Performance Group Services

report for:

State of Wisconsin – Division of Facilities Development
University of Wisconsin-Superior: Barstow Hall Exhaust Study Final Report
Project Number: 12-359

December 14, 2012
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Karges-Faulconbridge, Inc.
Engineers

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Title Page

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Executive Summary

Karges-Faulconbridge, Inc. (KFI) was contracted to perform a study to determine issues with the lab hood exhaust and HVAC systems controls. The goal of the study was to create a list of prioritized issues and proposed solutions separated in a low-cost and capital investment list.

The results of the study uncovered a significant list of deficiencies with the controls systems, which is resulting in a significant problem with the air-side balance of the supply and exhaust systems in the building.

We believe that there are several items that can be accomplished in a relatively short timeframe to correct most of the building airflow and pressurization problems. Most importantly, if the two-position operation of the exhaust dampers is altered so that the dampers are only maintain one position (as set by a TAB professional), the hood flows should be reliable and repeatable. Based on some of the controls issues that were observed, the rebalancing work will need to be a combined effort of both a TAB professional and pneumatic controls technician in order to properly correct controls related issues and set airflows to design requirements. We have estimated approximately $99,000 for corrective actions for these immediate recommendations.

The most efficient operation of the lab supply and exhaust systems would be through a DDC controls upgrade. The basic DDC upgrade requires adding air valves to both the supply and exhaust ductwork to each lab that allows for the DDC system to control the amount of exhaust from the lab and hoods based on actual hood use. The corresponding supply air valve also modulates to maintain the required supply CFM based on the active exhaust. This type of system provides good control of the lab supply and exhaust flows, and also provides energy savings for reduced airflow when hoods are not in use. The first cost is also much higher for this system, estimated at $615,500 for the Barstow Hall labs.

To offer increased efficiency upon the DDC variable volume hood and supply controls, retro-fitting combination sashes onto the hoods can result in further energy savings. This allows the user to open smaller sash areas, without having to open the entire hood face for smaller activities under the hoods. The estimated cost for this project (including the DDC, variable volume upgrade): $736,400.

Detailed results from the investigation, as well as the narrative of recommendations are included in the body of the report.

Investigation Results and Observations

Casey Batenhorst and Matt Josephson were on site Tuesday, October 30, 2012 to begin the survey of existing systems at Barstow Hall on the UW-Superior Campus. One follow-up site visit was performed for after-hours testing on November 27, 2012. Below is a list of tasks that were performed and documented observations.

Lab Exhaust Fans

KFI verified the existing airflow to lab exhaust fans EF-3, 4, 5 & 6. KFI's measurements are compared to the 2010 measurements for TD Test & Balance Inc.

1. KFI's measured static pressures, amps, and RPM values were repeatable to reported values.
2. The existing exhaust fan units themselves did not show any signs of needing immediate repair or replacement.
3. Exhaust fans 3&4 have larger motor sheaves installed (as per the 2011 TAB report), causing the difference in airflow from the design documents. This appears to have been a post-design modification, as all exhaust fans have identical model numbers and are scheduled for identical static pressures on the 2010 design documents.
4. The CFMs for EF-3 & 5 (serving lab 010A) were raised by 435 CFM each by a construction revision #1.
5. All four fans were measured when the system switched to unoccupied mode. We did not observe a significant change in flow. (Per University staff, this most likely occurred when some controls rework was recently performed due to a control system failure during a power outage).
6. Exhaust fans are a vent-utility set type. Picture 1: EF-3 & EF-5. Picture 2: EF-4 & EF-6.
7. The handwritten tags and factory stamped tags do not match. The handwritten tags appear to match the design document fan locations, and all references to exhaust fans are based on these tags. Appendix A contains a handwritten schematic of fan locations and tags.
8. EF-5 belt was observed to be slipping, and should be replaced by the University staff.

Fan	Design (cfm)	2010 Measurement (cfm)	2012 Measurement (cfm)	2012 Unoccupied Measurement (cfm)	Comments
EF-3	7,975	10,050	9,222	8,788	
EF-5	7,975	7,940	6,700	6,344	Belt Slipping
EF-4	7,540	9,880	10,070	9,686	
EF-6	7,540	7,565	7,920	8,283	
Totals	31,030	35,435	33,912	33,101	

Picture 1

Picture 2

Lab Exhaust Hoods

KFI measured hood face velocities at 28 fume hoods in the building. All flows were measured with all fans operational (occupied mode), and hood sash heights at the noted stops. The hoods are constant volume; when the sash is open, air is drawn through the hood face. When the sash is down (closed), air is drawn through louvers at the top of the hood frame.

