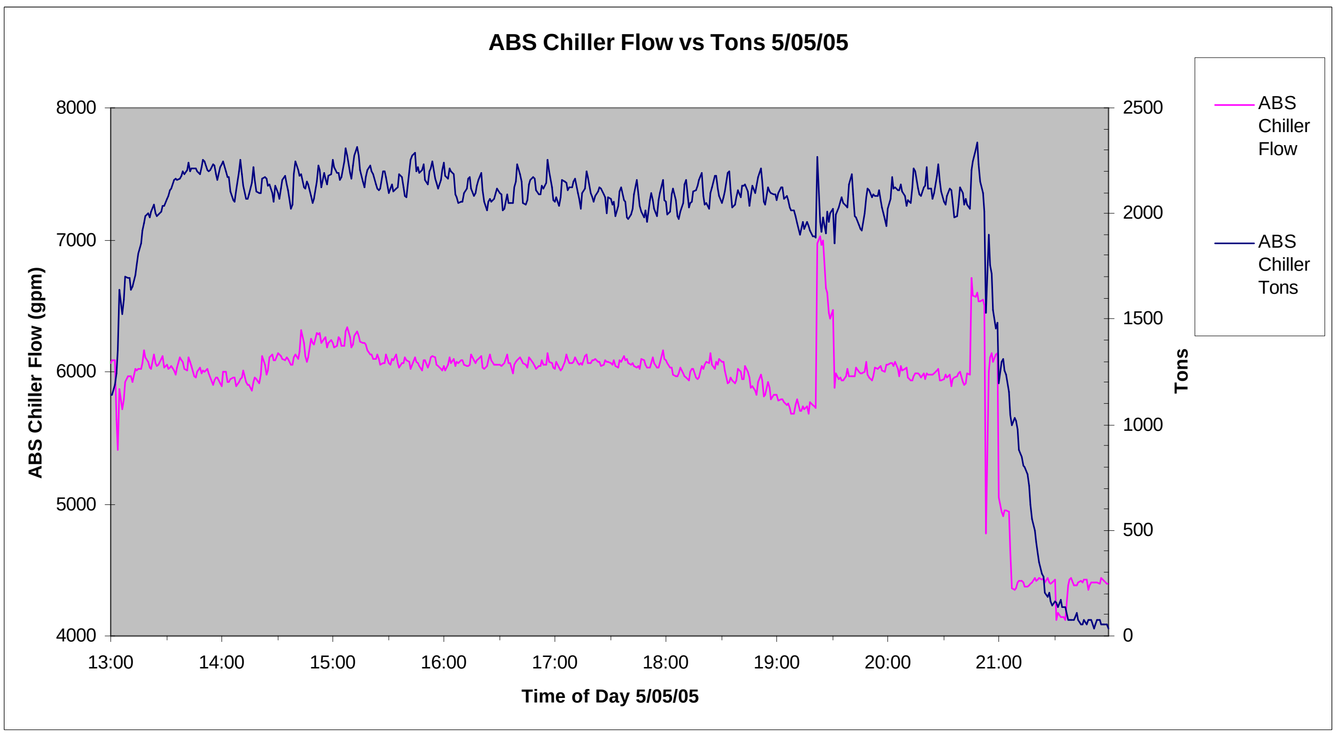

Figure 17 – ABS chilled water flow (gpm) and ABS tons versus time of day 05/05/05

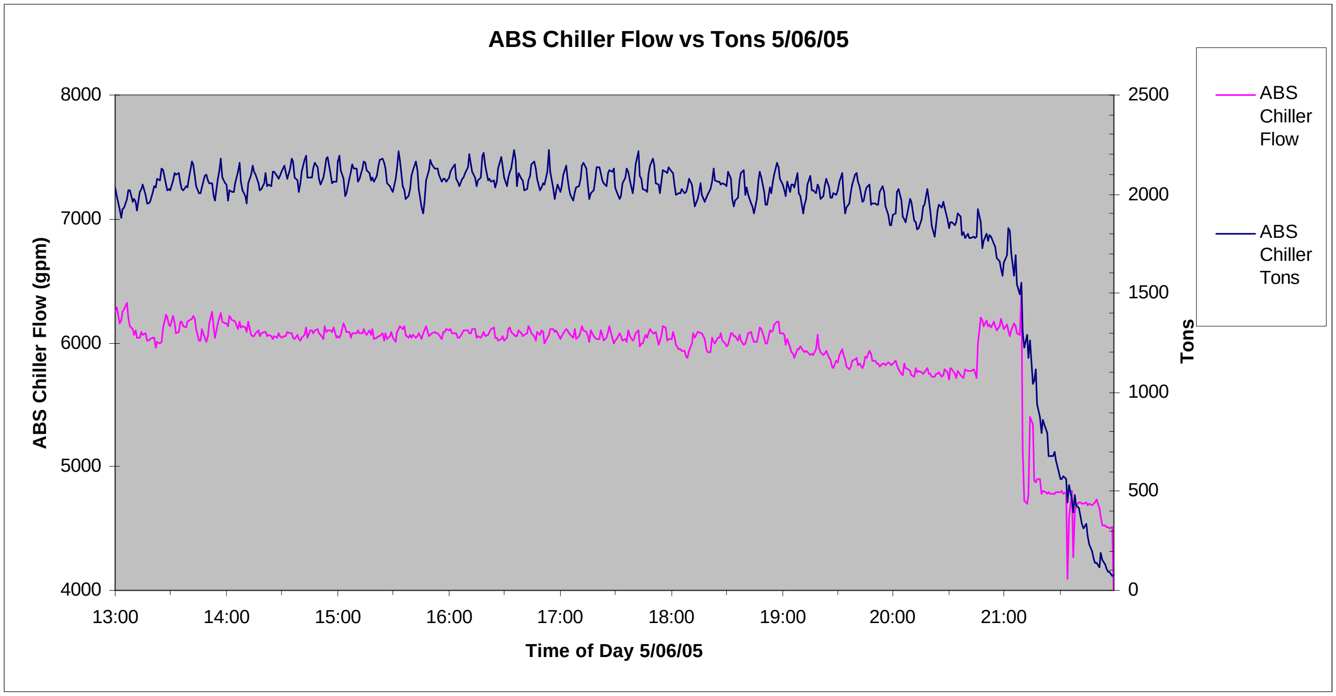

Figure 18 – ABS chiller water flow (gpm) and ABS tons versus time of day 05/06/05

The next set of data was taken on May 9-13. Figures 19-23 show the same relationship as the earlier graphs during the week of May 5.

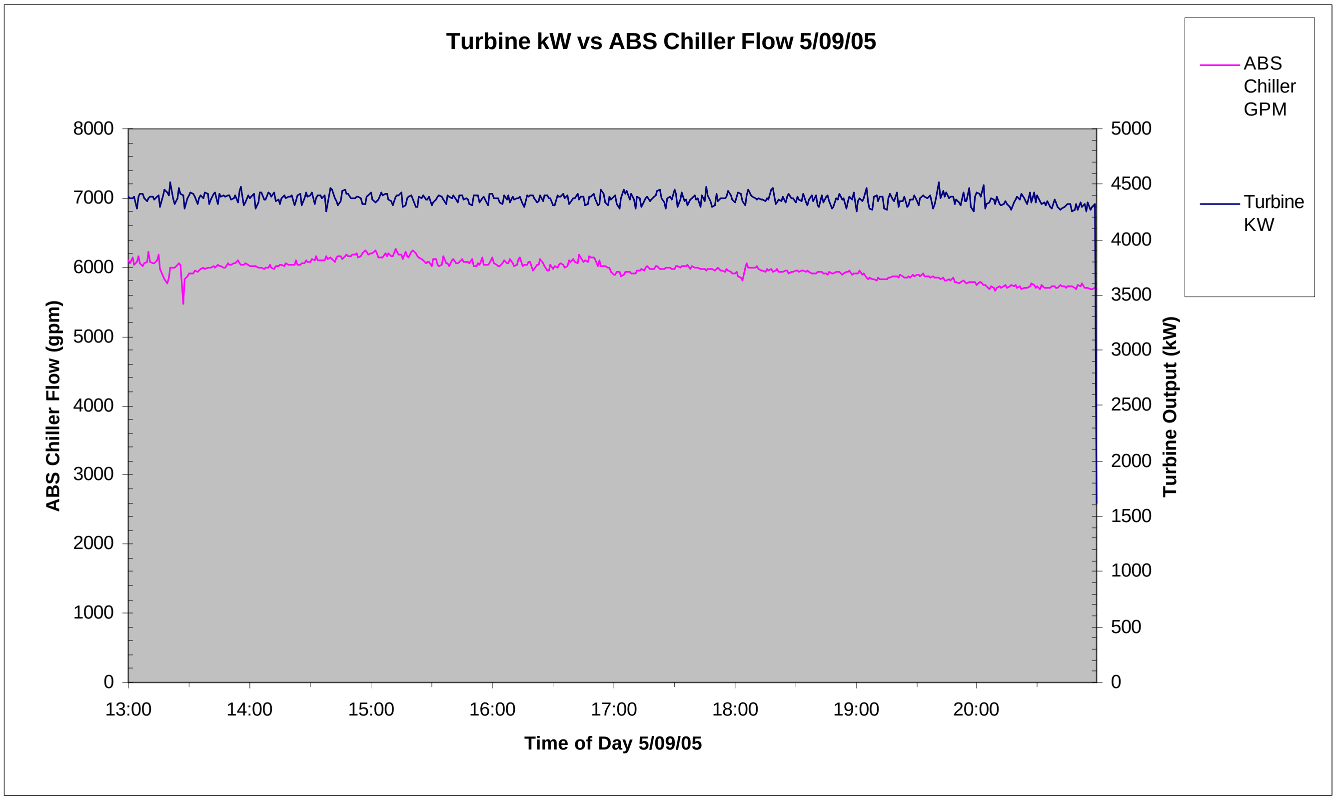

Figure 19 – Turbine kW output and ABS chilled water flow versus time of day 05/09/05

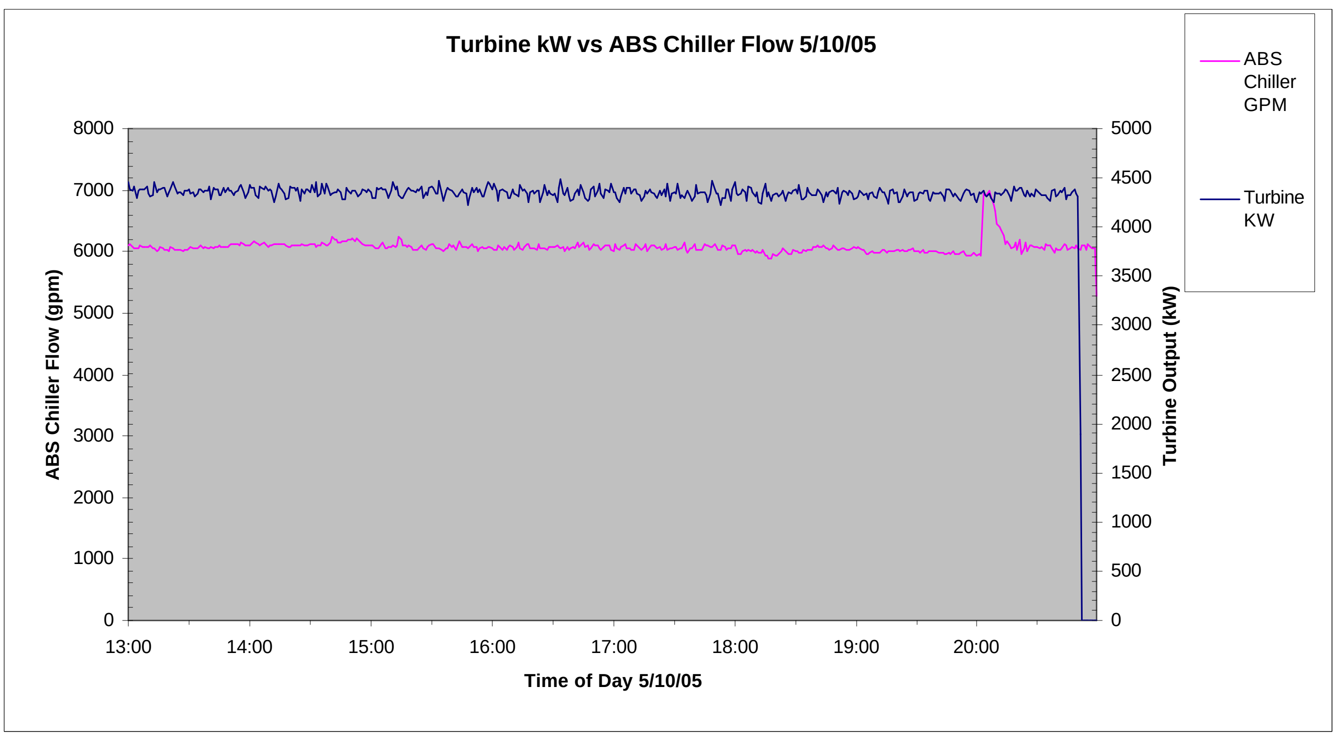

Figure 20 – Turbine kW output and ABS chilled water flow versus time of day 05/10/05

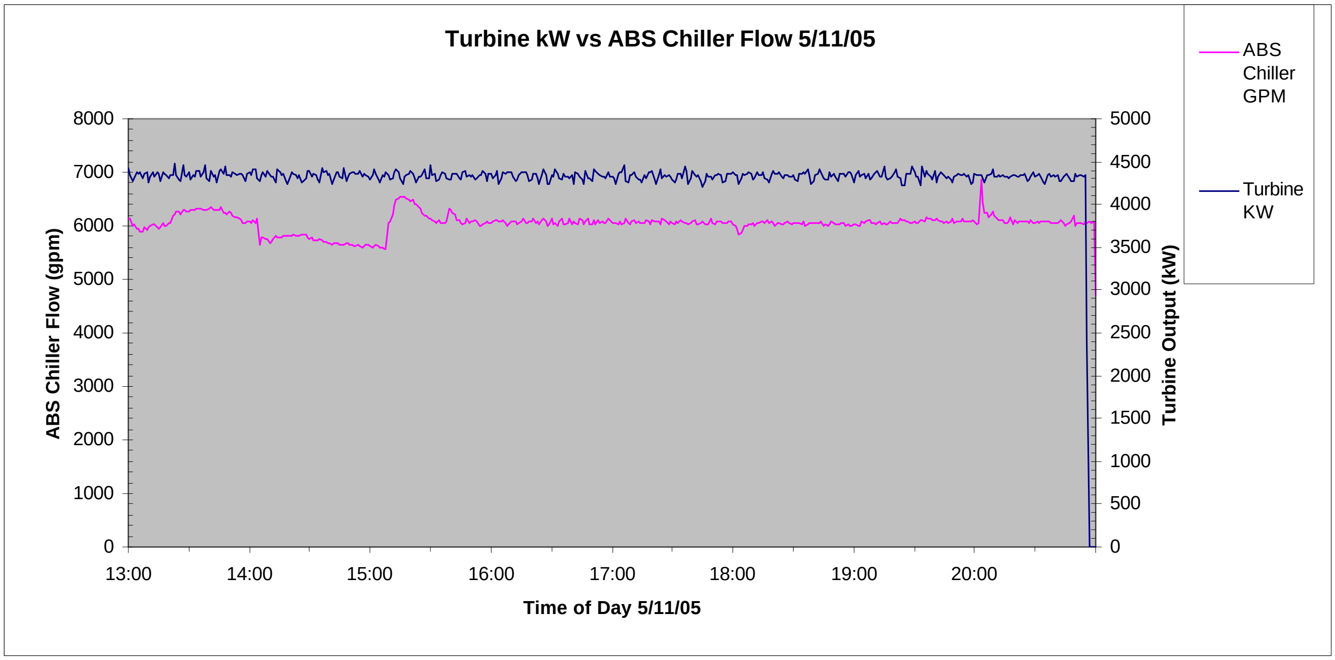

Figure 21 – Turbine kW output and ABS chilled water flow versus time of day 05/11/05

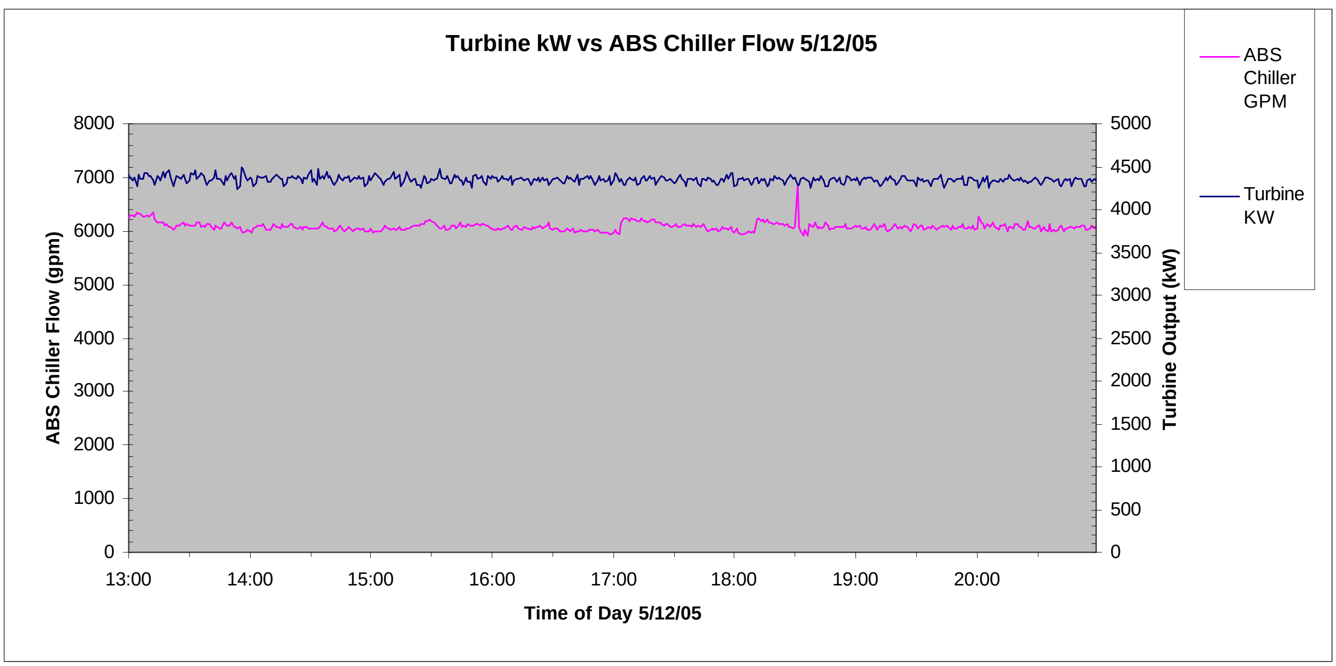

Figure 22 – Turbine kW output and ABS chilled water flow versus time of day 05/12/05

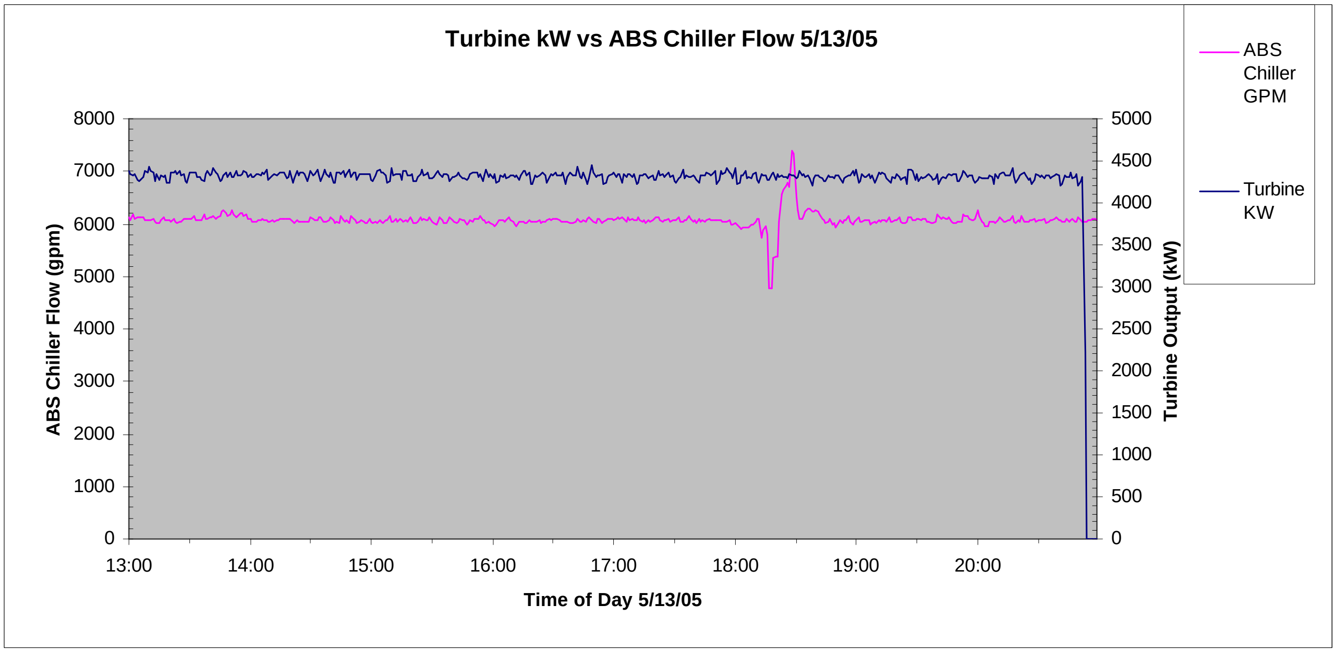

Figure 23 – Turbine kW output and ABS chilled water flow versus time of day 05/13/05

Figures 24 - 28 show the relationship between the turbine output and the inlet air temperature, based on use of inlet air cooling. This data shows the same relationship as the earlier May data did.

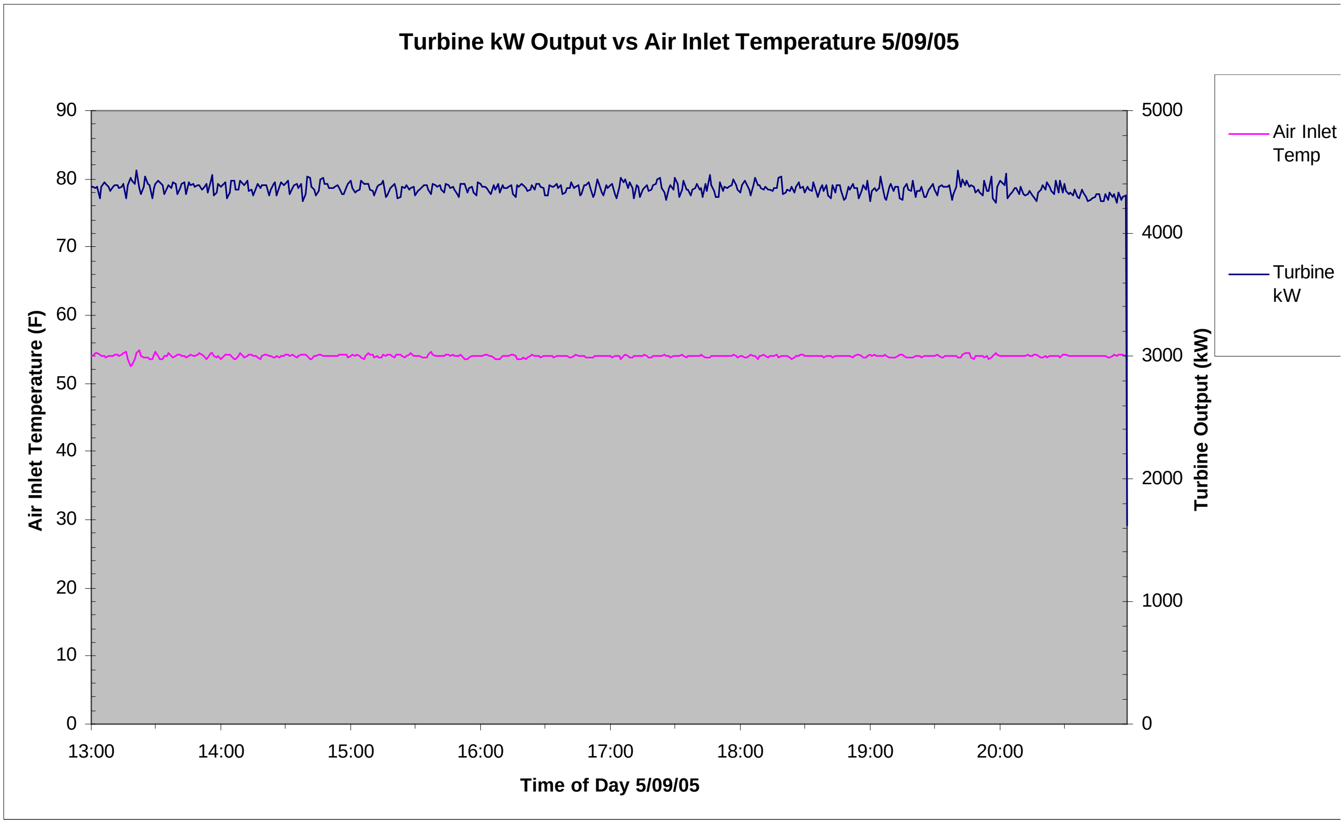

Figure 24 – Turbine kW output and air inlet temperature versus time of day 05/09/05

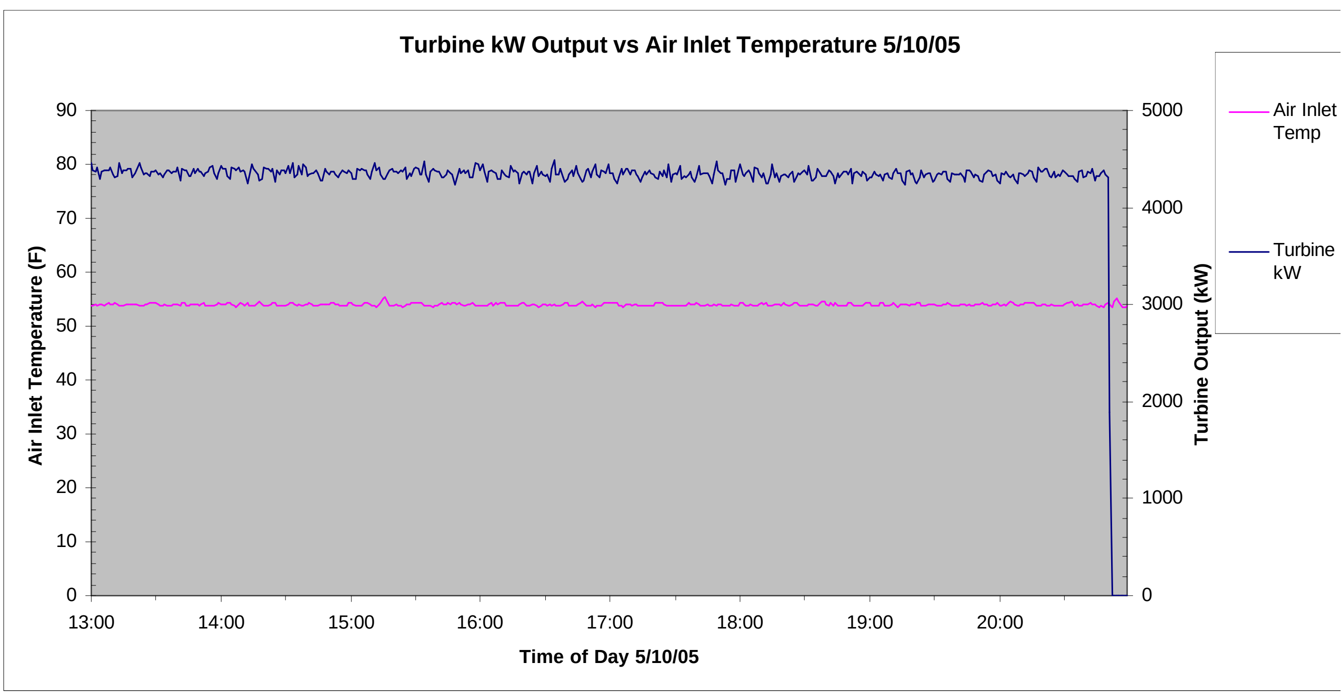

Figure 25 – Turbine kW output and air inlet temperature versus time of day 05/10/05

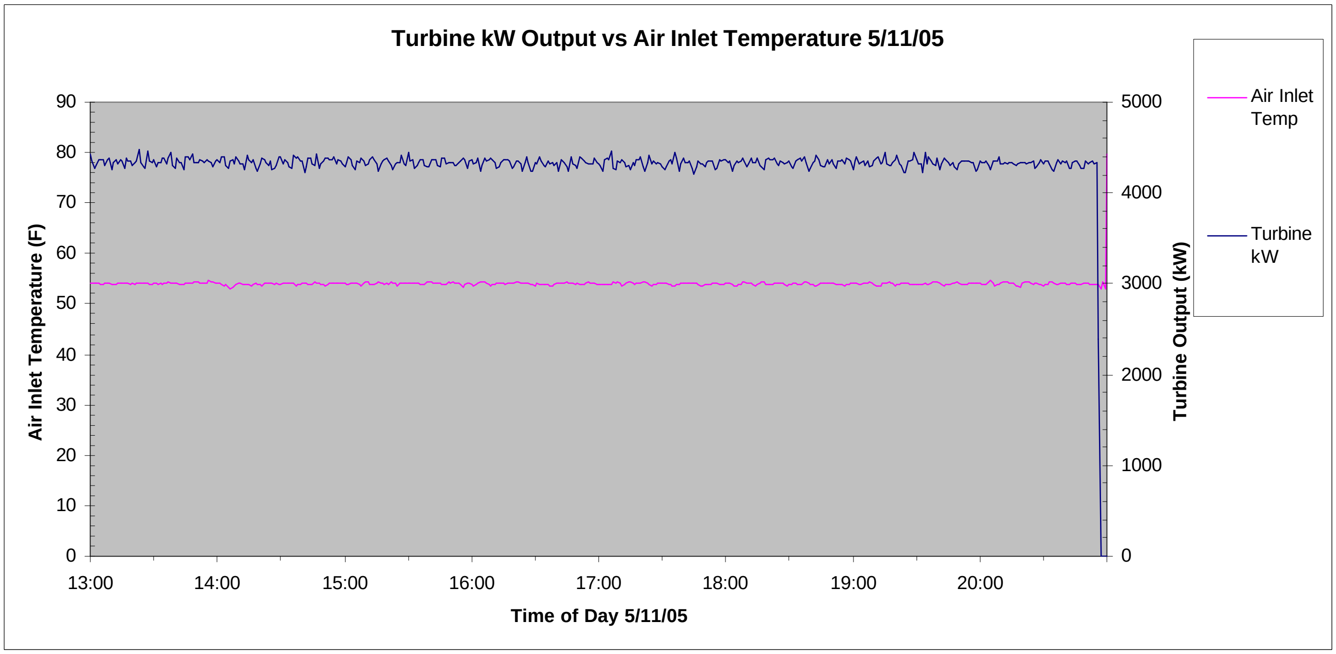

Figure 26 – Turbine kW output and air inlet temperature versus time of day 05/11/05

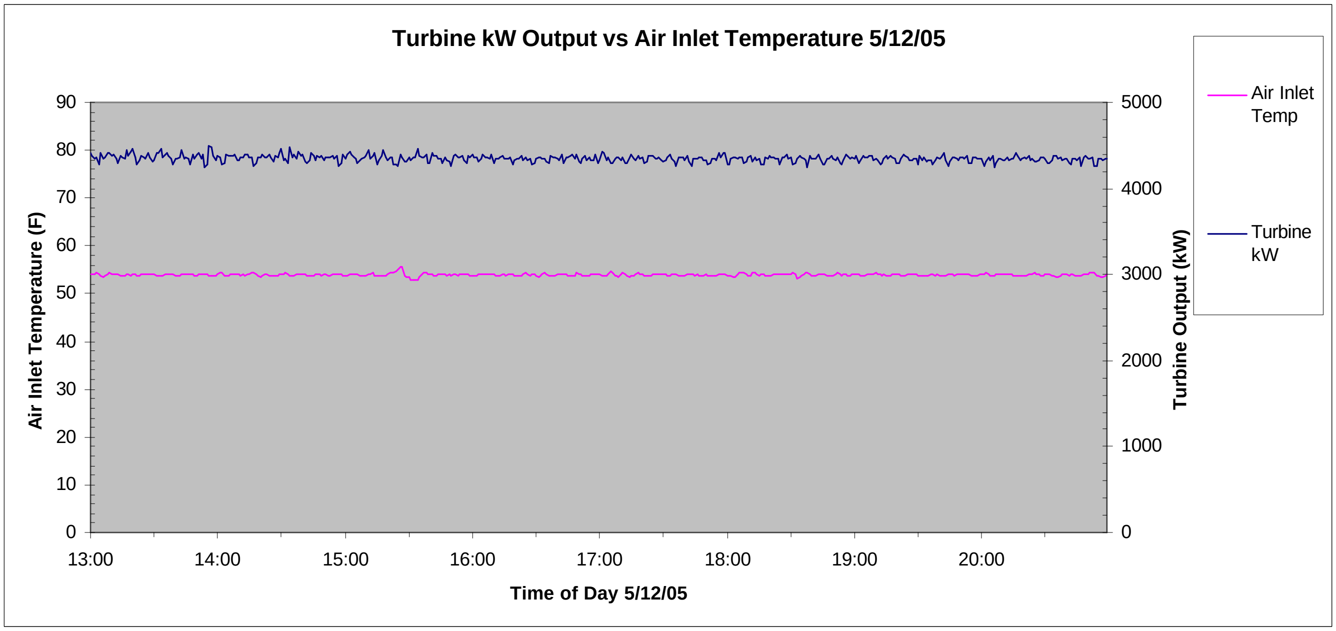

Figure 27 – Turbine kW output and air inlet temperature versus time of day 05/12/05

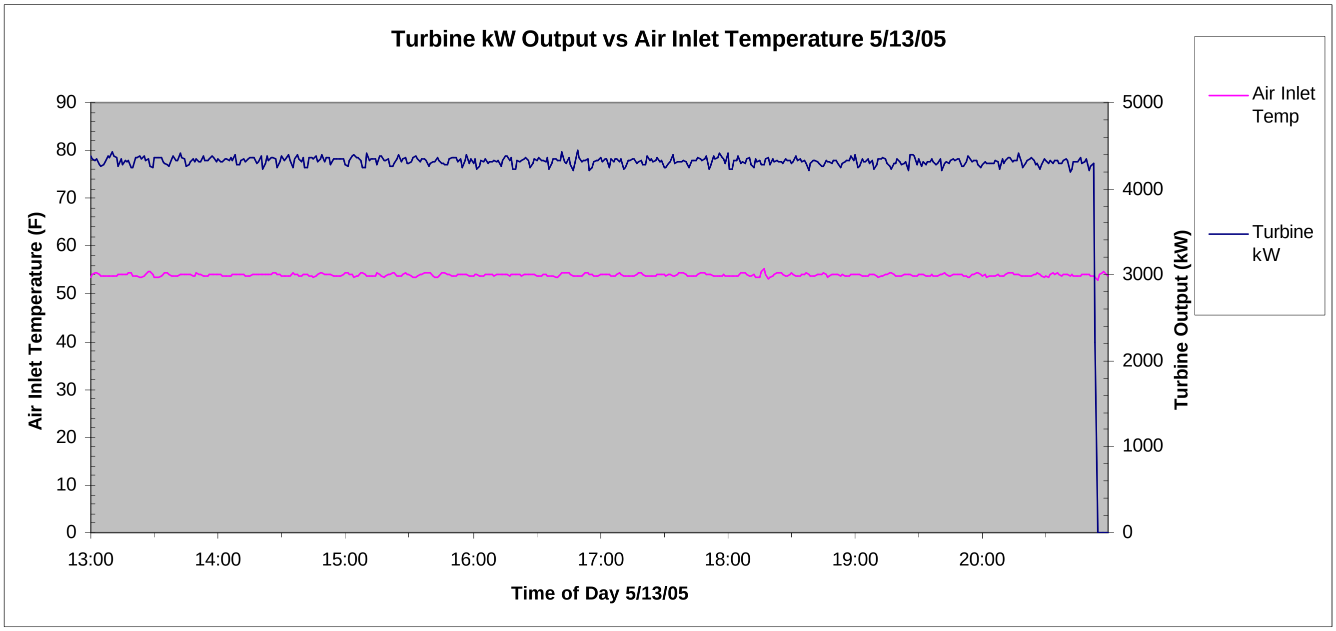

Figure 28 – Turbine kW output and air inlet temperature versus time of day 05/13/05

Figures 29 – 33 show the correlation between the turbine output kW and the ABS chiller tons. All of these graphs and those from earlier in May, show that the ABS tons did not vary more than approximately 50 tons even with a turbine output kW variation of between 500 to 1000 kW. The significant decrease in ABS tons on 5/9/05 (Figure 29) is likely due to a decrease in the site chilling load and is not reflective of any system degradation.

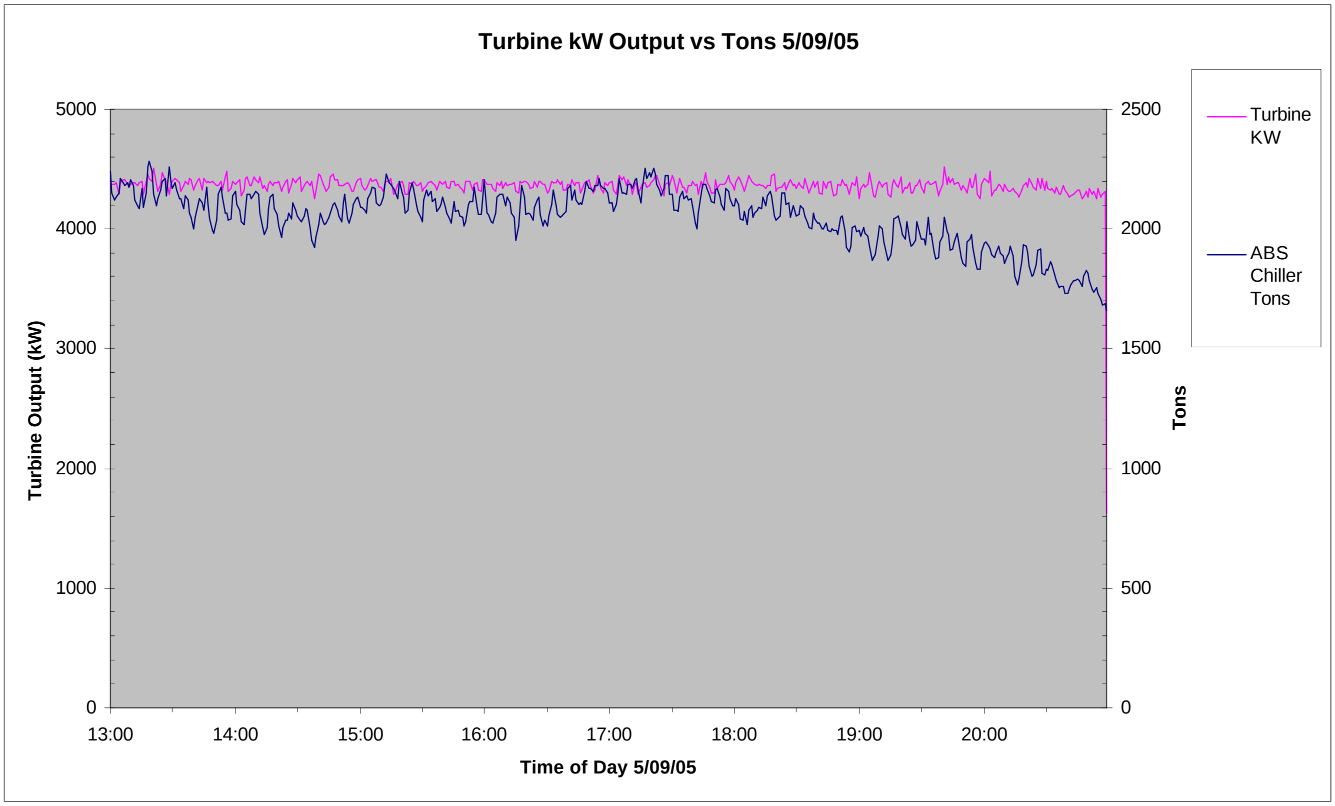

Figure 29 – Turbine output kW and ABS tons versus time of day 05/09/05

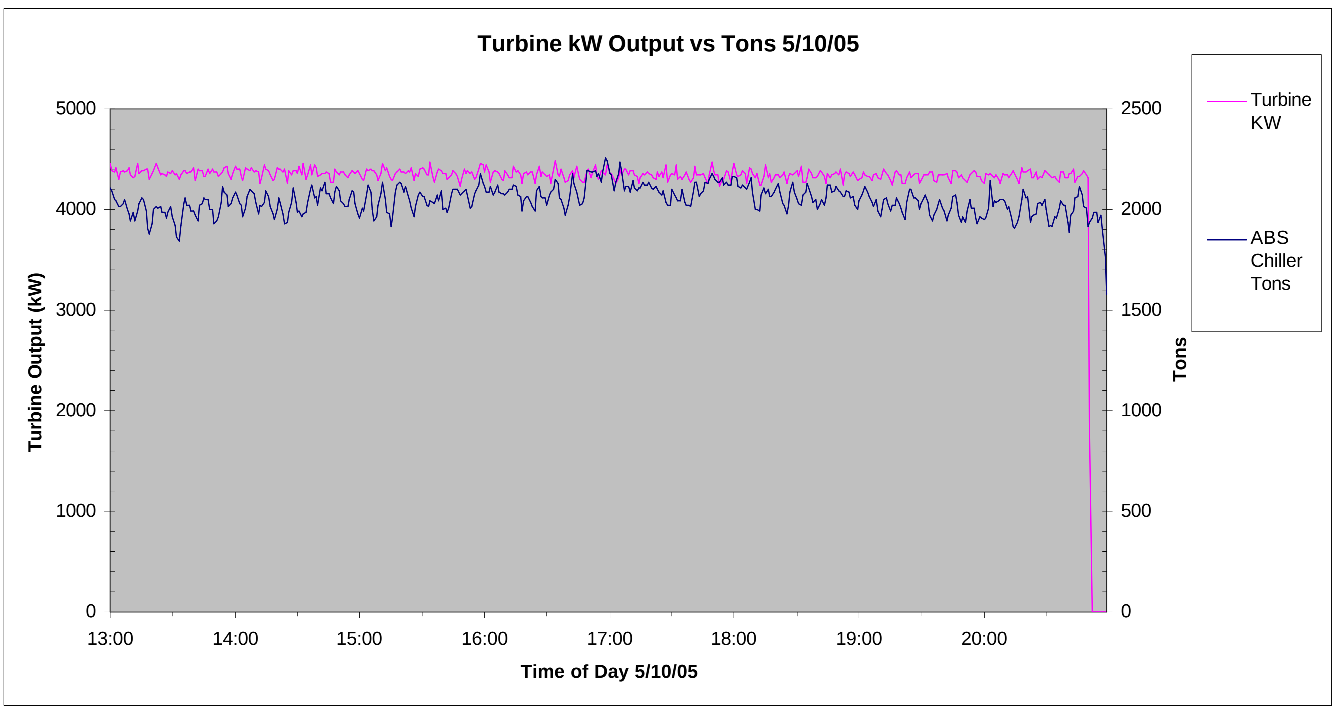

Figure 30 – Turbine output kW and ABS tons versus time of day 05/10/05

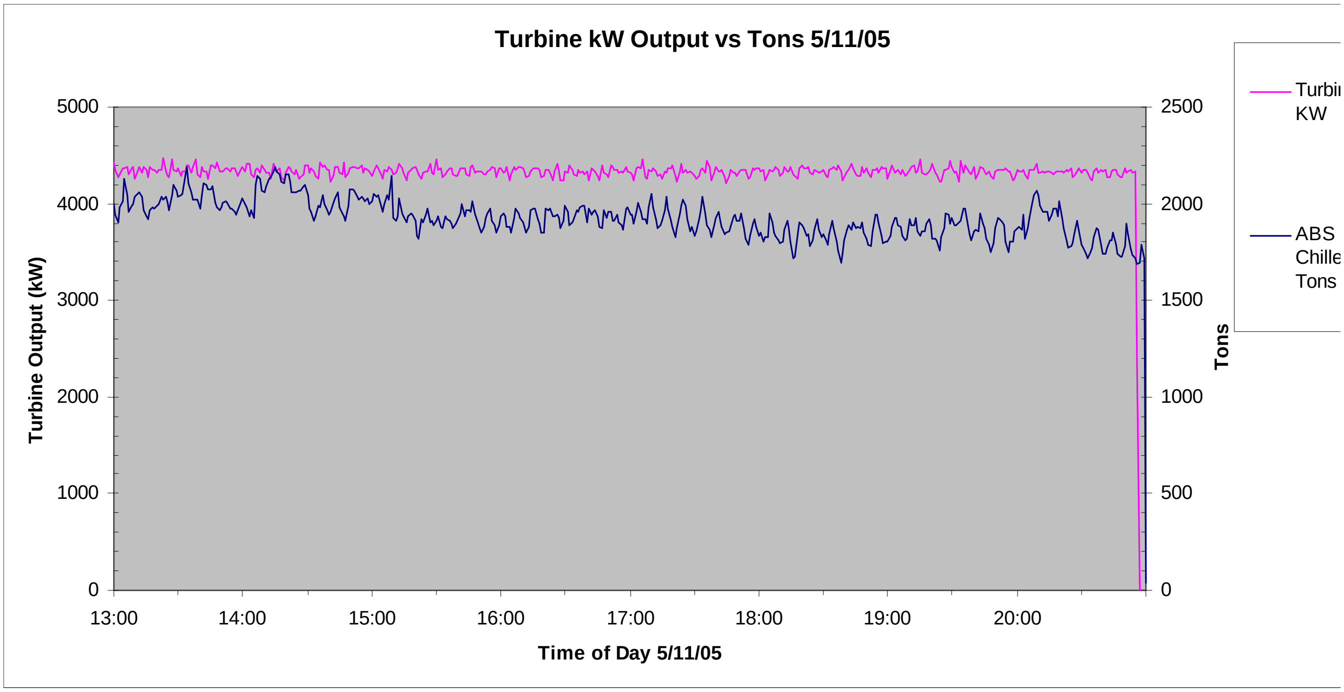

Figure 31 – Turbine output kW and ABS tons versus time of day 05/11/05

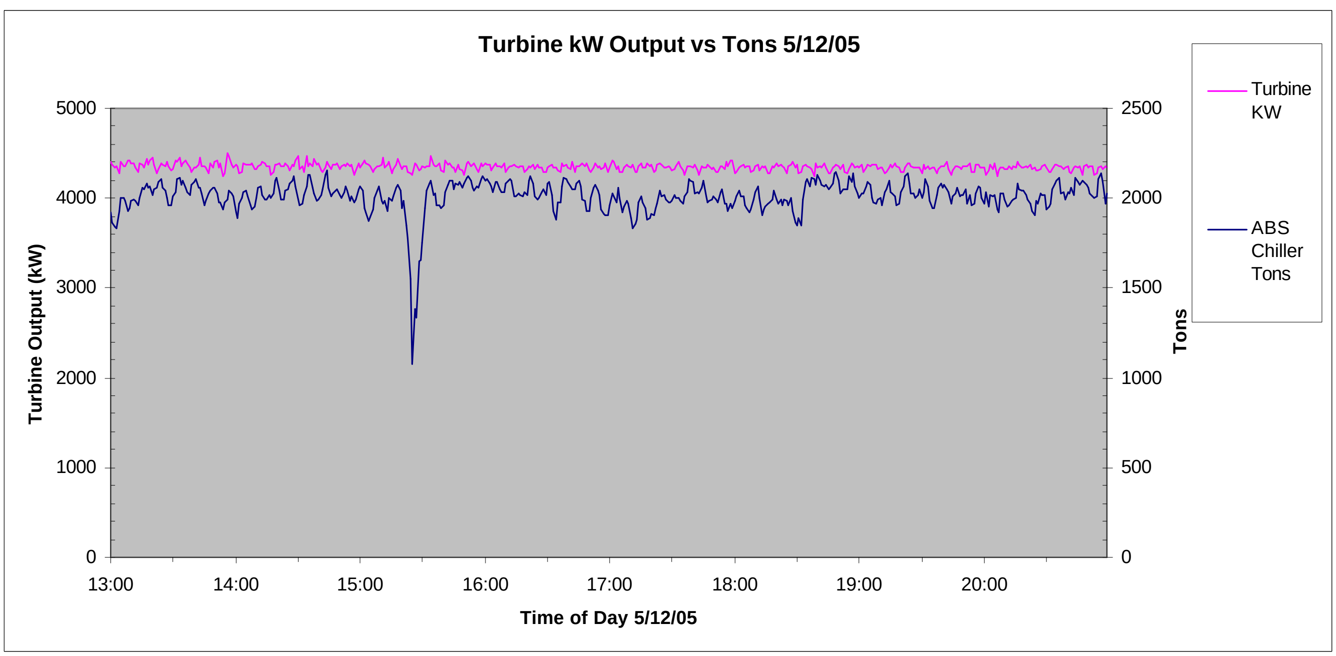

Figure 32 – Turbine output kW and ABS tons versus time of day 05/12/05

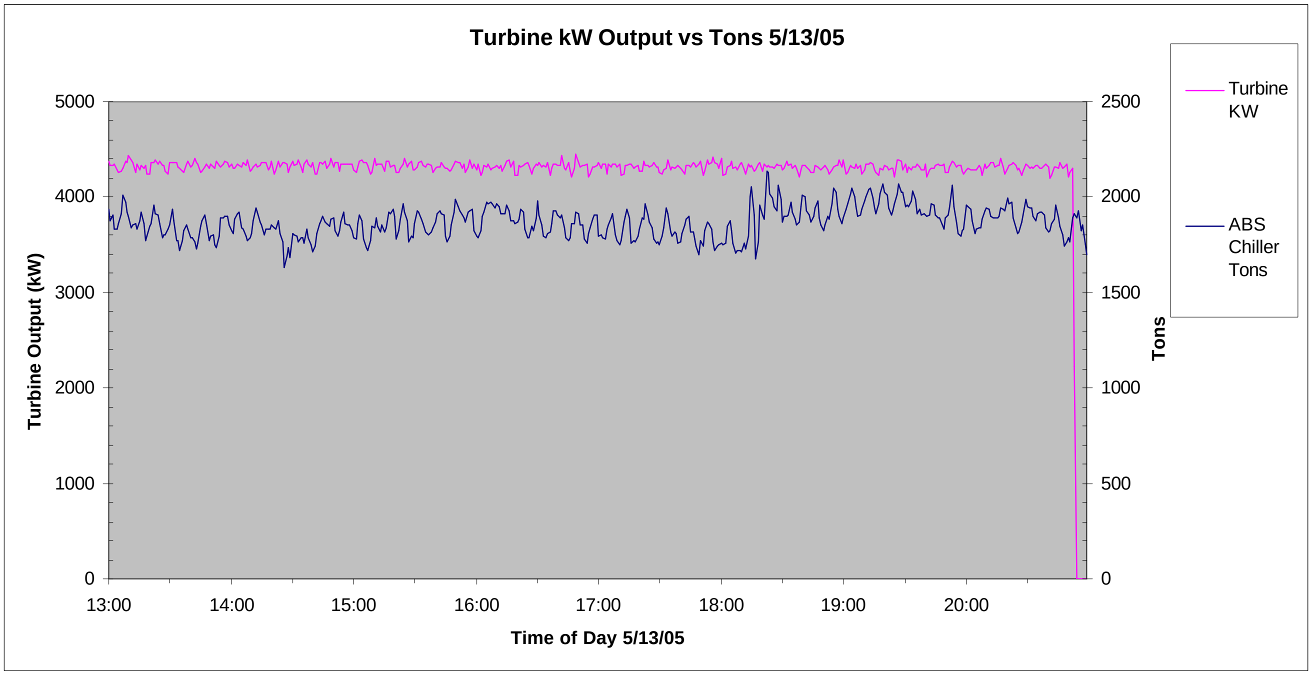

Figure 33 – Turbine output kW and ABS tons versus time of day 05/13/05

Figures 34-38 show the relationship between the turbine exhaust temperature and the chilled water tons from the ABS chiller. During the operational time period from 1 p.m. to 9 p.m., the turbine was operated at full load, so the exhaust temperature should have been, and was observed to be fairly constant at about 945 to 951 F. The ABS tons varied by about 200 tons during this same time frame, with the tons decreasing in the last hour.

