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Point-to-Point Verification of Monitored Sensors at Reynolds Army Clinic and Hospital Final Report

Submitted to:

Reynolds Army Clinic and Hospital
Fort Sill, Oklahoma

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Executive Summary

The U.S. Army Corps of Engineers awarded a contract to the Energy Systems Laboratory (ESL) at Texas A&M University through J & J Maintenance to perform a point-to-point verification of the newly upgraded Johnson Controls (JCI) Metasys (Version 12) system, operating at the 512,100 ft^2 Reynolds Army Community Hospital (RACH) facility. The RACH facility consists of two sections. A relatively older clinic section (212,000 ft^2), a newer hospital section (300,100 ft^2) both conditioned by a central air-conditioning system. The air handlers are single duct, constant volume (CAV) or variable air volume (VAV) systems with reheat. There are also a few dual duct constant volume systems. Chilled and hot water is provided by the central energy plant located adjacent to the complex. Heating water is generated by central plant steam through heat exchangers located inside the clinic and hospital. Three McQuay chillers and three natural gas boilers operate in this facility. The chilled water system uses a primary/secondary distribution system. The energy management control system (EMCS) control points for each plant and air handler (AHU) system were verified. The exceptions were three AHUs that serve the elevator rooms. These units are not controlled by the Johnson Controls system.

The emphasis of the point-to-point verification was specifically on points used in control algorithms for the heating, ventilation, and air conditioning (HVAC) systems. The control points investigated were temperature sensors, static pressure sensors, airflow sensors, and relative humidity sensors. Faulty sensors were identified, along with sensors that required relocating. Many of the temperature sensors required calibration. During this verification time period, it was not possible to calibrate all the temperature sensors. However, calibration procedures for supply, return, mixed, and preheat temperature sensors were provided to RACH facility personnel. They have been instructed to resume calibration as soon as outside weather conditions permit. ESL recommends that they be performed during winter months or when the outside temperature is less than 65 °F.

Fifteen VAV air handlers systems use a return air volume tracking control algorithm. Air flow stations are used to control and monitor supply and return air flow. However, it was found that all the flow stations were not functioning correctly. The pitot tube assemblies were clogged with dust. False signals were being used by the control sequence causing the supply and return fan VFDs to operate at maximum conditions (60 Hz). ESL recommended that each flow station be back flushed with compressed air and that hatches be installed upstream and downstream of each flow station for preventative maintenance. After back flushing, four air handlers could not be calibrated because of a faulty flow station. New control parameters for the airflow stations were downloaded to each DX-9100 controller to increase the response time and accuracy of the return air tracking algorithm.

During verification it was found that the static pressure signals provided to AHUs using VFDs were extremely low. After close investigation, it was determined that the static pressure sensors (Flow stations) were configured to measure velocity pressure instead of static pressure. Initial readings ranged from 0-0.3 in. H_2O. The pneumatic lines at the

flow station and transducer were corrected and static pressure measurements recorded. The correct values increased to approximately 1.0 in. H_2O. Supply fan speeds began decreasing once their static pressure setpoints were satisfied. Two static pressure sensors did not pass verification. ESL recommended that the sensors be cleaned in the same manner as the air flow stations (Back flush the sensor with compressed air).

The hospital air handlers use humidity control as part of their control algorithm. Some are controlled in the Direct Digital Control (DDC) and some use pneumatically controlled steam injectors. The majority of the humidity sensors monitor the return air. Six humidity sensors were verified to be out of range. AHU-225 and AHU-226 use supply and return air humidity for control. These two units serve the operating room of the hospital. Their supply humidity sensors for the operating rooms need replacing. Based on information published by Johnson controls, the humidity sensors cannot be calibrated. They can be factory repaired or replaced.

ESL has recommended that the following problem areas which were identified during the verification process be given immediate attention.

1. Replace return air humidity sensors for AHU-155, AHU-245, AHU-345, and AHU-355.
2. Replace supply air humidity sensors for AHU-225 and AHU-226.
3. Clean and/or replace the flow stations for AHU-145, AHU-120, AHU220, and AHU-355.
4. Clean and/or replace static pressure sensors (flow stations) for AHU-175, AHU-355, AHU-240, and AHU-40.
5. Repair and/or replace the secondary chilled water flow meter and the main bypass flow meter.
6. Relocate the differential pressure sensors for the clinic and hospital. Place the sensors near the end of each loop.

Each of these items has a direct impact on energy savings for RACH. Correcting these items before the commissioning phase begins is extremely important. Control sequence modifications using these components cannot be implemented until they are corrected.

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Introduction

A point-to-point verification of the heating, ventilating, and air conditioning (HVAC) system of the Reynolds Army Community Hospital (RACH) in Fort Sill, Oklahoma was done by the Energy Systems Laboratory (ESL) of Texas A&M University. Work began on January 12, 2004 and was completed on July 2, 2004. The facility consists of a clinic section having 212,000 ft^2 and a hospital section with 300,100 ft^2. Both sections are contained in one building for a total of 512,000 ft^2. The clinic section of the facility is occupied from 0700 hours – 1700 hours while the hospital side operates 24/7.

Verification of the facility began shortly after the completion of a $2 million upgrade of the Energy Management Control System (EMCS) by Johnson Controls from their existing 8540 pneumatic system to a direct digital control (DDC) Metasys version 12.0 system. Only the points read by the control system and used for control sequencing were verified.

In the following sections of this report detailed information will be provided for the type of equipment used for the point-to-point verification and calibration, calibration tolerances for the devices requiring calibration, areas that require attention prior to calibration, and calibration procedures. The remaining sections will focus on the central plant, clinic, and hospital areas. Each section will contain individual field data for each component tested and calibrated.

Verification/Calibration Equipment

Flow measurement
Airside:
A VelociCalc® Plus Air Velocity Meter, Model 8386A, was used to verify and calibrate air flow stations, temperature sensors, relative humidity sensors, and static pressure sensors. The specifications for this multifunction meter are as follows.

Velocity from thermal sensor:
- Range: 0-9999 Ft/min
- Accuracy: ±3 % of reading or ±3 Ft/min which ever is greater

Velocity from a pitot tube:
- Range: 250-15500 Ft/min
- Accuracy: ±1.5 % at 2000 Ft/min

Temperature:
- Range: 14-140°F
- Accuracy: ±0.5 %

Relative Humidity:
- Range: 0-95% RH
- Accuracy: ±3.0 %

Static/Differential Pressure:
- Range: -5 - +15 in. H_2O
- Accuracy: ±1.0 % of reading ±0.005 in. H_2O

Waterside:
A Panametric flow meter was used to verify the chilled water flow meters. It is an ultrasonic type flow meter, model PT868. This meter was configured for the Transit-time mode. Ultrasonic pulses are emitted from the meter into the fluid medium in order to calculate flow velocities through cross correlation and various digital signal processing techniques. The flow accuracy for this configuration (Transit-time mode) is dependent on pipe diameter. For pipe diameters greater than 6 inches, the accuracy is 2% of reading for velocities less than 1 Ft/sec. Pipe diameters less than 6 inches have an accuracy of 2-5% of reading.

Temperature measurement
Digital Thermometer:
A Fluke 54-II Digital Thermometer was used to measure temperature. The electronic offset function maximizes overall accuracy by compensating for thermocouple errors. This instrument has an accuracy of ±(0.05% of reading +0.5°F). The range for a K-type thermocouple is –328°F to 2,501°F.

Temperature Probe:
In place of the standard bead thermocouple that comes with the digital thermometer, a Fluke 80PK-24 SureGrip Air Probe was used attached to the digital thermometer in order to gain temperature measurements.

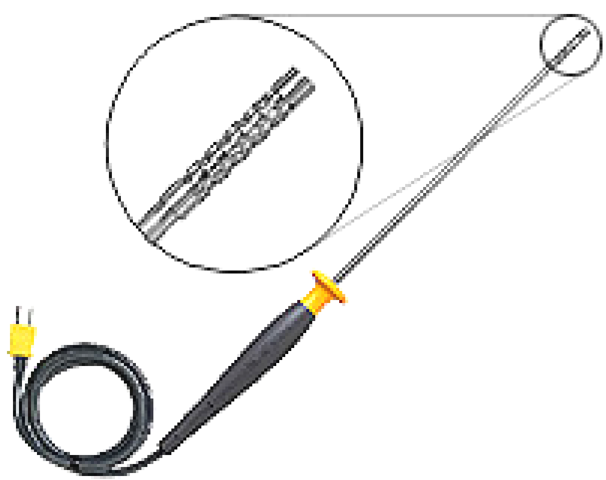

Figure 1: Fluke 80PK-24 Probe

The probe is 8.5” long and made from Inconel (See Figure 1). The measurement range is –40.0°F to 1,500.8°F. This probe is compatible with K-type thermocouples. Error generated by the probe is reduced by the electronic offset function within the digital thermometer. A perforated baffle surrounds the probe to protect it during use.

Relative Humidity measurement
The HOBO® Logger, model H08-007-02, is a portable device designed to trend relative humidity for extended periods of time. These loggers were placed adjacent to existing

humidity sensors inside the air handler for point-to-point comparison. The operating range of these loggers is 0-95% relative humidity non-condensing. The accuracy is ±5% for the full operating range.

Electro-pneumatic transducer Calibration
The Flute 743B Documenting Process Calibrator can act either as a measurement or as a source device. It is capable of calibrating temperature, pressure, voltage, current, resistance, and frequency. The system supports devices using either linear or square root functions. It also acts as a data logger. The 743B Calibrator allows for downloading procedures and instructions from a PC.

Calibration Tolerances

Temperature sensors used in the energy management control system (EMCS) upgrade were TEP and TEA series Platinum sensors. TEP (Probe type) sensors were used for supply air, return air, and chilled water (water side) temperature sensing. The TEA (Averaging type) series Platinum sensors were used for sensing mixed air and preheat air temperatures. These 1000 ohm sensors are configured as passive inputs for their designated controller. The accuracy of these sensors is ±1°F at 70°F. Johnson Control does not provide information on whether the percent error of the sensing element is based on the measured value or full scale.

The differential pressure transducers used in the upgrade were manufactured by Setra with specification provided by Johnson Controls. The published performance data for these transducers state that the standard accuracy is ±0.5% full scale (FS). The factory set zero output (4 ma) is within ±0.16 ma and the span output (20 ma) is set to within the same tolerance.

NOTE: Calibration tolerances are based on published information provided by Johnson Controls.

Verification/Calibration Procedures

According to the “As built” mechanical drawings for the RACH facility, there are thirty seven air handler units serving the complex. There are fifteen VAV air handler systems and nineteen constant volume systems. Three of the constant volume systems are thermostatically controlled. They provide cooling for the elevator equipment. Since these units are not monitored by the Metasys control system they were not calibrated at this time. These units are listed as AHU-401, AHU-402, and AHU-403.

Temperature Sensors

Readings from the DX-9100 controller were compared with measured temperatures in order to determine which sensors were out of calibration. When ever possible, the sensor accuracy was compared at two different temperatures before calibrations were made. The offsets for supply air temperature and return air temperature were found by using the following procedure. Figure 2 illustrates the typical air handler configuration for the variable air volume and constant volume systems at this facility.

Procedure:

1. Manually close the Preheat valve and Chilled Water valves on the air handler (See Figure 2).
2. Modulate outside air and return air dampers to maintain a 55°F mixed air temperature. To maintain a 55°F mixed air temperature override the mixed air set point in the controller or manually fix the outside and return air dampers.
3. Wait for the system to stabilize (approx. 15 min.).
4. Record the corresponding SAT and RAT values from the DX-9100 controller and TSI.
5. Once all values have been recorded. Open the return air damper and then close the outside air damper. Wait for the system to stabilize.
6. Record the SAT and RAT values from the DX-9100 controller and TSI.
7. Calculate the offset between the DX-9100 controller and the measured values for each corresponding point. Determine the average offset.
8. Use the average offset values to adjust the digital counts of the controller.

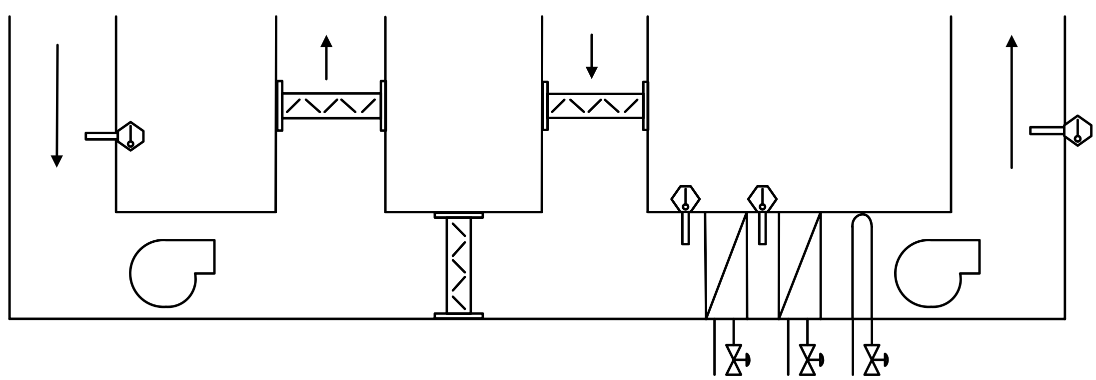

Figure 2: Typical Air Handler Schematic

Preheat and mixed air use averaging temperature sensors which can make comparison to a single point probe difficult. The following procedure described is for calibrating mixed air temperature (MAT) and preheat temperature (PHT) sensors using the existing Supply air temperature (SAT) and Return air temperature (RAT) sensors located on the air handler (See Figure 2). This is a two-point calibration procedure. In using this procedure the assumption is made that the SAT and RAT temperature sensors have recently been calibrated.