The velocity monitors are a TSI EverWatch model. The sensors are approximately 10 years old. Per the manufacturer, the product is obsolete. The replacement model is FHM10-01, and uses the same sensor as the original. The replacement cost is between $810-$950, depending on the model options chosen.

1. KFI found that only approximately 12 hoods had measured face velocities that were repeatable to the 2010 report; some readings were significantly higher, and some readings were significantly lower than the reported values.
2. Only approximately 10 of the hood face velocity monitors were reading reasonably accurate when compared to KFI's measured value.
3. Two hoods were observed to have no power supply to the hood face velocity monitors.
4. The face velocity monitors also had unreliable span readings. Most of the monitors held a reasonable range (10-15 FPM) of readings with the sashes open, but we did observe several units would bounce between 40-50 FPM range with no measureable variance anywhere close to these values.
5. Copies of the installation and recalibration procedures were obtained from the manufacturer. Due to the large file size, they will be sent along with this report.
    i. Based on a photo of the sensor installation, the existing installations roughly appear to match the manufacturer's recommended dimensions for installation.

Hood	Desing Velocity (fpm)	2010 Measurement (fpm)	2012 Measurement (fpm)	2012 Monitor Reading (fpm)	2012 Unoccupied Reading (fpm)
1	100	5	n/a - disabled	n/a - disabled	-
2	100	68	107	105-125	-
3	100	63	85	95-100	-
4	100	85	85	105-115	-
5	100	93	81	90-100	-
6	100	38	80	110-135	-
7	100	82	64	115-160	-
8	100	15	130	130-135	-
9	100	57	66	No power	-
10	100	68	91	No power	-
12	100	35	37	70	-
13	100	138	119	175-185	-
15	100	42	107	130-140	-
16	100	146	228	130	-
17	100	154	45	5 to 15	-
18	100	133	81	65	-
19	100	103	<30	35	-
20	100	124	194	130	-
21	100	136	130	115-125	-
22	100	137	148	135-140	-
23	100	140	98	110-115	-
24	100	148	144	215	130
25	100	107	105	175	50
26	100	143	138	160	<30
27	100	142	133	160	95
28	100	112	136	135-140	125
29	100	159	150	50	150
30	100	158	172	180-190	50
32	100	133	140	170-195	-

Observed damper positions serving hoods are not maintaining reliable minimum positions to maintain the required 100 FPM face velocity. KFI observed damper positions anywhere from 15% to 100% open. An example of this would be in room 309; four hoods are mounted side-by-side and connected to the same exhaust main. We observed that none of the damper positions were anywhere close to the same, and the face velocities reflected this, as we measured 228 FPM, 81 FPM, 45 FPM, and <30 FPM at the four hoods.

When the system scheduled to unoccupied mode, we observed that all four lab exhaust fans (EF-3, 4, 5, 6) all remained operational. The hood exhaust valves were observed in various stages of operation when the system was toggled to unoccupied. Some dampers were operational, some hoods had actuators that operated, but was slipping on the shaft, and some actuators failed to modulate at all. For example, **Picture 3** below shows an actuator that has been mounted in an inefficient manner. Due to the angle of installation, as we observed the actuator to stroke, part-way through the rotation the damper stopped rotating, and the actuator continued to drive until the linkage socket joint buckled and popped the actuator through the remainder of the stroke. The red arrow in **Picture 4** below shows a pneumatic line that was disconnected.

Picture 3

Picture 4

We were not able to view damper type as requested. There were no access panels installed that we could locate. Determining damper type would require disassembling ductwork.