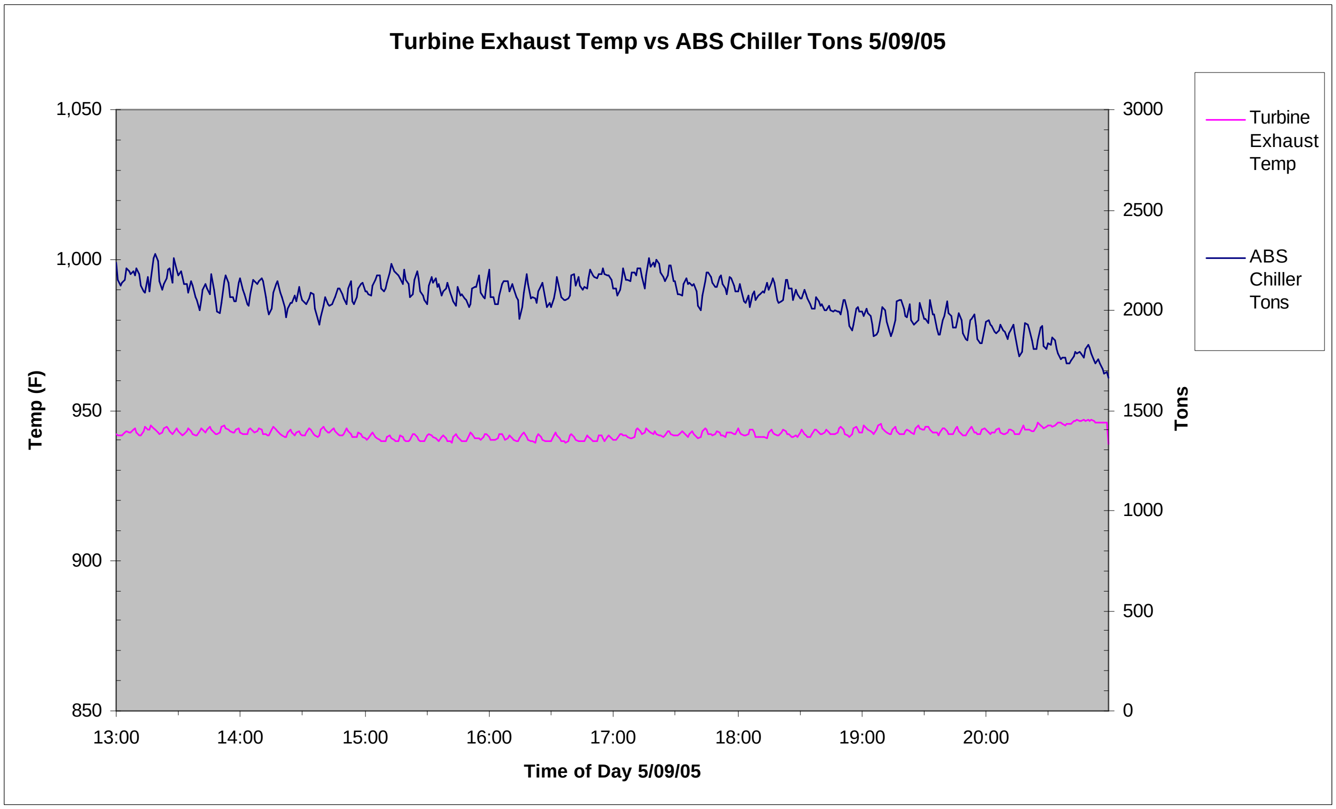

Figure 34 – Turbine exhaust temperature and ABS tons versus time of day 05/09/05

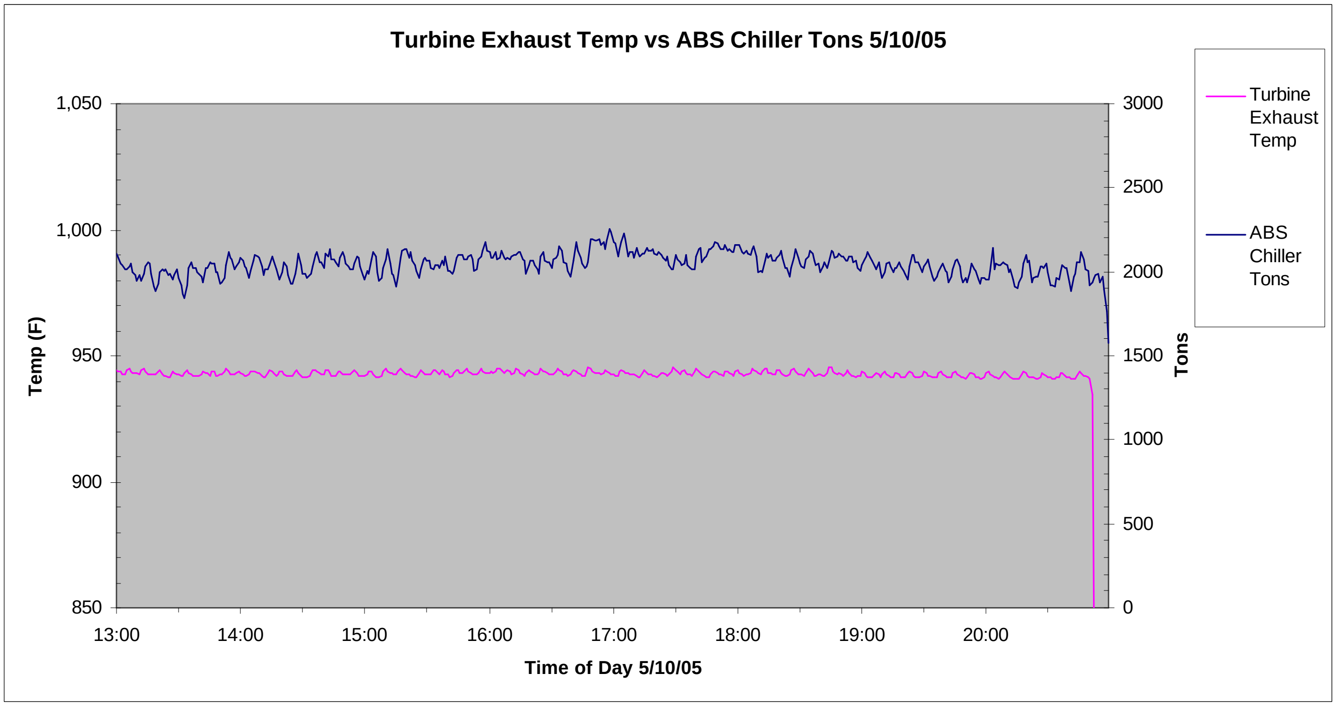

Figure 35 – Turbine exhaust temperature and ABS tons versus time of day 05/10/05

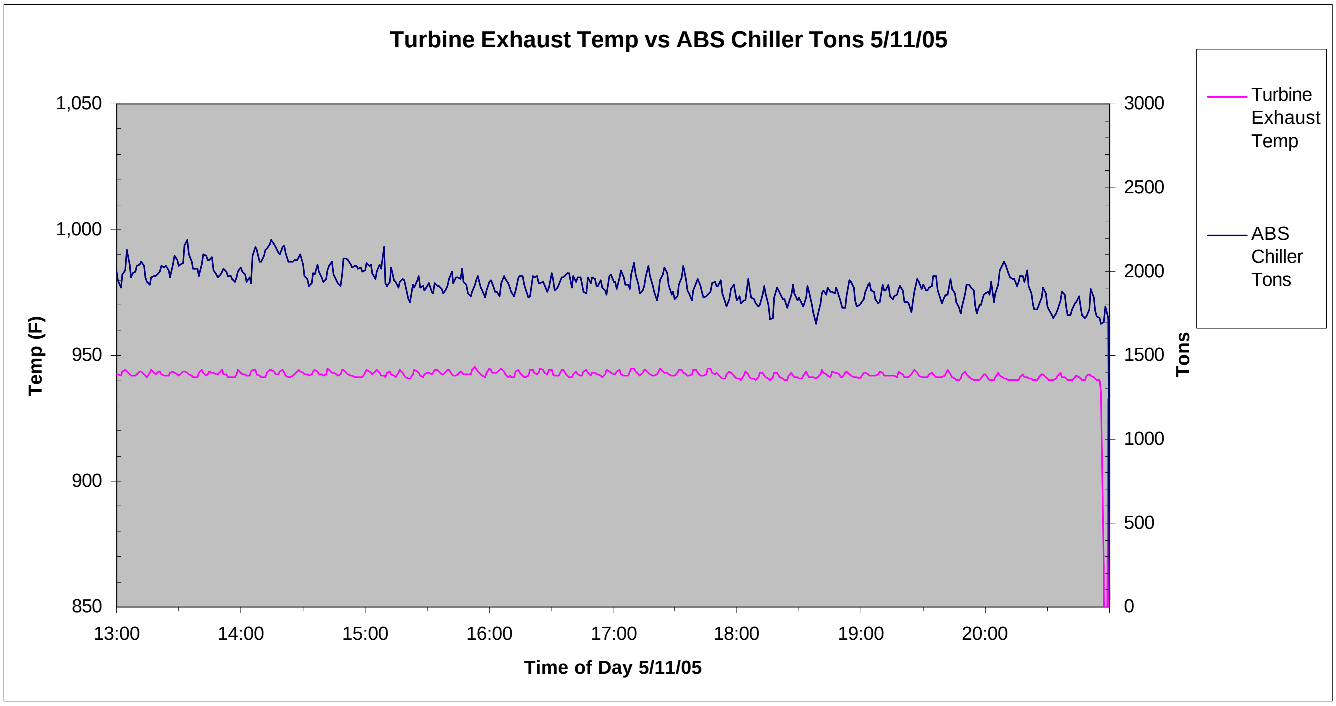

Figure 36 – Turbine exhaust temperature and ABS tons versus time of day 05/11/05

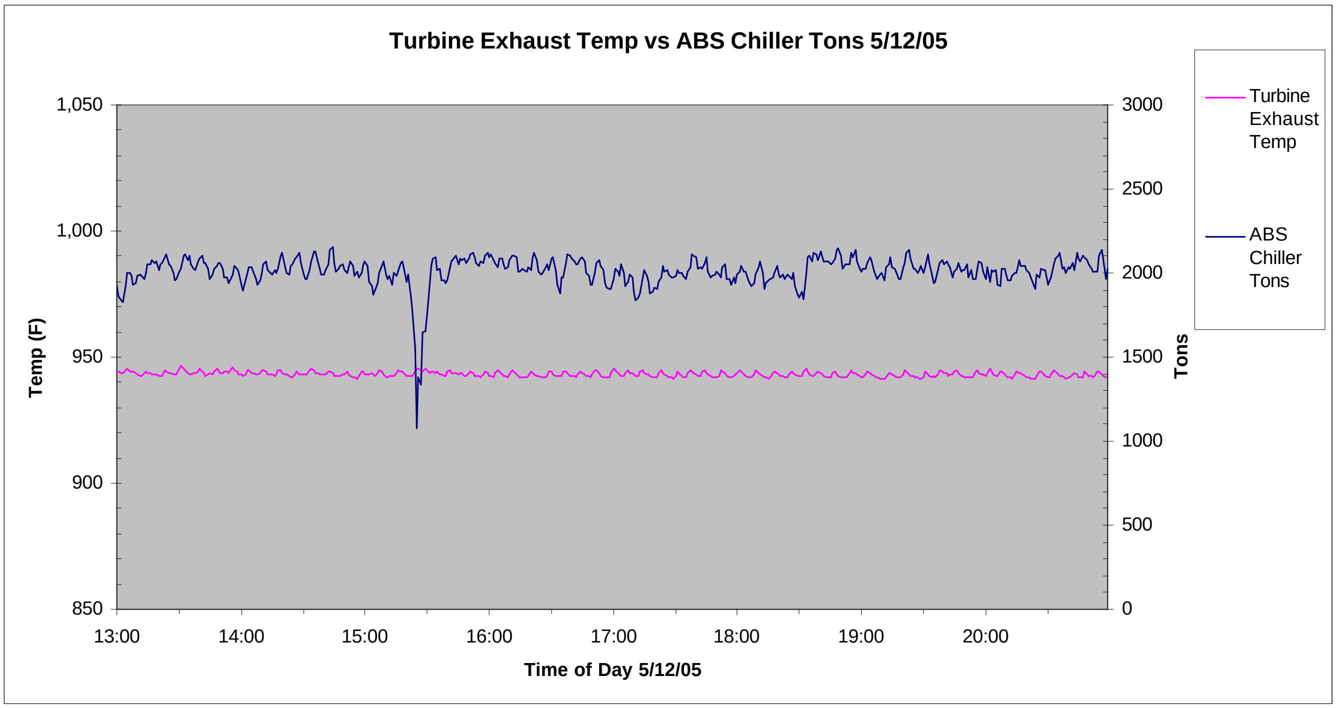

Figure 37 – Turbine exhaust temperature and ABS tons versus time of day 05/12/05

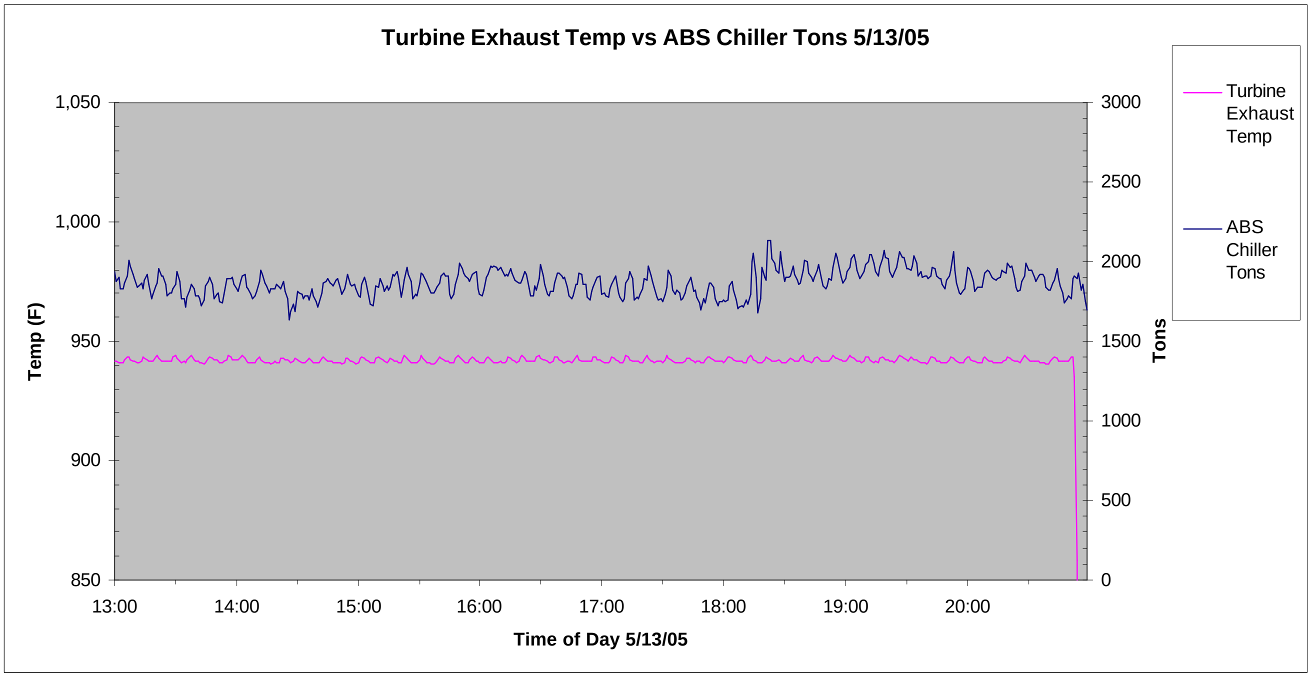

Figure 38 – Turbine exhaust temperature and ABS tons versus time of day 05/13/05

Figures 39 – 43 show that the relationship between turbine exhaust temperature and inlet air temperature is essentially a constant over the time period. This was expected as the turbine was run at full load and, with inlet air cooling, the turbine inlet air temperature did not change.

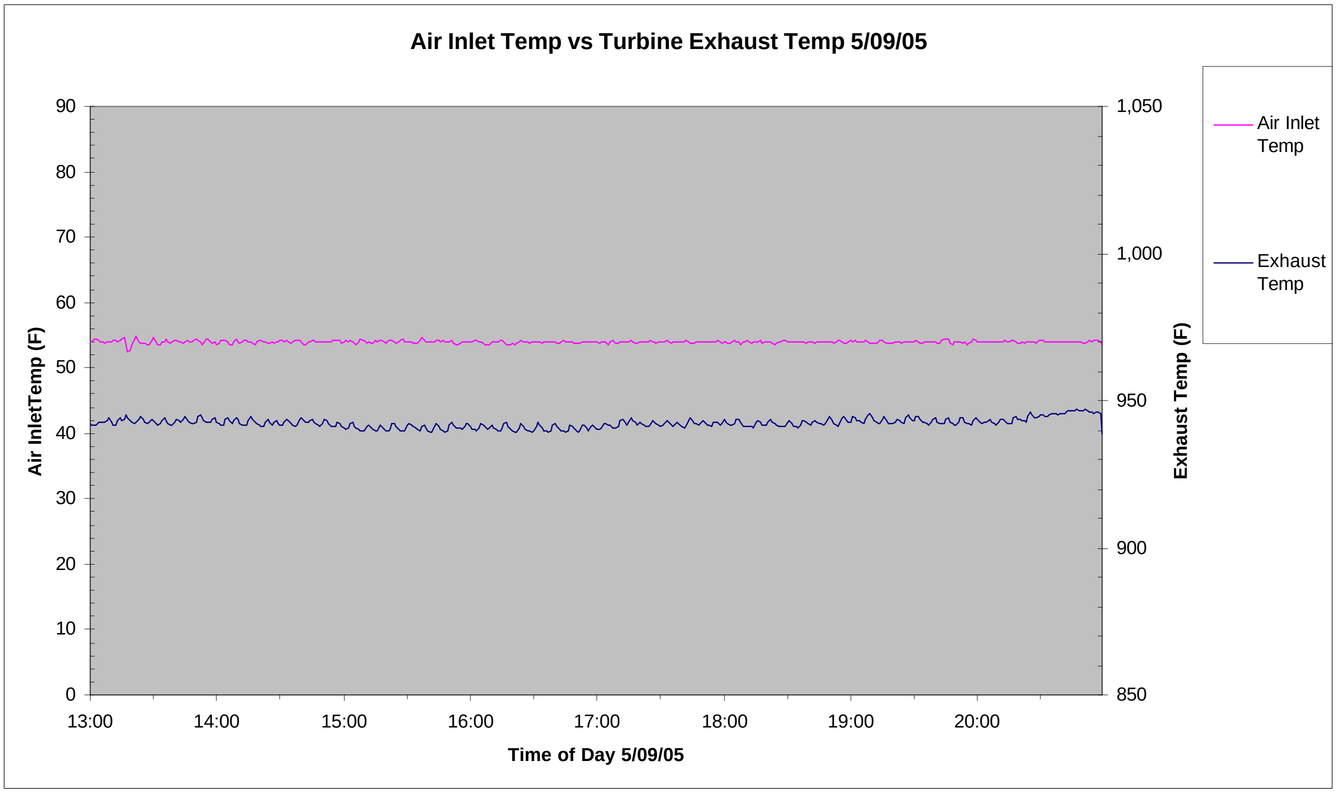

Figure 39 – Turbine exhaust and air inlet temperatures versus time of day 05/09/05

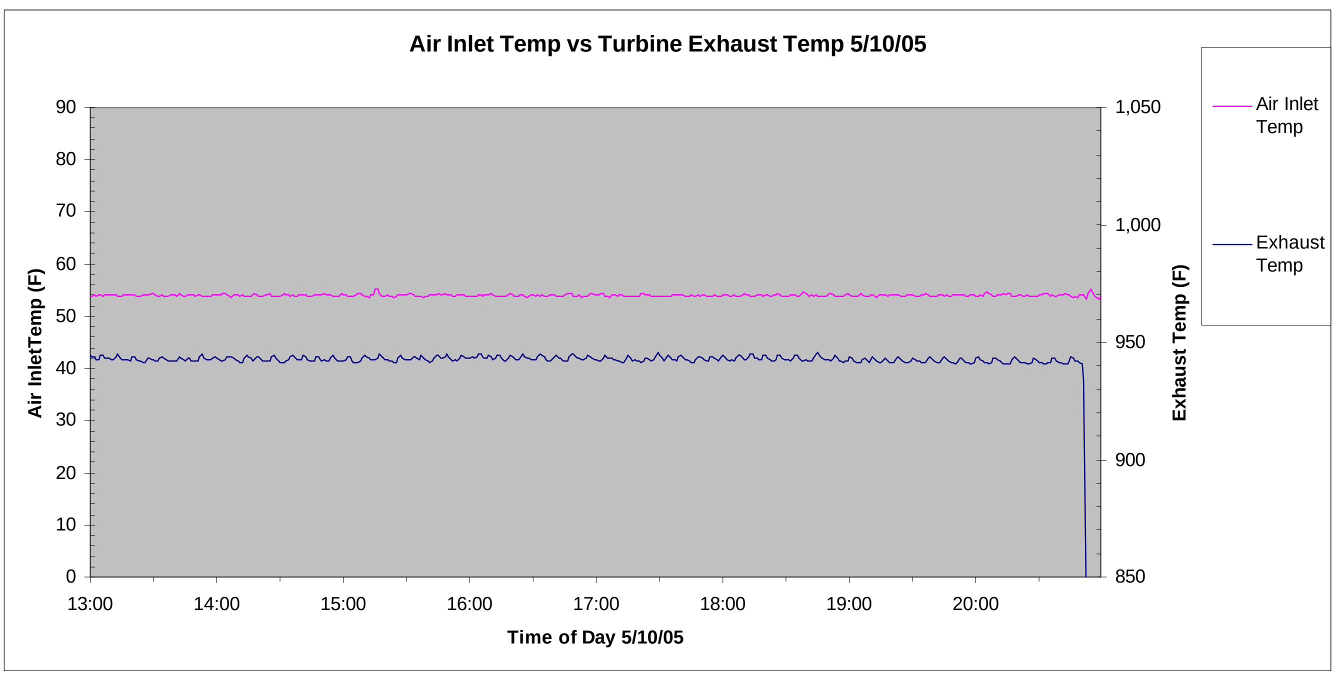

Figure 40 – Turbine exhaust and air inlet temperatures versus time of day 05/10/05

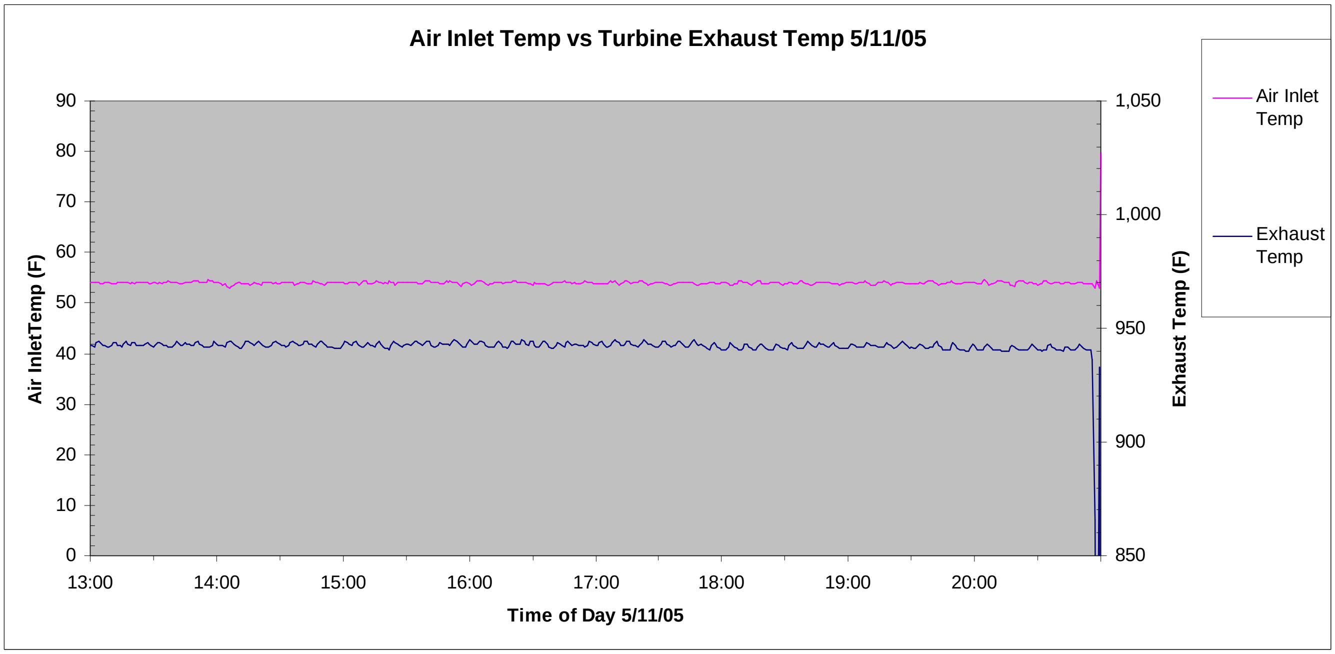

Figure 41 – Turbine exhaust and air inlet temperatures versus time of day 05/11/05

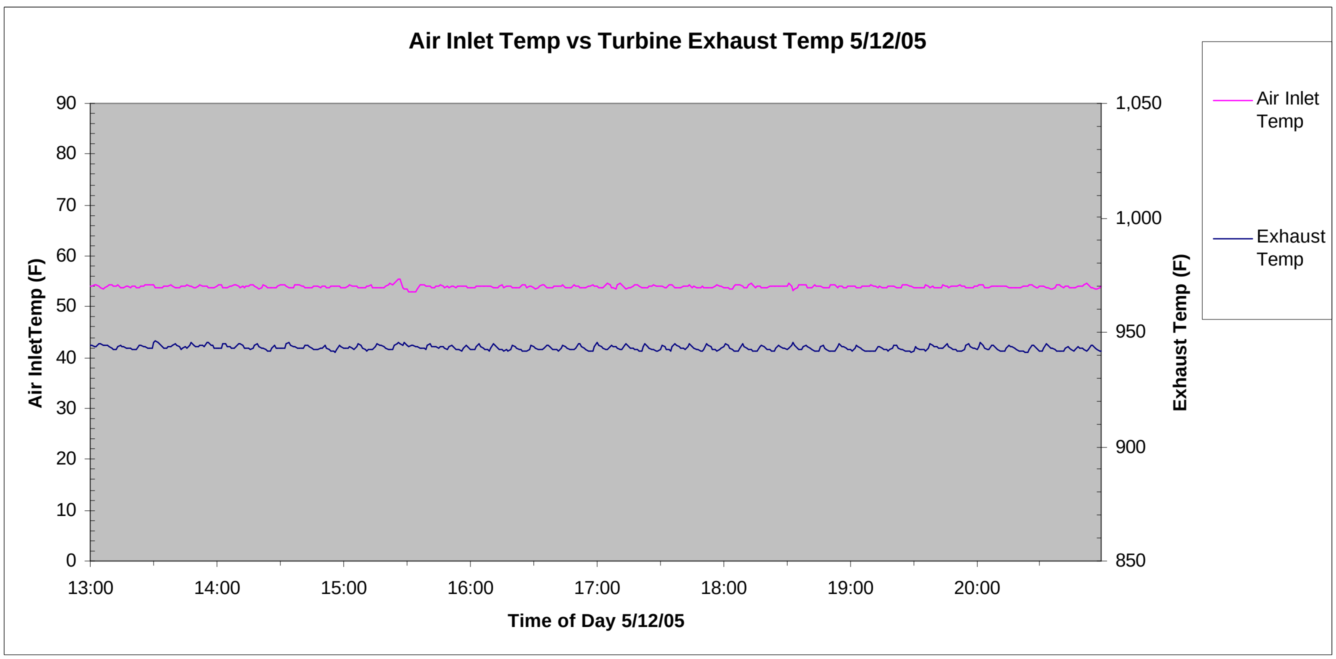

Figure 42 – Turbine exhaust and air inlet temperatures versus time of day 05/12/05

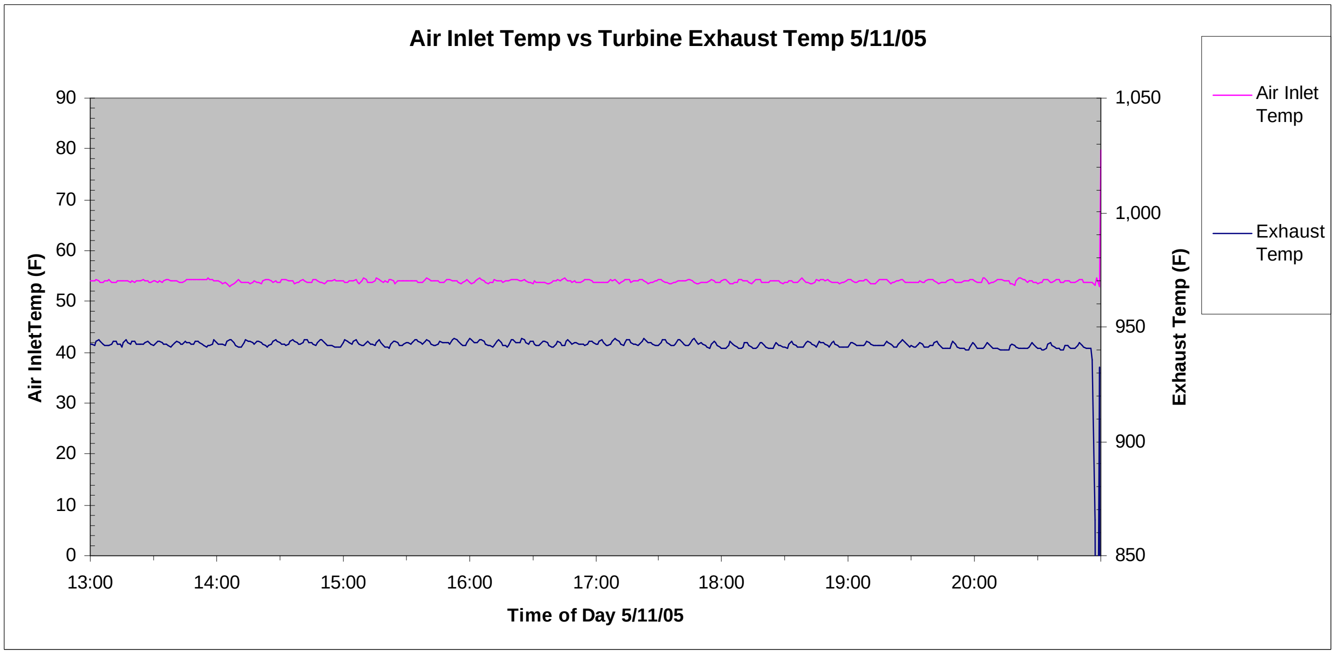

Figure 43 – Turbine exhaust and air inlet temperatures versus time of day 05/13/05

Figures 44 – 48 show that if the chilled water flow rate remained essentially constant, then the ABS chiller tons followed the chilled water pattern, but with a wider variation of approximately 100 plus tons.

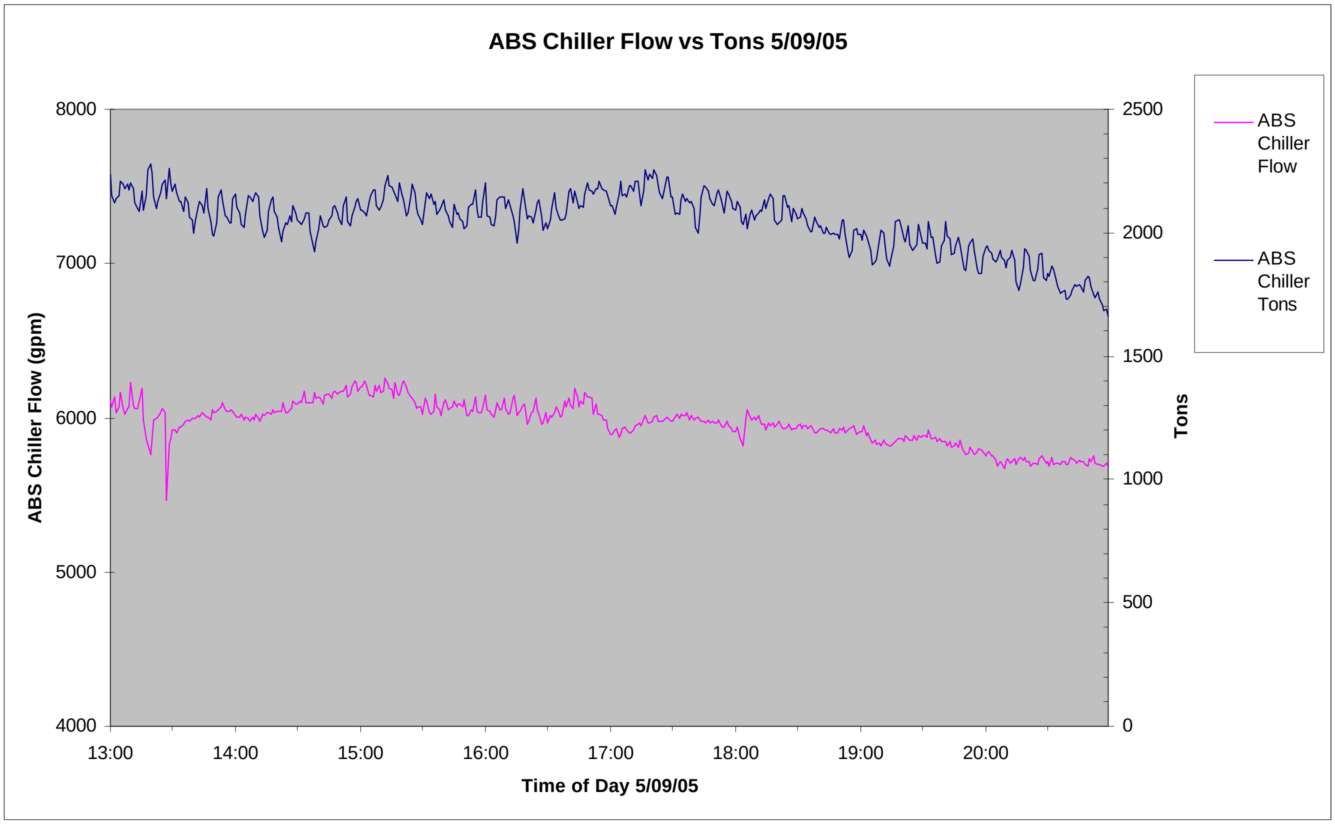

Figure 44 – ABS chilled water flow and ABS tons versus time of day 05/09/05

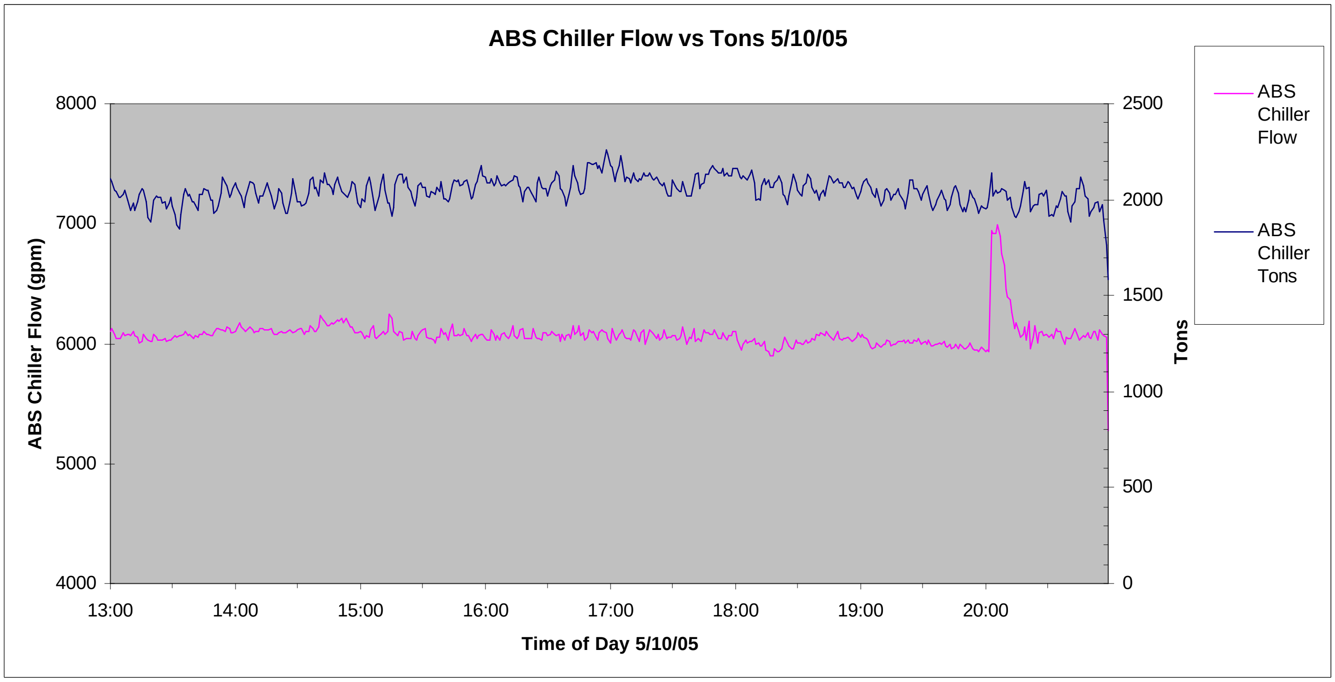

Figure 45 – ABS chilled water flow and ABS tons versus time of day 05/10/05

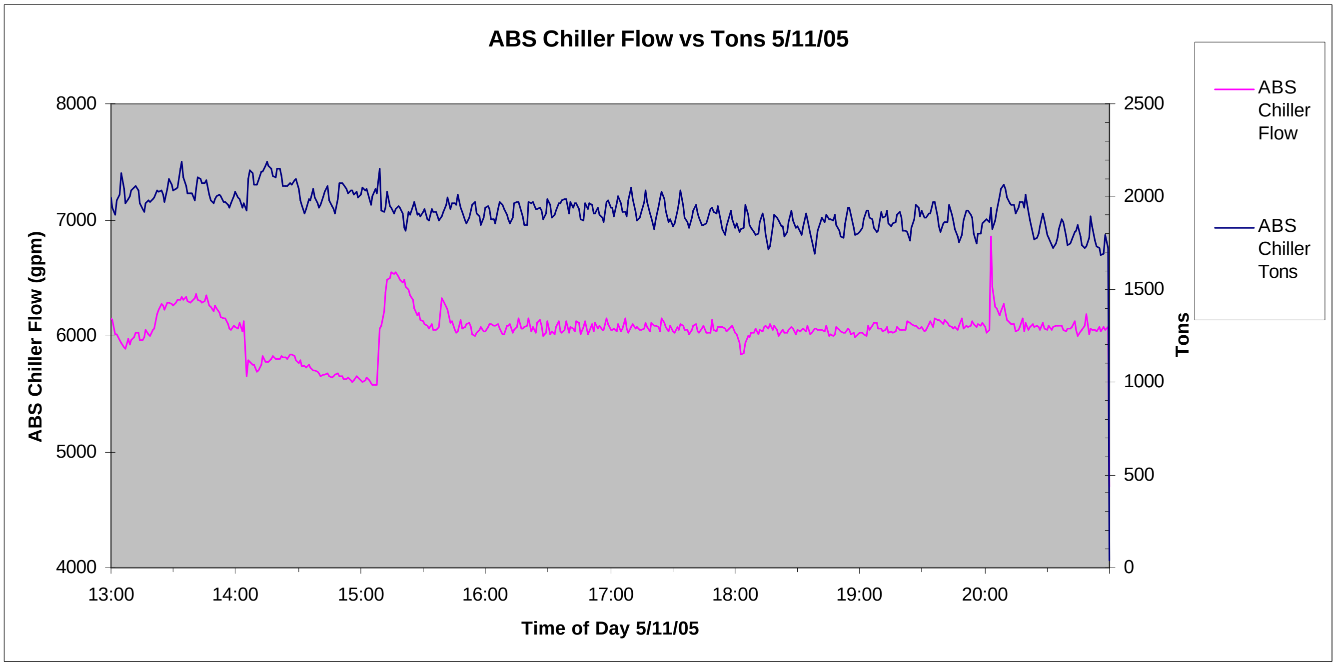

Figure 46 – ABS chilled water flow and ABS tons versus time of day 05/11/05

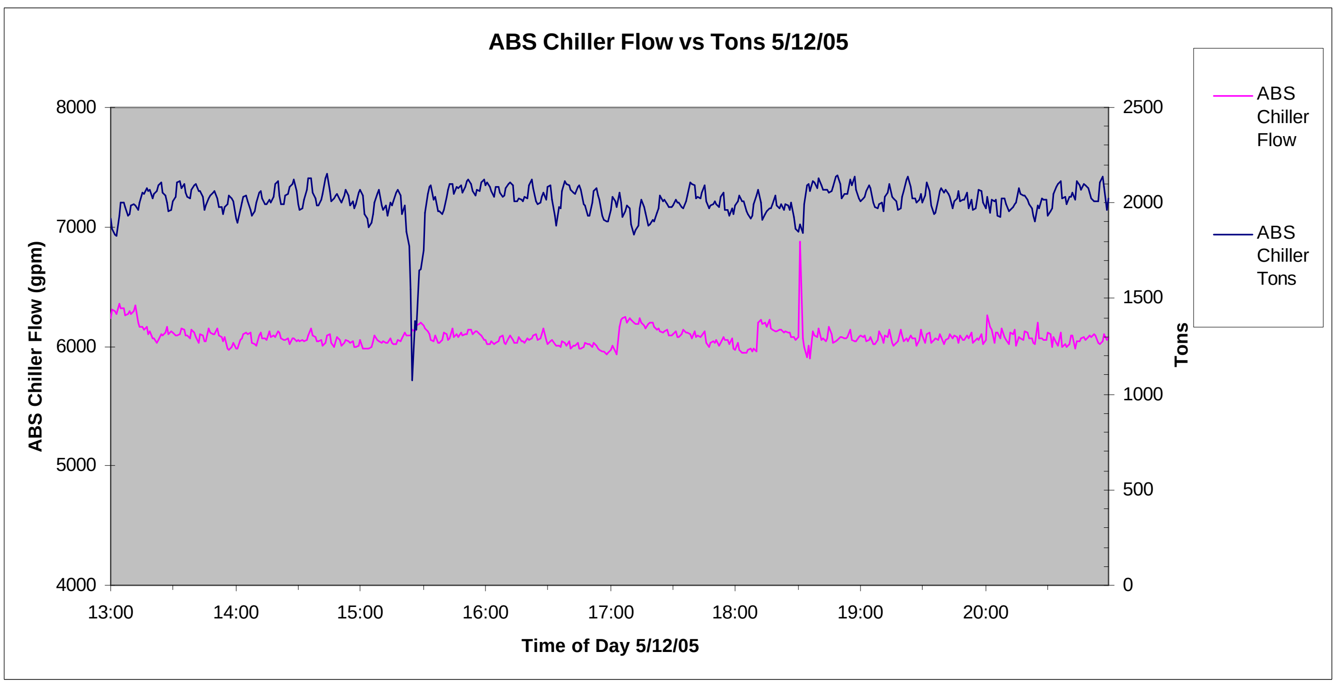

Figure 47 – ABS chilled water flow and ABS tons versus time of day 05/12/05

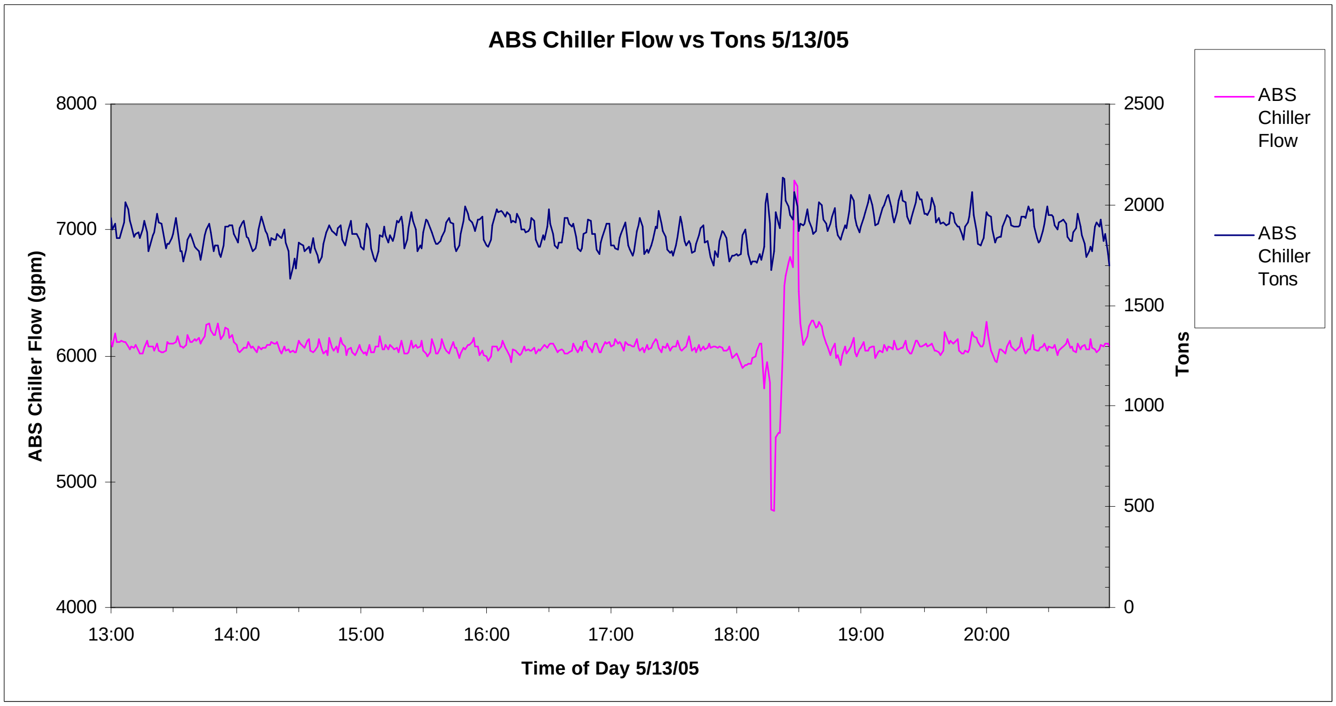

Figure 48 – ABS chilled water flow and ABS tons versus time of day 05/13/05

Figures 49 – 53 show the relationship between ambient air temperature and the turbine exhaust temperature. As indicated the turbine exhaust temperature does not have any direct relationship to the ambient air temperature.