Procedure:

1. Manually close the Preheat valve and Chilled Water valves on the air handler.
2. Modulate outside air and return air dampers to maintain a 55°F mixed air temperature. To maintain a 55°F mixed air temperature override the mixed air set point in the controller or manually fix the outside and return air dampers.
3. Wait for the system to stabilize (approx. 15 min.). The MAT, PHT and SAT should be reading ± 1.5°F of each other. The SAT will normally read slightly higher than the MAT and PHT because of the heat generated from the fan.
4. Record the MAT, PHT, and the SAT values from the DX-9100 controller.
5. Once all values have been recorded, open the return air damper and then close the outside air damper. Wait for the system to stabilize.
6. Record the MAT, PHT, and SAT values from the DX-9100 controller.
7. Calculate the offset between the MAT and SAT and the offset between the PHT and SAT sensors.
8. Use the offset values to adjust the digital counts of the controller.

The criteria for determining which sensors to calibrate takes into account the heat gain across the fan and a tolerance of ±1.0°F for the accuracy of the averaging sensors used. The heat gain across each fan was calculated by making the assumption that the fan brake horsepower is 70% of its maximum motor horsepower and that sensible heat is the only contribution to the temperature rise across the fan. Therefore the following equation can be used to solve for the temperature difference.

$$\dot{q} = \dot{m} c_p \Delta T$$

Where, $\dot{q}$ is the sensible heat transfer from the motor, $\dot{m}$ is mass flow rate of the air, and c_p is the specific heat of air. The average temperature increase from the fan for each air handler was approximately 1.0°F. The offset values provided in the calibration tables for the mixed air and preheat temperature sensors, take into account the heat gain across the supply fan.

Flow Stations

The air handler units operating on VAV systems use a return air volume tracking algorithm in order to control the return air fan speed. The fan is ramped as needed based on a predetermined differential between supply and return air flow. The differential setpoint is based on the design specifications of the building. Initially, there was a significant difference between measured flow, and the flow read by the DX-9100 controllers. There were many variables in this particular airflow system that created error in the actual flow reading displayed by the DX controller. Software settings, pneumatic transducers incorrectly sized for their corresponding airflow station, and clogged flow stations all contributed to the total error. For example, during verification it was not uncommon to find that the High CFM limit programmed in the controller did not correlate to the flow necessary for the Setra pressure transducers to output 20 mA. In some cases the square root function, which linearized the input signal to the controller, was not enabled. In addition to these problems, it was found that some of the pneumatic transducers installed did not match what was stated in the control drawings, which were provided by Johnson Controls.

The maximum CFM, or High CFM limit, listed in the controller is used to determine the airflow through the flow station. The controller processes the mA signal that it receives from the transducer as a percentage of the total transducer span and associates that with the percentage of the CFM range for the air handler. The AI (analog input) point setup allows the designer to choose whether this association is linear or uses a square root function. For pitot tube style flow stations, the association should use the square root function. This makes it necessary to have the correct maximum CFM entered in the AI configuration for each controller in addition to the square root function being enabled.

The most important factor in accurate return air volume tracking control is the response or performance of the flow station. The flow stations at RACH use a multi-pitot tube configuration to send an average velocity pressure signal to the input transducer (See Figure 3). The following fundamental equation is used to convert velocity pressure to a velocity. This equation can only be used if the fluid media is air.

$$Velocity = 4005 * \sqrt{v_p}$$

where v_p is velocity pressure, in inches of water column, and the *velocity* is in feet per minute (FPM). The air flow, in CFM, can then be determined by multiplying the calculated velocity by the cross sectional area of the duct. The maximum CFM equals the airflow for a 20 mA output signal from the transducer (100% of its range). The controller can interpolate for slightly higher velocity pressures, but accuracy is lost.

The most common problem associated with pitot type flow station is the sizing of the transducers. The transducers achieve their greatest accuracy when measuring a differential pressure in the upper half of their range. If the velocity pressure is too low, the signal will be compromised because the magnitude of the noise signal is comparable to the actual signal. The DX-9100 controller cannot distinguish between the actual signal and typical input signal noise.

Figure 3: Return Airflow Station for AHU-130

Figure 3 is a photograph of a flow station located on the return airside of air handler 130. It is accessible from the return fan plenum. The flow stations used in the other air handlers are not accessible. Notice the excessive amount of dust on the tubing and that some of the tubes that measure the total pressure are completely covered with dust. The blockage is causing the averaging sensor to send a skewed signal to the transducer. In order to illustrate this further, a more detailed picture is provided (See Figure 4).

ESL recommended that each and every flow station be cleaned. Compressed air was used to back flush the tubing assembly. Pressurization of the flow station pitot tubes will force dust from the clogged ports into the ductwork. For future cleanings it is important to remember to remove the lines connecting the transducer or the high pressure will damage it. Service doors should be installed in the ductwork before and after the flow station to remove the excess debris and for preventative maintenance.

Before calibration began on the flow stations, each flow station under went a preliminary test to determine if calibration was possible. A TSI, Veloci-Calc meter, was used to measure the velocity of the air in the duct which was then compared to the measured differential pressure signal generated from the flow station (Measured with a second TSI). The pressure signal was converted to a velocity. If both velocity readings were within 20 % of each other then the flow station could be calibrated. If either flow station (SA or RA) did not meet the criteria (20 % error) then neither of the flow stations were calibrated for that air handler. The flow stations that satisfied the 20% error criteria were calibrated using the following procedure.

Procedure:

1. Verify and/or correct the maximum CFM value in the GX-9100 commissioning software, enable the square root function, and download the corrections to the controller. The CFM values entered are based on actual transducer information.
2. The VFDs for each fan (supply and return) were put in manual mode at 60 Hz, simultaneously.
3. Velocity or flow was measured with the TSI and compared with the actual controller reading. All values were recorded.
4. Calculate the percent error.
5. Repeat steps 2-4 cycling the VFDs simultaneously down to 40 Hz. in increments of 10 Hz.
6. Verify that the 20% error requirement is satisfied at each tested frequency.

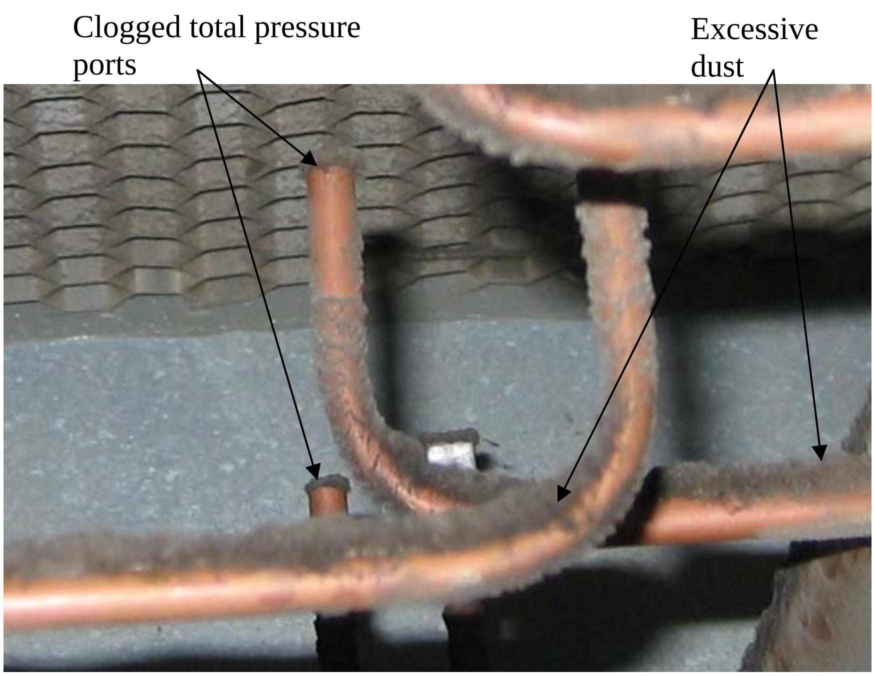

Figure 4: View of Clogged Pitot Tubes

In most cases the flow stations were able to be calibrated. There were four air handlers that could not be calibrated because of flow station problems. They were AHU-145, AHU-120, AHU-220, and AHU-355.

Static Pressure Sensors

The static pressure sensors for the air handlers were typically located about 2/3 of the way down the longest run. The static pressure sensor is used to modulate the supply air fan. Normally static pressure is taken with a single pitot tube extending into the duct or a plate mounted flush on the side of the duct with a small hole exposed to the airflow. However, at RACH this was not the case. Flow stations were used as static pressure sensors. In many cases, both high (total pressure) and low (static pressure) ports were connected to the Setra pressure transducer. When this is the case, the velocity pressure is read by the controller instead of the static pressure. Velocity pressure will never reach the static pressure setpoint so the supply fan motor runs at 100% all the time. For static pressure to be read, the "low" port on the flow station needs to be connected to the "high" port on the transducer. The "high" port on the flow station should be connected. The reference, "low", port on the transducer should be exposed to the surrounding atmospheric conditions.

A two point calibration procedure was performed on the static pressure sensors. The supply side VFD was put in manual mode during calibration. The VFD was first commanded to 60 Hz and then 40 Hz. At each calibration point the static pressure was measured with a TSI meter and compared with the value displayed at the controller.

Return Air Humidity Sensors

Sensors monitoring return air humidity control the steam humidifiers for the supply air of the hospital units. Incorrect readings in either direction could cause discomfort to patients while low humidity readings would also result in an excess usage of steam. While some humidity sensors allow for small calibrated adjustments, many of the sensors had offsets that went far beyond the calibration limits and required replacement.

Central Plant

The central plant located adjacent to the facility provides chilled water, steam, and domestic hot water to the building. Two 500-ton McQuay chillers and one 350-ton chiller supply chilled water to the complex. The chilled water uses a primary/secondary loop system (See Figure 5). A small 38-ton chiller is installed in the hospital for emergency use. Three natural gas steam boilers are used for steam production (two at 350-BHP and one at 250-BHP). Heat exchangers inside the clinic and hospital are used to provide heating water (40% glycol mix) in the hospital and clinic. Measurement points for steam and hot water were not accessible for verification.

Temperature Calibration

Both supply and return temperatures were measured on the condenser and evaporator (Chilled water) sides of each of the 3 chillers in the central plant. These measurements were done by directly measuring the temperature of a continuous stream of water from each pipe. The results are shown in Table 1. A temperature difference less than one degree is the acceptable tolerance. Only single point verification was performed on the sensors. Creating large temperature span would cause cooling problems in the hospital and clinic areas.

Table 1: Temperature Sensor Measurements for Central Plant Chillers

Chiller Name	Point Name	DX-9100 (° F)	Measured (° F)	Temperature Difference (°F)
M-1	CWS	76.3	76.3	0
	CWR	82.1	81.6	0.5
	CHWS	40.8	40	0.8
	CHWR	51.4	50.9	0.5
M-2	CWS	79.8	79.1	0.7
	CWR	86.2	86	0.2
	CHWS	42.5	41.3	1.2
	CHWR	53.4	53.5	-0.1
M-3	CWS	78.1	77.4	0.7
	CWR	84.5	84.4	0.1
	CHWS	43.4	41.8	1.6
	CHWS after calibration	41.9	42	-0.1
	CHWS 2nd point	43.7	44	-0.3
	CHWR	57.2	56.4	0.8

The temperature sensor for the chilled water supply on chiller M-3 required calibration. Once the sensor was adjusted, the chilled water supply setpoint was increased a few degrees to check the response of the sensor. The new temperature values were recorded.

Differential Pressure Sensors

Secondary chilled water loop differential pressure was measured for both the hospital and clinic sides of the complex. Return pressure was measured independently of supply and then subtracted to find differential pressure. For the hospital, it was necessary to disconnect the tubing to the DP sensor to gain access to the water pressure directly. DX readings were taken before and after measurements to ensure that the value did not change during the time it took to take the measurements (See Table 2).

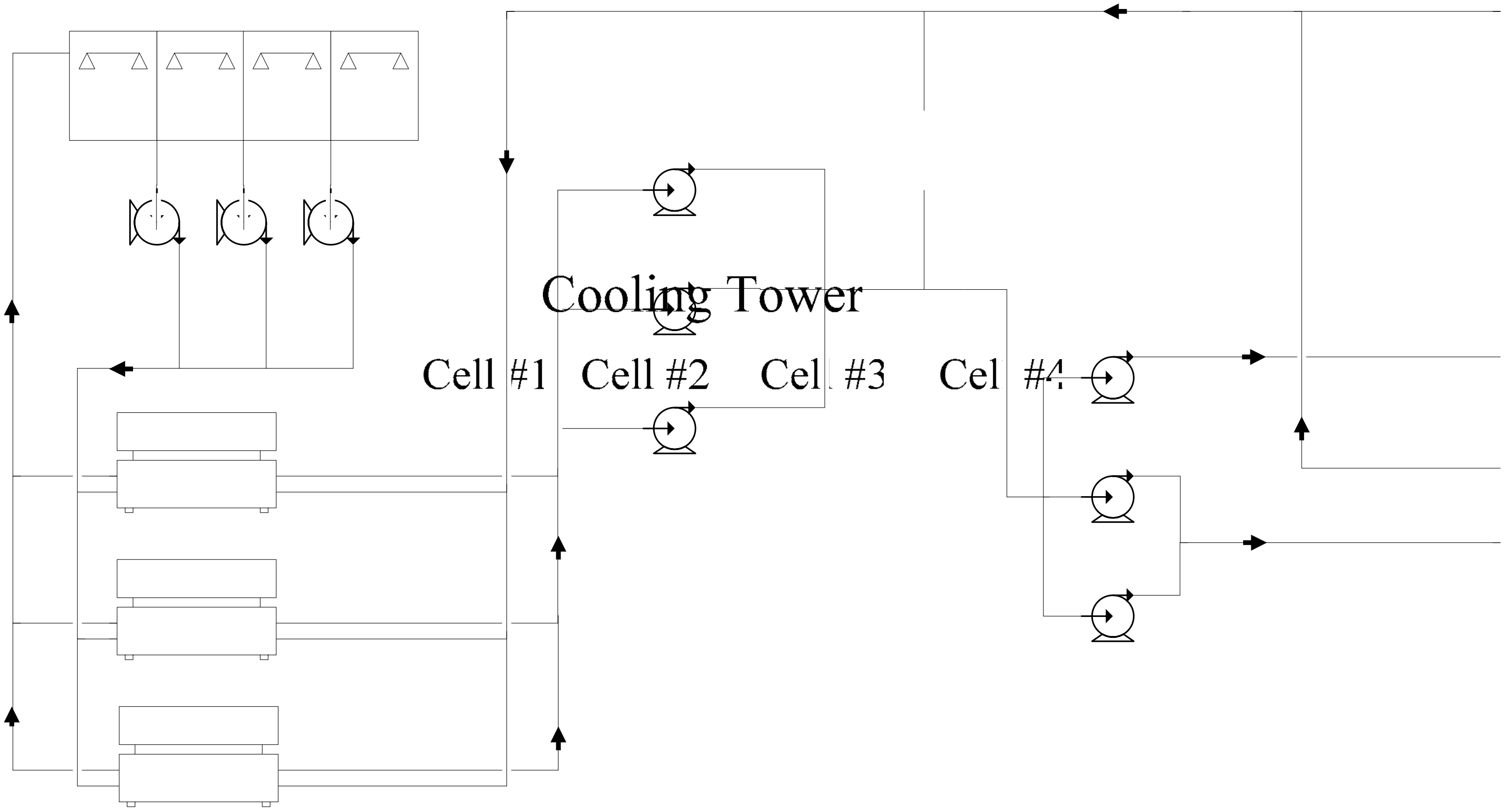

Figure 5: Central Plant Chilled Water Loop Schematic

Table 2: Chilled Water DP Sensor Verification

DP Sensor	Pump Setting	DX-9100 DP (psi)	Measured DP (psi)	Difference (psi)
Clinic	60 Hz	17.3	18.0	-0.7
	40 Hz	12.0	12.0	0.0
Hospital	40 Hz	8.6	9.0	-0.4
	50 Hz	14.8	16.0	-1.2