Lab 010A

KFI measured flow to Lab 010A to be 643 CFM. The reported value from 2010 was 515 CFM, and the design total from the 2010 plans was 1160 CFM (485 CFM from hood, 5x100 CFM drops in space, and 175 CFM from Lab 012). KFI observed several issues with this installation:

1. Design documents call for a 12”x12” duct run from the main to this lab. Installed duct is only a 12”⌀ duct, which has significantly less area (1 ft^2 vs 0.785 ft^2).
2. Rough field estimates appear to indicate that even the original design document undersized this duct, and a 16”⌀ to 18”⌀ (or equivalent) duct may be required.
3. The installation of ductwork to this zone is not ideal:
    i. The take-off for this duct run is installed directly on an elbow, which does not provide ideal conditions. See pictures below. **Picture 5**: Side view of duct take-off directly on elbow. Duct main continues horizontally to the left and vertically up through a chase. **Picture 6**: View of installation below the chase.

Picture 5

Picture 6

ii. The exhaust duct from the main to Lab 010A has an excessive number of elbows/transitions. The actual installation has three (3) 90˚ elbows and four (4) 45˚ elbows between the duct main and Lab 010A. This also causes excessive pressure drop, and reduces flow from the space.

4. We traced this system from the lab up to the fan and did not observe any crushed or damaged ductwork.

Supply Diffusers and Ductwork

The displacement diffusers on the supply system are plugged with dust/debris. This restriction in supply airflow could be contributing to the negative pressure of the building which was evident on the day of testing. See pictures below. **Picture 7**: Diffuser plugged with debris. **Picture 8**: Is a close-up view of the diffuser in picture 3. **Picture 9**: A different example of plugged diffuser.

Picture 7

Picture 8

Picture 9

We disassembled one diffuser and attempted to clean it in Lab 9 (**Pictures 10 & 11**). We were able to shake out some of the debris, but most of the debris appeared to be stuck onto the diffuser and would require a combination of vacuuming and washing the diffuser to thoroughly clean the unit. Note that the dark areas in **Picture 11** are not shadows; that is the dust/debris stuck to diffuser. Just dumping out the loose particulate resulted in an increase in 20 cfm. We also observed sections of this this duct to be both internally lined, and insulated externally. The ductwork also contained bugs/debris. (**Pictures 12 & 13**)

Picture 10

Picture 11

Picture 12

Picture 13

AHU Inspection

The AHU are in good condition. We did not document any major deficiencies from the physical inspection. We did observe that bugs are bypassing the filter racks and were observed in the AHU downstream of the filters, and subsequently in the supply ductwork. Per University staff, this has been an ongoing problem. The filter racks were replaced when the coils were replaced several years ago, which appeared to help, but not entirely solve the problem. The filter racks did not have any excessively large gaps, but were most likely shifting or vibrating in the racks to allow the bugs to bypass.

The measured supply flows for the AHU systems are relatively close to design. The TAB report from 2010 has a note indicating an issue with the OA damper control of AHU-3. If the proper amount of minimum outside air is not maintained reliably on this unit, it would be contributing to the negative pressure problems of the building.

AHU	Design (cfm)	2010 Measurement (cfm)	2012 Measurement (cfm)	Comments
AHU-1	10,445	8,960	10,150	
AHU-2	9,675	10,140	11,926	
AHU-3	7,450	7,455	6,280	Mixed Air Unit
AHU-4	14,155	16,070	12,000	
Totals	41,725	42,625	40,356	

Room Supply VAV Controls

Supply VAV damper positions mostly observed at 100% open (not controlling). Also observed damper actuators that were missing/removed/disconnected. **Picture 17**: the damper-actuator linkage has been disconnected.

Picture 17

The VAV reheat valves appeared to respond to setpoint adjustment. The VAV dampers did not respond to any changes in setpoint or when the system scheduled to unoccupied. VAV pneumatic thermostats appear to require recalibration. We observed several units with temperatures over setpoint, but the stat was controlling the VAV to heating mode. When the setpoint was significantly adjusted, the stat shut down the heating coil.

The chart below is displays the sampling data of the actual room supply VAV measurements. As the data shows, the actual room diffuser proportioning is not an issue. The balancing issue that should be considered is the proportional balancing of the total system to bring each room back to design flow. The industry standard is typically +/-10% from design (in a lab facility, the tolerance is typically specified to be lower). As can be seen from the sample data, we have some rooms that are acceptable, some rooms that are too far above design, and some rooms that are too far below design.