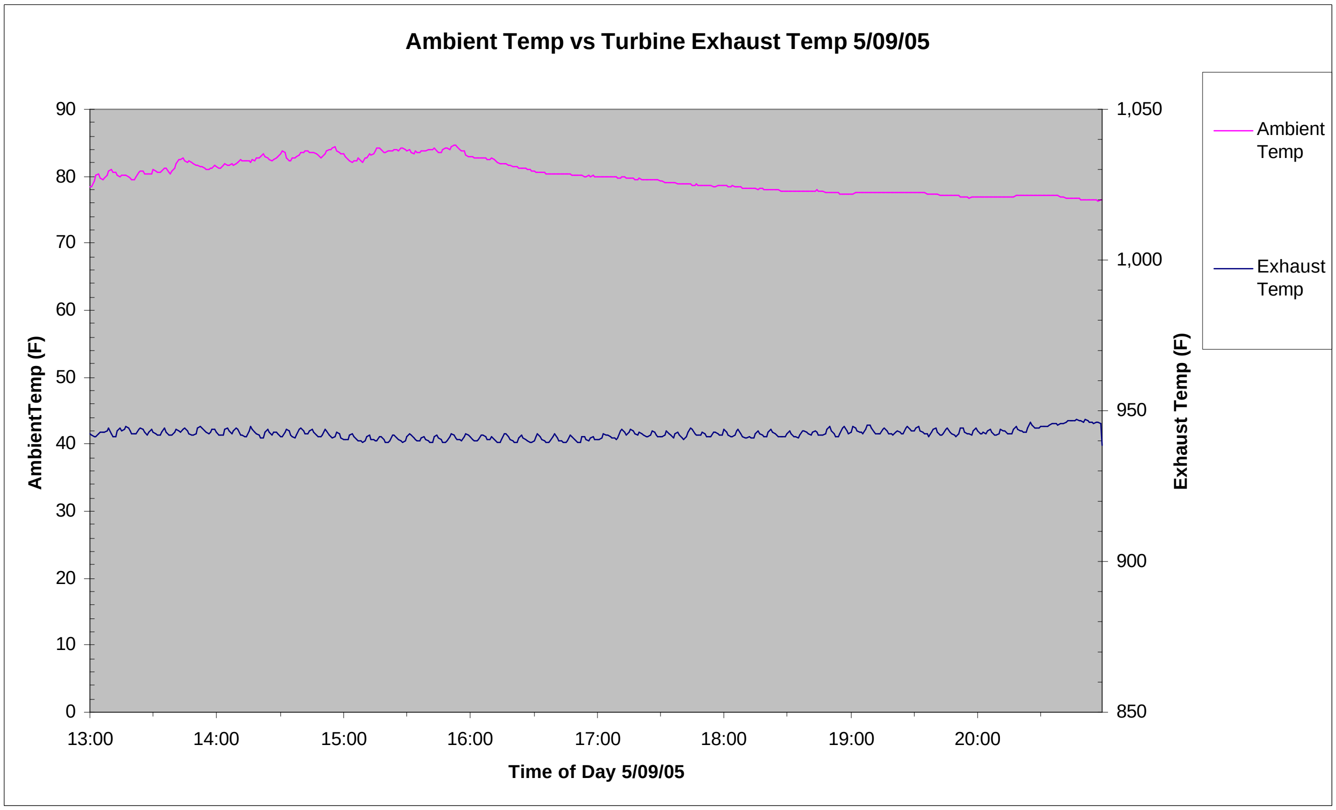

Figure 49 – Ambient and turbine exhaust temperatures versus time of day 05/09/05

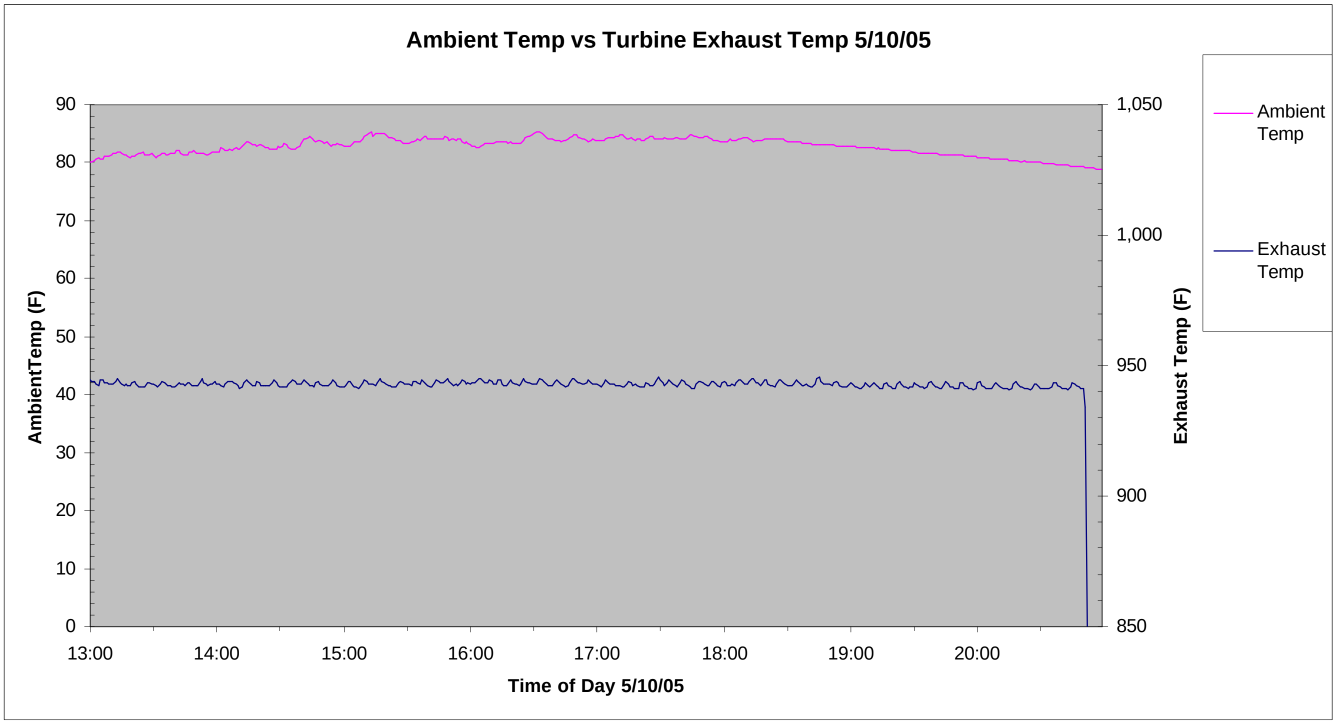

Figure 50 – Ambient and turbine exhaust temperatures versus time of day 05/10/05

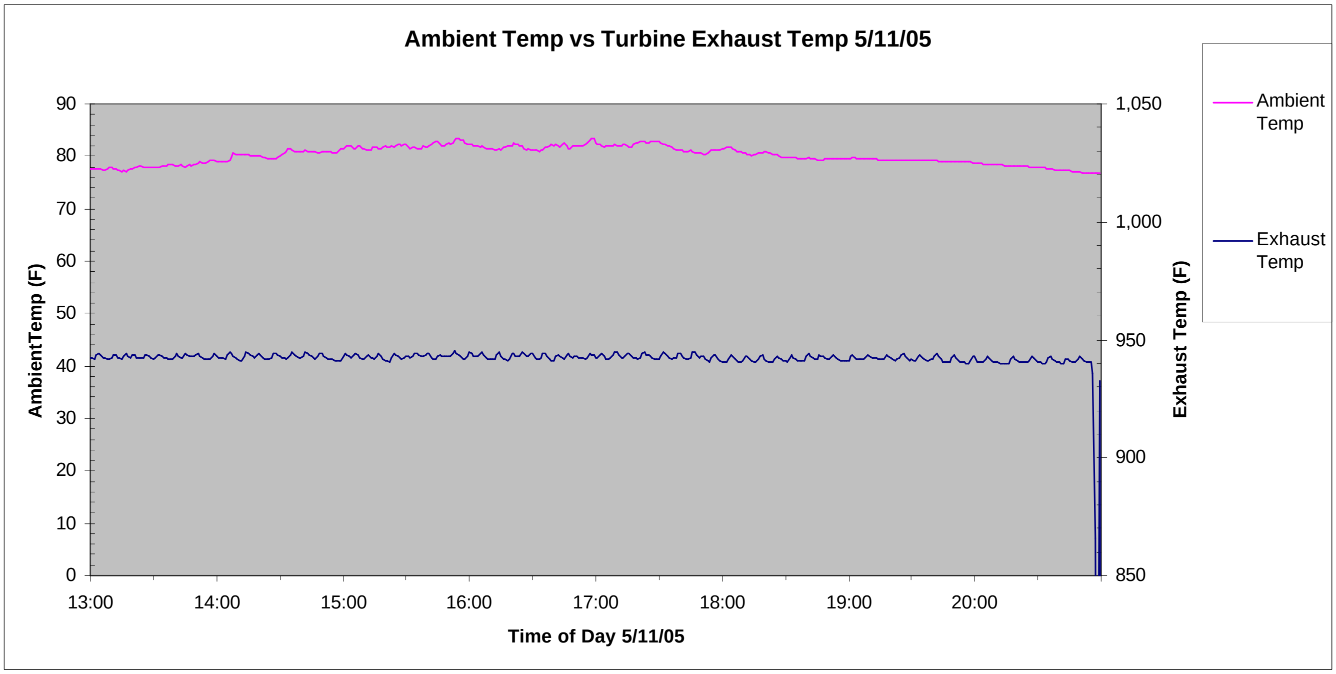

Figure 51 – Ambient and turbine exhaust temperatures versus time of day 05/11/05

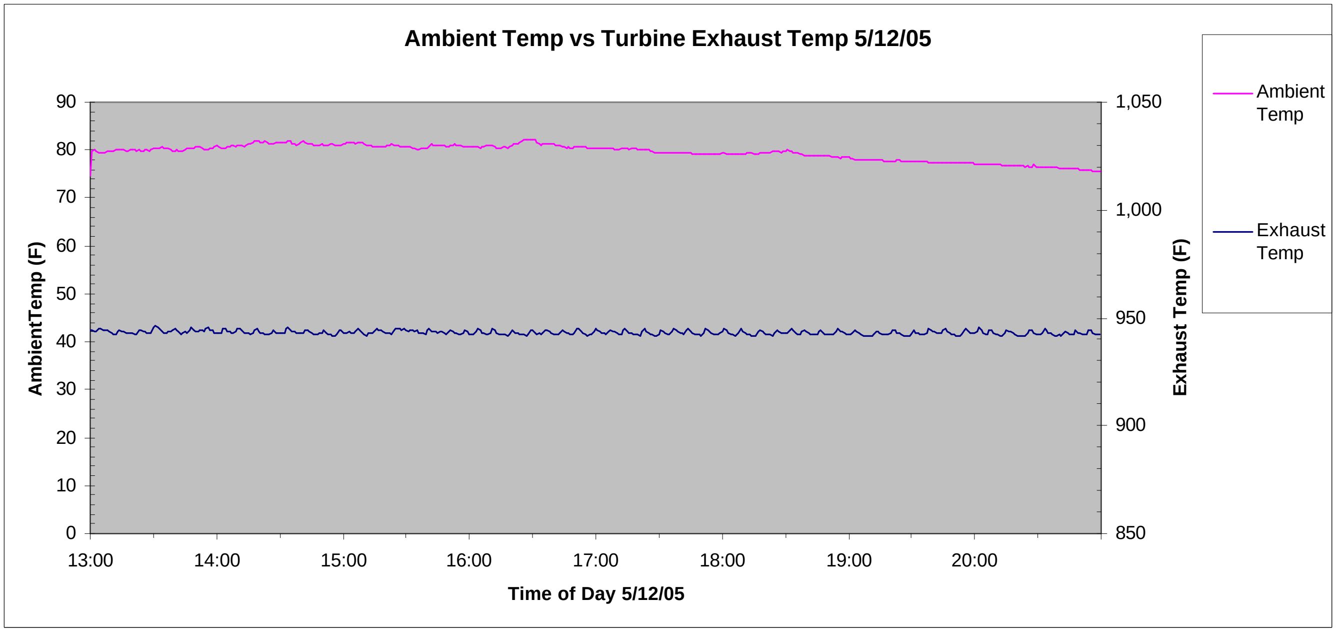

Figure 52 – Ambient and turbine exhaust temperatures versus time of day 05/12/05

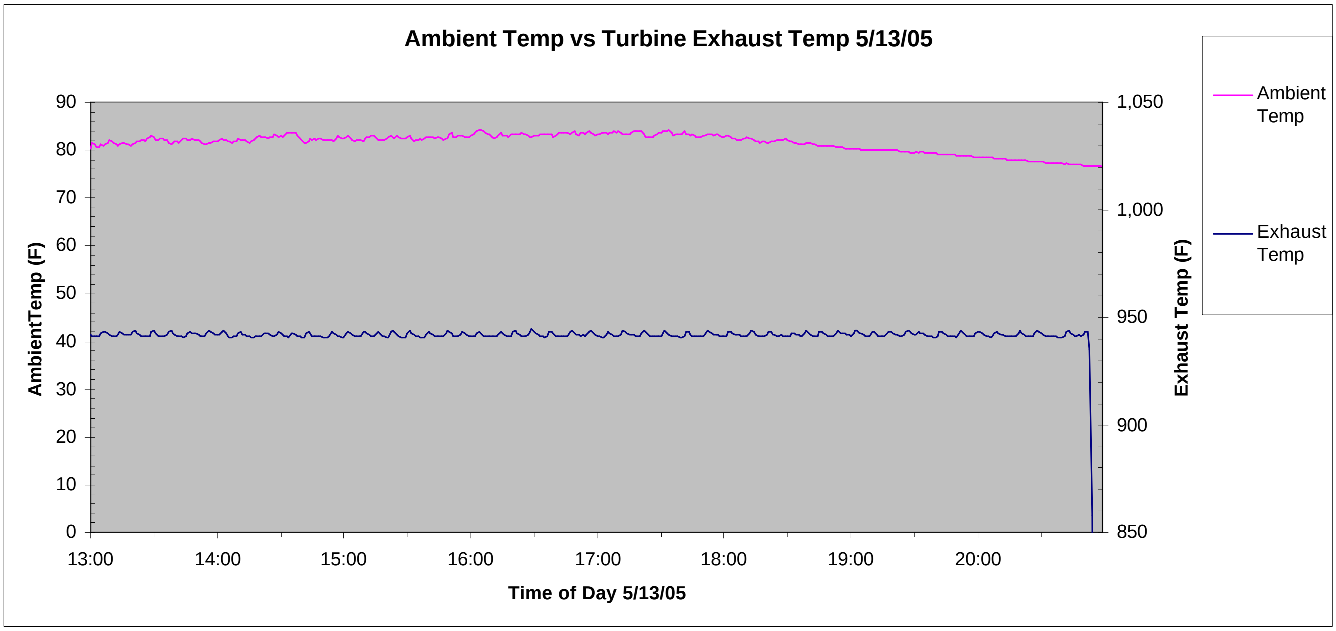

Figure 53 – Ambient and turbine exhaust temperatures versus time of day 05/13/05

Figures 54 through 58 show the ambient temperature variations and the impact on the turbine exhaust Flow. As expected due to inlet air cooling, the ambient temperature did not impact the exhaust flow.

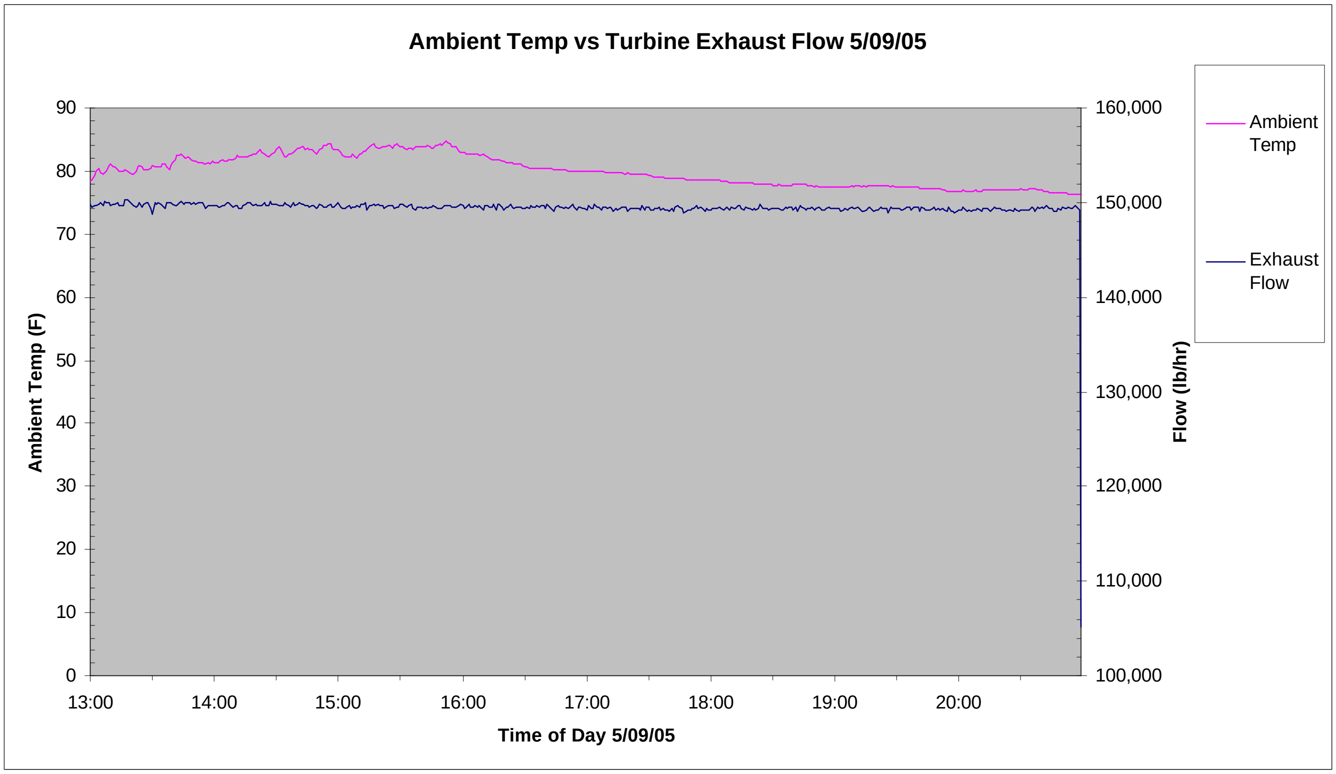

Figure 54 – Ambient temperature and turbine exhaust flow versus time of day 05/09/05

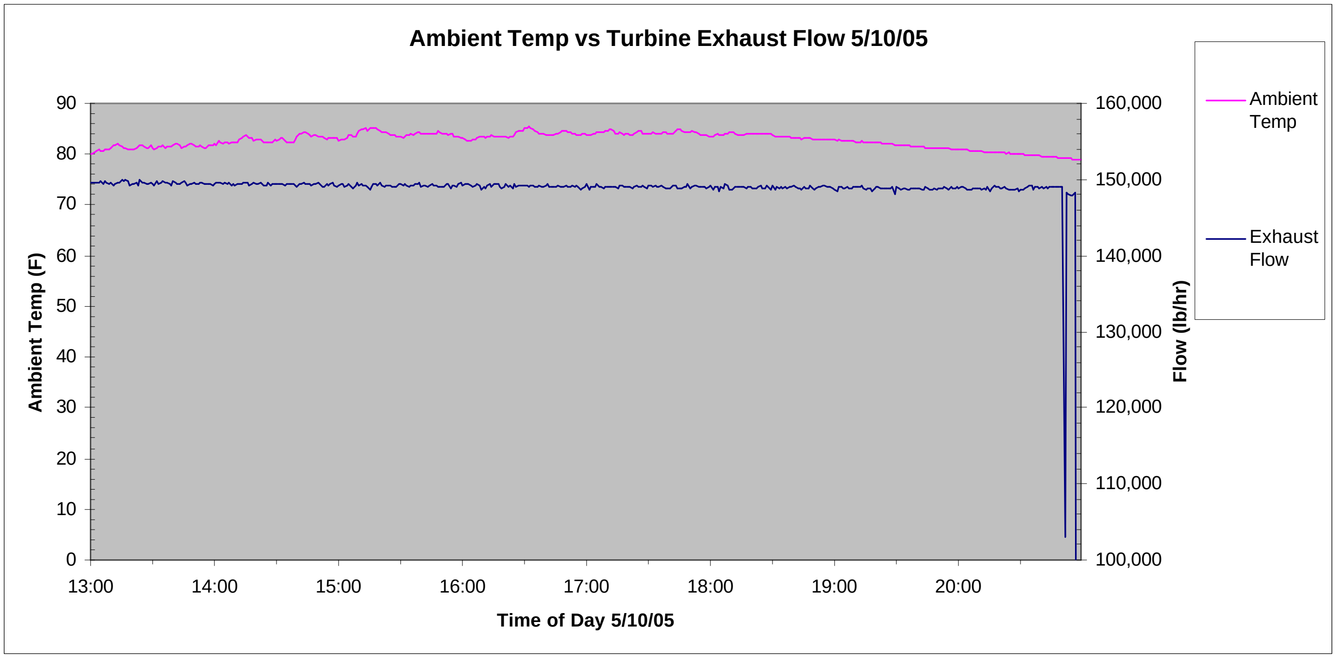

Figure 55 – Ambient temperature and turbine exhaust flow versus time of day 05/10/05

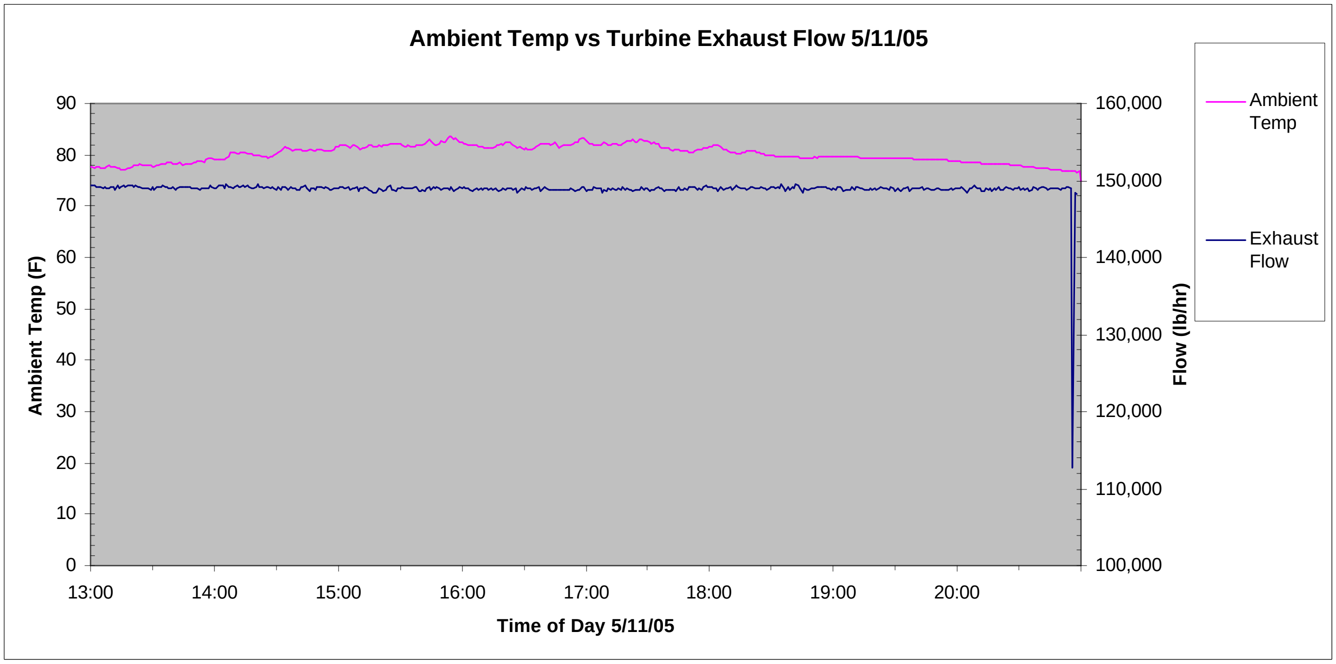

Figure 56 – Ambient temperature and turbine exhaust flow versus time of day 05/11/05

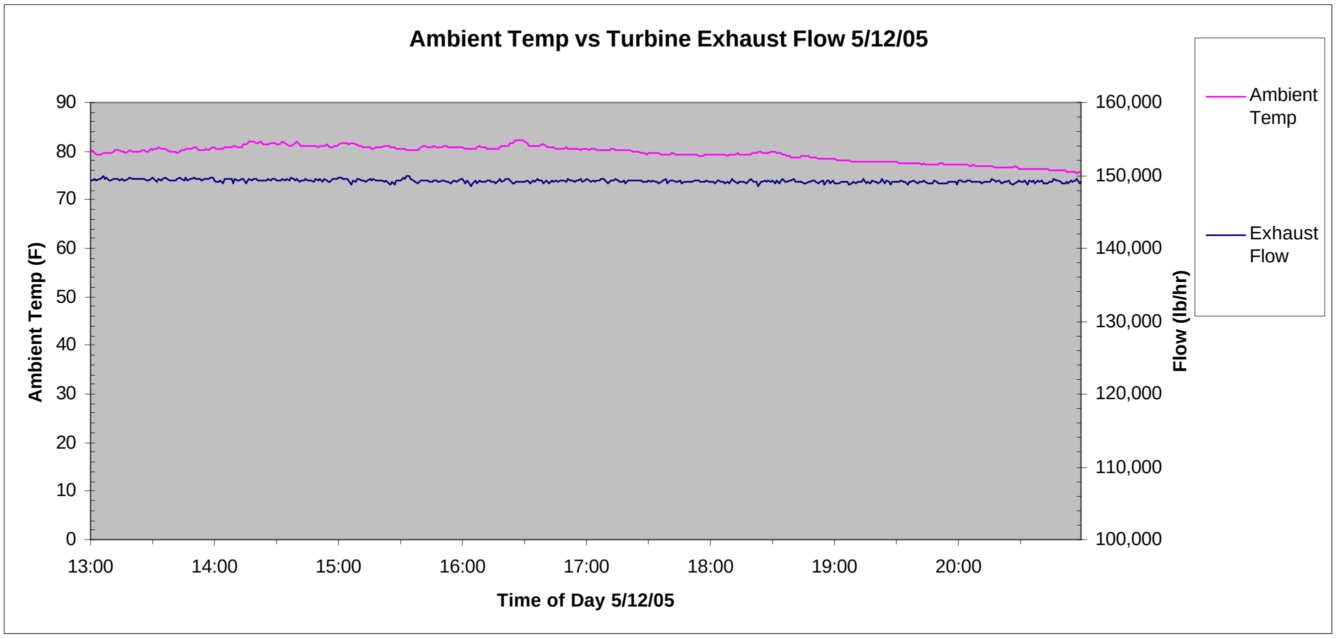

Figure 57 – Ambient temperature and Turbine exhaust flow versus time of day 05/12/05

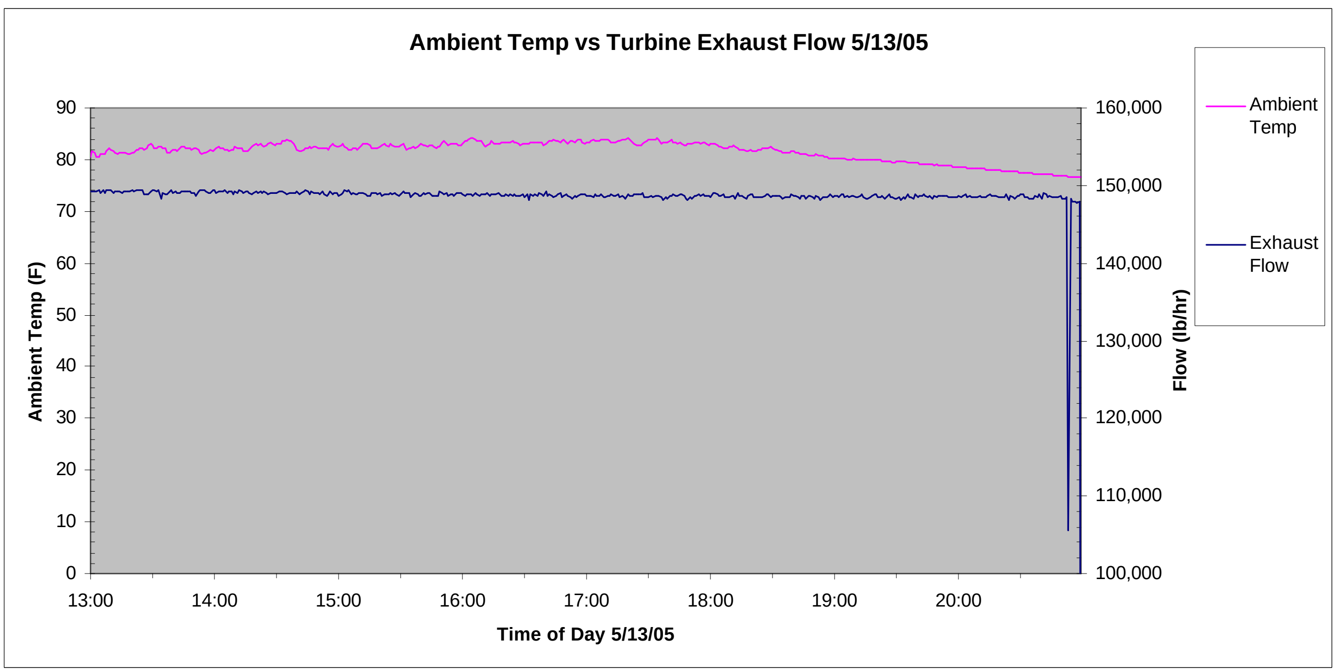

Figure 58 – Ambient temperature and turbine exhaust flow versus time of day 05/13/05

Figures 59 through 63 show that the turbine exhaust flow did not have a direct impact on the ABS chiller tons. Both the tons and the exhaust flow were relatively constant over the time periods recorded.

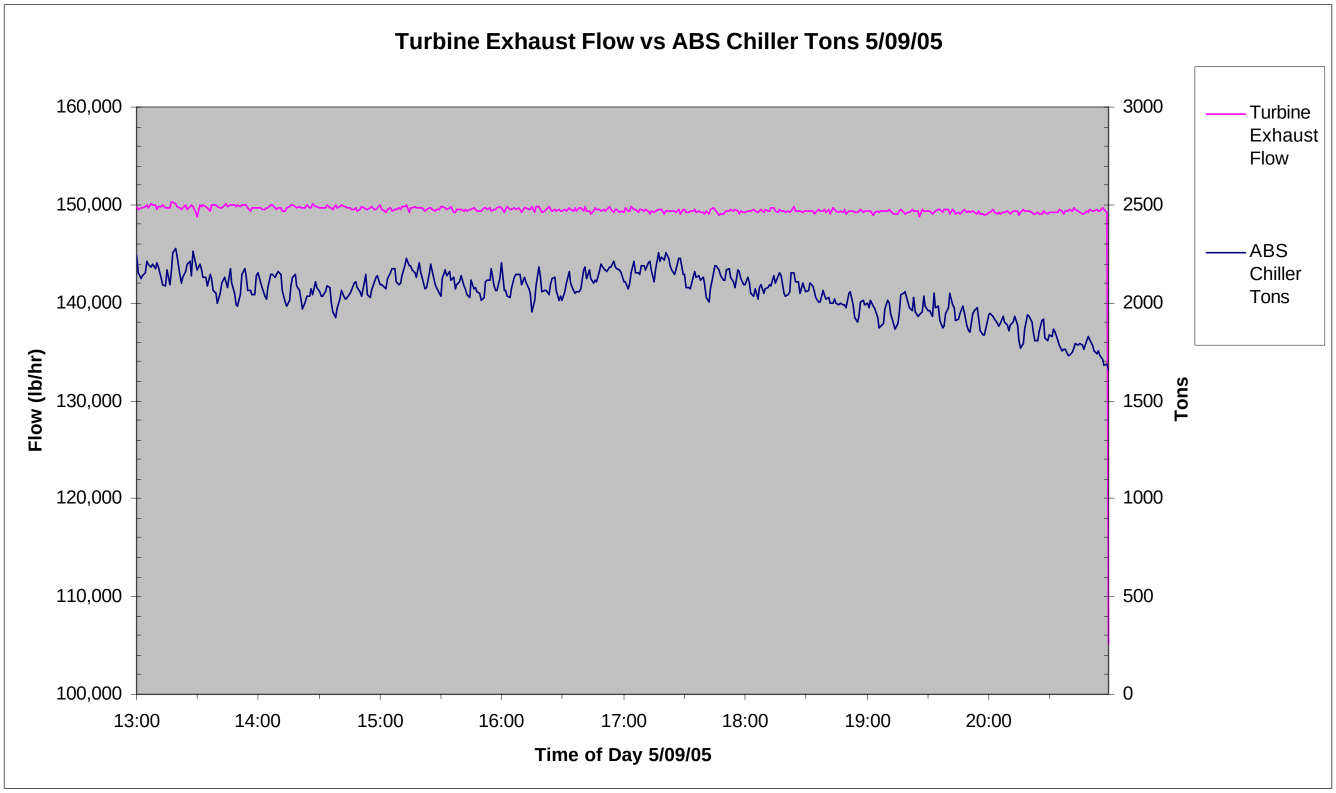

Figure 59 – Turbine exhaust flow and ABS tons versus time of day 5/09/05

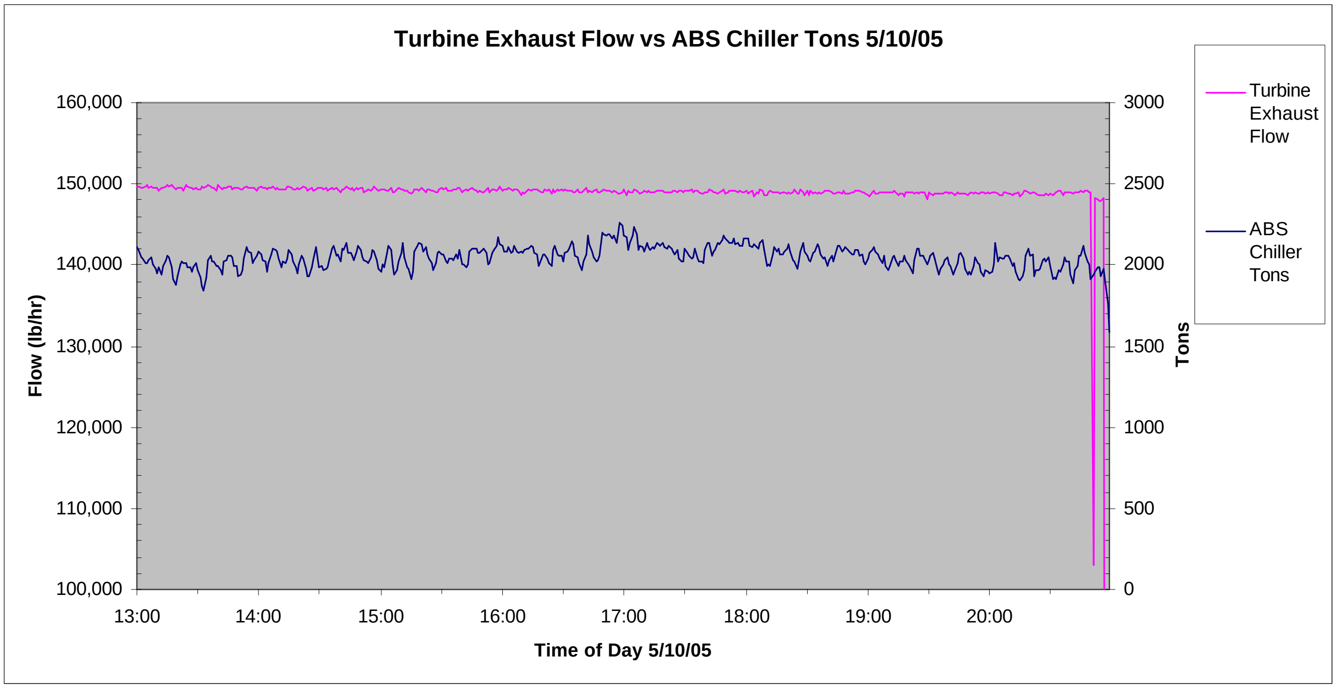

Figure 60 – Turbine exhaust flow and ABS tons versus time of day 5/10/05

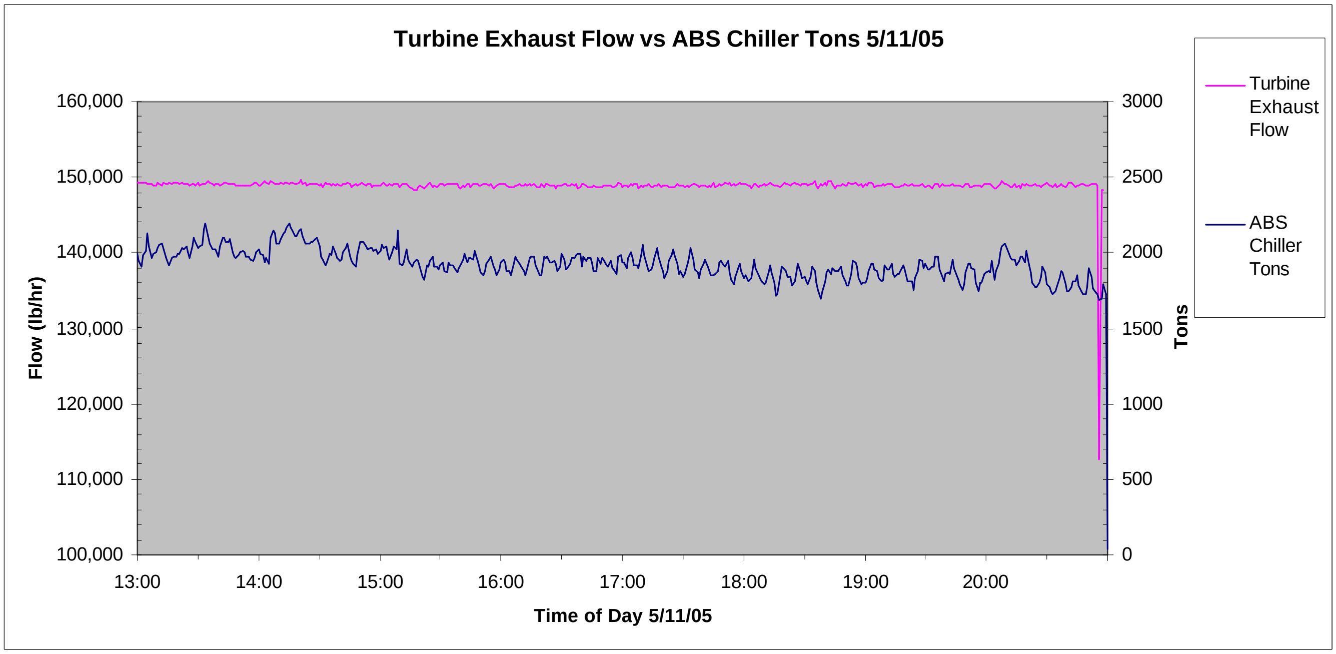

Figure 61 – Turbine exhaust flow and ABS tons versus time of day 5/11/05

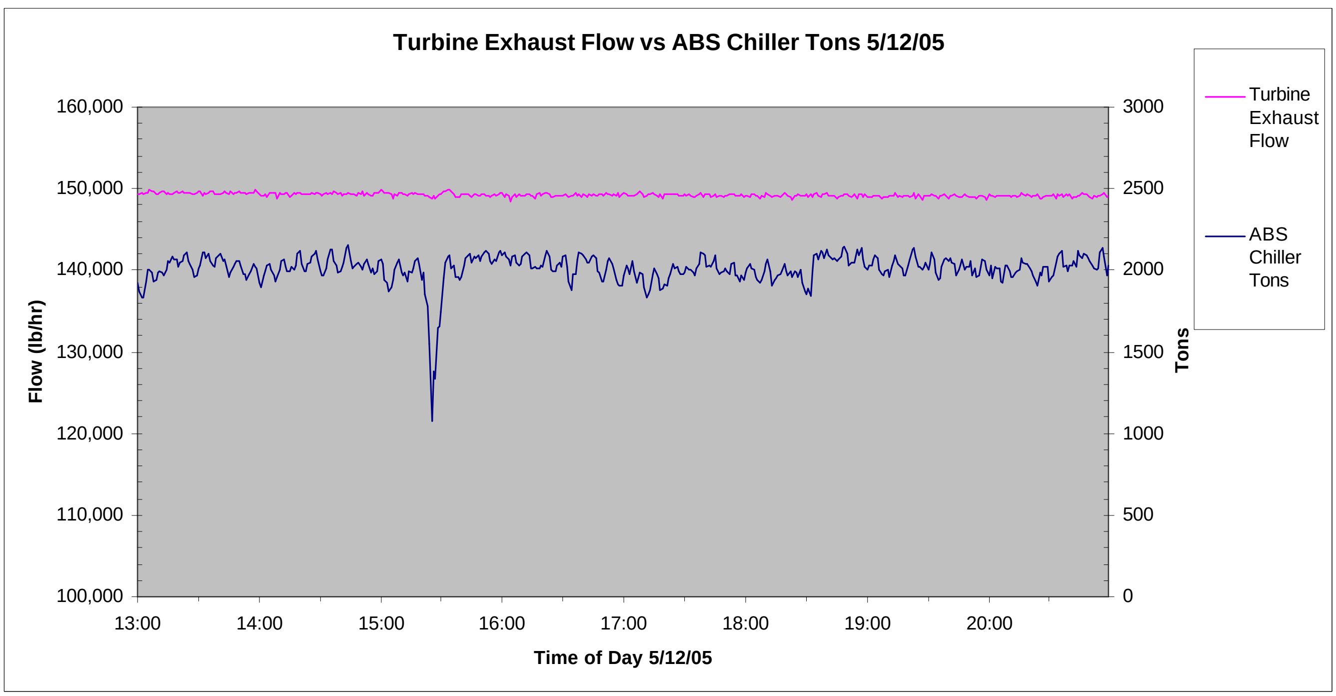

Figure 62 – Turbine exhaust flow and ABS tons versus time of day 5/12/05

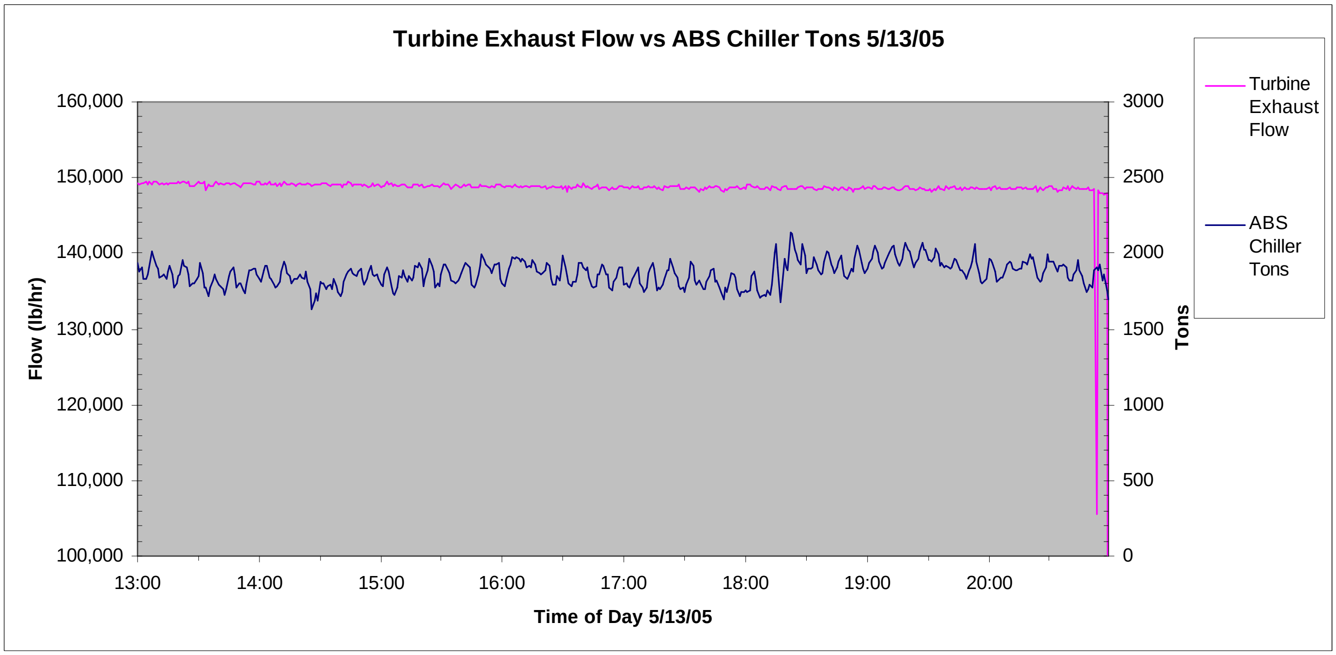

Figure 63 – Turbine exhaust flow and ABS tons versus time of day 5/13/05

Figures 64 through 68 show the relationship between turbine exhaust flow and turbine exhaust temperature. Both values stayed essentially the same during the test.