Before these measurements were taken, the secondary chilled water loop pumps were placed in hand and the system was allowed to settle in order to minimize fluctuation. The pumps were then ramped down in order to allow for a 2-point verification. Neither of the differential pressure sensors required calibration. Both sensors are located too close to the central plant. ESL recommends that both sensors be relocated to the ends of their perspective loops and adjust the differential setpoints accordingly.

Flow Meters

The flow meters for the main bypass of the chilled water loop and the secondary chilled water loop were checked using a Panametric flow meter for comparison against the paddle wheel type flow meters that are currently connected to the Metasys system. Both flow meters currently installed are made by Flow Research Corporation. The data collected between the Metasys trend data for the Main Bypass Flow and measured data found using the Panametric flow meter is shown in Figure 6.

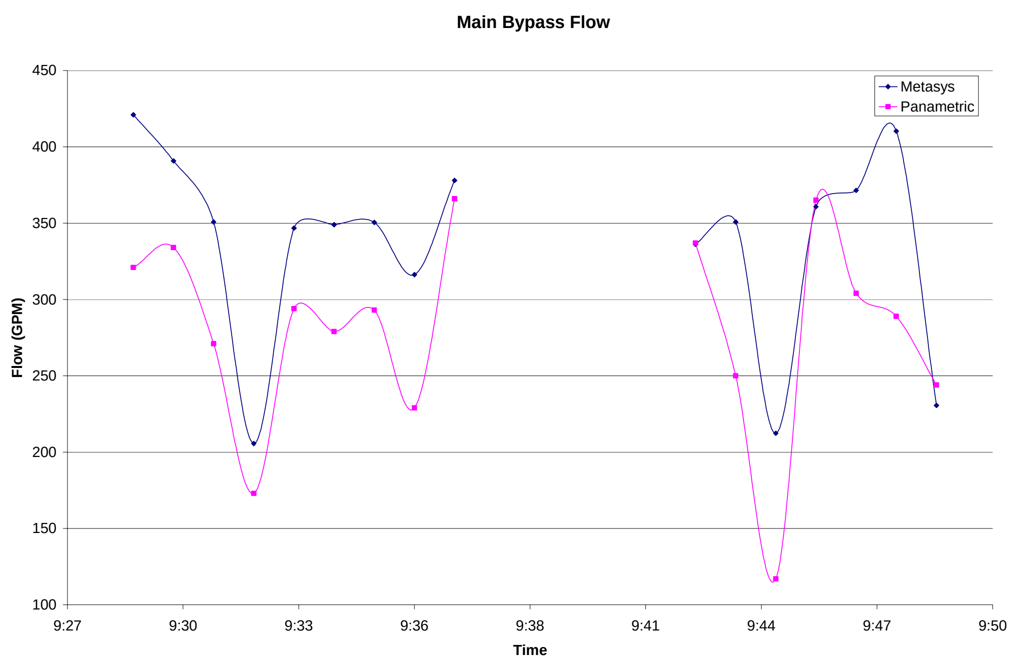

Figure 6: Main Bypass Flow

Approximately 20 minutes of “Snap-shot” data from the Panametric flow meter and the secondary loop flow meter was collected. Because these are “Snap-shot” data points, they cannot be compared directly. The response time of the Panametric flow meter and the paddle wheel type flow meter are not the same. Also, the Panametric flow meter uses an integrating algorithm to calculate the flow where the DX-9100 controller does not. The DX-9100 controller can only provide instantaneous values from the paddle wheel type flow meter. The “Snap-shot” data was averaged over the time period of the data collection. The average offset of Metasys trend data compared with the Panametric flow meter was approximately 57 GPM with Metasys reading higher than the Panametric. It is not possible at this time to determine if the bypass flow meter is out of calibration. Further data collection is needed in addition to testing and calibration of the signal transducers.

One reason for signal discrepancy may be caused by inclusion of multiple transducers in the wiring from the flow meter to the controller. For this particular meter, the output of the flow meter is converted into a mA signal and then into a voltage signal by a second transducer. It is then inputted into the DX-9100 controller. The error in converting from mA to voltage is a possible contributing factor for discrepancies in the flow. It should also be noted that Flow Research flow meters have difficulty accurately measuring velocities of less than 1 ft/s or a flow of 150 GPM for the 8” bypass line. Flows less than 150 GPM will contain a larger error.

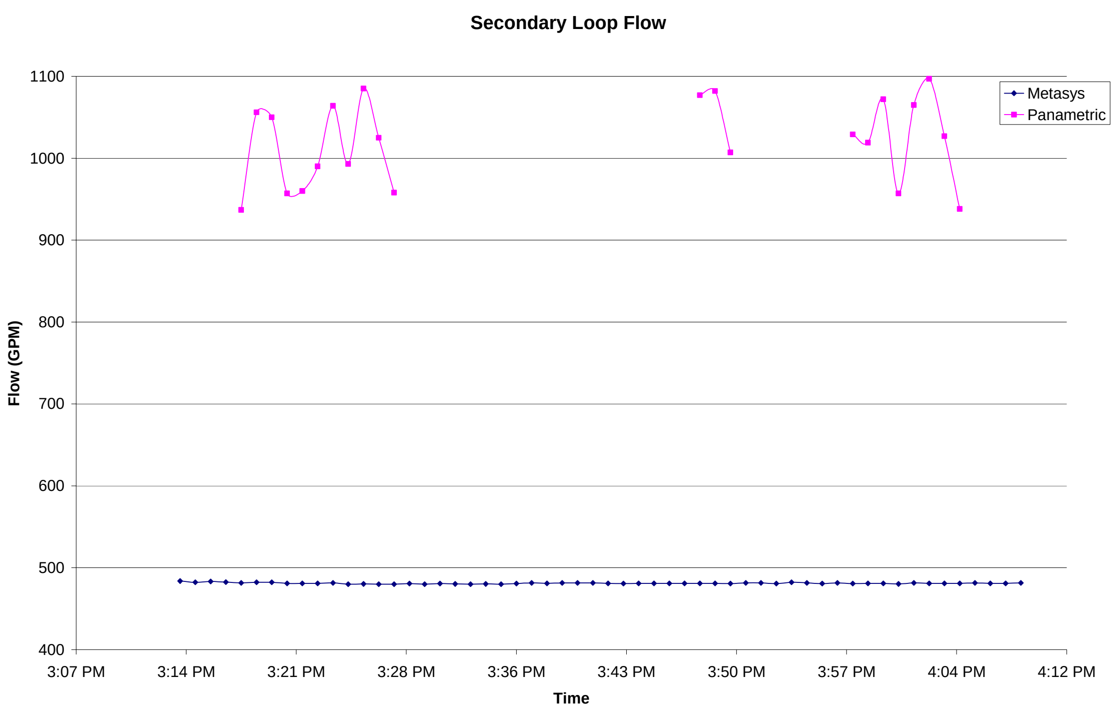

Figure 7: Secondary Chilled Water Loop Flow

Figure 7 illustrates the data collected for the secondary chilled water loop flow meter. The average offset measured between the flow meters was 539 GPM. Metasys showed the flow to vary between 480 GPM and 483 GPM. The Panametric flow meter measured flow values that varied between 937 GPM and 1097 GPM. The average flow for the Panametric flow meter during the twenty minute time period was 1020 GPM. Based on the data collected for the chilled water loop flow meter, the meter has failed. However, further investigation is needed to determine why the input signal is constant (i.e. paddle wheel blades are broken, loose or bad electrical connections, etc…). Currently neither of these flow meters are used for central plant control operation. For this reason, the flow meters have not been calibrated or repaired at this time.

Clinic Section

AHU 20

This is a single duct constant volume unit that serves the northwest corner of the hospital basement. Temperature measurements taken to verify the sensors for this unit are shown in Table 3.

Table 3: AHU 20 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-20	DAT	60.3	60.0	0.3	73.3	73.0	0.3
	RAT	74.1	74.5	-0.4	74.7	74.7	0.0
	MAT	58.8	61.0	-2.2	79.9	73.2	6.7
	PHT				71.0	71.5	-0.5

During initial testing, the mixed air sensor on AHU 20 was identified as needing calibration. However, the offset between the DX-9100 controller and the TSI probe was not consistent. The difference in offsets between the readings at different temperatures indicates that this sensor is drifting or that the slope of the calibration curve is incorrect. It is recommended that the sensor be replaced before trying to adjust the digital counts of the analog input point in question.

AHU 40

Air handler 40 is a single duct variable air volume system with variable frequency drives (VFDs) on both its return and supply air fans. This system serves the majority of the clinic basement including autopsy, computer repair, corridors, offices, ADPE Fixx center, equipment management, reproduction center, housekeeping, elevator lobby, conference room, orderly supply room, women’s locker, telephone equipment room, and inventory management. The supply air was designed to have a flow between 17,640 CFM and 22,520 CFM while the return air modulates from 10,030 to 13,550 CFM. The transducers chosen for the flow station are the appropriate size to accommodate these flows given the duct sizing.

Table 4: AHU 40 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-40	SA	Rectangle	62	18	7.75	0.5	21,948
	RA	Rectangle	34	32	7.56	0.25	15,130

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.346" while the velocity pressure derived from measured flows was 0.513". The return flow transducer had a 0.09" velocity pressure while measured flows gave a velocity pressure of 0.031". For this size duct, the velocity pressure difference translated into an error of 3,974 CFM for supply air and 3,846 CFM on return air. These readings required that the flow station be thoroughly cleaned before changes could be made to the Johnson program that would allow for correct measurements. Once the station had been cleaned, the Johnson program was changed. The maximum flow reading for supply air was decreased from 30,000 to 21,948 while the maximum flow for return air was increased from 9,496 to 15,130 CFM. Flow measurements taken after these changes were made are displayed in the table below.

Table 5: AHU 40 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-40	SA	11800	12632	-7	14400	15440	-7	17300	17968	-4
	RA	7650	8096	-6	9670	10336	-7	12520	11746	6

The maximum error found in this test was 7%. This is within the acceptable range. The static pressure sensor for this unit was found and measured after corrections were make to the connection of the flow station that reads the static pressure. A 2-point calibration was done to verify the accuracy of the flows station in the table below. The flow station is within tolerances.

Table 6: AHU 40 Static Pressure Measurements

Air Handler Name	Readings					
	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-40	0.3	0.3	0.0	1.3	1.1	0.2

Initial temperature measurements are shown in Table 7. The discharge air temperature and return air temperature sensors were calibrated during the 1st and 2nd visits by ESL engineers. The supply/discharge air temperature sensor now reads 0.5°F above measured temperature. The return air temperature sensor had to be relocated in order to move it into the air stream. It now reads within tolerance.

Table 7: AHU 40 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-40	DAT	60.3	66.3	-6.0	63.0	73.3	-10.3
	RAT	72.8	74.3	-1.5	73.1	74.9	-1.8
	MAT	64.9	69.1	-4.2	72.7	73.3	-0.6
	PHT	66.8	67.8	-1.0	73.2	72.4	0.8

Final calibration of the mixed air and preheat temperature sensors was performed by RACH personnel. The results are shown below in Table 8.

Table 8: AHU 40 Preheat and Mixed Air Temperature Sensor Calibration

		Readings					
		1st readings			2nd readings		
Air Handler 40	Sensor Name	SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	63.8	63.8	-1	75.5	75.9	-1.4
	PHT	63.8	62.6	0.2	75.5	74.2	0.3
After Calibration	MAT	66.9	65.7	0.2	76.8	75.9	-0.1
	PHT	66.9	65.8	0.1	76.8	75.5	0.3

AHU 110

Air handler 110 is a single duct variable air volume system with variable frequency drives (VFDs) on both its return and supply air fans. It is located in section B, near the NW corner of the 1st floor. The air handler serves the west corridor, Procedure room, exam rooms, chief Peds, reception waiting, office, lounge, south corridor, clinical support, chief ambulatory, supply room, podiatry, orthopedic, physical asst, and orthopedic surgeon. The supply air for the unit is designed to operate between 7,525 and 11,185 CFM while the return air was designed for 5,030 to 8,690 CFM. The maximum CFM listed in the controller for this air handler was incorrect given the duct sizing. Original programming listed the supply air and return air maximum CFMs as 14,000 and 9,288, respectively. This offset may have been an attempt to compensate for dirt in the flow stations when the programming was done, as time went by, the readings grew further apart from measured values. The calculated maximum flows, based on the transducer range, for AHU 110 are listed below in Table 9.