Room/Diffuser	Design CFM	2012 Measurement (cfm)
Lab 9		
Outlet 1	955	810
Outlet 2	835	805
Total	1,790	1,615
Lab 107		
Outlet 1	235	225
Outlet 2	235	240
Outlet 3	235	210
Outlet 4	235	230
Outlet 5	235	222
Outlet 6	235	224
Total	1,410	1,351
Lab 204		
Outlet 1	170	137
Outlet 2	175	130
Outlet 3	175	135
Outlet 4	175	130
Total	695	532
Lab 209		
Outlet 1	225	235
Outlet 2	225	295
Total	450	530
Lab 309		
Outlet 1	460	545
Outlet 2	460	495
Outlet 3	460	510
Outlet 4	460	490
Outlet 5	460	550
Outlet 6	460	500
Total	2,760	3,090

Hydronic Analysis

KFI took a hydronic sample from the chilled water loop. A sample was sent to a chemical lab for analysis. The results indicated fluid appears to be untreated municipal water, with no corrosion-inhibitors or freeze-protection for system. Refer to the enclosed lab report in Appendix B of this report. Without glycol protection, coupled with the fact that there have been problems with the freezestat operation, there may have been some freezing events in coils causing the leaks.

Miscellaneous

We also observed that the hood exhaust dampers require air to actuate open. In other words, upon a loss of compressor, the dampers fail closed. This would appear to be a safety concern in the lab, and should be reconsidered for future controls work.

Recommendations

Low-Cost Recommendations

After a functional test review of the systems, we believe there are several steps that can be taken to correct the inconsistent flow problems within the system. These issues should be able to be resolved in a reasonably quick timeframe as well.

The following items are recommended by KFI, and currently understood to be planned for upcoming work by the University as per the January 8 meeting:

1. Disassemble and clean the displacement diffusers. This can be done by facility staff.
    a. Estimated Time: 30 minutes per diffuser.

2. The ductwork should be cleaned or replaced.
    a. Estimated Cost: \$1-2/ft^2 for cleaning. \$4-6/ft^2 for replacement.

3. Treat hydronic chilled water system as recommended by Closed Systems Labs. Additional information would be required to properly estimate the size of the system for estimation purposes.
    a. Estimated Cost: Typically around \$12/gal for premix solution.

The following items are recommended by KFI as additional low-cost items for a future project:

4. The filter racks should be sealed by a combination of gaskets and blank-off plates to prevent the bugs from bypassing filters.
    a. Estimated Cost: **\$4,000 total**

5. Replace the exhaust ductwork from the main to Lab 010A with properly sized ductwork, and limited transitions. The ductwork should attach to the main in an appropriate location to allow for favorable inlet conditions.
    a. Estimated Cost: **\$3,000**

6. The exhaust dampers controls should be altered to prevent the exhaust dampers from modulating. The pneumatic actuator should be disconnected from the damper shaft, and pneumatic lines verified to be capped. The existing damper can be used for balancing purposes by means of fastening a mechanical stopping device to the shaft to allow adjustment and fastening by the balancer.

    Similarly on the supply side, the remainder of the VAV dampers should be detached from the actuator, and provided with a mechanical adjustment/stop device.
    a. Estimated Cost: **\$28,000**

7. Replace existing hood face velocity monitors with TSI's recommended upgrade model FHM10-01. If existing sensor locations do not meet manufacturer requirements, they should be moved so that systems operate accurately.
    a. Estimated Cost: **$29,000**

8. The same result of lowering the flow at night can be accomplished by disabling one of the exhaust fans on each system, as originally intended. The dampers should be utilized to proportionally balance the exhaust systems so that each hood achieves the target 100 fpm face velocity. If the exhaust dampers hold the same position in unoccupied mode, disabling the 2nd fan on each system should maintain the proportional balance and lower the flow across each system equally at night.

    The new hood face velocity sensors should also be calibrated at this time.

    We would also recommend rebalancing the general exhaust fans.
    a. Estimated Exhaust TAB Cost: **$15,000**

9. AHU-1, 2 and 4 have two speed fans and drop to the low speed at night. The low speed should approximately be set to drop to half volume (similar to the exhaust system). The VAV damper can be utilized to proportionally balance the supply systems to design criteria, and mechanically locked into position. The flows to each room should be balanced so that each room is slightly negative to the hall.