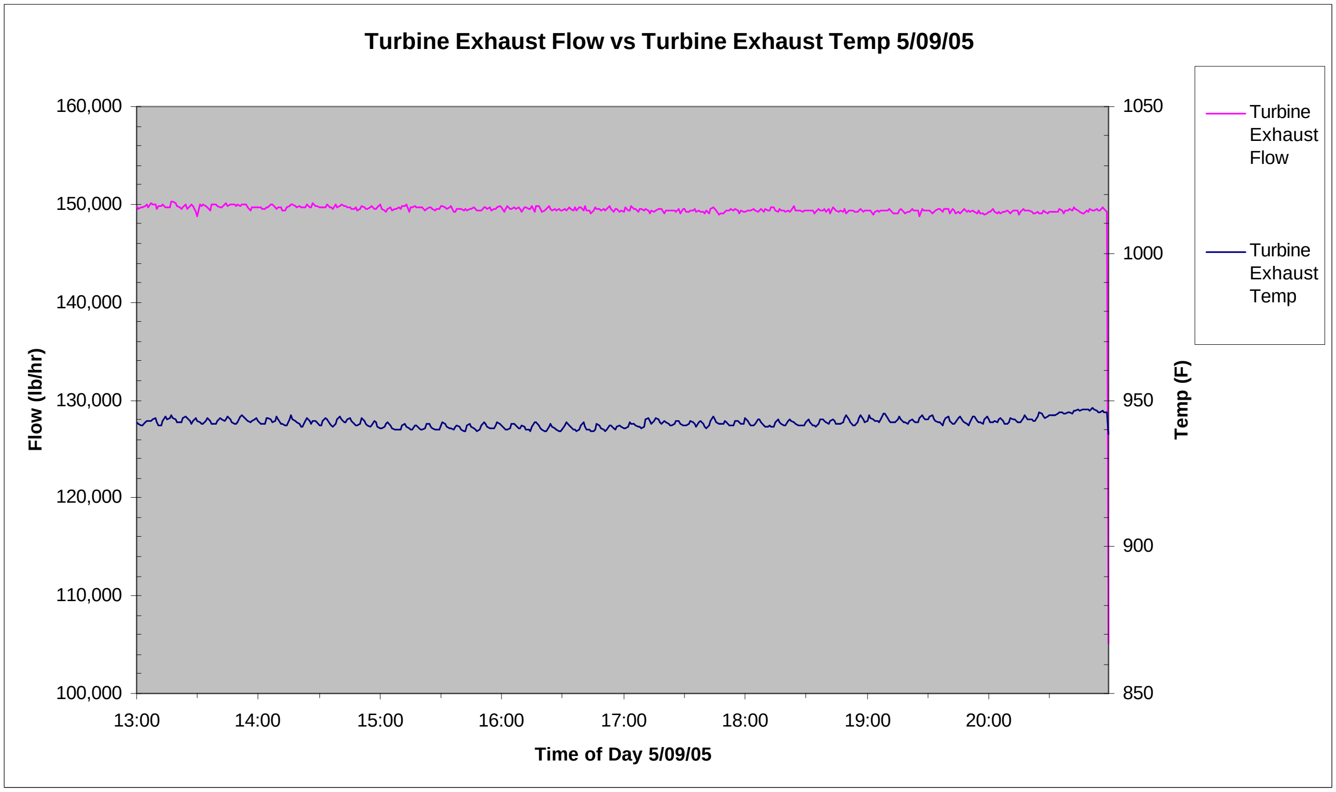

Figure 64 – Turbine exhaust flow and turbine exhaust temperature versus time of day 5/09/05

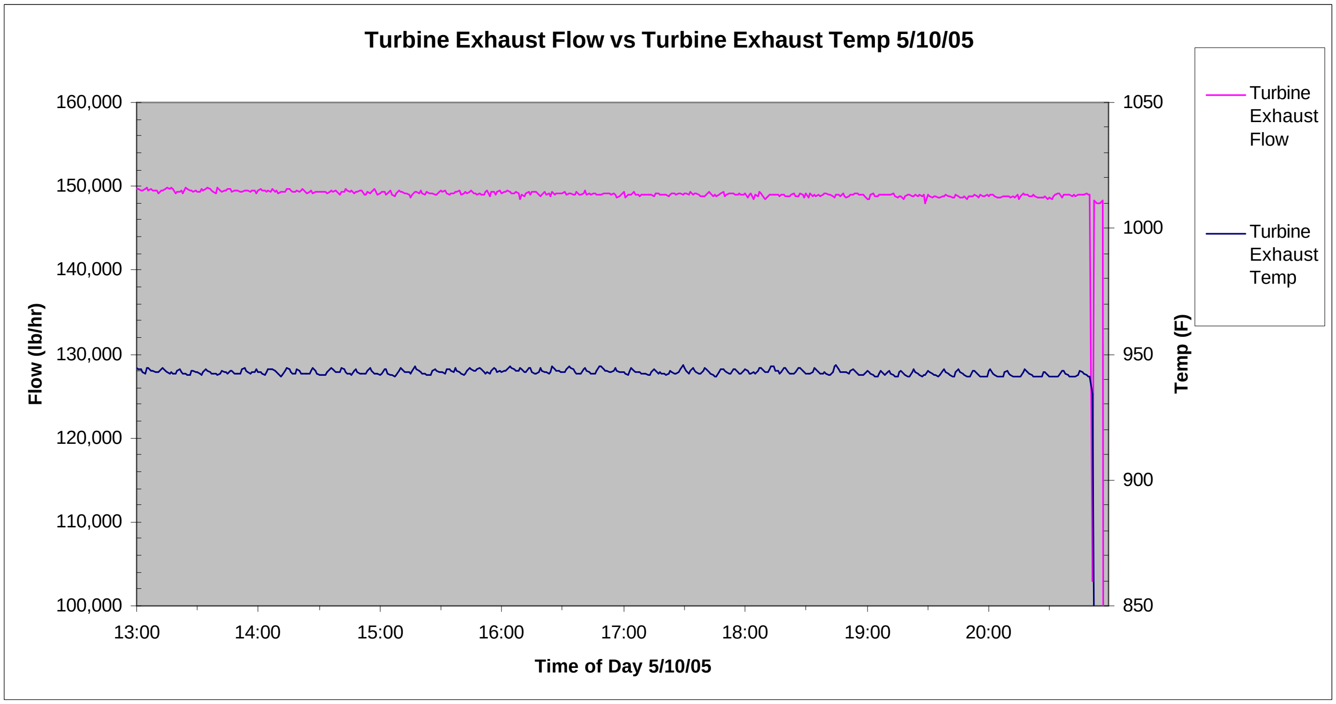

Figure 65 – Turbine exhaust flow and turbine exhaust temperature versus time of day 5/10/05

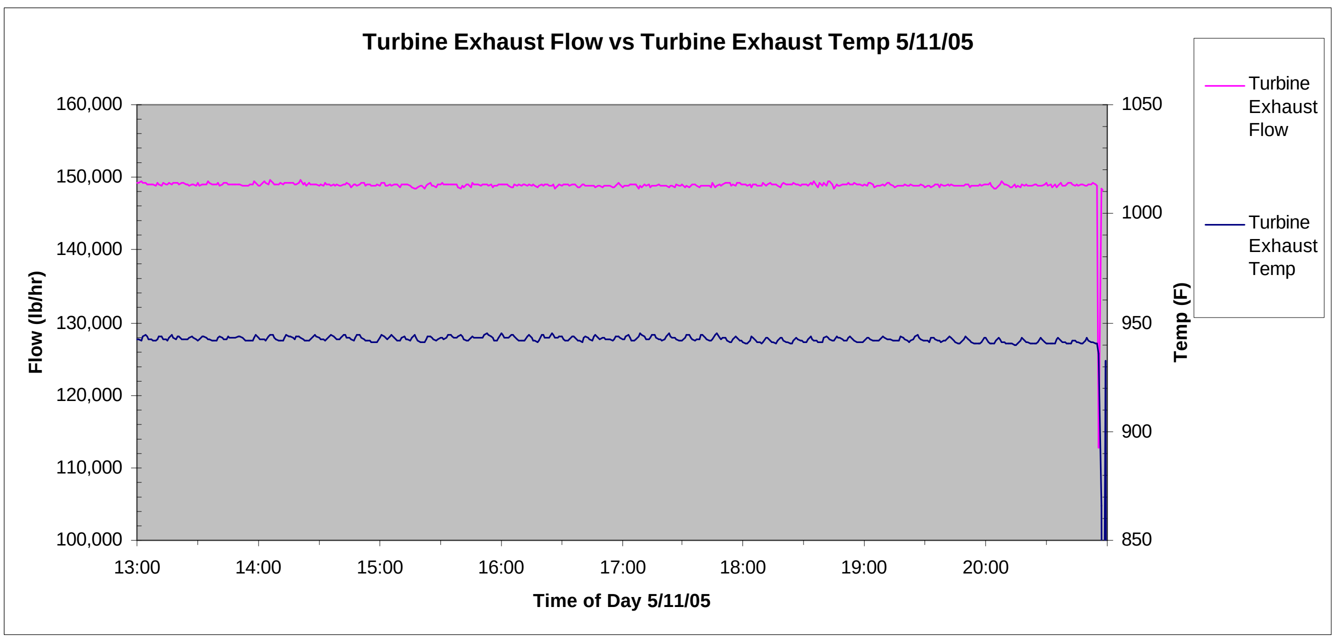

Figure 66 – Turbine exhaust flow and turbine exhaust temperature versus time of day 5/11/05

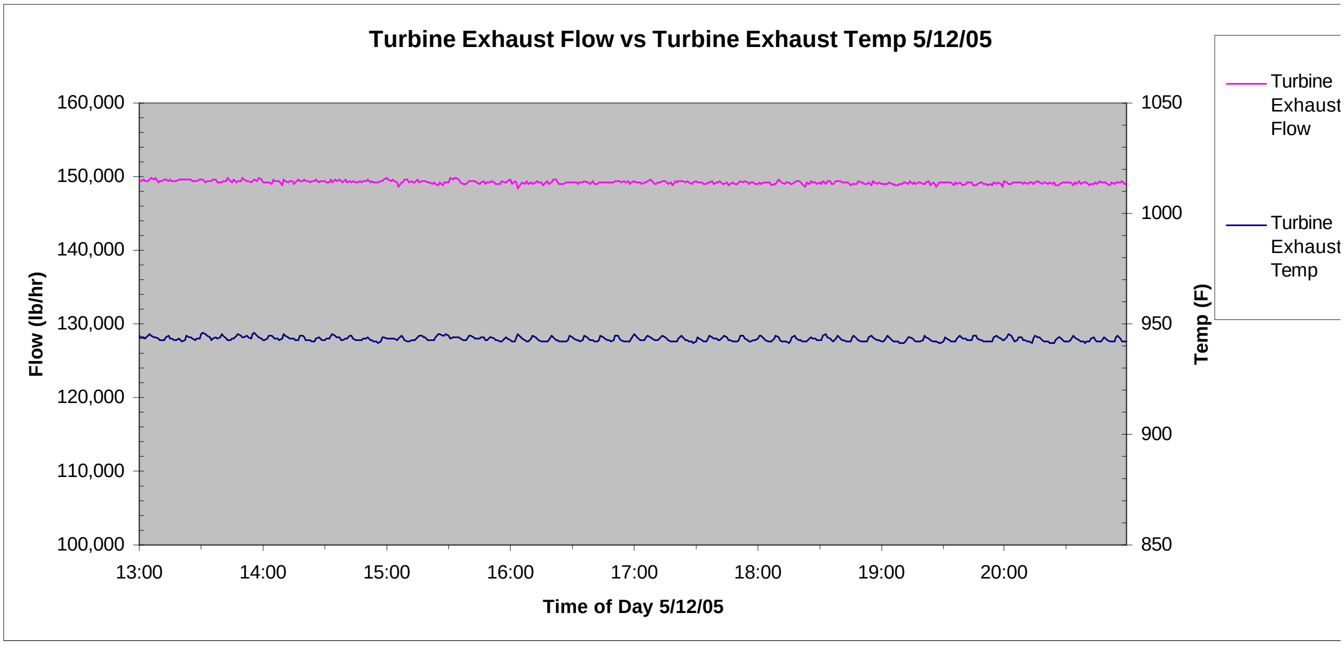

Figure 67 – Turbine exhaust flow and turbine exhaust temperature versus time of day 5/12/05

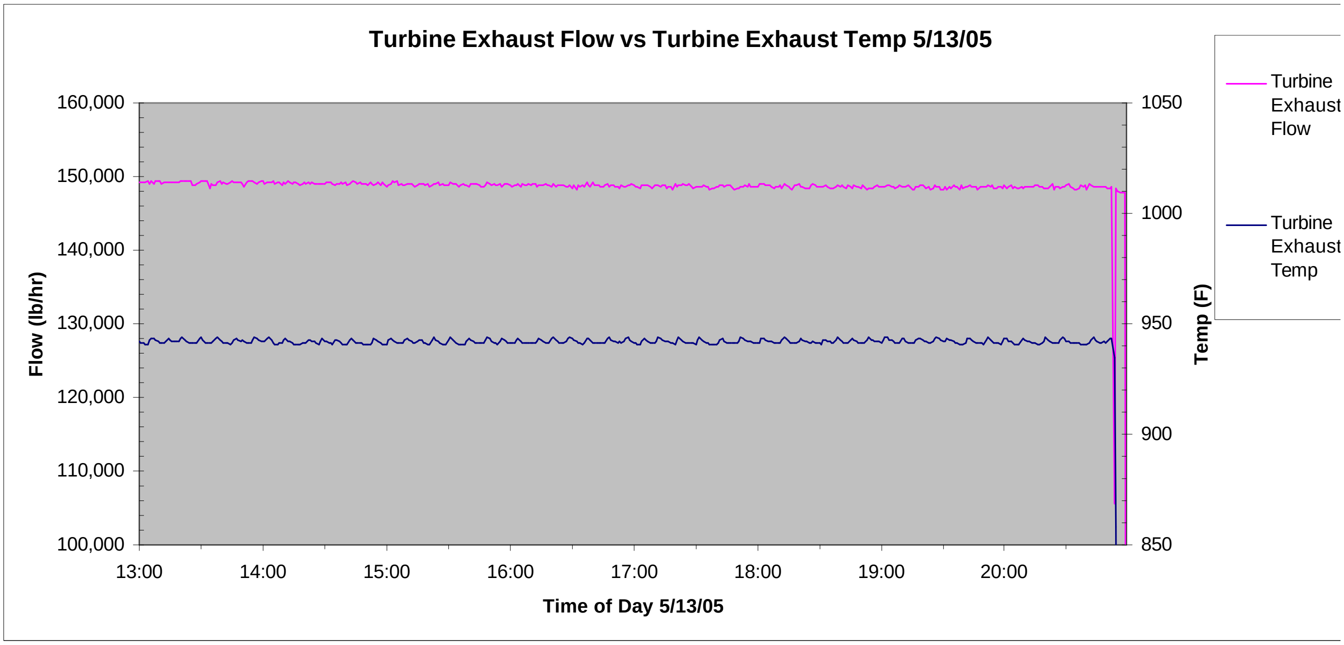

Figure 68 – Turbine exhaust flow and turbine exhaust temperature versus time of day 5/13/05

Figures 69 through 73 show the relationship between the fuel input for the turbine in MMBtu/h (10^6 Btu/h) and the kW output from the turbine. The fuel requirements are based on HHV. The graphs indicated that both variables were essentially constant during the recording period.

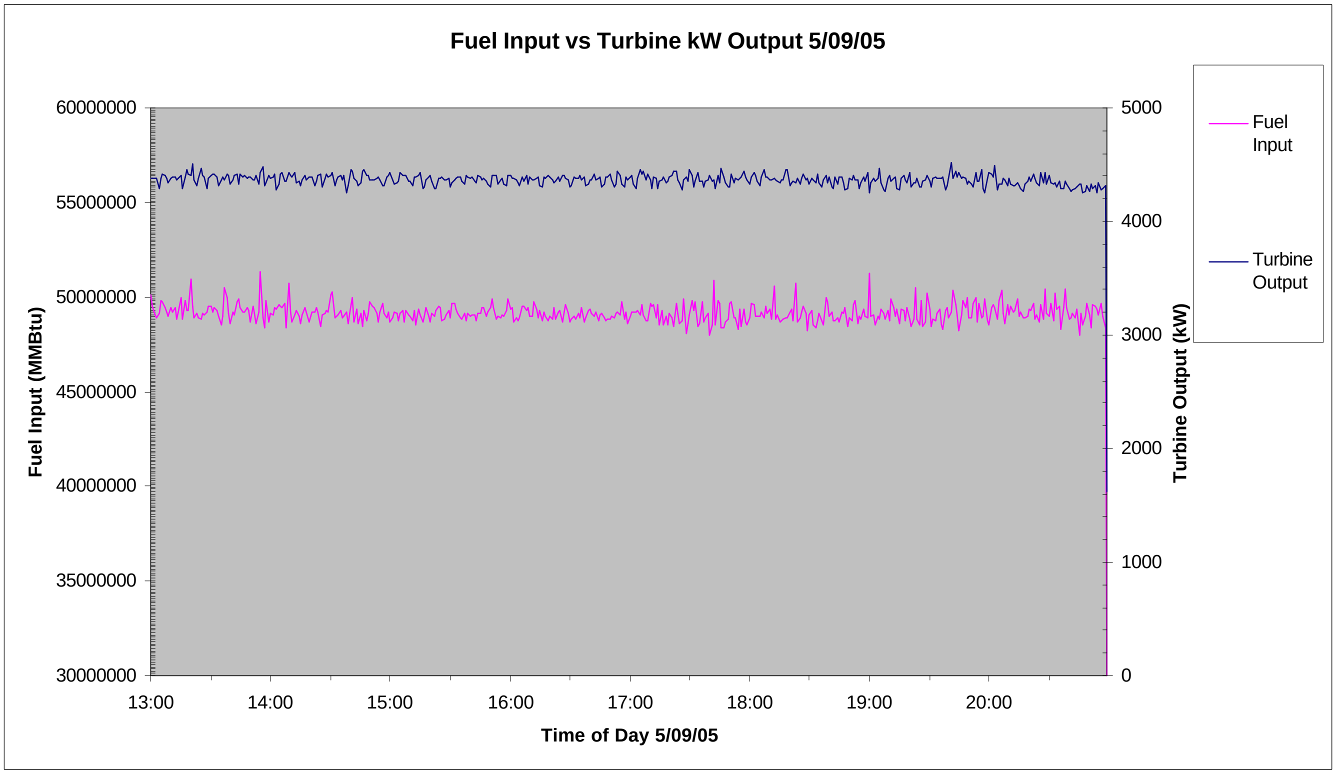

Figure 69 – Turbine fuel input and turbine kW output versus time of day 5/09/05

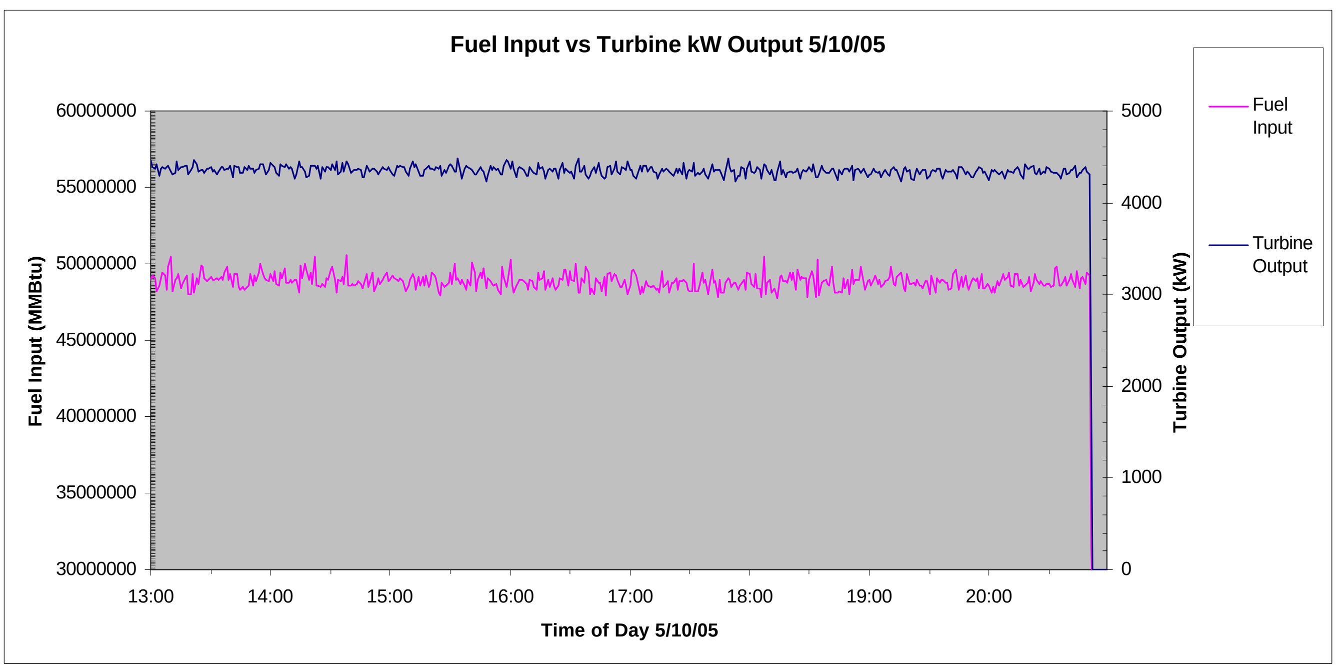

Figure 70 – Turbine fuel input and turbine kW output versus time of day 5/10/05

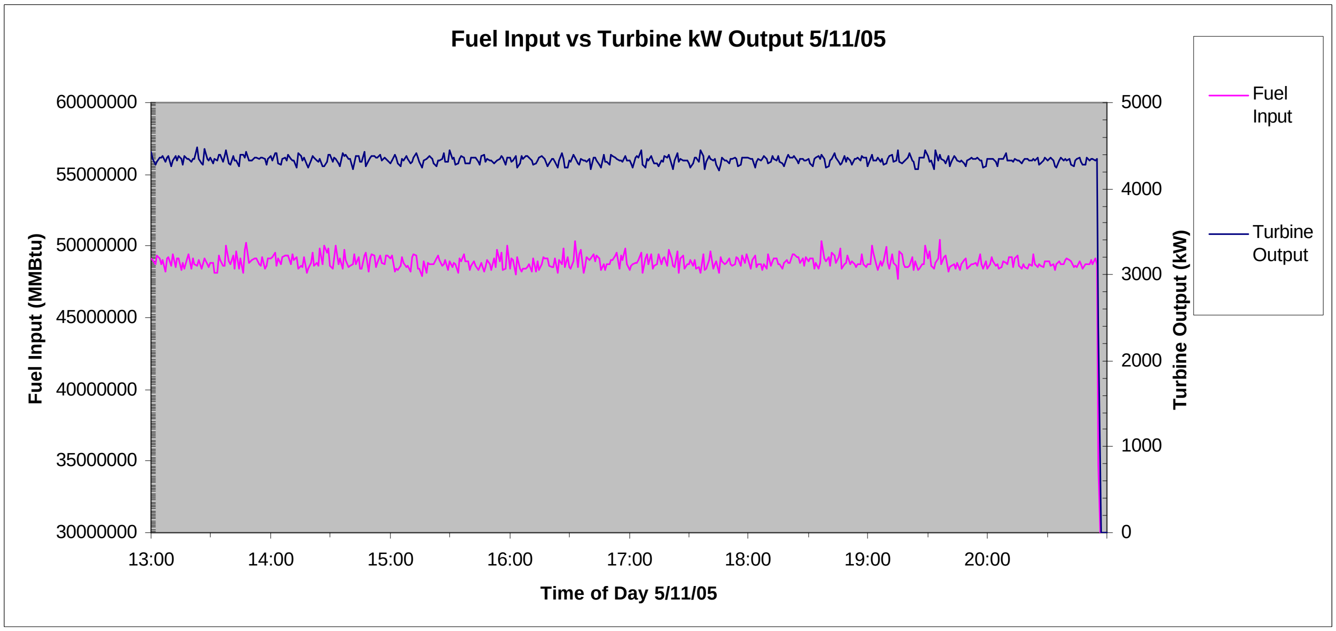

Figure 71 – Turbine fuel input and turbine kW output versus time of day 5/11/05

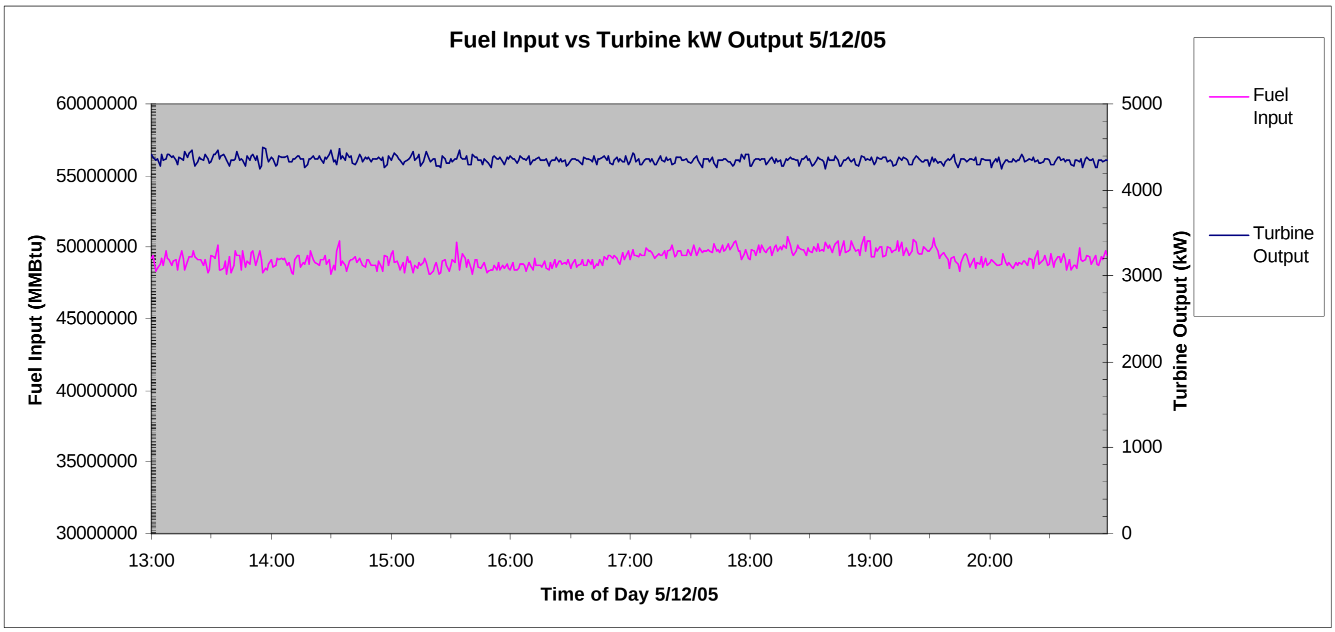

Figure 72 – Turbine fuel input and turbine kW output versus time of day 5/12/05

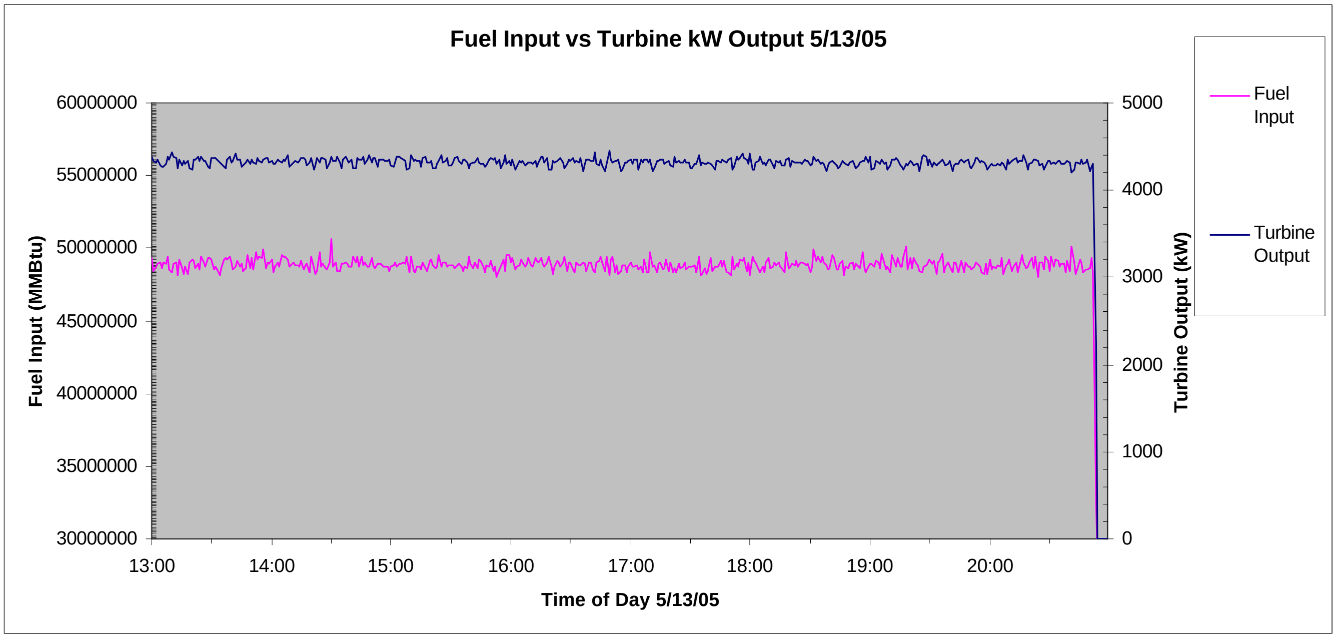

Figure 73 – Turbine fuel input and turbine kW output versus time of day 5/13/05

Figures 74 through 78 show show the relationship between the turbine exhaust heat which was essentially constant and the amount of ABS tons during the recorded times. The ABS tons show a fairly constant value, with some decrease over each of the days.

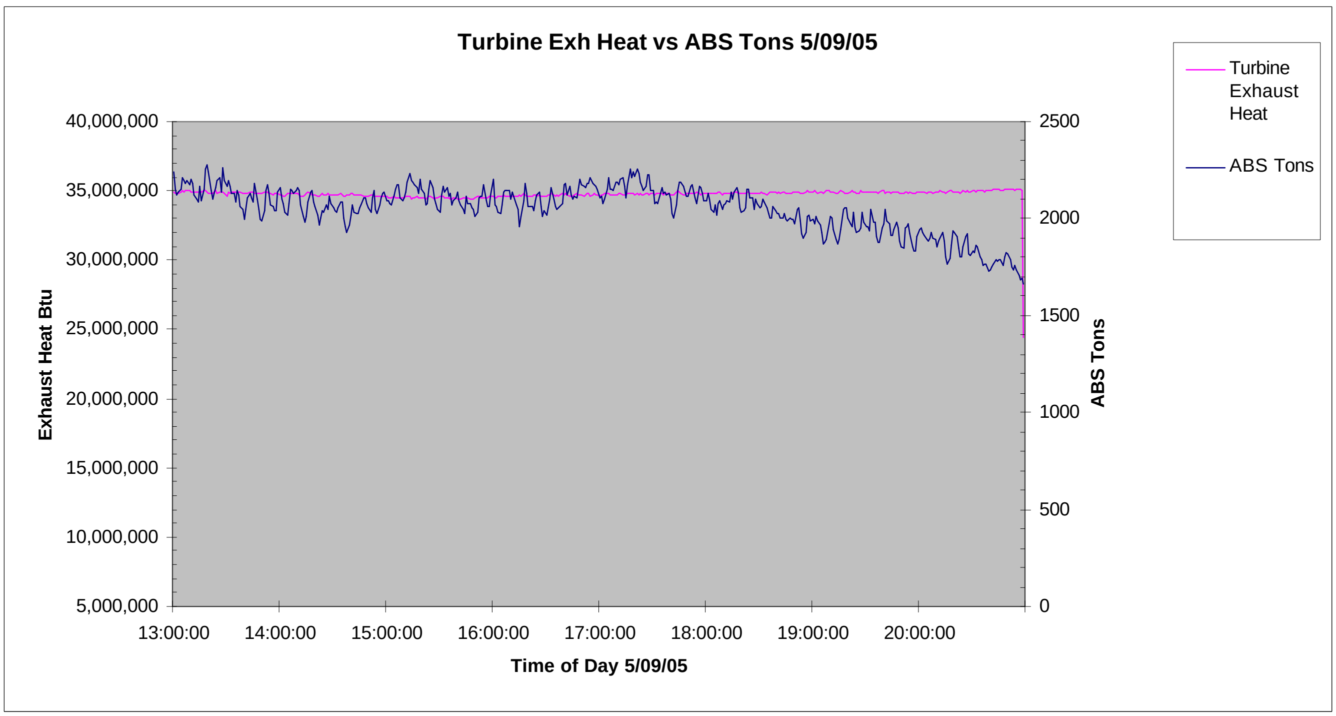

Figure 74 – Turbine exhaust heat and ABS tons versus time of day 5/09/05

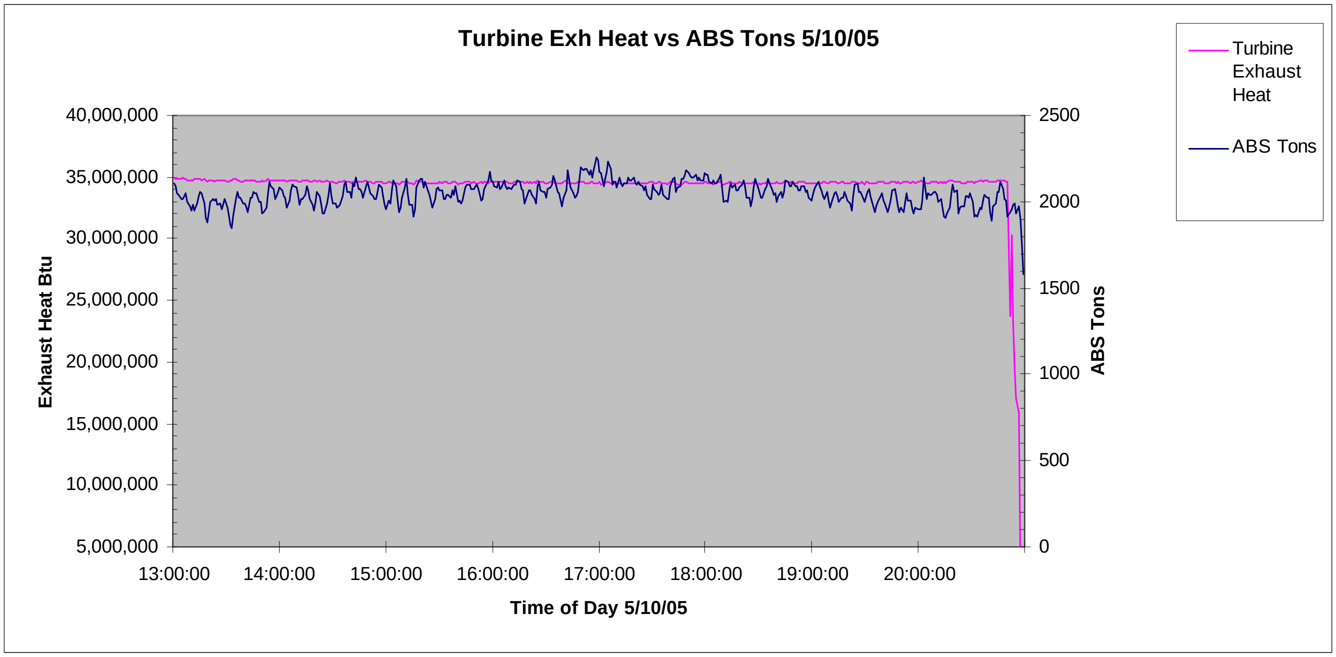

Figure 75 – Turbine exhaust heat and ABS tons versus time of day 5/10/05

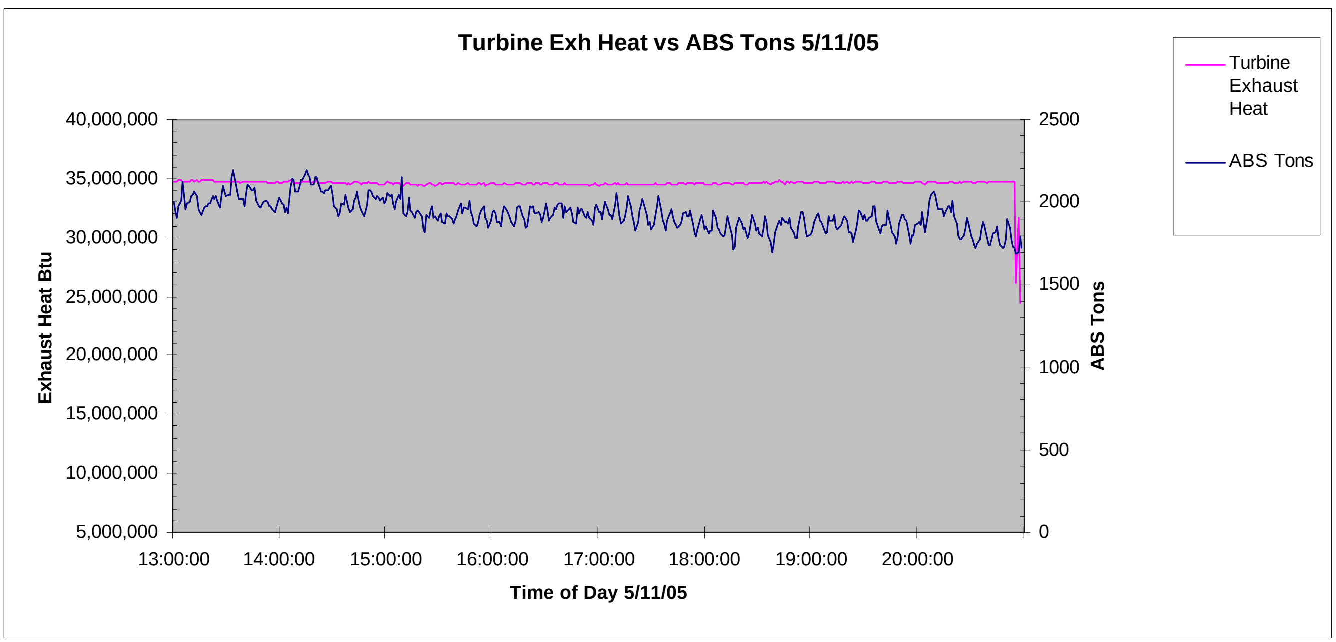

Figure 76 – Turbine exhaust heat and ABS tons versus time of day 5/11/05

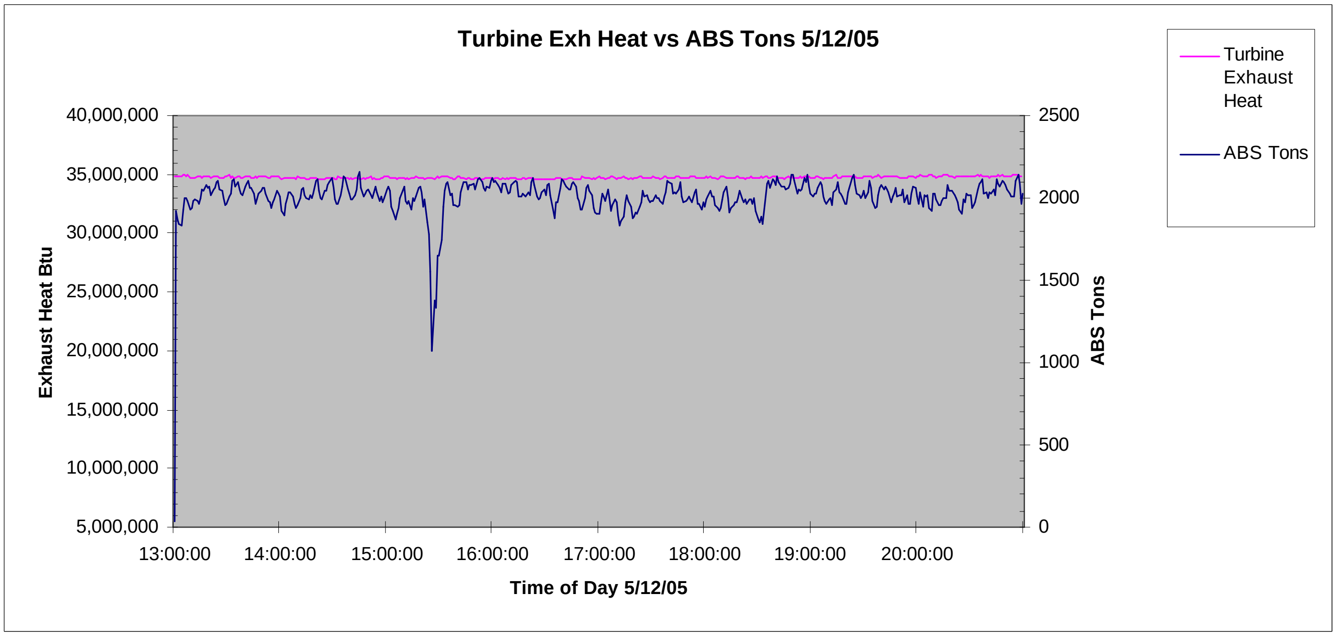

Figure 77 – Turbine exhaust heat and ABS tons versus time of day 5/12/05

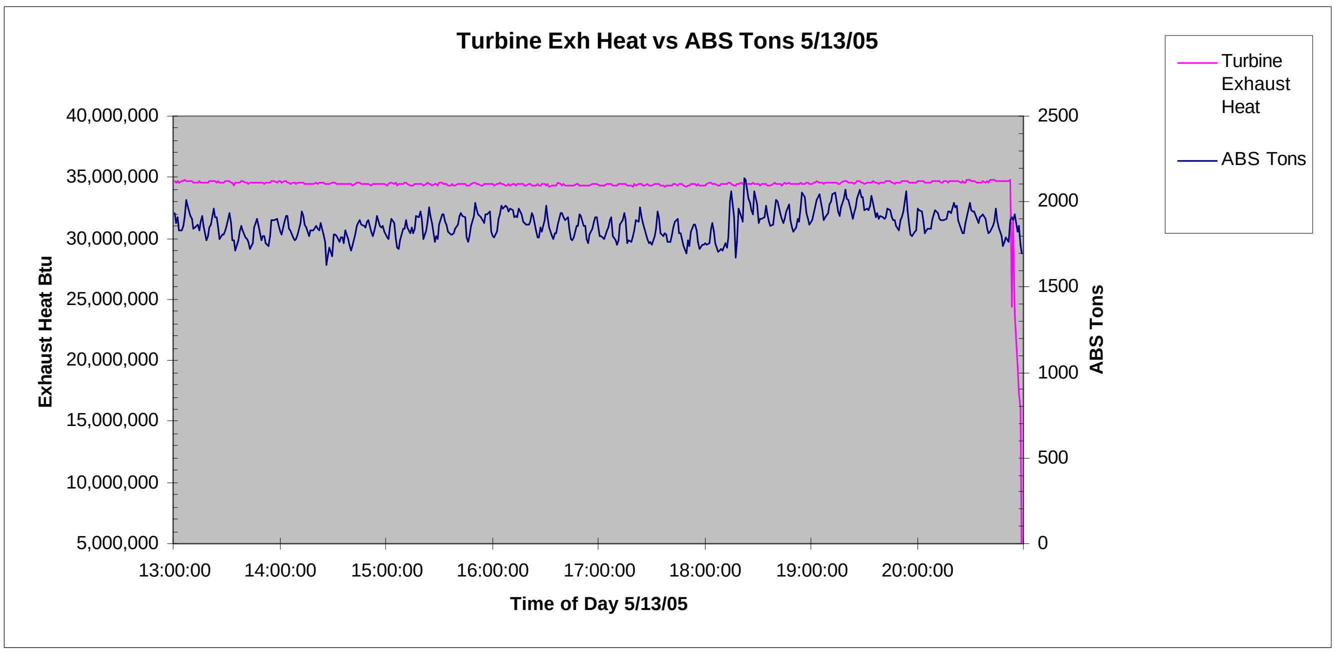

Figure 78 – Turbine exhaust heat and ABS tons versus time of day 5/13/05

Figures 79 through 83 show the relationship between the ABS chiller tons and the CHP gross efficiency. Gross CHP efficiency is defined as the sum of the electrical output converted to MMBtu plus the chiller recovered heat in MMBtu, divided by the fuel input (HHV) in MMBtu. In some of the early data, such as this, the definition of gross efficiency uses the ABS tons converted to MMBtu instead of the chiller recovered heat.

The difference is the chiller COP. Since the thermal heat recovered for chilling was greater than the equivalent kW, the relationship between the tons and CHP efficiency is an identical pattern.