Table 9: AHU 110 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-110	SA	Oval	31	21	3.86	0.5	10,942
	RA	Rectangle	34	22	5.19	0.25	10,402

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.54” while the velocity pressure derived from measured flows was 0.624”. The transducers for airflow on this air handler were of the correct size and did not need to be replaced. After cleaning of the flow stations and program changes, the following measurements were taken to ensure that the air flow stations were now reading correctly (See Table 10).

Table 10: AHU 110 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-110	SA	5983	7260	-21	7263	9088	-25	9418	10808	-15
	RA	5260	5000	5	6513	6340	3	7811	7588	3

The static pressure sensor for this air handler was not connected correctly. Modifications to the pneumatic tubing were made to correct the situation. The results are shown in Table 11.

Table 11: AHU 110 Static Pressure Measurements

Air Handler Name	Readings					
	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-110	0.1	0.1	0.0	0.4	0.4	0.0

Temperature readings were also taken for this air handler (See Table 12). The discharge air and return air temperature sensors are within specified tolerances, but the mixed air and preheat temperature sensors still require calibration. These are averaging sensors so their calibration must be done using the procedure described in the Calibration section. Due to the need for a two point calibration, the calibration of these sensors must wait until cold weather would allow for a proper temperature variation in the calibration process without creating problems within the space conditioned by this air handler.

Table 12: AHU 110 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-110	DAT	60.5	60.6	-0.1	71.9	71.8	0.1
	RAT	72.4	72.2	0.2	72.8	72.6	0.2
	MAT	59.3	60.9	-1.6	69.8	71.8	-2.0
	PHT	58.5	62.2	-3.7	69.8	71.1	-1.3

AHU 120

This is a single duct VAV system that is located on the NW corner of the 1St floor, section B. It is a single duct VAV system that serves exam rooms, corridors, offices, and lobbies in the first floor of the clinic. The supply air for the unit varies from 8,470 CFM to 14,450 CFM while the return air is controlled between 6,410 and 12,390 CFM. As of yet, we have been unable to calibrate the flow stations for this air handler due to problems with the supply side air flow station. Attempts to clean this flow station have been unsuccessful. It will be necessary to either install hatches to physically clean the pitot tubes and/or replace the flow station before this air handler will run as designed. The current maximum flows in the controller (See Table 13) are different given the duct sizing, and should be adjusted once the flow stations are operating correctly.

Table 13: AHU 120 Transducer Maximum Flow

AHU Number and Location	Design Transducer	Max CFM for Design Transducer	Max CFM by AHU Design	Max CFM in Controller
AHU 120 RA-F	0.25	15,909	12,390	15,000
AHU 120 SA-F	0.5	13,145	14,450	14,000

Static pressure readings (See Table 14) between the field measurements and JCI readings were minimal once the flow station was connected so that static pressure would be read instead of velocity pressure.

Table 14: AHU 120 Static Pressure Measurements

Air Handler Name	Readings					
	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-120	0.3	0.3	0.0	0.9	1.0	-0.1

Initial temperature measurements (See Table 15) determined that the return air, mixed air, and preheat temperature sensors required calibration. The return air temperature sensor has been calibrated. The mixed air and preheat temperature sensors await cold weather which would allow a two point calibration before they are corrected.

Table 15: AHU 120 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-120	DAT	59.5	59.8	-0.3	76.5	76.5	0.0
	RAT	75.1	73.9	1.2	75.2	74.7	0.5
	MAT	63.0	67.7	-4.7	70.7	73.0	-2.3
	PHT	63.0	66.5	-3.5	70.8	73.3	-2.5

AHU 130

This is a single duct VAV system that serves the northeast corner of the clinic's first floor. It serves several treatment and exam rooms as well as the drug monitoring clinic and a few offices. The air handler is designed to provide between 8,470 and 17,720 CFM of conditioned air into the space. Return air is designed to have a flow between 7,710 and 16,690 CFM.

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.12" while the velocity pressure derived from measured flows was 0.192". The return flow transducer had a 0.024" velocity pressure while measured flows gave a velocity pressure of 0.081". Both flow stations were back flushed with compressed air. The return airflow station is located in a vertical duct so that any dirt or trash falls directly on the honeycomb airflow straighteners or the total pressure pitot tubes. It is accessible from inside the air handler. The dirt was removed by hand from this flow station in addition to using compressed air. On the day of cleaning, the controller read 6,000 CFM initially with a 0.06" velocity pressure. After cleaning was done, the fans were locked in at 60 Hz. and a velocity pressure of 0.19" was observed which corresponded to a 17,680 CFM flow. Measured flow was 15,700 CFM. This change caused the return fan frequency to drop from 60 to 47 Hz when it was released. It was later noted that the wrong High Limit CFM was in the controller. The maximum flow entered in the controller was changed from 32,750 CFM on supply and 20,000 CFM on return to the values shown in Table 16.

Table 16: AHU 130 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-130	SA	Rectangle	40	35	9.72	0.5	27,533
	RA	Rectangle	62	22	9.47	0.25	18,968

Initially, the supply air flow station did not respond as expected. Further investigation revealed that the transducer measuring supply air velocity pressure was wired to the AI point for static pressure and that the AI point for supply airflow was connected to the static pressure transducer. This problem was corrected and testing was restarted. Table 17 displays the final calibration results.

Table 17: AHU 130 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-130	SA	12220	13112	-7	15140	16448	-9	17620	19008	-8
	RA	9078	10608	-17	11707	13096	-12	14671	15424	-5

The return air is within tolerance but it does not measure as accurately as the supply air. One of the reasons for this is the flow station is mounted in a horizontal position and trash buildup has accumulated on top of the honeycomb flow straighteners blocking air flow to some of the pitot tubes. This is skewing the output signal.

Static pressure was verified. The offset for the static pressure sensor was within tolerance. No calibration was required (See Table 18).

Table 18: AHU 130 Static Pressure Measurements

Air Handler Name	Readings					
	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-130	0.4	0.3	0.1	1.1	1.0	0.1

Initial measurements of the temperature sensors for AHU 130 showed that all the sensors on this unit required calibration (See Table 19).

Table 19: AHU 130 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-130	DAT	60.9	59.9	1.0	74.5	73.3	1.2
	RAT	70.4	73.5	-3.1	70.0	73.9	-3.9
	MAT	70.2	61.9	8.3	72.2	70.6	1.6
	PHT	61.6	61.7	-0.1	71.1	68.6	2.5

The discharge and return air temperature sensors for this unit were calibrated by RACH personnel. No calibration data was recorded. However, these sensors were verified by ESL Engineers. The mixed air and preheat temperature sensors were later calibrated using the method described in the calibration section (Table 20).

Table 20: AHU 130 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 130	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	64.5	59.6	3.9	75.8	71.1	3.7
	PHT	64.5	62.7	0.8	75.8	73.5	1.3
After Calibration	MAT	65.5	63.1	1.4	76.3	74.4	0.9
	PHT	65.5	64.3	0.2	76.3	74.7	0.6

AHU 140

This is a single duct VAV system that is located on the southeast corner of the clinic's first floor, section D, and serves the Chief Primary Care, Supervisor Clerk, pharmacy, office records, records, specimen collection, reception specimen collection, lounge, corridor, SW pharmacy, NE pharmacy, and SE pharmacy. The supply air for the AHU operates between 6,840 and 9,330 CFM while the return air is controlled between 6,090 and 8,580 CFM.

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.17" while the velocity pressure derived from measured flows was 0.12". The return flow transducer had a 0.001" velocity pressure while measured flows gave a velocity pressure of 0.002". Initially, the Johnson Controls program listed 13,000 CFM for the maximum flow of supply air and 25,000 CFM for the maximum flow of return air. These values have been changed to those listed in Table 21.

Table 21: AHU 140 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-140	SA	Oval	33	20	3.99	0.5	11,292
	RA	Rectangle	46	20	6.39	0.25	12,794

The transducers of both supply and return air were calibrated by ESL personnel to minimize error. After the flow stations were cleaned, measurements were taken to determine % error between the DX Panel readings and measured flows. As seen in Table 22, the error was minimal and errors for both the supply and return CFMs were in the same direction.

Table 22: AHU 140 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-140	SA	5406	5232	3	6850	6656	3	8186	8016	2
	RA	2986	2964	1	3770	3660	3	4718	4232	10

With both return and supply fans running at 60 Hertz, the air handler is using less than half the maximum return airflow that it was designed for. The return air duct is oversized given the flow it is accommodating. Although our measurements came out close to those on the DX Panel, they could just as easily been out of tolerance given the inherent problems of correctly measuring velocity pressure at such a low velocity. It is suggested that RACH replace this transducer with one that uses a 0 - 0.1” velocity pressure scale.

Static pressure readings for this air handler were extremely low. After close inspection it was determined that the pneumatic lines were connected incorrectly. Once the repairs were made, testing resumed. The results are shown in Table 23.

Table 23: AHU 140 Static Pressure Measurements

Air Handler Name	Readings					
	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-140	0.2	0.2	0.0	0.6	0.6	0.0

Initial temperature measurements are shown in Table 24. The mixed air temperature sensor was the only sensor that was out of the acceptable tolerance.

Table 24: AHU 140 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-140	DAT	59.6	58.9	0.7	76.2	75.3	0.9
	RAT	74.1	72.9	1.2	73.7	74.3	-0.6
	MAT	58.5	61.3	-2.8	73.5	73.5	0.0
	PHT	59.1	57.8	1.3	73.6	72.4	1.2

The mixed air sensor was calibrated as shown in the Table 25.

Table 25: AHU 140 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 140	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	66.2	64	1.2	76.4	74.8	0.6
	PHT	66.2	64.9	0.3	76.4	75.3	0.1
After Calibration	MAT	76.6	75.9	-0.3	67.7	66.5	0.2
	PHT	76.6	75.4	0.2	67.7	66.3	0.4

AHU 210

This is a single duct VAV system that serves conference rooms, a computer room, and offices on the second floor of the clinic. Supply airflow for the unit is scheduled to be maintained between 4,260 and 9,030 CFM. Return airflow is meant to be maintained at 2,830 to 7,600 CFM. The transducer range for the supply air flow station was wrong. This may have been an oversight on Johnson Controls during installation. According to the bill of material on the control drawings, the correct size is stated. The correct transducer range (0 – 0.5”) was installed by Johnson Controls after being notified by RACH personnel. A section of return air duct upstream and downstream of the return air flow station does not match what is stated in the mechanical “AS BUILT” drawings. The duct and flow station are smaller than specifications. Either the duct was modified during initial construction and not documented or it was changed at a later date for reasons unknown.

Maximum flows programmed in the controller were changed from 32,752 on supply air and 7,000 on return air to the flows listed in Table 27. Initially the program for the supply airflow point was configured as a linear input. The input configuration was modified to incorporate the square root function. This will correct the software input signal translation.

Table 26: AHU 210 Flow Station Setup

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-210	SA	Oval	38	17	4.06	0.5	11,485
	RA	Rectangle	24	18	3.00	0.25	6,008

The supply and return air flow stations have been calibrated (See table 27). The percent error for supply and return airflows are in the same direction. The tracking of return air to supply air for this air handler will be even more accurate as compared to having the percent error in opposite directions.

Table 27: AHU 210 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-210	SA	6305	6712	-6	7880	8648	-10	9752	10392	-7
	RA	3327	3638	-9	4570	4692	-3	5417	5644	-4

The static pressure sensor for this air handler was not connected correctly. Modifications to the pneumatic tubing were made to correct the situation. The calibration results are shown in Table 28.

Table 28: AHU 210 Static Pressure Measurements

Air Handler Name	Readings					
	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-210	0.2	0.2	0.0	0.6	0.6	0.0

Initial measurements shown in Table 29, verified that the discharge and return temperature sensors did not need calibration.

Table 29: AHU 210 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-210	DAT	58.1	57.5	0.6	73.5	73.5	0.0
	RAT	75.3	74.7	0.6	75.9	75.7	0.2
	MAT	62.4	62.9	-0.5	74.4	74.0	0.4
	PHT	61.8	62.9	-1.1	73.6	74.0	-0.4

Initial measurements showed the need for calibration of the preheat temperature sensor. The mixed air temperature sensor initially did not need calibration at this instant. However, it was later observed that the mixed air temperature sensor had drifted out of calibration. The mixed air temperature sensor was recalibrated.

Table 30: AHU 210 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 210	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	64.7	65.4	-1.7	75.4	76.5	-2.1
	PHT		63.4	0.3		75.2	-0.8
After Calibration	MAT	66.5	65.6	-0.1	76	75.6	-0.6
	PHT		64.7	0.8		75.3	-0.3

AHU 220

This single duct VAV system that several offices on the second floor of the clinic and the ophthalmology department. The air handler schedule shows that this unit was designed to provide between 5,520 and 7,700 CFM of conditioned air to the space and pull 4,815 to 6,995 CFM of return air from the space. Initially both the transducer for the return air and supply air flow stations were the wrong range. They have been replaced with transducers of the correct range. Inspection of the flow stations before testing revealed that one of the ports for the supply air flow station had broken away from the internal tubing. The flow stations on this air handler cannot be calibrated until the flow station is repaired or replaced. Currently the JCI program lists the maximum CFMs for this air handler to be 8,955 CFM on supply and 2,832 CFM for return. These numbers are incorrect, but due the problem with the supply air flow station, they have been left as is to avoid any air quality and pressurization problems that may develop as a result of changes.