    In addition, the AHUs should each be rebalanced as necessary as part of the supply VAV work. The minimum outside air damper position should be set as designed. This is critical to the overall pressure balance of the building.
    a. Estimated Cost: **$10,000**

10. There are a number of general pneumatic controls related items that would require investigation and correction for this project. Specifically:
    a. Correct the function of the lab exhaust systems so that two of the four lab exhaust fans shut down when the schedule turns to unoccupied mode at night.
    b. Correct damper functions of AHU-3.
    c. As part of verifying and correcting general function of the control system as noted in items a & b above, we have budgeted for other unforeseen corrections of the actuators and control systems, and assisting the balancer as required to properly set up all systems to maintain required flows.
    d. Estimated Total Cost: **$10,000**

Capital Investment Recommendations

The most energy efficient operation of the hood systems would result from a complete controls upgrade. There are several options described below. Please note that these costs do not include any of the low-cost recommendations, as it is assumed that the low-cost fixes have already been executed.

Convert building HVAC systems from constant volume to variable volume air systems.
The existing supply and exhaust air systems serving lab spaces and fume hoods are constant volume. Significant energy savings can be realized when converting to variable air volume (VAV) systems, without sacrificing lab safety.

The base recommendation is to convert the Constant Volume (CV) air system to a Variable Air Volume (VAV) system. From previous experience, this can result in an approximate 20% airflow reduction. Airflow control valves are added to the supply air, fume hood exhaust, and constant volume exhaust systems (combined flammable storage cabinets and snorkels). Sash controls, zone presence sensors, and room controls are installed to provide room control. **Picture 18** below is an example of a new control valve.

Picture 18

The building ventilation airflow is dictated by the exhaust airflow requirements of the fume hoods. The method being proposed of reducing the fume hood exhaust airflow rates is by blanking off the fume hood bypass grill and installing air volume control valves on the exhaust air duct to maintain constant face velocities across the fume hood sash opening. As the sash opening closes so does the control valve and thus the exhausted airflow. To provide a balanced VAV system, the supply air will also have airflow control valves to vary additional flow to and from the lab space, maintaining pressure relationships with adjacent space. In addition, any constant volume (CV) exhausts from the lab space should be controlled with a CV airflow control valve. Flammable storage cabinets and lab exhaust snorkels are examples of this application. Estimated Costs:

- Convert hoods from CV to VAV: $28,000
- Upgrade whole-building controls to DDC: $198,000
- Exhaust and supply valves (installed with controls): $252,000
- Whole-building Test & Balance: $40,000
- Engineering: $41,500
- Contingency: $56,000
- **Estimated Total: $615,500**

Fume Hoods Retrofitted with Combination Sashes

Assuming the existing hoods have been converted to VAV operation, the existing fume hood sashes could be replaced with combination sashes. Combination sashes reduce exhaust airflow by an estimated additional 20% over vertical single sashes. This can be accomplished by allowing the user to set-up and perform experiments with smaller vertical sash panes instead of raising the whole horizontal sash. The airflow savings, however, is dependent upon proper habits and will require training. Estimated Costs:

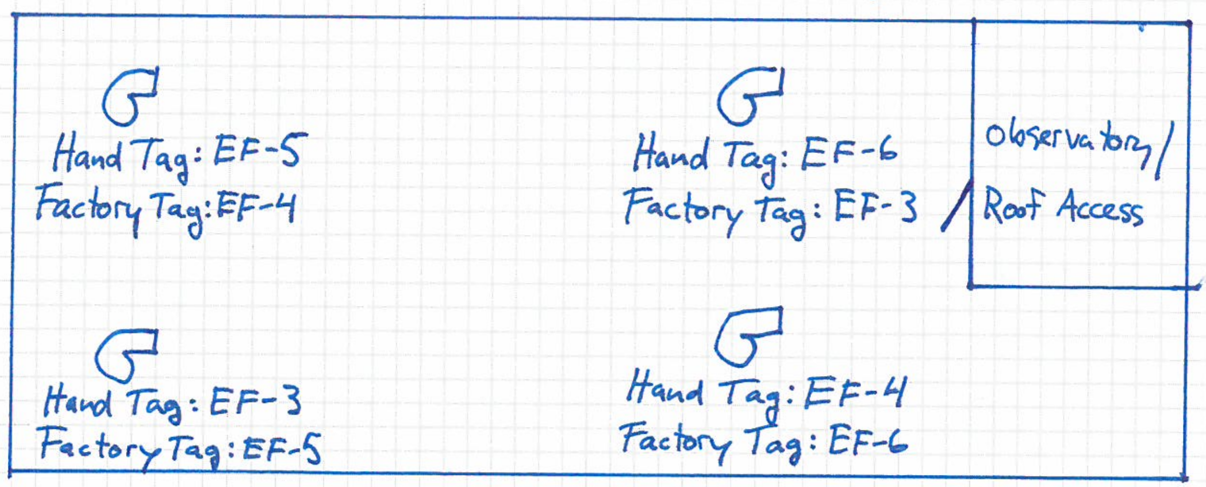
- Convert hoods from CV to VAV (with combination sashes): $140,000
- Upgrade whole-building controls to DDC: $198,000
- Exhaust and supply valves (installed with controls): $252,000
- Whole-building Test & Balance: $40,000
- Engineering: $50,400
- Contingency: $56,000
- **Estimated Total: $736,400**