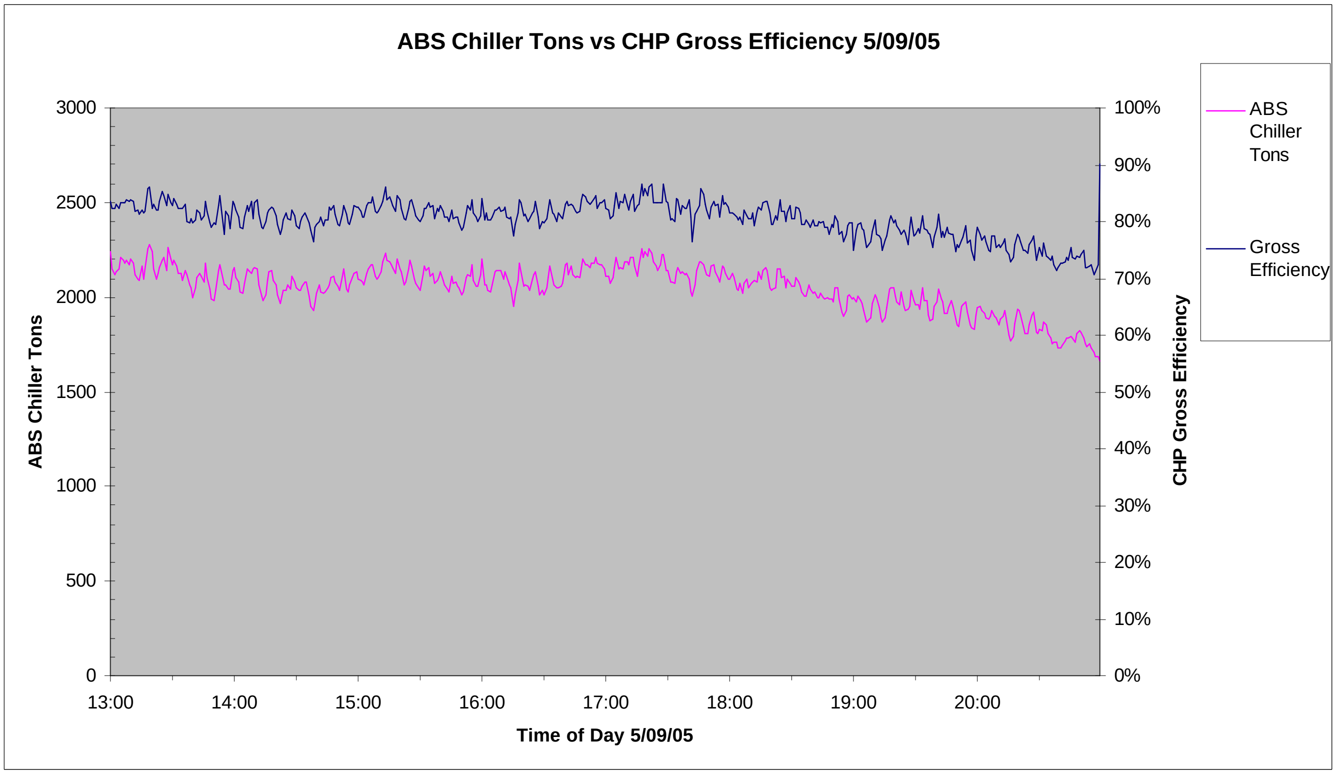

Figure 79 – ABS chiller tons and CHP gross efficiency versus time of day 5/09/05

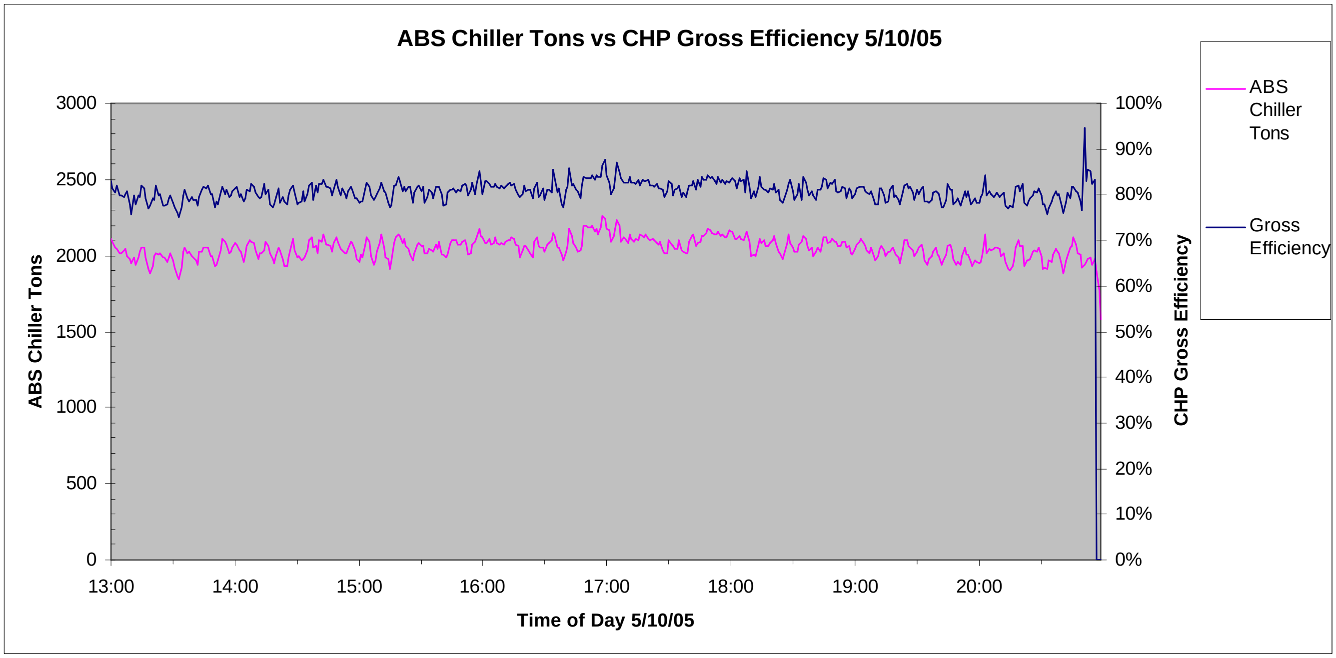

Figure 80 – ABS chiller tons and CHP gross efficiency versus time of day 5/10/05

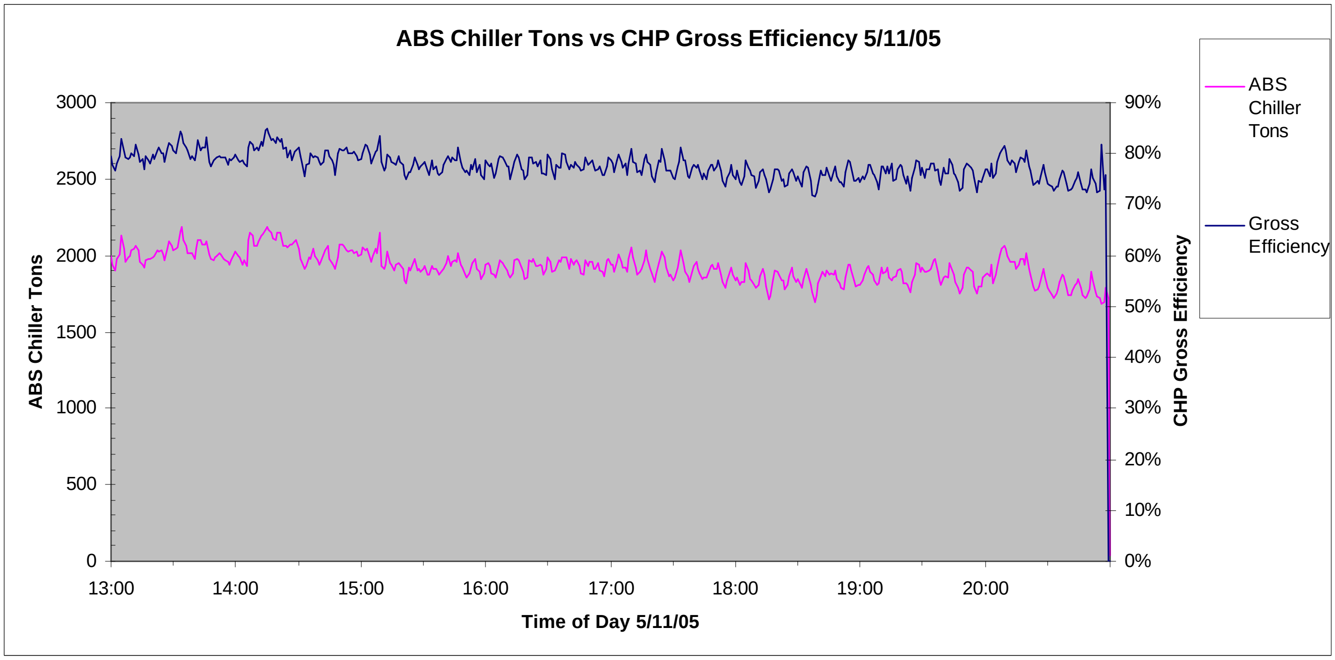

Figure 81 – ABS chiller tons and CHP gross efficiency versus time of day 5/11/05

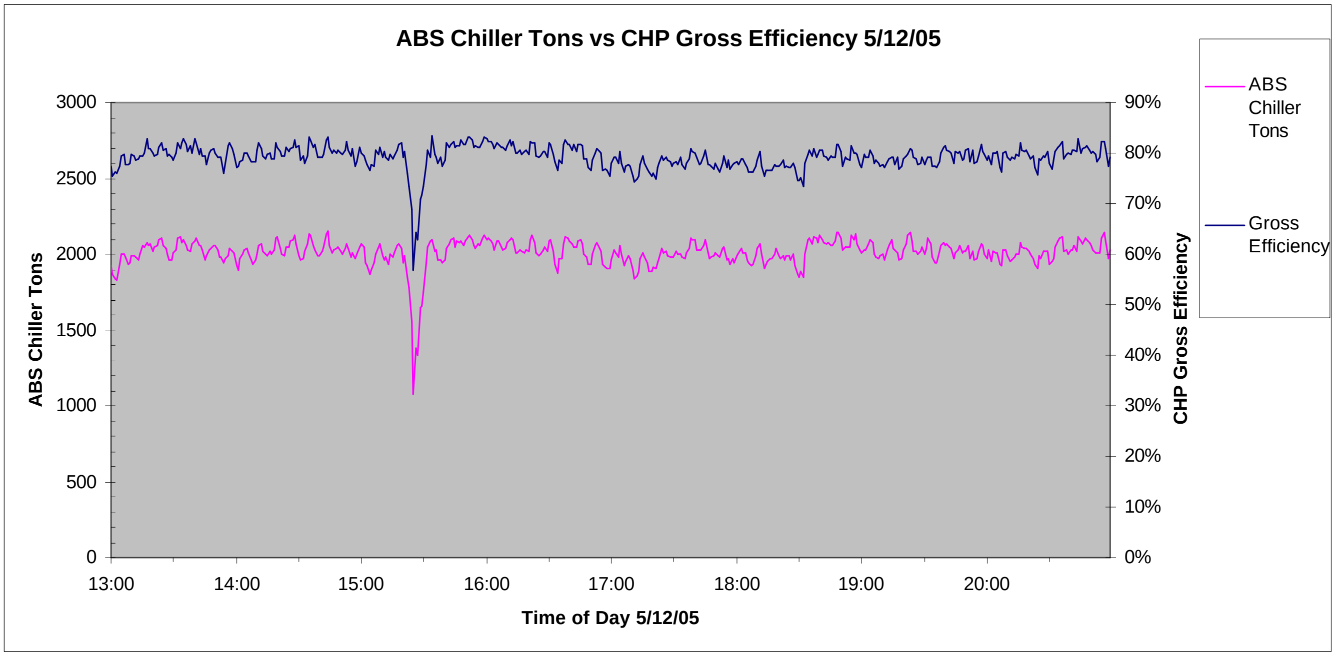

Figure 82 – ABS chiller tons and CHP gross efficiency versus time of day 5/12/05

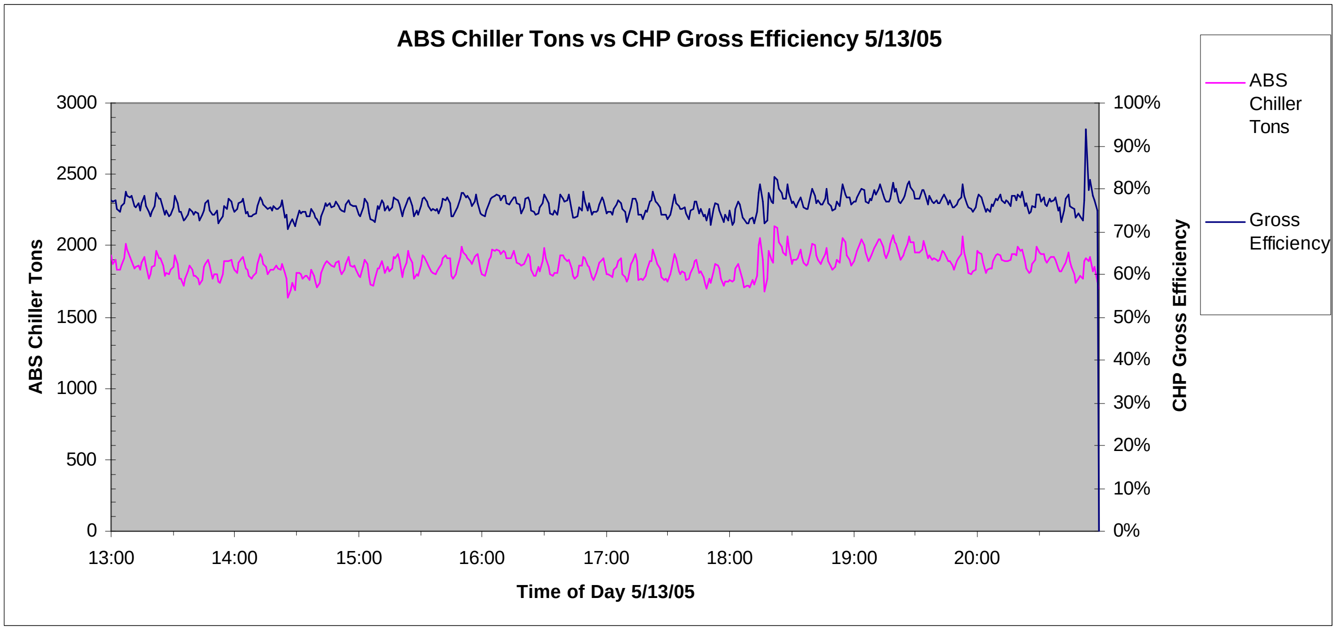

Figure 83 – ABS chiller tons and CHP gross efficiency versus time of day 5/13/05

Figures 84 through 88 show the relationship between turbine kW output and the CHP gross efficiency. Since the turbine kW converted to heat is a smaller part of the thermal heat total, the gross efficiency did not have a direct track to the efficiency.

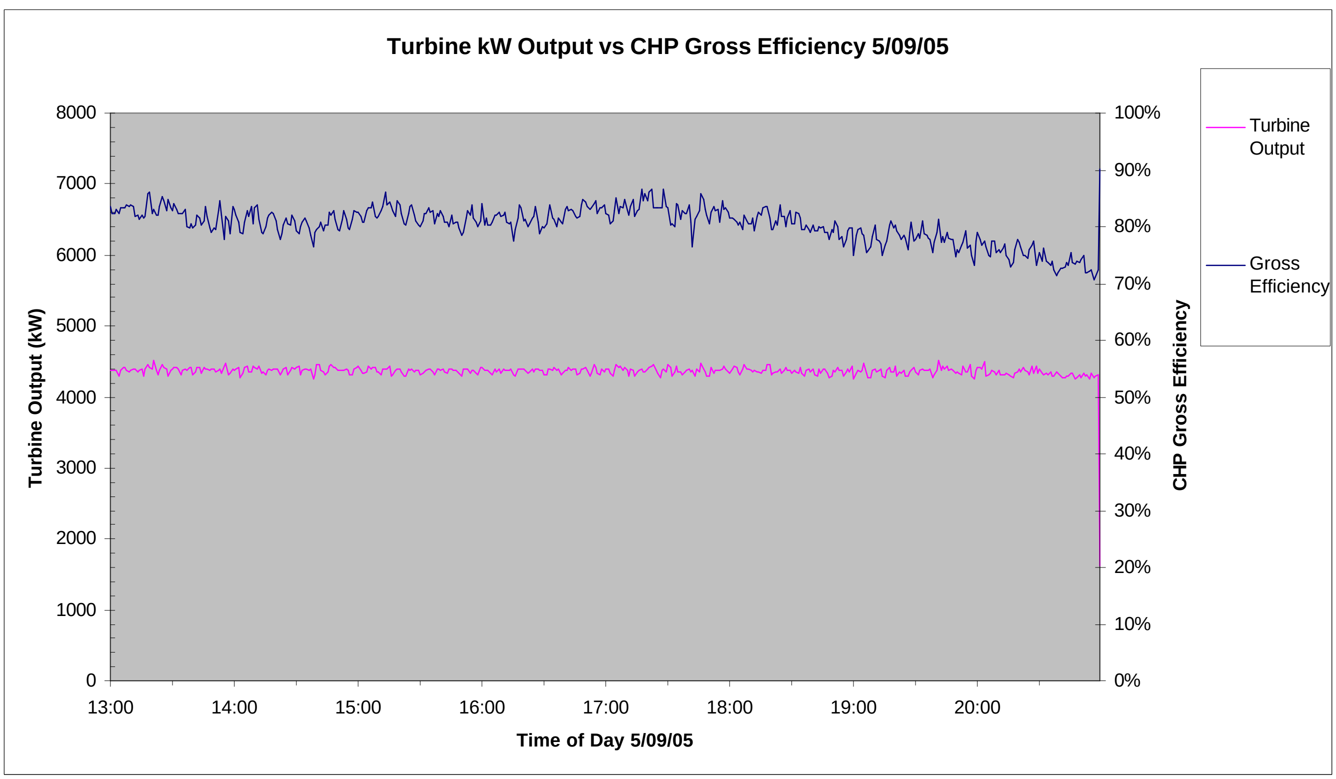

Figure 84 – Turbine kW output and CHP gross efficiency versus time of day 5/09/05

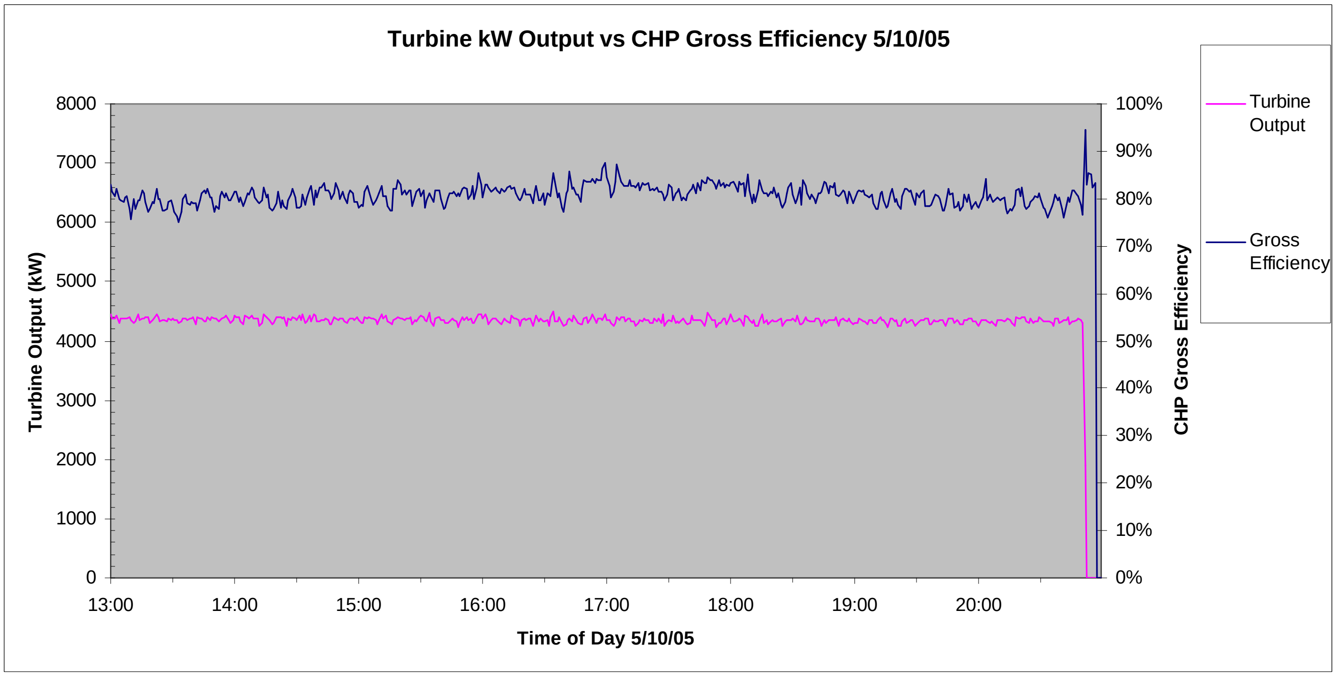

Figure 85 – Turbine kW output and CHP gross efficiency versus time of day 5/10/05

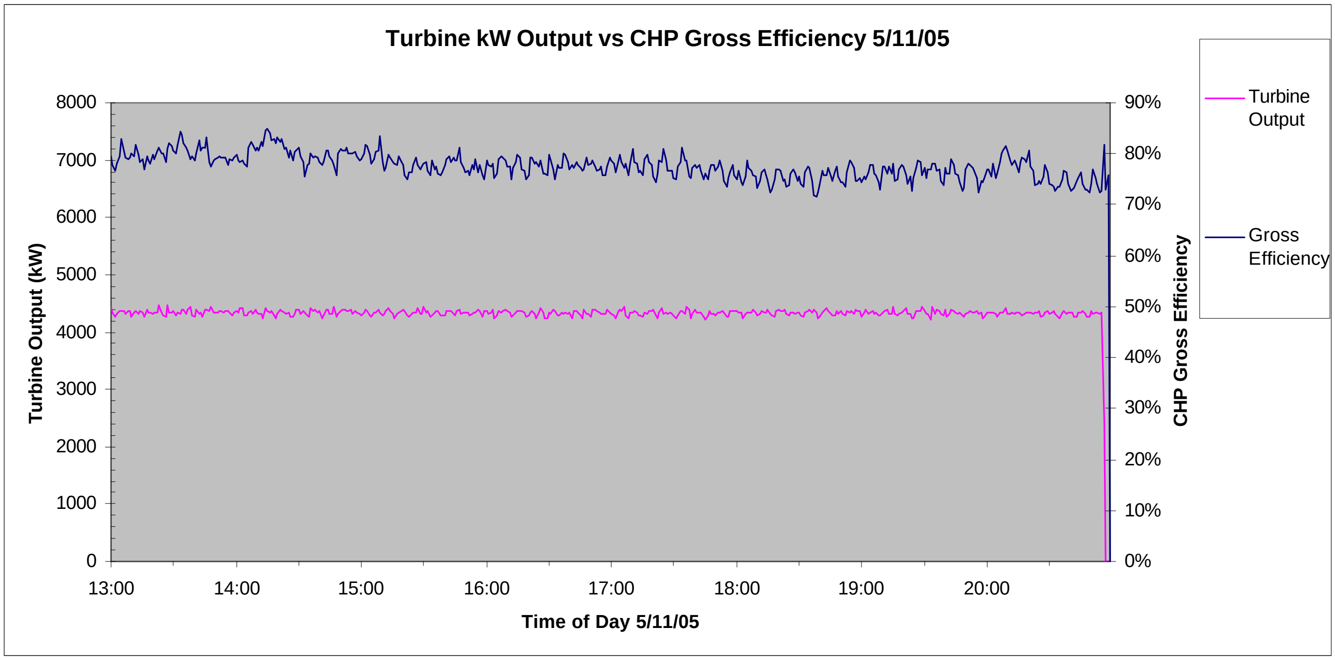

Figure 86 – Turbine kW output and CHP gross efficiency versus time of day 5/11/05

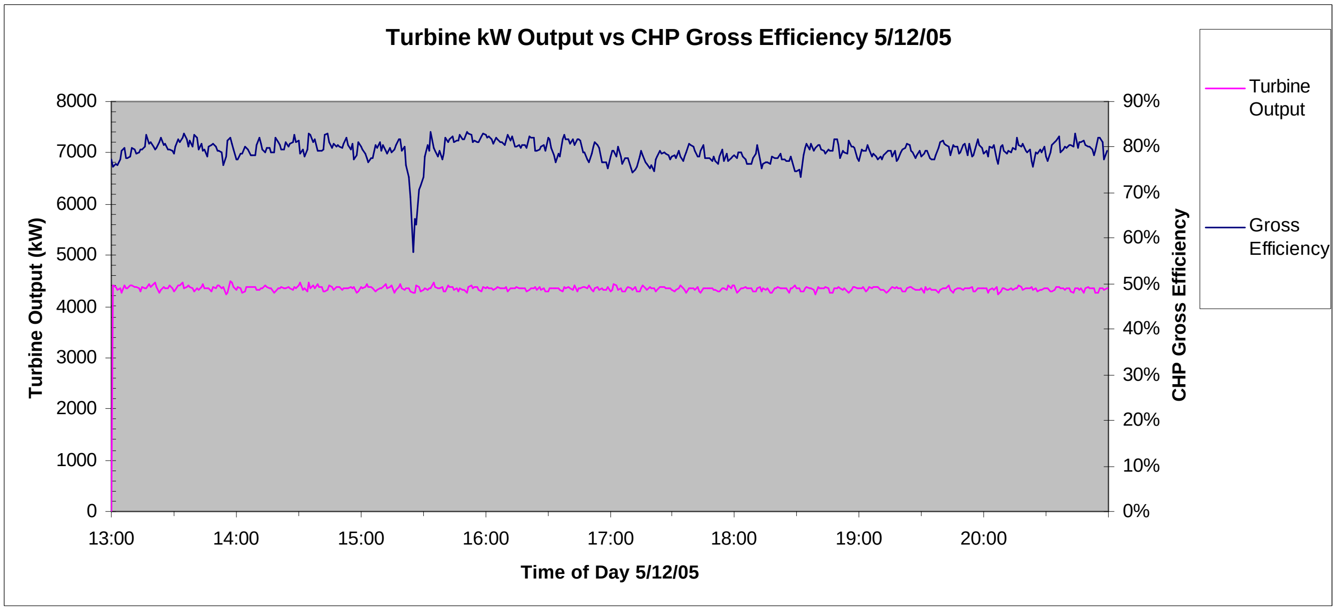

Figure 87 – Turbine kW output and CHP gross efficiency versus time of day 5/12/05

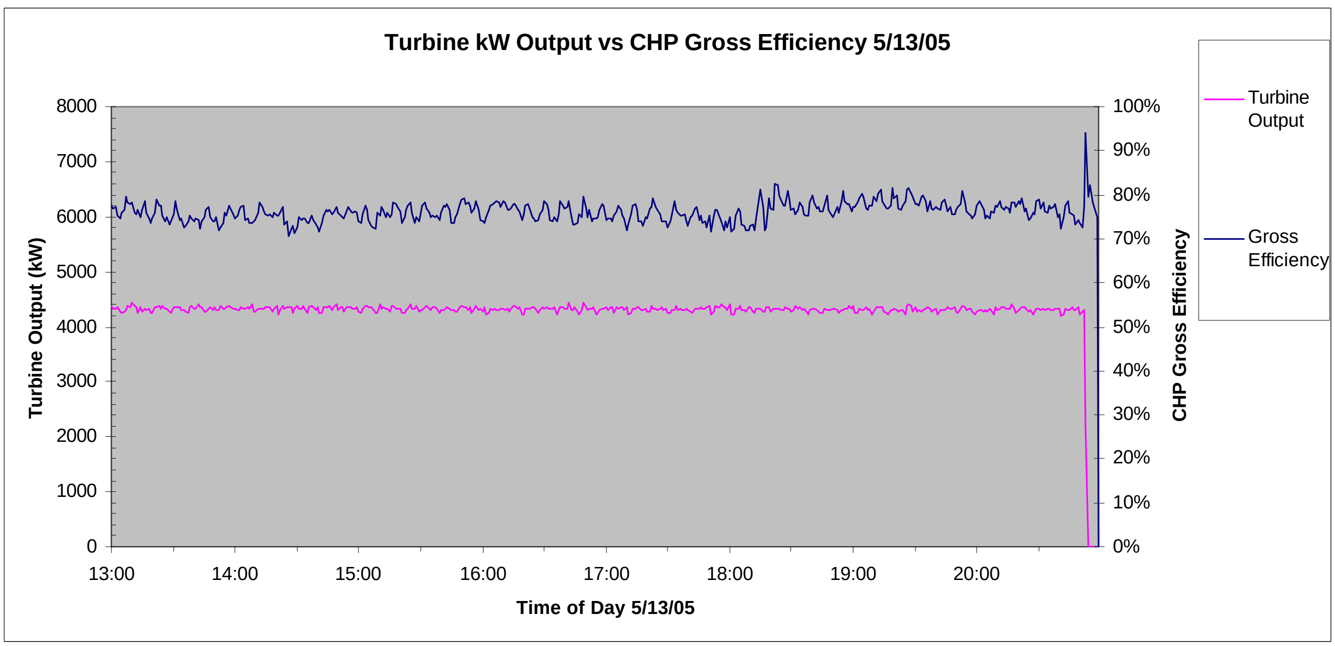

Figure 88 – Turbine kW output and CHP gross efficiency versus time of day 5/13/05

Figures 89 through 93 show the relationship between the ABS chiller tons and both the turbine efficiency and the CHP efficiency. As stated previously, the ABS tons and CHP efficiency show a direct relationship, while the turbine efficiency remained essentially constant and no direct relationship.

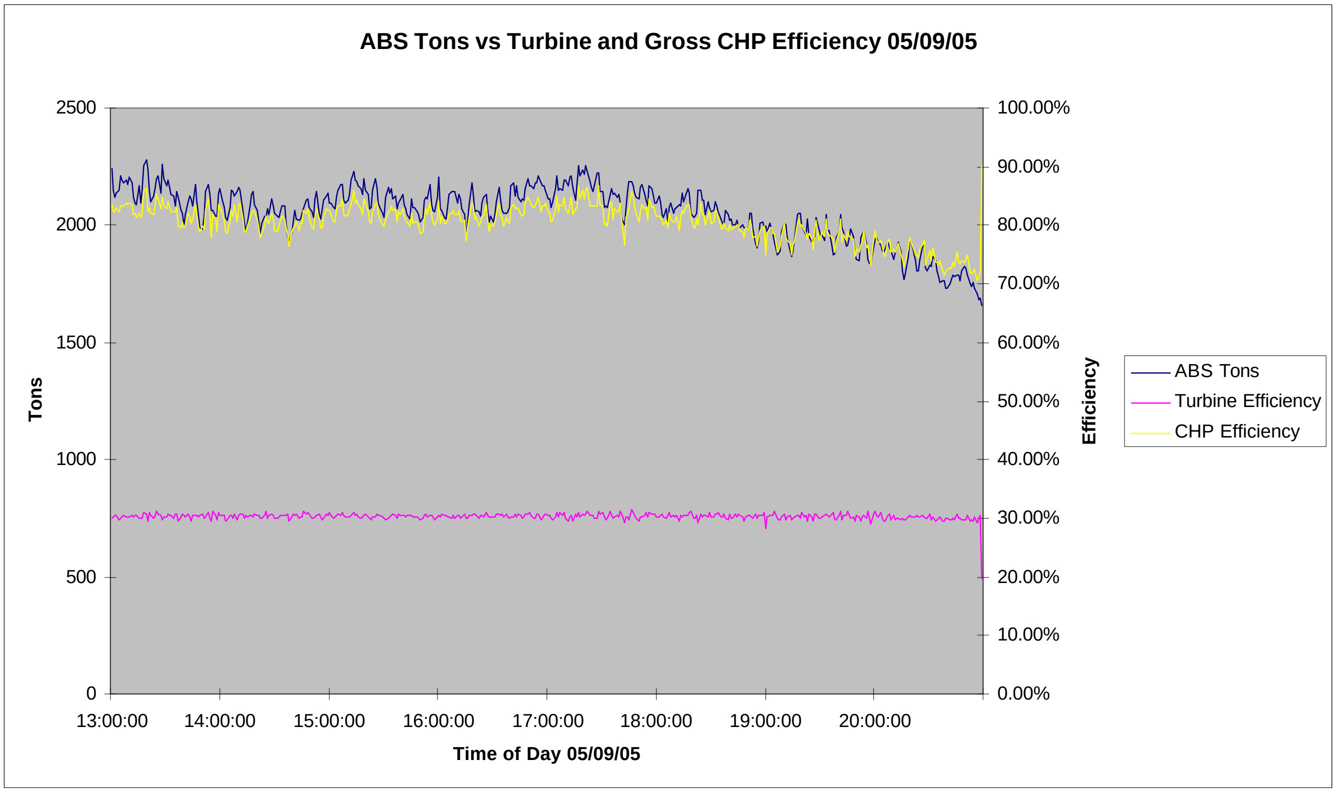

Figure 89 – ABS tons and turbine and CHP gross efficiencies versus time of day 5/09/05

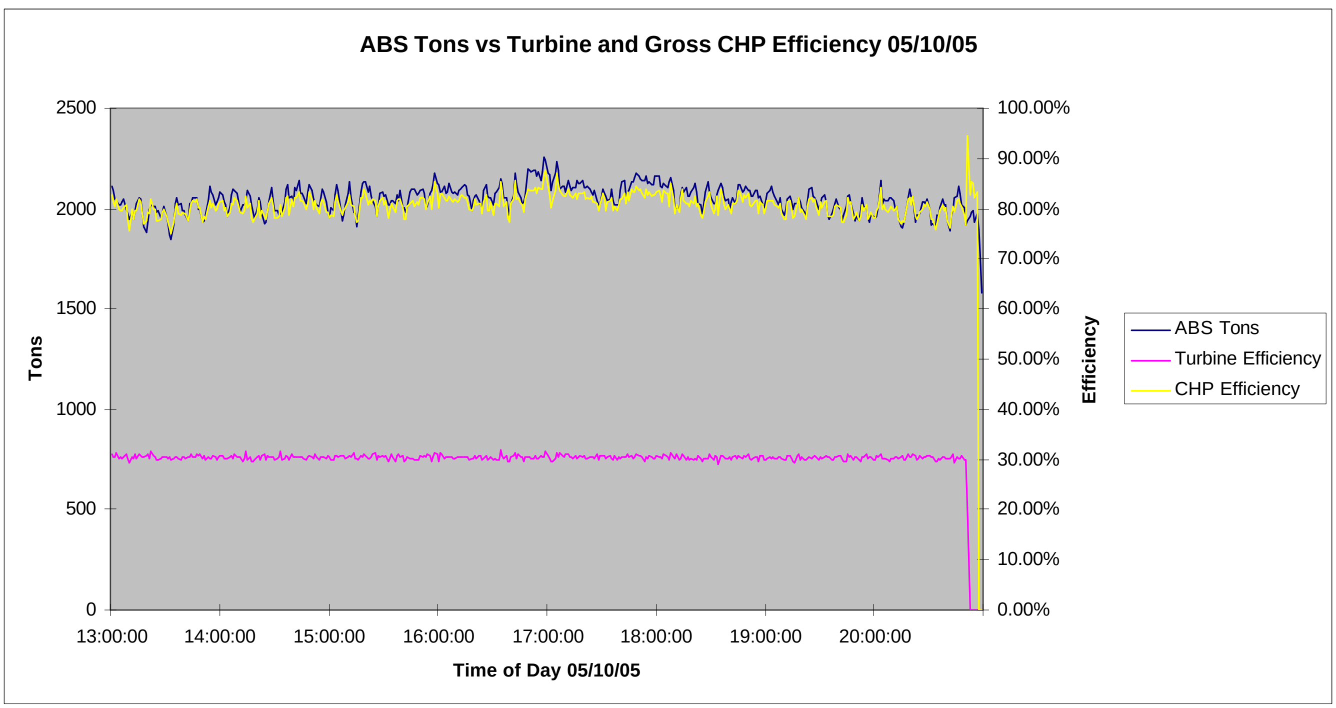

Figure 90 – ABS tons and turbine and CHP gross efficiencies versus time of day 5/10/05

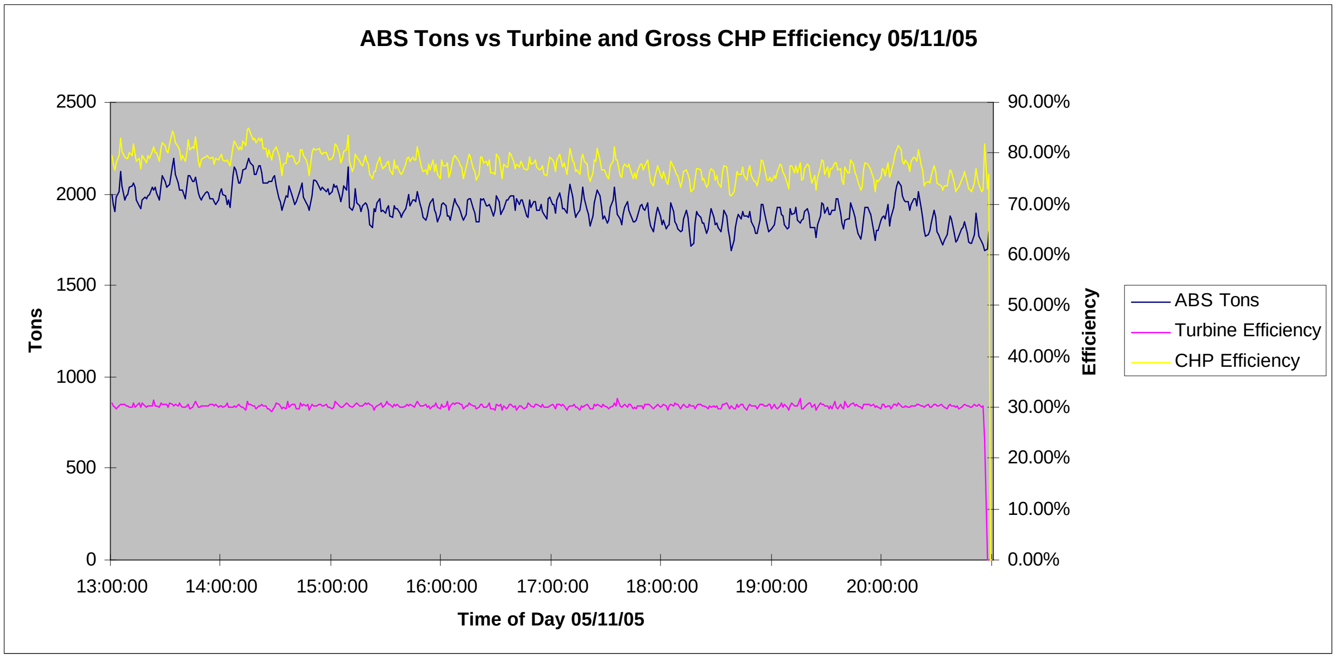

Figure 91 – ABS tons and turbine and CHP gross efficiencies versus time of day 5/11/05

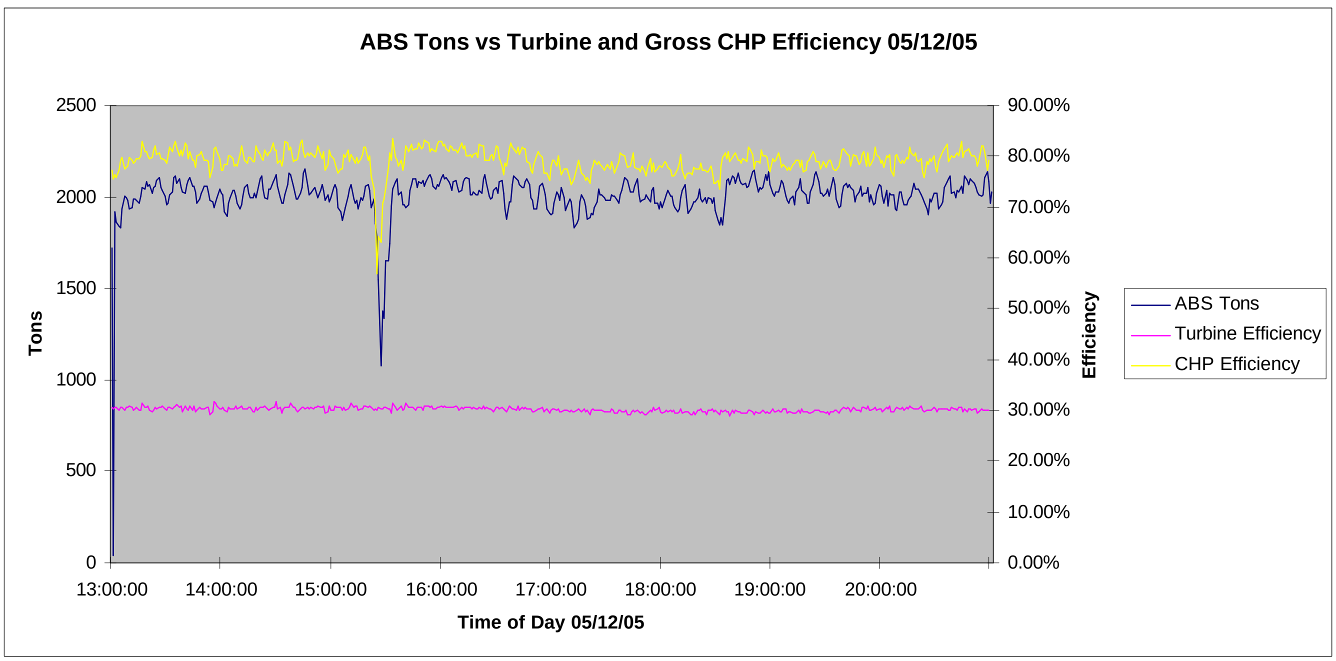

Figure 92 – ABS tons and turbine and CHP gross efficiencies versus time of day 5/12/05

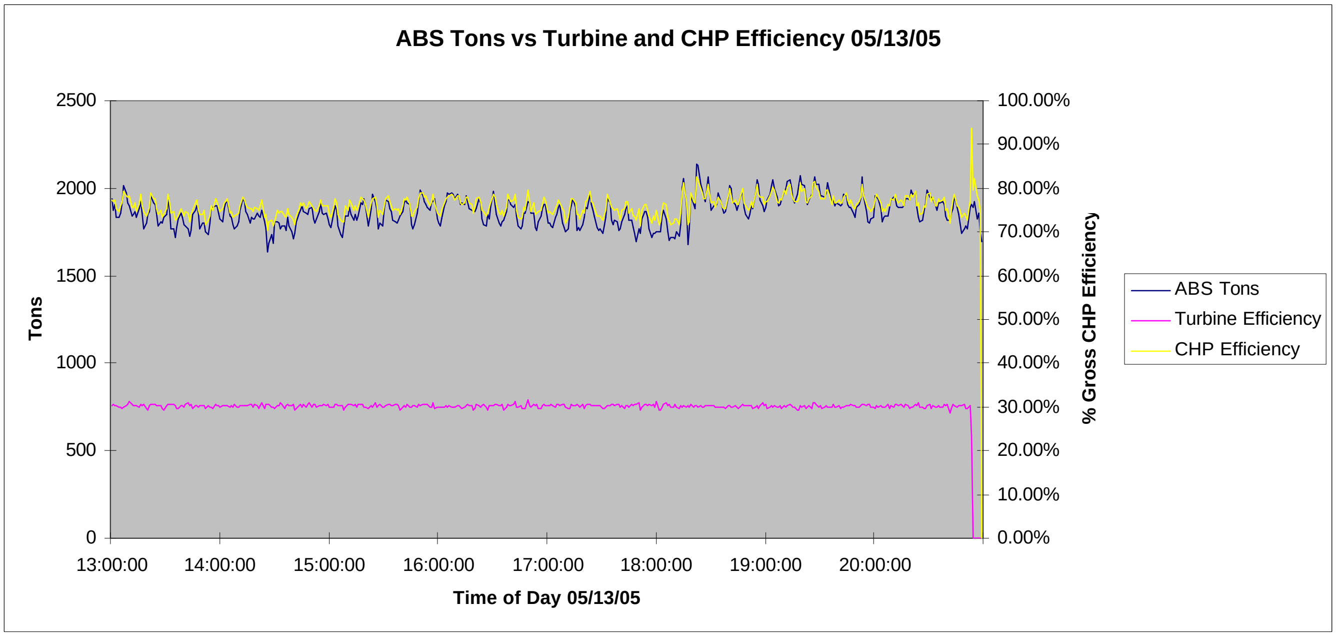

Figure 93 – ABS tons and turbine and CHP gross efficiencies versus time of day 5/13/05

Figures 94-105 from May 16 show the same relationships as those from May 9 through May 13.