The static pressure sensor for this air handler was not connected correctly. Modifications to the pneumatic tubing were made to correct the situation. The results of the calibration are shown in Table 31.

Table 31: AHU 220 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-220	0.5	0.4	0.1	1.2	1.1	0.1

The corrected static pressure sensor will allow the supply air fan to modulate as needed. However, due to a broken pressure port on the supply air flow station, the return fan has to operate in manual mode. The signal from the supply flow station is extremely low, causing the return fan to idle at minimum speed. Once the flow station is repaired or replaced, the flow stations can be calibrated.

Initial temperature readings showed the need for calibration of return and preheat temperature sensors. The mixed air temperature sensor was marginal and was adjusted to bring it closer in line with the other sensors.

Table 32: AHU 220 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-220	DAT	60.5	60.8	-0.3	73.8	74.3	-0.5
	RAT	72.1	73.5	-1.4	72.5	74.0	-1.5
	MAT	59.7	60.4	-0.7	73.2	74.0	-0.8
	PHT	59.0	60.4	-1.4	72.5	74.0	-1.5

After the first set of calibrations, the return and preheat temperature sensors were tested to be within tolerance. Unfortunately, the mixed air temperature sensor was no longer within the required tolerance and recalibration was necessary (See Table 33).

Table 33: AHU 220 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 220	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	63.9	61.5	1.4	76.6	74.7	0.9
After Calibration	MAT	76.6	74.7	0.9	65	64	0

All temperature sensors for this unit have now been calibrated and are within tolerances.

AHU 230

This single duct VAV system serves several exam rooms and work rooms, conference rooms, offices, and a minor surgery area. The unit sends between 7,320 and 10,025 CFM of conditioned air to the space and pulls between 5,285 and 7,990 CFM of return air from the space. While both supply and return flow stations were connected to transducers of the correct size, the maximum CFMs listed in the controller were incorrect. Initial values for maximum CFM were 24,992 CFM on supply and 10,496 CFM for return. The controller software program for the supply airflow point was configured as a linear input. The input configuration was modified to incorporate the square root function. This will correct the software input signal translation. The corrected maximum CFM values have been entered into the controller's program and are listed below in Table 34.

Table 34: AHU 230 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-230	SA	Circle	32		5.59	0.5	15,817
	RA	Rectangle	42	20	5.83	0.25	11,681

After the flow stations had been cleaned out and programming changes made, the percent errors on each flow stations was within reasonable limits as shown in Table 35. One thing that should be noted about the flow station error is that signal from the supply flow station read higher than the measured value while the return air signal was lower than its measured value. This means for a given supply airflow, the return fan will run faster than necessary to supply the return flow that the program requires. However, even taking this additional error into account, the flow stations are still within 20% of the correct value.

Table 35: AHU 230 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-230	SA	6750	7284	-8	8550	9126	-7	10349	10912	-5
	RA	5447	4800	12	6510	6160	5	8150	7592	7

The static pressure sensor was calibrated using a two point process. Table 36 reflects the static pressure for this air handler with both supply and return fans running at 40 Hz and then at 60 Hz.

Table 36: AHU 230 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-230	0.2	0.1	0.1	0.5	0.4	0.1

This air handler was only able to provide a very low static pressure even running at full speed. However, it supplied the scheduled amount of air to the space.

Temperature measurements were taken for the unit as shown in Table 37. Initially all of the temperature sensors required calibration.

Table 37: AHU 230 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-240	DAT	58.5	60.5	-2.0	74.7	73.1	1.6
	RAT	73.2	73.0	0.2	73.3	73.3	0.0
	MAT	67.8	66.4	1.4	75.0	73.1	1.9
	PHT	67.2	65.7	1.5	74.4	72.6	1.8

Discharge air and return air were the first sensors to be calibrated. After they read correctly, the mixed air and preheat temperature sensors were calibrated as shown in Table 38. All sensors for this air handler are now calibrated.

Table 38: AHU 230 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 230	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	65.7	62.7	2	73.7	71.5	1.2
	PHT	65.7	64	0.7	73.7	71.9	0.8
After Calibration	MAT	65	64	0	73.9	73.1	-0.2
	PHT	65	64.5	-0.5	73.9	73.2	-0.3

AHU 240

This is a single duct VAV system that serves conference rooms, offices, a library and records areas. It is a variable speed unit where the supply air is modulated as needed from 5,060 to 10,135 CFM and return air varies between 4,250 and 9,325 CFM. The maximum CFM for the supply flow transducer has been changed from 24,992 CFM. The controller software program for the supply airflow point was configured as a linear input.

The input configuration was modified to incorporate the square root function. This will correct the software input signal translation. The return flow maximum CFM has also been changed from 10,496 CFM to that which is seen in Table 39.

Table 39: AHU 240 Flow Station Setup

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-240	SA	Oval	39	18	4.39	0.5	12,438
	RA	Rectangle	34	20	4.72	0.25	9,456

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.247" while the velocity pressure derived from measured flows was 0.234". The return flow transducer had a 0.128" velocity pressure while measured flows gave a velocity pressure of 0.07". After cleaning the flow stations and the correct flow station CFM values downloaded into the controller, the flow stations were calibrated (See Table 40).

Table 40: AHU 240 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-240	SA	6307	6128	3	7639	7580	1	8809	8936	-1
	RA	4507	4244	6	5783	5488	5	7217	6586	9

The static pressure sensor was also connected correctly and tested. While the offset is only 0.2, the sensor only shifted 0.2" while measured static pressure changed 0.6". This indicates that there is a problem with the static pressure flow station. ESL recommended that this sensor be cleaned or replaced.

Table 41: AHU 240 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-240	0.4	0.2	0.2	0.6	0.8	-0.2

Initial temperature measurements showed that discharge air, mixed air, and preheat temperature sensors all required calibration (See Table 42). The return air temperature sensor did not require calibration.

Table 42: AHU 240 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-240	DAT	58.5	60.5	-2.0	74.7	73.1	1.6
	RAT	73.2	73.0	0.2	73.3	73.3	0.0
	MAT	67.8	66.4	1.4	75.0	73.1	1.9
	PHT	67.2	65.7	1.5	74.4	72.6	1.8

The discharge air temperature sensor was corrected in the first stage of calibration. The mixed air and preheat temperature sensors were then calibrated as shown in the Table 43.

Table 43: AHU 240 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 240	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	59.5	55.1	3.4	74.7	71.4	2.3
	PHT	59.5	59.1	-0.6	74.7	73.8	-0.1
After Calibration	MAT	59.8	58.8	0	75.1	73.5	0.6
	PHT	59.8	59.3	-0.5	75.1	74	0.1

AHU 250

This is a constant volume penthouse unit that serves the west atrium section of the clinic. It is located on the northwest corner of the roof. Temperature measurements showed (See Table 44) that the return air, mixed air, and preheat temperature sensors all required calibration.

Table 44: AHU 250 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-250	DAT	50.2	50.4	-0.2	50.2	50.3	-0.1
	RAT	66.8	73.1	-6.3	67.6	73.3	-5.7
	MAT	58.2	57.0	1.2	60.0	56.0	4.0
	PHT	56.1	57.0	-0.9	56.7	56.0	0.7

The temperature sensors for this air handler were not calibrated. They will have to be calibrated as weather permits. The calibration procedure requires that the outside air temperature be below 65 °F.

AHU 260

This is a constant volume penthouse unit that serves the eastern waiting rooms in the atrium of the clinic. It is located on the northeast corner of the roof. Temperature measurements showed (See Table 45) that the discharge air, return air, mixed air, and preheat temperature sensors all required calibration.

Table 45: AHU 260 Initial Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-260	DAT	61.9	61.0	0.9	68.0	67.5	0.5
	RAT	71.5	72.7	-1.2	71.6	73.3	-1.7
	MAT	59.3	59.3	0.0	65.7	66.3	-0.6
	PHT	60.6	60.7	-0.1	65.7	64.4	1.3

Temperature sensors for this air handler were not calibrated. They will have to be calibrated as weather permits. The calibration procedure requires that the outside air temperature be below 65 °F.

Hospital Section

AHU 55

This constant volume unit serves the basement of the hospital and conditions the CADD area, FMB Administration, CPR storage, silver recovery, mail service, Muari Room, assembly area, electric and structural shops as well as the female locker room and several corridors. It is a large unit driven by a 20 hp motor that is designed to supply 22,545 CFM into the conditioned space. The Air-handling Unit Schedule requires a minimum outside airflow of 8,490 CFM.

Table 46: AHU 55 Initial Mixed Air and Preheat Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 55	PHT	58.2	56.6	0.6	75.9	76.7	-1.8
	MAT		54.7	2.5		74	0.9

The mixed air and preheat temperature sensors have been identified as needing calibration (See Table 46). However, these sensors were not calibrated. The calibration procedures could not be performed because the ambient outside weather conditions did not meet the required minimum outside air temperature requirements. See Calibration section.

AHU 56

This is a small constant volume unit serving the basement switchgear room. It is designed to provide 5,040 CFM of conditioned air into the space. Table 47 shows the results of the verification. The preheat temperature sensor does not require calibration.

Table 47: AHU 56 Initial Preheat Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU-56	PHT	72.9	73.5	-0.6	37.6	37.2	0.4

AHU 115

This is a constant volume unit that serves the dental clinic and physical therapy areas. It is designed to provide 15,585 CFM of air. Table 48 shows the results of the verification. The preheat temperature sensor requires calibration.

Table 48: AHU 115 Initial Mixed Air and Preheat Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 115	PHT	69.8	71.1	-2.3	71.5	73.7	-3.2
	MAT		68.9	-0.1		70.3	0.2

AHU 116

This air handler is a constant volume unit that uses 100% outside air and serves the oral surgery area. It is designed to supply 2,440 CFM of air. There is no mixed air temperature sensor used in the control algorithm. This air handler does have freeze protection. One calibration point for the preheat sensor can be obtain (See Table 49).

There is no return air flow to generate the second point. Calibration of this sensor has not been completed.

Table 49: AHU 116 Initial Preheat Temperature Sensor Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 116	PHT	47.7	43.2	3.5			

AHU 125

This air handler is a single duct VAV system using VFDs on the supply air and return air fans. It is located in the southeast corner of the clinic's first floor and serves the pathology and nuclear medicine areas. The conditioned space contains several corridors, the blood donor area, film sorting, computer room, pathology, waiting areas, telephone room, cytology, the gamma camera and a conference room. The supply air for the AHU varies between 12,110 and 15,990 CFM while the discharge air is controlled between 2,755 and 6,635 CFM.

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.29" while the velocity pressure derived from measured flows was 0.422". The return flow transducer had a 0.11" velocity pressure while measured flows gave a velocity pressure of 0.093". Initially, the DX-9100 software contained 17,500 for the maximum flow of supply air and 6,900 for the maximum flow of return air. These values have been changed to those listed in Table 50.

Table 50: AHU 125 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-125	SA	Oval	52	16	5.40	0.5	15,282
	RA	Rectangle	36	14	3.50	0.5	9,912

Initially, both the supply and the return transducers that were installed were the wrong pressure range. Johnson Controls replaced the transducer with the correct size according to the control drawings. After the flow stations were cleaned, measurements were taken to determine the percent error between the DX Panel readings and measured flows. As seen in Table 51 the error was within tolerance.

Table 51: AHU 125 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-125	SA	9001	8424	6	11433	10296	10	13657	12320	10
	RA	2543	2484	2	3497	3350	4	4263	4212	1

The static pressure sensor for this air handler was not connected correctly. Modifications to the pneumatic tubing were made to correct the situation. The results of the calibration are shown in Table 52.

Table 52: AHU 125 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-125-1	0.2	0.1	0.1	0.9	0.8	0.1
AHU-125-2	0.2	0.2	0.0	1.0	1.1	-0.1

The supply and return air temperature sensors both required calibration. This was done by comparing the TSI measurement to that displayed by the DX panel. Results of the calibration are displayed in Table 53. The second readings for the verification stage were not taken. However, the second point was checked after calibration.

Table 53: AHU 125 Supply and Return Air Temperature Calibration

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
AHU 125 initial	SAT	59.2	58.1	1.1			
	RAT	72.7	71.5	1.2			
AHU 125 after calibration	SAT	58.1	58.4	-0.3	42.7	42.7	0
	RAT	71.7	71.8	-0.1	71.7	71.8	-0.1

Measurements of the mixed air temperature and preheat sensors determined that both of these sensors also required calibration (See Table 54). However, because of the ambient weather requirement for calibration, they were not calibrated at this time.

Table 54: AHU 125 Mixed Air and Preheat Sensor Verification

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 125	PHT	42.7	40	1.7	58.9	56.5	1.4
	MAT		40.4	1.3		51.4	6.5

AHU 135

This air handler is a single duct VAV system using VFDs on both the return air and supply air fans. It serves radiology, several X-ray rooms, and computer rooms, patient preparation areas, diagnostic services, the darkroom, male locker room, mammography, ultrasound rooms, and various corridors. The unit supplies between 11,460 CFM and 20,690 CFM.

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.2" while the velocity pressure derived from measured flows was 0.24". The return flow transducer had a 0.21" velocity pressure while measured flows gave a velocity pressure of 0.19". After the flow stations were cleaned, the maximum flows in the DX-9100 controller were changed from 20,000 for supply and 22,000 for return to their appropriate values as listed in Table 55.

Table 55: AHU 135 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-135	SA	Oval	43	24	6.31	0.5	17,865
	RA	Circle	38		7.88	0.5	22,304

Once the changes were downloaded into the controller, measurements were taken to compare actual flow with the displayed flow values of the controller (See Table 56). Error on both flow stations was within the accepted tolerance. Supply flow read lower than the actual flow while return flow read higher than actual flow.