Appendix A – Rooftop Exhaust Fan Schematic

← North

Handwritten EF Tags match 2010 EF locations (M201)

All KFI references are to handwritten tags.



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Appendix B – Hydronic Test Report

Closed System Labs Inc.

Ensuring longevity with chemistry.

DEC 5, 2012

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Hydronic Loops

HVAC LABORATORY REPORT

Safe Zones	Opacity/Color	pH	Conductivity	Hardness	Nitrite	Phosphate	Molybdate	Freeze Point	Corrosion	Prescribed Action
CW	clear/colored	9-10	<1500	<50	700-1200	>1000	>50	~winter lows	A Copper/Iron 0/0	

Barstow Hall [CW: xxxx gal • Xxx-Xxx • Xxsoftened Make-Up]

CW	DEC 5	clear/colorless	7.8	555	50	0	0	0	+32 (0%)	A Copper/Iron 0/0	Fluid appears to be untreated municipal water, with no corrosion-inhibitors or freeze-protection. No evidence of past or on-going corrosion. If glycol will not be used, non-nitrite corrosion inhibitors should be added to protect system. Please advise of system volume and metals present (steel, copper, aluminum) you'd like specific inhibitors prescribed.

LEGEND	Protective	Borderline	Destructive

- **Add:** Number of unit doses to be fed into system.
- **Alkalinity:** Measure of total alkalinity in ppm as calcium carbonate; values in the safe zone counter acidification caused by degrading glycol.
- **Conductivity:** Measure of dissolved inorganic salts in µmhos/cm; values in the safe zone reduce corrosion.
- **Copper:** Measure of copper ions in ppb; values in the safe zone indicate copper pipe is protected.
- **Corrosion:** Grade assigned to corrosion rate; A = < 0.1 mpy, B = < 0.2 mpy, C = < 0.3 mpy, D = < 0.4 mpy, F = > 0.5 mpy.
- **Freeze Point:** Measure of °F temperature at which a fluid freezes; values 5° below local winter lows prevent freezing.
- **Hardness:** Measure of total hardness in ppm as calcium carbonate; values in the safe zone reduce scaling.
- **Iron:** Measure of iron ions in ppb; values in the safe zone indicate iron and steel pipe are protected.
- **Molybdate:** Measure of molybdate as Mo^{+6} in ppm; values in the safe zone inhibit corrosion.
- **Nitrite:** Measure of sodium nitrite in ppm; values in the safe zone inhibit corrosion.
- **Opacity/Color:** Indication of corrosion products, organic matter and particulates present.
- **pH:** Measure of acidic or basic conditions; values in the safe zone reduce corrosion.
- **Phosphate:** Measure of orthophosphate in ppm; values in the safe zone inhibit scaling and corrosion.
- **Sarcosinate:** Measure of sodium lauroyl sarcosinate in ppm; values in the safe zone inhibit corrosion.
- **Sulfite:** Measure of sodium sulfite in ppm; values in the safe zone inhibit corrosion.
- **Sulfate:** Measure of sulfate in ppm; values in the safe zone reduce interference with corrosion inhibitors.
- **System:** CW (Chilled Water), HP (Heat Pump), HW (Heated Water), MU (Make-Up).