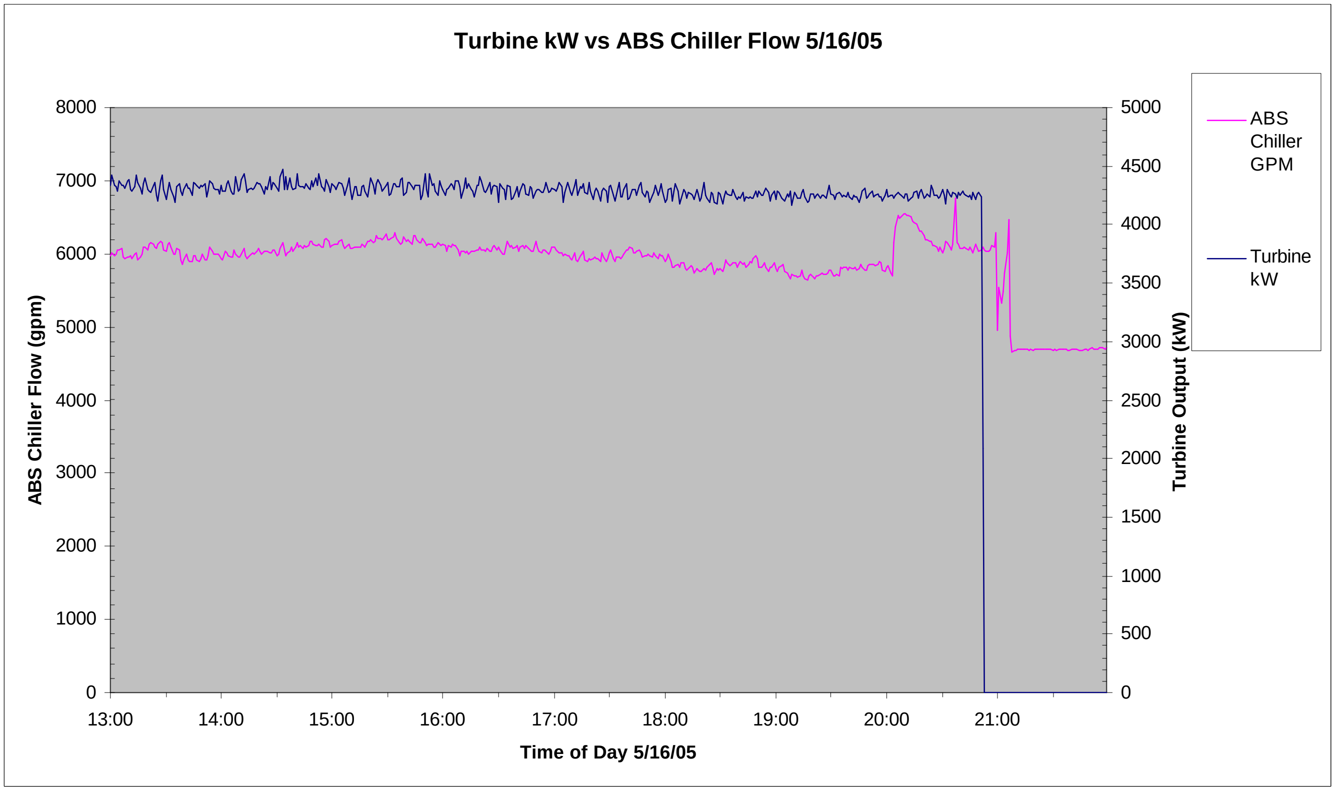

Figure 94 – Turbine kW output and ABS chiller water flow versus time of day 5/16/05

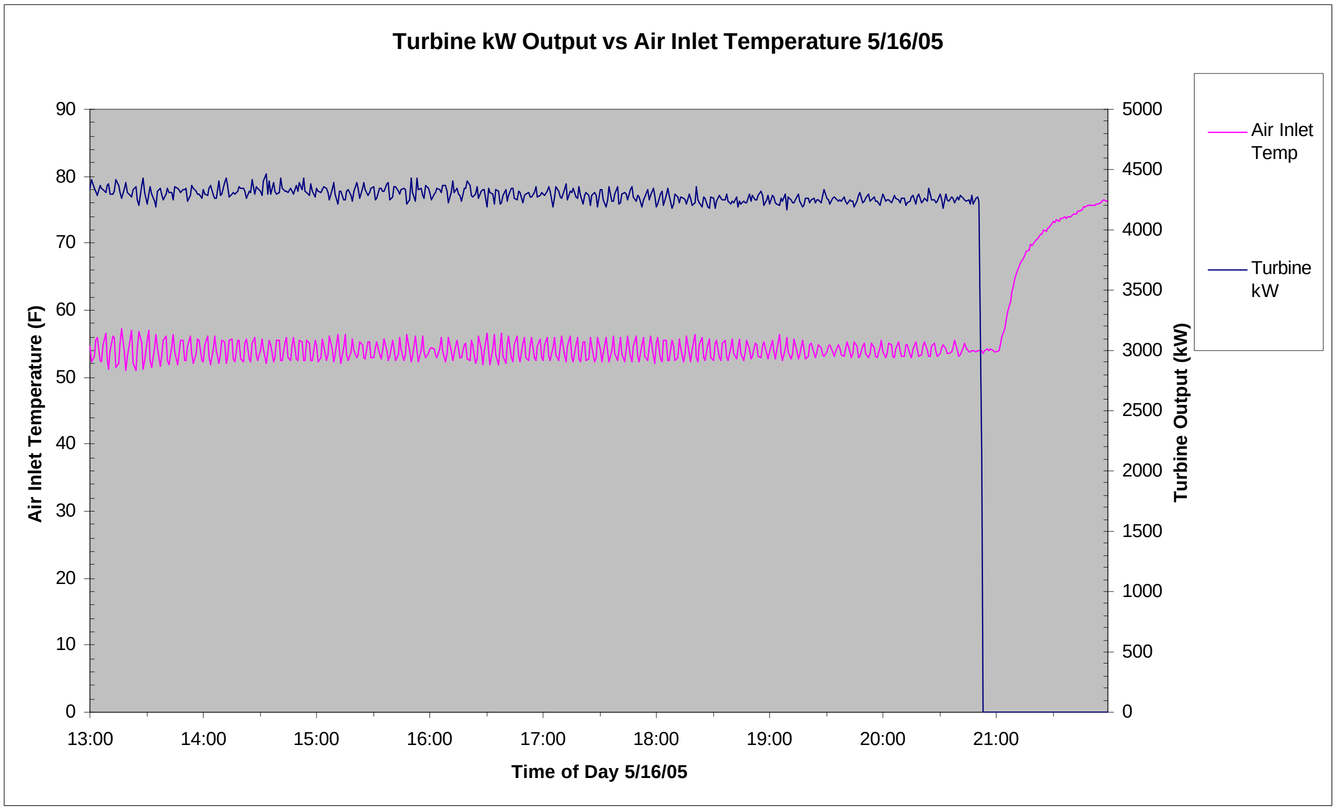

Figure 95– Turbine kW output and air inlet temperature versus time of day 5/16/05

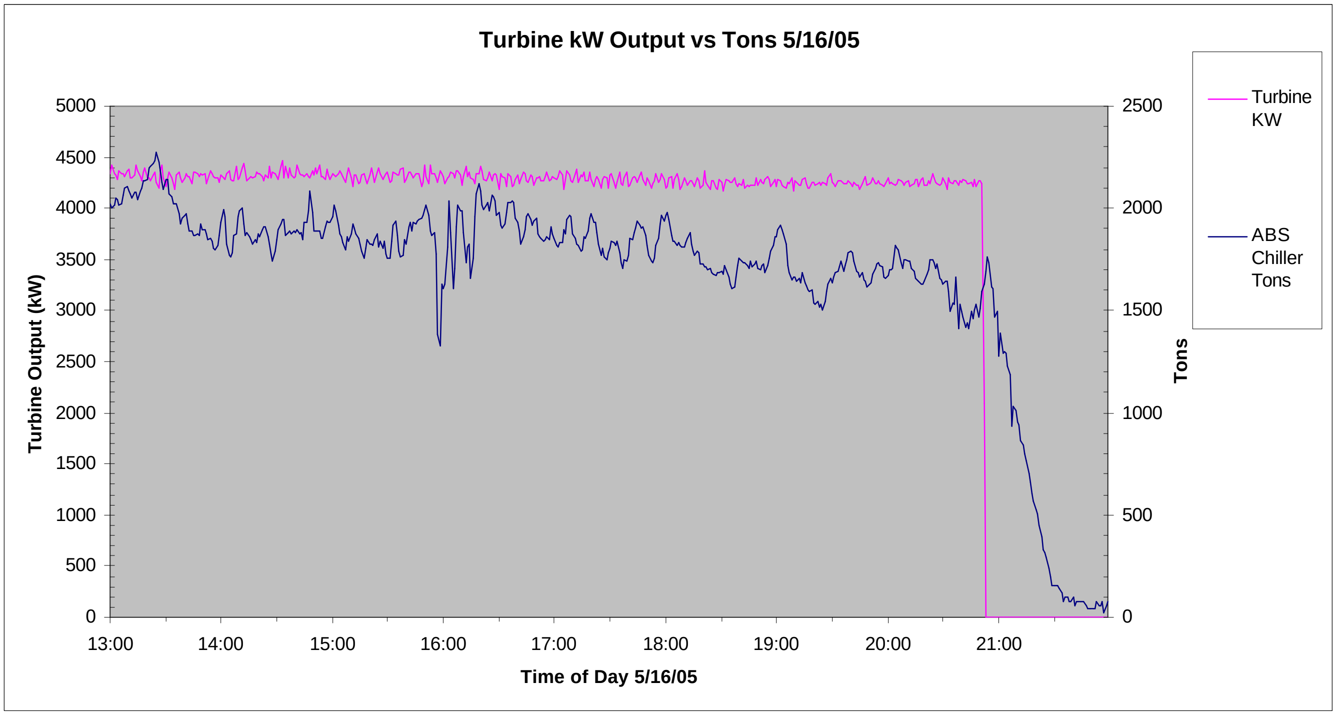

Figure 96– Turbine kW output and chiller tons versus time of day 5/16/05

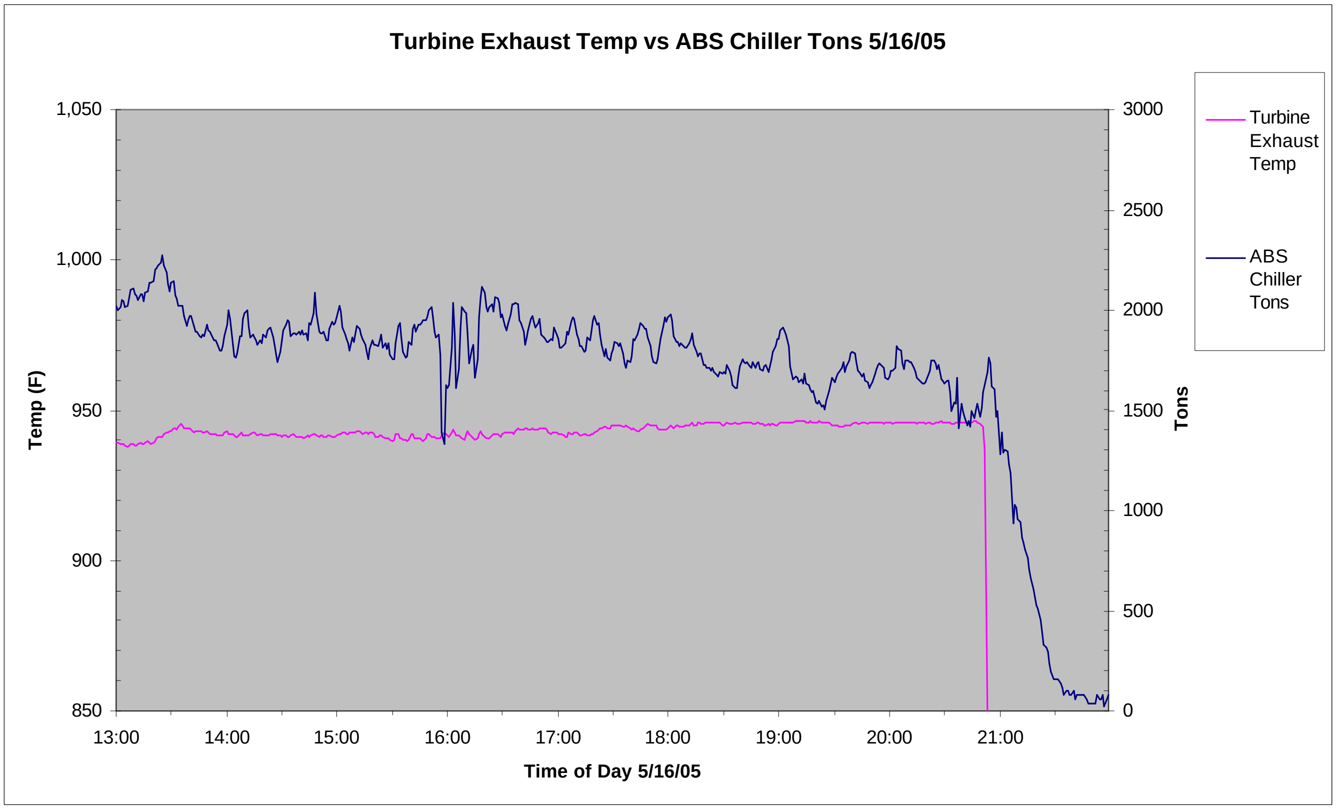

Figure 97– Turbine exhaust temperature and ABS tons versus time of day 5/16/05

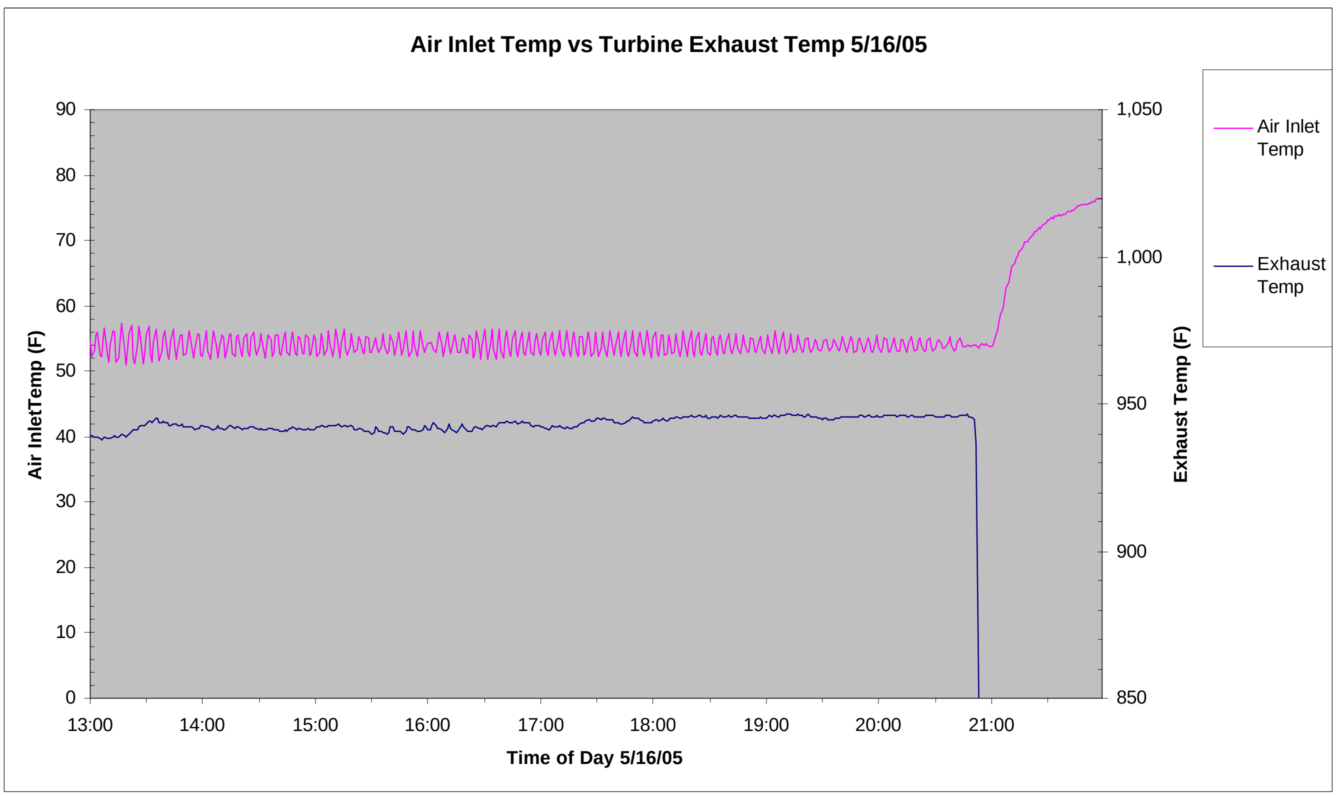

Figure 98– Air inlet and turbine exhaust temperatures versus time of day 5/16/05

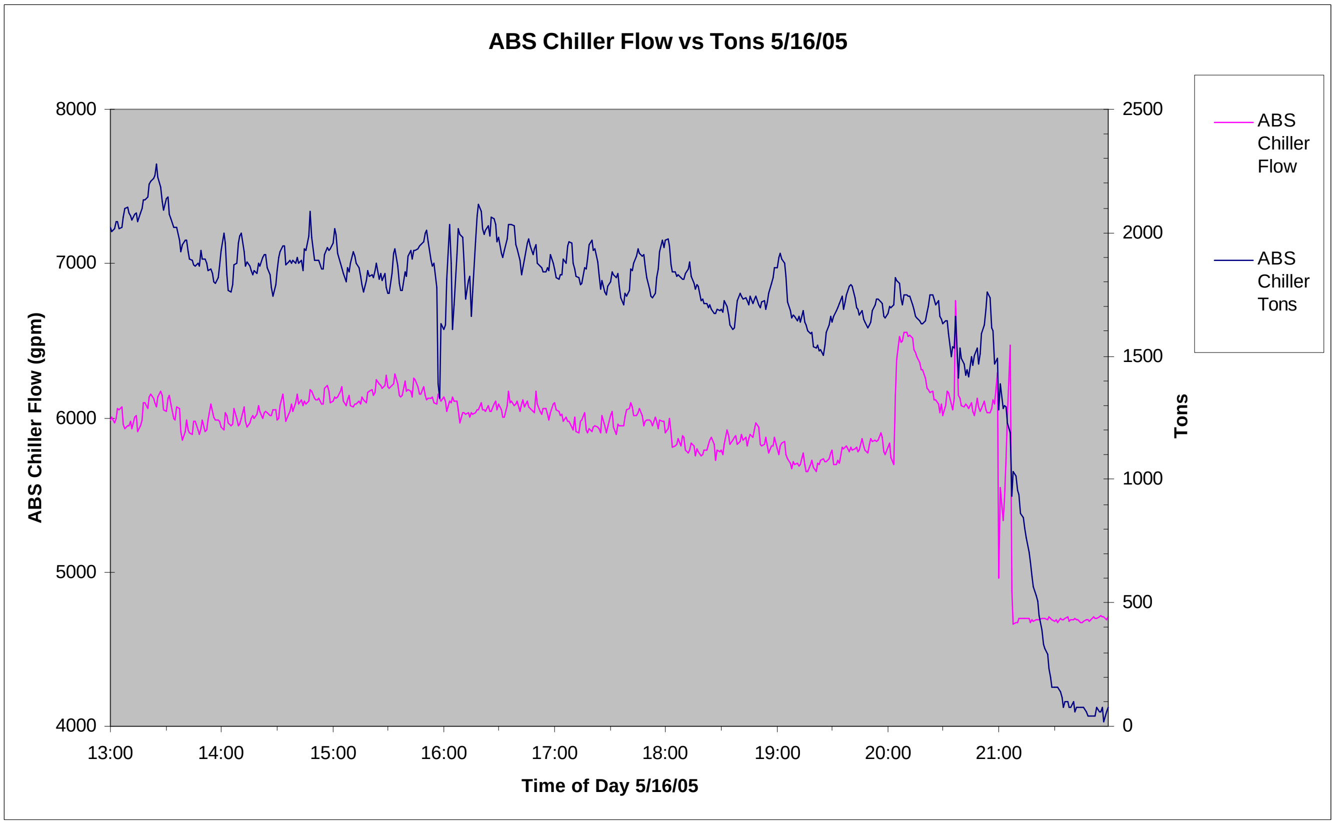

Figure 99– ABS chilled water flow and ABS tons versus time of day 5/16/05

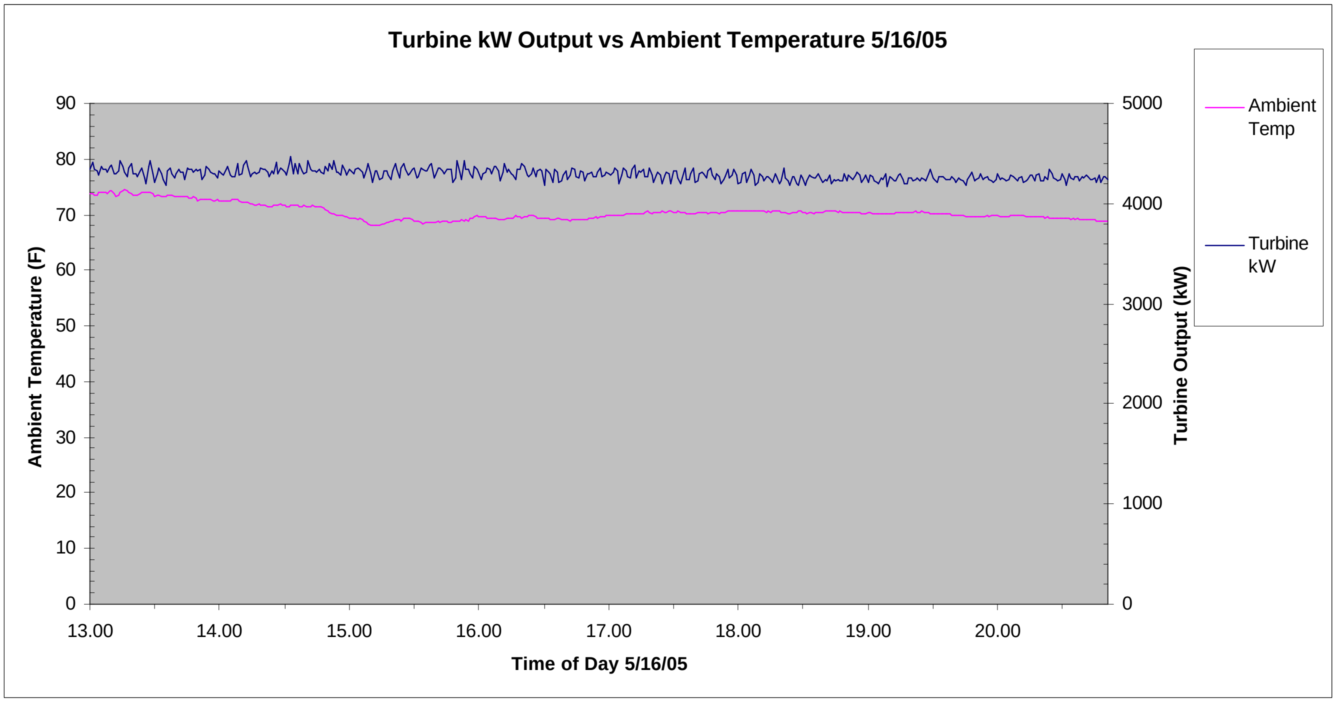

Figure 100– Turbine kW output and ambient temperature versus time of day 5/16/05

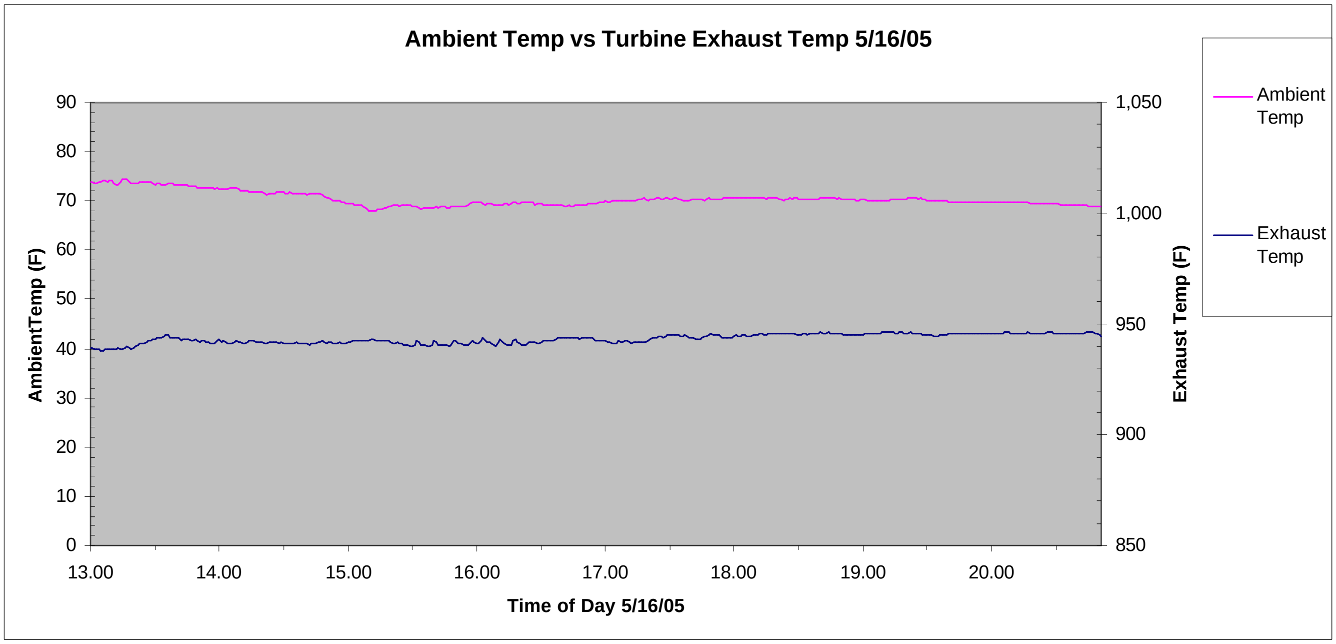

Figure 101– Ambient and turbine exhaust temperatures versus time of day 5/16/05

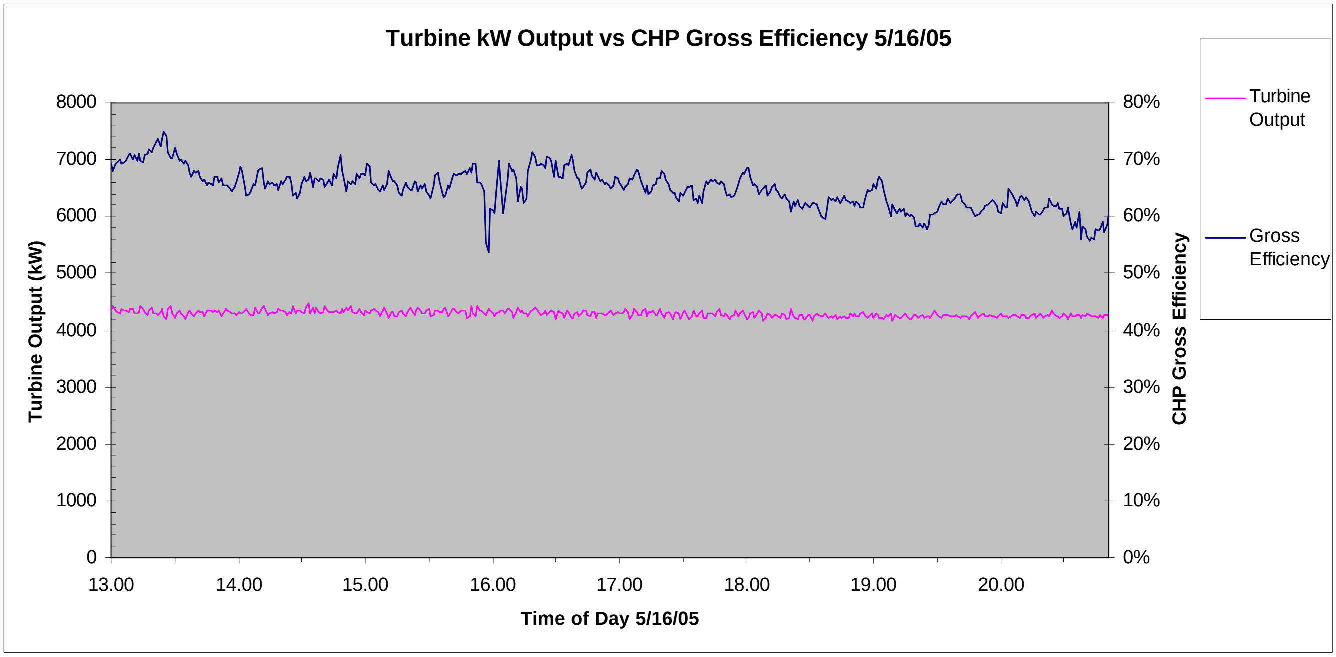

Figure 102– Turbine kW output and CHP gross efficiency versus time of day 5/16/05

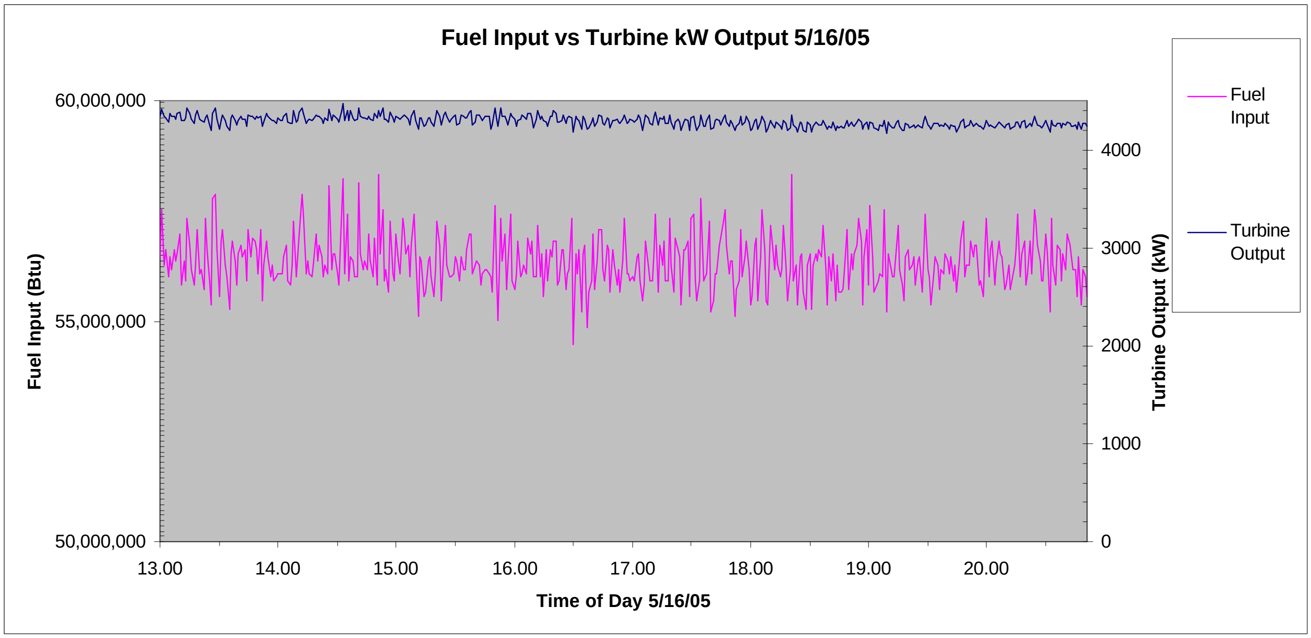

Figure 103– Turbine fuel input and turbine kW output versus time of day 5/16/05

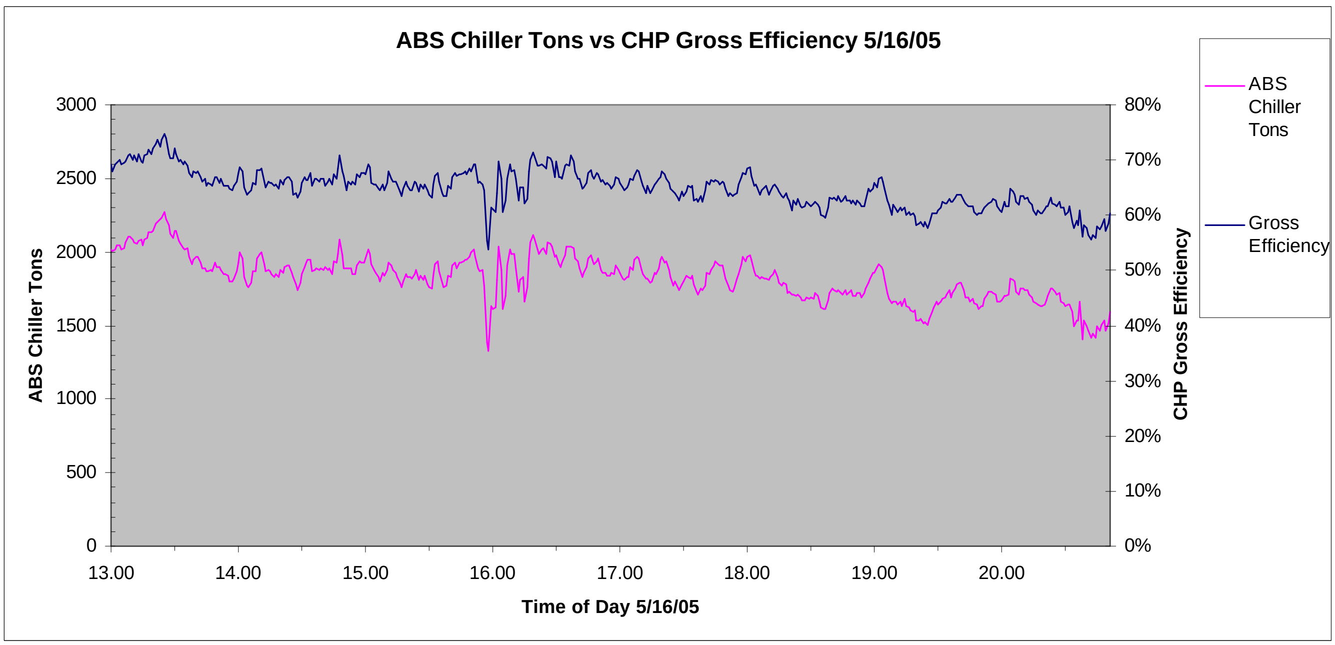

Figure 104– ABS tons and CHP gross efficiency versus time of day 5/16/05

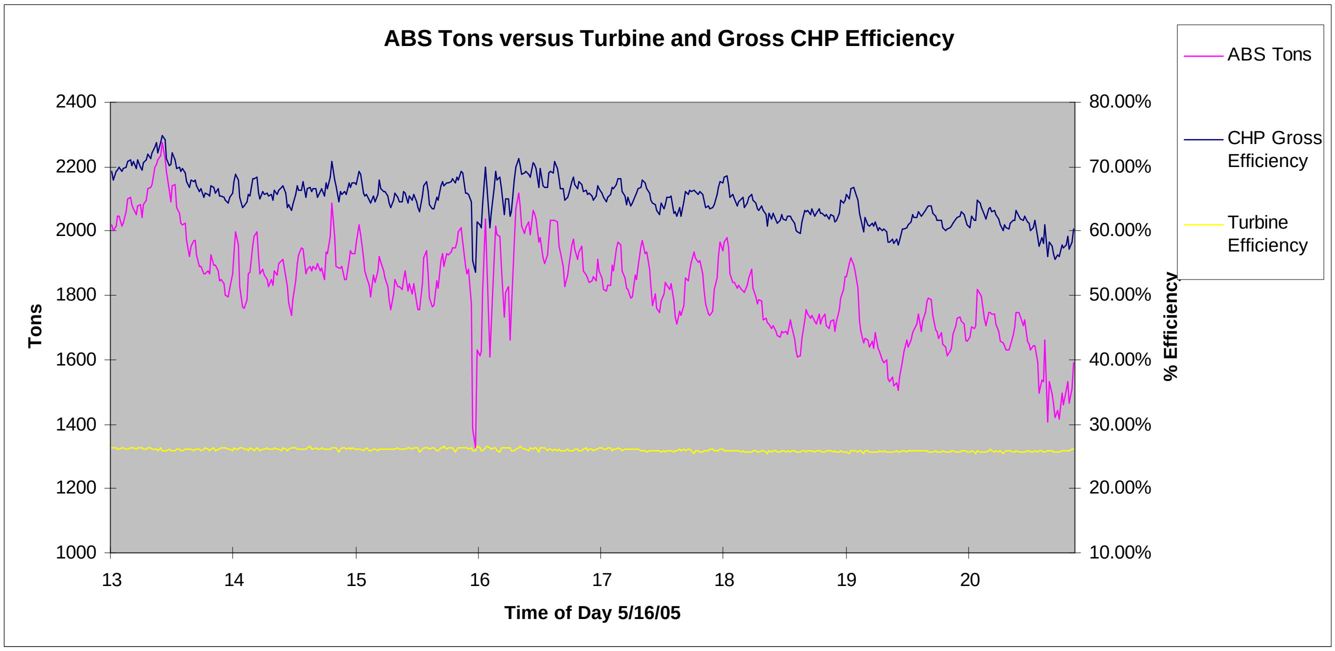

Figure 105– ABS tons and turbine and CHP gross Efficiencies versus time of day 5/16/05

Figures 106 through 120 show the same variables as the other days in May, except each graph shows multiple days. For the majority of the graphs, you can see the daily variations in at least one of the two variables.