Table 56: AHU 135 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-135	SA	10485	9600	8	11010	10432	5	12073	11032	9
	RA	8900	9707	-9	11200	12520	-12	14080	15264	-8

The static pressure sensor for this air handler was not connected correctly. Modifications to the pneumatic tubing were made to correct the situation. The results of the calibration are shown in Table 57. Measurements taken at low and high fan speeds verified that the flow station was working correctly.

Table 57: AHU 135 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-135	0.4	0.4	0.0	1.8	1.8	0.0

The supply and return air temperature sensors were calibrated by RACH personnel. However, calibration data was not recorded. ESL Engineers spot checked these sensors prior to verification of the mixed air and preheat temperature sensors. The results are displayed in the Table 58 indicate that the sensors require calibration.

Table 58: AHU 135 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 135	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	69.7	71.3	-2.6	75.2	75.7	-1.5
	PHT		69.9	-1.2		75.1	-0.9
After Calibration	MAT	62.2	61.4	-0.2	75.4	75.2	-0.8
	PHT		61.4	-0.2		75.4	-1

Return air humidity was monitored for 24 hours using a HOBO® Relative humidity logger and compared with trended data from EMCS. The sensor was found to read an average 7%RH higher than measured. This sensor should not need replacement.

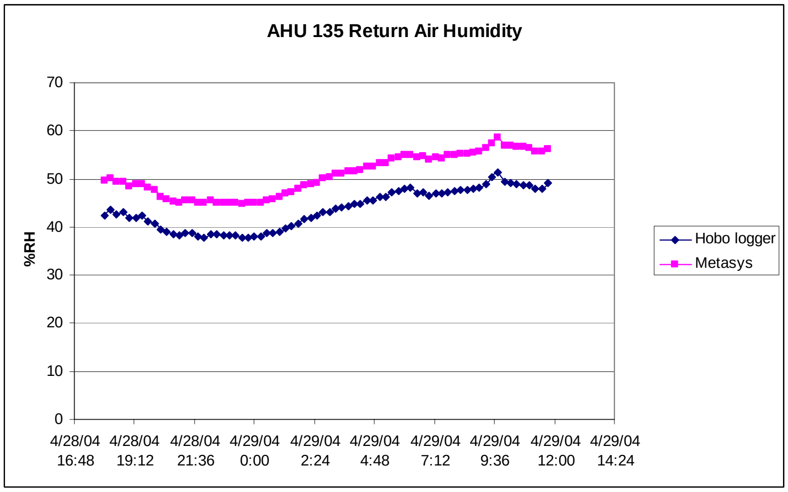

Figure 8: AHU 135 Return Air Humidity

AHU 145

This is a single duct VAV system that serves the admitting and emergency areas of the hospital in addition to exam rooms, a nurse station, cynecology, trauma, and ambulance dispatch. The supply air for the AHU varies between 7,440 and 9,155 CFM.

Before cleaning of the flow stations, the initial velocity pressure measured at the supply flow transducer was 0.18" while the velocity pressure derived from measured flows was 0.22". The return flow transducer had a 0.48" velocity pressure while measured flows gave a velocity pressure of 0.12". Initially, the Johnson Controls contained 11,000 for the maximum flow of supply air and 11,000 for the maximum flow of return air. Table 59 lists the design CFM required compared to the values programmed in the DX-9100 controller.

Table 59: AHU 145 CFM Comparison

AHU Number and Location	Design Transducer	Max CFM for Design Transducer	Max CFM by AHU Design	Max CFM in Controller
AHU 145 RA-F	0.25	8,900	6,995	11,000
AHU 145 SA-F	0.5	12,136	9,155	11,000

This air handler could not be calibrated due to the error between the air velocity measured by the TSI flow meters and the air velocity calculated by using the velocity pressure measured by the flow station. Parameters in this controller were not adjusted.

Table 60: AHU 145 Flow Station Verification Measurements

Air Handler Name	Duct Location	Average Velocity (FPM)	AFMS Pressure Reading (" H_2O)	AFMS Velocity (FPM)	Percent Error
AHU-145	SA	1570	0.06	981	-60
	RA	1359	0.44	2657	49

Attempts at cleaning this air handler's flow stations have been unsuccessful. It will be necessary to remove the flow stations for cleaning and/or replacement. The flow station that serves as a static pressure sensor is not in need of cleaning or any remaining calibration. A two point verification was done to ensure that static pressure read correctly at both high and low pressures. The results are shown in Table 61 below.

Table 61: AHU 145 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-145	0.2	0.3	-0.1	1.3	1.4	-0.1

The supply and return air temperature sensors were calibrated by RACH personnel. However, calibration data was not recorded. ESL Engineers spot checked these sensors prior to verification of the mixed air and preheat temperature sensors. The results are displayed in the Table 62 indicate that the sensors require calibration.

Table 62: AHU 145 Mixed Air and Preheat Temperature Sensor Verification

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 145	PHT	54.2	53.9	-0.7	70.3	71.3	-2
	MAT		55.1	-1.9		72.5	-3.2

The return air humidity sensor was verified by placing a Hobo logger inside the air handler next to the existing humidity sensor (See Figure 9). This sensor does not require replacement.

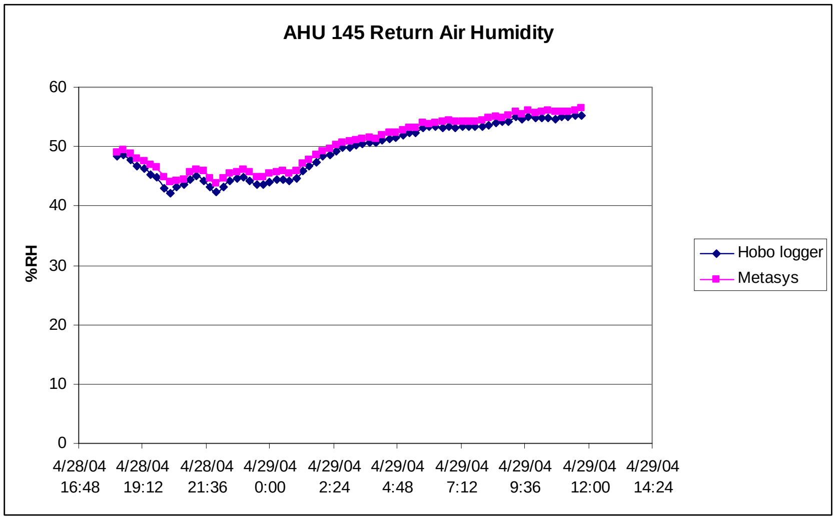

Figure 9: AHU 145 Return Air Humidity

AHU 155

This is a constant volume unit that services the food service and dining facilities for the hospital. The unit is designed to supply 19,050 CFM of conditioned air to the space using a 25 hp motor.

Both the discharge air temperature sensor and the return air temperature sensor were calibrated using the two-point calibration process. Data collected before and after calibration is displayed in Table 63.

Table 63: AHU 155 Discharge and Return air Temperature Sensor Calibration

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
AHU 155 Initial	DAT	57.8	56.8	1	67.6	66.6	1
	RAT	74.7	73.3	1.4	75.1	74.2	0.9
AHU 155 Final	DAT	66.6	66.5	0.1	57.3	57.1	0.2
	RAT	74.3	74.3	0	74.2	73.8	0.4

The mixed air and preheat temperature sensors also required calibration. This was done after discharge and return temperature sensors were calibrated. The mixed air temperature sensor still contains a larger offset at higher temperatures (Sensor drift) than it does at lower temperatures, but it is accurate for the temperature range that it might be utilized for control purposes. We recommend monitoring this sensor periodically to make sure it does not drift any farther.

Table 64: AHU 155 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 155 Initial	PHT	66.6	64.7	0.9	57.3	55.5	0.8
	MAT		61.6	4		55.8	0.5
AHU 155 Final	PHT	69	67.5	0.5	74.7	73.4	0.3
	MAT		67.9	0.1		72.6	1.1

A return air humidity sensor modulates the steam humidifier valve for the supply air to the space. This sensor was found to read 25% too high (See Figure 10). Calibration of this sensor is not possible; replace sensor.

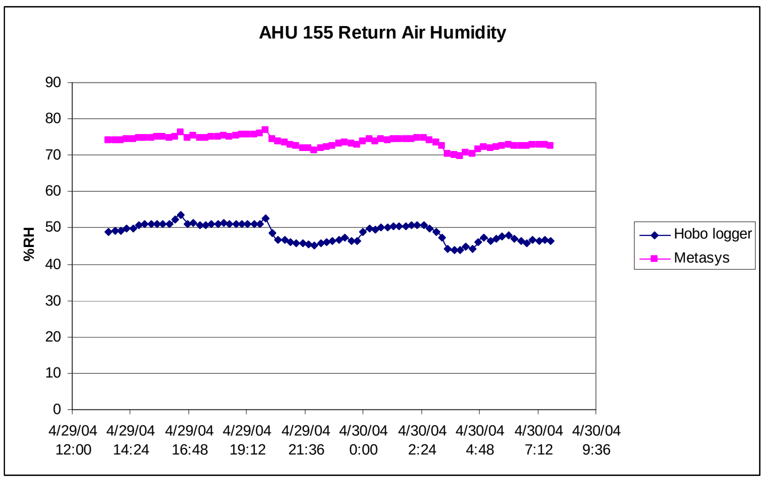

Figure 10: AHU 155 Return Air Humidity

AHU 165

This is a single duct VAV system that serves the occupational therapy area and patient services. The unit is scheduled to supply between 4,240 and 6,590 CFM to the area. The maximum return airflow that AHU 165 is designed to pull from the space is 4,735 CFM.

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.19" while the velocity pressure derived from measured flows was 0.147". The return flow transducer had a 0.04" velocity pressure while measured flows gave a velocity pressure of 0.088". These are small offsets but the impact on flow is significant. The difference of 0.043" on supply equates to 562 CFM or 13.6% of the total flow. The 0.048" difference in return air velocity pressure becomes 1,413 CFM or 32.6% of the total flow.

After cleaning of the flow stations, the maximum CFM listed in the DX-9100 controller was changed. Initially the supply air flow station contained 13,000 CFM as its maximum CFM while return flow was set at 12,000 CFM. The adjusted values for maximum CFM can be found in Table 65

Table 65: AHU 165 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-165	SA	Oval	33	15	3.10	0.5	8,785
	RA	Rectangle	35	15	3.65	0.25	7,301

When these changes had been downloaded to the controller, measurements were taken to compare the DX-9100 readings with the actual flows (See Table 66). While each flow station has an error of less than 20%, the error for supply is in the opposite direction as the error for return. This increases the total error for the system. These measurements were made after two attempts to clean the flow station. For more accurate readings, an access panel would be needed so that the flow stations may be cleaned from the interior.

Table 66: AHU 165 Flow Station Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-165	SA	4107	4688	-14	5094	5800	-14	5792	6664	-15
	RA	3843	3456	10	4838	4324	11	5838	5008	14

The static pressure sensor for this air handler was not connected correctly. Modifications to the pneumatic tubing were made to correct the situation. Measurements of static pressure were taken using a TSI. The calibration results are shown in Table 67.

Table 67: AHU 165 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-165	0.7	0.7	0.0	2.9	2.9	0.0

AHU 175

This is a single duct VAV system that serves the inpatient pharmacy and several offices on the first floor of the hospital. The unit was originally designed to provide a maximum

9,950 CFM of conditioned air to the space while pulling a maximum of 9,045 CFM in return air from the space. Comparison of velocity pressures revealed that the flow stations were in need of calibration. At 60 Hz, the supply flow station measured velocity pressure to be 0.19” while the calculated velocity pressure based on TSI measurements of flow was 0.22”. For return air, the flow station measured 0.1” while 0.12” was the calculated velocity pressure. In addition to cleaning of the flow station, the 0 - 0.5” range transducer for return air had to be replaced with one having the correct 0 – 0.25” range. The maximum flow values entered into the control program were changed from their original 6,500 CFM on supply and 24,000 CFM on return to the values listed in the Table 68.

Table 68: AHU 175 Flow Station Parameters

Air Handler Name	Duct Name	Duct shape	Duct Dimension (in.)		Duct Area (Ft^2)	Transducer Range (" H_2O)	Transducer Maximum CFM
AHU-175	SA	Circle	26		3.69	0.5	10,441
	RA	Rectangle	39	21	5.69	0.25	11,389

After cleaning the flow stations, changes were made to the control programs; flow measurements were taken and compared to Johnson readings. Unfortunately, while the supply air flow station and the return air flow station both read within 20% of the measured values, the errors are in opposite directions. Johnson controls reads a higher flow for supply air than does the measurements while the return air flow from Johnson is lower than the measured flow (See Table 69). This increases the error for the overall system. Considering these errors, the flow measurement system on this air handler is border line. Recommend removing the flow stations from HVAC system for cleaning and/or replacement.

Table 69: AHU 175 Flow Station Calibration Error

Air Handler Name	Duct Location	40 Hertz			50 Hertz			60 Hertz		
		Measured	DX Reading	% Error	Measured	DX Reading	% Error	Measured	DX Reading	% Error
AHU-175	SA	4203	4525	-8	5440	5680	-4	6688	6864	-3
	RA	6825	5780	15	7775	7070	9	9550	8128	15

The flow station used in static pressure measurement was checked using a 2 point calibration (See Table 70). The controller is displaying higher values than what is actually measured. Recommend using compressed air to back flush the flow station pitot tubes and verify that the digital counts on the controller have not been modified.

Table 70: AHU 175 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-175	0.3	0.1	0.2	1.5	1.1	0.4

It was not necessary to calibrate the return air temperature sensor for AHU 175. However, the supply/discharge air temperature sensor needed calibration (See Table 71). Then two point verification indicates that the higher the supply temperature, the greater the offset from the measured temperature. This could be caused by sensor drift or the calibration curve set at the factory is wrong. The calibration procedure shifted the offset so that at normal discharge/supply temperatures there is very little difference between the measured temperature and the temperature displayed by the Johnson program.