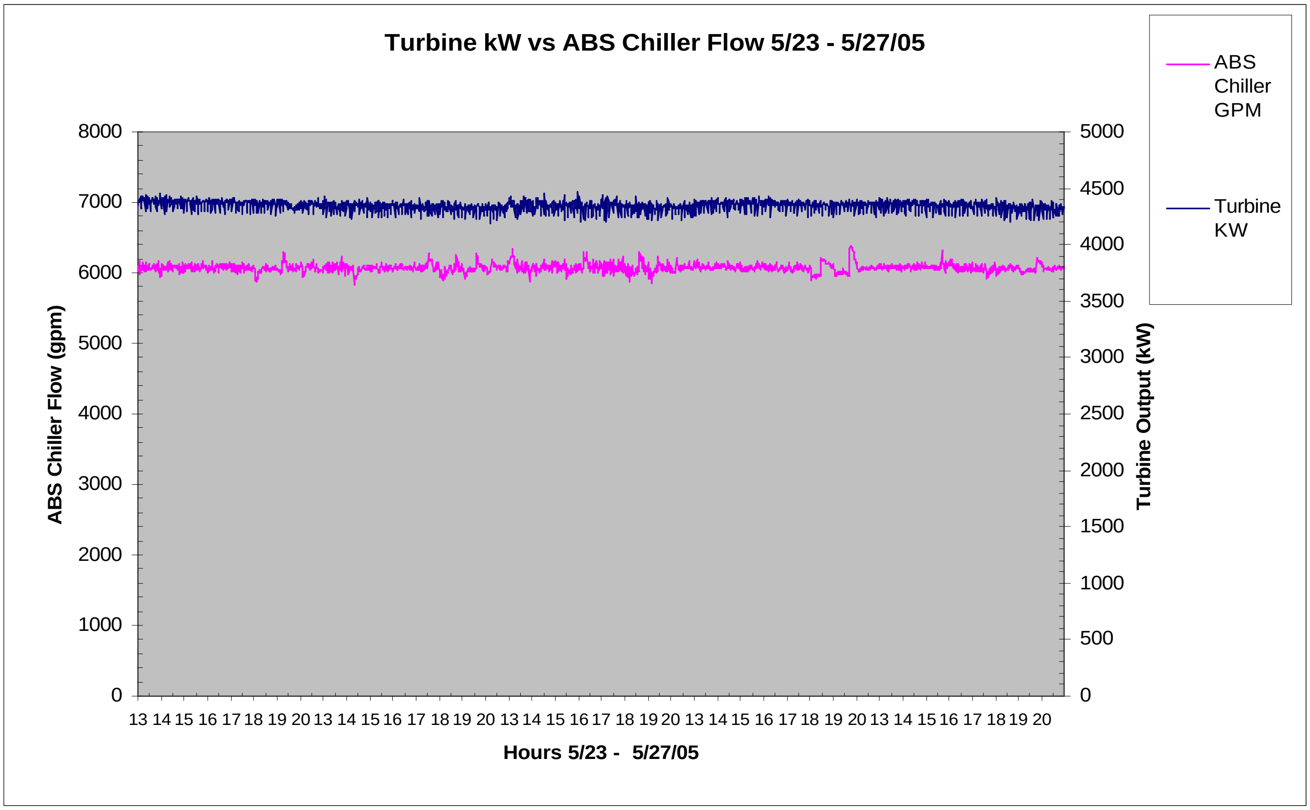

Figure 106– Turbine kW output and ABS chilled water flow versus time 5/23- 27/05

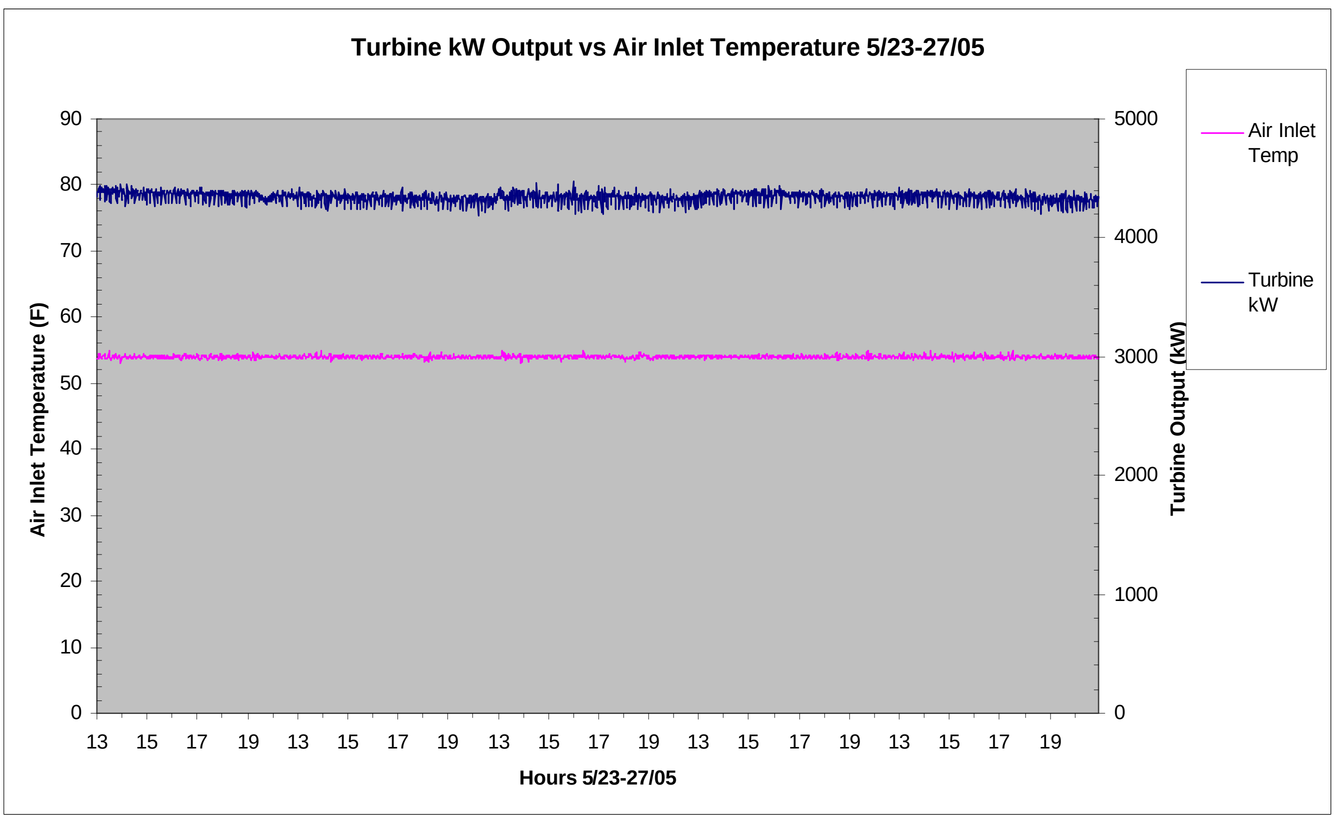

Figure 107– Turbine kW output and air inlet temperature versus time 5/23- 27/05

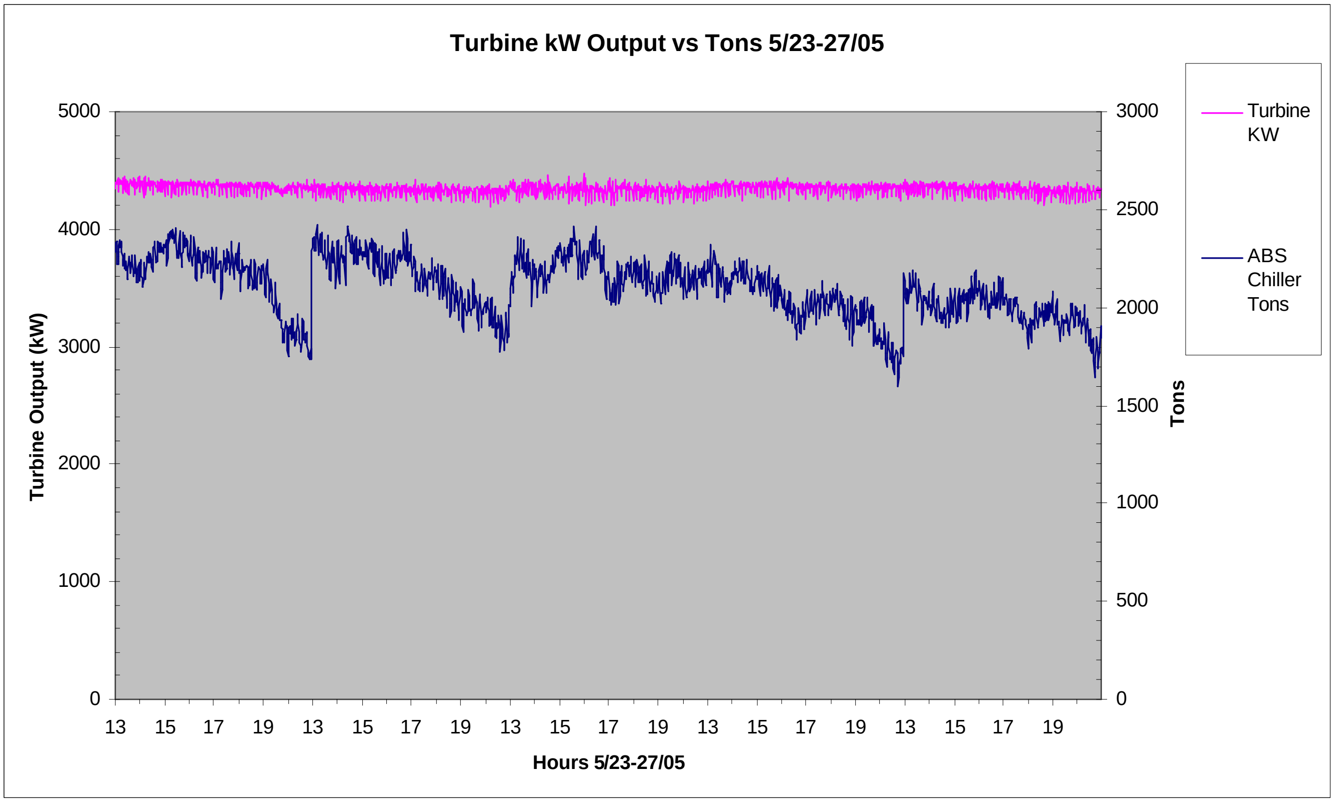

Figure 108– Turbine kW output and ABS tons versus time 5/23- 27/05

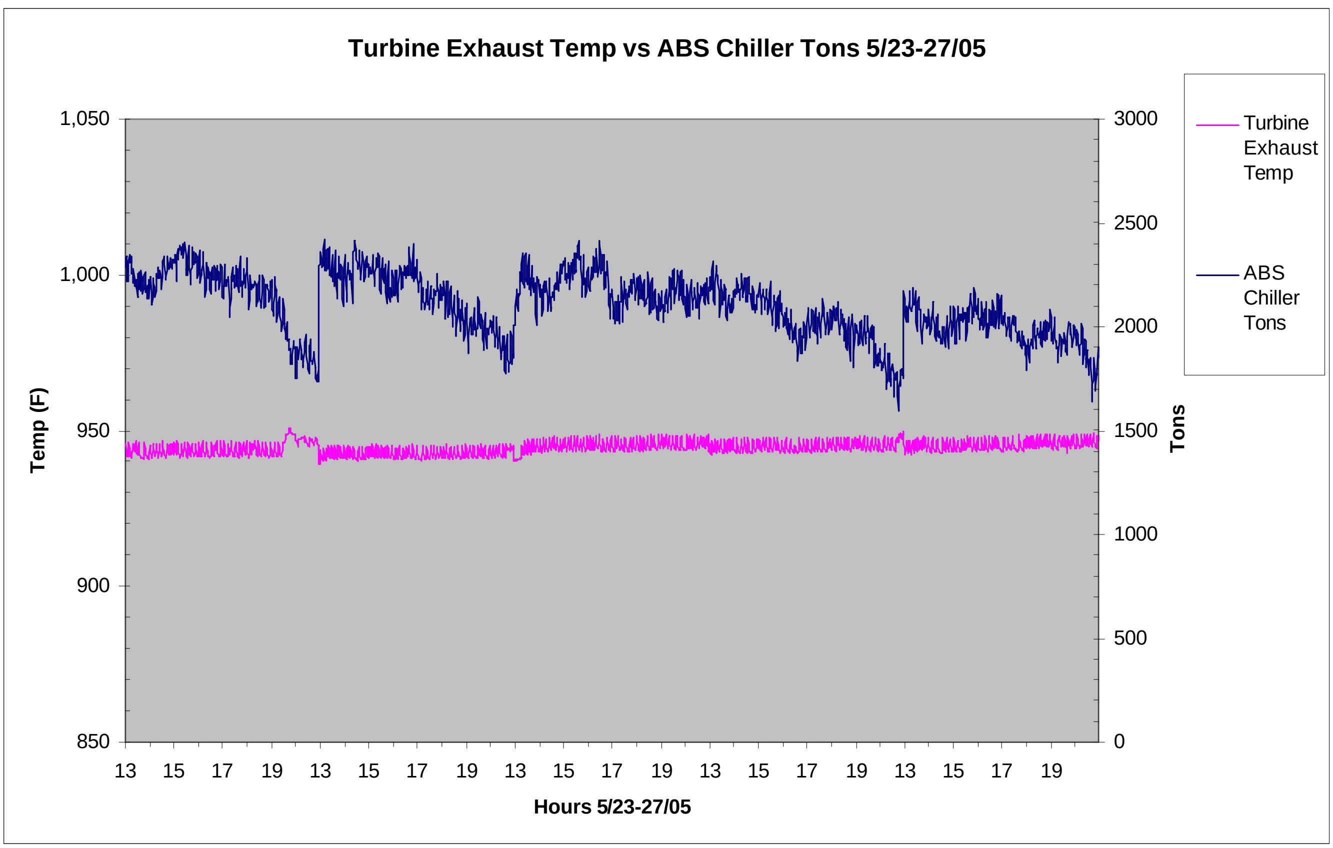

Figure 109– Turbine exhaust temperature and ABS tons versus time 5/23- 27/05

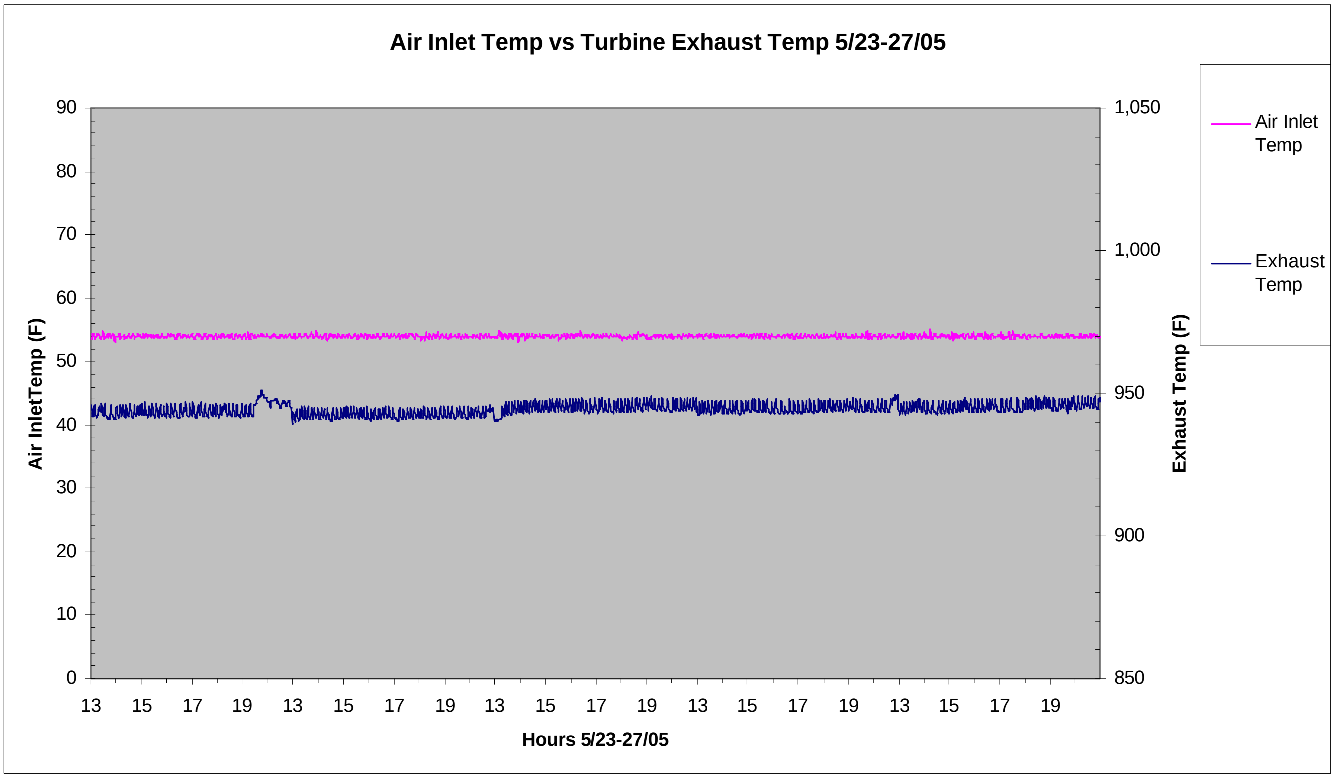

Figure 110 – Air inlet and turbine exhaust temperatures versus time 5/23- 27/05

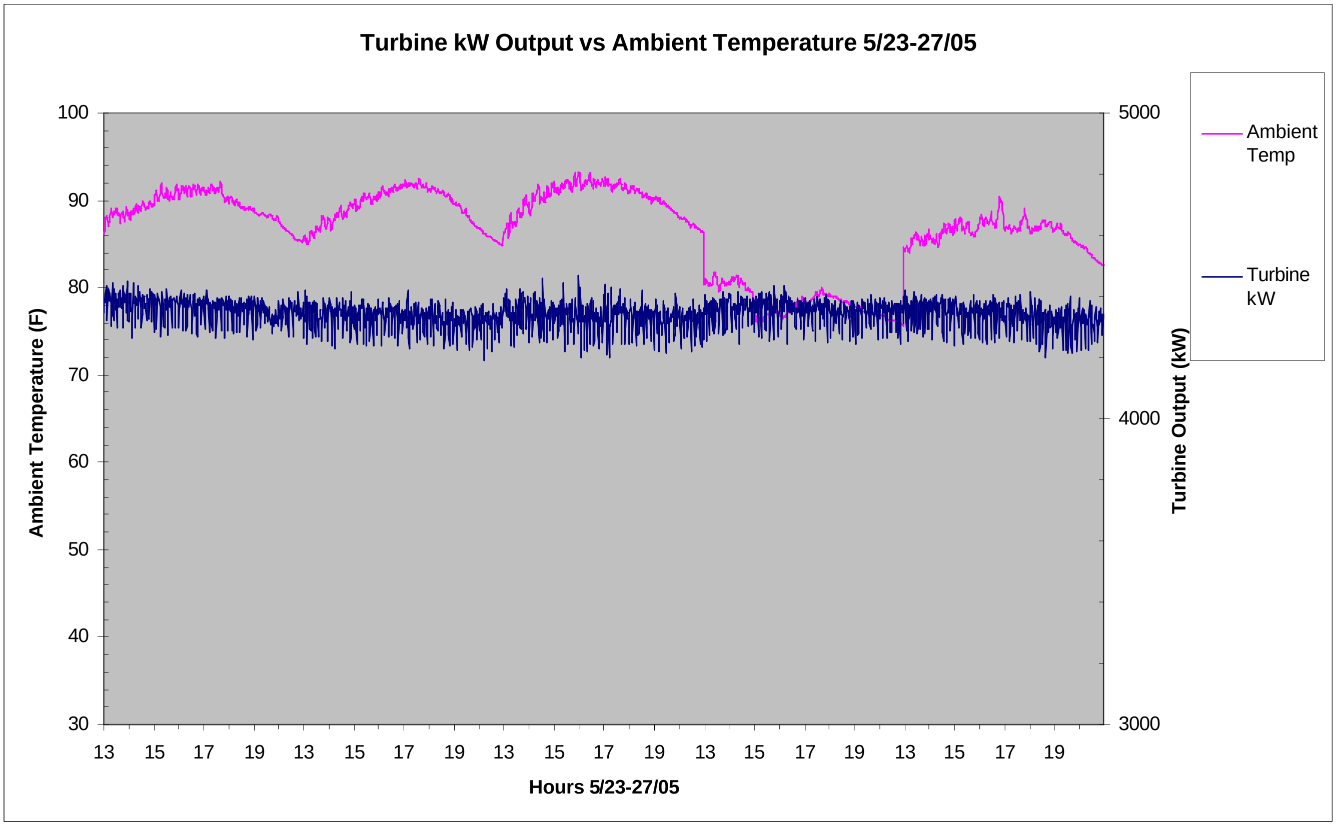

Figure 111 – Turbine kW output and ambient temperature versus time 5/23- 27/05

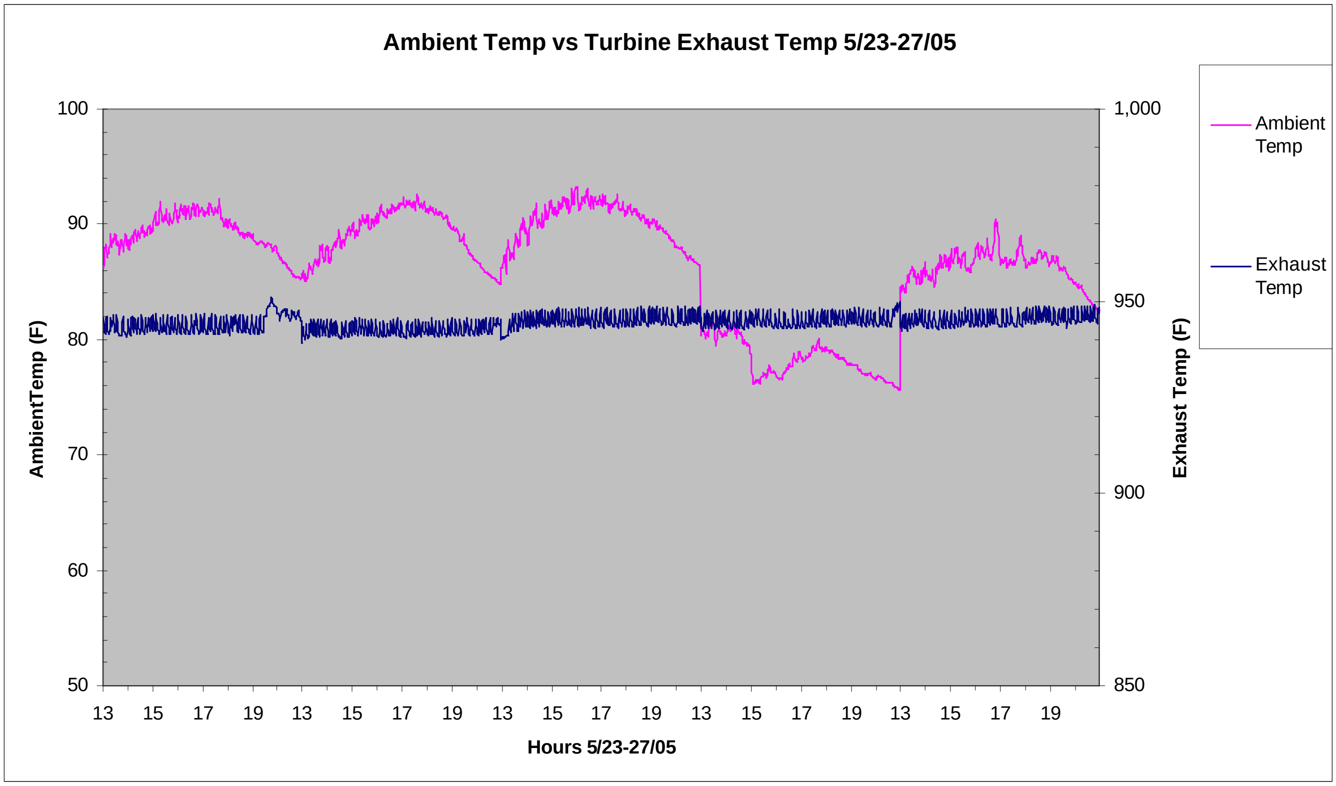

Figure 112 – Ambient and turbine exhaust temperatures versus time 5/23 - 27/05

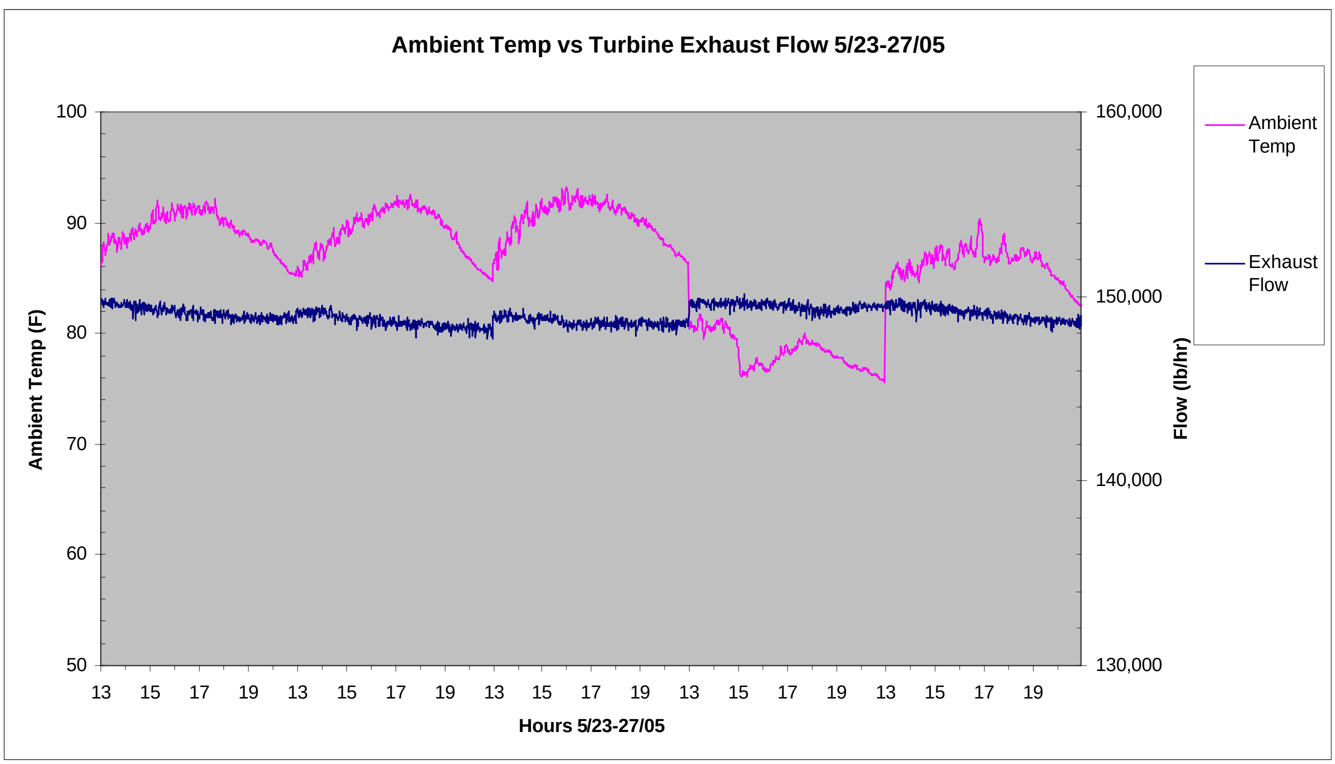

Figure 113 – Ambient temperature and turbine exhaust flow versus time 5/23 – 27/05

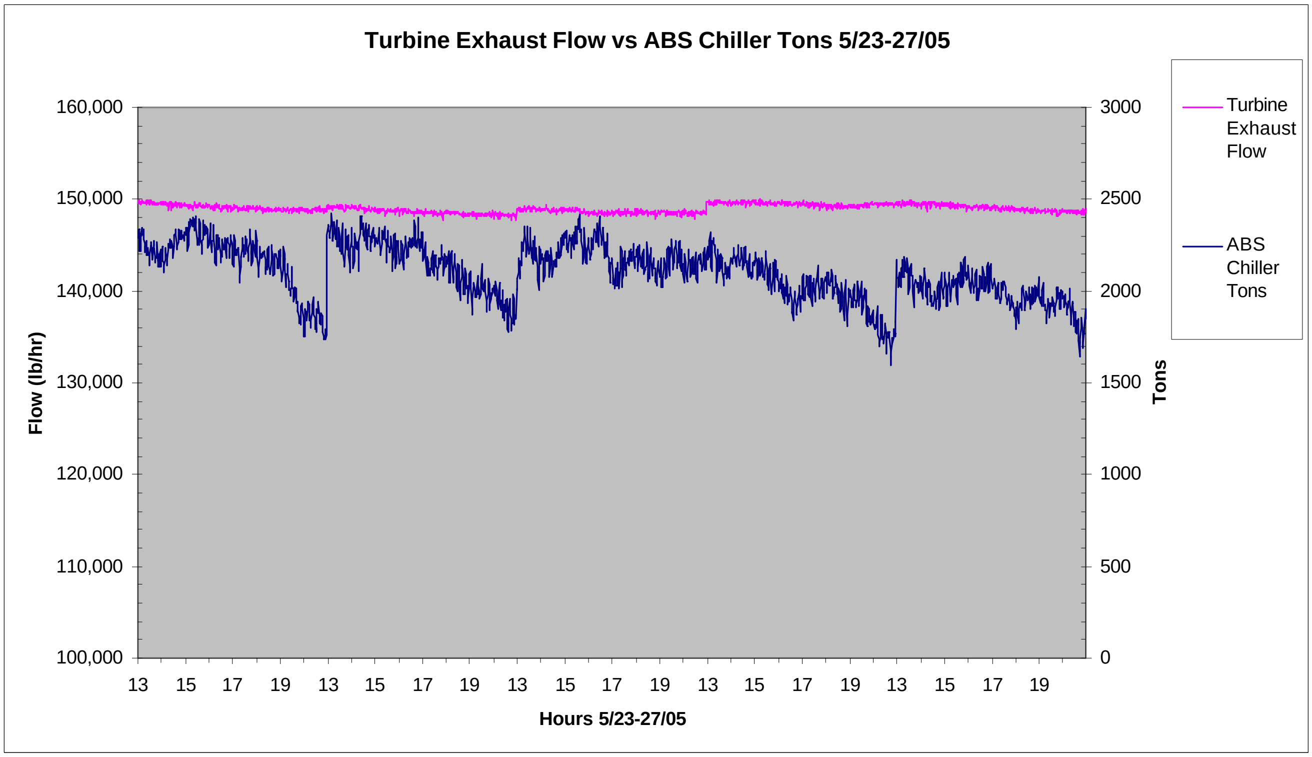

Figure 114 – Turbine exhaust flow and ABS tons versus time 5/5/23 - 27/05

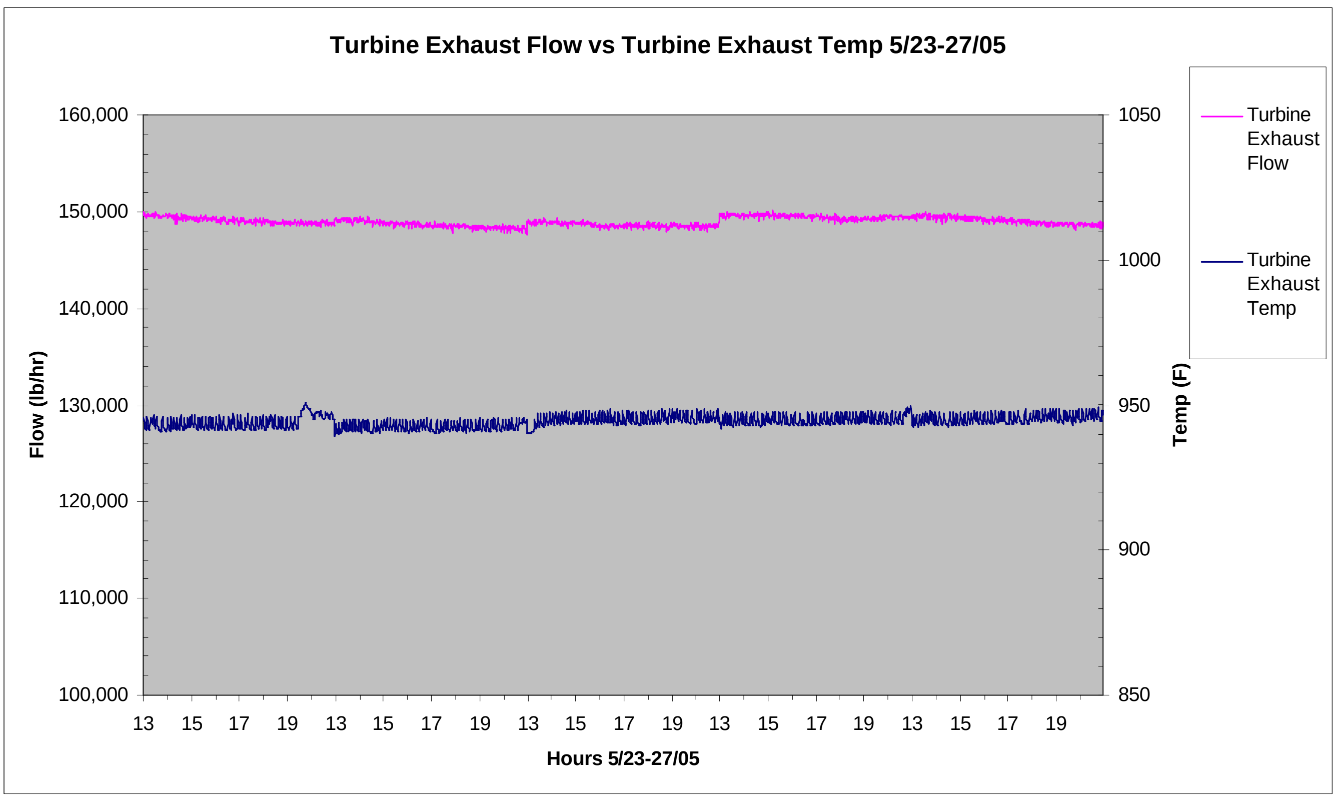

Figure 115 – Turbine exhaust flow and turbine exhaust temperature versus time 5/23 - 27/05

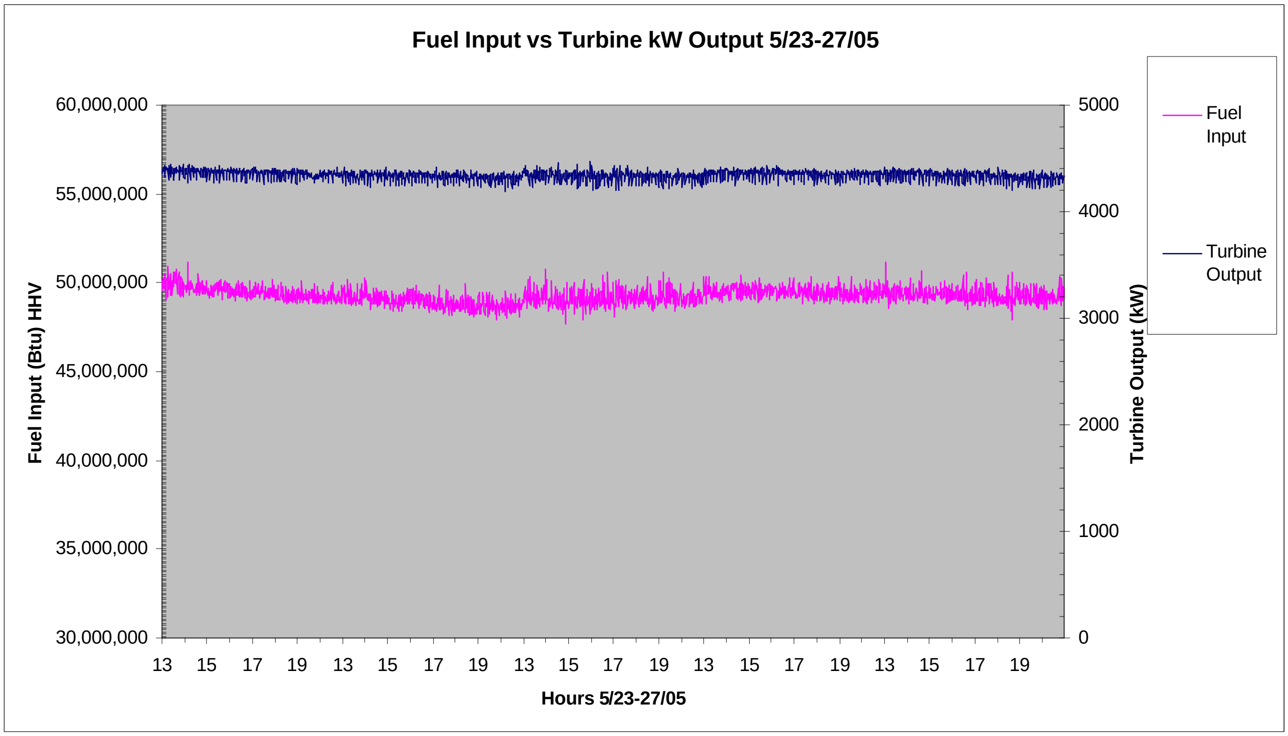

Figure 116 – Turbine fuel input and turbine kW output versus time 5/23 - 27/05

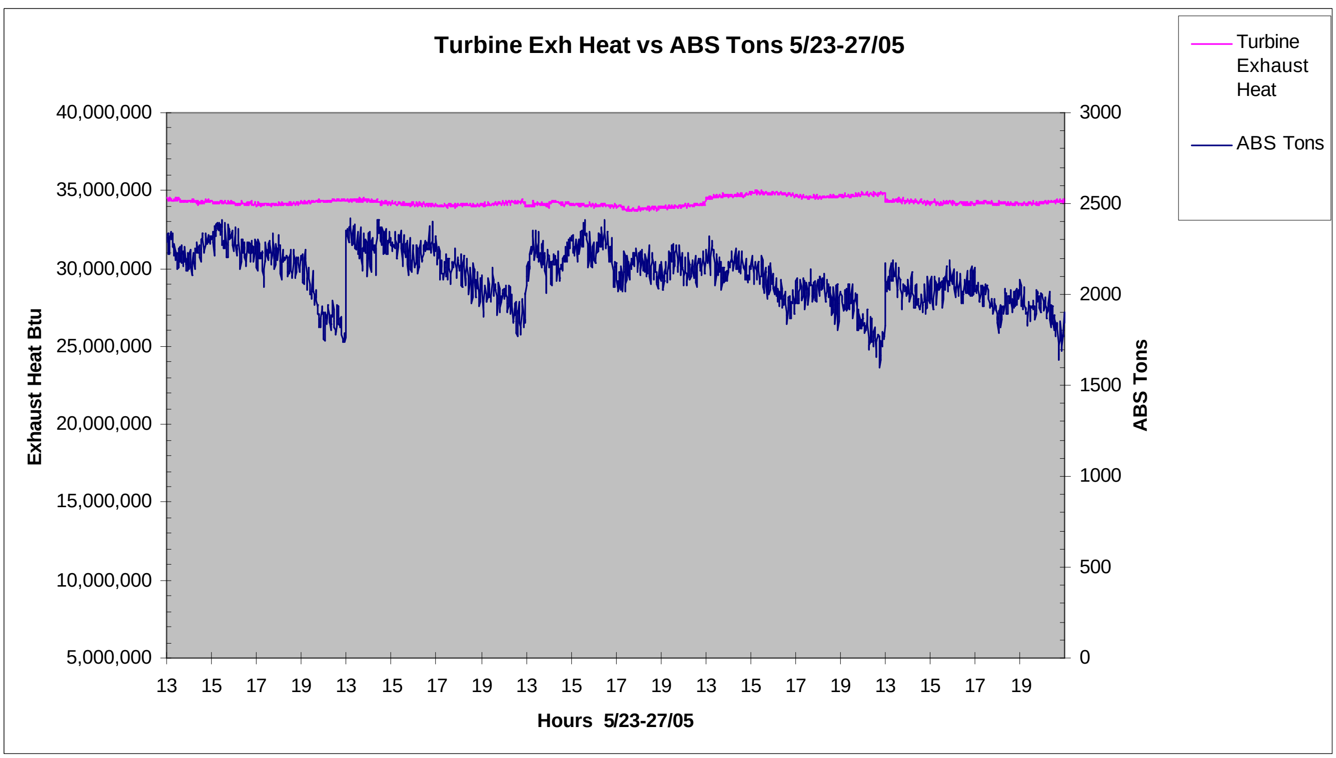

Figure 117 – Turbine exhaust heat and ABS tons versus time 5/23 - 27/05

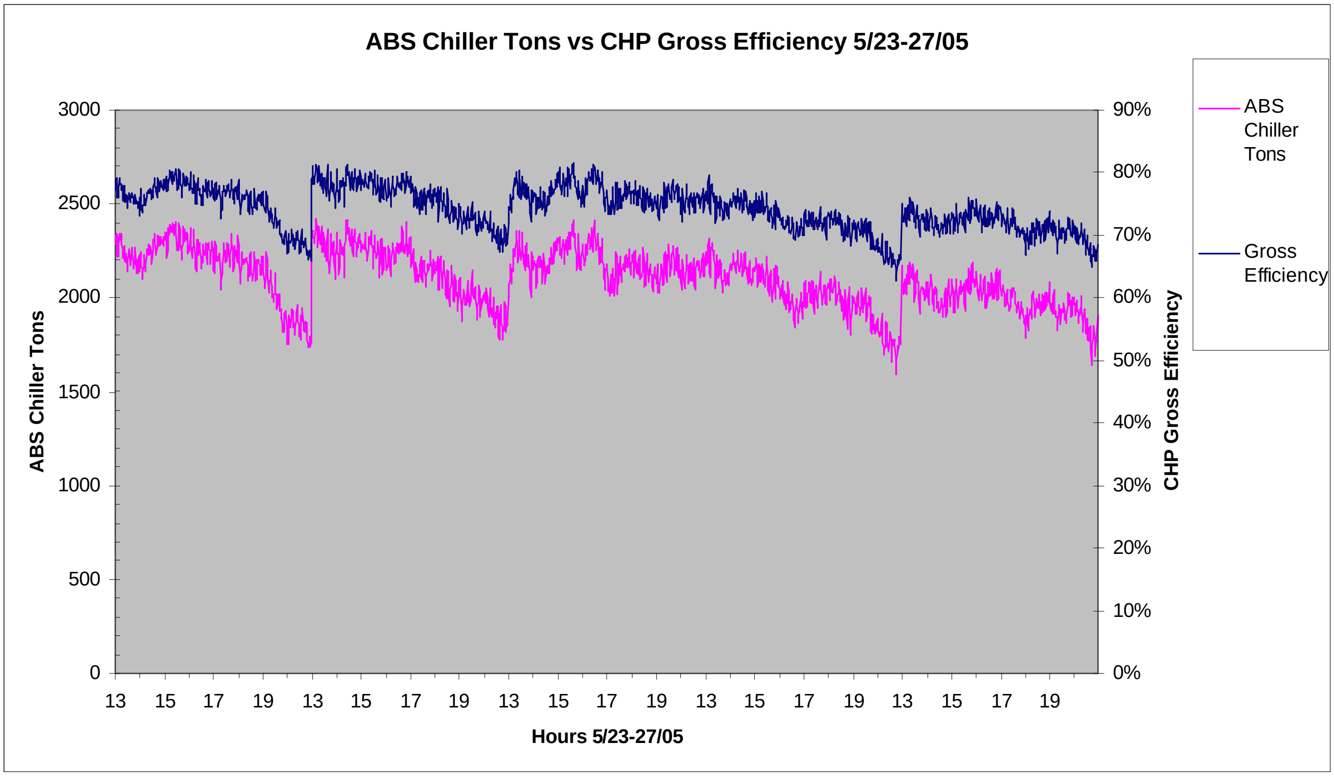

Figure 118 – ABS tons and CHP gross efficiency versus time 5/23 - 27/05

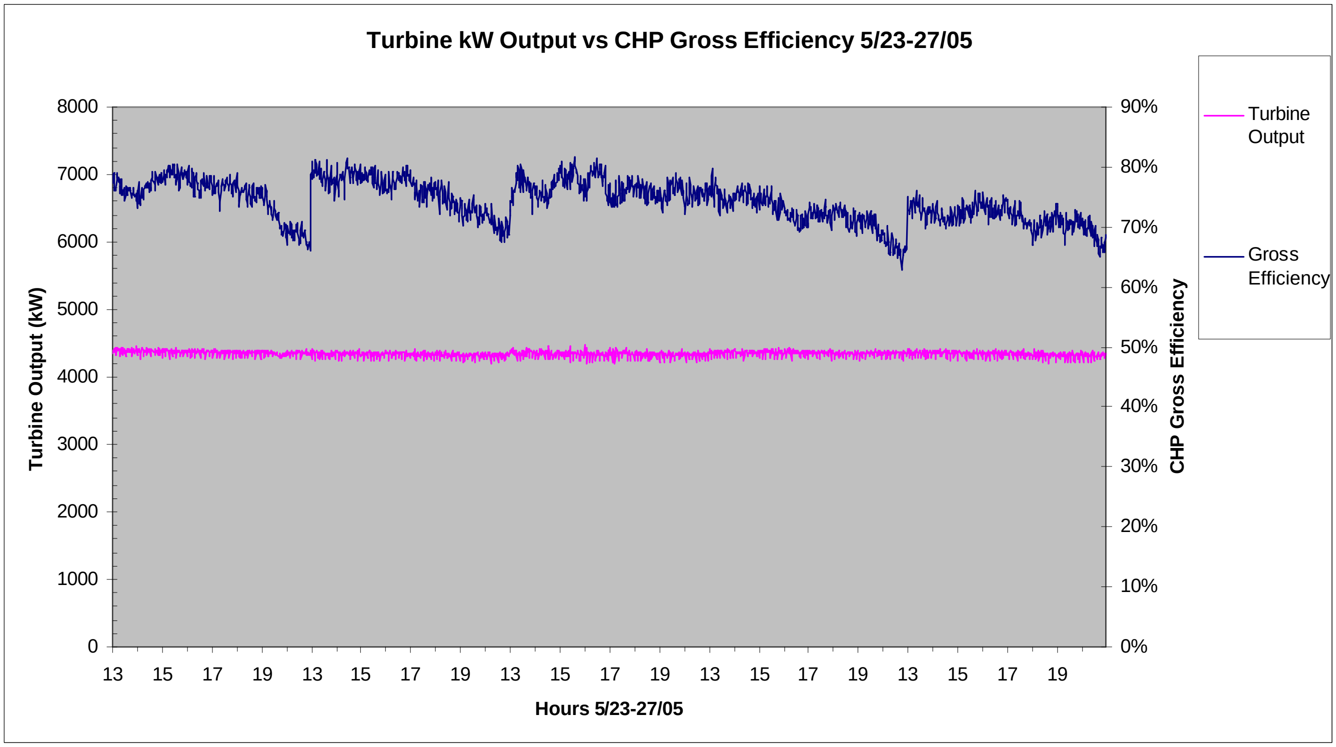

Figure 119 – Turbine kW output and CHP gross efficiency versus time 5/23 - 27/05

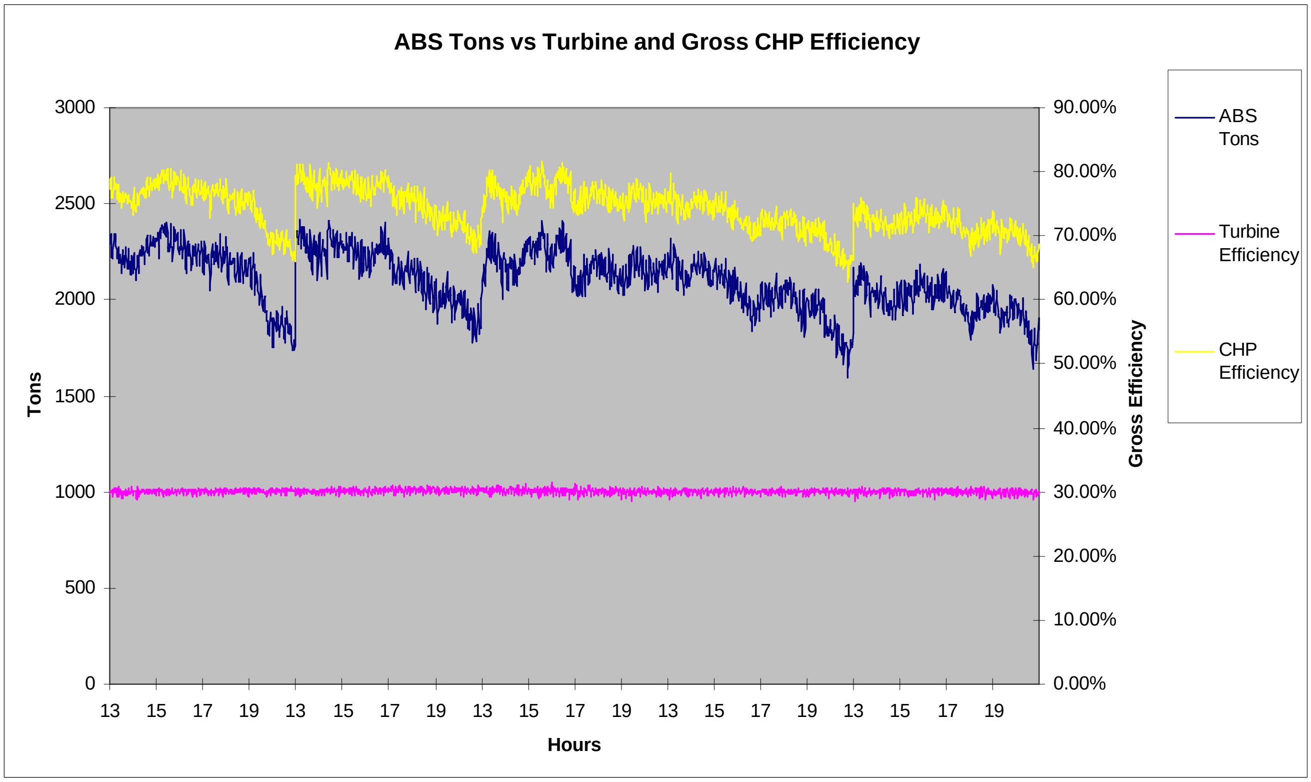

Figure 120 – ABS tons and CHP gross efficiency versus time 5/23 - 27/05

Figures 121 through 135 show the same variables as the other days in May, except each graph shows multiple days. For the majority of the graphs, you can see the daily variations in at least one of the two variables.

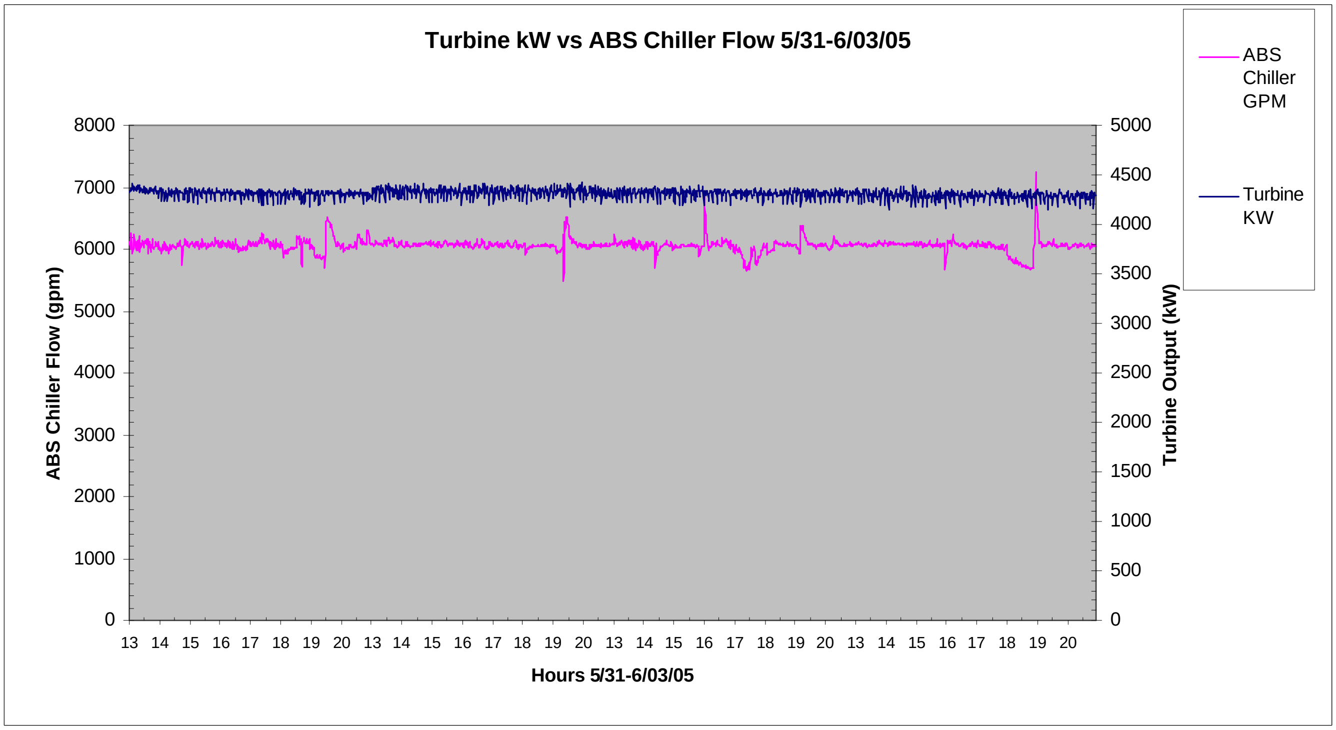

Figure 121 – Turbine kW output and ABS chilled water flow versus time 5/31 – 6/03/05

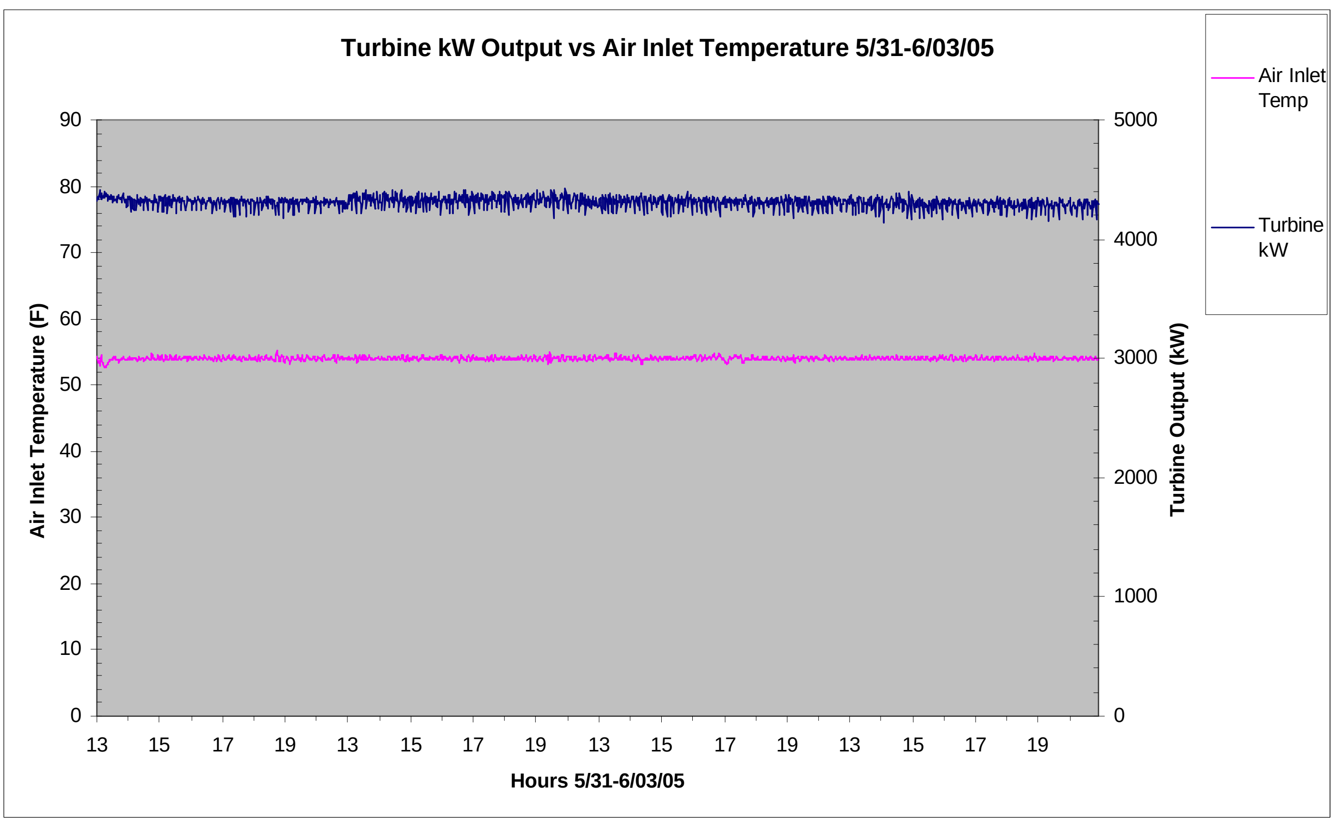

Figure 122 – Turbine kW output and air inlet temperature versus time 5/31 – 6/03/05

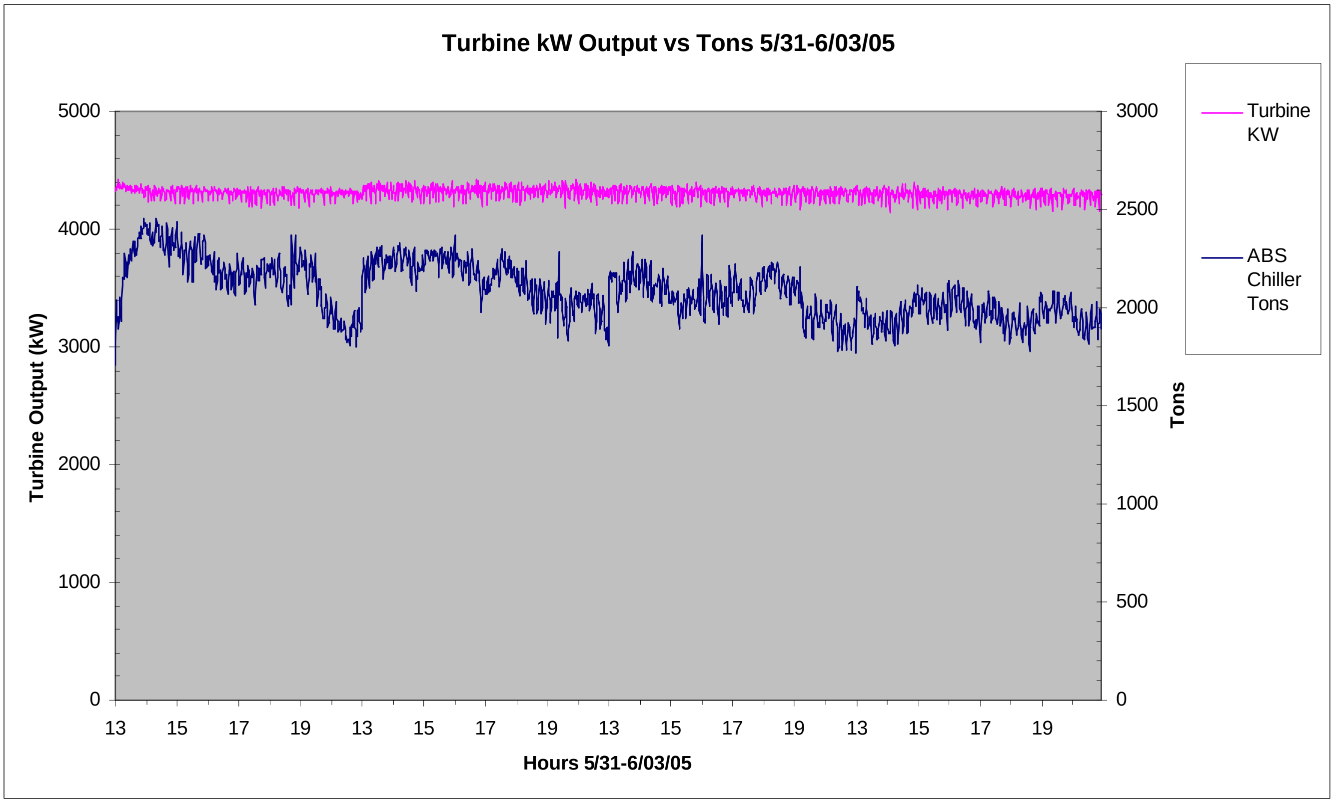

Figure 123 – Turbine kW output and ABS tons versus time 5/31 – 6/03/05

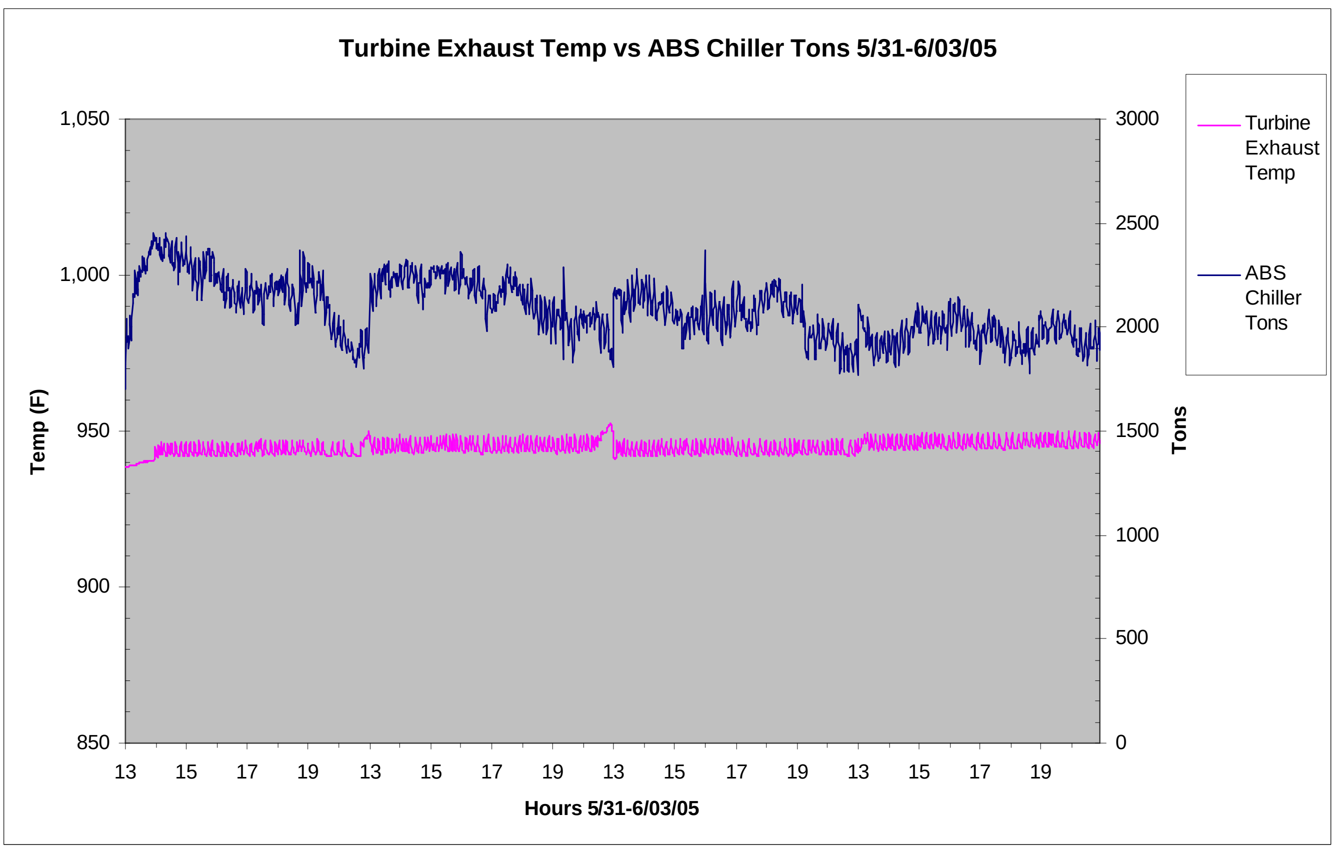

Figure 124 – Turbine exhaust temperature and ABS tons versus time 5/31 – 6/03/05

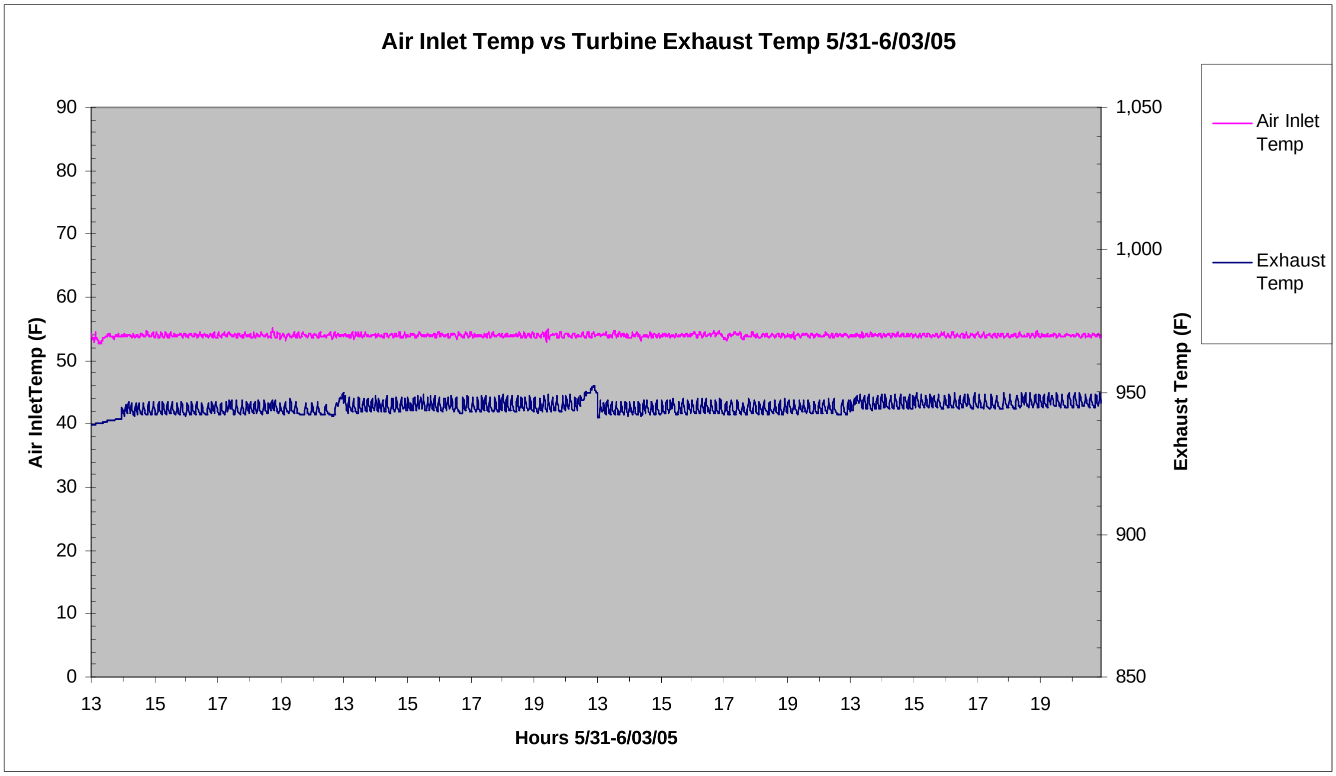

Figure 125 – Air inlet temperature and ABS tons versus time 5/31 – 6/03/05

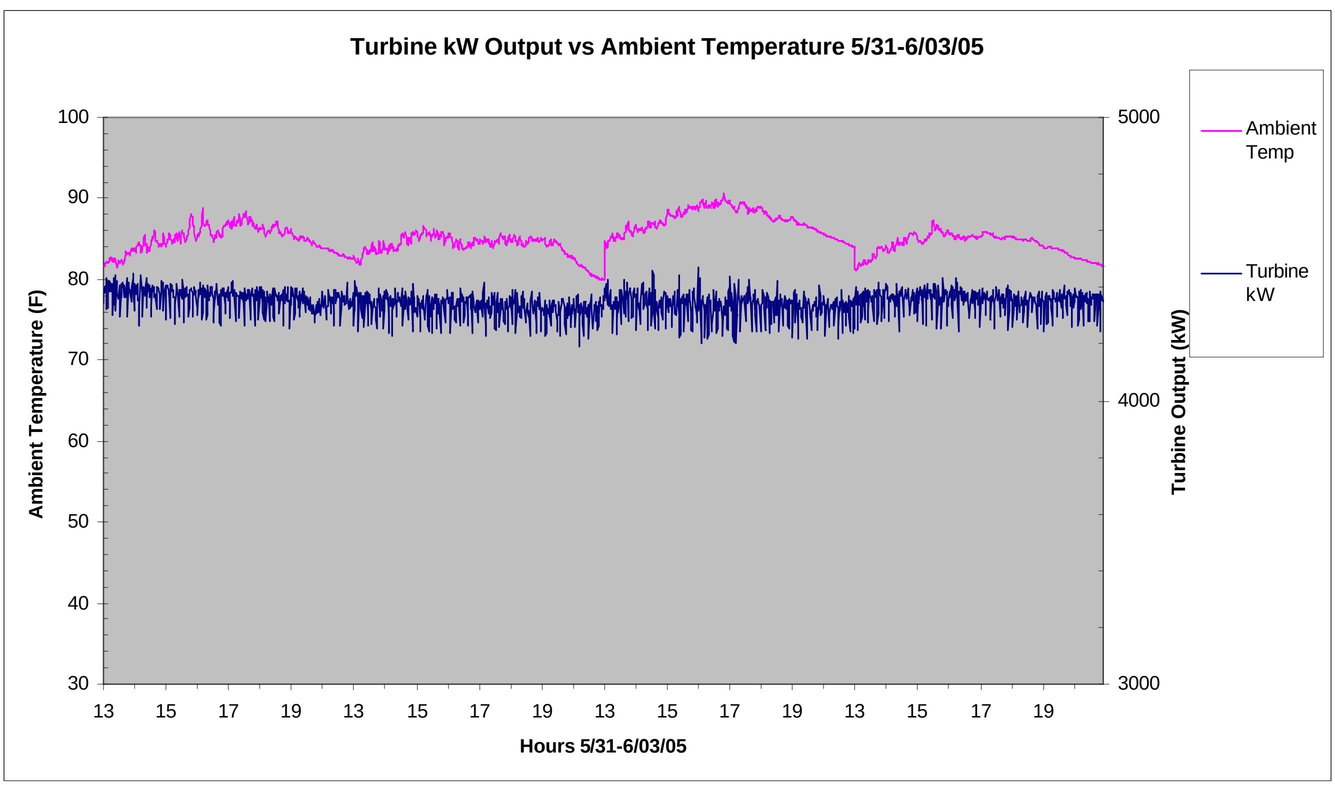

Figure 126 – Turbine kW output and ambient temperature versus time 5/31 – 6/03/05

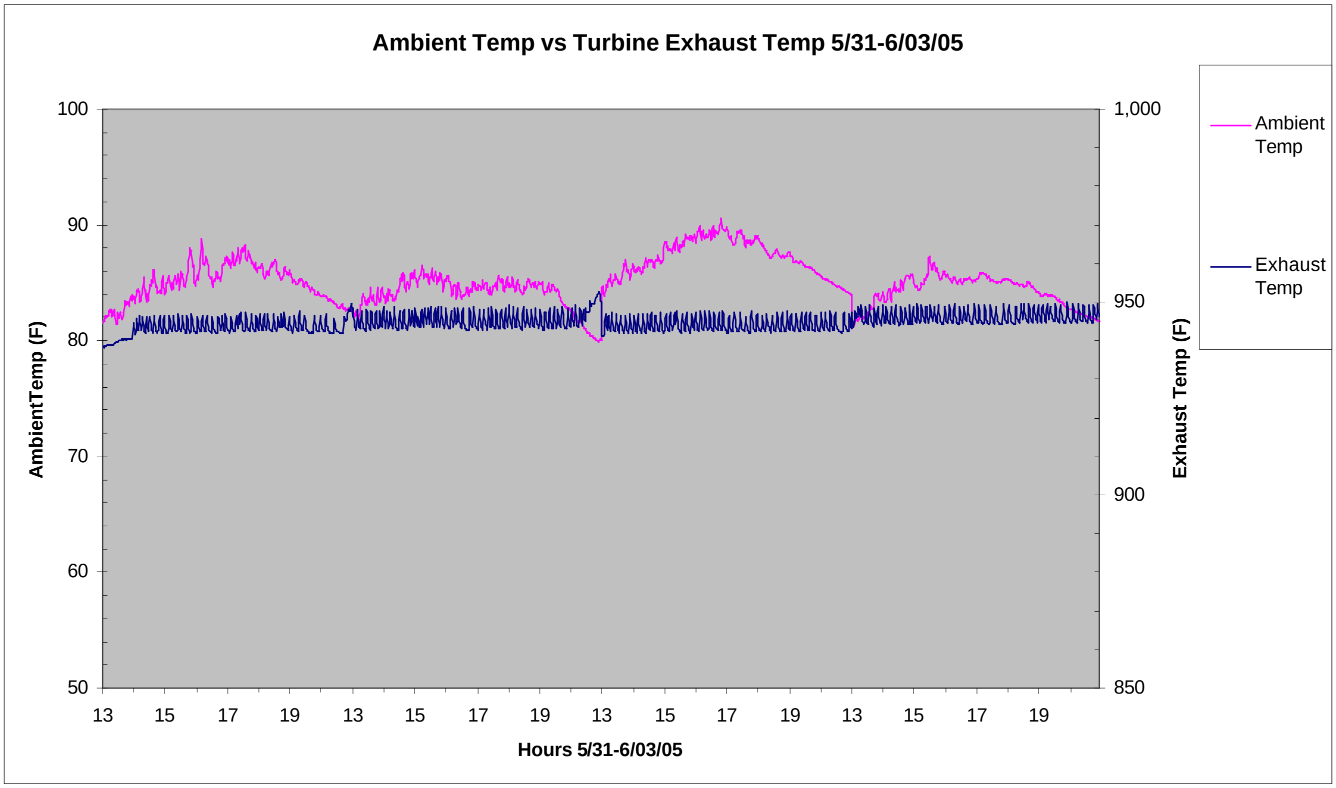

Figure 127 – Ambient and turbine exhaust temperatures versus time 5/31 – 6/03/05

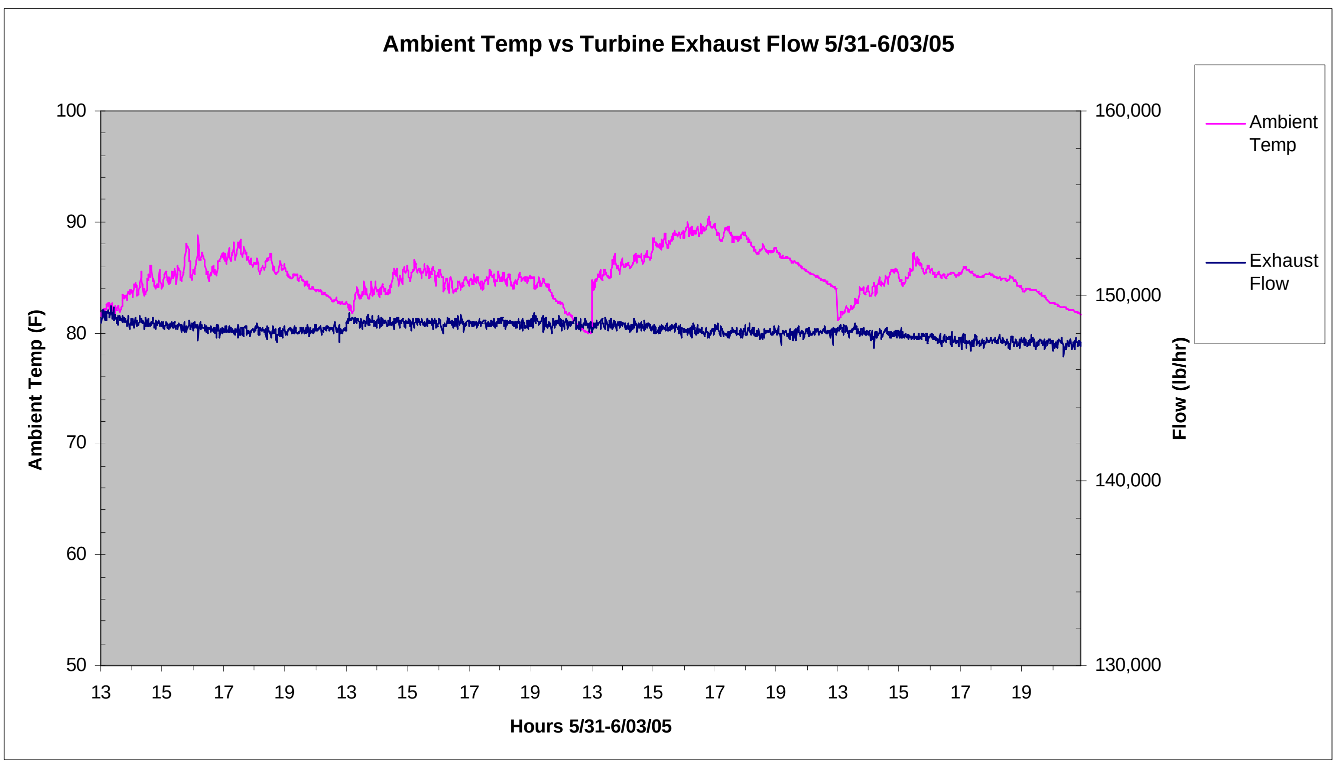

Figure 128 – Ambient temperature and turbine exhaust flow versus time 5/31 – 6/03/05

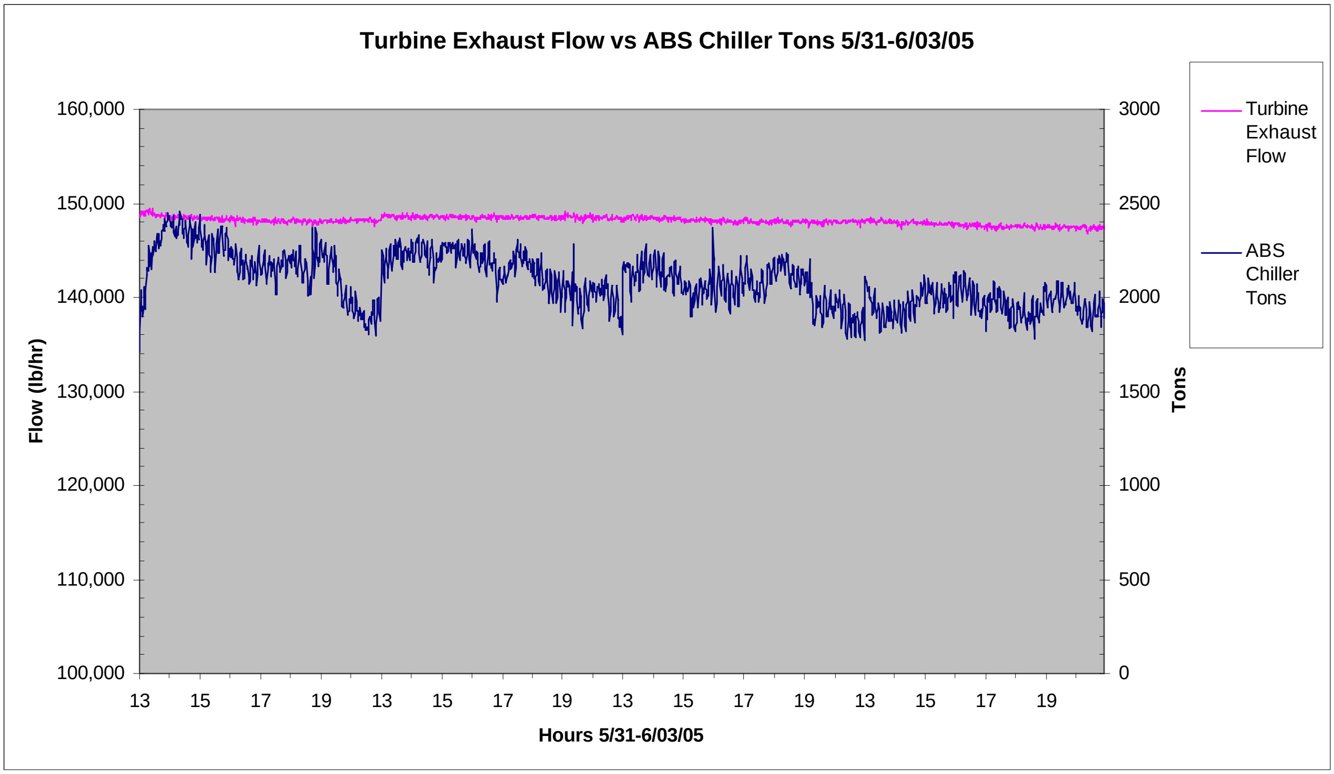

Figure 129 – Turbine exhaust flow and ABS tons versus time 5/31 – 6/03/05

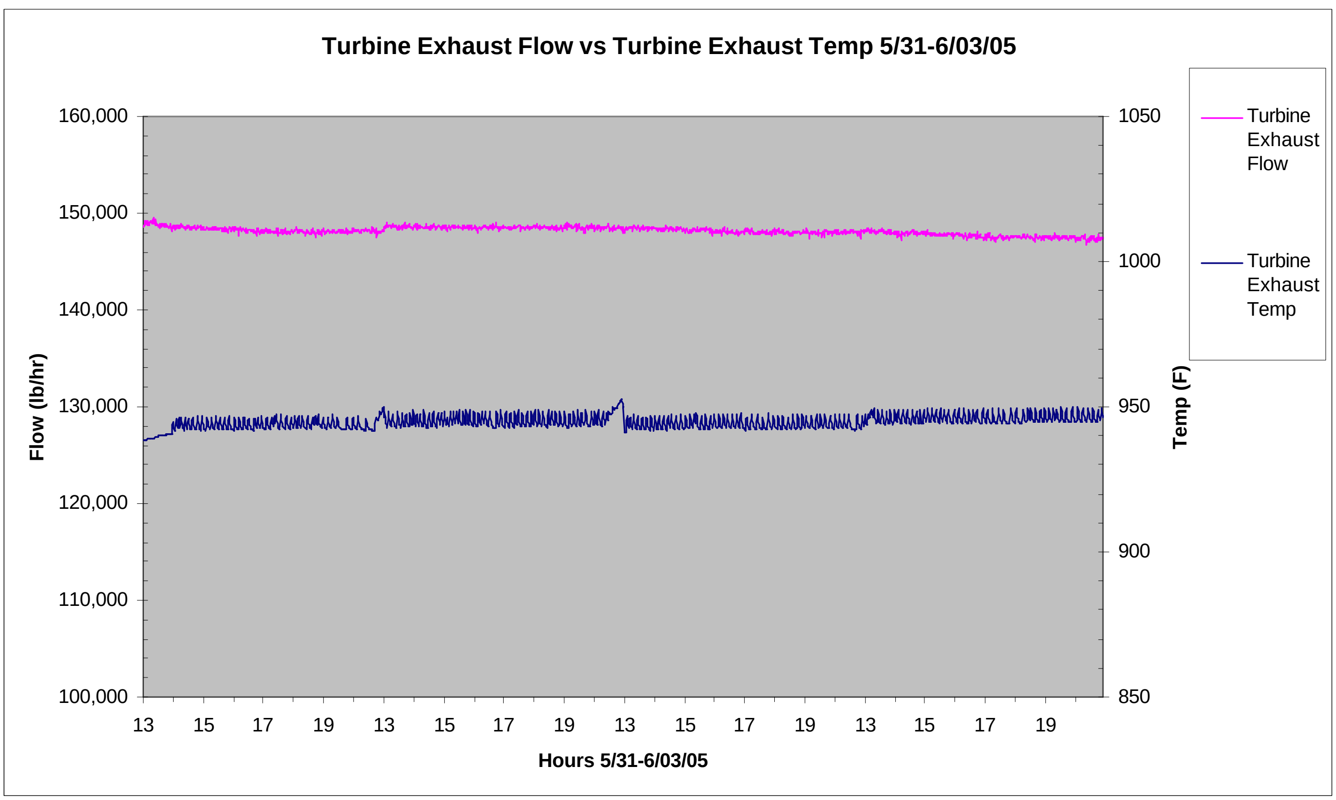

Figure 130 – Turbine exhaust flow and turbine exhaust temperature versus time 5/31 – 6/03/05

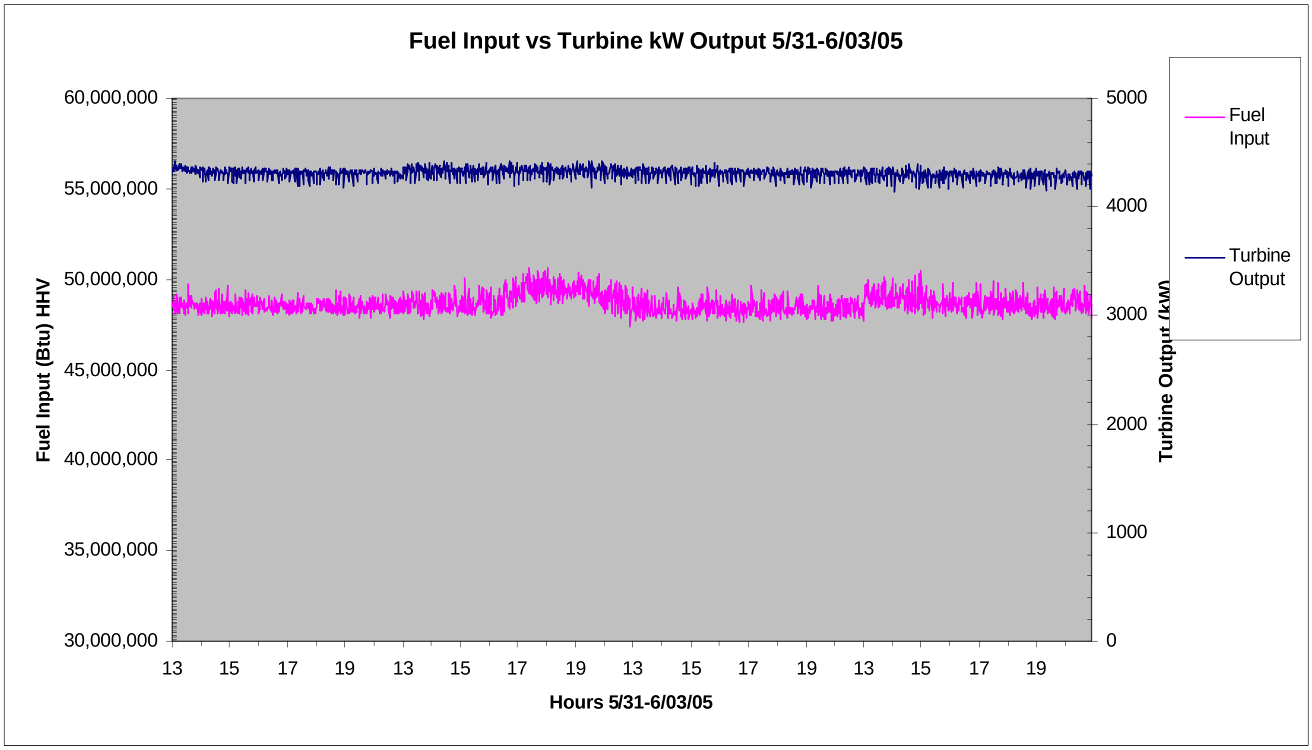

Figure 131 – Turbine fuel input and turbine kW output versus time 5/31 – 6/03/05

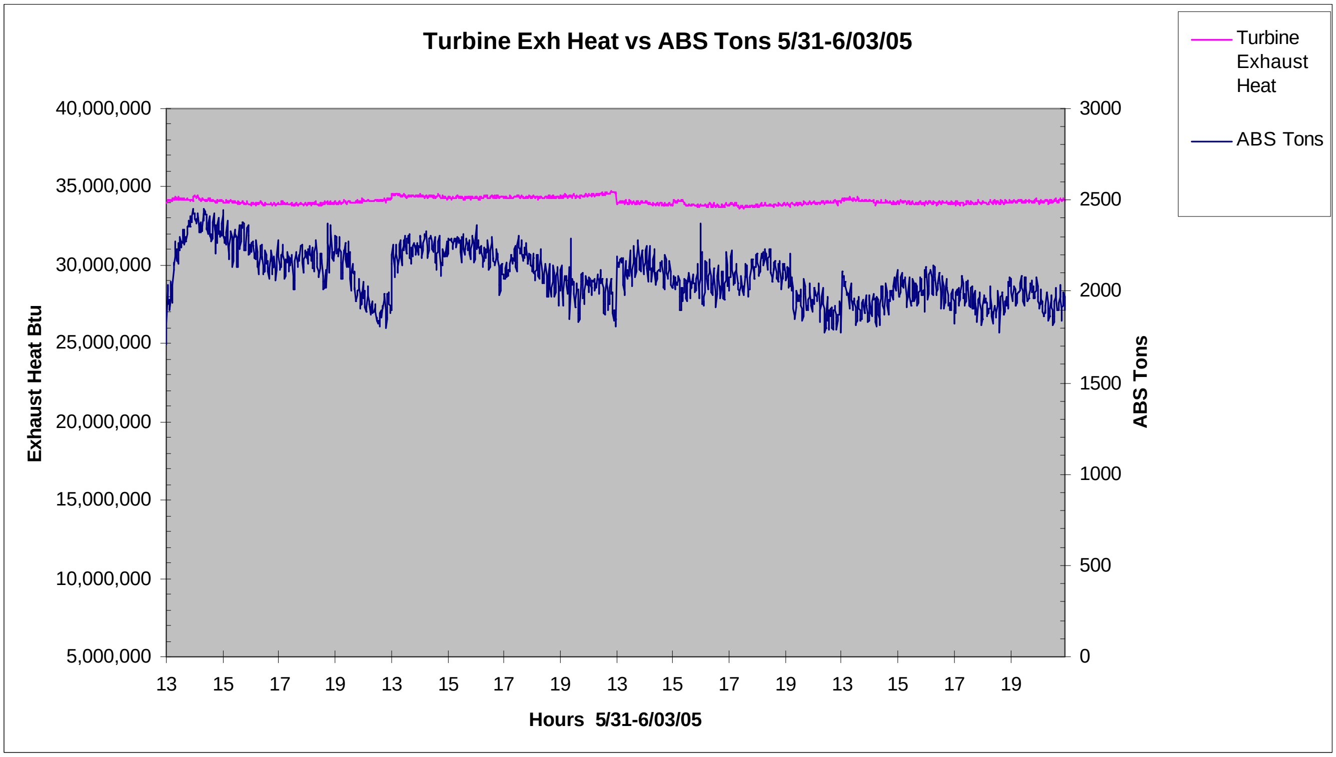

Figure 132 – Turbine exhaust heat and ABS tons versus time 5/31 – 6/03/05

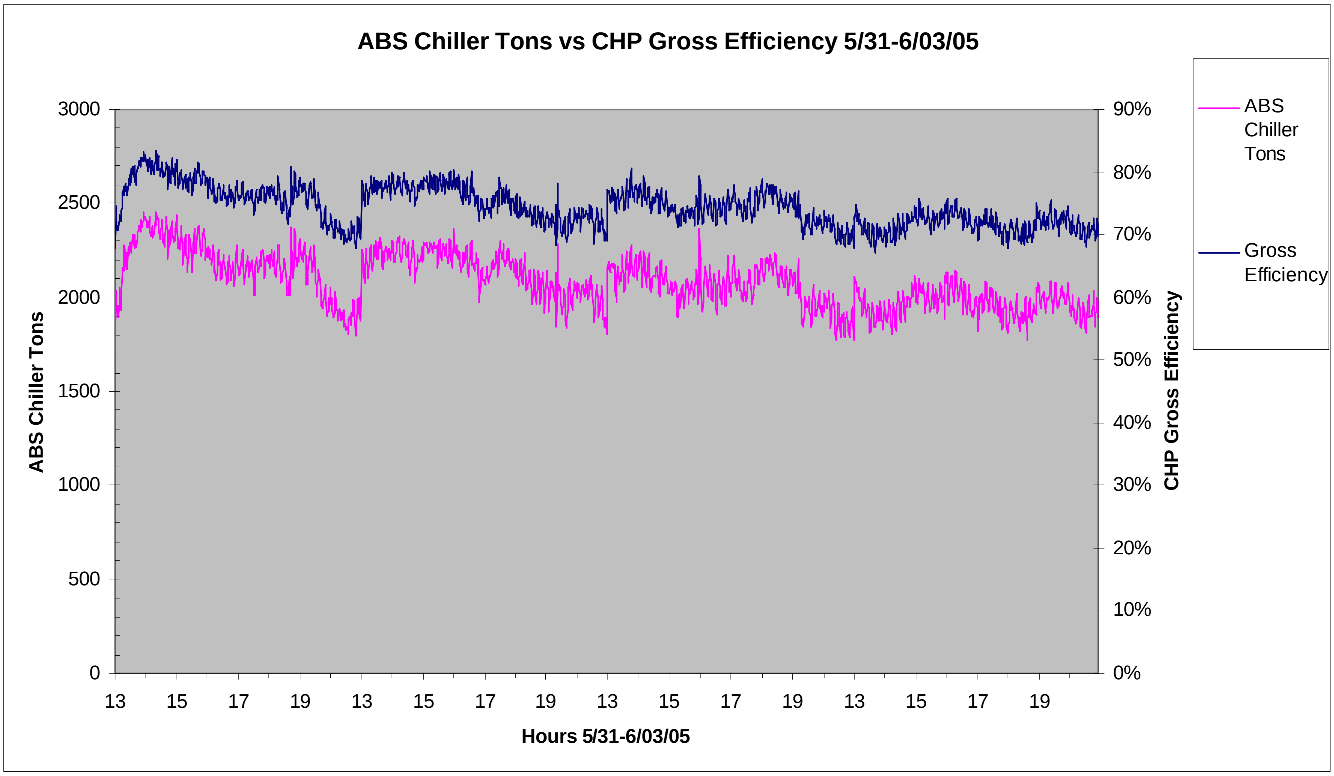

Figure 133 – ABS tons and CHP gross efficiency versus time 5/31 – 6/03/05

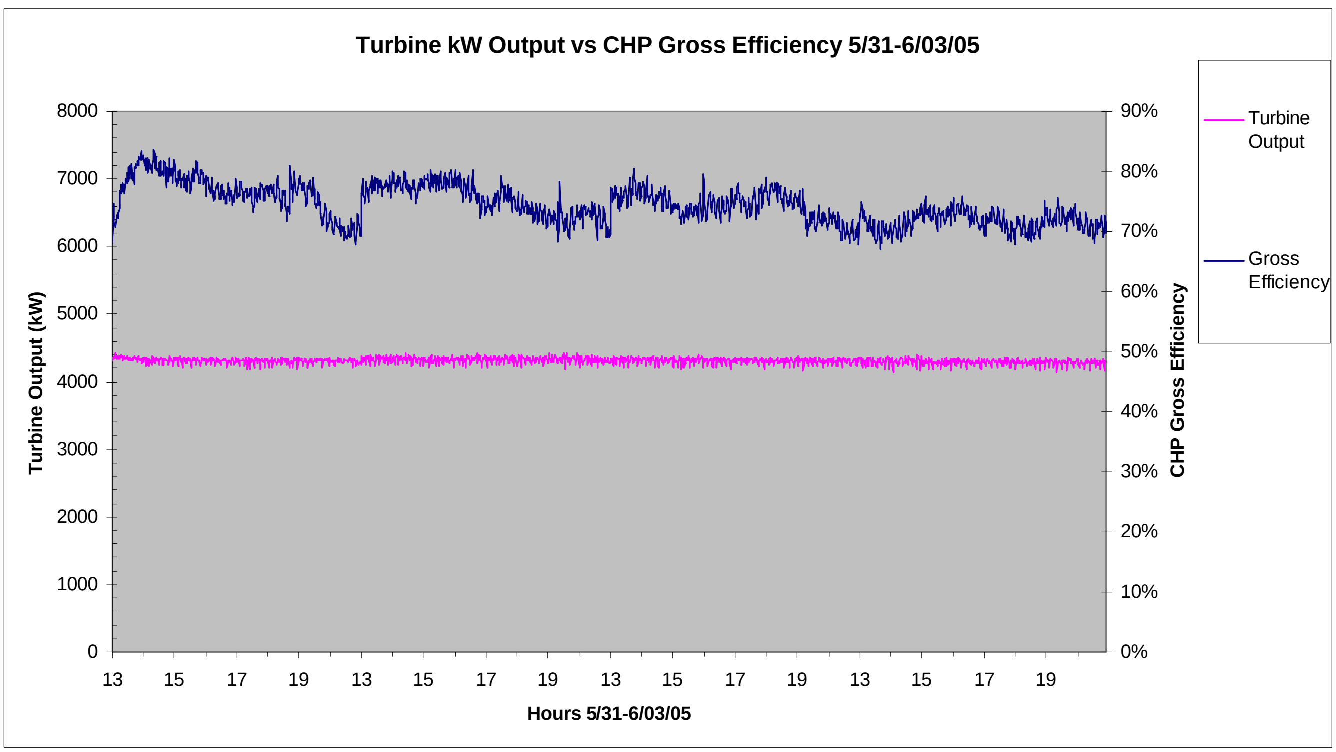

Figure 134 – Turbine kW output and CHP gross efficiency versus time 5/31 – 6/03/05

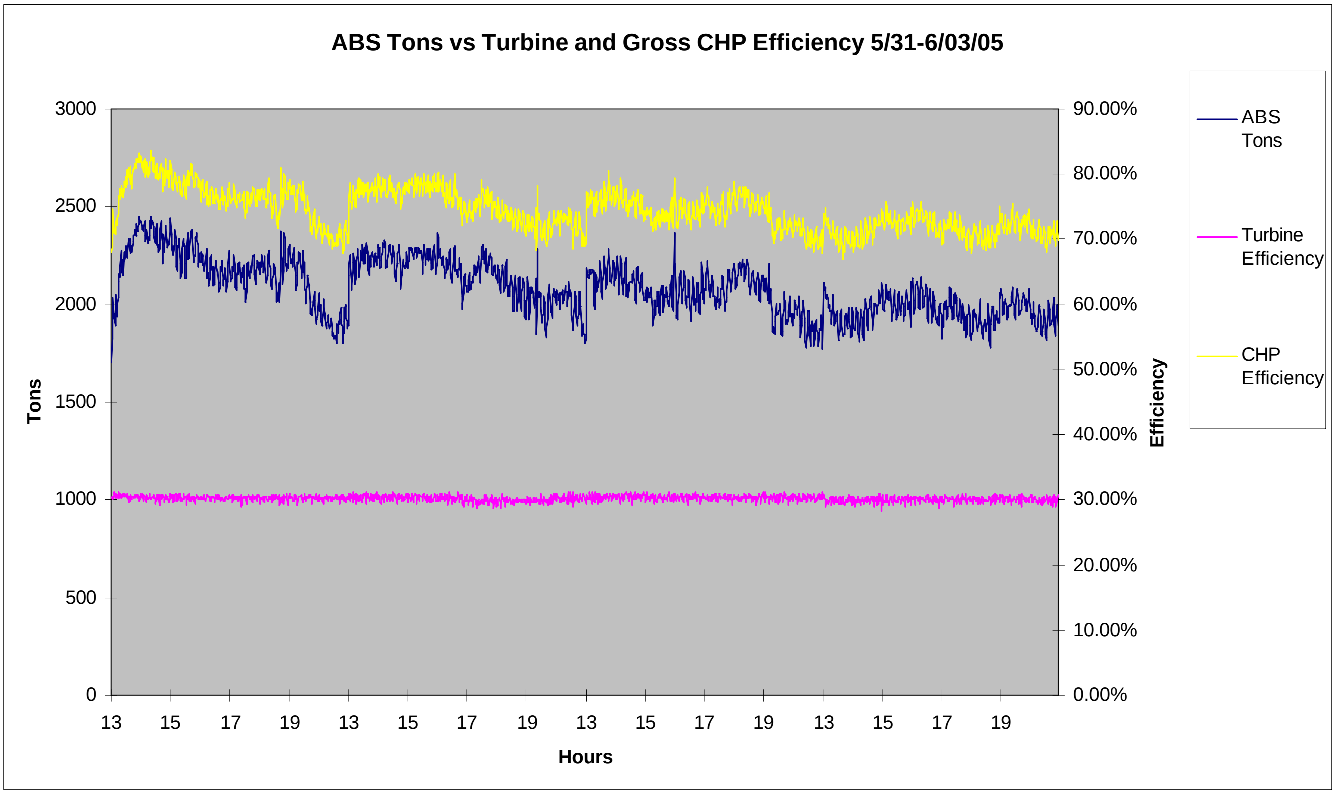

Figure 135 – ABS tons and turbine and gross efficiencies versus time 5/31 – 6/03/05

* * * *

PART 4

SUMMARY OF FINDINGS AND OBSERVATIONS

The following is a summary of key observations about the CHP system operating conditions and performance during this testing period:

- The CHP system was operated for an average of 9 hours per day (1 pm to 9 pm).

- The system chilling demand varied daily from an average low of 39 tons to an average peak of 2528 tons.

- The average ambient temperature during each daily testing period (1pm to 9pm) varied from an average low of 88ºF to an average high of 92ºF. Turbine inlet cooling was active throughout the test period, providing approximately 56ºF inlet air to the combustion turbine.

- Throughout the testing period, the combustion turbine was operated at full load. The average turbine electrical output at full load was 4056 kW.

- The combustion turbine efficiency, operating at full load, was approximately 30 percent throughout the testing period, with one day day's data (May 16, 2005) showing an efficiency of 26 percent. Efficiency calculations were based on the Higher Heating Value of the fuel input.

- The absorption chiller output varied on a daily basis from an average low of 1700 tons to a high of 2528 tons. The average chiller output was 1932 tons during the month of May.

- The CHP system average gross efficiency varied between 65 percent and 79 percent and tracked closely with the absorption chiller output. Again, these efficiencies are based on HHV for the fuel input.

The following is a brief discussion of additional observations that warrant further investigation:

- During the testing period, it was noted that the diverter valve position fluctuated widely before settling on a designated set-point for a given chiller output. All of the readings show that the position of the diverter valve would stay at a position, such as 100 percent (fully open to the chiller) for three to four minutes and then would drop in the next two minutes to nominally 50 percent open, and then would go back to 100 percent open again in the next two minutes. This variation in the damper position is an anomaly that warrants further investigation. It is possible that a time delay or dampening mechanism needs to be installed to prevent this seeking action.

- It was observed that the three exhaust temperatures – the turbine exhaust, bypass exhaust and chiller entrance did not seem to be correct. The turbine exhaust outlet temperature should be the highest, the inlet temperature to the bypass stack the next highest and the chiller inlet temperature should be the lowest. Based on the average temperature data, the inlet to the chiller was the highest, the turbine next highest, and the bypass was the lowest. The average temperatures for the bypass and the turbine were within 2 Deg F and the difference between the chiller entrance and the bypass was over 5 Deg F. Burns & McDonnell has suggested that the next time these temperature instruments are calibrated, they all be calibrated to the same range of temperatures. For the purposes of this assessment, the chiller inlet temperature for the turbine exhaust was used, and it was assumed that the other two temperatures were equal.

- The relative temperatures of the exhaust streams above would also impact the determinations of the exhaust flows and the exhaust heat, which is based on the delta T of the exhaust. It was observed that the temperature in the inlet to the diverter valve bypass stack did not decrease as much as expected when the diverter valve position was at 50 percent versus the 100 percent value. Ideally, as the diverter valve closed to the chiller, the diverter valve bypass temperature should go up as more flow is going through this path. Ideally at 100 percent flow through the chiller, the flow through the bypass should be zero, and the temperature should be closer to ambient. However, the observations did not support this. The diverter valve bypass temperature did appear to follow the diverter damper position changes, but on a delayed basis. See the graphs below. Figure 136 shows the actual data, and Figure 137 shows the impact of a two minute delay on the bypass stack temperature.

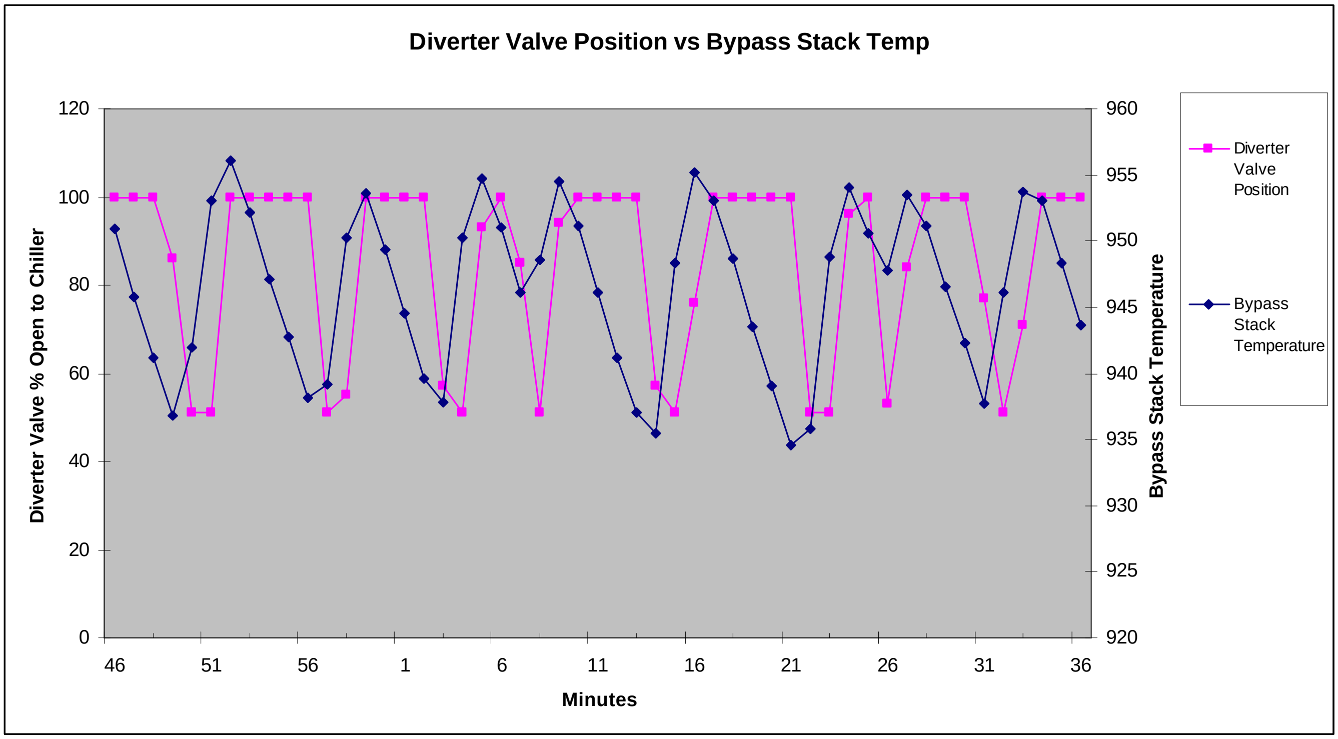

Figure 136 - Diverter valve position and bypass stack temperature versus time

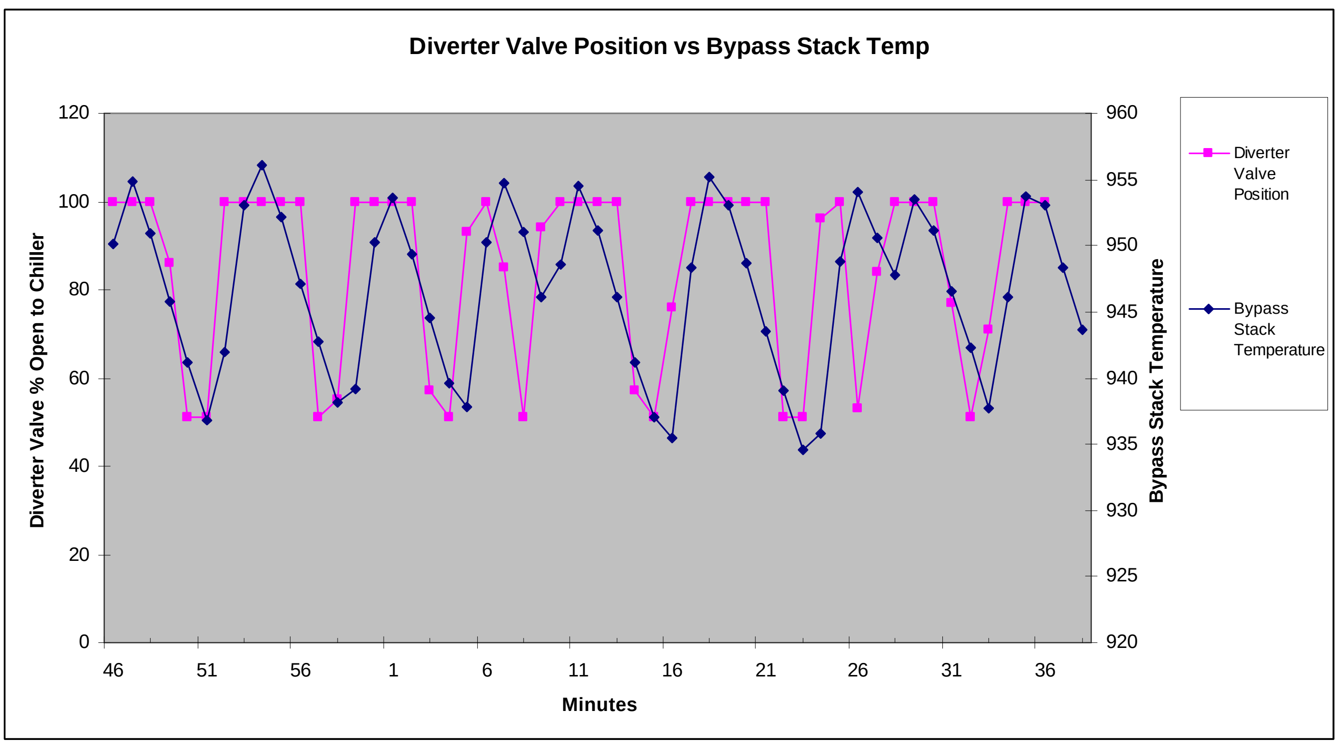

Figure 137 - Diverter valve position and bypass stack temperature with 2 Minute Offset versus time

* * * *

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