Table 71: AHU 175 Supply Air Temperature Sensor Calibration Measurements

AHU 175 Calibration	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
Before Calibration	SAT	47.1	46.9	0.2	62	61.2	0.8
After Calibration	SAT	45.8	46.2	-0.4	61.5	61.1	0.4

Verification measurements indicated that the mixed air temperature sensor required calibration (See Table 72). The preheat temperature sensor did not need calibrating at this time.

Table 72: AHU 175 Mixed Air Temperature Sensor Calibration

AHU 175 Calibration	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	PHT	45.8	44.8	0	61.5	60.2	0.3
	MAT		43	1.8		53.3	7.2
After Calibration	PHT	60.8	60.4	-0.6	72.4	71.1	0.3
	MAT		61.6	-1.8		71.1	0.3

AHU 215

This is a constant volume dual duct unit that serves the critical care patient areas, semi-intensive care patient rooms, the stepdown unit, nurses' stations, waiting rooms, and pulmonary lab. For humidity control, this system uses steam injection between the supply fan and the heating and cooling coils for the hot and cold decks, respectively. However, the location of the steam injector is of concern with respect to the cold deck. Steam is being injected into the system and then being removed before reaching the conditioned space. This is a waste of latent heat or energy. It is not clear at this time why the air handler was configured in this manner. Economics may have been the driving factor in the placement of the steam injector.

Initial measurements displayed that the cold and hot deck temperature sensors were accurate as was the return air temperature sensor. The mixed air and preheat averaging temperature sensors were compared with the average of the supply air sensors in order to develop a single offset (See Table 73). Both the mixed air and preheat temperature sensors were calibrated within acceptable tolerances.

Table 73: AHU 215 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 215	Sensor Name	Readings							
		1st readings				2nd readings			
		Cold Deck	Hot Deck	Sensor	Calibration Offset	Cold Deck	Hot Deck	Sensor	Calibration Offset
Before Calibration	MAT	61	63.2	60.2	0.9	71.9	70.5	69.7	0.5
	PHT	61	63.2	61	0.1	71.9	70.5	70.5	-0.3
After Calibration	MAT	64.4	64.3	63.3	0.05	72.4	72.1	70.9	0.35
	PHT	64.4	64.3	63.5	-0.15	72.4	72.1	71.4	-0.15

AHU 225

This air handler unit is a constant volume unit that serves number 1 and 2 operating rooms, decontamination area, patient areas for prior to and after surgery, family waiting room, anesthesiologist’s offices, and various corridors on the second floor. This air handler was replaced because the original unit did not meet design requirements. After replacing the air handler it discovered that the return air duct was too small to supply the air handler needs. In order to satisfy the supply air requirements, the outside air design requirements were modified. This unit runs with both the return air damper and the outside air damper at their 100% open position in order to operate within design parameters. Because this unit serves surgery rooms, it has 2 sets of filters. The first set is a typical air handler filter found in the unit itself. A second set of filters are HEPA filters that can be found in the supply air duct.

The supply air humidity sensor reads 14% higher than measured values. This error cannot be fully corrected by calibration and the sensor should be replaced.

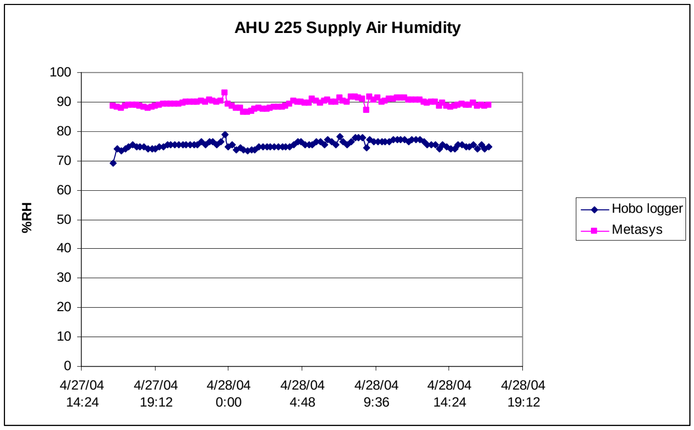

Figure 11: AHU 225 Supply Air Humidity

The return air humidity sensor read 6% higher than it should (See Figure 12). It does not require replacement at this time. We recommend monitoring this sensor. This air handler serves part of the operating rooms. Maintaining the correct amount of humidity is critical for this area.

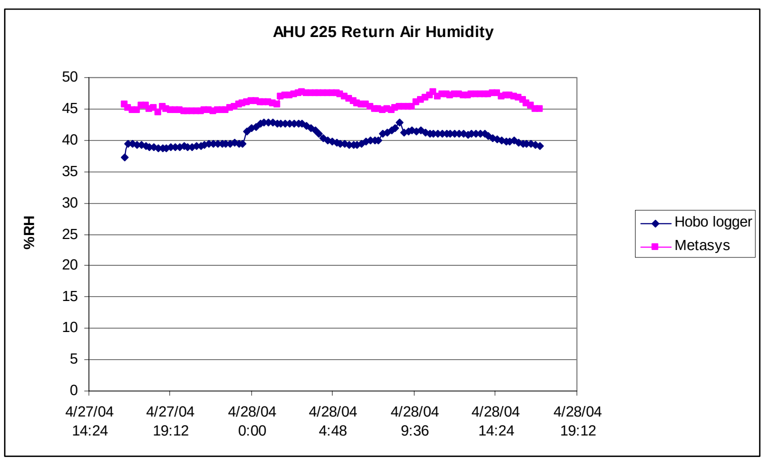

Figure 12: AHU 225 Return Air Humidity

Field measurements compared wit DX-9100 readings verify that the preheat temperature sensor is in need of calibration (See Table 74). Thisair handler has not been calibrated yet due to the lack of cold weather that is necessary to perform the two-point verification.

Table 74: AHU 225 Mixed Air and Preheat Temperature Sensor Verification

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 225	PHT	60.2	58.6	0.6	66.5	63.3	2.2
	MAT		58.7	0.5		65	0.5

AHU 226

This is a constant volume air handler unit that serves number 3 and 4 operating rooms. It conditions the equipment and clean storage rooms, soiled work rooms, the northern decontamination room, the isolation room, recovery areas, anesthesia work room, and several corridors. This air handler was replaced because the original unit did not meet design requirements. After replacing the air handler it discovered that the return air duct was too small to supply the air handler needs. In order to satisfy the supply air requirements, the outside air design requirements were modified. This unit runs with both the return air damper and outside air damper at their 100% open position in order to operate within design parameters.

Measurements were taken of return, mixed, preheat, and supply air temperature and then compared with Johnson calculations of temperature (See Table 75). The return and supply air temperature sensors did not require calibration. However, the offsets for preheat temperature and mixed air temperature make calibration of these sensors necessary.

Table 75: AHU 226 Mixed Air and Preheat Temperature Sensor Verification

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 226	PHT	71	63.2	6.8	62.6	54.4	7.2
	MAT		65.1	4.9		53.3	8.3

Calibration of the mixed air and preheat temperature sensors were not performed at this time. Ambient conditions did not meet the criteria for the calibration procedure. The supply air humidity sensor read 9% higher than measured using a HOBO® logger over the course of a day. This is outside the range that the humidity sensor can be calibrated. It should be replaced.

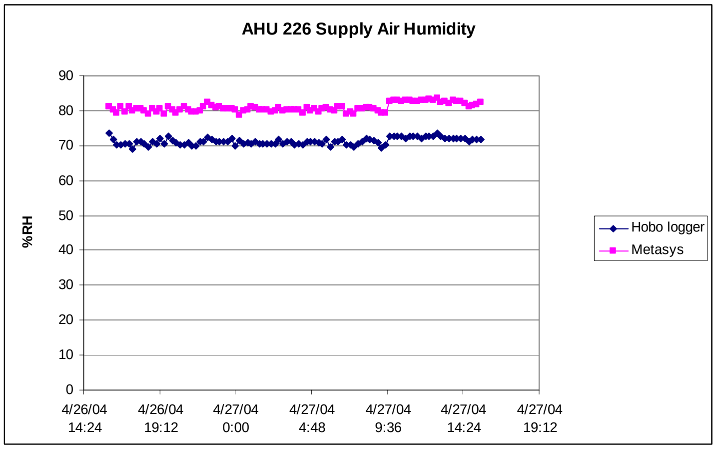

Figure 13: AHU 226 Supply Air Humidity

The offset for the return air humidity sensor varied but averaged about 4% higher than measured. (See Figure 14) This sensor is acceptable.

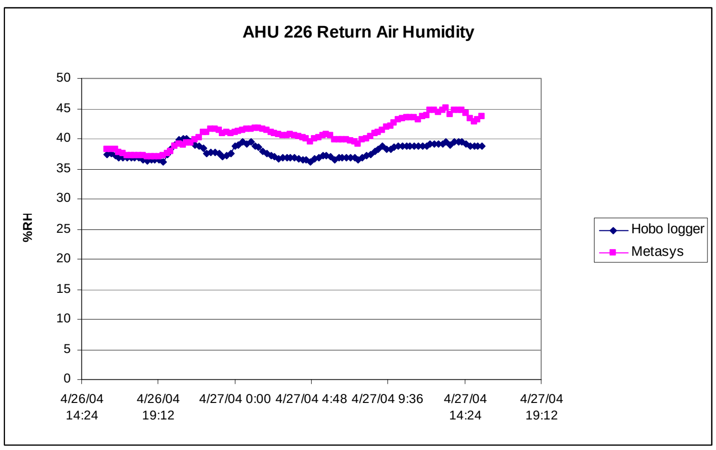

Figure 14: AHU 225 Return Air Humidity

AHU 235

This is a single duct constant volume air handler that serves the second floor West end nursing unit. It provides 12,350 CFM to the space using a 15 Hp motor.

Initial temperature measurements showed the need for calibration of both the return and supply air temperature sensors (See Table 76). Previously the supply temperature sensor developed more error as temperature increased. The offset has been shifted so that there is very little error in the supply temperature range used by the system. The return air temperature also reads correctly now.

Table 76: AHU 235 Supply and Return Air Temperature Sensor Calibration

AHU 235	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
Before Calibration	SAT	64.9	64.1	0.8	50.3	50.3	0
	RAT	72.1	71.4	0.7	72.9	72.6	0.3
After Calibration	SAT	65	64.5	0.5	51.5	51.9	-0.4
	RAT	72.8	72.6	0.2	71.5	71.5	0

Table 77 shows the calibration data for the mixed air temperature sensor and the preheat air temperature sensor. Initial measurements indicate that the sensors tend to drift at warmer temperatures. We recommend monitoring these sensors.

Table 77: AHU 235 Mixed Air and Preheat Temperature Sensor Measurements

Air Handler 235	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	70.3	68.9	0.4	76.4	76.6	-1.2
	PHT		69.5	-0.2		76.5	-1.1
After Calibration	MAT	70.3	69.9	-0.6	75.4	75.4	-1
	PHT		69.5	-0.2		74.7	-0.3

AHU 245

This is a single duct constant volume unit that serves the second floor East end nursing unit. It provides 12,520 CFM to the space. Both return air temperature and supply air temperature sensors required calibration. Table 78 shows the calibration results.

Table 78: AHU 245 Supply and Return Air Temperature Sensor Calibration

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
AHU 245 init	SAT	42.8	42.9	-0.1	70.2	69.4	0.8
	RAT	70.1	71.1	-1	72.8	73.5	-0.7
AHU 245 after	SAT	69.8	69.3	0.5	44.4	44.4	0
	RAT	73.2	73.2	0	73.2	73.2	0

Temperature measurements in Table 79, display the need for calibration of preheat and mixed air temperature sensors. While the preheat temperature sensor is now within calibration tolerances, there are continued problems with the mixed air temperature sensor. Initially, this sensor was out of calibration by as much as 4°F. If this sensor is to be a key component in the control algorithm in the air handler, it is recommended that the sensor be replaced.

Table 79: AHU 245 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler 245	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	MAT	51.6	48.4	2.2	72	67	4
	PHT		48.8	1.8		70.5	0.5
After Calibration	MAT	52.1	50	1.1	71.3	68.4	1.9
	PHT		50.4	0.7		71.3	-1

A return air humidity sensor modulates the steam humidifier valve for the supply air to the space. This sensor was found to read 22% higher than measured relative humidity (See Figure 15). This is too large an offset to calibrate. The sensor must be replaced.

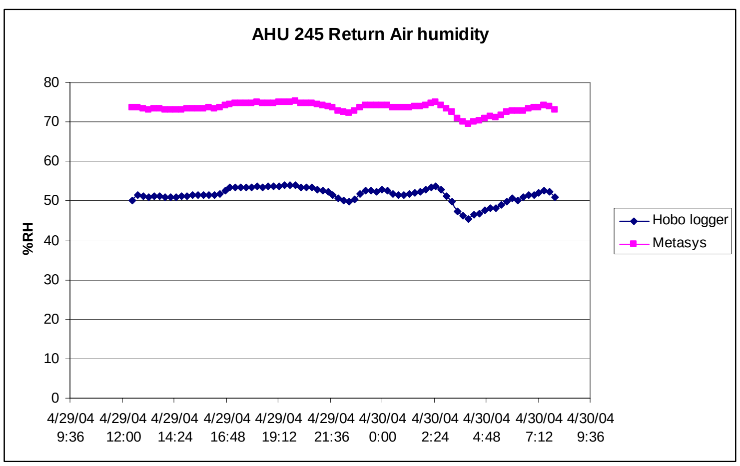

Figure 15: AHU 245 Return Air Humidity

AHU 315

This single duct constant volume unit is located in the obstetrics area and serves delivery rooms 2 and 3 along with a nursery, nurse's station, doctor's call room, maternal child education room, scrub room, female locker room, and sleep room. It provides 15,990 CFM of air into the space.

Measurements of the mixed air temperature and preheat sensors determined that both of these sensors also required calibration (See Table 80). However, because the ambient weather conditions did not meet the criteria for calibration, they were not calibrated at this time.

Table 80: AHU 315 Mixed Air and Preheat Temperature Sensor Verification

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 315	PHT	59.6	54	4.6	68.1	63.8	3.3
	MAT		55.1	3.5		58.8	8.3

A return air humidity sensor modulates the steam humidifier valve for the supply air to the space. This sensor was found to be only 3% higher than measured (See Figure 16), and does not need recalibrating.

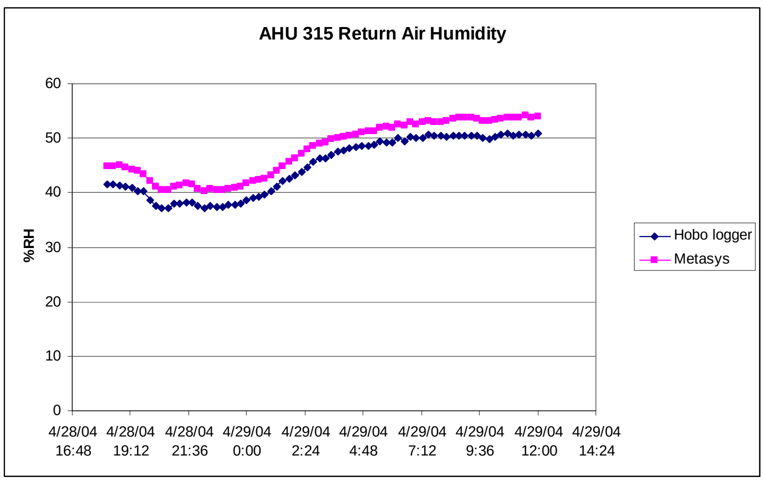

Figure 16: AHU 315 Return Air Humidity

AHU 316

This is the second unit serving the obstetrics labor and delivery unit. It is a single duct constant volume unit that conditions several labor and birthing rooms, the waiting area, delivery room 1, sterile storage, and a nurse's station. It supplies 9,140 CFM of conditioned air to the space.

When the temperature sensors on this air handler were checked, it was unnecessary to calibrate the discharge air temperature sensor or the return air temperature sensor, but the mixed air and preheat temperature sensors require calibration (See Table 81). However, because the ambient weather conditions did not meet the criteria for calibration, they were not calibrated at this time.

Table 81: AHU 316 Mixed Air and Preheat Temperature Sensor Verification

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 316	PHT	64.1	67.6	-4.5			
	MAT		67	-3.9			

A return air humidity sensor modulates the steam humidifier valve for the supply air to the space. This sensor was found to be only 2.5% higher than measured (See Figure 17). It is within acceptable tolerance for use in the humidity control algorithm.

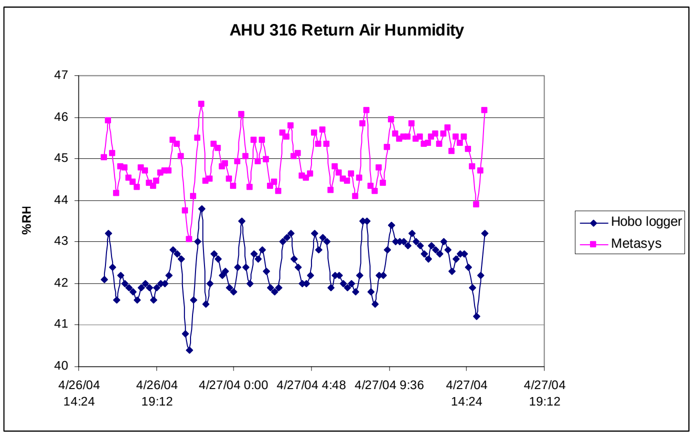

Figure 17: AHU 316 Return Air Humidity

AHU 325

This single duct constant volume unit serves the obstetrics nursing unit which consists of patient bedrooms, a lounge, dayroom, locker rooms, and corridor. The unit provides 9,750 CFM of conditioned air to the space. Both the preheat and mixed air temperature sensors are in need of calibration. The preheat air temperature sensor is accurate at low temperatures but drifts from the actual value at higher temperatures.

Table 82: AHU 325 Mixed Air and Preheat Temperature Sensor Calibration

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
AHU 325	PHT	58.2	57.2	0	65.4	65.7	-1.3
	MAT		58	-0.8		65.8	-1.4

AHU 335

This single duct constant volume unit serves the pediatrics nursing unit. 13,950 CFM of air is provided to the space by the unit.

Both the supply and return air temperature sensors were calibrated for this unit. See Table 83.

Table 83: AHU 335 Supply and Return Air Temperature Sensor Calibration

AHU 335	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
Before Calibration	SAT	59.8	59.5	0.3	79	78.1	0.9
	RAT	71.9	73.2	-1.3	74.4	76.3	-1.9
After Calibration	SAT	79.1	78.7	0.4	61.7	61.9	-0.2
	RAT	75.8	76.1	-0.3	73.4	73.2	0.2

Mixed air and preheat temperature sensors in this air handler also required calibration. After calibration the mixed air temperature sensor still read low at higher temperatures (See Table 84). This sensor is considered marginal. We recommend monitoring this sensor. If this sensor drifts out of calibration, replace it.

Table 84: AHU 335 Mixed Air and Preheat Temperature Sensor Calibration

AHU 335	Sensor Name	Readings					
		1st readings			2nd readings		
		SAT	Sensor	Calibration Offset	SAT	Sensor	Calibration Offset
Before Calibration	PHT	79.1	75.2	2.9	61.7	59.2	1.5
	MAT		75.9	2.2		57	3.7
After Calibration	PHT	73.7	73.3	-0.6	65.2	63.3	0.9
	MAT		73.9	-1.2		64.1	0.1

AHU 345
This is a single duct constant volume unit that serves the third floor east nursing unit. The unit provides 13,410 CFM of conditioned air to the space.

The return air and supply air temperature sensors did not require calibration by ESL personnel. However, it was necessary to calibrate the mixed air temperature and preheat temperature sensors (See Table 85). In both cases, the sensors were reading lower than the actual temperature. This has been corrected and the sensors are now within their accepted tolerance.

Table 85: AHU 345 Mixed Air and Preheat Temperature Sensors Calibration

<table>
<tr><th rowspan="3">Air Handler 345</th><th rowspan="3">Sensor Name</th><th colspan="6">Readings</th></tr>
<tr><th colspan="3">1st readings</th><th colspan="3">2nd readings</th></tr>
<tr><th>SAT</th><th>Sensor</th><th>Calibration Offset</th><th>SAT</th><th>Sensor</th><th>Calibration Offset</th></tr>
<tr><td rowspan="2">Before Calibration</td><td>MAT</td><td rowspan="2">59.6</td><td>56.5</td><td>2.1</td><td rowspan="2">72</td><td>69.2</td><td>1.8</td></tr>
<tr><td>PHT</td><td>57.2</td><td>1.4</td><td>69.7</td><td>1.3</td></tr>
<tr><td rowspan="2">After Calibration</td><td>MAT</td><td rowspan="2">62</td><td>61</td><td>0</td><td rowspan="2">72</td><td>71.4</td><td>-0.4</td></tr>
<tr><td>PHT</td><td>61.4</td><td>-0.4</td><td>71.9</td><td>-0.9</td></tr>
</table>

A return air humidity sensor modulates the steam humidifier valve for the supply air to the space. This sensor was found to read relative humidity to be 25% higher than measured (See Figure 18). The percentage listed is an average for the offset over the course of 24 hours. This is too large an offset to calibrate and the sensor must be replaced.

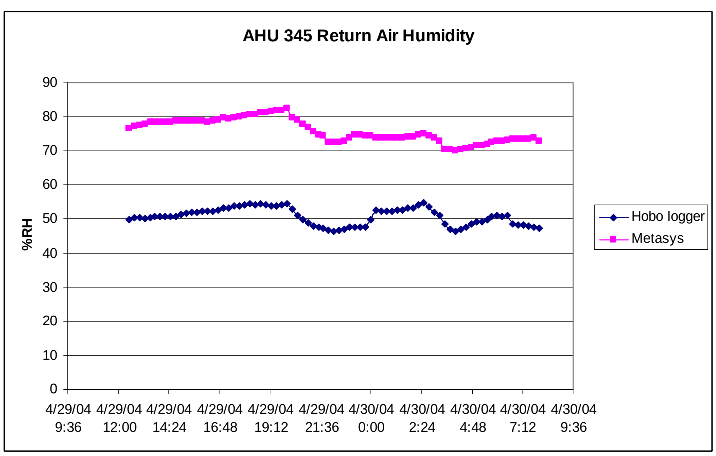

Figure 18: AHU 345 Return Air Humidity

AHU 355
This unit is a single duct VAV system that conditions areas on 3 floors. It serves the central core of the hospital. This includes the chapel and alcove, information desk, multiple corridors and elevator lobbies, conference rooms, classrooms, and consultation areas. The minimum supply airflow scheduled to be provided by this unit is 16,890 CFM while the maximum flow is 22,890 CFM. Return air is set to vary between 14,430 CFM and 20,430 CFM.

Before cleaning of the flow stations, the velocity pressure measured at the supply flow transducer was 0.34" while the velocity pressure derived from measured flows was 0.381". The return flow transducer had a 0.1" velocity pressure while measured flows gave a velocity pressure of 0.283". Unfortunately, using compressed air to clean the return airflow station has had little effect. It will be necessary to remove, clean and/or replace this flow station before it should be used in control calculations.

Initially, the return airflow transducer did not match the transducer listed in the specifications. The transducer installed measured from 0 - 0.5" water column while the transducer that should have been installed measures 0 - 0.25". Because of the use of a larger transducer, the value for maximum flow (transducer output of 20 mA) was programmed as 22,000 CFM. This is the largest amount that could be inputted into the controller. With a 46" x 30" duct, it would take 27,140 CFM as the maximum flow in order to see a 20 mA from the transducer. This means that even with a perfectly operational flow station, the EMCS reading would always be about 20% lower than the real flow. With a 0-0.25" transducer installed, the flow that would give a 20 mA output, maximum flow in controller, is 19,191 CFM. This is much closer to actual flows observed in the system. The supply airflow transducer was the correct size, but 16,000 CFM was entered as the maximum CFM as opposed to 18,623 CFM that should have been used given the duct size.

The static pressure was measured beside the flow station that acts as a static pressure sensor. The static pressure sensor develops an error of 20% when the fans are running at full speed as shown in Table 86. The flow station used for static pressure should be cleaned or replaced.

Table 86: AHU 355 Static Pressure Measurements

Air Handler Name	40 Hertz			60 Hertz		
	DX-9100	Field	Offset	DX-9100	Field	Offset
AHU-355	0.2	0.3	-0.1	0.8	1.0	-0.2

Calibration of the return air temperature sensor was unnecessary, but the supply air temperature sensor required calibration (See Table 87). Neither the mixed air temperature nor the preheat sensors required calibration on this air handler.

Table 87: AHU 355 Supply Air Temperature Sensor Calibration Measurements

Air Handler Name	Sensor Name	Readings					
		1st readings			2nd readings		
		DX-9100	Measured	Offset	DX-9100	Measured	Offset
AHU 355 init	SAT	56.5	57.4	-0.9	76.1	76.8	-0.7
AHU 355 after	SAT	77.4	77.4	0	57.3	57.7	-0.4

A return air humidity sensor modulates the steam humidifier valve for the supply air to the space. This sensor was found to read relative humidity to be 8% lower than measured relative humidity (See Figure 19). This is a greater offset than can be recalibrated on the relative humidity sensor.

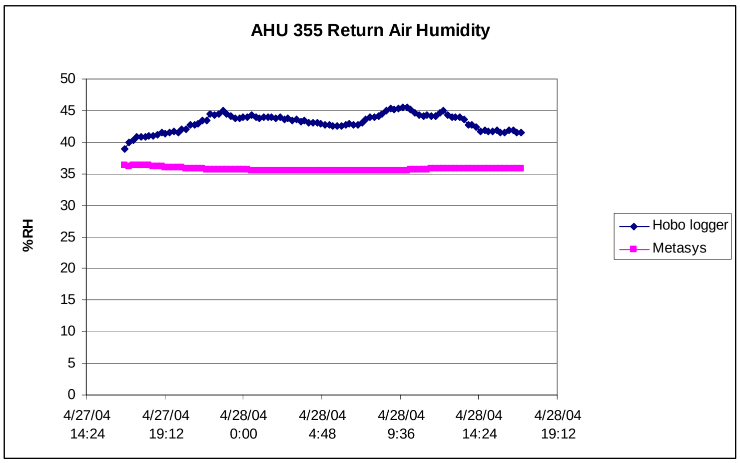

Figure 19: AHU 355 Return Air Humidity

Recommendations

The following recommendations are made based on the findings from the point-to-point verification at RACH.

1. Continue temperature sensor calibration on the remaining air handler units. There is still potential for thermal energy savings from temperature sensor calibration.

2. Replace return air humidity sensors for AHU-155, AHU-245, AHU-345, and AHU-355. This will aid in comfort for the areas served by these air handlers.

3. Replace supply air humidity sensors for AHU-225 and AHU-226. These air handlers serve the operating rooms of the hospital.

4. Clean and/or replace the flow stations for AHU-145, AHU-120, AHU220, and AHU-355. These corrections will improve the performance of the air handlers and reduce energy consumption during unoccupied periods.

5. Clean and/or replace static pressure sensors (flow stations) for AHU-175, AHU-355, AHU-240, and AHU-40. Correcting these sensors will help reduce the supply fan speed of the air handler and improve system response.

6. Repair and/or replace the secondary chilled water flow meter and the main bypass flow meter. These meters are only used for monitoring purpose. However, they can be useful in determining primary/secondary performance.

7. Relocate the differential pressure sensors for the clinic and hospital. Place the sensors near the end of each loop. This will provide information on how the loop is performing. Differential pressure reduction can have a significant impact on energy savings. Presently these sensors are located too close to the central plant.